

# **LAMMPS Users Manual**

Large-scale Atomic/Molecular Massively Parallel Simulator

<http://lammps.sandia.gov> – Sandia National Laboratories

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# LAMMPS Documentation

(22 Jun 2007 version of LAMMPS)

LAMMPS stands for Large-scale Atomic/Molecular Massively Parallel Simulator.

LAMMPS is a classical molecular dynamics simulation code designed to run efficiently on parallel computers. It was developed at Sandia National Laboratories, a US Department of Energy facility, with funding from the DOE. It is an open-source code, distributed freely under the terms of the GNU Public License (GPL).

The developers of LAMMPS are [Steve Plimpton](#), Paul Crozier, and Aidan Thompson who can be contacted at [sjplimp,pscrozi,athomps@sandia.gov](mailto:sjplimp,pscrozi,athomps@sandia.gov). The [LAMMPS WWW Site](http://lammps.sandia.gov) at <http://lammps.sandia.gov> has more information about the code and its uses.

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The LAMMPS documentation is organized into the following sections. If you find errors or omissions in this manual or have suggestions for useful information to add, please send an email to the developers so we can improve the LAMMPS documentation.

Once you are familiar with LAMMPS, you may want to bookmark [this page](#) at [Section\\_commands.html#comm](http://lammps.sandia.gov/Section_commands.html#comm) since it gives quick access to documentation for all LAMMPS commands.

[PDF file](#) of the entire manual, generated by [htmldoc](#)

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## 1. Introduction

These sections provide an overview of what LAMMPS can and can't do, describe what it means for LAMMPS to be an open-source code, and acknowledge the funding and people who have contributed to LAMMPS over the years.

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- 

### 1.1 What is LAMMPS

LAMMPS is a classical molecular dynamics code that models an ensemble of particles in a liquid, solid, or gaseous state. It can model atomic, polymeric, biological, metallic, granular, and coarse-grained systems using a variety of force fields and boundary conditions.

For examples of LAMMPS simulations, see the Publications page of the [LAMMPS WWW Site](#).

LAMMPS runs efficiently on single-processor desktop or laptop machines, but is designed for parallel computers. It will run on any parallel machine that compiles C++ and supports the [MPI](#) message-passing library. This includes distributed- or shared-memory parallel machines and Beowulf-style clusters.

LAMMPS can model systems with only a few particles up to millions or billions. See [this section](#) for information on LAMMPS performance and scalability, or the Benchmarks section of the [LAMMPS WWW Site](#).

LAMMPS is a freely-available open-source code, distributed under the terms of the [GNU Public License](#), which means you can use or modify the code however you wish. See [this section](#) for a brief discussion of the open-source philosophy.

LAMMPS is designed to be easy to modify or extend with new capabilities, such as new force fields, atom types, boundary conditions, or diagnostics. See [this section](#) for more details.

The current version of LAMMPS is written in C++. Earlier versions were written in F77 and F90. See [this section](#) for more information on different versions. All versions can be downloaded from the [LAMMPS WWW Site](#).

LAMMPS was originally developed under a US Department of Energy CRADA (Cooperative Research and Development Agreement) between two DOE labs and 3 companies. It is distributed by [Sandia National Labs](#). See [this section](#) for more information on LAMMPS funding and individuals who have contributed to LAMMPS.

In the most general sense, LAMMPS integrates Newton's equations of motion for collections of atoms, molecules, or macroscopic particles that interact via short- or long-range forces with a variety of initial and/or boundary conditions. For computational efficiency LAMMPS uses neighbor lists to keep track of nearby particles. The lists are optimized for systems with particles that are repulsive at short distances, so that the local density of particles never becomes too large. On parallel machines, LAMMPS uses spatial-decomposition techniques to partition the simulation domain into small 3d sub-domains, one of which is assigned to each processor. Processors communicate and store "ghost" atom information for atoms that border their sub-domain. LAMMPS is most efficient (in a parallel sense) for systems whose particles fill a 3d rectangular box with roughly uniform density.

## 1.2 LAMMPS features

This section highlights LAMMPS features, with pointers to specific commands which give more details. If LAMMPS doesn't have your favorite interatomic potential, boundary condition, or atom type, see [this section](#), which describes how you can add it to LAMMPS.

### Kinds of systems LAMMPS can simulate:

([atom style](#) command)

- atomic (e.g. box of Lennard–Jonesium)
- bead–spring polymers
- united–atom polymers or organic molecules
- all–atom polymers, organic molecules, proteins, DNA
- metals
- granular materials
- coarse–grained mesoscale models
- ellipsoidal particles
- point dipolar particles
- hybrid systems

### Force fields:

([pair style](#), [bond style](#), [angle style](#), [dihedral style](#), [improper style](#), [kspace style](#) commands)

- pairwise potentials: Lennard–Jones, Buckingham, Morse, Yukawa, Debye, soft, class 2 (COMPASS), tabulated
- charged pairwise potentials: Coulombic, point–dipole
- manybody potentials: EAM, Finnis/Sinclair EAM, modified EAM (MEAM), Stillinger–Weber, Tersoff, AI–REBO
- coarse–grain potentials: granular, DPD, GayBerne, colloidal
- bond potentials: harmonic, FENE, Morse, nonlinear, class 2, quartic (breakable)
- angle potentials: harmonic, CHARMM, cosine, cosine/squared, class 2 (COMPASS)
- dihedral potentials: harmonic, CHARMM, multi–harmonic, helix, class 2 (COMPASS), OPLS
- improper potentials: harmonic, cvff, class 2 (COMPASS)
- hybrid potentials: multiple pair, bond, angle, dihedral, improper potentials can be used in one simulation
- polymer potentials: all–atom, united–atom, bead–spring, breakable
- water potentials: TIP3P, TIP4P, SPC
- long–range Coulombics: Ewald, PPPM (similar to particle–mesh Ewald)
- CHARMM, AMBER, OPLS force–field compatibility

### Creation of atoms:

([read\\_data](#), [lattice](#), [create\\_atoms](#), [delete\\_atoms](#), [displace\\_atoms](#) commands)

- read in atom coords from files
- create atoms on one or more lattices (e.g. grain boundaries)
- delete geometric or logical groups of atoms (e.g. voids)
- displace atoms

## Ensembles, constraints, and boundary conditions:

([fix](#) command)

- 2d or 3d systems
- orthogonal or non-orthogonal (triclinic symmetry) simulation domains
- constant NVE, NVT, NPT, NPH integrators
- thermostating options for groups and geometric regions of atoms
- pressure control via Nose/Hoover barostatting in 1 to 3 dimensions
- simulation box deformation (tensile and shear)
- harmonic (umbrella) constraint forces
- independent or coupled rigid body integration
- SHAKE bond and angle constraints
- walls of various kinds
- targeted molecular dynamics (TMD) constraints
- non-equilibrium molecular dynamics (NEMD)
- variety of additional boundary conditions and constraints

## Integrators:

([run](#), [run\\_style](#), [temper](#) commands)

- velocity-Verlet integrator
- Brownian dynamics
- energy minimization via conjugate gradient relaxation
- rRESPA hierarchical timestepping
- parallel tempering (replica exchange)
- run multiple independent simulations simultaneously

## Output:

([dump](#), [restart](#) commands)

- log file of thermodynamic info
- text dump files of atom coords, velocities, other per-atom quantities
- binary restart files
- per-atom energy, stress, centro-symmetry parameter
- user-defined system-wide (log file) or per-atom (dump file) calculations
- atom snapshots in native, XYZ, XTC, DCD formats

## Pre- and post-processing:

Our group has also written and released a separate toolkit called [Pizza.py](#) which provides tools for doing setup, analysis, plotting, and visualization for LAMMPS simulations. [Pizza.py](#) is written in [Python](#) and is available for download from [the Pizza.py WWW site](#).

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### 1.3 LAMMPS non-features

LAMMPS is designed to efficiently compute Newton's equations of motion for a system of interacting particles. Many of the tools needed to pre- and post-process the data for such simulations are not included in the LAMMPS kernel for several reasons:

- the desire to keep LAMMPS simple
- they are not parallel operations
- other codes already do them
- limited development resources

Specifically, LAMMPS itself does not:

- run thru a GUI
- build molecular systems
- assign force-field coefficients automatically
- perform sophisticated analyses of your MD simulation
- visualize your MD simulation
- plot your output data

A few tools for pre- and post-processing tasks are provided as part of the LAMMPS package; they are described in [this section](#). However, many people use other codes or write their own tools for these tasks.

As noted above, our group has also written and released a separate toolkit called [Pizza.py](#) which addresses some of the listed bullets. It provides tools for doing setup, analysis, plotting, and visualization for LAMMPS simulations. Pizza.py is written in [Python](#) and is available for download from [the Pizza.py WWW site](#).

LAMMPS requires as input a list of initial atom coordinates and types, molecular topology information, and force-field coefficients assigned to all atoms and bonds. LAMMPS will not build molecular systems and assign force-field parameters for you.

For atomic systems LAMMPS provides a [create\\_atoms](#) command which places atoms on solid-state lattices (fcc, bcc, user-defined, etc). Assigning small numbers of force field coefficients can be done via the [pair coeff](#), [bond coeff](#), [angle coeff](#), etc commands. For molecular systems or more complicated simulation geometries, users typically use another code as a builder and convert its output to LAMMPS input format, or write their own code to generate atom coordinate and molecular topology for LAMMPS to read in.

For complicated molecular systems (e.g. a protein), a multitude of topology information and hundreds of force-field coefficients must typically be specified. We suggest you use a program like [CHARMM](#) or [AMBER](#) or other molecular builders to setup such problems and dump its information to a file. You can then reformat the file as LAMMPS input. Some of the tools in [this section](#) can assist in this process.

Similarly, LAMMPS creates output files in a simple format. Most users post-process these files with their own analysis tools or re-format them for input into other programs, including visualization packages. If you are convinced you need to compute something on-the-fly as LAMMPS runs, see [this section](#) for a discussion of how you can use the [dump](#) and [compute](#) and [fix](#) commands to print out data of your choosing. Keep in mind that complicated computations can slow down the molecular dynamics timestepping, particularly if the computations are not parallel, so it is often better to leave such analysis to post-processing codes.

A very simple (yet fast) visualizer is provided with the LAMMPS package – see the [xmovie](#) tool in [this section](#). It creates xyz projection views of atomic coordinates and animates them. We find it very useful for debugging purposes. For high-quality visualization we recommend the following packages:

- [VMD](#)
- [AtomEye](#)
- [PyMol](#)
- [Raster3d](#)
- [RasMol](#)

Other features that LAMMPS does not yet (and may never) support are discussed in [this section](#).

Finally, these are freely-available molecular dynamics codes, most of them parallel, which may be well-suited to the problems you want to model. They can also be used in conjunction with LAMMPS to perform complementary modeling tasks.

- [CHARMM](#)
- [AMBER](#)
- [NAMD](#)
- [NWChem](#)
- [DL\\_POLY](#)
- [Tinker](#)

CHARMM, AMBER, NAMD, NWChem, and Tinker are designed primarily for modeling biological molecules. CHARMM and AMBER use atom-decomposition (replicated-data) strategies for parallelism; NAMD and NWChem use spatial-decomposition approaches, similar to LAMMPS. Tinker is a serial code. DL\_POLY includes potentials for a variety of biological and non-biological materials; both a replicated-data and spatial-decomposition version exist.

---

## 1.4 Open source distribution

LAMMPS comes with no warranty of any kind. As each source file states in its header, it is a copyrighted code that is distributed free-of-charge, under the terms of the [GNU Public License](#) (GPL). This is often referred to as open-source distribution – see [www.gnu.org](http://www.gnu.org) or [www.opensource.org](http://www.opensource.org) for more details. The legal text of the GPL is in the LICENSE file that is included in the LAMMPS distribution.

Here is a summary of what the GPL means for LAMMPS users:

- (1) Anyone is free to use, modify, or extend LAMMPS in any way they choose, including for commercial purposes.
- (2) If you distribute a modified version of LAMMPS, it must remain open-source, meaning you distribute it under the terms of the GPL. You should clearly annotate such a code as a derivative version of LAMMPS.
- (3) If you release any code that includes LAMMPS source code, then it must also be open-sourced, meaning you distribute it under the terms of the GPL.
- (4) If you give LAMMPS files to someone else, the GPL LICENSE file and source file headers (including the copyright and GPL notices) should remain part of the code.

In the spirit of an open-source code, these are various ways you can contribute to making LAMMPS better. You can send email to the [developers](#) on any of these items.

- Point prospective users to the [LAMMPS WWW Site](#). Mention it in talks or link to it from your WWW site.
- If you find an error or omission in this manual or on the [LAMMPS WWW Site](#), or have a suggestion for something to clarify or include, send an email to the [developers](#).
- If you find a bug, [this section](#) describes how to report it.
- If you publish a paper using LAMMPS results, send the citation (and any cool pictures or movies if you like) to add to the Publications, Pictures, and Movies pages of the [LAMMPS WWW Site](#), with links and attributions back to you.

- Create a new Makefile.machine that can be added to the src/MAKE directory.
- The tools sub-directory of the LAMMPS distribution has various stand-alone codes for pre- and post-processing of LAMMPS data. More details are given in [this section](#). If you write a new tool that users will find useful, it can be added to the LAMMPS distribution.
- LAMMPS is designed to be easy to extend with new code for features like potentials, boundary conditions, diagnostic computations, etc. [This section](#) gives details. If you add a feature of general interest, it can be added to the LAMMPS distribution.
- The Benchmark page of the [LAMMPS WWW Site](#) lists LAMMPS performance on various platforms. The files needed to run the benchmarks are part of the LAMMPS distribution. If your machine is sufficiently different from those listed, your timing data can be added to the page.
- You can send feedback for the User Comments page of the [LAMMPS WWW Site](#). It might be added to the page. No promises.
- Cash. Small denominations, unmarked bills preferred. Paper sack OK. Leave on desk. VISA also accepted. Chocolate chip cookies encouraged.

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## 1.5 Acknowledgments and citations

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The following papers describe the parallel algorithms used in LAMMPS.

S. J. Plimpton, **Fast Parallel Algorithms for Short-Range Molecular Dynamics**, J Comp Phys, 117, 1-19 (1995).

S. J. Plimpton, R. Pollock, M. Stevens, **Particle-Mesh Ewald and rRESPA for Parallel Molecular Dynamics Simulations**, in Proc of the Eighth SIAM Conference on Parallel Processing for Scientific Computing, Minneapolis, MN (March 1997).

If you use LAMMPS results in your published work, please cite the J Comp Phys reference and include a pointer to the [LAMMPS WWW Site](#) (<http://lammps.sandia.gov>). A paper describing the latest version of LAMMPS is in the works; when it appears in print, you can check the [LAMMPS WWW Site](#) for a more current citation.

If you send me information about your publication, I'll be pleased to add it to the Publications page of the [LAMMPS WWW Site](#). Ditto for a picture or movie for the Pictures or Movies pages.

The core group of LAMMPS developers is at Sandia National Labs. They include [Steve Plimpton](#), Paul Crozier, and Aidan Thompson and can be contacted via email: [sjplimp](mailto:sjplimp), [pscrozi](mailto:pscrozi), [athomps](mailto:athomps) at sandia.gov.

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Ewald and PPPM solvers	Roy Pollock (LLNL)
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class 2 force fields	Eric Simon (Cray)
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msi2lmp tool	



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fix momentum and recenter	Naveen Michaud-Agrawal (Johns Hopkins U)
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- Steve Lustig (Dupont)
- Jim Belak (LLNL)

## 2. Getting Started

This section describes how to unpack, make, and run LAMMPS, for both new and experienced users.

- [2.1 What's in the LAMMPS distribution](#)
  - [2.2 Making LAMMPS](#)
  - [2.3 Making LAMMPS with optional packages](#)
  - [2.4 Building LAMMPS as a library](#)
  - [2.5 Running LAMMPS](#)
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### 2.1 What's in the LAMMPS distribution

When you download LAMMPS you will need to unzip and untar the downloaded file with the following commands, after placing the file in an appropriate directory.

```
gunzip lammps*.tar.gz
tar xvf lammps*.tar
```

This will create a LAMMPS directory containing two files and several sub-directories:

README	text file
LICENSE	the GNU General Public License (GPL)
bench	benchmark problems
doc	documentation
examples	simple test problems
potentials	embedded atom method (EAM) potential files
src	source files
tools	pre- and post-processing tools

---

### 2.2 Making LAMMPS

*Read this first:*

Building LAMMPS can be non-trivial. You will likely need to edit a makefile, there are compiler options, additional libraries can be used (MPI, FFT), etc. Please read this section carefully. If you are not comfortable with makefiles, or building codes on a Unix platform, or running an MPI job on your machine, please find a local expert to help you. Many compiling, linking, and run problems that users are not really LAMMPS issues – they are peculiar to the user's system, compilers, libraries, etc. Such questions are better answered by a local expert.

If you have a build problem that you are convinced is a LAMMPS issue (e.g. the compiler complains about a line of LAMMPS source code), then please send an email to the [developers](#).

If you succeed in building LAMMPS on a new kind of machine (which there isn't a similar Makefile for in the

distribution), send it to the developers and we'll include it in future LAMMPS releases.

### ***Building a LAMMPS executable:***

The src directory contains the C++ source and header files for LAMMPS. It also contains a top-level Makefile and a MAKE sub-directory with low-level Makefile.\* files for several machines. From within the src directory, type "make" or "gmake". You should see a list of available choices. If one of those is the machine and options you want, you can type a command like:

```
make linux
gmake mac
```

If you get no errors and an executable like `lmp_linux` or `lmp_mac` is produced, you're done; it's your lucky day.

### ***Errors that can occur when making LAMMPS:***

(1) If the make command breaks immediately with errors that indicate it can't find files with a "\*" in their names, this can be because your machine's make doesn't support wildcard expansion in a makefile. Try gmake instead of make. If that doesn't work, try using a -f switch with your make command to use Makefile.list which explicitly lists all the needed files, e.g.

```
make makelist
make -f Makefile.list linux
gmake -f Makefile.list mac
```

The first "make" command will create a current Makefile.list with all the file names in your src dir. The 2nd "make" command (make or gmake) will use it to build LAMMPS.

(2) Other errors typically occur because the low-level Makefile isn't setup correctly for your machine. If your platform is named "foo", you need to create a Makefile.foo in the MAKE sub-directory. Use whatever existing file is closest to your platform as a starting point. See the next section for more instructions.

### ***Editing a new low-level Makefile.foo:***

These are the issues you need to address when editing a low-level Makefile for your machine. With a couple exceptions, the only portion of the file you should need to edit is the "System-specific Settings" section.

(1) Change the first line of Makefile.foo to include the word "foo" and whatever other options you set. This is the line you will see if you just type "make".

(2) Set the paths and flags for your C++ compiler, including optimization flags. You can use g++, the open-source GNU compiler, which is available on all Unix systems. Vendor compilers often produce faster code. On boxes with Intel CPUs, we suggest using the free Intel icc compiler, which you can download from [Intel's compiler site](#).

(3) If you want LAMMPS to run in parallel, you must have an MPI library installed on your platform. If you do not use "mpicc" as your compiler/linker, then Makefile.foo needs to specify where the mpi.h file (-I switch) and the libmpi.a library (-L switch) is found. If you are installing MPI yourself, we recommend Argonne's MPICH 1.2 which can be downloaded from the [Argonne MPI site](#). LAM MPI should also work. If you are running on a big parallel platform, your system people or the vendor should have already installed a version of MPI, which will be faster than MPICH or LAM, so find out how to build and link with it. If you use MPICH or LAM, you will have to configure and build it for your platform. The MPI configure script should have compiler options to enable you to use the same compiler you are using for the LAMMPS build, which can avoid problems that may arise

when linking LAMMPS to the MPI library.

(4) If you just want LAMMPS to run on a single processor, you can use the STUBS library in place of MPI, since you don't need an MPI library installed on your system. See the Makefile.serial file for how to specify the `-I` and `-L` switches. You will also need to build the STUBS library for your platform before making LAMMPS itself. From the STUBS dir, type "make" and it will hopefully create a libmpi.a suitable for linking to LAMMPS. If the build fails, you will need to edit the STUBS/Makefile for your platform.

The file STUBS/mpi.cpp has a CPU timer function `MPI_Wtime()` that calls `gettimeofday()`. If your system doesn't support `gettimeofday()`, you'll need to insert code to call another timer. Note that the ANSI-standard function `clock()` rolls over after an hour or so, and is therefore insufficient for timing long LAMMPS simulations.

(5) If you want to use the particle-particle particle-mesh (PPPM) option in LAMMPS for long-range Coulombics, you must have a 1d FFT library installed on your platform. This is specified by a switch of the form `-DFFT_XXX` where XXX = INTEL, DEC, SGI, SCSL, or FFTW. All but the last one are native vendor-provided libraries. FFTW is a fast, portable library that should work on any platform. You can download it from [www.fftw.org](http://www.fftw.org). Use version 2.1.X, not the newer 3.0.X. Building FFTW for your box should be as simple as `./configure; make`. Whichever FFT library you have on your platform, you'll need to set the appropriate `-I` and `-L` switches in Makefile.foo.

If you examine `fft3d.c` and `fft3d.h` you'll see it's possible to add other vendor FFT libraries via `#ifdef` statements in the appropriate places. If you successfully add a new FFT option, like `-DFFT_IBM`, please send the [developers](#) an email; we'd like to add it to LAMMPS.

(6) If you don't plan to use PPPM, you don't need an FFT library. Use a `-DFFT_NONE` switch in the CCFLAGS setting of Makefile.foo, or exclude the KSPACE package (see below).

(7) There are a few other `-D` compiler switches you can set as part of CCFLAGS. The `read_data` and `dump` commands will read/write gzipped files if you compile with `-DGZIP`. It requires that your Unix support the "popen" command. Using one of the `-DPACK_ARRAY`, `-DPACK_POINTER`, and `-DPACK_MEMCPY` options can make for faster parallel FFTs (in the PPPM solver) on some platforms. The `-DPACK_ARRAY` setting is the default.

(8) The DEPFLAGS setting is how the C++ compiler creates a dependency file for each source file. This speeds re-compilation when source (\*.cpp) or header (\*.h) files are edited. Some compilers do not support dependency file creation, or may use a different switch than `-D`. GNU g++ works with `-D`. If your compiler can't create dependency files (a long list of errors involving \*.d files), then you'll need to create a Makefile.foo patterned after Makefile.tflop, which uses different rules that do not involve dependency files.

That's it. Once you have a correct Makefile.foo and you have pre-built the MPI and FFT libraries it will use, all you need to do from the src directory is type one of these 2 commands:

```
make foo
gmake foo
```

You should get the executable `lmp_foo` when the build is complete.

### ***Additional build tips:***

(1) Building LAMMPS for multiple platforms.

You can make LAMMPS for multiple platforms from the same src directory. Each target creates its own object sub-dir called `Obj_name` where it stores the system-specific \*.o files.

## (2) Cleaning up.

Typing "make clean" will delete all \*.o object files created when LAMMPS is built.

(3) On some machines with some compiler options, the Coulomb tabling option that is enabled by default for "long" [pair styles](#) such as *lj/cut/coul/long* and *lj/charmm/coul/long* does not work. Tables are used by these styles since it can offer a 2x speed-up. A symptom of this problem is getting wildly large energies on timestep 0 of the examples/peptide simulation.

Here are several work-arounds. Coulomb tables can be disabled by setting "table 0" in the [pair\\_modify](#) command.

The associated files (e.g. *pair\_lj\_cut\_coul\_long.cpp*) can be compiled at a lower optimization level like `-O2`, or with the compiler flag `-fno-strict-aliasing`. The latter can be done by adding something like these lines in your *Makefile.machine*:

```
NOALIAS =          -fno-strict-aliasing

pair_lj_cut_coul_long.o : pair_lj_cut_coul_long.cpp
    $(CC) $(CCFLAGS) $(NOALIAS) -c $<

pair_lj_charmm_coul_long.o : pair_lj_charmm_coul_long.cpp
    $(CC) $(CCFLAGS) $(NOALIAS) -c $<
```

On a Macintosh, try compiling the pair "long" files without the `-fast` compiler option.

## (4) Building for a Macintosh.

OS X is BSD Unix, so it already works. See the *Makefile.mac* file.

## (5) Building for MicroSoft Windows.

I've never done this, but LAMMPS is just standard C++ with MPI and FFT calls. You can use cygwin to build LAMMPS with a Unix make; see *Makefile.cygwin*. Or you should be able to pull all the source files into Visual C++ (ugh) or some similar development environment and build it. In the *src/MAKE/Windows* directory are some notes from users on how they built LAMMPS under Windows, so you can look at their instructions for tips. Good luck – we can't help you on this one.

## 2.3 Making LAMMPS with optional packages

The source code for LAMMPS is structured as a large set of core files that are always used plus additional packages, which are groups of files that enable a specific set of features. For example, force fields for molecular systems or granular systems are in packages. You can see the list of packages by typing "make package". The current list of packages is as follows:

asphere	aspherical particles and force fields
class2	class 2 force fields
colloid	colloidal particle force fields
dipole	point dipole particles and force fields
dpd	dissipative particle dynamics (DPD) force field
granular	force fields and boundary conditions for granular systems
kpspace	long-range Ewald and particle-mesh (PPPM) solvers

manybody	metal, 3-body, bond-order potentials
meam	modified embedded atom method (MEAM) potential
molecule	force fields for molecular systems
opt	optimized versions of a few pair potentials
poems	coupled rigid body motion
xtc	dump atom snapshots in XTC format

Any or all packages can be included or excluded when LAMMPS is built. The one exception is that to use the "opt" package, you must also be using the "molecule" and "manybody" packages. You may wish to exclude certain packages if you will never run certain kinds of simulations. This will keep you from having to build auxiliary libraries (see below) and will produce a smaller executable which may run a bit faster.

By default, LAMMPS includes only the "kspace", "manybody", and "molecule" packages. As described below, some packages require LAMMPS be linked to separately built library files, which will require editing of your src/MAKE/Makefile.machine.

Packages are included or excluded by typing "make yes-name" or "make no-name", where "name" is the name of the package. You can also type "make yes-all" or "make no-all" to include/exclude all optional packages. These commands work by simply moving files back and forth between the main src directory and sub-directories with the package name, so that the files are seen or not seen when LAMMPS is built. After you have included or excluded a package, you must re-make LAMMPS.

Additional make options exist to help manage LAMMPS files that exist in both the src directory and in package sub-directories. You do not normally need to use these commands unless you are editing LAMMPS files or have downloaded a patch from the LAMMPS WWW site. Typing "make package-update" will overwrite src files with files from the package directories if the package has been included. It should be used after a patch is installed, since patches only update the master package version of a file. Typing "make package-overwrite" will overwrite files in the package directories with src files. Typing "make package-check" will list differences between src and package versions of the same files.

To use the "meam" package you must build LAMMPS with the MEAM library in lib/meam, which computes the modified embedded atom method potential, which is a generalization of EAM potentials that can be used to model a wider variety of materials. This MEAM implementation was written by Greg Wagner at Sandia. To build LAMMPS with MEAM, you must use a low-level LAMMPS Makefile that includes the MEAM directory in its paths. See Makefile.linux\_meam as an example. You must also build MEAM itself as a library before building LAMMPS, so that LAMMPS can link against it. This requires a F90 compiler. The library is built by typing "make" from within the meam directory with the appropriate Makefile, e.g. "make -f Makefile.icc". If one of the provided Makefiles is not appropriate for your system you can edit or add one as needed.

Note that linking a Fortran library to a C++ code can be problematic (e.g. Fortran routine names can't be found due to non-standard underscore rules) and typically requires additional C++ or F90 libraries be included in the link. You may need to read documentation for your compiler about how to do this correctly.

To use the "poems" package you must build LAMMPS with the POEMS library in lib/poems, which computes the constrained rigid-body motion of articulated (jointed) multibody systems. POEMS was written and is distributed by Prof Kurt Anderson's group at Rensselaer Polytechnic Institute (RPI). To build LAMMPS with POEMS, you must use a low-level LAMMPS Makefile that includes the POEMS directory in its paths. See Makefile.g++\_poems as an example. You must also build POEMS itself as a library before building LAMMPS, so that LAMMPS can link against it. The POEMS library is built by typing "make" from within the poems directory with the appropriate Makefile, e.g. "make -f Makefile.g++". If one of the provided Makefiles is not appropriate for your system you can edit or add one as needed.

## 2.4 Building LAMMPS as a library

LAMMPS can be built as a library, which can then be called from another application or a scripting language. See [this section](#) for more info on coupling LAMMPS to other codes. Building LAMMPS as a library is done by typing

```
make makelib
make -f Makefile.lib foo
```

where foo is the machine name. The first "make" command will create a current Makefile.lib with all the file names in your src dir. The 2nd "make" command will use it to build LAMMPS as a library. This requires that Makefile.foo have a library target (lib) and system-specific settings for ARCHIVE and ARFLAGS. See Makefile.linux for an example. The build will create the file liblmp\_foo.a which another application can link to.

When used from a C++ program, the library allows one or more LAMMPS objects to be instantiated. All of LAMMPS is wrapped in a LAMMPS\_NS namespace; you can safely use any of its classes and methods from within your application code, as needed. See the sample code examples/couple/c++\_driver.cpp as an example.

When used from a C or Fortran program or a scripting language, the library has a simple function-style interface, provided in library.cpp and library.h. See the sample code examples/couple/c\_driver.cpp as an example.

You can add as many functions as you wish to library.cpp and library.h. In a general sense, those functions can access LAMMPS data and return it to the caller or set LAMMPS data values as specified by the caller. These 4 functions are currently included in library.cpp:

```
void lammps_open(int, char **, MPI_Comm, void **ptr);
void lammps_close(void *ptr);
int lammps_file(void *ptr, char *);
int lammps_command(void *ptr, char *);
```

The lammps\_open() function is used to initialize LAMMPS, passing in a list of strings as if they were [command-line arguments](#) when LAMMPS is run from the command line and a MPI communicator for LAMMPS to run under. It returns a ptr to the LAMMPS object that is created, and which should be used in subsequent library calls. Note that lammps\_open() can be called multiple times to create multiple LAMMPS objects.

The lammps\_close() function is used to shut down LAMMPS and free all its memory. The lammps\_file() and lammps\_command() functions are used to pass a file or string to LAMMPS as if it were an input file or single command read from an input script.

---

## 2.5 Running LAMMPS

By default, LAMMPS runs by reading commands from stdin; e.g. lmp\_linux < in.file. This means you first create an input script (e.g. in.file) containing the desired commands. [This section](#) describes how input scripts are structured and what commands they contain.

You can test LAMMPS on any of the sample inputs provided in the examples directory. Input scripts are named in.\* and sample outputs are named log.\*.name.P where name is a machine and P is the number of processors it was run on.

Here is how you might run one of the Lennard-Jones tests on a Linux box, using mpirun to launch a parallel job:

```
cd src
make linux
cp lmp_linux ../examples/lj
cd ../examples/lj
```



```
mpirun -np 4 lmp_linux <in.lj.nve
```

The screen output from LAMMPS is described in the next section. As it runs, LAMMPS also writes a log.lammps file with the same information.

Note that this sequence of commands copies the LAMMPS executable (lmp\_linux) to the directory with the input files. This may not be necessary, but some versions of MPI reset the working directory to where the executable is, rather than leave it as the directory where you launch mpirun from (if you launch lmp\_linux on its own and not under mpirun). If that happens, LAMMPS will look for additional input files and write its output files to the executable directory, rather than your working directory, which is probably not what you want.

If LAMMPS encounters errors in the input script or while running a simulation it will print an ERROR message and stop or a WARNING message and continue. See [this section](#) for a discussion of the various kinds of errors LAMMPS can or can't detect, a list of all ERROR and WARNING messages, and what to do about them.

LAMMPS can run a problem on any number of processors, including a single processor. In theory you should get identical answers on any number of processors and on any machine. In practice, numerical round-off can cause slight differences and eventual divergence of molecular dynamics phase space trajectories.

LAMMPS can run as large a problem as will fit in the physical memory of one or more processors. If you run out of memory, you must run on more processors or setup a smaller problem.

---

## 2.6 Command-line options

At run time, LAMMPS recognizes several optional command-line switches which may be used in any order. For example, lmp\_ibm might be launched as follows:

```
mpirun -np 16 lmp_ibm -var f tmp.out -log my.log -screen none <in.alloy
```

These are the command-line options:

```
-echo style
```

Set the style of command echoing. The style can be *none* or *screen* or *log* or *both*. Depending on the style, each command read from the input script will be echoed to the screen and/or logfile. This can be useful to figure out which line of your script is causing an input error. The default value is *log*. The echo style can also be set by using the [echo](#) command in the input script itself.

```
-partition 8x2 4 5 ...
```

Invoke LAMMPS in multi-partition mode. When LAMMPS is run on P processors and this switch is not used, LAMMPS runs in one partition, i.e. all P processors run a single simulation. If this switch is used, the P processors are split into separate partitions and each partition runs its own simulation. The arguments to the switch specify the number of processors in each partition. Arguments of the form MxN mean M partitions, each with N processors. Arguments of the form N mean a single partition with N processors. The sum of processors in all partitions must equal P. Thus the command "-partition 8x2 4 5" has 10 partitions and runs on a total of 25 processors.

The input script specifies what simulation is run on which partition; see the [variable](#) and [next](#) commands. This [howto section](#) gives examples of how to use these commands in this way. Simulations running on different partitions can also communicate with each other; see the [temper](#) command.

```
-in file
```

Specify a file to use as an input script. This is an optional switch when running LAMMPS in one-partition mode. If it is not specified, LAMMPS reads its input script from stdin – e.g. `lmp_linux < in.run`. This is a required switch when running LAMMPS in multi-partition mode, since multiple processors cannot all read from stdin.

`-log file`

Specify a log file for LAMMPS to write status information to. In one-partition mode, if the switch is not used, LAMMPS writes to the file `log.lammps`. If this switch is used, LAMMPS writes to the specified file. In multi-partition mode, if the switch is not used, a `log.lammps` file is created with hi-level status information. Each partition also writes to a `log.lammps.N` file where `N` is the partition ID. If the switch is specified in multi-partition mode, the hi-level logfile is named "file" and each partition also logs information to a `file.N`. For both one-partition and multi-partition mode, if the specified file is "none", then no log files are created. Using a [log](#) command in the input script will override this setting.

`-screen file`

Specify a file for LAMMPS to write its screen information to. In one-partition mode, if the switch is not used, LAMMPS writes to the screen. If this switch is used, LAMMPS writes to the specified file instead and you will see no screen output. In multi-partition mode, if the switch is not used, hi-level status information is written to the screen. Each partition also writes to a `screen.N` file where `N` is the partition ID. If the switch is specified in multi-partition mode, the hi-level screen dump is named "file" and each partition also writes screen information to a `file.N`. For both one-partition and multi-partition mode, if the specified file is "none", then no screen output is performed.

`-var name value`

Specify a variable that will be defined for substitution purposes when the input script is read. "Name" is the variable name which can be a single character (referenced as `$x` in the input script) or a full string (referenced as `${abc}`). The value can be any string. Using this command-line option is equivalent to putting the line "variable name index value" at the beginning of the input script. Defining a variable as a command-line argument overrides any setting for the same variable in the input script, since variables cannot be re-defined. See the [variable](#) command for more info on defining variables and [this section](#) for more info on using variables in input scripts.

---

## 2.7 LAMMPS screen output

As LAMMPS reads an input script, it prints information to both the screen and a log file about significant actions it takes to setup a simulation. When the simulation is ready to begin, LAMMPS performs various initializations and prints the amount of memory (in MBytes per processor) that the simulation requires. It also prints details of the initial thermodynamic state of the system. During the run itself, thermodynamic information is printed periodically, every few timesteps. When the run concludes, LAMMPS prints the final thermodynamic state and a total run time for the simulation. It then appends statistics about the CPU time and storage requirements for the simulation. An example set of statistics is shown here:

```
Loop time of 49.002 on 2 procs for 2004 atoms
```

```
Pair    time (%) = 35.0495 (71.5267)
Bond    time (%) = 0.092046 (0.187841)
Kspce   time (%) = 6.42073 (13.103)
Neigh   time (%) = 2.73485 (5.5811)
Comm    time (%) = 1.50291 (3.06703)
Outpt   time (%) = 0.013799 (0.0281601)
Other   time (%) = 2.13669 (4.36041)
```

```
Nlocal:    1002 ave, 1015 max, 989 min
Histogram: 1 0 0 0 0 0 0 0 0 1
```

```

Nghost:      8720 ave, 8724 max, 8716 min
Histogram: 1 0 0 0 0 0 0 0 0 1
Neighs:      354141 ave, 361422 max, 346860 min
Histogram: 1 0 0 0 0 0 0 0 0 1

Total # of neighbors = 708282
Ave neighs/atom = 353.434
Ave special neighs/atom = 2.34032
Number of reneighborings = 42
Dangerous reneighborings = 2

```

The first section gives the breakdown of the CPU run time (in seconds) into major categories. The second section lists the number of owned atoms (Nlocal), ghost atoms (Nghost), and pair-wise neighbors stored per processor. The max and min values give the spread of these values across processors with a 10-bin histogram showing the distribution. The total number of histogram counts is equal to the number of processors.

The last section gives aggregate statistics for pair-wise neighbors and special neighbors that LAMMPS keeps track of (see the [special\\_bonds](#) command). The number of times neighbor lists were rebuilt during the run is given as well as the number of potentially "dangerous" rebuilds. If atom movement triggered neighbor list rebuilding (see the [neigh\\_modify](#) command), then dangerous reneighborings are those that were triggered on the first timestep atom movement was checked for. If this count is non-zero you may wish to reduce the delay factor to insure no force interactions are missed by atoms moving beyond the neighbor skin distance before a rebuild takes place.

If an energy minimization was performed via the [minimize](#) command, additional information is printed, e.g.

```

Minimization stats:
  E initial, next-to-last, final = -0.895962 -2.94193 -2.94342
  Gradient 2-norm init/final= 1920.78 20.9992
  Gradient inf-norm init/final= 304.283 9.61216
  Iterations = 36
  Force evaluations = 177

```

The first line lists the initial and final energy, as well as the energy on the next-to-last iteration. The next 2 lines give a measure of the gradient of the energy (force on all atoms). The 2-norm is the "length" of this force vector; the inf-norm is the largest component. The last 2 lines are statistics on how many iterations and force-evaluations the minimizer required. Multiple force evaluations are typically done at each iteration to perform a 1d line minimization in the search direction.

If a [kspace\\_style](#) long-range Coulombics solve was performed during the run (PPPM, Ewald), then additional information is printed, e.g.

```

FFT time (% of Kspce) = 0.200313 (8.34477)
FFT Gflps 3d 1d-only = 2.31074 9.19989

```

The first line gives the time spent doing 3d FFTs (4 per timestep) and the fraction it represents of the total KSpace time (listed above). Each 3d FFT requires computation (3 sets of 1d FFTs) and communication (transposes). The total flops performed is  $5N\log_2(N)$ , where  $N$  is the number of points in the 3d grid. The FFTs are timed with and without the communication and a Gflop rate is computed. The 3d rate is with communication; the 1d rate is without (just the 1d FFTs). Thus you can estimate what fraction of your FFT time was spent in communication, roughly 75% in the example above.

---

## 2.8 Tips for users of previous LAMMPS versions

LAMMPS 2003 is a complete C++ rewrite of LAMMPS 2001, which was written in F90. Features of earlier versions of LAMMPS are listed in [this section](#). The F90 and F77 versions (2001 and 99) are also freely distributed as open-source codes; check the [LAMMPS WWW Site](#) for distribution information if you prefer those versions. The 99 and 2001 versions are no longer under active development; they do not have all the features of LAMMPS 2003.

If you are a previous user of LAMMPS 2001, these are the most significant changes you will notice in LAMMPS 2003:

- (1) The names and arguments of many input script commands have changed. All commands are now a single word (e.g. `read_data` instead of `read data`).
- (2) All the functionality of LAMMPS 2001 is included in LAMMPS 2003, but you may need to specify the relevant commands in different ways.
- (3) The format of the data file can be streamlined for some problems. See the [read\\_data](#) command for details. The data file section "Nonbond Coeff" has been renamed to "Pair Coeff" in LAMMPS 2003.
- (4) Binary restart files written by LAMMPS 2001 cannot be read by LAMMPS 2003 with a [read\\_restart](#) command. This is because they were output by F90 which writes in a different binary format than C or C++ writes or reads. Use the *restart2data* tool provided with LAMMPS 2001 to convert the 2001 restart file to a text data file. Then edit the data file as necessary before using the LAMMPS 2003 [read\\_data](#) command to read it in.
- (5) There are numerous small numerical changes in LAMMPS 2003 that mean you will not get identical answers when comparing to a 2001 run. However, your initial thermodynamic energy and MD trajectory should be close if you have setup the problem for both codes the same.

## 3. Commands

This section describes how a LAMMPS input script is formatted and what commands are used to define a LAMMPS simulation.

- [3.1 LAMMPS input script](#)
  - [3.2 Parsing rules](#)
  - [3.3 Input script structure](#)
  - [3.4 Commands listed by category](#)
  - [3.5 Commands listed alphabetically](#)
- 

### 3.1 LAMMPS input script

LAMMPS executes by reading commands from an input script (text file), one line at a time. When the input script ends, LAMMPS exits. Each command causes LAMMPS to take some action. It may set an internal variable, read in a file, or run a simulation. Most commands have default settings, which means you only need to use the command if you wish to change the default.

In many cases, the ordering of commands in an input script is not important. However the following rules apply:

(1) LAMMPS does not read your entire input script and then perform a simulation with all the settings. Rather, the input script is read one line at a time and each command takes effect when it is read. Thus this sequence of commands:

```
timestep 0.5
run      100
run      100
```

does something different than this sequence:

```
run      100
timestep 0.5
run      100
```

In the first case, the specified timestep (0.5 fmsec) is used for two simulations of 100 timesteps each. In the 2nd case, the default timestep (1.0 fmsec) is used for the 1st 100 step simulation and a 0.5 fmsec timestep is used for the 2nd one.

(2) Some commands are only valid when they follow other commands. For example you cannot set the temperature of a group of atoms until atoms have been defined and a group command is used to define which atoms belong to the group.

(3) Sometimes command B will use values that can be set by command A. This means command A must precede command B in the input script if it is to have the desired effect. For example, the [read\\_data](#) command initializes the system by setting up the simulation box and assigning atoms to processors. If default values are not desired, the [processors](#) and [boundary](#) commands need to be used before [read\\_data](#) to tell LAMMPS how to map processors to the simulation box.

Many input script errors are detected by LAMMPS and an ERROR or WARNING message is printed. [This section](#) gives more information on what errors mean. The documentation for each command lists restrictions on

how the command can be used.

---

## 3.2 Parsing rules

Each non-blank line in the input script is treated as a command. LAMMPS commands are case sensitive. Command names are lower-case, as are specified command arguments. Upper case letters may be used in file names or user-chosen ID strings.

Here is how each line in the input script is parsed by LAMMPS:

- (1) If the line ends with a `"` character (with no trailing whitespace), the command is assumed to continue on the next line. The next line is concatenated to the previous line by removing the `"` character and newline. This allows long commands to be continued across two or more lines.
- (2) All characters from the first `#` character onward are treated as comment and discarded.
- (3) The line is searched repeatedly for `$` characters which indicate variables that are replaced with a text string. If the `$` is followed by curly brackets, then the variable name is the text inside the curly brackets. If no curly brackets follow the `$`, then the variable name is the character immediately following the `$`. Thus `${myTemp}` and `$x` refer to variable names "myTemp" and "x". See the [variable](#) command for details of how strings are assigned to variables and how they are substituted for in input scripts.
- (4) The line is broken into "words" separated by whitespace (tabs, spaces). Note that words can thus contain letters, digits, underscores, or punctuation characters.
- (5) The first word is the command name. All successive words in the line are arguments.
- (6) Text with spaces can be enclosed in double quotes so it will be treated as a single argument. See the [dump](#) [modify](#) or [fix print](#) commands for examples. A `#` or `$` character that in text between double quotes will not be treated as a comment or substituted for as a variable.

---

## 3.3 Input script structure

This section describes the structure of a typical LAMMPS input script. The "examples" directory in the LAMMPS distribution contains many sample input scripts; the corresponding problems are discussed in [this section](#), and animated on the [LAMMPS WWW Site](#).

A LAMMPS input script typically has 4 parts:

1. Initialization
2. Atom definition
3. Settings
4. Run a simulation

The last 2 parts can be repeated as many times as desired. I.e. run a simulation, change some settings, run some more, etc. Each of the 4 parts is now described in more detail. Remember that almost all the commands need only be used if a non-default value is desired.

### (1) Initialization

Set parameters that need to be defined before atoms are created or read-in from a file.

The relevant commands are [units](#), [dimension](#), [newton](#), [processors](#), [boundary](#), [atom\\_style](#), [atom\\_modify](#).

If force-field parameters appear in the files that will be read, these commands tell LAMMPS what kinds of force fields are being used: [pair\\_style](#), [bond\\_style](#), [angle\\_style](#), [dihedral\\_style](#), [improper\\_style](#).

## (2) Atom definition

There are 3 ways to define atoms in LAMMPS. Read them in from a data or restart file via the [read\\_data](#) or [read\\_restart](#) commands. These files can contain molecular topology information. Or create atoms on a lattice (with no molecular topology), using these commands: [lattice](#), [region](#), [create\\_box](#), [create\\_atoms](#). The entire set of atoms can be duplicated to make a larger simulation using the [replicate](#) command.

## (3) Settings

Once atoms and molecular topology are defined, a variety of settings can be specified: force field coefficients, simulation parameters, output options, etc.

Force field coefficients are set by these commands (they can also be set in the read-in files): [pair\\_coeff](#), [bond\\_coeff](#), [angle\\_coeff](#), [dihedral\\_coeff](#), [improper\\_coeff](#), [kspace\\_style](#), [dielectric](#), [special\\_bonds](#).

Various simulation parameters are set by these commands: [neighbor](#), [neigh\\_modify](#), [group](#), [timestep](#), [reset\\_timestep](#), [run\\_style](#), [min\\_style](#), [min\\_modify](#).

Fixes impose a variety of boundary conditions, time integration, and diagnostic options. The [fix](#) command comes in many flavors.

Various computations can be specified for execution during a simulation using the [compute](#), [compute\\_modify](#), and [variable](#) commands.

Output options are set by the [thermo](#), [dump](#), and [restart](#) commands.

## (4) Run a simulation

A molecular dynamics simulation is run using the [run](#) command. Energy minimization (molecular statics) is performed using the [minimize](#) command. A parallel tempering (replica-exchange) simulation can be run using the [temper](#) command.

---

## 3.4 Commands listed by category

This section lists all LAMMPS commands, grouped by category. The [next section](#) lists the same commands alphabetically. Note that some style options for some commands are part of specific LAMMPS packages, which means they cannot be used unless the package was included when LAMMPS was built. Not all packages are included in a default LAMMPS build. These dependencies are listed as Restrictions in the command's documentation.

Initialization:

[atom\\_modify](#), [atom\\_style](#), [boundary](#), [dimension](#), [newton](#), [processors](#), [units](#)

Atom definition:

[create\\_atoms](#), [create\\_box](#), [lattice](#), [read\\_data](#), [read\\_restart](#), [region](#), [replicate](#)

Force fields:

[angle\\_coeff](#), [angle\\_style](#), [bond\\_coeff](#), [bond\\_style](#), [dielectric](#), [dihedral\\_coeff](#), [dihedral\\_style](#), [improper\\_coeff](#), [improper\\_style](#), [kspace\\_modify](#), [kspace\\_style](#), [pair\\_coeff](#), [pair\\_modify](#), [pair\\_style](#), [pair\\_write](#), [special\\_bonds](#)

Settings:

[communicate](#), [dipole](#), [group](#), [mass](#), [min\\_modify](#), [min\\_style](#), [neigh\\_modify](#), [neighbor](#), [reset\\_timestep](#), [run\\_style](#), [set](#), [shape](#), [timestep](#), [velocity](#)

Fixes:

[fix](#), [fix\\_modify](#), [unfix](#)

Computes:

[compute](#), [compute\\_modify](#), [uncompute](#)

Output:

[dump](#), [dump\\_modify](#), [restart](#), [thermo](#), [thermo\\_modify](#), [thermo\\_style](#), [undump](#), [write\\_restart](#)

Actions:

[delete\\_atoms](#), [delete\\_bonds](#), [displace\\_atoms](#), [displace\\_box](#), [minimize](#), [run](#), [temper](#)

Miscellaneous:

[clear](#), [echo](#), [if](#), [include](#), [jump](#), [label](#), [log](#), [next](#), [print](#), [shell](#), [variable](#)

---

### 3.5 Individual commands

This section lists all LAMMPS commands alphabetically, with a separate listing below of styles within certain commands. The [previous section](#) lists the same commands, grouped by category. Note that some style options for some commands are part of specific LAMMPS packages, which means they cannot be used unless the package was included when LAMMPS was built. Not all packages are included in a default LAMMPS build. These dependencies are listed as Restrictions in the command's documentation.

<a href="#">angle_coeff</a>	<a href="#">angle_style</a>	<a href="#">atom_modify</a>	<a href="#">atom_style</a>	<a href="#">bond_coeff</a>	<a href="#">bond_style</a>
<a href="#">boundary</a>	<a href="#">change_box</a>	<a href="#">clear</a>	<a href="#">communicate</a>	<a href="#">compute</a>	<a href="#">compute_modify</a>
<a href="#">create_atoms</a>	<a href="#">create_box</a>	<a href="#">delete_atoms</a>	<a href="#">delete_bonds</a>	<a href="#">dielectric</a>	<a href="#">dihedral_coeff</a>
<a href="#">dihedral_style</a>	<a href="#">dimension</a>	<a href="#">dipole</a>	<a href="#">displace_atoms</a>	<a href="#">displace_box</a>	<a href="#">dump</a>
<a href="#">dump_modify</a>	<a href="#">echo</a>	<a href="#">fix</a>	<a href="#">fix_modify</a>	<a href="#">group</a>	<a href="#">if</a>
<a href="#">improper_coeff</a>	<a href="#">improper_style</a>	<a href="#">include</a>	<a href="#">jump</a>	<a href="#">kspace_modify</a>	<a href="#">kspace_style</a>
<a href="#">label</a>	<a href="#">lattice</a>	<a href="#">log</a>	<a href="#">mass</a>	<a href="#">minimize</a>	<a href="#">min_modify</a>
<a href="#">min_style</a>	<a href="#">neigh_modify</a>	<a href="#">neighbor</a>	<a href="#">newton</a>	<a href="#">next</a>	<a href="#">pair_coeff</a>
<a href="#">pair_modify</a>	<a href="#">pair_style</a>	<a href="#">pair_write</a>	<a href="#">print</a>	<a href="#">processors</a>	<a href="#">read_data</a>
<a href="#">read_restart</a>	<a href="#">region</a>	<a href="#">replicate</a>	<a href="#">reset_timestep</a>	<a href="#">restart</a>	<a href="#">run</a>



<a href="#">run_style</a>	<a href="#">set</a>	<a href="#">shape</a>	<a href="#">shell</a>	<a href="#">special_bonds</a>	<a href="#">temper</a>
<a href="#">thermo</a>	<a href="#">thermo_modify</a>	<a href="#">thermo_style</a>	<a href="#">timestep</a>	<a href="#">uncompute</a>	<a href="#">undump</a>
<a href="#">unfix</a>	<a href="#">units</a>	<a href="#">variable</a>	<a href="#">velocity</a>	<a href="#">write_restart</a>	

Fix commands. See the [fix](#) command for one-line descriptions of each style or click on the style itself for a full description:

<a href="#">addforce</a>	<a href="#">aveforce</a>	<a href="#">ave/atom</a>	<a href="#">ave/spatial</a>	<a href="#">ave/time</a>	<a href="#">com</a>	<a href="#">deform</a>	<a href="#">deposit</a>
<a href="#">drag</a>	<a href="#">efield</a>	<a href="#">enforce2d</a>	<a href="#">freeze</a>	<a href="#">gran/diag</a>	<a href="#">gravity</a>	<a href="#">gyration</a>	<a href="#">heat</a>
<a href="#">indent</a>	<a href="#">langevin</a>	<a href="#">lineforce</a>	<a href="#">msd</a>	<a href="#">momentum</a>	<a href="#">nph</a>	<a href="#">npt</a>	<a href="#">npt/asphere</a>
<a href="#">nve</a>	<a href="#">nve/asphere</a>	<a href="#">nve/dipole</a>	<a href="#">nve/gran</a>	<a href="#">nve/limit</a>	<a href="#">nve/noforce</a>	<a href="#">nvt</a>	<a href="#">nvt/asphere</a>
<a href="#">nvt/sllod</a>	<a href="#">orient/fcc</a>	<a href="#">planeforce</a>	<a href="#">poems</a>	<a href="#">pour</a>	<a href="#">print</a>	<a href="#">rdf</a>	<a href="#">recenter</a>
<a href="#">rigid</a>	<a href="#">setforce</a>	<a href="#">shake</a>	<a href="#">spring</a>	<a href="#">spring/rg</a>	<a href="#">spring/self</a>	<a href="#">temp/rescale</a>	<a href="#">tmd</a>
<a href="#">viscous</a>	<a href="#">wall/gran</a>	<a href="#">wall/lj126</a>	<a href="#">wall/lj93</a>	<a href="#">wall/reflect</a>	<a href="#">wiggle</a>		

Compute commands. See the [compute](#) command for one-line descriptions of each style or click on the style itself for a full description:

<a href="#">attribute/atom</a>	<a href="#">centro/atom</a>	<a href="#">coord/atom</a>	<a href="#">ebond/atom</a>	<a href="#">epair/atom</a>	<a href="#">etotal/atom</a>
<a href="#">ke/atom</a>	<a href="#">pressure</a>	<a href="#">rotate/dipole</a>	<a href="#">rotate/gran</a>	<a href="#">stress/atom</a>	<a href="#">temp</a>
<a href="#">temp/deform</a>	<a href="#">temp/asphere</a>	<a href="#">temp/dipole</a>	<a href="#">temp/partial</a>	<a href="#">temp/ramp</a>	<a href="#">temp/region</a>
<a href="#">variable</a>	<a href="#">variable/atom</a>				

Pair\_style potentials. See the [pair\\_style](#) command for an overview of pair potentials. Click on the style itself for a full description:

<a href="#">none</a>	<a href="#">hybrid</a>	<a href="#">airebo</a>	<a href="#">buck</a>
<a href="#">buck/coul/cut</a>	<a href="#">buck/coul/long</a>	<a href="#">colloid</a>	<a href="#">dipole/cut</a>
<a href="#">dpd</a>	<a href="#">eam</a>	<a href="#">eam/opt</a>	<a href="#">eam/alloy</a>
<a href="#">eam/alloy/opt</a>	<a href="#">eam/fs</a>	<a href="#">eam/fs/opt</a>	<a href="#">gayberne</a>
<a href="#">gran/hertzian</a>	<a href="#">gran/history</a>	<a href="#">gran/no_history</a>	<a href="#">lj/charmm/coul/charmm</a>
<a href="#">lj/charmm/coul/charmm/implicit</a>	<a href="#">lj/charmm/coul/long</a>	<a href="#">lj/charmm/coul/long/opt</a>	<a href="#">lj/class2</a>
<a href="#">lj/class2/coul/cut</a>	<a href="#">lj/class2/coul/long</a>	<a href="#">lj/cut</a>	<a href="#">lj/cut/opt</a>
<a href="#">lj/cut/coul/cut</a>	<a href="#">lj/cut/coul/debye</a>	<a href="#">lj/cut/coul/long</a>	<a href="#">lj/cut/coul/long/tip4p</a>
<a href="#">lj/expand</a>	<a href="#">lj/smooth</a>	<a href="#">meam</a>	<a href="#">morse</a>
<a href="#">morse/opt</a>	<a href="#">soft</a>	<a href="#">sw</a>	<a href="#">table</a>
<a href="#">tersoff</a>	<a href="#">yukawa</a>		

Bond\_style potentials. See the [bond\\_style](#) command for an overview of bond potentials. Click on the style itself for a full description:

<a href="#">none</a>	<a href="#">hybrid</a>	<a href="#">class2</a>	<a href="#">fene</a>
<a href="#">fene/expand</a>	<a href="#">harmonic</a>	<a href="#">morse</a>	<a href="#">nonlinear</a>
<a href="#">quartic</a>			

Angle\_style potentials. See the [angle\\_style](#) command for an overview of angle potentials. Click on the style itself for a full description:

<a href="#">none</a>	<a href="#">hybrid</a>	<a href="#">charmm</a>	<a href="#">class2</a>
<a href="#">cosine</a>	<a href="#">cosine/squared</a>	<a href="#">harmonic</a>	

---

Dihedral\_style potentials. See the [dihedral\\_style](#) command for an overview of dihedral potentials. Click on the style itself for a full description:

<a href="#">none</a>	<a href="#">hybrid</a>	<a href="#">charmm</a>	<a href="#">class2</a>
<a href="#">harmonic</a>	<a href="#">helix</a>	<a href="#">multi/harmonic</a>	<a href="#">opls</a>

---

Improper\_style potentials. See the [improper\\_style](#) command for an overview of improper potentials. Click on the style itself for a full description:

<a href="#">none</a>	<a href="#">hybrid</a>	<a href="#">class2</a>	<a href="#">cvff</a>
<a href="#">harmonic</a>			

---

Kspace solvers. See the [kpace\\_style](#) command for an overview of Kspace solvers. Click on the style itself for a full description:

<a href="#">ewald</a>	<a href="#">pppm</a>	<a href="#">pppm/tip4p</a>
-----------------------	----------------------	----------------------------

## 4. How-to discussions

The following sections describe what commands can be used to perform certain kinds of LAMMPS simulations.

- [4.1 Restarting a simulation](#)
- [4.2 2d simulations](#)
- [4.3 CHARMM and AMBER force fields](#)
- [4.4 Running multiple simulations from one input script](#)
- [4.5 Parallel tempering](#)
- [4.6 Granular models](#)
- [4.7 TIP3P water model](#)
- [4.8 TIP4P water model](#)
- [4.9 SPC water model](#)
- [4.10 Coupling LAMMPS to other codes](#)
- [4.11 Visualizing LAMMPS snapshots](#)
- [4.12 Non-orthogonal simulation boxes](#)
- [4.13 NEMD simulations](#)
- [4.14 Aspherical particles](#)
- [4.15 Output from LAMMPS](#)

The example input scripts included in the LAMMPS distribution and highlighted in [this section](#) also show how to setup and run various kinds of problems.

---

### 4.1 Restarting a simulation

There are 3 ways to continue a long LAMMPS simulation. Multiple [run](#) commands can be used in the same input script. Each run will continue from where the previous run left off. Or binary restart files can be saved to disk using the [restart](#) command. At a later time, these binary files can be read via a [read\\_restart](#) command in a new script. Or they can be converted to text data files and read by a [read\\_data](#) command in a new script. [This section](#) discusses the *restart2data* tool that is used to perform the conversion.

Here we give examples of 2 scripts that read either a binary restart file or a converted data file and then issue a new run command to continue where the previous run left off. They illustrate what settings must be made in the new script. Details are discussed in the documentation for the [read\\_restart](#) and [read\\_data](#) commands.

Look at the *in.chain* input script provided in the *bench* directory of the LAMMPS distribution to see the original script that these 2 scripts are based on. If that script had the line

```
restart          50 tmp.restart
```

added to it, it would produce 2 binary restart files (tmp.restart.50 and tmp.restart.100) as it ran.

This script could be used to read the 1st restart file and re-run the last 50 timesteps:

```
read_restart     tmp.restart.50

neighbor         0.4 bin
neigh_modify     every 1 delay 1

fix             1 all nve
```

```
fix                2 all langevin 1.0 1.0 10.0 904297

timestep           0.012

run                50
```

Note that the following commands do not need to be repeated because their settings are included in the restart file: *units*, *atom\_style*, *special\_bonds*, *pair\_style*, *bond\_style*. However these commands do need to be used, since their settings are not in the restart file: *neighbor*, *fix*, *timestep*.

If you actually use this script to perform a restarted run, you will notice that the thermodynamic data match at step 50 (if you also put a "thermo 50" command in the original script), but do not match at step 100. This is because the [fix langevin](#) command uses random numbers in a way that does not allow for perfect restarts.

As an alternate approach, the restart file could be converted to a data file using this tool:

```
restart2data tmp.restart.50 tmp.restart.data
```

Then, this script could be used to re-run the last 50 steps:

```
units              lj
atom_style         bond
pair_style         lj/cut 1.12
pair_modify        shift yes
bond_style         fene
special_bonds      0.0 1.0 1.0

read_data          tmp.restart.data

neighbor           0.4 bin
neigh_modify       every 1 delay 1

fix                1 all nve
fix                2 all langevin 1.0 1.0 10.0 904297

timestep           0.012

reset_timestep     50
run                50
```

Note that nearly all the settings specified in the original *in.chain* script must be repeated, except the *pair\_coeff* and *bond\_coeff* commands since the new data file lists the force field coefficients. Also, the [reset\\_timestep](#) command is used to tell LAMMPS the current timestep. This value is stored in restart files, but not in data files.

---

## 4.2 2d simulations

Use the [dimension](#) command to specify a 2d simulation.

Make the simulation box periodic in z via the [boundary](#) command. This is the default.

If using the [create box](#) command to define a simulation box, set the z dimensions narrow, but finite, so that the *create\_atoms* command will tile the 3d simulation box with a single z plane of atoms – e.g.

```
create box 1 -10 10 -10 10 -0.25 0.25
```

If using the [read\\_data](#) command to read in a file of atom coordinates, set the "zlo zhi" values to be finite but narrow, similar to the `create_box` command settings just described. For each atom in the file, assign a z coordinate so it falls inside the z-boundaries of the box – e.g. 0.0.

Use the [fix enforce2d](#) command as the last defined fix to insure that the z-components of velocities and forces are zeroed out every timestep. The reason to make it the last fix is so that any forces induced by other fixes will be zeroed out.

Many of the example input scripts included in the LAMMPS distribution are for 2d models.

---

### 4.3 CHARMM and AMBER force fields

There are many different ways to compute forces in the [CHARMM](#) and [AMBER](#) molecular dynamics codes, only some of which are available as options in LAMMPS. A force field has 2 parts: the formulas that define it and the coefficients used for a particular system. Here we only discuss formulas implemented in LAMMPS. Setting coefficients is done in the input data file via the [read\\_data](#) command or in the input script with commands like [pair\\_coeff](#) or [bond\\_coeff](#). See [this section](#) for additional tools that can use CHARMM or AMBER to assign force field coefficients and convert their output into LAMMPS input.

See ([MacKerell](#)) for a description of the CHARMM force field. See ([Cornell](#)) for a description of the AMBER force field.

These style choices compute force field formulas that are consistent with common options in CHARMM or AMBER. See each command's documentation for the formula it computes.

- [bond\\_style](#) harmonic
  - [angle\\_style](#) charmm
  - [dihedral\\_style](#) charmm
  - [pair\\_style](#) lj/charmm/coul/charmm
  - [pair\\_style](#) lj/charmm/coul/charmm/implicit
  - [pair\\_style](#) lj/charmm/coul/long
  
  - [special\\_bonds](#) charmm
  - [special\\_bonds](#) amber
- 

### 4.4 Running multiple simulations from one input script

This can be done in several ways. See the documentation for individual commands for more details on how these examples work.

If "multiple simulations" means continue a previous simulation for more timesteps, then you simply use the [run](#) command multiple times. For example, this script

```
units lj
atom_style atomic
read_data data.lj
run 10000
run 10000
run 10000
run 10000
run 10000
```

would run 5 successive simulations of the same system for a total of 50,000 timesteps.

If you wish to run totally different simulations, one after the other, the `clear` command can be used in between them to re-initialize LAMMPS. For example, this script

```
units lj
atom_style atomic
read_data data.lj
run 10000
clear
units lj
atom_style atomic
read_data data.lj.new
run 10000
```

would run 2 independent simulations, one after the other.

For large numbers of independent simulations, you can use `variables` and the `next` and `jump` commands to loop over the same input script multiple times with different settings. For example, this script, named `in.polymer`

```
variable d index run1 run2 run3 run4 run5 run6 run7 run8
cd $d
read_data data.polymer
run 10000
cd ..
clear
next d
jump in.polymer
```

would run 8 simulations in different directories, using a `data.polymer` file in each directory. The same concept could be used to run the same system at 8 different temperatures, using a temperature variable and storing the output in different log and dump files, for example

```
variable a loop 8
variable t index 0.8 0.85 0.9 0.95 1.0 1.05 1.1 1.15
log log.$a
read data.polymer
velocity all create $t 352839
fix 1 all nvt $t $t 100.0
dump 1 all atom 1000 dump.$a
run 100000
next t
next a
jump in.polymer
```

All of the above examples work whether you are running on 1 or multiple processors, but assumed you are running LAMMPS on a single partition of processors. LAMMPS can be run on multiple partitions via the `"-partition"` command-line switch as described in [this section](#) of the manual.

In the last 2 examples, if LAMMPS were run on 3 partitions, the same scripts could be used if the "index" and "loop" variables were replaced with *universe*-style variables, as described in the `variable` command. Also, the "next t" and "next a" commands would need to be replaced with a single "next a t" command. With these modifications, the 8 simulations of each script would run on the 3 partitions one after the other until all were finished. Initially, 3 simulations would be started simultaneously, one on each partition. When one finished, that partition would then start the 4th simulation, and so forth, until all 8 were completed.

---

## 4.5 Parallel tempering

The `temper` command can be used to perform a parallel tempering or replica–exchange simulation where multiple copies of a simulation are run at different temperatures on different sets of processors, and Monte Carlo temperature swaps are performed between pairs of copies.

Use the `–procs` and `–in` [command–line switches](#) to launch LAMMPS on multiple partitions.

In your input script, define a set of temperatures, one for each processor partition, using the `variable` command:

```
variable t proc 300.0 310.0 320.0 330.0
```

Define a fix of style `nvt` or `langevin` to control the temperature of each simulation:

```
fix myfix all nvt $t $t 100.0
```

Use the `temper` command in place of a `run` command to perform a simulation where tempering exchanges will take place:

```
temper 100000 100 $t myfix 3847 58382
```

---

## 4.6 Granular models

To run a simulation of a granular model, you will want to use the following commands:

- `atom_style` granular
- `fix nve/gran`
- `fix gravity`
- `thermo_style` gran

Use one of these 3 pair potentials:

- `pair_style` gran/history
- `pair_style` gran/no\_history
- `pair_style` gran/hertzian

These commands implement fix options specific to granular systems:

- `fix freeze`
- `fix gran/diag`
- `fix pour`
- `fix viscous`
- `fix wall/gran`

The fix style *freeze* zeroes both the force and torque of frozen atoms, and should be used for granular system instead of the fix style *setforce*.

For computational efficiency, you can eliminate needless pairwise computations between frozen atoms by using this command:

- `neigh_modify` exclude
-

## 4.7 TIP3P water model

The TIP3P water model as implemented in CHARMM ([MacKerell](#)) specifies a 3-site rigid water molecule with charges and Lennard–Jones parameters assigned to each of the 3 atoms. In LAMMPS the [fix shake](#) command can be used to hold the two O–H bonds and the H–O–H angle rigid. A bond style of *harmonic* and an angle style of *harmonic* or *charmm* should also be used.

These are the additional parameters (in real units) to set for O and H atoms and the water molecule to run a rigid TIP3P–CHARMM model with a cutoff. The K values can be used if a flexible TIP3P model (without fix shake) is desired. If the LJ epsilon and sigma for HH and OH are set to 0.0, it corresponds to the original 1983 TIP3P model ([Jorgensen](#)).

O mass = 15.9994  
H mass = 1.008

O charge = -0.834  
H charge = 0.417

LJ epsilon of OO = 0.1521  
LJ sigma of OO = 3.188  
LJ epsilon of HH = 0.0460  
LJ sigma of HH = 0.4000  
LJ epsilon of OH = 0.0836  
LJ sigma of OH = 1.7753

K of OH bond = 450  
r0 of OH bond = 0.9572

K of HOH angle = 55  
theta of HOH angle = 104.52

These are the parameters to use for TIP3P with a long-range Coulombic solver (Ewald or PPPM in LAMMPS):

O mass = 15.9994  
H mass = 1.008

O charge = -0.830  
H charge = 0.415

LJ epsilon of OO = 0.102  
LJ sigma of OO = 3.1507  
LJ epsilon, sigma of OH, HH = 0.0

K of OH bond = 450  
r0 of OH bond = 0.9572

K of HOH angle = 55  
theta of HOH angle = 104.52

---



## 4.8 TIP4P water model

The four-point TIP4P rigid water model extends the traditional three-point TIP3P model by adding an additional site, usually massless, where the charge associated with the oxygen atom is placed. This site M is located at a fixed distance away from the oxygen along the bisector of the HOH bond angle. A bond style of *harmonic* and an angle style of *harmonic* or *charmm* should also be used.

Currently, only a four-point model for long-range Coulombics is implemented via the LAMMPS [pair style lj/cut/coul/long/tip4p](#). We plan to add a cutoff version in the future. For both models, the bond lengths and bond angles should be held fixed using the [fix shake](#) command.

These are the additional parameters (in real units) to set for O and H atoms and the water molecule to run a rigid TIP4P model with a cutoff ([Jorgensen](#)). Note that the OM distance is specified in the [pair\\_style](#) command, not as part of the pair coefficients.

O mass = 15.9994

H mass = 1.008

O charge = -1.040

H charge = 0.520

r0 of OH bond = 0.9572

theta of HOH angle = 104.52

OM distance = 0.15

LJ epsilon of O-O = 0.1550

LJ sigma of O-O = 3.1536

LJ epsilon, sigma of OH, HH = 0.0

These are the parameters to use for TIP4P with a long-range Coulombic solver (Ewald or PPPM in LAMMPS):

O mass = 15.9994

H mass = 1.008

O charge = -1.0484

H charge = 0.5242

r0 of OH bond = 0.9572

theta of HOH angle = 104.52

OM distance = 0.1250

LJ epsilon of O-O = 0.16275

LJ sigma of O-O = 3.16435

LJ epsilon, sigma of OH, HH = 0.0

---

## 4.9 SPC water model

The SPC water model specifies a 3-site rigid water molecule with charges and Lennard-Jones parameters assigned to each of the 3 atoms. In LAMMPS the [fix shake](#) command can be used to hold the two O-H bonds and

the H–O–H angle rigid. A bond style of *harmonic* and an angle style of *harmonic* or *charmm* should also be used.

These are the additional parameters (in real units) to set for O and H atoms and the water molecule to run a rigid SPC model with long-range Coulombics (Ewald or PPPM in LAMMPS).

O mass = 15.9994

H mass = 1.008

O charge = -0.820

H charge = 0.410

LJ epsilon of OO = 0.1553

LJ sigma of OO = 3.166

LJ epsilon, sigma of OH, HH = 0.0

r0 of OH bond = 1.0

theta of HOH angle = 109.47

---

## 4.10 Coupling LAMMPS to other codes

LAMMPS is designed to allow it to be coupled to other codes. For example, a quantum mechanics code might compute forces on a subset of atoms and pass those forces to LAMMPS. Or a continuum finite element (FE) simulation might use atom positions as boundary conditions on FE nodal points, compute a FE solution, and return interpolated forces on MD atoms.

LAMMPS can be coupled to other codes in at least 3 ways. Each has advantages and disadvantages, which you'll have to think about in the context of your application.

(1) Define a new [fix](#) command that calls the other code. In this scenario, LAMMPS is the driver code. During its timestepping, the fix is invoked, and can make library calls to the other code, which has been linked to LAMMPS as a library. This is the way the [POEMS](#) package that performs constrained rigid-body motion on groups of atoms is hooked to LAMMPS. See the [fix\\_poems](#) command for more details. See [this section](#) of the documentation for info on how to add a new fix to LAMMPS.

(2) Define a new LAMMPS command that calls the other code. This is conceptually similar to method (1), but in this case LAMMPS and the other code are on a more equal footing. Note that now the other code is not called during the timestepping of a LAMMPS run, but between runs. The LAMMPS input script can be used to alternate LAMMPS runs with calls to the other code, invoked via the new command. The [run](#) command facilitates this with its *every* option, which makes it easy to run a few steps, invoke the command, run a few steps, invoke the command, etc.

In this scenario, the other code can be called as a library, as in (1), or it could be a stand-alone code, invoked by a `system()` call made by the command (assuming your parallel machine allows one or more processors to start up another program). In the latter case the stand-alone code could communicate with LAMMPS thru files that the command writes and reads.

See [this section](#) of the documentation for how to add a new command to LAMMPS.

(3) Use LAMMPS as a library called by another code. In this case the other code is the driver and calls LAMMPS as needed. Or a wrapper code could link and call both LAMMPS and another code as libraries. Again, the [run](#) command has options that allow it to be invoked with minimal overhead (no setup or clean-up) if you wish to do

multiple short runs, driven by another program.

[This section](#) of the documentation describes how to build LAMMPS as a library. Once this is done, you can interface with LAMMPS either via C++, C, or Fortran (or any other language that supports a vanilla C-like interface, e.g. a scripting language). For example, from C++ you could create one (or more) "instances" of LAMMPS, pass it an input script to process, or execute individual commands, all by invoking the correct class methods in LAMMPS. From C or Fortran you can make function calls to do the same things. `Library.cpp` and `library.h` contain such a C interface with the functions:

```
void lammmps_open(int, char **, MPI_Comm, void **);
void lammmps_close(void *);
void lammmps_file(void *, char *);
char *lammmps_command(void *, char *);
```

The functions contain C++ code you could write in a C++ application that was invoking LAMMPS directly. Note that LAMMPS classes are defined within a LAMMPS namespace (`LAMMPS_NS`) if you use them from another C++ application.

Two of the routines in `library.cpp` are of particular note. The `lammmps_open()` function initiates LAMMPS and takes an MPI communicator as an argument. It returns a pointer to a LAMMPS "object". As with C++, the `lammmps_open()` function can be called multiple times, to create multiple instances of LAMMPS.

LAMMPS will run on the set of processors in the communicator. This means the calling code can run LAMMPS on all or a subset of processors. For example, a wrapper script might decide to alternate between LAMMPS and another code, allowing them both to run on all the processors. Or it might allocate half the processors to LAMMPS and half to the other code and run both codes simultaneously before syncing them up periodically.

`Library.cpp` contains a `lammmps_command()` function to which the caller passes a single LAMMPS command (a string). Thus the calling code can read or generate a series of LAMMPS commands (e.g. an input script) one line at a time and pass it thru the library interface to setup a problem and then run it.

A few other sample functions are included in `library.cpp`, but the key idea is that you can write any functions you wish to define an interface for how your code talks to LAMMPS and add them to `library.cpp` and `library.h`. The routines you add can access any LAMMPS data. The `examples/couple` directory has example C++ and C codes which show how a stand-alone code can link LAMMPS as a library, run LAMMPS on a subset of processors, grab data from LAMMPS, change it, and put it back into LAMMPS.

---

## 4.11 Visualizing LAMMPS snapshots

LAMMPS itself does not do visualization, but snapshots from LAMMPS simulations can be visualized (and analyzed) in a variety of ways.

LAMMPS snapshots are created by the [dump](#) command which can create files in several formats. The native LAMMPS dump format is a text file (see "dump atom" or "dump custom") which can be visualized by the [xmovie](#) program, included with the LAMMPS package. This produces simple, fast 2d projections of 3d systems, and can be useful for rapid debugging of simulation geometry and atom trajectories.

Several programs included with LAMMPS as auxiliary tools can convert native LAMMPS dump files to other formats. See the [Section\\_tools](#) doc page for details. The first is the [ch2lmp](#) tool, which contains a `lammmps2pdb` Perl script which converts LAMMPS dump files into PDB files. The second is the [lmp2arc](#) tool which converts LAMMPS dump files into Accelrys's Insight MD program files. The third is the [lmp2cfg](#) tool which converts LAMMPS dump files into CFG files which can be read into the [AtomEye](#) visualizer.

A Python-based toolkit distributed by our group can read native LAMMPS dump files, including custom dump files with additional columns of user-specified atom information, and convert them to various formats or pipe them into visualization software directly. See the [Pizza.py WWW site](#) for details. Specifically, Pizza.py can convert LAMMPS dump files into PDB, XYZ, [Ensight](#), and VTK formats. Pizza.py can pipe LAMMPS dump files directly into the Raster3d and RasMol visualization programs. Pizza.py has tools that do interactive 3d OpenGL visualization and one that creates SVG images of dump file snapshots.

LAMMPS can create XYZ files directly (via "dump xyz") which is a simple text-based file format used by many visualization programs including [VMD](#).

LAMMPS can create DCD files directly (via "dump dcd") which can be read by [VMD](#) in conjunction with a CHARMM PSF file. Using this form of output avoids the need to convert LAMMPS snapshots to PDB files. See the [dump](#) command for more information on DCD files.

LAMMPS can create XTC files directly (via "dump xtc") which is GROMACS file format which can also be read by [VMD](#) for visualization. See the [dump](#) command for more information on XTC files.

---

## 4.12 Non-orthogonal simulation boxes

By default, LAMMPS uses an orthogonal simulation box to encompass the particles. The [boundary](#) command sets the boundary conditions of the box (periodic, non-periodic, etc). If the box size is xprd by yprd by zprd then the 3 mutually orthogonal edge vectors of an orthogonal simulation box are  $a = (xprd, 0, 0)$ ,  $b = (0, yprd, 0)$ , and  $c = (0, 0, zprd)$ .

LAMMPS also allows non-orthogonal simulation boxes (triclinic symmetry) to be defined with 3 additional "tilt" parameters which change the edge vectors of the simulation box to be  $a = (xprd, 0, 0)$ ,  $b = (xy, yprd, 0)$ , and  $c = (xz, yz, zprd)$ . The xy, xz, and yz parameters can be positive or negative. The simulation box must be periodic in both dimensions associated with a tilt factor. For example, if  $xz \neq 0.0$ , then the x and z dimensions must be periodic.

To avoid extremely tilted boxes (which would be computationally inefficient), no tilt factor can skew the box more than half the distance of the parallel box length, which is the 1st dimension in the tilt factor (x for xz). For example, if  $xlo = 2$  and  $xhi = 12$ , then the x box length is 10 and the xy tilt factor must be between -5 and 5. Similarly, both xz and yz must be between  $-(xhi - xlo)/2$  and  $+(yhi - ylo)/2$ . Note that this is not a limitation, since if the maximum tilt factor is 5 (as in this example), then configurations with tilt = ..., -15, -5, 5, 15, 25, ... are all equivalent.

You tell LAMMPS to use a non-orthogonal box when the simulation box is defined. This happens in one of 3 ways. If the [create\\_box](#) command is used with a region of style *prism*, then a non-orthogonal domain is setup. See the [region](#) command for details. If the [read\\_data](#) command is used to define the simulation box, and the header of the data file contains a line with the "xy xz yz" keyword, then a non-orthogonal domain is setup. See the [read\\_data](#) command for details. Finally, if the [read\\_restart](#) command reads a restart file which was written from a simulation using a triclinic box, then a non-orthogonal box will be enabled for the restarted simulation.

Note that you can define a non-orthogonal box with all 3 tilt factors = 0.0, so that it is initially orthogonal. This is necessary if the box will become non-orthogonal. Alternatively, you can use the [change\\_box](#) command to convert a simulation box from orthogonal to non-orthogonal and vice versa.

One use of non-orthogonal boxes is to model solid-state crystals with triclinic symmetry. The [lattice](#) command can be used with non-orthogonal basis vectors to define a lattice that will tile a non-orthogonal simulation box via the [create\\_atoms](#) command. Note that while the box edge vectors a,b,c cannot be arbitrary vectors (e.g. a must

be aligned with the x axis), it is possible to rotate any crystal's basis vectors so that they meet these restrictions.

A second use of non-orthogonal boxes is to shear a bulk solid to study the response of the material. The [fix deform](#) command can be used for this purpose. It allows dynamic control of the xy, xz, and yz tilt factors as a simulation runs.

Another use of non-orthogonal boxes is to perform non-equilibrium MD (NEMD) simulations, as discussed in the next section.

---

### 4.13 NEMD simulations

Non-equilibrium molecular dynamics or NEMD simulations are typically used to measure a fluid's rheological properties such as viscosity. In LAMMPS, such simulations can be performed by first setting up a non-orthogonal simulation box (see the preceding Howto section).

A shear strain can be applied to the simulation box at a desired strain rate by using the [fix deform](#) command. The [fix nvt/sllod](#) command can be used to thermostat the sheared fluid and integrate the SLLOD equations of motion for the system. Fix nvt/sllod uses [compute temp/deform](#) to compute a thermal temperature by subtracting out the streaming velocity of the shearing atoms. The velocity profile or other properties of the fluid can be monitored via the [fix ave/spatial](#) command.

As discussed in the previous section on non-orthogonal simulation boxes, the amount of tilt or skew that can be applied is limited by LAMMPS for computational efficiency to be 1/2 of the parallel box length. However, [fix deform](#) can continuously strain a box by an arbitrary amount. As discussed in the [fix deform](#) command, when the tilt value reaches a limit, the box is re-shaped to the opposite limit which is an equivalent tiling of periodic space. The strain rate can then continue to change as before. In a long NEMD simulation these box re-shaping events may occur many times.

In a NEMD simulation, the "remap" option of [fix deform](#) should be set to "remap v", since that is what [fix nvt/sllod](#) assumes to generate a velocity profile consistent with the applied shear strain rate.

---

### 4.14 Aspherical particles

LAMMPS supports ellipsoidal particles via the [atom\\_style ellipsoid](#) and [shape](#) commands. The latter command defines the 3 axes (diameters) of a general ellipsoid. The [pair\\_style gayberne](#) command can be used to define a Gay-Berne (GB) potential for how ellipsoidal particles interact with each other and with spherical particles. The GB potential is like a Lennard-Jones (LJ) potential, generalized for orientation-dependent interactions.

The orientation of ellipsoidal particles is stored as a quaternion. See the [set](#) command for a brief explanation of quaternions and how the orientation of such particles can be initialized. The data file read by the [read\\_data](#) command contains quaternions for each atom in the Atoms section if [atom\\_style ellipsoid](#) is being used. The [compute temp/asphere](#) command can be used to calculate the temperature of a group of ellipsoidal particles, taking account of rotational degrees of freedom. The motion of the particles can be integrated via the [fix nve/asphere](#), [fix nvt/asphere](#), or [fix npt/asphere](#) commands. All of these commands are part of the ASPHERE package in LAMMPS.

Computationally, the cost for two ellipsoidal particles to interact is 30 times (or more) expensive than for 2 spherical LJ particles. Thus if you are modeling a system with many spherical particles (e.g. as the solvent), then you should insure sphere-sphere interactions are computed with a cheaper potential than GB. This can be done by setting the particle's 3 shape parameters to all be equal (a sphere). Additionally, the corresponding GB potential

coefficients can be set so the GB potential will treat the pair of particles as LJ spheres. Details are given in the doc page for the [pair\\_style gayberne](#). Alternatively, the [pair\\_style hybrid](#) potential can be used, with the sphere-sphere interactions computed by another pair potential, such as [pair\\_style lj/cut](#).

---

## 4.15 Output from LAMMPS

There are two basic kinds of LAMMPS output. The first is thermodynamic output, which is a list of quantities printed every few timesteps to the screen and logfile. The second is dump files, which contain snapshots of atoms and various per-atom values and are written at a specified frequency. A simulation prints one set of thermodynamic output; it may generate zero, or one, or multiple dump files. LAMMPS gives you a variety of ways to determine what quantities are computed and printed when thermodynamic info or dump files are output. There are also two fixes which perform time and spatial averaging of user-defined quantities, `fix ave/time` and `fix ave/spatial`. These produce their own output files and are described below.

The frequency and format of thermodynamic output is set by the [thermo](#), [thermo\\_style](#), and [thermo\\_modify](#) commands. The [thermo\\_style](#) command also specifies what values are calculated and written out. Pre-defined keywords can be specified (e.g. `press`, `etotal`, etc) which include time-averaged versions of temperature, pressure, and a few other variables (`tave`, `pave`, etc). Three additional kinds of keywords can also be specified (`c_ID`, `f_ID`, `v_name`), where a [compute](#) or [fix](#) or [variable](#) provides the value(s) to be output. Each of these are described in turn.

In LAMMPS, a [compute](#) comes in two flavors: ones that compute one or more global values (e.g. temperature, kinetic energy tensor) and ones that compute one or more per-atom values. Only the former can be used for thermodynamic output. The user-defined ID of the compute is used along with an optional subscript as part of the [thermo\\_style](#) command. E.g. `c_myTemp` outputs the single scalar value generated by the compute; `c_myTemp[2]` would output the 2nd vector value.

[Fixes](#) can also generate values to output with thermodynamic output, e.g. the energy of an indenter's interaction with the simulation atoms. These values are accessed via the same format as compute's values, as `f_ID` or `f_ID[N]`. See the doc pages for individual fix commands to see which ones generate thermodynamic values.

Input script variables of various kinds are defined by the [variable](#) command. All kinds except the atom-style variable can be used for thermodynamic output. A variable with name "abc" is referenced in a `thermo_style` command as `v_abc`.

The variable formula defined in the input script can contain math functions (`add`, `exp`, etc), atom values (`xN`, `fxN`), **groups quantities** (`mass()`, `vcm()`, etc), **references to thermodynamic quantities** (e.g. `temp`, `volume`, etc), or **references to other variables or computes**. Thus a variable is the most general way to define some quantity you want calculated and output with thermodynamic info.

Dump file output is specified by the [dump](#) and [dump\\_modify](#) commands. There are several pre-defined formats (`dump atom`, `dump xtc`, etc). There is also a [dump custom](#) format where you specify what values are output with each atom. Pre-defined keywords can be specified (e.g. `tag`, `type`, `x`, etc). Two additional kinds of keywords can also be specified (`c_ID`, `f_ID`), where a [compute](#) or [fix](#) provides the values to be output.

"Computes" that generate per-atom values can be accessed by the `dump custom` command. These are computes that have the word "atom" in their style name, e.g. `ke/atom`, `stress/atom`, etc. The values are accessed as described above: `c_myKE` or `c_myStress[2]`. The "compute variable/atom" command takes a user-defined atom-style "variable" as input and calculates its value for each atom. Since this compute can be accessed by the `dump custom` command, this is a general way to define some quantity you want calculated and output in a dump file.

**Fixes** can also generate values to output to dump files. For example, the "fix ave/atom" command does time-averaging of atom quantities, such as velocity or energy or stress which can then be output in a dump file. These values are accessed as describe above, as f\_ID or f\_ID[N].

Two other fixes are of particular note for output. The **fix ave/time** command does not produce values for thermodynamic output, but allows for time-averaging of **compute** quantities and outputs its results to a file. Thus it can be used to output thermodynamic kinds of global quantities on any desired timescale.

The "fix ave/spatial" command does not produce values for thermodynamic or dump output, but allows for spatial-averaging of

or uses fix ave/atom as input

---

**(Cornell)** Cornell, Cieplak, Bayly, Gould, Merz, Ferguson, Spellmeyer, Fox, Caldwell, Kollman, JACS 117, 5179–5197 (1995).

**(Horn)** Horn, Swope, Pitner, Madura, Dick, Hura, and Head-Gordon, J Chem Phys, 120, 9665 (2004).

**(MacKerell)** MacKerell, Bashford, Bellott, Dunbrack, Evanseck, Field, Fischer, Gao, Guo, Ha, et al, J Phys Chem, 102, 3586 (1998).

**(Jorgensen)** Jorgensen, Chandrasekhar, Madura, Impey, Klein, J Chem Phys, 79, 926 (1983).



## 5. Example problems

The LAMMPS distribution includes an examples sub-directory with several sample problems. Each problem is in a sub-directory of its own. Most are 2d models so that they run quickly, requiring at most a couple of minutes to run on a desktop machine. Each problem has an input script (in.\*) and produces a log file (log.\*) and dump file (dump.\*) when it runs. Some use a data file (data.\*) of initial coordinates as additional input. A few sample log file outputs on different machines and different numbers of processors are included in the directories to compare your answers to. E.g. a log file like log.crack.foo.P means it ran on P processors of machine "foo".

The dump files produced by the example runs can be animated using the xmovie tool described in the [Additional Tools](#) section of the LAMMPS documentation. Animations of many of these examples can be viewed on the [Movies](#) section of the [LAMMPS WWW Site](#).

These are the sample problems in the examples sub-directories:

colloid	big colloid particles in a small particle solvent, 2d system
crack	crack propagation in a 2d solid
dipole	point dipolar particles, 2d system
ellipse	ellipsoidal particles in spherical solvent, 2d system
flow	Couette and Poiseuille flow in a 2d channel
friction	frictional contact of spherical asperities between 2d surfaces
indent	spherical indenter into a 2d solid
meam	MEAM test for SiC and shear (same as shear examples)
melt	rapid melt of 3d LJ system
micelle	self-assembly of small lipid-like molecules into 2d bilayers
min	energy minimization of 2d LJ melt
nemd	non-equilibrium MD of 2d sheared system
obstacle	flow around two voids in a 2d channel
peptide	dynamics of a small solvated peptide chain (5-mer)
pour	pouring of granular particles into a 3d box, then chute flow
rigid	rigid bodies modeled as independent or coupled
shear	sideways shear applied to 2d solid, with and without a void

Here is how you might run and visualize one of the sample problems:

```
cd indent
cp ../../src/lmp_linux .           # copy LAMMPS executable to this dir
lmp_linux <in.indent               # run the problem
```

Running the simulation produces the files *dump.indent* and *log.lammps*. You can visualize the dump file as follows:



```
../../tools/xmovie/xmovie -scale dump.indent
```

There is also a directory "couple" in the examples sub-directory, which contains a stand-alone code umbrella.cpp that links LAMMPS as a library. The README describes how to build the code. The code itself runs LAMMPS on a subset of processors, sets up a LAMMPS problem by invoking LAMMPS input script commands one at a time, does a run, grabs atom coordinates, changes one atom position, puts them back into LAMMPS, and does another run.

This illustrates how an umbrella code could include new models and physics while using LAMMPS to perform MD, or how the umbrella code could call both LAMMPS and some other code to perform a coupled calculation.

## 6. Performance & scalability

LAMMPS performance on several prototypical benchmarks and machines is discussed on the Benchmarks page of the [LAMMPS WWW Site](#) where CPU timings and parallel efficiencies are listed. Here, the benchmarks are described briefly and some useful rules of thumb about their performance are highlighted.

These are the 5 benchmark problems:

1. LJ = atomic fluid, Lennard–Jones potential with 2.5 sigma cutoff (55 neighbors per atom), NVE integration
2. Chain = bead–spring polymer melt of 100–mer chains, FENE bonds and LJ pairwise interactions with a  $2^{1/6}$  sigma cutoff (5 neighbors per atom), NVE integration
3. EAM = metallic solid, Cu EAM potential with 4.95 Angstrom cutoff (45 neighbors per atom), NVE integration
4. Chute = granular chute flow, frictional history potential with 1.1 sigma cutoff (7 neighbors per atom), NVE integration
5. Rhodo = rhodopsin protein in solvated lipid bilayer, CHARMM force field with a 10 Angstrom LJ cutoff (440 neighbors per atom), particle–particle particle–mesh (PPPM) for long–range Coulombics, NPT integration

The input files for running the benchmarks are included in the LAMMPS distribution, as are sample output files. Each of the 5 problems has 32,000 atoms and runs for 100 timesteps. Each can be run as a serial benchmark (on one processor) or in parallel. In parallel, each benchmark can be run as a fixed–size or scaled–size problem. For fixed–size benchmarking, the same 32K atom problem is run on various numbers of processors. For scaled–size benchmarking, the model size is increased with the number of processors. E.g. on 8 processors, a 256K–atom problem is run; on 1024 processors, a 32–million atom problem is run, etc.

A useful metric from the benchmarks is the CPU cost per atom per timestep. Since LAMMPS performance scales roughly linearly with problem size and timesteps, the run time of any problem using the same model (atom style, force field, cutoff, etc) can then be estimated. For example, on a 1.7 GHz Pentium desktop machine (Intel icc compiler under Red Hat Linux), the CPU run–time in seconds/atom/timestep for the 5 problems is

Problem:	LJ	Chain	EAM	Chute	Rhodopsin
CPU/atom/step:	4.55E–6	2.18E–6	9.38E–6	2.18E–6	1.11E–4
Ratio to LJ:	1.0	0.48	2.06	0.48	24.5

The ratios mean that if the atomic LJ system has a normalized cost of 1.0, the bead–spring chains and granular systems run 2x faster, while the EAM metal and solvated protein models run 2x and 25x slower respectively. The bulk of these cost differences is due to the expense of computing a particular pairwise force field for a given number of neighbors per atom.

Performance on a parallel machine can also be predicted from the one–processor timings if the parallel efficiency can be estimated. The communication bandwidth and latency of a particular parallel machine affects the efficiency. On most machines LAMMPS will give fixed–size parallel efficiencies on these benchmarks above 50% so long as the atoms/processor count is a few 100 or greater – i.e. on 64 to 128 processors. Likewise, scaled–size parallel efficiencies will typically be 80% or greater up to very large processor counts. The benchmark data on the [LAMMPS WWW Site](#) gives specific examples on some different machines, including a run of 3/4 of a billion LJ atoms on 1500 processors that ran at 85% parallel efficiency.

## 7. Additional tools

LAMMPS is designed to be a computational kernel for performing molecular dynamics computations. Additional pre- and post-processing steps are often necessary to setup and analyze a simulation. A few additional tools are provided with the LAMMPS distribution and are described in this section.

Our group has also written and released a separate toolkit called [Pizza.py](#) which provides tools for doing setup, analysis, plotting, and visualization for LAMMPS simulations. Pizza.py is written in [Python](#) and is available for download from [the Pizza.py WWW site](#).

Note that many users write their own setup or analysis tools or use other existing codes and convert their output to a LAMMPS input format or vice versa. The tools listed here are included in the LAMMPS distribution as examples of auxiliary tools. Some of them are not actively supported by Sandia, as they were contributed by LAMMPS users. If you have problems using them, we can direct you to the authors.

The source code for each of these codes is in the tools sub-directory of the LAMMPS distribution. There is a Makefile (which you may need to edit for your platform) which will build several of the tools which reside in that directory. Some of them are larger packages in their own sub-directories with their own Makefiles.

- [amber2lammps](#)
- [binary2txt](#)
- [ch2lmp](#)
- [chain](#)
- [data2xmovie](#)
- [lmp2arc](#)
- [lmp2cfg](#)
- [lmp2traj](#)
- [matlab](#)
- [micelle2d](#)
- [msi2lmp](#)
- [pymol\\_asphere](#)
- [restart2data](#)
- [thermo\\_extract](#)
- [xmovie](#)

---

### amber2lmp tool

The amber2lmp sub-directory contain two Python scripts for converting files back-and-forth between the AMBER MD code and LAMMPS. See the README file in amber2lmp for more information.

These tools were written by Keir Novik while he was at Queen Mary University of London. Keir is no longer there and cannot support these tools which are out-of-date with respect to the current LAMMPS version (and maybe with respect to AMBER as well). Since we don't use these tools at Sandia, you'll need to experiment with them and make necessary modifications yourself.

---

### binary2txt tool

The file binary2txt.cpp converts one or more binary LAMMPS dump file into ASCII text files. The syntax for running the tool is

```
binary2txt file1 file2 ...
```

which creates file1.txt, file2.txt, etc. This tool must be compiled on a platform that can read the binary file created by a LAMMPS run, since binary files are not compatible across all platforms.

---

## ch2lmp tool

The ch2lmp sub-directory contains tools for converting files back-and-forth between the CHARMM MD code and LAMMPS.

They are intended to make it easy to use CHARMM as a builder and as a post-processor for LAMMPS. Using charmm2lammps.pl, you can convert an ensemble built in CHARMM into its LAMMPS equivalent. Using lammps2pdb.pl you can convert LAMMPS atom dumps into pdb files.

See the README file in the ch2lmp sub-directory for more information.

These tools were created by Pieter in't Veld (pjintve at sandia.gov) and Paul Crozier (pscrozi at sandia.gov) at Sandia.

---

## chain tool

The file chain.f creates a LAMMPS data file containing bead-spring polymer chains and/or monomer solvent atoms. It uses a text file containing chain definition parameters as an input. The created chains and solvent atoms can strongly overlap, so LAMMPS needs to run the system initially with a "soft" pair potential to un-overlap it. The syntax for running the tool is

```
chain <def.chain > data.file
```

See the def.chain or def.chain.ab files in the tools directory for examples of definition files. This tool was used to create the system for the [chain benchmark](#).

---

## data2xmovie tool

The file data2xmovie.c converts a LAMMPS data file into a snapshot suitable for visualizing with the [xmovie](#) tool, as if it had been output with a dump command from LAMMPS itself. The syntax for running the tool is

```
data2xmovie options <infile > outfile
```

See the top of the data2xmovie.c file for a discussion of the options.

---

## lmp2arc tool

The lmp2arc sub-directory contains a tool for converting LAMMPS output files to the format for Accelrys's Insight MD code (formerly MSI/Biosym and its Discover MD code). See the README file for more information.

This tool was written by John Carpenter (Cray), Michael Peachey (Cray), and Steve Lustig (Dupont). John is now at the Mayo Clinic (jec at mayo.edu), but still fields questions about the tool.

This tool was updated for the current LAMMPS C++ version by Jeff Greathouse at Sandia (jagreat at sandia.gov).

---

## Imp2cfg tool

The Imp2cfg sub-directory contains a tool for converting LAMMPS output files into a series of \*.cfg files which can be read into the [AtomEye](#) visualizer. See the README file for more information.

This tool was written by Ara Kooser at Sandia (askoose at sandia.gov).

---

## Imp2traj tool

The Imp2traj sub-directory contains a tool for converting LAMMPS output files into 3 analysis files. One file can be used to create contour maps of the atom positions over the course of the simulation. The other two files provide density profiles and dipole moments. See the README file for more information.

This tool was written by Ara Kooser at Sandia (askoose at sandia.gov).

---

## matlab tool

The matlab sub-directory contains several [MATLAB](#) scripts for post-processing LAMMPS output. The scripts include readers for log and dump files, a reader for radial distribution output from the [fix rdf](#) command, a reader for EAM potential files, and a converter that reads LAMMPS dump files and produces CFG files that can be visualized with the [AtomEye](#) visualizer.

See the README.pdf file for more information.

These scripts were written by Arun Subramaniyan at Purdue Univ (asubrama at purdue.edu).

---

## micelle2d tool

The file micelle2d.f creates a LAMMPS data file containing short lipid chains in a monomer solution. It uses a text file containing lipid definition parameters as an input. The created molecules and solvent atoms can strongly overlap, so LAMMPS needs to run the system initially with a "soft" pair potential to un-overlap it. The syntax for running the tool is

```
micelle2d <def.micelle2d > data.file
```

See the def.micelle2d file in the tools directory for an example of a definition file. This tool was used to create the system for the [micelle example](#).

---

## msi2Imp tool

The msi2Imp sub-directory contains a tool for creating LAMMPS input data files from Accelrys's Insight MD code (formerly MSI/Biosysm and its Discover MD code). See the README file for more information.

This tool was written by John Carpenter (Cray), Michael Peachey (Cray), and Steve Lustig (Dupont). John is now at the Mayo Clinic (jec at mayo.edu), but still fields questions about the tool.

This tool may be out-of-date with respect to the current LAMMPS and Insight versions. Since we don't use it at Sandia, you'll need to experiment with it yourself.

---

## pymol\_asphere tool

The pymol\_asphere sub-directory contains a tool for converting a LAMMPS dump file that contains orientation info for ellipsoidal particles into an input file for the [PyMol visualization package](#).

Specifically, the tool triangulates the ellipsoids so they can be viewed as true ellipsoidal particles within PyMol. See the README and examples directory within pymol\_asphere for more information.

This tool was written by Mike Brown at Sandia.

---

## restart2data tool

The file restart2data.cpp converts a binary LAMMPS restart file into an ASCII data file. The syntax for running the tool is

```
restart2data restart-file data-file
```

This tool must be compiled on a platform that can read the binary file created by a LAMMPS run, since binary files are not compatible across all platforms.

Note that a text data file has less precision than a binary restart file. Hence, continuing a run from a converted data file will typically not conform as closely to a previous run as will restarting from a binary restart file.

If a "%" appears in the specified restart-file, the tool expects a set of multiple files to exist. See the [restart](#) and [write\\_restart](#) commands for info on how such sets of files are written by LAMMPS, and how the files are named.

---

## thermo\_extract tool

The thermo\_extract tool reads one or more LAMMPS log files and extracts a thermodynamic value (e.g. Temp, Press). It spits out the time,value as 2 columns of numbers so the tool can be used as a quick way to plot some quantity of interest. See the header of the thermo\_extract.c file for the syntax of how to run it and other details.

This tool was written by Vikas Varshney at Wright Patterson AFB (vikas.varshney at gmail.com).

---

## xmovie tool

The xmovie tool is an X-based visualization package that can read LAMMPS dump files and animate them. It is in its own sub-directory with the tools directory. You may need to modify its Makefile so that it can find the appropriate X libraries to link against.

The syntax for running xmovie is

```
xmovie options dump.file1 dump.file2 ...
```

If you just type "xmovie" you will see a list of options. Note that by default, LAMMPS dump files are in scaled coordinates, so you typically need to use the `-scale` option with xmovie. When xmovie runs it opens a visualization window and a control window. The control options are straightforward to use.

Xmovie was mostly written by Mike Uttormark (U Wisconsin) while he spent a summer at Sandia. It displays 2d projections of a 3d domain. While simple in design, it is an amazingly fast program that can render large numbers of atoms very quickly. It's a useful tool for debugging LAMMPS input and output and making sure your simulation is doing what you think it should. The animations on the Examples page of the [LAMMPS WWW site](#)

were created with xmovie.

I've lost contact with Mike, so I hope he's comfortable with us distributing his great tool!

## 8. Modifying & extending LAMMPS

LAMMPS is designed in a modular fashion so as to be easy to modify and extend with new functionality. In fact, about 75% of its source code is files added in this fashion.

In this section, changes and additions users can make are listed along with minimal instructions. The best way to add a new feature is to find a similar feature in LAMMPS and look at the corresponding source and header files to figure out what it does. You will need some knowledge of C++ to be able to understand the hi-level structure of LAMMPS and its class organization, but functions (class methods) that do actual computations are written in vanilla C-style code and operate on simple C-style data structures (vectors and arrays).

Most of the new features described in this section require you to write a new C++ derived class (except for exceptions described below, where you can make small edits to existing files). Creating a new class requires 2 files, a source code file (\*.cpp) and a header file (\*.h). The derived class must provide certain methods to work as a new option. Depending on how different your new feature is compared to existing features, you can either derive from the base class itself, or from a derived class that already exists. Enabling LAMMPS to invoke the new class is as simple as adding two lines to the style\_user.h file, in the same syntax as other LAMMPS classes are specified in the style.h file.

The advantage of C++ and its object-orientation is that all the code and variables needed to define the new feature are in the 2 files you write, and thus shouldn't make the rest of LAMMPS more complex or cause side-effect bugs.

Here is a concrete example. Suppose you write 2 files pair\_foo.cpp and pair\_foo.h that define a new class PairFoo that computes pairwise potentials described in the classic 1997 [paper](#) by Foo, et al. If you wish to invoke those potentials in a LAMMPS input script with a command like

```
pair_style foo 0.1 3.5
```

you put your 2 files in the LAMMPS src directory, add 2 lines to the style\_user.h file, and re-make the code.

The first line added to style\_user.h would be

```
PairStyle(foo,PairFoo)
```

in the #ifdef PairClass section, where "foo" is the style keyword in the pair\_style command, and PairFoo is the class name in your C++ files.

The 2nd line added to style\_user.h would be

```
#include "pair_foo.h"
```

in the #ifdef PairInclude section, where pair\_foo.h is the name of your new include file.

When you re-make LAMMPS, your new pairwise potential becomes part of the executable and can be invoked with a pair\_style command like the example above. Arguments like 0.1 and 3.5 can be defined and processed by your new class.

Here is a list of the new features that can be added in this way:



- [Atom styles](#)
- [Bond, angle, dihedral, improper potentials](#)
- [Compute styles](#)
- [Dump styles](#)
- [Fix styles](#) which include integrators, temperature and pressure control, force constraints, boundary conditions, diagnostic output, etc
- [Input script commands](#)
- [Kspace computations](#)
- [Minimization solvers](#)
- [Pairwise potentials](#)
- [Region styles](#)

As illustrated by the pairwise example, these options are referred to in the LAMMPS documentation as the "style" of a particular command.

The instructions below give the header file for the base class that these styles are derived from. Public variables in that file are ones used and set by the derived classes which are also used by the base class. Sometimes they are also used by the rest of LAMMPS. Virtual functions in the base class header file which are set = 0 are ones you must define in your new derived class to give it the functionality LAMMPS expects. Virtual functions that are not set to 0 are functions you can optionally define.

Additionally, new output options can be added directly to the thermo.cpp, dump\_custom.cpp, and variable.cpp files as explained in these sections:

- [Dump custom output options](#)
- [Thermodynamic output options](#)
- [Variable options](#)

---

Here are additional guidelines for modifying LAMMPS and adding new functionality:

- Think about whether what you want to do would be better as a pre- or post-processing step. Many computations are more easily and more quickly done that way.
  - Don't do anything within the timestepping of a run that isn't parallel. E.g. don't accumulate a bunch of data on a single processor and analyze it. You run the risk of seriously degrading the parallel efficiency.
  - If your new feature reads arguments or writes output, make sure you follow the unit conventions discussed by the [units](#) command.
  - If you add something you think is truly useful and doesn't impact LAMMPS performance when it isn't used, send an email to the [developers](#). We might be interested in adding it to the LAMMPS distribution.
- 
- 

## Atom styles

Classes that define an atom style are derived from the Atom class. The atom style determines what quantities are associated with an atom. A new atom style can be created if one of the existing atom styles does not define all the arrays you need to store and communicate with atoms.

Atom\_vec\_atomic.cpp is a simple example of an atom style.

Here is a brief description of methods you define in your new derived class. See atom.h for details.

grow	re-allocate atom arrays to longer lengths
------	---

copy	copy info for one atom to another atom's array locations
pack_comm	store an atom's info in a buffer communicated every timestep
unpack_comm	retrieve an atom's info from the buffer
pack_reverse	store an atom's info in a buffer communicating partial forces
unpack_reverse	retrieve an atom's info from the buffer
pack_border	store an atom's info in a buffer communicated on neighbor re-builds
unpack_border	retrieve an atom's info from the buffer
pack_exchange	store all an atom's info to migrate to another processor
unpack_exchange	retrieve an atom's info from the buffer
size_restart	number of restart quantities associated with proc's atoms
pack_restart	pack atom quantities into a buffer
unpack_restart	unpack atom quantities from a buffer
create_atom	create an individual atom of this style
data_atom	parse an atom line from the data file
memory_usage	tally memory allocated by atom arrays

The constructor of the derived class sets values for several variables that you must set when defining a new atom style. The atom arrays themselves are defined in atom.cpp. Search for the word "customize" and you will find locations you will need to modify.

---

## Bond, angle, dihedral, improper potentials

Classes that compute molecular interactions are derived from the Bond, Angle, Dihedral, and Improper classes. New styles can be created to add new potentials to LAMMPS.

Bond\_harmonic.cpp is the simplest example of a bond style. Ditto for the harmonic forms of the angle, dihedral, and improper style commands.

Here is a brief description of methods you define in your new derived bond class. See bond.h, angle.h, dihedral.h, and improper.h for details.

compute	compute the molecular interactions
coeff	set coefficients for one bond type
equilibrium_distance	length of bond, used by SHAKE
write & read_restart	writes/reads coeffs to restart files
single	force and energy of a single bond

---

## Compute styles

Classes that compute scalar and vector quantities like temperature and the pressure tensor, as well as classes that compute per-atom quantities like kinetic energy and the centro-symmetry parameter are derived from the

Compute class. New styles can be created to add new calculations to LAMMPS.

Compute\_temp.cpp is a simple example of computing a scalar temperature. Compute\_ke\_atom.cpp is a simple example of computing per-atom kinetic energy.

Here is a brief description of methods you define in your new derived class. See compute.h for details.

compute_scalar	compute a scalar quantity
compute_vector	compute a vector of quantities
compute_peratom	compute one or more quantities per atom
pack_comm	pack a buffer with items to communicate
unpack_comm	unpack the buffer
pack_reverse	pack a buffer with items to reverse communicate
unpack_reverse	unpack the buffer
memory_usage	tally memory usage

---

## Dump styles

### Dump custom output options

Classes that dump per-atom info to files are derived from the Dump class. To dump new quantities or in a new format, a new derived dump class can be added, but it is typically simpler to modify the DumpCustom class contained in the dump\_custom.cpp file.

Dump\_atom.cpp is a simple example of a derived dump class.

Here is a brief description of methods you define in your new derived class. See dump.h for details.

write_header	write the header section of a snapshot of atoms
count	count the number of lines a processor will output
pack	pack a proc's output data into a buffer
write_data	write a proc's data to a file

See the [dump](#) command and its *custom* style for a list of keywords for atom information that can already be dumped by DumpCustom. It includes options to dump per-atom info from Compute classes, so adding a new derived Compute class is one way to calculate new quantities to dump.

Alternatively, you can add new keywords to the dump custom command. Search for the word "customize" in dump\_custom.cpp to see the half-dozen or so locations where code will need to be added.

---

## Fix styles

In LAMMPS, a "fix" is any operation that is computed during timestepping that alters some property of the system. Essentially everything that happens during a simulation besides force computation, neighbor list construction, and output, is a "fix". This includes time integration (update of coordinates and velocities), force constraints or boundary conditions (SHAKE or walls), and diagnostics (compute a diffusion coefficient). New styles can be created to add new options to LAMMPS.

Fix\_setforce.cpp is a simple example of setting forces on atoms to prescribed values. There are dozens of fix options already in LAMMPS; choose one as a template that is similar to what you want to implement.

Here is a brief description of methods you can define in your new derived class. See fix.h for details.

setmask	determines when the fix is called during the timestep
init	initialization before a run
setup	called immediately before the 1st timestep
initial_integrate	called at very beginning of each timestep
pre_exchange	called before atom exchange on re-neighboring steps
pre_neighbor	called before neighbor list build
post_force	called after pair & molecular forces are computed
final_integrate	called at end of each timestep
end_of_step	called at very end of timestep
write_restart	dumps fix info to restart file
restart	uses info from restart file to re-initialize the fix
grow_arrays	allocate memory for atom-based arrays used by fix
copy_arrays	copy atom info when an atom migrates to a new processor
memory_usage	report memory used by fix
pack_exchange	store atom's data in a buffer
unpack_exchange	retrieve atom's data from a buffer
pack_restart	store atom's data for writing to restart file
unpack_restart	retrieve atom's data from a restart file buffer
size_restart	size of atom's data
maxsize_restart	max size of atom's data
initial_integrate_respa	same as initial_integrate, but for rRESPA
post_force_respa	same as post_force, but for rRESPA
final_integrate_respa	same as final_integrate, but for rRESPA
pack_comm	pack a buffer to communicate a per-atom quantity
unpack_comm	unpack a buffer to communicate a per-atom quantity
pack_reverse_comm	pack a buffer to reverse communicate a per-atom quantity
unpack_reverse_comm	unpack a buffer to reverse communicate a per-atom quantity
thermo	compute quantities for thermodynamic output

Typically, only a small fraction of these methods are defined for a particular fix. Setmask is mandatory, as it determines when the fix will be invoked during the timestep. Fixes that perform time integration (*nve*, *nvt*, *npt*) implement initial\_integrate and final\_integrate to perform velocity Verlet updates. Fixes that constrain forces implement post\_force. Fixes that perform diagnostics typically implement end\_of\_step. For an end\_of\_step fix, one of your fix arguments must be the variable "nevery" which is used to determine when to call the fix. By convention, this is the first argument the fix defines (after the ID, group-ID, style).

If the fix needs to store information for each atom that persists from timestep to timestep, it can manage that memory and migrate the info with the atoms as they move from processors to processor by implementing the grow\_arrays, copy\_arrays, pack\_exchange, and unpack\_exchange methods. Similarly, the pack\_restart and

unpack\_restart methods can be implemented to store information about the fix in restart files. If you wish an integrator or force constraint fix to work with rRESPA (see the [run\\_style](#) command), the initial\_integrate, post\_force\_integrate, and final\_integrate\_respa methods can be implemented. The thermo method enables a fix to contribute values to thermodynamic output, as printed quantities and/or to be summed to the potential energy of the system.

---

## Input script commands

New commands can be added to LAMMPS input scripts by adding new classes that have a "command" method and are listed in the Command sections of style.h (or style\_user.h). For example, the create\_atoms, read\_data, velocity, and run commands are all implemented in this fashion. When such a command is encountered in the LAMMPS input script, LAMMPS simply creates a class with the corresponding name, invokes the "command" method of the class, and passes it the arguments from the input script. The command method can perform whatever operations it wishes on LAMMPS data structures.

The single method your new class must define is as follows:

command	operations performed by the new command
---------	---

Of course, the new class can define other methods and variables as needed.

---

## Kspace computations

Classes that compute long-range Coulombic interactions via K-space representations (Ewald, PPPM) are derived from the KSpace class. New styles can be created to add new K-space options to LAMMPS.

Ewald.cpp is an example of computing K-space interactions.

Here is a brief description of methods you define in your new derived class. See kspace.h for details.

init	initialize the calculation before a run
setup	computation before the 1st timestep of a run
compute	every-timestep computation
memory_usage	tally of memory usage

---

## Minimization solvers

Classes that perform energy minimization derived from the Min class. New styles can be created to add new minimization algorithms to LAMMPS.

Min\_cg.cpp is an example of conjugate gradient minimization.

Here is a brief description of methods you define in your new derived class. See min.h for details.

init	initialize the minimization before a run
run	perform the minimization

memory_usage	tally of memory usage
--------------	-----------------------

## Pairwise potentials

Classes that compute pairwise interactions are derived from the Pair class. In LAMMPS, pairwise calculation include manybody potentials such as EAM or Tersoff where particles interact without a static bond topology. New styles can be created to add new pair potentials to LAMMPS.

Pair\_lj\_cut.cpp is a simple example of a Pair class, though it includes some optional methods to enable its use with rRESPA.

Here is a brief description of the class methods in pair.h:

compute	workhorse routine that computes pairwise interactions
settings	reads the input script line with arguments you define
coeff	set coefficients for one i,j type pair
init_one	perform initialization for one i,j type pair
init_style	initialization specific to this pair style
write & read_restart	write/read i,j pair coeffs to restart files
write & read_restart_settings	write/read global settings to restart files
single	force and energy of a single pairwise interaction between 2 atoms
compute_inner/middle/outer	versions of compute used by rRESPA

The inner/middle/outer routines are optional.

## Region styles

Classes that define geometric regions are derived from the Region class. Regions are used elsewhere in LAMMPS to group atoms, delete atoms to create a void, insert atoms in a specified region, etc. New styles can be created to add new region shapes to LAMMPS.

Region\_sphere.cpp is an example of a spherical region.

Here is a brief description of methods you define in your new derived class. See region.h for details.

match	determine whether a point is in the region
-------	--

## Thermodynamic output options

There is one class that computes and prints thermodynamic information to the screen and log file; see the file thermo.cpp.

There are several styles defined in thermo.cpp: "one", "multi", "granular", etc. There is also a flexible "custom" style which allows the user to explicitly list keywords for quantities to print when thermodynamic info is output. See the [thermo\\_style](#) command for a list of defined quantities.

The thermo styles (one, multi, etc) are simply lists of keywords. Adding a new style thus only requires defining a

new list of keywords. Search for the word "customize" with references to "thermo style" in thermo.cpp to see the two locations where code will need to be added.

New keywords can also be added to thermo.cpp to compute new quantities for output. Search for the word "customize" with references to "keyword" in thermo.cpp to see the several locations where code will need to be added.

Note that the [thermo\\_style custom](#) command already allows for thermo output of quantities calculated by [fixes](#), [computes](#), and [variables](#). Thus, it may be simpler to compute what you wish via one of those constructs, than by adding a new keyword to the thermo command.

---

## Variable options

There is one class that computes and stores [variable](#) information in LAMMPS; see the file variable.cpp. The value associated with a variable can be periodically printed to the screen via the [print](#), [fix print](#), or [thermo\\_style custom](#) commands. Variables of style "equal" can compute complex equations that involve the following types of arguments:

thermo keywords = ke, vol, atoms, ... other variables = v\_a, v\_myvar, ... math functions = div(x,y), mult(x,y), add(x,y), ... group functions = mass(group), xcm(group,x), ... atom values = x**123**, y**3**, vx**34**, ... compute values = c\_mytemp**0**, c\_thermo\_pressure**3**, ...

Adding keywords for the [thermo\\_style custom](#) command (which can then be accessed by variables) was discussed [here](#) on this page.

Adding a new math function of one or two arguments can be done by editing one section of the Variable::evaluate() method. Search for the word "customize" to find the appropriate location.

Adding a new group function can be done by editing one section of the Variable::evaluate() method. Search for the word "customize" to find the appropriate location. You may need to add a new method to the Group class as well (see the group.cpp file).

Accessing a new atom-based vector can be done by editing one section of the Variable::evaluate() method. Search for the word "customize" to find the appropriate location.

Adding new [compute styles](#) (whose calculated values can then be accessed by variables) was discussed [here](#) on this page.

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(**Foo**) Foo, Morefoo, and Maxfoo, J of Classic Potentials, 75, 345 (1997).

## 9. Errors

This section describes the various kinds of errors you can encounter when using LAMMPS.

9.1 [Common problems](#)

9.2 [Reporting bugs](#)

9.3 [Error & warning messages](#)

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### 9.1 Common problems

If two LAMMPS runs do not produce the same answer on different machines or different numbers of processors, this is typically not a bug. In theory you should get identical answers on any number of processors and on any machine. In practice, numerical round-off can cause slight differences and eventual divergence of molecular dynamics phase space trajectories within a few 100s or few 1000s of timesteps. However, the statistical properties of the two runs (e.g. average energy or temperature) should still be the same.

If the [velocity](#) command is used to set initial atom velocities, a particular atom can be assigned a different velocity when the problem on different machines. Obviously, this means the phase space trajectories of the two simulations will rapidly diverge. See the discussion of the *loop* option in the [velocity](#) command for details.

A LAMMPS simulation typically has two stages, setup and run. Most LAMMPS errors are detected at setup time; others like a bond stretching too far may not occur until the middle of a run.

LAMMPS tries to flag errors and print informative error messages so you can fix the problem. Of course LAMMPS cannot figure out your physics mistakes, like choosing too big a timestep, specifying invalid force field coefficients, or putting 2 atoms on top of each other! If you find errors that LAMMPS doesn't catch that you think it should flag, please send an email to the [developers](#).

If you get an error message about an invalid command in your input script, you can determine what command is causing the problem by looking in the log.lammps file or using the [echo command](#) to see it on the screen. For a given command, LAMMPS expects certain arguments in a specified order. If you mess this up, LAMMPS will often flag the error, but it may read a bogus argument and assign a value that is valid, but not what you wanted. E.g. trying to read the string "abc" as an integer value and assigning the associated variable a value of 0.

Generally, LAMMPS will print a message to the screen and exit gracefully when it encounters a fatal error. Sometimes it will print a WARNING and continue on; you can decide if the WARNING is important or not. If LAMMPS crashes or hangs without spitting out an error message first then it could be a bug (see [this section](#)) or one of the following cases:

LAMMPS runs in the available memory a processor allows to be allocated. Most reasonable MD runs are compute limited, not memory limited, so this shouldn't be a bottleneck on most platforms. Almost all large memory allocations in the code are done via C-style malloc's which will generate an error message if you run out of memory. Smaller chunks of memory are allocated via C++ "new" statements. If you are unlucky you could run out of memory just when one of these small requests is made, in which case the code will crash or hang (in parallel), since LAMMPS doesn't trap on those errors.

Illegal arithmetic can cause LAMMPS to run slow or crash. This is typically due to invalid physics and numerics that your simulation is computing. If you see wild thermodynamic values or NaN values in your LAMMPS output, something is wrong with your simulation.



In parallel, one way LAMMPS can hang is due to how different MPI implementations handle buffering of messages. If the code hangs without an error message, it may be that you need to specify an MPI setting or two (usually via an environment variable) to enable buffering or boost the sizes of messages that can be buffered.

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## 9.2 Reporting bugs

If you are confident that you have found a bug in LAMMPS, please send an email to the [developers](#).

First, check the "New features and bug fixes" section of the [LAMMPS WWW site](#) to see if the bug has already been reported or fixed.

If not, the most useful thing you can do for us is to isolate the problem. Run it on the smallest number of atoms and fewest number of processors and with the simplest input script that reproduces the bug.

In your email, describe the problem and any ideas you have as to what is causing it or where in the code the problem might be. We'll request your input script and data files if necessary.

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## 9.3 Error &warning Messages

These are two alphabetic lists of the [ERROR](#) and [WARNING](#) messages LAMMPS prints out and the reason why. If the explanation here is not sufficient, the documentation for the offending command may help. Grepping the source files for the text of the error message and staring at the source code and comments is also not a bad idea! Note that sometimes the same message can be printed from multiple places in the code.

### Errors:

#### *1–3 bond count is inconsistent*

An inconsistency was detected when computing the number of 1–3 neighbors for each atom. This likely means something is wrong with the bond topologies you have defined.

#### *1–4 bond count is inconsistent*

An inconsistency was detected when computing the number of 1–4 neighbors for each atom. This likely means something is wrong with the bond topologies you have defined.

#### *All angle coeffs are not set*

All angle coefficients must be set in the data file or by the `angle_coeff` command before running a simulation.

#### *All bond coeffs are not set*

All bond coefficients must be set in the data file or by the `bond_coeff` command before running a simulation.

#### *All dihedral coeffs are not set*

All dihedral coefficients must be set in the data file or by the `dihedral_coeff` command before running a simulation.

#### *All dipole moments are not set*

For atom styles that define dipole moments for each atom type, all moments must be set in the data file or by the `dipole` command before running a simulation.

#### *All improper coeffs are not set*

All improper coefficients must be set in the data file or by the `improper_coeff` command before running a simulation.

#### *All masses are not set*

For atom styles that define masses for each atom type, all masses must be set in the data file or by the `mass` command before running a simulation. They must also be set before using the `velocity` command.

#### *All pair coeffs are not set*

All pair coefficients must be set in the data file or by the pair\_coeff command before running a simulation.

*All shapes are not set*  
All atom types must have a shape setting, even if the particles are spherical.

*All universe/uloop variables must have same # of values*  
Self-explanatory.

*All variables in next command must be same style*  
Self-explanatory.

*Angle atom missing in delete\_bonds*  
The delete\_bonds command cannot find one or more atoms in a particular angle on a particular processor.  
The pairwise cutoff is too short or the atoms are too far apart to make a valid angle.

*Angle atom missing in set command*  
The set command cannot find one or more atoms in a particular angle on a particular processor. The pairwise cutoff is too short or the atoms are too far apart to make a valid angle.

*Angle atoms %d %d %d missing on proc %d at step %d*  
One or more of 3 atoms needed to compute a particular angle are missing on this processor. Typically this is because the pairwise cutoff is set too short or the angle has blown apart and an atom is too far away.

*Angle coeff for hybrid has invalid style*  
Angle style hybrid uses another angle style as one of its coefficients. The angle style used in the angle\_coeff command or read from a restart file is not recognized.

*Angle coeffs are not set*  
No angle coefficients have been assigned in the data file or via the angle\_coeff command.

*Angle style hybrid cannot have hybrid as an argument*  
Self-explanatory.

*Angle style hybrid cannot use same angle style twice*  
Self-explanatory.

*Angle\_coeff command before angle\_style is defined*  
Coefficients cannot be set in the data file or via the angle\_coeff command until an angle\_style has been assigned.

*Angle\_coeff command before simulation box is defined*  
The angle\_coeff command cannot be used before a read\_data, read\_restart, or create\_box command.

*Angle\_coeff command when no angles allowed*  
The chosen atom style does not allow for angles to be defined.

*Angle\_style command when no angles allowed*  
The chosen atom style does not allow for angles to be defined.

*Angles assigned incorrectly*  
Angles read in from the data file were not assigned correctly to atoms. This means there is something invalid about the topology definitions.

*Angles defined but no angle types*  
The data file header lists angles but no angle types.

*Another input script is already being processed*  
Cannot attempt to open a 2nd input script, when the original file is still being processed.

*Atom IDs must be consecutive for dump dcd*  
Self-explanatory.

*Atom IDs must be consecutive for dump xtc*  
Self-explanatory.

*Atom IDs must be consecutive for dump xyz*  
Self-explanatory.

*Atom count is inconsistent, cannot write restart file*  
Sum of atoms across processors does not equal initial total count. This is probably because you have lost some atoms.

*Atom in too many rigid bodies – boost MAXBODY*

Fix poems has a parameter MAXBODY (in fix\_poems.cpp) which determines the maximum number of rigid bodies a single atom can belong to (i.e. a multibody joint). The bodies you have defined exceed this limit.

*Atom style hybrid cannot have hybrid as an argument*  
Self-explanatory.

*Atom style hybrid cannot use same atom style twice*  
Self-explanatory.

*Atom\_modify command after simulation box is defined*  
The atom\_modify command cannot be used after a read\_data, read\_restart, or create\_box command.

*Atom\_style command after simulation box is defined*  
The atom\_style command cannot be used after a read\_data, read\_restart, or create\_box command.

*Attempting to rescale a 0.0 temperature*  
Cannot rescale a temperature that is already 0.0.

*Bad FENE bond*  
Two atoms in a FENE bond have become so far apart that the bond cannot be computed.

*Bad grid of processors*  
The 3d grid of processors defined by the processors command does not match the number of processors LAMMPS is being run on.

*Bad principal moments*  
Fix rigid did not compute the principal moments of inertia of a rigid group of atoms correctly.

*Bad slab parameter*  
Kspace\_modify value for the slab/volume keyword must be  $\geq 2.0$ .

*Bitmapped lookup tables require int/float be same size*  
Cannot use pair tables on this machine, because of word sizes. Use the pair\_modify command with table 0 instead.

*Bitmapped table in file does not match requested table*  
Setting for bitmapped table in pair\_coeff command must match table in file exactly.

*Bitmapped table is incorrect length in table file*  
Number of table entries is not a correct power of 2.

*Bond and angle potentials must be defined for TIP4P*  
Cannot use TIP4P pair potential unless bond and angle potentials are defined.

*Bond atom missing in delete\_bonds*  
The delete\_bonds command cannot find one or more atoms in a particular bond on a particular processor.  
The pairwise cutoff is too short or the atoms are too far apart to make a valid bond.

*Bond atom missing in set command*  
The set command cannot find one or more atoms in a particular bond on a particular processor. The pairwise cutoff is too short or the atoms are too far apart to make a valid bond.

*Bond atoms %d %d missing on proc %d at step %d*  
One or more of 2 atoms needed to compute a particular bond are missing on this processor. Typically this is because the pairwise cutoff is set too short or the bond has blown apart and an atom is too far away.

*Bond coeff for hybrid has invalid style*  
Bond style hybrid uses another bond style as one of its coefficients. The bond style used in the bond\_coeff command or read from a restart file is not recognized.

*Bond coeffs are not set*  
No bond coefficients have been assigned in the data file or via the bond\_coeff command.

*Bond potential must be defined for SHAKE*  
Cannot use fix shake unless bond potential is defined.

*Bond style hybrid cannot have hybrid as an argument*  
Self-explanatory.

*Bond style hybrid cannot use same bond style twice*  
The sub-style arguments of bond\_style hybrid cannot be duplicated. Check the input script.

*Bond style quartic cannot be used with 3,4-body interactions*

No angle, dihedral, or improper styles can be defined when using bond style quartic.

*Bond\_coeff command before bond\_style is defined*  
Coefficients cannot be set in the data file or via the bond\_coeff command until an bond\_style has been assigned.

*Bond\_coeff command before simulation box is defined*  
The bond\_coeff command cannot be used before a read\_data, read\_restart, or create\_box command.

*Bond\_coeff command when no bonds allowed*  
The chosen atom style does not allow for bonds to be defined.

*Bond\_style command when no bonds allowed*  
The chosen atom style does not allow for bonds to be defined.

*Bonds assigned incorrectly*  
Bonds read in from the data file were not assigned correctly to atoms. This means there is something invalid about the topology definitions.

*Bonds defined but no bond types*  
The data file header lists bonds but no bond types.

*Both sides of boundary must be periodic*  
Cannot specify a boundary as periodic only on the lo or hi side. Must be periodic on both sides.

*Boundary command after simulation box is defined*  
The boundary command cannot be used after a read\_data, read\_restart, or create\_box command.

*Box bounds are invalid*  
The box boundaries specified in the read\_data file are invalid. The lo value must be less than the hi value for all 3 dimensions.

*Can only wiggle zcylinder wall in z dim*  
The Self-explanatory.

*Cannot (yet) use PPPM with triclinic box*  
This feature is not yet supported.

*Cannot (yet) use fix ave/spatial with triclinic box*  
This feature is not yet supported.

*Cannot build parse tree for variable that is not atom style*  
Only atom style variables can be evaluated once per atom.

*Cannot change dump\_modify every for dump dcd*  
The frequency of writing dump dcd snapshots cannot be changed.

*Cannot compute PPPM G*  
LAMMPS failed to compute a valid approximation for the PPPM g\_ewald factor that partitions the computation between real space and k-space.

*Cannot compute PPPM X grid spacing*  
LAMMPS failed to compute a valid PPPM grid spacing in the x dimension.

*Cannot compute PPPM Y grid spacing*  
LAMMPS failed to compute a valid PPPM grid spacing in the y dimension.

*Cannot compute PPPM Z grid spacing*  
LAMMPS failed to compute a valid PPPM grid spacing in the z dimension.

*Cannot create an atom map unless atoms have IDs*  
The simulation requires a mapping from global atom IDs to local atoms, but the atoms that have been defined have no IDs.

*Cannot create atoms with undefined lattice*  
Must use the lattice command before using the create\_atoms command.

*Cannot create\_box after simulation box is defined*  
The create\_box command cannot be used after a read\_data, read\_restart, or create\_box command.

*Cannot dump scaled coords with triclinic box*  
Use dump custom with x,y,z instead.

*Cannot evaluate variable*  
Self-explanatory.

*Cannot find delete\_bonds group ID*

Group ID used in the delete\_bonds command does not exist.

*Cannot fix deform on a non-periodic boundary*

Only a periodic boundary can be modified.

*Cannot have both pair\_modify shift and tail set to yes*

These 2 options are contradictory.

*Cannot open EAM potential file %s*

The specified EAM potential file cannot be opened. Check that the path and name are correct.

*Cannot open MEAM potential file %s*

The specified MEAM potential file cannot be opened. Check that the path and name are correct.

*Cannot open Stillinger-Weber potential file %s*

The specified SW potential file cannot be opened. Check that the path and name are correct.

*Cannot open Tersoff potential file %s*

The specified Tersoff potential file cannot be opened. Check that the path and name are correct.

*Cannot open dir to search for restart file*

Using a "\*" in the name of the restart file will open the current directory to search for matching file names.

*Cannot open dump file*

The output file for the dump command cannot be opened. Check that the path and name are correct.

*Cannot open file %s*

The specified file cannot be opened. Check that the path and name are correct.

*Cannot open fix ave/spatial file %s*

Self-explanatory.

*Cannot open fix ave/time file %s*

Self-explanatory.

*Cannot open fix com file %s*

The output file for the fix com command cannot be opened. Check that the path and name are correct.

*Cannot open fix gran/diag file %s*

The output file for the fix gran/diag command cannot be opened. Check that the path and name are correct.

*Cannot open fix gyration file %s*

Self-explanatory.

*Cannot open fix msd file %s*

The output file for the fix msd command cannot be opened. Check that the path and name are correct.

*Cannot open fix poems file %s*

The specified file cannot be opened. Check that the path and name are correct.

*Cannot open fix rdf file %s*

The output file for the fix rdf command cannot be opened. Check that the path and name are correct.

*Cannot open fix tmd file %s*

The output file for the fix tmd command cannot be opened. Check that the path and name are correct.

*Cannot open gzipped file*

LAMMPS is attempting to open a gzipped version of the specified file but was unsuccessful. Check that the path and name are correct.

*Cannot open input script %s*

Self-explanatory.

*Cannot open input script %s*

Self-explanatory.

*Cannot open log.lammps*

The default LAMMPS log file cannot be opened. Check that the directory you are running in allows for files to be created.

*Cannot open logfile %s*

The LAMMPS log file specified in the input script cannot be opened. Check that the path and name are

correct.

*Cannot open logfile*  
The LAMMPS log file named in a command-line argument cannot be opened. Check that the path and name are correct.

*Cannot open pair\_write file*  
The specified output file for pair energies and forces cannot be opened. Check that the path and name are correct.

*Cannot open restart file %s*  
Self-explanatory.

*Cannot open screen file*  
The screen file specified as a command-line argument cannot be opened. Check that the directory you are running in allows for files to be created.

*Cannot open universe log file*  
For a multi-partition run, the master log file cannot be opened. Check that the directory you are running in allows for files to be created.

*Cannot open universe screen file*  
For a multi-partition run, the master screen file cannot be opened. Check that the directory you are running in allows for files to be created.

*Cannot read\_data after simulation box is defined*  
The read\_data command cannot be used after a read\_data, read\_restart, or create\_box command.

*Cannot read\_restart after simulation box is defined*  
The read\_restart command cannot be used after a read\_data, read\_restart, or create\_box command.

*Cannot replicate 2d simulation in z dimension*  
The replicate command cannot replicate a 2d simulation in the z dimension.

*Cannot replicate with fixes that store atom quantities*  
Either fixes are defined that create and store atom-based vectors or a restart file was read which included atom-based vectors for fixes. The replicate command cannot duplicate that information for new atoms. You should use the replicate command before fixes are applied to the system.

*Cannot run 2d simulation with nonperiodic Z dimension*  
Use the boundary command to make the z dimension periodic in order to run a 2d simulation.

*Cannot set both respa pair and inner/middle/outer*  
In the rRESPA integrator, you must compute pairwise potentials either all together (pair), or in pieces (inner/middle/outer). You can't do both.

*Cannot set dipole for this atom style*  
This atom style does not support dipole settings for each atom type.

*Cannot set dump\_modify flush for dump xtc*  
Self-explanatory.

*Cannot set mass for this atom style*  
This atom style does not support mass settings for each atom type. Instead they are defined on a per-atom basis in the data file.

*Cannot set respa middle without inner/outer*  
In the rRESPA integrator, you must define both a inner and outer setting in order to use a middle setting.

*Cannot set shape for this atom style*  
The atom style does not support this setting.

*Cannot set this attribute for this atom style*  
The attribute being set does not exist for the defined atom style.

*Cannot skew triclinic box in z for 2d simulation*  
Self-explanatory.

*Cannot use Ewald with 2d simulation*  
The kspace style ewald cannot be used in 2d simulations. You can use 2d Ewald in a 3d simulation; see the kspace\_modify command.

*Cannot use Ewald with triclinic box*

This feature is not yet supported.

*Cannot use PPPM with 2d simulation*  
 The kspace style ppm cannot be used in 2d simulations. You can use 2d PPPM in a 3d simulation; see the kspace\_modify command.

*Cannot use atom style ellipsoid for 2d simulation*  
 2d ellipsoids are not yet supported.

*Cannot use atom vector in variable unless atom map exists*  
 Atom maps are on by default, but can be turned off by the atom\_modify command.

*Cannot use delete\_atoms unless atoms have IDs*  
 Your atoms do not have IDs, so the delete\_atoms command cannot be used.

*Cannot use delete\_bonds with non-molecular system*  
 Your choice of atom style does not have bonds.

*Cannot use dump bond with non-molecular system*  
 Your choice of atom style does not have bonds.

*Cannot use fix deform for 0 timestep run*  
 Cannot reshape or resize the box in 0 timesteps.

*Cannot use fix deform trapezoidal on a box with zero tilt*  
 The trapezoidal style alters the current strain.

*Cannot use fix nph on a non-periodic dimension*  
 Only periodic dimensions can be controlled with this fix.

*Cannot use fix nph with triclinic box*  
 This feature is not yet supported.

*Cannot use fix nph without per-type mass defined*  
 The defined atom style uses per-atom mass, not per-type mass.

*Cannot use fix npt on a non-periodic dimension*  
 Only periodic dimensions can be controlled with this fix.

*Cannot use fix npt with triclinic box*  
 This feature is not yet supported.

*Cannot use fix npt without per-type mass defined*  
 The defined atom style uses per-atom mass, not per-type mass.

*Cannot use fix nvt without per-type mass defined*  
 The defined atom style uses per-atom mass, not per-type mass.

*Cannot use fix poems with atom style granular*  
 This fix is not yet enabled for this atom style.

*Cannot use fix pour with triclinic box*  
 This feature is not yet supported.

*Cannot use fix shake with non-molecular system*  
 Your choice of atom style does not have bonds.

*Cannot use kspace solver on system with no charge*  
 No atoms in system have a non-zero charge.

*Cannot use nonperiodic boundaries with Ewald*  
 For kspace style ewald, all 3 dimensions must have periodic boundaries unless you use the kspace\_modify command to define a 2d slab with a non-periodic z dimension.

*Cannot use nonperiodic boundaries with PPPM*  
 For kspace style ppm, All 3 dimensions must have periodic boundaries unless you use the kspace\_modify command to define a 2d slab with a non-periodic z dimension.

*Cannot use pair tail corrections with 2d simulations*  
 The correction factors are only currently defined for 3d systems.

*Cannot use rRESPA with full neighbor lists*  
 Defined pair style uses full neighbor lists (as opposed to half neighbor lists), which are incompatible with the current implementation of rRESPA.

*Cannot use region INF when box does not exist*

Regions that extend to the box boundaries can only be used after the `create_box` command has been used.

*Cannot use set atom with no atom IDs defined*  
 Atom IDs are not defined, so they cannot be used to identify an atom.

*Cannot use velocity create loop all unless atoms have IDs*  
 Atoms in the simulation to do not have IDs, so this style of velocity creation cannot be performed.

*Cannot use velocity create loop all with non-contiguous atom IDs*  
 Atoms in the simulation to do not have consecutive IDs, so this style of velocity creation cannot be performed.

*Cannot use wall in periodic dimension*  
 Self-explanatory.

*Cannot zero momentum of 0 atoms*  
 The collection of atoms for which momentum is being computed has no atoms.

*Compute ID for fix ave/spatial does not exist*  
 Self-explanatory.

*Compute ID for fix ave/time does not exist*  
 Self-explanatory.

*Compute coord/atom cutoff is longer than pairwise cutoff*  
 Cannot compute coordination at distances longer than the pair cutoff, since those atoms are not in the neighbor list.

*Compute pressure must use group all*  
 Self-explanatory.

*Compute pressure temp ID does not compute temperature*  
 The compute ID assigned to a pressure computation must compute temperature.

*Compute rotate/dipole requires atom attributes dipole, omega*  
 The atom style defined does not have these attributes.

*Compute temp/asphere requires atom attributes quat, angmom*  
 The atom style defined does not have these attributes.

*Compute temp/dipole requires atom attributes omega, shape*  
 The atom style defined does not have these attributes.

*Could not create 3d FFT plan*  
 The FFT setup in pppm failed.

*Could not create 3d remap plan*  
 The FFT setup in pppm failed.

*Could not find compute ID to delete*  
 Self-explanatory.

*Could not find compute etotal/atom pre-compute ID*  
 The compute ID for calculating per-atom pairwise energy does not exist.

*Could not find compute group ID*  
 Self-explanatory.

*Could not find compute pressure temp ID*  
 The compute ID for calculating temperature does not exist.

*Could not find compute variable name*  
 The variable being used by a compute is not defined.

*Could not find compute variable name*  
 The variable name accessed by compute variable/atom does not exist.

*Could not find compute\_modify ID*  
 Self-explanatory.

*Could not find delete\_atoms group ID*  
 Group ID used in the `delete_atoms` command does not exist.

*Could not find delete\_atoms region ID*  
 Region ID used in the `delete_atoms` command does not exist.

*Could not find displace\_atoms group ID*



A group ID used in the `displace_atoms` command does not exist.

*Could not find dump custom compute ID*  
 The compute ID needed by dump custom to compute a per-atom quantity does not exist.

*Could not find dump group ID*  
 A group ID used in the dump command does not exist.

*Could not find fix ID to delete*  
 Self-explanatory.

*Could not find fix group ID*  
 A group ID used in the fix command does not exist.

*Could not find fix poems group ID*  
 A group ID used in the fix poems command does not exist.

*Could not find fix recenter group ID*  
 A group ID used in the fix recenter command does not exist.

*Could not find fix rigid group ID*  
 A group ID used in the fix rigid command does not exist.

*Could not find fix spring couple group ID*  
 Self-explanatory.

*Could not find fix\_modify ID*  
 A fix ID used in the fix\_modify command does not exist.

*Could not find fix\_modify press ID*  
 The compute ID for computing pressure does not exist.

*Could not find fix\_modify temp ID*  
 The compute ID for computing temperature does not exist.

*Could not find set group ID*  
 Group ID specified in set command does not exist.

*Could not find thermo compute ID*  
 Compute ID specified in thermo\_style command does not exist.

*Could not find thermo custom compute ID*  
 The compute ID needed by thermo style custom to compute a requested quantity does not exist.

*Could not find thermo custom fix ID*  
 The fix ID needed by thermo style custom to compute a requested quantity does not exist.

*Could not find thermo custom variable ID*  
 The variable name needed by thermo style custom to compute a requested quantity does not exist.

*Could not find thermo fix ID*  
 Fix ID specified in thermo\_style command does not exist.

*Could not find thermo\_modify drot ID*  
 The compute ID needed by thermo style custom to compute rotational energy of dipolar atoms does not exist.

*Could not find thermo\_modify grot ID*  
 The compute ID needed by thermo style custom to compute rotational energy of granular atoms does not exist.

*Could not find thermo\_modify press ID*  
 The compute ID needed by thermo style custom to compute pressure does not exist.

*Could not find thermo\_modify temp ID*  
 The compute ID needed by thermo style custom to compute temperature does not exist.

*Could not find undump ID*  
 A dump ID used in the undump command does not exist.

*Could not find velocity group ID*  
 A group ID used in the velocity command does not exist.

*Could not find velocity temp ID*  
 The compute ID needed by the velocity command to compute temperature does not exist.

*Could not pre-compute in variable*

A compute required to evaluate a variable does not have its pre-compute defined.

*Could not find dump\_modify ID*  
Self-explanatory.

*Create\_atoms command before simulation box is defined*  
The create\_atoms command cannot be used before a read\_data, read\_restart, or create\_box command.

*Create\_atoms region ID does not exist*  
A region ID used in the create\_atoms command does not exist.

*Create\_box region ID does not exist*  
A region ID used in the create\_box command does not exist.

*Create\_box region must be of type inside*  
The region used in the create\_box command must not be an "outside" region. See the region command for details.

*Cyclic loop in joint connections*  
Fix poems cannot (yet) work with coupled bodies whose joints connect the bodies in a ring (or cycle).

*Degenerate lattice primitive vectors*  
Invalid set of 3 lattice vectors for lattice command.

*Delete\_atoms command before simulation box is defined*  
The delete\_atoms command cannot be used before a read\_data, read\_restart, or create\_box command.

*Delete\_atoms cutoff > ghost cutoff*  
Cannot delete atoms further away than a processor knows about.

*Delete\_bonds command before simulation box is defined*  
The delete\_bonds command cannot be used before a read\_data, read\_restart, or create\_box command.

*Delete\_bonds command with no atoms existing*  
No atoms are yet defined so the delete\_bonds command cannot be used.

*Did not assign all atoms correctly*  
Atoms read in from a data file were not assigned correctly to processors. This is likely due to some atom coordinates being outside a non-periodic simulation box.

*Did not find all elements in MEAM library file*  
The requested elements were not found in the MEAM file.

*Did not find fix shake partner info*  
Could not find bond partners implied by fix shake command. This error can be triggered if the delete\_bonds command was used before fix shake, and it removed bonds without resetting the 1-2, 1-3, 1-4 weighting list via the special keyword.

*Did not find keyword in table file*  
Keyword used in pair\_coeff command was not found in table file.

*Dihedral atom missing in delete\_bonds*  
The delete\_bonds command cannot find one or more atoms in a particular dihedral on a particular processor. The pairwise cutoff is too short or the atoms are too far apart to make a valid dihedral.

*Dihedral atom missing in set command*  
The set command cannot find one or more atoms in a particular dihedral on a particular processor. The pairwise cutoff is too short or the atoms are too far apart to make a valid dihedral.

*Dihedral atoms %d %d %d %d missing on proc %d at step %d*  
One or more of 4 atoms needed to compute a particular dihedral are missing on this processor. Typically this is because the pairwise cutoff is set too short or the dihedral has blown apart and an atom is too far away.

*Dihedral charmm is incompatible with Pair style*  
Dihedral style charmm must be used with a pair style charmm in order for the 1-4 epsilon/sigma parameters to be defined.

*Dihedral coeff for hybrid has invalid style*  
Dihedral style hybrid uses another dihedral style as one of its coefficients. The dihedral style used in the dihedral\_coeff command or read from a restart file is not recognized.

*Dihedral coeffs are not set*

No dihedral coefficients have been assigned in the data file or via the `dihedral_coeff` command.

*Dihedral style hybrid cannot have hybrid as an argument*  
Self-explanatory.

*Dihedral style hybrid cannot use same dihedral style twice*  
Self-explanatory.

*Dihedral\_coeff command before dihedral\_style is defined*  
Coefficients cannot be set in the data file or via the `dihedral_coeff` command until an `dihedral_style` has been assigned.

*Dihedral\_coeff command before simulation box is defined*  
The `dihedral_coeff` command cannot be used before a `read_data`, `read_restart`, or `create_box` command.

*Dihedral\_coeff command when no dihedrals allowed*  
The chosen atom style does not allow for dihedrals to be defined.

*Dihedral\_style command when no dihedrals allowed*  
The chosen atom style does not allow for dihedrals to be defined.

*Dihedrals assigned incorrectly*  
Dihedrals read in from the data file were not assigned correctly to atoms. This means there is something invalid about the topology definitions.

*Dihedrals defined but no dihedral types*  
The data file header lists dihedrals but no dihedral types.

*Dimension command after simulation box is defined*  
The dimension command cannot be used after a `read_data`, `read_restart`, or `create_box` command.

*Dipole command before simulation box is defined*  
The dipole command cannot be used before a `read_data`, `read_restart`, or `create_box` command.

*Displace\_atoms command before simulation box is defined*  
The `displace_atoms` command cannot be used before a `read_data`, `read_restart`, or `create_box` command.

*Domain too large for neighbor bins*  
The domain has become extremely large so that neighbor bins cannot be used. Most likely, one or more atoms have been blown out of the simulation box to a great distance.

*Dump custom compute ID does not compute peratom info*  
The compute ID used must compute peratom info, not a global scalar or vector quantity.

*Dump custom compute ID does not compute scalar per atom*  
The compute ID used must compute a single peratom datum.

*Dump custom compute ID does not compute vector per atom*  
The compute ID used must compute a vector of peratom data.

*Dump custom compute ID vector is not large enough*  
The compute ID vector of peratom data is not as large as is being accessed.

*Dump dcd must use group all*  
Self-explanatory.

*Dump dcd of non-matching # of atoms*  
Every snapshot written by `dump dcd` must contain the same # of atoms.

*Dump xtc must use group all*  
Self-explanatory.

*Dump xtc must use group all*  
Self-explanatory.

*Dump\_modify region ID does not exist*  
Self-explanatory.

*Dumping an atom quantity that isn't allocated*  
The chosen atom style does not define the per-atom vector being dumped.

*Failed to allocate %d bytes for array %s*  
Your LAMMPS simulation has run out of memory. You need to run a smaller simulation or on more processors.

*Failed to reallocate %d bytes for array %s*

Your LAMMPS simulation has run out of memory. You need to run a smaller simulation or on more processors.

*Final box dimension due to fix deform is < 0.0*  
Self-explanatory.

*Fix ave/spatial compute does not calculate per-atom info*  
Only computes that calculate a per-atom quantity (not a scalar or vector quantity can be used with fix ave/spatial).

*Fix ave/time compute does not calculate a scalar*  
Only computes that calculate a scalar or vector quantity (not a per-atom quantity) can be used with fix ave/time.

*Fix ave/time compute does not calculate a vector*  
Only computes that calculate a scalar or vector quantity (not a per-atom quantity) can be used with fix ave/time.

*Fix command before simulation box is defined*  
The fix command cannot be used before a read\_data, read\_restart, or create\_box command.

*Fix deform is changing yz by too much with changing xy*  
When both yz and xy are changing, it induces changes in xz if the box must flip from one tilt extreme to another. Thus it is not allowed for yz to grow so much that a flip is induced.

*Fix deform tilt factors require triclinic box*  
Cannot deform the tilt factors of a simulation box unless it is a triclinic (non-orthogonal) box.

*Fix deform volume setting is invalid*  
Cannot use volume style unless other dimensions are being controlled.

*Fix deposit region ID does not exist*  
Self-explanatory

*Fix freeze requires atom attribute torque*  
The atom style defined does not have this attribute.

*Fix gran/diag is incompatible with Pair style*  
Must use atom style granular.

*Fix gran/diag requires atom attributes radius, rmass, omega*  
The atom style defined does not have these attributes.

*Fix heat group has no atoms*  
Self-explanatory.

*Fix langevin period must be > 0.0*  
The time window for temperature relaxation must be > 0

*Fix langevin region ID does not exist*  
Self-explanatory.

*Fix momentum group has no atoms*  
Self-explanatory.

*Fix msd group has no atoms*  
Cannot compute diffusion for no atoms.

*Fix npb periods must be > 0.0*  
The time window for pressure relaxation must be > 0

*Fix npt periods must be > 0.0*  
The time window for temperature or pressure relaxation must be > 0

*Fix nvt period must be > 0.0*  
The time window for temperature relaxation must be > 0

*Fix orient/fcc file open failed*  
The fix orient/fcc command could not open a specified file.

*Fix orient/fcc file read failed*  
The fix orient/fcc command could not read the needed parameters from a specified file.

*Fix orient/fcc found self twice*  
The neighbor lists used by fix orient/fcc are messed up. If this error occurs, it is likely a bug, so send an

email to the [developers](#).

*Fix pour region ID does not exist*  
Self-explanatory.

*Fix pour requires atom attributes radius, rmass*  
The atom style defined does not have these attributes.

*Fix rdf requires a pair style be defined*  
Cannot use the rdf fix unless a pair style with a cutoff has been defined.

*Fix recenter group has no atoms*  
Self-explanatory.

*Fix shake cannot be used with minimization*  
Cannot use fix shake while doing an energy minimization since it turns off bonds that should contribute to the energy.

*Fix temp/rescale region ID does not exist*  
Self-explanatory.

*Fix tmd must come after integration fixes*  
Any fix tmd command must appear in the input script after all time integration fixes (nve, nvt, npt). See the fix tmd documentation for details.

*Fix wall/gran is incompatible with Pair style*  
Must use a granular pair style to define the parameters needed for this fix.

*Fix wall/gran requires atom attributes radius, omega, torque*  
The atom style defined does not have these attributes.

*Fix\_modify press ID does not compute pressure*  
The compute ID assigned to the fix must compute pressure.

*Fix\_modify temp ID does not compute temperature*  
The compute ID assigned to the fix must compute temperature.

*Found no restart file matching pattern*  
When using a "\*" in the restart file name, no matching file was found.

*Granular pair styles do not use pair\_coeff settings*  
The pair\_coeff command cannot be used with granular force fields.

*Gravity must point in -y to use with fix pour in 2d*  
Gravity must be pointing "down" in a 2d box.

*Gravity must point in -z to use with fix pour in 3d*  
Gravity must be pointing "down" in a 3d box, i.e. theta = 180.0.

*Group ID does not exist*  
A group ID used in the group command does not exist.

*Group command before simulation box is defined*  
The group command cannot be used before a read\_data, read\_restart, or create\_box command.

*Group region ID does not exist*  
A region ID used in the group command does not exist.

*Illegal ... command*  
\*\* DELETE\_POSSIBLE Self-explanatory. Check the input script syntax and compare to the documentation for the command. You can use -echo screen as a command-line option when running LAMMPS to see the offending line.

*Illegal Stillinger-Weber parameter*  
One or more of the coefficients defined in the potential file is invalid.

*Illegal Tersoff parameter*  
One or more of the coefficients defined in the potential file is invalid.

*Illegal fix heat attempt*  
The velocity rescaling about to be performed by fix heat is invalid.

*Illegal simulation box*  
The lower bound of the simulation box is greater than the upper bound.

*Improper atom missing in delete\_bonds*

The delete\_bonds command cannot find one or more atoms in a particular improper on a particular processor. The pairwise cutoff is too short or the atoms are too far apart to make a valid improper.

*Improper atom missing in set command*  
 The set command cannot find one or more atoms in a particular improper on a particular processor. The pairwise cutoff is too short or the atoms are too far apart to make a valid improper.

*Improper atoms %d %d %d %d missing on proc %d at step %d*  
 One or more of 4 atoms needed to compute a particular improper are missing on this processor. Typically this is because the pairwise cutoff is set too short or the improper has blown apart and an atom is too far away.

*Improper coeff for hybrid has invalid style*  
 Improper style hybrid uses another improper style as one of its coefficients. The improper style used in the improper\_coeff command or read from a restart file is not recognized.

*Improper coeffs are not set*  
 No improper coefficients have been assigned in the data file or via the improper\_coeff command.

*Improper style hybrid cannot have hybrid as an argument*  
 Self-explanatory.

*Improper style hybrid cannot use same improper style twice*  
 Self-explanatory.

*Improper\_coeff command before improper\_style is defined*  
 Coefficients cannot be set in the data file or via the improper\_coeff command until an improper\_style has been assigned.

*Improper\_coeff command before simulation box is defined*  
 The improper\_coeff command cannot be used before a read\_data, read\_restart, or create\_box command.

*Improper\_coeff command when no impropers allowed*  
 The chosen atom style does not allow for impropers to be defined.

*Improper\_style command when no impropers allowed*  
 The chosen atom style does not allow for impropers to be defined.

*Impropers assigned incorrectly*  
 Impropers read in from the data file were not assigned correctly to atoms. This means there is something invalid about the topology definitions.

*Impropers defined but no improper types*  
 The data file header lists improper but no improper types.

*Incorrect args for angle coefficients*  
 Self-explanatory. Check the input script or data file.

*Incorrect args for bond coefficients*  
 Self-explanatory. Check the input script or data file.

*Incorrect args for dihedral coefficients*  
 Self-explanatory. Check the input script or data file.

*Incorrect args for improper coefficients*  
 Self-explanatory. Check the input script or data file.

*Incorrect args for pair coefficients*  
 Self-explanatory. Check the input script or data file.

*Incorrect args in pair\_style command*  
 Self-explanatory.

*Incorrect atom format in data file*  
 Number of values per atom line in the data file is not consistent with the atom style.

*Incorrect boundaries with slab Ewald*  
 Must have periodic x,y dimensions and non-periodic z dimension to use 2d slab option with Ewald.

*Incorrect boundaries with slab PPPM*  
 Must have periodic x,y dimensions and non-periodic z dimension to use 2d slab option with PPPM.

*Incorrect element names in EAM potential file*  
 The element names in the EAM file do not match those requested.

*Incorrect format in MEAM potential file*

Incorrect number of words per line in the potential file.

*Incorrect format in Stillinger–Weber potential file*

Incorrect number of words per line in the potential file.

*Incorrect format in TMD target file*

Format of file read by fix tmd command is incorrect.

*Incorrect format in Tersoff potential file*

Incorrect number of words per line in the potential file.

*Incorrect multiplicity arg for dihedral coefficients*

Self-explanatory. Check the input script or data file.

*Incorrect sign arg for dihedral coefficients*

Self-explanatory. Check the input script or data file.

*Incorrect velocity format in data file*

Each atom style defines a format for the Velocity section of the data file. The read-in lines do not match.

*Incorrect weight arg for dihedral coefficients*

Self-explanatory. Check the input script or data file.

*Input line too long after variable substitution*

This is a hard (very large) limit defined in the input.cpp file.

*Input line too long: %s*

This is a hard (very large) limit defined in the input.cpp file.

*Insertion region extends outside simulation box*

Region specified with fix insert command extends outside the global simulation box.

*Insufficient Jacobi rotations for POEMS body*

Eigensolve for rigid body was not sufficiently accurate.

*Insufficient Jacobi rotations for rigid body*

Eigensolve for rigid body was not sufficiently accurate.

*Invalid angle style*

The choice of angle style is unknown.

*Invalid angle type in Angles section of data file*

Angle type must be positive integer and within range of specified angle types.

*Invalid angle type index for fix shake*

Self-explanatory.

*Invalid atom ID in Angles section of data file*

Atom IDs must be positive integers and within range of defined atoms.

*Invalid atom ID in Atoms section of data file*

Atom IDs must be positive integers.

*Invalid atom ID in Bonds section of data file*

Atom IDs must be positive integers and within range of defined atoms.

*Invalid atom ID in Dihedrals section of data file*

Atom IDs must be positive integers and within range of defined atoms.

*Invalid atom ID in Impropers section of data file*

Atom IDs must be positive integers and within range of defined atoms.

*Invalid atom ID in Velocities section of data file*

Atom IDs must be positive integers and within range of defined atoms.

*Invalid atom mass for fix shake*

Mass specified in fix shake command must be > 0.0.

*Invalid atom style*

The choice of atom style is unknown.

*Invalid atom type in Atoms section of data file*

Atom types must range from 1 to specified # of types.

*Invalid atom type in create\_atoms command*

The create\_box command specified the range of valid atom types. An invalid type is being requested.

*Invalid atom type in neighbor exclusion list*

Atom types must range from 1 to Ntypes inclusive.

*Invalid atom type index for fix shake*

Atom types must range from 1 to Ntypes inclusive.

*Invalid atom types in fix rdf command*

Atom types must range from 1 to Ntypes inclusive.

*Invalid atom types in pair\_write command*

Atom types must range from 1 to Ntypes inclusive.

*Invalid atom vector in variable*

An atom vector specified in a variable definition is not recognized.

*Invalid bond style*

The choice of bond style is unknown.

*Invalid bond type in Bonds section of data file*

Bond type must be positive integer and within range of specified bond types.

*Invalid bond type index for fix shake*

Self-explanatory. Check the fix shake command in the input script.

*Invalid coeffs for this angle style*

Cannot set class 2 coeffs in data file for this angle style.

*Invalid coeffs for this dihedral style*

Cannot set class 2 coeffs in data file for this dihedral style.

*Invalid coeffs for this improper style*

Cannot set class 2 coeffs in data file for this improper style.

*Invalid command-line argument*

One or more command-line arguments is invalid. Check the syntax of the command you are using to launch LAMMPS.

*Invalid compute ID in variable*

A compute specified in a variable definition is not defined.

*Invalid compute ID index in variable*

The argument index of a compute specified in a variable definition is not valid.

*Invalid compute style*

Self-explanatory.

*Invalid cutoffs in pair\_write command*

Inner cutoff must be larger than 0.0 and less than outer cutoff.

*Invalid d1 or d2 value for pair colloid coeff*

Neither d1 or d2 can be < 0.

*Invalid data file section: Angle Coeffs*

Atom style does not allow angles.

*Invalid data file section: AngleAngle Coeffs*

Atom style does not allow impropers.

*Invalid data file section: AngleAngleTorsion Coeffs*

Atom style does not allow dihedrals.

*Invalid data file section: AngleTorsion Coeffs*

Atom style does not allow dihedrals.

*Invalid data file section: Angles*

Atom style does not allow angles.

*Invalid data file section: Bond Coeffs*

Atom style does not allow bonds.

*Invalid data file section: BondAngle Coeffs*

Atom style does not allow angles.

*Invalid data file section: BondBond Coeffs*

Atom style does not allow angles.

*Invalid data file section: BondBond13 Coeffs*



Atom style does not allow dihedrals.

*Invalid data file section: Bonds*  
Atom style does not allow bonds.

*Invalid data file section: Dihedral Coeffs*  
Atom style does not allow dihedrals.

*Invalid data file section: Dihedrals*  
Atom style does not allow dihedrals.

*Invalid data file section: EndBondTorsion Coeffs*  
Atom style does not allow dihedrals.

*Invalid data file section: Improper Coeffs*  
Atom style does not allow impropers.

*Invalid data file section: Impropers*  
Atom style does not allow impropers.

*Invalid data file section: MiddleBondTorsion Coeffs*  
Atom style does not allow dihedrals.

*Invalid dihedral style*  
The choice of dihedral style is unknown.

*Invalid dihedral type in Dihedrals section of data file*  
Dihedral type must be positive integer and within range of specified dihedral types.

*Invalid dump dcd filename*  
Filenames used with the dump dcd style cannot be binary or compressed or cause multiple files to be written.

*Invalid dump frequency*  
Dumps frequency must be 1 or greater.

*Invalid dump style*  
The choice of dump style is unknown.

*Invalid dump xtc filename*  
Filenames used with the dump xtc style cannot be binary or compressed or cause multiple files to be written.

*Invalid dump xyz filename*  
Filenames used with the dump xyz style cannot be binary or cause files to be written by each processor.

*Invalid dump\_modify threshold operator*  
Operator keyword used for threshold specification is not recognized.

*Invalid fix style*  
The choice of fix style is unknown.

*Invalid flag in force field section of restart file*  
Unrecognized entry in restart file.

*Invalid flag in header section of restart file*  
Unrecognized entry in restart file.

*Invalid flag in type arrays section of restart file*  
Unrecognized entry in restart file.

*Invalid group ID in neigh\_modify command*  
A group ID used in the neigh\_modify command does not exist.

*Invalid improper style*  
The choice of improper style is unknown.

*Invalid improper type in Impropers section of data file*  
Improper type must be positive integer and within range of specified improper types.

*Invalid keyword in dump custom command*  
One or more attribute keywords are not recognized.

*Invalid keyword in pair table parameters*  
Keyword used in list of table parameters is not recognized.

*Invalid keyword in thermo\_style custom command*

One or more specified keywords are not recognized.

*Invalid kspace style*  
The choice of kspace style is unknown.

*Invalid mass line in data file*  
Self-explanatory.

*Invalid math/group function in variable*  
Self-explanatory.

*Invalid natoms for dump dcd*  
Natoms is initially 0 which is not valid for the dump dcd style. Natoms must be constant for the duration of the simulation.

*Invalid natoms for dump xtc*  
Natoms is initially 0 which is not valid for the dump xtc style.

*Invalid natoms for dump xyz*  
Natoms is initially 0 which is not valid for the dump xyz style.

*Invalid option in lattice command for non-custom style*  
Certain lattice keywords are not supported unless the lattice style is "custom".

*Invalid order of forces within respa levels*  
For respa, ordering of force computations within respa levels must obey certain rules. E.g. bonds cannot be compute less frequently than angles, pairwise forces cannot be computed less frequently than kspace, etc.

*Invalid pair style*  
The choice of pair style is unknown.

*Invalid pair table cutoff*  
Cutoffs in pair\_coeff command are not valid with read-in pair table.

*Invalid pair table length*  
Length of read-in pair table is invalid

*Invalid random number seed in set command*  
Random number seed must be > 0.

*Invalid region style*  
The choice of region style is unknown.

*Invalid seed for Park random # generator*  
The random number generator cannot be given a seed <= 0.

*Invalid shape line in data file*  
Self-explanatory.

*Invalid shape line in data file*  
Self-explanatory.

*Invalid style in pair\_write command*  
Self-explanatory. Check the input script.

*Invalid thermo keyword in variable*  
Self-explanatory.

*Invalid type for dipole set*  
Dipole command must set a type from 1–N where N is the number of atom types.

*Invalid type for mass set*  
Mass command must set a type from 1–N where N is the number of atom types.

*Invalid type for shape set*  
Atom type is out of bounds.

*Invalid value in set command*  
The value specified for the setting is invalid, likely because it is too small or too large.

*Invalid variable in next command*  
Next command in input script must set variables from "a" to "z".

*Invalid variable name in variable*  
Self-explanatory.

*Invalid variable name*

Variable name used in an input script line is invalid.

*Invalid variable style with next command*

Variable styles *equal* and *world* cannot be used in a next command.

*Invoked pair single on pair style none*

A command (e.g. a dump) attempted to invoke the single() function on a pair style none, which is illegal.

You are probably attempting to compute per-atom quantities with an undefined pair style.

*KSpace style has not yet been set*

Cannot use kspace\_modify command until a kspace style is set.

*KSpace style is incompatible with Pair style*

Setting a kspace style requires that a pair style with a long-range Coulombic component be selected.

*Keyword %s in MEAM parameter file not recognized*

Self-explanatory.

*Kspace style requires atom attribute q*

The atom style defined does not have these attributes.

*Label wasn't found in input script*

Self-explanatory.

*Lattice orient vectors are not orthogonal*

The three specified lattice orientation vectors must be mutually orthogonal.

*Lattice orient vectors are not right-handed*

The three specified lattice orientation vectors must create a right-handed coordinate system such that  $\mathbf{a}_1 \times \mathbf{a}_2 = \mathbf{a}_3$ .

*Lattice primitive vectors are colinear*

The specified lattice primitive vectors do not form a unit cell with non-zero volume.

*Lattice settings are not compatible with 2d simulation*

One or more of the specified lattice vectors has a non-zero z component.

*Lattice spacings are invalid*

Each x,y,z spacing must be  $> 0$ .

*Lattice style incompatible with simulation dimension*

2d simulation can use sq, sq2, or hex lattice. 3d simulation can use sc, bcc, or fcc lattice.

*Lost atoms via displacement: original %.15g current %.15g*

Moving atoms via the displace\_atoms command lost one or more atoms.

*Lost atoms: original %.15g current %.15g*

A thermodynamic computation has detected lost atoms.

*MEAM library error %d*

A call to the MEAM Fortran library returned an error.

*Marsaglia RNG cannot use 0 seed*

The random number generator used for the fix langevin command cannot use 0 as an initial seed.

*Mass command before simulation box is defined*

The mass command cannot be used before a read\_data, read\_restart, or create\_box command.

*Min\_style command before simulation box is defined*

The min\_style command cannot be used before a read\_data, read\_restart, or create\_box command.

*Minimize command before simulation box is defined*

The minimize command cannot be used before a read\_data, read\_restart, or create\_box command.

*More than one fix deform*

Only one fix deform can be defined at a time.

*More than one fix freeze*

Only one of these fixes can be defined, since the granular pair potentials access it.

*More than one fix shake*

Only one fix shake can be defined.

*Must define angle\_style before Angle Coeffs*

Must use an angle\_style command before reading a data file that defines Angle Coeffs.

*Must define angle\_style before BondAngle Coeffs*

Must use an angle\_style command before reading a data file that defines Angle Coeffs.

*Must define angle\_style before BondBond Coeffs*

Must use an angle\_style command before reading a data file that defines Angle Coeffs.

*Must define bond\_style before Bond Coeffs*

Must use a bond\_style command before reading a data file that defines Bond Coeffs.

*Must define dihedral\_style before AngleAngleTorsion Coeffs*

Must use a dihedral\_style command before reading a data file that defines AngleAngleTorsion Coeffs.

*Must define dihedral\_style before AngleTorsion Coeffs*

Must use a dihedral\_style command before reading a data file that defines AngleTorsion Coeffs.

*Must define dihedral\_style before BondBond13 Coeffs*

Must use a dihedral\_style command before reading a data file that defines BondBond13 Coeffs.

*Must define dihedral\_style before Dihedral Coeffs*

Must use a dihedral\_style command before reading a data file that defines Dihedral Coeffs.

*Must define dihedral\_style before EndBondTorsion Coeffs*

Must use a dihedral\_style command before reading a data file that defines EndBondTorsion Coeffs.

*Must define dihedral\_style before MiddleBondTorsion Coeffs*

Must use a dihedral\_style command before reading a data file that defines MiddleBondTorsion Coeffs.

*Must define improper\_style before AngleAngle Coeffs*

Must use an improper\_style command before reading a data file that defines AngleAngle Coeffs.

*Must define improper\_style before Improper Coeffs*

Must use an improper\_style command before reading a data file that defines Improper Coeffs.

*Must define pair\_style before Pair Coeffs*

Must use a pair\_style command before reading a data file that defines Pair Coeffs.

*Must have more than one processor partition to temper*

Cannot use the temper command with only one processor partition. Use the -partition command-line option.

*Must read Atoms before Angles*

The Atoms section of a data file must come before an Angles section.

*Must read Atoms before Bonds*

The Atoms section of a data file must come before a Bonds section.

*Must read Atoms before Dihedrals*

The Atoms section of a data file must come before a Dihedrals section.

*Must read Atoms before Improvers*

The Atoms section of a data file must come before an Improvers section.

*Must read Atoms before Velocities*

The Atoms section of a data file must come before a Velocities section.

*Must set both respa inner and outer*

Cannot use just the inner or outer option with respa without using the other.

*Must specify a region in fix deposit*

The region keyword must be specified with this fix.

*Must specify a region in fix pour*

The region keyword must be specified with this fix.

*Must use -in switch with multiple partitions*

A multi-partition simulation cannot read the input script from stdin. The -in command-line option must be used to specify a file.

*Must use a block or cylinder region with fix pour*

Self-explanatory.

*Must use a block region with fix pour for 2d simulations*

Self-explanatory.

*Must use a molecular atom style with fix poems molecule*

Self-explanatory.

*Must use a molecular atom style with fix rigid molecule*

Self-explanatory.

*Must use a z-axis cylinder with fix pour*

The axis of the cylinder region used with the fix insert command must be oriented along the z dimension.

*Must use charged atom style with fix efield*

The atom style being used does not allow atoms to have assigned charges. Hence it will not work with this fix which generates a force due to an E-field acting on charge.

*Must use fix gravity with fix pour*

Insertion of granular particles must be done under the influence of gravity.

*Must use molecular atom style with neigh\_modify exclude molecule*

The atom style must define a molecule ID to use the exclude option.

*Must use region with side = in with fix deposit*

Self-explanatory

*Must use region with side = in with fix pour*

Self-explanatory.

*Must use special\_bonds = 1,1,1 with bond style quartic*

The settings for the special\_bonds command must be set as indicated when using bond style quartic.

*Needed topology not in data file*

The header of the data file indicated that bonds or angles or dihedrals or impropers would be included, but they were not present.

*Neighbor delay must be 0 or multiple of every setting*

The delay and every parameters set via the neigh\_modify command are inconsistent. If the delay setting is non-zero, then it must be a multiple of the every setting.

*Neighbor list overflow, boost neigh\_modify one or page*

There are too many neighbors of a single atom. Use the neigh\_modify command to increase the neighbor page size and the max number of neighbors allowed for one atom.

*Neighbor multi not allowed with granular*

Self-explanatory.

*Neighbor multi not allowed with rRESPA*

Self-explanatory.

*Newton bond change after simulation box is defined*

The newton command cannot be used to change the newton bond value after a read\_data, read\_restart, or create\_box command.

*No angles allowed with this atom style*

Self-explanatory. Check data file.

*No atoms in data file*

The header of the data file indicated that atoms would be included, but they were not present.

*No basis atoms in lattice*

Basis atoms must be defined for lattice style user.

*No bonds allowed with this atom style*

Self-explanatory. Check data file.

*No dihedrals allowed with this atom style*

Self-explanatory. Check data file.

*No dump custom arguments specified*

The dump custom command requires that atom quantities be specified to output to dump file.

*No impropers allowed with this atom style*

Self-explanatory. Check data file.

*No matching element in EAM potential file*

The EAM potential file does not contain elements that match the requested elements.

*No rigid bodies defined*

The fix specification did not end up defining any rigid bodies.

*Non integer # of swaps in temper command*

Swap frequency in temper command must evenly divide the total # of timesteps.

*One or more atoms belong to multiple rigid bodies*  
Two or more rigid bodies defined by the fix rigid command cannot contain the same atom.

*One or zero atoms in rigid body*  
Any rigid body defined by the fix rigid command must contain 2 or more atoms.

*Out of range atoms – cannot compute PPPM*  
One or more atoms are attempting to map their charge to a PPPM grid point that is not owned by a processor. This is usually because an atom has moved to far in a single timestep.

*POEMS fix must come before NPT/NPH fix*  
NPT/NPH fix must be defined in input script after all poems fixes, else the fix contribution to the pressure virial is incorrect.

*PPPM grid is too large*  
The global PPPM grid is larger than OFFSET in one or more dimensions. OFFSET is currently set to 4096. You likely need to decrease the requested precision.

*PPPM order cannot be greater than %d*  
Self-explanatory.

*PPPM stencil extends too far, reduce PPPM order*  
The grid points that atom charge are mapped to cannot extend further than one neighbor processor away. Reducing the PPPM order via the kspace\_modify command will reduce the stencil distance.

*Pair coeff for hybrid has invalid style*  
Style in pair coeff must have been listed in pair\_style command.

*Pair cutoff < Respa interior cutoff*  
One or more pairwise cutoffs are too short to use with the specified rRESPA cutoffs.

*Pair distance < table inner cutoff*  
Two atoms are closer together than the pairwise table allows.

*Pair distance > table outer cutoff*  
Two atoms are further apart than the pairwise table allows.

*Pair gayberne epsilon a,b,c coeffs are not all set*  
Each atom type involved in pair\_style gayberne must have these 3 coefficients set at least once.

*Pair gayberne requires atom attributes quat, torque*  
The atom style defined does not have these attributes.

*Pair granular requires atom attributes radius, omega, torque*  
The atom style defined does not have these attributes.

*Pair inner cutoff < Respa interior cutoff*  
One or more pairwise cutoffs are too short to use with the specified rRESPA cutoffs.

*Pair inner cutoff >= Pair outer cutoff*  
The specified cutoffs for the pair style are inconsistent.

*Pair style MEAM requires newton pair on*  
See the newton command. This is a restriction to use the MEAM potential.

*Pair style Stillinger–Weber requires atom IDs*  
This is a requirement to use the SW potential.

*Pair style Stillinger–Weber requires newton pair on*  
See the newton command. This is a restriction to use the SW potential.

*Pair style Tersoff requires atom IDs*  
This is a requirement to use the Tersoff potential.

*Pair style Tersoff requires newton pair on*  
See the newton command. This is a restriction to use the Tersoff potential.

*Pair style buck/coul/cut requires atom attribute q*  
The atom style defined does not have this attribute.

*Pair style buck/coul/long requires atom attribute q*  
The atom style defined does not have these attributes.

*Pair style does not support bond\_style quartic*

The pair style does not have a single() function, so it can not be invoked by bond\_style quartic.

*Pair style does not support computing per-atom energy*

The pair style does not have a single() function, so it can not be used to dump per-atom energy.

*Pair style does not support computing per-atom stress*

The pair style does not have a single() function, so it can not be used to dump per-atom stress.

*Pair style does not support pair\_write*

The pair style does not have a single() function, so it can not be invoked by the pair\_write command.

*Pair style does not support rRESPA inner/middle/outer*

You are attempting to use rRESPA options with a pair style that does not support them.

*Pair style dpd requires atom style dpd*

Must use atom\_style dpd or atom\_style hybrid with dpd as a sub-style in order to use this pair style.

*Pair style granular with history requires atoms have IDs*

Atoms in the simulation do not have IDs, so history effects cannot be tracked by the granular pair potential.

*Pair style hybrid cannot have hybrid as an argument*

Self-explanatory.

*Pair style hybrid cannot use same pair style twice*

The sub-style arguments of pair\_style hybrid cannot be duplicated. Check the input script.

*Pair style is incompatible with KSpace style*

If a pair style with a long-range Coulombic component is selected, then a kspace style must also be used.

*Pair style lj/charmm/coul/charmm requires atom attribute q*

The atom style defined does not have these attributes.

*Pair style lj/charmm/coul/long requires atom attribute q*

The atom style defined does not have these attributes.

*Pair style lj/class2/coul/cut requires atom attribute q*

The atom style defined does not have this attribute.

*Pair style lj/class2/coul/long requires atom attribute q*

The atom style defined does not have this attribute.

*Pair style lj/cut/coul/cut requires atom attribute q*

The atom style defined does not have this attribute.

*Pair style lj/cut/coul/long requires atom attribute q*

The atom style defined does not have this attribute.

*Pair style lj/cut/coul/long/tip4p requires atom IDs*

There are no atom IDs defined in the system and the TIP4P potential requires them to find O,H atoms with a water molecule.

*Pair style lj/cut/coul/long/tip4p requires atom attribute q*

The atom style defined does not have these attributes.

*Pair style lj/cut/coul/long/tip4p requires newton pair on*

This is because the computation of constraint forces within a water molecule adds forces to atoms owned by other processors.

*Pair table cutoffs must all be equal to use with KSpace*

When using pair style table with a long-range KSpace solver, the cutoffs for all atom type pairs must all be the same, since the long-range solver starts at that cutoff.

*Pair table parameters did not set N*

List of pair table parameters must include N setting.

*Pair\_coeff command before pair\_style is defined*

Self-explanatory.

*Pair\_coeff command before simulation box is defined*

The pair\_coeff command cannot be used before a read\_data, read\_restart, or create\_box command.

*Pair\_modify command before pair\_style is defined*

Self-explanatory.

*Pair\_style granular command before simulation box is defined*

This pair style cannot be used before a simulation box is defined.

*Pair\_write command before pair\_style is defined*  
Self-explanatory.

*Potential file has duplicate entry*  
The potential file for a SW or Tersoff potential has more than one entry for the same 3 ordered elements.

*Potential file is missing an entry*  
The potential file for a SW or Tersoff potential does not have a needed entry.

*Potential with shear history requires newton pair off*  
Granular potentials that include shear history effects can only be run with a newton setting where pairwise newton is "off".

*Precompute ID for fix ave/spatial does not exist*  
The compute used by fix ave/spatial requires a second pre-computation compute, which isn't defined.

*Precompute ID for fix ave/time does not exist*  
The compute used by fix ave/time requires a second pre-computation compute, which isn't defined.

*Press ID for fix nph does not exist*  
The compute ID needed to compute pressure for the fix does not exist.

*Press ID for fix npt does not exist*  
The compute ID needed to compute pressure for the fix does not exist.

*Press ID for thermo does not exist*  
The compute ID needed to compute pressure for thermodynamics does not exist.

*Proc grid in z != 1 for 2d simulation*  
There cannot be more than 1 processor in the z dimension of a 2d simulation.

*Processor partitions are inconsistent*  
The total number of processors in all partitions must match the number of processors LAMMPS is running on.

*Processors command after simulation box is defined*  
The processors command cannot be used after a read\_data, read\_restart, or create\_box command.

*Quaternion creation numeric error*  
A numeric error occurred in the creation of a rigid body by the fix rigid command.

*Quotes in a single arg*  
A single word should not be quoted in the input script; only a set of words with intervening spaces should be quoted.

*R0 < 0 for fix spring command*  
Equilibrium spring length is invalid.

*Region intersect region ID does not exist*  
Self-explanatory.

*Region union region ID does not exist*  
One or more of the region IDs specified by the region union command does not exist.

*Replacing a fix, but new style != old style*  
A fix ID can be used a 2nd time, but only if the style matches the previous fix. In this case it is assumed you wish to reset a fix's parameters. This error may mean you are mistakenly re-using a fix ID when you do not intend to.

*Replicate command before simulation box is defined*  
The replicate command cannot be used before a read\_data, read\_restart, or create\_box command.

*Replicate did not assign all atoms correctly*  
Atoms replicated by the replicate command were not assigned correctly to processors. This is likely due to some atom coordinates being outside a non-periodic simulation box.

*Respa inner cutoffs are invalid*  
The first cutoff must be  $\leq$  the second cutoff.

*Respa levels must be  $\geq 1$*   
Self-explanatory.

*Respa middle cutoffs are invalid*



The first cutoff must be  $\leq$  the second cutoff.

*Reuse of compute ID*  
A compute ID cannot be used twice.

*Reuse of dump ID*  
A dump ID cannot be used twice.

*Reuse of region ID*  
A region ID cannot be used twice.

*Rigid body has degenerate moment of inertia*  
Fix poems will only work with bodies (collections of atoms) that have non-zero principal moments of inertia. This means they must be 3 or more non-collinear atoms, even with joint atoms removed.

*Rigid fix must come before NPT/NPH fix*  
NPT/NPH fix must be defined in input script after all rigid fixes, else the rigid fix contribution to the pressure virial is incorrect.

*Run command before simulation box is defined*  
The run command cannot be used before a read\_data, read\_restart, or create\_box command.

*Run command start value is after start of run*  
Self-explanatory.

*Run command stop value is before end of run*  
Self-explanatory.

*Run command upto value is before current timestep*  
Self-explanatory.

*Run\_style command before simulation box is defined*  
The run\_style command cannot be used before a read\_data, read\_restart, or create\_box command.

*Set command before simulation box is defined*  
The set command cannot be used before a read\_data, read\_restart, or create\_box command.

*Set command with no atoms existing*  
No atoms are yet defined so the set command cannot be used.

*Set region ID does not exist*  
Region ID specified in set command does not exist.

*Shake angles have different bond types*  
All 3-atom angle-constrained SHAKE clusters specified by the fix shake command that are the same angle type, must also have the same bond types for the 2 bonds in the angle.

*Shake atoms %d %d %d %d missing on proc %d at step %d*  
The 4 atoms in a single shake cluster specified by the fix shake command are not all accessible to a processor. This probably means an atom has moved too far.

*Shake atoms %d %d %d missing on proc %d at step %d*  
The 3 atoms in a single shake cluster specified by the fix shake command are not all accessible to a processor. This probably means an atom has moved too far.

*Shake atoms %d %d missing on proc %d at step %d*  
The 2 atoms in a single shake cluster specified by the fix shake command are not all accessible to a processor. This probably means an atom has moved too far.

*Shake cluster of more than 4 atoms*  
A single cluster specified by the fix shake command can have no more than 4 atoms.

*Shake clusters are connected*  
A single cluster specified by the fix shake command must have a single central atom with up to 3 other atoms bonded to it.

*Shake determinant = 0.0*  
The determinant of the matrix being solved for a single cluster specified by the fix shake command is numerically invalid.

*Shake fix must come before NPT/NPH fix*  
NPT fix must be defined in input script after SHAKE fix, else the SHAKE fix contribution to the pressure virial is incorrect.

*Shape command before simulation box is defined*

Self-explanatory.

*Substitution for undefined variable*

The variable specified with a \$ symbol in an input script command has not been previously defined with a variable command.

*TIP4P hydrogen has incorrect atom type*

The TIP4P pairwise computation found an H atom whose type does not agree with the specified H type.

*TIP4P hydrogen is missing*

The TIP4P pairwise computation failed to find the correct H atom within a water molecule.

*TMD target file did not list all group atoms*

The target file for the fix tmd command did not list all atoms in the fix group.

*Target T for fix npt cannot be 0.0*

Self-explanatory.

*Target T for fix nvt cannot be 0.0*

Self-explanatory.

*Temp ID for fix nph does not exist*

The compute ID needed to compute temperature for the fix does not exist.

*Temp ID for fix npt does not exist*

The compute ID needed to compute temperature for the fix does not exist.

*Temp ID for fix nvt does not exist*

The compute ID needed to compute temperature for the fix does not exist.

*Temp ID for fix temp/rescale does not exist*

The compute ID needed to compute temperature for the fix does not exist.

*Temp ID of press ID for fix nph does not exist*

The compute ID needed to compute temperature within the pressure compute ID for the fix does not exist.

*Temp ID of press ID for fix npt does not exist*

The compute ID needed to compute temperature within the pressure compute ID for the fix does not exist.

*Temper command before simulation box is defined*

The temper command cannot be used before a read\_data, read\_restart, or create\_box command.

*Temperature region ID does not exist*

The region ID specified in the temperature command does not exist.

*Tempering fix ID is not defined*

The fix ID specified by the temper command does not exist.

*Tempering fix is not valid*

The fix specified by the temper command is not one that controls temperature (nvt or langevin).

*Thermo compute ID does not compute scalar info*

The specified compute ID does not compute a scalar quantity as requested.

*Thermo compute ID does not compute vector info*

The specified compute ID does not compute a vector quantity as requested.

*Thermo compute ID vector is not large enough*

The specified compute ID does not compute a large enough vector quantity for the requested index.

*Thermo style does not use drot*

Cannot use thermo\_modify to set this parameter since the thermo\_style is not computing this quantity.

*Thermo style does not use grot*

Cannot use thermo\_modify to set this parameter since the thermo\_style is not computing this quantity.

*Thermo style does not use press*

Cannot use thermo\_modify to set this parameter since the thermo\_style is not computing this quantity.

*Thermo style does not use temp*

Cannot use thermo\_modify to set this parameter since the thermo\_style is not computing this quantity.

*Thermo\_modify press ID does not compute pressure*

The specified compute ID does not compute pressure.

*Thermo\_modify temp ID does not compute temperature*

The specified compute ID does not compute temperature.

*Thermo\_style command before simulation box is defined*  
 The thermo\_style command cannot be used before a read\_data, read\_restart, or create\_box command.

*Thermodynamics must compute PE for temper*  
 The thermo style must insure that thermodynamics computations include potential energy when tempering is performed.

*Thermodynamics not computed on tempering swap steps*  
 The thermo command must insure that thermodynamics (including energy) is computed on the timesteps that tempering swaps are attempted.

*Timestep must be  $\geq 0$*   
 Specified timestep size is invalid.

*Too big a problem to replicate with molecular atom style*  
 Molecular problems cannot become bigger than  $2^{31}$  atoms (or bonds, etc) when replicated, else the atom IDs and other quantities cannot be stored in 32 bit quantities.

*Too few bits for lookup table*  
 Table size specified via pair\_modify command does not work with your machine's floating point representation.

*Too many exponent bits for lookup table*  
 Table size specified via pair\_modify command does not work with your machine's floating point representation.

*Too many groups*  
 The maximum number of atom groups (including the "all" group) is given by MAX\_GROUP in group.cpp and is 32.

*Too many mantissa bits for lookup table*  
 Table size specified via pair\_modify command does not work with your machine's floating point representation.

*Too many masses for fix shake*  
 The fix shake command cannot list more masses than there are atom types.

*Too many total bits for bitmapped lookup table*  
 Table size specified via pair\_modify command is too large. Note that a value of N generates a  $2^N$  size table.

*Too many touching neighbors – boost MAXTOUCH*  
 A granular simulation has too many neighbors touching one atom. The MAXTOUCH parameter in fix\_shear\_history.cpp must be set larger and LAMMPS must be re-built.

*Tree structure in joint connections*  
 Fix poems cannot (yet) work with coupled bodies whose joints connect the bodies in a tree structure.

*Triclinic box must be periodic in skewed dimensions*  
 This is a requirement for using a non-orthogonal box. E.g. to set a non-zero xy tilt, both x and y must be periodic dimensions.

*Triclinic box skew is too large*  
 The displacement in a skewed direction must be less than half the box length in that dimension. E.g. the xy tilt must be between -half and +half of the x box length.

*Unbalanced quotes in input line*  
 No matching end double quote was found following a leading double quote.

*Unexpected end of data file*  
 LAMMPS hit the end of the data file while attempting to read a section. Something is wrong with the format of the data file.

*Units command after simulation box is defined*  
 The units command cannot be used after a read\_data, read\_restart, or create\_box command.

*Universe/uloop variable count < # of partitions*  
 A universe or uloop style variable must specify a number of values  $\geq$  to the number of processor partitions.

*Unknown command: %s*

The command is not known to LAMMPS. Check the input script.

*Unknown identifier in data file: %s*

A section of the data file cannot be read by LAMMPS.

*Unknown section in data file: %s*

The keyword for a section of the data file is not recognized by LAMMPS.

*Unknown table style in pair\_style command*

Style of table is invalid for use with pair\_style table command.

*Unrecognized lattice type in MEAM file 1*

The lattice type in an entry of the MEAM library file is not valid.

*Unrecognized lattice type in MEAM file 2*

The lattice type in an entry of the MEAM parameter file is not valid.

*Use of compute temp/ramp with undefined lattice*

Must use lattice command with compute temp/ramp command if units option is set to lattice.

*Use of displace\_atoms with undefined lattice*

Must use lattice command with displace\_atoms command if units option is set to lattice.

*Use of fix ave/spatial with undefined lattice*

A lattice must be defined to use fix ave/spatial with units = lattice.

*Use of fix deform with undefined lattice*

A lattice must be defined to use fix deform with units = lattice.

*Use of fix deposit with undefined lattice*

Must use lattice command with compute fix deposit command if units option is set to lattice.

*Use of fix indent with undefined lattice*

The lattice command must be used to define a lattice before using the fix indent command.

*Use of fix recenter with undefined lattice*

Must use lattice command with fix recenter command if units option is set to lattice.

*Use of region with undefined lattice*

If scale = lattice (the default) for the region command, then a lattice must first be defined via the lattice command.

*Use of velocity with undefined lattice*

If scale = lattice (the default) for the velocity set or velocity ramp command, then a lattice must first be defined via the lattice command.

*Using fix nvt/sllod with inconsistent fix deform remap option*

Fix nvt/sllod requires that deforming atoms have a velocity profile provided by "remap v" as a fix deform option.

*Using fix nvt/sllod with no fix deform defined*

Self-explanatory.

*Variable compute ID does not compute scalar info*

The specified compute ID does not compute a scalar quantity as requested.

*Variable compute ID vector is not large enough*

The specified compute ID does not compute a large enough vector quantity for the requested index.

*Variable equal keyword used before initial run*

Cannot evaluate the variable at this stage of input script.

*Variable equal keyword used before simulation box defined*

Cannot evaluate the variable at this stage of input script.

*Variable group ID does not exist*

A group specified in a variable definition does not exist.

*Velocity command before simulation box is defined*

The velocity command cannot be used before a read\_data, read\_restart, or create\_box command.

*Velocity command with no atoms existing*

A velocity command has been used, but no atoms yet exist.

*Velocity ramp in z for a 2d problem*

Self-explanatory.

*Velocity temp ID does not compute temperature*

The compute ID given to the velocity command must compute temperature.

*World variable count doesn't match # of partitions*

A world-style variable must specify a number of values equal to the number of processor partitions.

*Write\_restart command before simulation box is defined*

The write\_restart command cannot be used before a read\_data, read\_restart, or create\_box command.

*Zero-length lattice orient vector*

Self-explanatory.

## Warnings:

*FENE bond too long: %d %d %d %g*

A FENE bond has stretched dangerously far. It's interaction strength will be truncated to attempt to prevent the bond from blowing up.

*FENE bond too long: %d %g*

A FENE bond has stretched dangerously far. It's interaction strength will be truncated to attempt to prevent the bond from blowing up.

*Fix recenter should come after all other integration fixes*

Other fixes may change the position of the center-of-mass, so fix recenter should come last.

*Fix wall/reflect should come after all other integration fixes*

This is because other integration fixes may alter the coordinates of an atom, so you want to reflect it back into the box only after the other fixes have made their adjustments.

*Group for fix\_modify temp != fix group*

The fix\_modify command is specifying a temperature computation that computes a temperature on a different group of atoms than the fix itself operates on. This is probably not what you want to do.

*Less insertions than requested*

Less atom insertions occurred on this timestep due to the fix insert command than were scheduled. This is probably because there were too many overlaps detected.

*Lost atoms: original %.15g current %.15g*

A thermodynamic computation has detected lost atoms.

*Mismatch between velocity and compute groups*

The temperature computation used by the velocity command will not be on the same group of atoms that velocities are being set for.

*More than one compute centro/atom*

It is not efficient to use compute centro/atom more than once.

*More than one compute coord/atom*

It is not efficient to use compute coord/atom more than once.

*More than one compute epair/atom*

It is not efficient to use compute epair/atom more than once.

*More than one compute etotal/atom*

It is not efficient to use compute etotal/atom more than once.

*More than one compute ke/atom*

It is not efficient to use compute ke/atom more than once.

*More than one compute stress/atom*

It is not efficient to use compute stress/atom more than once.

*More than one fix msd*

It is not efficient to use fix msd more than once.

*More than one fix poems*

It is not efficient to use fix poems more than once.

*More than one fix rigid*

It is not efficient to use fix rigid more than once.

*No fixes defined, atoms won't move*

If you are not using a fix like nve, nvt, npt then atom velocities and coordinates will not be updated during timestepping.

*No joints between rigid bodies, use fix rigid instead*

The bodies defined by fix poems are not connected by joints. POEMS will integrate the body motion, but it would be more efficient to use fix rigid.

*One or more respa levels compute no forces*

This is computationally inefficient.

*Particle deposition was unsuccessful*

The fix deposit command was not able to insert as many atoms as needed. The requested volume fraction may be too high, or other atoms may be in the insertion region.

*Replacing a fix, but new group != old group*

The ID and style of a fix match for a fix you are changing with a fix command, but the new group you are specifying does not match the old group.

*Replicating in a non-periodic dimension*

The parameters for a replicate command will cause a non-periodic dimension to be replicated; this may cause unwanted behavior.

*Resetting angle\_style to restart file value*

The angle style defined in the LAMMPS input script does not match that of the restart file.

*Resetting bond\_style to restart file value*

The bond style defined in the LAMMPS input script does not match that of the restart file.

*Resetting boundary settings to restart file values*

The boundary settings defined in the LAMMPS input script do not match that of the restart file.

*Resetting dihedral\_style to restart file value*

The dihedral style defined in the LAMMPS input script does not match that of the restart file.

*Resetting dimension to restart file value*

The dimension value defined in the LAMMPS input script does not match that of the restart file.

*Resetting improper\_style to restart file value*

The improper style defined in the LAMMPS input script does not match that of the restart file.

*Resetting newton bond to restart file value*

The value of the newton setting for bonds defined in the LAMMPS input script does not match that of the restart file.

*Resetting pair\_style to restart file value*

The pair style defined in the LAMMPS input script does not match that of the restart file.

*Resetting reneighboring criteria during minimization*

Minimization requires that neigh\_modify settings be delay = 0, every = 1, check = yes. Since these settings were not in place, LAMMPS changed them and will restore them to their original values after the minimization.

*Resetting unit\_style to restart file value*

The unit style defined in the LAMMPS input script does not match that of the restart file.

*Restart file used different # of processors*

The restart file was written out by a LAMMPS simulation running on a different number of processors. Due to round-off, the trajectories of your restarted simulation may diverge a little more quickly than if you ran on the same # of processors.

*Restart file used different 3d processor grid*

The restart file was written out by a LAMMPS simulation running on a different 3d grid of processors. Due to round-off, the trajectories of your restarted simulation may diverge a little more quickly than if you ran on the same # of processors.

*Restart file used different newton pair setting*

The restart file was written out by a LAMMPS simulation running with a different value of the newton pair setting. The new simulation will use the value from the input script.

*Restart file version does not match LAMMPS version*

The version of LAMMPS that wrote the restart file does not match the version of LAMMPS that is reading the restart file. Generally this shouldn't be a problem, since restart file formats won't change very often if at all. But if they do, the code will probably crash trying to read the file. Versions of LAMMPS are specified by a date.

*Shake determinant < 0.0*

The determinant of the quadratic equation being solved for a single cluster specified by the fix shake command is numerically suspect. LAMMPS will set it to 0.0 and continue.

*Slab parameter < 2.0 may cause unphysical behavior*

The kspace\_modify slab parameter should be larger to insure periodic grids padded with empty space do not overlap.

*System is not charge neutral, net charge = %g*

The total charge on all atoms on the system is not 0.0, which is not valid for Ewald or PPPM.

*Table inner cutoff >= outer cutoff*

You specified an inner cutoff for a Coulombic table that is longer than the global cutoff. Probably not what you wanted.

*Temperature for NPH is not for group all*

User-assigned temperature to NPH fix does not compute temperature for all atoms. Since NPH computes a global pressure, the kinetic energy contribution from the temperature is assumed to also be for all atoms. Thus the pressure used by NPH could be inaccurate.

*Temperature for NPT is not for group all*

User-assigned temperature to NPT fix does not compute temperature for all atoms. Since NPT computes a global pressure, the kinetic energy contribution from the temperature is assumed to also be for all atoms. Thus the pressure used by NPT could be inaccurate.

*Temperature for thermo pressure is not for group all*

User-assigned temperature to thermo via the thermo\_modify command does not compute temperature for all atoms. Since thermo computes a global pressure, the kinetic energy contribution from the temperature is assumed to also be for all atoms. Thus the pressure printed by thermo could be inaccurate.

*Using compute temp/deform with inconsistent fix deform remap option*

Fix nvt/sllod assumes deforming atoms have a velocity profile provided by "remap v" or "remap none" as a fix deform option.

*Using compute temp/deform with no fix deform defined*

Self-explanatory.

*Using pair tail corrections with nonperiodic system*

This is probably a bogus thing to do, since tail corrections are computed by integrating the density of a periodic system out to infinity.

*Variable equal keyword used with non-current thermo*

The evaluation of the variable may be inaccurate as a result.

## 10. Future and history

This section lists features we are planning to add to LAMMPS, features of previous versions of LAMMPS, and features of other parallel molecular dynamics codes I've distributed.

### 10.1 [Coming attractions](#)

### 10.2 [Past versions](#)

---

#### 10.1 Coming attractions

The current version of LAMMPS incorporates nearly all the features from previous parallel MD codes developed at Sandia. These include earlier versions of LAMMPS itself, Warp and ParaDyn for metals, and GranFlow for granular materials.

These are new features we'd like to eventually add to LAMMPS. Some are being worked on; some haven't been implemented because of lack of time or interest; others are just a lot of work!

- Monte Carlo bond–swapping for polymers (was in Fortran LAMMPS)
  - torsional shear boundary conditions and temperature calculation
  - NPT with changing box shape (Parinello–Rahman)
  - bond creation potentials
  - long–range point dipole solver
  - REBO bond–order potential
  - ReaxFF force field from Bill Goddard's group
- 

#### 10.2 Past versions

LAMMPS development began in the mid 1990s under a cooperative research & development agreement (CRADA) between two DOE labs (Sandia and LLNL) and 3 companies (Cray, Bristol Myers Squibb, and Dupont). Soon after the CRADA ended, a final F77 version of the code, LAMMPS 99, was released. As development of LAMMPS continued at Sandia, the memory management in the code was converted to F90; a final F90 version was released as LAMMPS 2001.

The current LAMMPS is a rewrite in C++ and was first publicly released in 2004. It includes many new features, including features from other parallel molecular dynamics codes written at Sandia, namely ParaDyn, Warp, and GranFlow. ParaDyn is a parallel implementation of the popular serial DYNAMO code developed by Stephen Foiles and Murray Daw for their embedded atom method (EAM) metal potentials. ParaDyn uses atom– and force–decomposition algorithms to run in parallel. Warp is also a parallel implementation of the EAM potentials designed for large problems, with boundary conditions specific to shearing solids in varying geometries. GranFlow is a granular materials code with potentials and boundary conditions peculiar to granular systems. All of these codes (except ParaDyn) use spatial–decomposition techniques for their parallelism.

These older codes are available for download from the [LAMMPS WWW site](#), except for Warp & GranFlow which were primarily used internally. A brief listing of their features is given here.

##### LAMMPS 2001

- F90 + MPI
- dynamic memory
- spatial–decomposition parallelism



- NVE, NVT, NPT, NPH, rRESPA integrators
- LJ and Coulombic pairwise force fields
- all-atom, united-atom, bead-spring polymer force fields
- CHARMM-compatible force fields
- class 2 force fields
- 3d/2d Ewald & PPPM
- various force and temperature constraints
- SHAKE
- Hessian-free truncated-Newton minimizer
- user-defined diagnostics

## LAMMPS 99

- F77 + MPI
- static memory allocation
- spatial-decomposition parallelism
- most of the LAMMPS 2001 features with a few exceptions
- no 2d Ewald & PPPM
- molecular force fields are missing a few CHARMM terms
- no SHAKE

## Warp

- F90 + MPI
- spatial-decomposition parallelism
- embedded atom method (EAM) metal potentials + LJ
- lattice and grain-boundary atom creation
- NVE, NVT integrators
- boundary conditions for applying shear stresses
- temperature controls for actively sheared systems
- per-atom energy and centro-symmetry computation and output

## ParaDyn

- F77 + MPI
- atom- and force-decomposition parallelism
- embedded atom method (EAM) metal potentials
- lattice atom creation
- NVE, NVT, NPT integrators
- all serial DYNAMO features for controls and constraints

## GranFlow

- F90 + MPI
- spatial-decomposition parallelism
- frictional granular potentials
- NVE integrator
- boundary conditions for granular flow and packing and walls
- particle insertion

## angle\_style charmm command

### Syntax:

```
angle_style charmm
```

### Examples:

```
angle_style charmm  
angle_coeff 1 300.0 107.0 50.0 3.0
```

### Description:

The *charmm* angle style uses the potential

$$E = K(\theta - \theta_0)^2 + K_{UB}(r - r_{UB})^2$$

with an additional Urey-Bradley term based on the distance  $r$  between the 1st and 3rd atoms in the angle.  $K$ ,  $\theta_0$ ,  $K_{ub}$ , and  $r_{ub}$  are coefficients defined for each angle type.

See [\(MacKerell\)](#) for a description of the CHARMM force field.

The following coefficients must be defined for each angle type via the [angle\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- $K$  (energy/radian<sup>2</sup>)
- $\theta_0$  (degrees)
- $K_{ub}$  (energy/distance<sup>2</sup>)
- $r_{ub}$  (distance)

$\theta_0$  is specified in degrees, but LAMMPS converts it to radians internally; hence the units of  $K$  are in energy/radian<sup>2</sup>.

### Restrictions:

This angle style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[angle\\_coeff](#)

**Default:** none

---

**(MacKerell)** MacKerell, Bashford, Bellott, Dunbrack, Evanseck, Field, Fischer, Gao, Guo, Ha, et al, J Phys Chem, 102, 3586 (1998).

## angle\_style class2 command

### Syntax:

```
angle_style class2
```

### Examples:

```
angle_style class2
angle_coeff * 75.0
```

### Description:

The *class2* angle style uses the potential

$$\begin{aligned}
 E &= E_a + E_{bb} + E_{ba} \\
 E_a &= K_2(\theta - \theta_0)^2 + K_3(\theta - \theta_0)^3 + K_4(\theta - \theta_0)^4 \\
 E_{bb} &= M(r_{ij} - r_1)(r_{jk} - r_2) \\
 E_{ba} &= N_1(r_{ij} - r_1)(\theta - \theta_0) + N_2(r_{jk} - r_2)(\theta - \theta_0)
 \end{aligned}$$

where  $E_a$  is the angle term,  $E_{bb}$  is a bond–bond term, and  $E_{ba}$  is a bond–angle term.  $\theta_0$  is the equilibrium angle and  $r_1$  and  $r_2$  are the equilibrium bond lengths.

See [\(Sun\)](#) for a description of the COMPASS *class2* force field.

For this style, coefficients for the  $E_a$  formula can be specified in the input script or data file. These are the 4 coefficients:

- $\theta_0$  (degrees)
- $K_2$  (energy/radian<sup>2</sup>)
- $K_3$  (energy/radian<sup>2</sup>)
- $K_4$  (energy/radian<sup>2</sup>)

$\theta_0$  is specified in degrees, but LAMMPS converts it to radians internally; hence the units of  $K$  are in energy/radian<sup>2</sup>.

Coefficients for the  $E_{bb}$  and  $E_{ba}$  formulas can only be specified in the data file.

For the  $E_{bb}$  formula, the coefficients are listed under a "BondBond Coeffs" heading and each line lists 3 coefficients:

- $M$  (energy/distance<sup>2</sup>)
- $r_1$  (distance)
- $r_2$  (distance)

For the  $E_{ba}$  formula, the coefficients are listed under a "BondAngle Coeffs" heading and each line lists 4 coefficients:

- N1 (energy/distance<sup>2</sup>)
- N2 (energy/distance<sup>2</sup>)
- r1 (distance)
- r2 (distance)

The theta0 value in the Eba formula is not specified, since it is the same value from the Ea formula.

**Restrictions:**

This angle style can only be used if LAMMPS was built with the "class2" package. See the [Making LAMMPS](#) section for more info on packages.

**Related commands:**

[angle\\_coeff](#)

**Default:** none

---

(Sun) Sun, J Phys Chem B 102, 7338–7364 (1998).

## angle\_coeff command

### Syntax:

```
angle_coeff N args
```

- N = angle type (see asterik form below)
- args = coefficients for one or more angle types

### Examples:

```
angle_coeff 1 300.0 107.0
angle_coeff * 5.0
angle_coeff 2*10 5.0
```

### Description:

Specify the angle force field coefficients for one or more angle types. The number and meaning of the coefficients depends on the angle style. Angle coefficients can also be set in the data file read by the [read\\_data](#) command or in a restart file.

N can be specified in one of two ways. An explicit numeric value can be used, as in the 1st example above. Or a wild-card asterik can be used to set the coefficients for multiple angle types. This takes the form "\*" or "\*n" or "n\*" or "m\*n". If N = the number of angle types, then an asterik with no numeric values means all types from 1 to N. A leading asterik means all types from 1 to n (inclusive). A trailing asterik means all types from n to N (inclusive). A middle asterisk means all types from m to n (inclusive).

Note that using an angle\_coeff command can override a previous setting for the same angle type. For example, these commands set the coeffs for all angle types, then overwrite the coeffs for just angle type 2:

```
angle_coeff * 200.0 107.0 1.2
angle_coeff 2 50.0 107.0
```

A line in a data file that specifies angle coefficients uses the exact same format as the arguments of the angle\_coeff command in an input script, except that wild-card asterisks should not be used since coefficients for all N types must be listed in the file. For example, under the "Angle Coeffs" section of a data file, the line that corresponds to the 1st example above would be listed as

```
1 300.0 107.0
```

---

Here is an alphabetic list of angle styles defined in LAMMPS. Click on the style to display the formula it computes and coefficients specified by the associated [angle\\_coeff](#) command:

- [angle\\_style none](#) – turn off angle interactions
- [angle\\_style hybrid](#) – define multiple styles of angle interactions
- [angle\\_style charmm](#) – CHARMM angle
- [angle\\_style class2](#) – COMPASS (class 2) angle
- [angle\\_style cosine](#) – cosine angle potential
- [angle\\_style cosine/squared](#) – cosine squared angle potential
- [angle\\_style harmonic](#) – harmonic angle

---

**Restrictions:**

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

An angle style must be defined before any angle coefficients are set, either in the input script or in a data file.

**Related commands:**

[angle\\_style](#)

**Default:** none

## angle\_style cosine command

### Syntax:

```
angle_style cosine
```

### Examples:

```
angle_style cosine  
angle_coeff * 75.0
```

### Description:

The *cosine* angle style uses the potential

$$E = K[1 + \cos(\theta)]$$

where K is defined for each angle type.

The following coefficients must be defined for each angle type via the [angle\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- K (energy)

### Restrictions:

This angle style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[angle\\_coeff](#)

**Default:** none

## angle\_style cosine/squared command

### Syntax:

```
angle_style cosine/squared
```

### Examples:

```
angle_style cosine/squared  
angle_coeff 2*4 75.0 100.0
```

### Description:

The *cosine/squared* angle style uses the potential

$$E = K[\cos(\theta) - \cos(\theta_0)]^2$$

where  $\theta_0$  is the equilibrium value of the angle, and  $K$  is a prefactor. Note that the usual 1/2 factor is included in  $K$ .

The following coefficients must be defined for each angle type via the [angle\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- $K$  (energy)
- $\theta_0$  (degrees)

$\theta_0$  is specified in degrees, but LAMMPS converts it to radians internally.

### Restrictions:

This angle style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[angle\\_coeff](#)

**Default:** none



## angle\_style harmonic command

### Syntax:

```
angle_style harmonic
```

### Examples:

```
angle_style harmonic  
angle_coeff 1 300.0 107.0
```

### Description:

The *harmonic* angle style uses the potential

$$E = K(\theta - \theta_0)^2$$

where theta0 is the equilibrium value of the angle, and K is a prefactor. Note that the usual 1/2 factor is included in K.

The following coefficients must be defined for each angle type via the [angle\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- K (energy/radian^2)
- theta0 (degrees)

Theta0 is specified in degrees, but LAMMPS converts it to radians internally; hence the units of K are in energy/radian^2.

**Restrictions:** none

This angle style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

**Related commands:**

[angle\\_coeff](#)

**Default:** none

## angle\_style hybrid command

### Syntax:

```
angle_style hybrid style1 style2 ...
```

- style1,style2 = list of one or more angle styles

### Examples:

```
angle_style hybrid harmonic cosine  
angle_coeff 1 harmonic 80.0 1.2  
angle_coeff 2* cosine 50.0
```

### Description:

The *hybrid* style enables the use of multiple angle styles in one simulation. An angle style is assigned to each angle type. For example, angles in a polymer flow (of angle type 1) could be computed with a *harmonic* potential and angles in the wall boundary (of angle type 2) could be computed with a *cosine* potential. The assignment of angle type to style is made via the [angle\\_coeff](#) command or in the data file.

In the `angle_coeff` command, the first coefficient sets the angle style and the remaining coefficients are those appropriate to that style. In the example above, the 2 `angle_coeff` commands would set angles of angle type 1 to be computed with a *harmonic* potential with coefficients 80.0, 1.2 for K, r0. All other angle types (2–N) would be computed with a *cosine* potential with coefficient 50.0 for K.

If the angle *class2* potential is one of the hybrid styles, it requires additional BondBond and BondAngle coefficients be specified in the data file. These lines must also have an additional "class2" argument added after the angle type. For angle types which are assigned to other hybrid styles, use the style name (e.g. "harmonic") appropriate to that style. The BondBond and BondAngle coeffs for that angle type will then be ignored.

An angle style of *none* can be specified as an argument to `angle_style hybrid` and the corresponding `angle_coeff` commands, if you desire to turn off certain angle types.

### Restrictions:

This angle style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[angle\\_coeff](#)

**Default:** none

## angle\_style none command

### Syntax:

```
angle_style none
```

### Examples:

```
angle_style none
```

### Description:

Using an angle style of none means angle forces are not computed, even if triplets of angle atoms were listed in the data file read by the [read\\_data](#) command.

**Restrictions:** none

**Related commands:** none

**Default:** none

## angle\_style command

### Syntax:

```
angle_style style
```

- style = *none* or *hybrid* or *charmm* or *class2* or *cosine* or *cosine/squared* or *harmonic*

### Examples:

```
angle_style harmonic
angle_style charmm
angle_style hybrid harmonic cosine
```

### Description:

Set the formula(s) LAMMPS uses to compute angle interactions between triplets of atoms, which remain in force for the duration of the simulation. The list of angle triplets is read in by a [read\\_data](#) or [read\\_restart](#) command from a data or restart file.

Hybrid models where angles are computed using different angle potentials can be setup using the *hybrid* angle style.

The coefficients associated with a angle style can be specified in a data or restart file or via the [angle\\_coeff](#) command.

All angle potentials store their coefficient data in binary restart files which means `angle_style` and [angle\\_coeff](#) commands do not need to be re-specified in an input script that restarts a simulation. See the [read\\_restart](#) command for details on how to do this. The one exception is that `angle_style hybrid` only stores the list of sub-styles in the restart file; angle coefficients need to be re-specified.

IMPORTANT NOTE: When both an angle and pair style is defined, the [special\\_bonds](#) command often needs to be used to turn off (or weight) the pairwise interaction that would otherwise exist between 3 bonded atoms.

In the formulas listed for each angle style, *theta* is the angle between the 3 atoms in the angle.

---

Here is an alphabetic list of angle styles defined in LAMMPS. Click on the style to display the formula it computes and coefficients specified by the associated [angle\\_coeff](#) command:

- [angle\\_style none](#) – turn off angle interactions
  - [angle\\_style hybrid](#) – define multiple styles of angle interactions
  - [angle\\_style charmm](#) – CHARMM angle
  - [angle\\_style class2](#) – COMPASS (class 2) angle
  - [angle\\_style cosine](#) – cosine angle potential
  - [angle\\_style cosine/squared](#) – cosine squared angle potential
  - [angle\\_style harmonic](#) – harmonic angle
- 

### Restrictions:

Angle styles can only be set for atom\_styles that allow angles to be defined.

Most angle styles are part of the "molecular" package. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info on packages. The doc pages for individual bond potentials tell if it is part of a package.

**Related commands:**

[angle\\_coeff](#)

**Default:**

`angle_style none`

## atom\_modify command

### Syntax:

```
atom_modify keyword value ...
```

- one or more keyword/value pairs may be appended
- keyword = *map*

*map* value = *array* or *hash*

### Examples:

```
atom_modify map hash
```

### Description:

Modify properties of the atom style selected within LAMMPS.

The *map* keyword determines how atom ID lookup is done for molecular problems. Lookups are performed by bond (angle, etc) routines in LAMMPS to find the local atom index associated with a global atom ID. When the *array* value is used, each processor stores a lookup table of length N, where N is the total # of atoms in the system. This is the fastest method for most simulations, but a processor can run out of memory to store the table for very large simulations. The *hash* value uses a hash table to perform the lookups. This method can be slightly slower than the *array* method, but its memory cost is proportional to N/P on each processor, where P is the total number of processors running the simulation.

### Restrictions:

This command must be used before the simulation box is defined by a [read\\_data](#) or [create\\_box](#) command.

**Related commands:** none

### Default:

By default, atomic (non-molecular) problems do not allocate maps. For molecular problems, the option default is *map = array*.

## atom\_style command

### Syntax:

```
atom_style style args
```

- *style* = *angle* or *atomic* or *bond* or *charge* or *dipole* or *dpd* or *ellipsoid* or *full* or *granular* or *molecular* or *hybrid*

*args* = none for any style except *hybrid*

*hybrid args* = list of one or more sub-styles

### Examples:

```
atom_style atomic
atom_style bond
atom_style full
atom_style hybrid charge bond
```

### Description:

Define what style of atoms to use in a simulation. This determines what attributes are associated with the atoms. This command must be used before a simulation is setup via a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

Once a style is assigned, it cannot be changed, so use a style general enough to encompass all attributes. E.g. with style *bond*, angular terms cannot be used or added later to the model. It is OK to use a style more general than needed, though it may be slightly inefficient.

The choice of style affects what quantities are stored by each atom, what quantities are communicated between processors to enable forces to be computed, and what quantities are listed in the data file read by the [read\\_data](#) command.

These are the attributes of each style. All styles store coordinates, velocities, atom IDs and types.

- *angle* = bonds and angles – e.g. bead-spring polymers with stiffness
- *atomic* = only the default values
- *bond* = bonds – e.g. bead-spring polymers
- *charge* = charge
- *dipole* = charge and dipole moment
- *dpd* = default values, also communicates velocities
- *ellipsoid* = quaternion for particle orientation, angular velocity/momentum
- *full* = molecular + charge – e.g. biomolecules, charged polymers
- *granular* = granular atoms with rotational properties
- *molecular* = bonds, angles, dihedrals, impropers – e.g. all-atom polymers

Typically, simulations require only a single (non-hybrid) atom style. If some atoms in the simulation do not have all the properties defined by a particular style, use the simplest style that defines all the needed properties by any atom. For example, if some atoms in a simulation are charged, but others are not, use the *charge* style. If some atoms have bonds, but others do not, use the *bond* style. The only scenario where the *hybrid* style is needed is if there is no single style which defines all needed properties of all atoms. E.g. if you want charged DPD particles, you would need to use "atom\_style hybrid dpd charge". When a hybrid style is used, atoms store and

communicate the union of all quantities implied by the individual styles.

LAMMPS can be extended with new atom styles; see [this section](#).

### **Restrictions:**

This command cannot be used after the simulation box is defined by a [read\\_data](#) or [create\\_box](#) command.

The *angle*, *bond*, *full*, and *molecular* styles are part of the "molecular" package. The *granular* style is part of the "granular" package. The *dpd* style is part of the "dpd" package. The *dipole* style is part of the "dipole" package. The *ellipsoid* style is part of the "ellipsoid" package. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

### **Related commands:**

[read\\_data](#), [pair\\_style](#)

### **Default:**

atom\_style atomic



## bond\_style class2 command

### Syntax:

```
bond_style class2
```

### Examples:

```
bond_style class2  
bond_coeff 1 1.0 100.0 80.0 80.0
```

### Description:

The *class2* bond style uses the potential

$$E = K_2(r - r_0)^2 + K_3(r - r_0)^3 + K_4(r - r_0)^4$$

where  $r_0$  is the equilibrium bond distance.

See [\(Sun\)](#) for a description of the COMPASS class2 force field.

The following coefficients must be defined for each bond type via the [bond\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- $R_0$  (distance)
- $K_2$  (energy/distance<sup>2</sup>)
- $K_3$  (energy/distance<sup>2</sup>)
- $K_4$  (energy/distance<sup>2</sup>)

### Restrictions:

This bond style can only be used if LAMMPS was built with the "class2" package. See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:** none

---

**(Sun)** Sun, J Phys Chem B 102, 7338–7364 (1998).

## bond\_coeff command

### Syntax:

```
bond_coeff N args
```

- N = bond type (see asterisk form below)
- args = coefficients for one or more bond types

### Examples:

```
bond_coeff 5 80.0 1.2
bond_coeff * 30.0 1.5 1.0 1.0
bond_coeff 1*4 30.0 1.5 1.0 1.0
bond_coeff 1 harmonic 200.0 1.0
```

### Description:

Specify the bond force field coefficients for one or more bond types. The number and meaning of the coefficients depends on the bond style. Bond coefficients can also be set in the data file read by the [read\\_data](#) command or in a restart file.

N can be specified in one of two ways. An explicit numeric value can be used, as in the 1st example above. Or a wild-card asterisk can be used to set the coefficients for multiple bond types. This takes the form "\*" or "\*n" or "n\*" or "m\*n". If N = the number of bond types, then an asterisk with no numeric values means all types from 1 to N. A leading asterisk means all types from 1 to n (inclusive). A trailing asterisk means all types from n to N (inclusive). A middle asterisk means all types from m to n (inclusive).

Note that using a bond\_coeff command can override a previous setting for the same bond type. For example, these commands set the coeffs for all bond types, then overwrite the coeffs for just bond type 2:

```
bond_coeff * 100.0 1.2
bond_coeff 2 200.0 1.2
```

A line in a data file that specifies bond coefficients uses the exact same format as the arguments of the bond\_coeff command in an input script, except that wild-card asterisks should not be used since coefficients for all N types must be listed in the file. For example, under the "Bond Coeffs" section of a data file, the line that corresponds to the 1st example above would be listed as

```
5 80.0 1.2
```

---

Here is an alphabetic list of bond styles defined in LAMMPS. Click on the style to display the formula it computes and coefficients specified by the associated [bond\\_coeff](#) command:

- [bond\\_style none](#) – turn off bonded interactions
- [bond\\_style hybrid](#) – define multiple styles of bond interactions
- [bond\\_style class2](#) – COMPASS (class 2) bond
- [bond\\_style fene](#) – FENE (finite-extensible non-linear elastic) bond
- [bond\\_style fene/expand](#) – FENE bonds with variable size particles
- [bond\\_style harmonic](#) – harmonic bond

- [bond\\_style morse](#) – Morse bond
  - [bond\\_style nonlinear](#) – nonlinear bond
  - [bond\\_style quartic](#) – breakable quartic bond
- 

**Restrictions:**

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

A bond style must be defined before any bond coefficients are set, either in the input script or in a data file.

**Related commands:**

[bond\\_style](#)

**Default:** none

## bond\_style fene command

### Syntax:

```
bond_style fene
```

### Examples:

```
bond_style fene  
bond_coeff 1 30.0 1.5 1.0 1.0
```

### Description:

The *fene* bond style uses the potential

$$E = -0.5K R_0^2 \ln \left[ 1 - \left( \frac{r}{R_0} \right)^2 \right] + 4\epsilon \left[ \left( \frac{\sigma}{r} \right)^{12} - \left( \frac{\sigma}{r} \right)^6 \right] + \epsilon$$

to define a finite extensible nonlinear elastic (FENE) potential ([Kremer](#)), used for bead–spring polymer models. The first term is attractive, the 2nd Lennard–Jones term is repulsive. The first term extends to  $R_0$ , the maximum extent of the bond. The 2nd term is cutoff at  $2^{1/6}$  sigma, the minimum of the LJ potential.

The following coefficients must be defined for each bond type via the [bond\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- $K$  (energy/distance<sup>2</sup>)
- $R_0$  (distance)
- epsilon (energy)
- sigma (distance)

### Restrictions:

This bond style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:** none

---

**(Kremer)** Kremer, Grest, J Chem Phys, 92, 5057 (1990).

## bond\_style fene/expand command

### Syntax:

```
bond_style fene/expand
```

### Examples:

```
bond_style fene/expand  
bond_coeff 1 30.0 1.5 1.0 1.0 0.5
```

### Description:

The *fene/expand* bond style uses the potential

$$E = -0.5KR_0 \ln \left[ 1 - \left( \frac{(r - \Delta)}{R_0} \right)^2 \right] + 4\epsilon \left[ \left( \frac{\sigma}{(r - \Delta)} \right)^{12} - \left( \frac{\sigma}{(r - \Delta)} \right)^6 \right] + \epsilon$$

to define a finite extensible nonlinear elastic (FENE) potential ([Kremer](#)), used for bead–spring polymer models. The first term is attractive, the 2nd Lennard–Jones term is repulsive.

The *fene/expand* bond style is similar to *fene* except that an extra shift factor of delta (positive or negative) is added to *r* to effectively change the bead size of the bonded atoms. The first term now extends to  $R_0 + \text{delta}$  and the 2nd term is cutoff at  $2^{1/6} \sigma + \text{delta}$ .

The following coefficients must be defined for each bond type via the [bond\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- K (energy/distance<sup>2</sup>)
- R0 (distance)
- epsilon (energy)
- sigma (distance)
- delta (distance)

### Restrictions:

This bond style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:** none

---

(**Kremer**) Kremer, Grest, J Chem Phys, 92, 5057 (1990).

## bond\_style harmonic command

### Syntax:

```
bond_style harmonic
```

### Examples:

```
bond_style harmonic  
bond_coeff 5 80.0 1.2
```

### Description:

The *harmonic* bond style uses the potential

$$E = K(r - r_0)^2$$

where  $r_0$  is the equilibrium bond distance. Note that the usual 1/2 factor is included in  $K$ .

The following coefficients must be defined for each bond type via the [bond\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- $K$  (energy/distance<sup>2</sup>)
- $r_0$  (distance)

### Restrictions:

This bond style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:** none

## bond\_style hybrid command

### Syntax:

```
bond_style hybrid style1 style2 ...
```

- style1,style2 = list of one or more bond styles

### Examples:

```
bond_style hybrid harmonic fene  
bond_coeff 1 harmonic 80.0 1.2  
bond_coeff 2* fene 30.0 1.5 1.0 1.0
```

### Description:

The *hybrid* style enables the use of multiple bond styles in one simulation. A bond style is assigned to each bond type. For example, bonds in a polymer flow (of bond type 1) could be computed with a *fene* potential and bonds in the wall boundary (of bond type 2) could be computed with a *harmonic* potential. The assignment of bond type to style is made via the [bond\\_coeff](#) command or in the data file.

In the `bond_coeff` command, the first coefficient sets the bond style and the remaining coefficients are those appropriate to that style. In the example above, the 2 `bond_coeff` commands would set bonds of bond type 1 to be computed with a *harmonic* potential with coefficients 80.0, 1.2 for K, r0. All other bond types (2–N) would be computed with a *fene* potential with coefficients 30.0, 1.5, 1.0, 1.0 for K, R0, epsilon, sigma.

A bond style of *none* can be specified as an argument to `bond_style hybrid` and the corresponding `bond_coeff` commands, if you desire to turn off certain bond types.

### Restrictions:

This bond style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:** none

## bond\_style morse command

### Syntax:

```
bond_style morse
```

### Examples:

```
bond_style morse  
bond_coeff 5 1.0 2.0 1.2
```

### Description:

The *morse* bond style uses the potential

$$E = D \left[ 1 - e^{-\alpha(r-r_0)} \right]^2$$

where  $r_0$  is the equilibrium bond distance,  $\alpha$  is a stiffness parameter, and  $D$  determines the depth of the potential well.

The following coefficients must be defined for each bond type via the [bond\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- $D$  (energy)
- $\alpha$  (inverse distance)
- $r_0$  (distance)

### Restrictions:

This bond style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:** none



## **bond\_style none command**

### **Syntax:**

```
bond_style none
```

### **Examples:**

```
bond_style none
```

### **Description:**

Using a bond style of none means bond forces are not computed, even if pairs of bonded atoms were listed in the data file read by the [read\\_data](#) command.

**Restrictions:** none

**Related commands:** none

**Default:** none

## bond\_style nonlinear command

### Syntax:

```
bond_style nonlinear
```

### Examples:

```
bond_style nonlinear  
bond_coeff 2 100.0 1.1 1.4
```

### Description:

The *nonlinear* bond style uses the potential

$$E = \frac{\epsilon(r - r_0)^2}{[\lambda^2 - (r - r_0)^2]}$$

to define an anharmonic spring ([Rector](#)) of equilibrium length  $r_0$  and maximum extension  $\lambda$ .

The following coefficients must be defined for each bond type via the [bond\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- epsilon (energy)
- $r_0$  (distance)
- $\lambda$  (distance)

### Restrictions:

This bond style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:** none

---

**(Rector)** Rector, Van Swol, Henderson, Molecular Physics, 82, 1009 (1994).

## bond\_style quartic command

### Syntax:

```
bond_style quartic
```

### Examples:

```
bond_style quartic
bond_coeff 2 1200 -0.55 0.25 1.3 34.6878
```

### Description:

The *quartic* bond style uses the potential

$$E = K(r - R_c)^2(r - R_c - B_1)(r - R_c - B_2) + U_0 + 4\epsilon \left[ \left( \frac{\sigma}{r} \right)^{12} - \left( \frac{\sigma}{r} \right)^6 \right] + \epsilon$$

to define a bond that can be broken as the simulation proceeds (e.g. due to a polymer being stretched). The sigma and epsilon used in the LJ portion of the formula are both set equal to 1.0 by LAMMPS.

The following coefficients must be defined for each bond type via the [bond\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- K (energy/distance^2)
- B1 (distance)
- B2 (distance)
- Rc (distance)
- U0 (energy)

This potential was constructed to mimic the FENE bond potential for coarse-grained polymer chains. When monomers with sigma = epsilon = 1.0 are used, the following choice of parameters gives a quartic potential that looks nearly like the FENE potential: K = 1200, B1 = -0.55, B2 = 0.25, Rc = 1.3, and U0 = 34.6878. Different parameters can be specified using the [bond\\_coeff](#) command, but you will need to choose them carefully so they form a suitable bond potential.

Rc is the cutoff length at which the bond potential goes smoothly to a local maximum. If a bond length ever becomes > Rc, LAMMPS "breaks" the bond, which means two things. First, the bond potential is turned off by setting its type to 0, and is no longer computed. Second, a pairwise interaction between the two atoms is turned on, since they are no longer bonded.

LAMMPS does the second task via a computational sleight-of-hand. It subtracts the pairwise interaction as part of the bond computation. When the bond breaks, the subtraction stops. For this to work, the pairwise interaction must always be computed by the [pair\\_style](#) command, whether the bond is broken or not. This means that [special\\_bonds](#) must be set to 1,1,1, as indicated as a restriction below.

Note that when bonds are dumped to a file via [dump bond](#), bonds with type 0 are not included. The [delete\\_bonds](#) command can also be used to query the status of broken bonds or permanently delete them, e.g.:

```
delete_bonds all stats
```

```
delete_bonds all bond 0 remove
```

**Restrictions:**

This bond style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

The *quartic* style requires that [special\\_bonds](#) parameters be set to 1,1,1. Three- and four-body interactions (angle, dihedral, etc) cannot be used with *quartic* bonds.

**Related commands:**

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:** none

## bond\_style command

### Syntax:

```
bond_style style args
```

- *style* = *none* or *hybrid* or *class2* or *fene* or *fene/expand* or *harmonic* or *morse* or *nonlinear* or *quartic*

```
args = none for any style except hybrid  
hybrid args = list of one or more styles
```

### Examples:

```
bond_style harmonic  
bond_style fene  
bond_style hybrid harmonic fene
```

### Description:

Set the formula(s) LAMMPS uses to compute bond interactions between pairs of atoms. In LAMMPS, a bond differs from a pairwise interaction, which are set via the [pair\\_style](#) command. Bonds are defined between specified pairs of atoms and remain in force for the duration of the simulation (unless the bond breaks which is possible in some bond potentials). The list of bonded atoms is read in by a [read\\_data](#) or [read\\_restart](#) command from a data or restart file. By contrast, pair potentials are typically defined between all pairs of atoms within a cutoff distance and the set of active interactions changes over time.

Hybrid models where bonds are computed using different bond potentials can be setup using the *hybrid* bond style.

The coefficients associated with a bond style can be specified in a data or restart file or via the [bond\\_coeff](#) command.

All bond potentials store their coefficient data in binary restart files which means `bond_style` and [bond\\_coeff](#) commands do not need to be re-specified in an input script that restarts a simulation. See the [read\\_restart](#) command for details on how to do this. The one exception is that `bond_style hybrid` only stores the list of sub-styles in the restart file; bond coefficients need to be re-specified.

**IMPORTANT NOTE:** When both a bond and pair style is defined, the [special\\_bonds](#) command often needs to be used to turn off (or weight) the pairwise interaction that would otherwise exist between 2 bonded atoms.

In the formulas listed for each bond style,  $r$  is the distance between the 2 atoms in the bond.

---

Here is an alphabetic list of bond styles defined in LAMMPS. Click on the style to display the formula it computes and coefficients specified by the associated [bond\\_coeff](#) command:

- [bond\\_style none](#) – turn off bonded interactions
- [bond\\_style hybrid](#) – define multiple styles of bond interactions
- [bond\\_style class2](#) – COMPASS (class 2) bond
- [bond\\_style fene](#) – FENE (finite-extensible non-linear elastic) bond
- [bond\\_style fene/expand](#) – FENE bonds with variable size particles

- [bond\\_style harmonic](#) – harmonic bond
  - [bond\\_style morse](#) – Morse bond
  - [bond\\_style nonlinear](#) – nonlinear bond
  - [bond\\_style quartic](#) – breakable quartic bond
- 

**Restrictions:**

Bond styles can only be set for atom styles that allow bonds to be defined.

Most bond styles are part of the "molecular" package. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info on packages. The doc pages for individual bond potentials tell if it is part of a package.

**Related commands:**

[bond\\_coeff](#), [delete\\_bonds](#)

**Default:**

`bond_style none`

## boundary command

### Syntax:

```
boundary x y z
```

- $x, y, z = p$  or  $s$  or  $f$  or  $m$ , one or two letters

```
p is periodic
f is non-periodic and fixed
s is non-periodic and shrink-wrapped
m is non-periodic and shrink-wrapped with a minimum value
```

### Examples:

```
boundary p p f
boundary p fs p
boundary s f fm
```

### Description:

Set the style of boundaries for the global simulation box in each dimension. A single letter assigns the same style to both the lower and upper face of the box. Two letters assigns the first style to the lower face and the second style to the upper face. The initial size of the simulation box is set by the [read\\_data](#), [read\\_restart](#), or [create\\_box](#) commands.

The style *p* means the box is periodic, so that particles interact across the boundary, and they can exit one end of the box and re-enter the other end. A periodic dimension can change in size due to constant pressure boundary conditions or box deformation (see the [fix npt](#) and [fix deform](#) commands). The *p* style must be applied to both faces of a dimension.

The styles *f*, *s*, and *m* mean the box is non-periodic, so that particles do not interact across the boundary and do not move from one side of the box to the other. For style *f*, the position of the face is fixed. If an atom moves outside the face it may be lost. For style *s*, the position of the face is set so as to encompass the atoms in that dimension (shrink-wrapping), no matter how far they move. For style *m*, shrink-wrapping occurs, but is bounded by the value specified in the data or restart file or set by the [create\\_box](#) command. For example, if the upper *z* face has a value of 50.0 in the data file, the face will always be positioned at 50.0 or above, even if the maximum *z*-extent of all the atoms becomes less than 50.0.

### Restrictions:

This command cannot be used after the simulation box is defined by a [read\\_data](#) or [create\\_box](#) command.

### Related commands:

See the [thermo\\_modify](#) command for a discussion of lost atoms.

### Default:

```
boundary p p p
```

## change\_box command

### Syntax:

```
change_box style
```

- style = *ortho* or *triclinic*

```
ortho = convert simulation box from non-orthogonal (triclinic) to orthogonal
triclinic = convert simulation box from orthogonal to non-orthogonal (triclinic)
```

### Examples:

```
change_box ortho
change_box triclinic
```

### Description:

By default LAMMPS runs a simulation in an orthogonal, axis-aligned simulation box. LAMMPS can also run simulations in [non-orthogonal \(triclinic\) simulation boxes](#). A box is defined as either orthogonal or non-orthogonal when it is created via the [create\\_box](#), [read\\_data](#), or [read\\_restart](#) commands.

This command allows you to toggle the existing simulation box from orthogonal to non-orthogonal and vice versa. For example, an initial equilibration simulation can be run in an orthogonal box, the box can be toggled to non-orthogonal, and then a [non-equilibrium MD \(NEMD\) simulation](#) can be run with deformation via the [fix deform](#) command.

Note that if the simulation box is currently non-orthogonal and has non-zero tilt in xy, yz, or xz, then it cannot be converted to an orthogonal box.

### Restrictions:

At the point in the input script when this command is issued, no [dumps](#) can be active, nor can a [fix ave/spatial](#) or [fix deform](#) be active. This is because these commands test whether the simulation box is orthogonal when they are first issued. Note that these commands can appear in your script before a `change_box` command is issued, so long as an [undump](#) or [unfix](#) command is also used to turn them off.

**Related commands:** none

**Default:** none



## clear command

### Syntax:

```
clear
```

### Examples:

```
(commands for 1st simulation)
clear
(commands for 2nd simulation)
```

### Description:

This command deletes all atoms, restores all settings to their default values, and frees all memory allocated by LAMMPS. Once a clear command has been executed, it is as if LAMMPS were starting over, with only the exceptions noted below. This command enables multiple jobs to be run sequentially from one input script.

These settings are not affected by a clear command: the working directory ([shell](#) command), log file status ([log](#) command), echo status ([echo](#) command), and input script variables ([variable](#) command).

**Restrictions:** none

**Related commands:** none

**Default:** none

## communicate command

### Syntax:

```
communicate style
```

- style = *single* or *multi*

### Examples:

```
communicate multi
```

### Description:

This command sets the style of inter-processor communication that occurs each timestep as atom coordinates and other properties are exchanged between neighboring processors.

The default style is *single* which means each processor acquires information for ghost atoms that are within a single distance from its sub-domain. The distance is the maximum of the neighbor cutoff for all atom type pairs.

For many systems this is an efficient algorithm, but for systems with widely varying cutoffs for different type pairs, the *multi* style can be faster. In this case, each atom type is assigned its own distance cutoff for communication purposes, and fewer atoms will be communicated. See the [neighbor multi](#) command for a neighbor list construction option that may also be beneficial for simulations of this kind.

**Restrictions:** none

**Related commands:**

[neighbor](#)

**Default:**

style = single

## compute command

### Syntax:

```
compute ID group-ID style args
```

- ID = user-assigned name for the computation
- group-ID = ID of the group of atoms to perform the computation on
- style = one of a list of possible style names (see below)
- args = arguments used by a particular style

### Examples:

```
compute 1 all temp
compute newtemp flow temp/partial 1 1 0
compute 3 all ke/atom
```

### Description:

Create a computation that will be performed on a group of atoms.

In LAMMPS, a "compute" is used in several ways. There are two kinds of computes, "global" computes that calculate one or more values for the entire group of atoms, and "per-atom" computes that calculate one or more values for each atom in the group. The latter has the word "atom" in its style name.

The results of global computes can be output via the [thermo\\_style custom](#) or [fix ave/time](#) command. Or the values can be referenced in a [variable equal](#) command. The results of computes that calculate a global temperature or pressure can be used by fixes that do thermostating or barostating and when atom velocities are created.

The results of per-atom computes can be output directly via the [dump custom](#) command or the [fix ave/spatial](#) command. Or the per-atom values can be time-averaged via the [fix ave/atom](#) command and then output via the [dump custom](#) or [fix ave/spatial](#) commands.

LAMMPS creates its own global computes for thermodynamic output. Two computes are always created, named "thermo\_temp" and "thermo\_pressure", as if these commands had been invoked:

```
compute thermo_temp all temp
compute thermo_pressure all pressure thermo_temp
```

Additional computes are created if the thermo style requires it. See the documentation for the [thermo\\_style](#) command.

The dumping of atom snapshots and fixes that compute temperature or pressure also create computes as required. These are discussed in the documentation for the [dump custom](#) and specific [fix](#) commands.

In all these cases, the default computes can be replaced by computes defined by the user in the input script, as described by the [thermo\\_modify](#), [fix modify](#), and [dump](#) commands.

Properties of either a default or user-defined compute can be modified via the [compute\\_modify](#) command.

Computes can be deleted with the [uncompute](#) command.

Code for new computes can be added to LAMMPS (see [this section](#) of the manual) and the results of their calculations accessed in the various ways described above.

Each compute style has its own doc page which describes its arguments and what it does. Here is an alphabetic list of compute styles defined in LAMMPS:

- [attribute/atom](#) – attribute (x,v,f,etc) of each atom
- [centro/atom](#) – centro-symmetry parameter for each atom
- [coord/atom](#) – coordination number for each atom
- [ebond/atom](#) – bond energy for each atom
- [epair/atom](#) – pairwise energy for each atom
- [etotal/atom](#) – total energy (ke + epair) for each atom
- [ke/atom](#) – kinetic energy for each atom
- [pressure](#) – total pressure and pressure tensor
- [rotate/dipole](#) – rotational energy of dipolar atoms
- [rotate/gran](#) – rotational energy of granular atoms
- [stress/atom](#) – stress tensor for each atom
- [temp](#) – temperature of group of atoms
- [temp/asphere](#) – temperature of aspherical particles
- [temp/deform](#) – temperature excluding box deformation velocity
- [temp/dipole](#) – temperature of point dipolar particles
- [temp/partial](#) – temperature excluding one or more dimensions of velocity
- [temp/ramp](#) – temperature excluding ramped velocity component
- [temp/region](#) – temperature of a region of atoms
- [variable](#) – calculate a scalar value from a variable
- [variable/atom](#) – calculate a formula for each atom

**Restrictions:** none

**Related commands:**

[uncompute](#), [compute\\_modify](#)

**Default:** none

## compute attribute/atom command

### Syntax:

```
compute ID group-ID attribute/atom style
```

- ID, group-ID are documented in [compute](#) command
- attribute/atom = style name of this compute command
- style = *x* or *y* or *z* or *vx* or *vy* or *vz* or *fx* or *fy* or *fz* or *xyz* or *v* or *f*

### Examples:

```
compute 1 all attribute/atom vy
compute mine all attribute/atom xyz
```

### Description:

Define a computation that calculates (or simply stores) one or more attributes for each atom in a group. This is useful for input to the [fix ave/spatial](#) command to do spatial averaging by layers or to the [fix ave/atom](#) command to perform time-averaging of per-atom quantities. The attribute values could also be output directly by the [dump custom](#) command, but it has keywords that output these quantities without the need to define an additional compute.

The styles *x*, *y*, *z*, *vx*, *vy*, *vz*, *fx*, *fy*, and *fz* each store a single scalar value per atom. The styles *xyz*, *v*, and *f* each store a vector of 3 quantities per atom. The various commands that reference this compute use a different syntax for accessing scalar versus vector values.

**Restrictions:** none

### Related commands:

[fix ave/atom](#), [fix ave/spatial](#), [dump custom](#)

**Default:** none

## compute centro/atom command

### Syntax:

```
compute ID group-ID centro/atom
```

- ID, group-ID are documented in [compute](#) command
- centro/atom = style name of this compute command

### Examples:

```
compute 1 all centro/atom
```

### Description:

Define a computation that calculates the centro-symmetry parameter for each atom in a group. This can be output via the [dump custom](#) command. In solid state systems the centro-symmetry parameter is a useful measure of the local lattice disorder around an atom and can be used to characterize whether the atom is part of a perfect lattice, a local defect (e.g. a dislocation or stacking fault), or at a surface.

This parameter is computed using the following formula from [\(Kelchner\)](#)

$$P = \sum_{i=1}^6 |\vec{R}_i + \vec{R}_{i+6}|^2$$

where the 12 nearest neighbors are found and  $R_i$  and  $R_{i+6}$  are the vectors from the central atom to the opposite pair of nearest neighbors. Atoms not in the group are included in the 12 neighbors used in this calculation.

The neighbor list needed to compute this quantity is constructed each time the calculation is performed (i.e. each time a snapshot of atoms is dumped). Thus it can be inefficient to compute/dump this quantity too frequently or to have multiple compute/dump commands, each of a *centro/atom* style.

**Restrictions:** none

**Related commands:** none

**Default:** none

---

**(Kelchner)** Kelchner, Plimpton, Hamilton, Phys Rev B, 58, 11085 (1998).

## compute coord/atom command

### Syntax:

```
compute ID group-ID coord/atom cutoff
```

- ID, group-ID are documented in [compute](#) command
- coord/atom = style name of this compute command
- cutoff = distance within which to count coordination neighbors (distance units)

### Examples:

```
compute 1 all coord/atom 2.0
```

### Description:

Define a computation that calculates the coordination number for each atom in a group. This can be output via the [dump custom](#) command.

The coordination number is defined as the number of neighbor atoms within the specified cutoff distance from the central atom. Atoms not in the group are included in the coordination number of atoms in the group.

The neighbor list needed to compute this quantity is constructed each time the calculation is performed (i.e. each time a snapshot of atoms is dumped). Thus it can be inefficient to compute/dump this quantity too frequently or to have multiple compute/dump commands, each of a *coord/atom* style.

**Restrictions:** none

**Related commands:** none

**Default:** none

## compute ebond/atom command

### Syntax:

```
compute ID group-ID ebond/atom
```

- ID, group-ID are documented in [compute](#) command
- ebond/atom = style name of this compute command

### Examples:

```
compute 1 all ebond/atom
```

### Description:

Define a computation that computes the per-atom bond energy for each atom in a group. This can be output via the [dump custom](#) command.

The bond energy for each atom is computed by looping over the atoms it is bonded to and computing the bond energy associated with the defined [bond\\_style](#) command for each I-J bond (divided by 2). Thus the sum of per-atom bond energy for all atoms should give the total bond energy of the system.

If two atoms are bonded and only one of them is in the compute group, the energy of the bond is included in the per-atom energy of the atom in the group.

Computation of per-atom bond energy requires a loop thru the bond list and inter-processor communication, so it can be inefficient to compute/dump this quantity too frequently or to have multiple compute/dump commands, each of a *ebond/atom* style.

**Restrictions:** none

**Related commands:** none

**Default:** none



## compute epair/atom command

### Syntax:

```
compute ID group-ID epair/atom
```

- ID, group-ID are documented in [compute](#) command
- epair/atom = style name of this compute command

### Examples:

```
compute 1 all epair/atom
```

### Description:

Define a computation that computes the per-atom pairwise energy for each atom in a group. This can be output via the [dump custom](#) command.

The pairwise energy for each atom is computed by looping over its neighbors and computing the energy associated with the defined [pair\\_style](#) command for each I,J pair (divided by 2). Thus the sum of per-atom energy for all atoms should give the total pairwise energy of the system.

If two atoms interact and only one of them is in the compute group, the energy of the pairwise interaction is included in the per-atom energy of the atom in the group.

For force fields that include a contribution to the pairwise energy that is computed as part of dihedral terms (i.e. 1–4 interactions), this contribution is NOT included in the per-atom pairwise energy.

Computation of per-atom pairwise energy requires a loop thru the neighbor list and inter-processor communication, so it can be inefficient to compute/dump this quantity too frequently or to have multiple compute/dump commands, each of a *epair/atom* style.

### Restrictions:

Some pair potentials do not allow the calculation of per-atom energy via this command. An error will be generated if this is the case.

**Related commands:** none

**Default:** none

## compute etotal/atom command

### Syntax:

```
compute ID group-ID etotal/atom compute-ID
```

- ID, group-ID are documented in [compute](#) command
- etotal/atom = style name of this compute command
- compute-ID = ID of compute that calculates per-atom pairwise energy

### Examples:

```
compute 1 all etotal/atom atomEng
```

### Description:

Define a computation that computes the total energy (kinetic + pairwise) for each atom in a group. This can be output via the [dump custom](#) command.

IMPORTANT NOTE: The per-atom total energy does NOT include contributions due to bonds, angles, dihedrals, impropers that the atom is part of, or a long-range Coulombic contribution. The bond contribution can be computed separately via the [compute ebond/atom](#) command. Currently, there is no way in LAMMPS to calculate per-atom energy from angles, dihedrals, improper, or long-range interactions.

The kinetic energy for each atom is computed the same way as in the [compute ke/atom](#) command, namely as  $\frac{1}{2} m v^2$ .

The pairwise energy for each atom is computed the same way as in the [compute epair/atom](#) command. In fact, the last argument to this command is the ID of the epair/atom compute that performs this calculation.

### Restrictions:

Some pair potentials do not allow the calculation of per-atom energy and via the auxiliary [compute epair/atom](#) compute that is an argument to this command.

### Related commands:

[compute epair/atom](#)

**Default:** none

## compute ke/atom command

### Syntax:

```
compute ID group-ID ke/atom
```

- ID, group-ID are documented in [compute](#) command
- ke/atom = style name of this compute command

### Examples:

```
compute 1 all ke/atom
```

### Description:

Define a computation that calculates the per-atom kinetic energy for each atom in a group. This can be output via the [dump custom](#) command.

The kinetic energy is simply  $\frac{1}{2} m v^2$ , where  $m$  is the mass and  $v$  is the velocity of each atom.

**Restrictions:** none

**Related commands:**

[dump custom](#)

**Default:** none

## compute\_modify command

### Syntax:

```
compute_modify compute-ID keyword value ...
```

- compute-ID = ID of the compute to modify
- one or more keyword/value pairs may be listed
- keyword = *extra* or *dynamic*

```
extra value = N
  N = # of extra degrees of freedom to subtract
dynamic value = yes or no
  yes/no = do or do not recompute the number of atoms contributing to the temperature
```

### Examples:

```
compute_modify myTemp extra 0
compute_modify newtemp dynamic yes extra 600
```

### Description:

Modify one or more parameters of a previously defined compute. Not all compute styles support all parameters.

The *extra* keyword refers to how many degrees-of-freedom are subtracted (typically from  $3N$ ) as a normalizing factor in a temperature computation. Only computes that compute a temperature use this option. The default is 3 which is a correction factor for an ensemble of velocities with zero total linear momentum.

The *dynamic* keyword determines whether the number of atoms  $N$  in the compute group is re-computed each time a temperature is computed. Only compute styles that compute a temperature use this option. By default,  $N$  is assumed to be constant. If you are adding atoms to the system (see the [fix pour](#) or [fix deposit](#) commands) or expect atoms to be lost (e.g. due to evaporation), then this option can be used to insure the temperature is correctly normalized.

**Restrictions:** none

### Related commands:

[compute](#)

### Default:

The option defaults are `extra = 3` and `dynamic = no`.

## compute pressure command

### Syntax:

```
compute ID group-ID pressure compute-ID
```

- ID, group-ID are documented in [compute](#) command
- pressure = style name of this compute command
- compute-ID = ID of compute that calculates temperature

### Examples:

```
compute 1 all pressure myTemp
```

### Description:

Define a computation that calculates the pressure of atoms averaged over the entire system. The specified group must be "all". See the [dump custom](#) command for how to dump the per-atom stress tensor if you want more localized information about pressure (stress) in your system.

The pressure is computed by the standard formula

$$P = \frac{Nk_B T}{V} + \frac{\sum_i^N \mathbf{r}_i \cdot \mathbf{f}_i}{dV}$$

where N is the number of atoms in the system (see discussion of DOF below),  $k_B$  is the Boltzmann constant, T is the temperature, d is the dimensionality of the system (2 or 3 for 2d/3d), V is the system volume (or area in 2d), and the second term is the virial, computed within LAMMPS for all pairwise as well as 2-body, 3-body, 4-body, and long-range interactions. [Fixes](#) that impose constraints (e.g. the [fix shake](#) command) also contribute to the virial term.

A 6-component pressure tensor is also calculated by this compute which can be output by the [thermo\\_style custom](#) command. The formula for the components of the tensor is the same as in above formula, except that the first term uses the components of the kinetic energy tensor ( $v_x * v_y$  instead of  $v^2$  for temperature) and the second term uses  $R_x * F_y$  for the  $W_{xy}$  component of the virial tensor, etc.

The temperature and kinetic energy tensor is not calculated by this compute, but rather by the temperature compute specified as the last argument of the command. Normally this compute should calculate the temperature of all atoms for consistency with the virial term, but any compute style that calculates temperature can be used, e.g. one that excludes frozen atoms or other degrees of freedom.

Note that the N in the above formula is really degrees-of-freedom/d where the DOF is specified by the temperature compute. See the various [compute temperature](#) styles for details.

**Restrictions:** none

### Related commands:

[compute temp](#), [thermo\\_style](#)

**Default:** none

## compute rotate/dipole command

### Syntax:

```
compute ID group-ID rotate/dipole
```

- ID, group-ID are documented in [compute](#) command
- rotate/dipole = style name of this compute command

### Examples:

```
compute 1 all rotate/dipole
```

### Description:

Define a computation that calculates the total rotational energy of a group of atoms with point dipole moments.

The rotational energy is calculated as the sum of  $\frac{1}{2} I w^2$  over all the atoms in the group, where  $I$  is the moment of inertia of a disk/spherical (2d/3d) particle, and  $w$  is its angular velocity.

**Restrictions:** none

**Related commands:** none

**Default:** none

## compute rotate/gran command

### Syntax:

```
compute ID group-ID rotate/gran
```

- ID, group-ID are documented in [compute](#) command
- rotate/gran = style name of this compute command

### Examples:

```
compute 1 all rotate/gran
```

### Description:

Define a computation that calculates the total rotational energy of a group of granular atoms.

The rotational energy is calculated as the sum of  $\frac{1}{2} I w^2$  over all the atoms in the group, where  $I$  is the moment of inertia of a disk/spherical (2d/3d) particle, and  $w$  is its angular velocity.

**Restrictions:** none

**Related commands:** none

**Default:** none



## compute stress/atom command

### Syntax:

```
compute ID group-ID stress/atom keyword value ...
```

- ID, group-ID are documented in [compute](#) command
- stress/atom = style name of this compute command
- zero or more keyword/arg pairs may be appended
- keyword = *ke* or *pair* or *bond*

```
ke arg = yes or no
    yes/no = include/exclude kinetic energy contribution to stress
pair arg = yes or no
    yes/no = include/exclude pairwise energy contribution to stress
bond arg = yes or no
    yes/no = include/exclude bond energy contribution to stress
```

### Examples:

```
compute 1 mobile stress/atom
```

```
compute 1 all stress/atom ke no
```

### Description:

Define a computation that computes the per-atom stress tensor for each atom in a group. The 6 components can be output via the [dump custom](#) command.

The stress tensor for each atom is the sum of 3 terms in the following formula. Any of the terms can be excluded by setting the *ke*, *pair*, or *bond* keywords to *no*. The *ab* component of stress on atom *I* is as follows, where *a* and *b* take on values x,y,z to generate the 6 components of the symmetric tensor:

$$S_{ab} = - \left[ m v_a v_b + \frac{1}{2} \sum_{j=1}^{N_p} (a_i - a_j) F_{p_{ij}} + \frac{1}{2} \sum_{j=1}^{N_b} (a_i - a_j) F_{b_{ij}} \right]$$

The first term is a kinetic energy contribution for atom *I*. The second term is a pairwise energy contribution where *J* loops over the *N<sub>p</sub>* neighbors of atom *I*, and *F<sub>p</sub>* is one of 3 components of force on atom *I* due to the pairwise interaction with atom *J*. The third term is a bond energy contribution where *J* loops over the *N<sub>b</sub>* bonds which atom *I* is part of, and *F<sub>b</sub>* is one of 3 components of force on atom *I* due to the bonded interaction with atom *J*.

If two atoms interact, either pairwise or in a bond, and only one of them is in the compute group, the interaction is included in the per-atom stress of the atom in the group.

For force fields that include a contribution to the pairwise interaction that is computed as part of dihedral terms (i.e. 1–4 interactions), this contribution is NOT included in the per-atom pairwise stress.

**IMPORTANT NOTE:** The per-atom stress does NOT include contributions due to angles, dihedrals, impropers that the atom is part of, or a long-range Coulombic contribution. Currently, there is no way in LAMMPS to

calculate per-atom stress from angles, dihedrals, improper, or long-range interactions.

Note that as defined above, per-atom stress is the negative of the per-atom pressure tensor. It is also really a stress-volume formulation. It would need to be divided by a per-atom volume to have units of stress, but an individual atom's volume is not easy to compute in a deformed solid. Thus, if you sum the diagonal components of the per-atom stress tensor for all atoms in the system and divide the sum by  $3V$ , where  $V$  is the volume of the system, you should get  $-P$ , where  $P$  is the total pressure of the system (assuming there is no angle, dihedral, improper, or long-range contribution to the total pressure).

Computation of per-atom stress tensor components requires a loop thru the pairwise and bond neighbor lists and inter-processor communication, so it can be inefficient to compute/dump this quantity too frequently or to have multiple compute/dump commands, each of a *stress/atom* style.

**Restrictions:**

Some pair potentials do not allow the calculation of per-atom stress via this command. An error will be generated if this is the case.

**Related commands:** none

**Default:**

The option defaults are ke = yes, pair = yes, bond = yes.

## compute temp command

### Syntax:

```
compute ID group-ID temp
```

- ID, group-ID are documented in [compute](#) command
- temp = style name of this compute command

### Examples:

```
compute 1 all temp  
compute myTemp mobile temp
```

### Description:

Define a computation that calculates the temperature of a group of atoms. A compute of this style can be used by any command that computes a temperature, e.g. [thermo\\_modify](#), [fix temp/rescale](#), [fix npt](#), etc.

The temperature is calculated by the formula  $KE = \text{dim}/2 N k T$ , where KE = total kinetic energy of the group of atoms (sum of  $1/2 m v^2$ ), dim = 2 or 3 = dimensionality of the simulation, N = number of atoms in the group, k = Boltzmann constant, and T = temperature.

A 6-component kinetic energy tensor is also calculated by this compute for use in the computation of a pressure tensor. The formula for the components of the tensor is the same as the above formula, except that  $v^2$  is replaced by  $v_x * v_y$  for the xy component, etc.

The number of atoms contributing to the temperature is assumed to be constant for the duration of the run; use the *dynamic* option of the [compute\\_modify](#) command if this is not the case.

This compute subtracts out degrees-of-freedom due to fixes that constrain molecular motion, such as [fix shake](#) and [fix rigid](#). This means the temperature of groups of atoms that include these constraints will be computed correctly. If needed, the subtracted degrees-of-freedom can be altered using the *extra* option of the [compute\\_modify](#) command.

**Restrictions:** none

### Related commands:

[compute temp/partial](#), [compute temp/region](#), [compute pressure](#)

**Default:** none

## compute temp/asphere command

### Syntax:

```
compute ID group-ID temp/asphere
```

- ID, group-ID are documented in [compute](#) command
- temp/asphere = style name of this compute command

### Examples:

```
compute 1 all temp/asphere  
compute myTemp mobile temp/asphere
```

### Description:

Define a computation that calculates the temperature of a group of aspherical or ellipsoidal particles. The computation is similar to [compute\\_temp](#), however, additional degrees of freedom (2 or 3) are incorporated for particles where the principal moments of inertia are unequal. The associated kinetic energy thus includes a rotational term  $KE_{\text{rotational}} = 1/2 I w^2$ , where  $I$  is the moment of inertia and  $w$  is the angular velocity.

### Restrictions:

Can only be used if LAMMPS was built with the "asphere" package.

### Related commands:

[compute temp](#)

**Default:** none

## compute temp/deform command

### Syntax:

```
compute ID group-ID temp/deform
```

- ID, group-ID are documented in [compute](#) command
- temp/deform = style name of this compute command

### Examples:

```
compute myTemp all temp/deform
```

### Description:

Define a computation that calculates the temperature of a group of atoms, after subtracting out a streaming velocity induced by the simulation box changing size and/or shape, for example in a non-equilibrium MD (NEMD) simulation. The size/shape change is induced by use of the [fix deform](#) command. A compute of this style is created by the [fix nvt/sllod](#) command to compute the thermal temperature of atoms for thermostating purposes. A compute of this style can also be used by any command that computes a temperature, e.g. [thermo\\_modify](#), [fix temp/rescale](#), [fix npt](#), etc.

The deformation fix changes the box size and/or shape over time, so each point in the simulation box can be thought of as having a "streaming" velocity. For example, if the box is being sheared in x, relative to y, then points at the bottom of the box (low y) have a small x velocity, while points at the top of the box (hi y) have a large x velocity. This position-dependent streaming velocity is subtracted from each atom's actual velocity to yield a thermal velocity which is used to compute the temperature.

IMPORTANT NOTE: [Fix deform](#) has an option for remapping either atom coordinates or velocities to the changing simulation box. To use this compute, fix deform should NOT remap atom positions, but rather should let atoms respond to the changing box by adjusting their own velocities (or let fix deform remap the atom velocities). If fix deform does remap atom positions, their velocity is not changed, and thus they do not have the streaming velocity assumed by this compute. LAMMPS will warn you if the fix deform setting is not consistent with this compute.

The temperature is calculated by the formula  $KE = \text{dim}/2 N k T$ , where KE = total kinetic energy of the group of atoms (sum of  $1/2 m v^2$ ), dim = 2 or 3 = dimensionality of the simulation, N = number of atoms in the group, k = Boltzmann constant, and T = temperature. Note that v in the kinetic energy formula is the atom's thermal velocity.

A 6-component kinetic energy tensor is also calculated by this compute for use in the computation of a pressure tensor. The formula for the components of the tensor is the same as the above formula, except that  $v^2$  is replaced by  $v_x * v_y$  for the xy component, etc.

The number of atoms contributing to the temperature is assumed to be constant for the duration of the run; use the *dynamic* option of the [compute\\_modify](#) command if this is not the case.

This compute subtracts out degrees-of-freedom due to fixes that constrain molecular motion, such as [fix shake](#) and [fix rigid](#). This means the temperature of groups of atoms that include these constraints will be computed correctly. If needed, the subtracted degrees-of-freedom can be altered using the *extra* option of the [compute\\_modify](#) command.

**Restrictions:** none

**Related commands:**

[compute temp/ramp](#), [fix deform](#), [fix nvt/sllod](#)

**Default:** none

## compute temp/dipole command

### Syntax:

```
compute ID group-ID temp/dipole
```

- ID, group-ID are documented in [compute](#) command
- temp/dipole = style name of this compute command

### Examples:

```
compute 1 all temp/dipole  
compute myTemp mobile temp/dipole
```

### Description:

Define a computation that calculates the temperature of a group of particles that include a point dipole. The computation is similar to [compute\\_temp](#), however, additional degrees of freedom are included to account for the rotational state of the particles. The associated kinetic energy includes a rotational term  $KE_{\text{rotational}} = 1/2 I w^2$ , where  $I$  is the moment of inertia and  $w$  is the angular velocity.

### Restrictions:

Can only be used if LAMMPS was built with the "dipole" package.

### Related commands:

[compute temp](#)

**Default:** none

## compute temp/partial command

### Syntax:

```
compute ID group-ID temp/partial xflag yflag zflag
```

- ID, group-ID are documented in [compute](#) command
- temp/partial = style name of this compute command
- xflag,yflag,zflag = 0/1 for whether to exclude/include this dimension

### Examples:

```
compute newT flow temp/partial 1 1 0
```

### Description:

Define a compute to calculate the temperature of a group of atoms, after excluding one or more velocity components. A compute of this style can be used by any command that computes a temperature, e.g. [thermo\\_modify](#), [fix temp/rescale](#), [fix npt](#), etc.

The temperature is calculated by the formula  $KE = \text{dim}/2 N k T$ , where KE = total kinetic energy of the group of atoms (sum of  $1/2 m v^2$ ), dim = dimensionality of the simulation, N = number of atoms in the group, k = Boltzmann constant, and T = temperature. The calculation of KE excludes the x, y, or z dimensions if xflag, yflag, or zflag = 0. The dim parameter is adjusted to give the correct number of degrees of freedom.

A 6-component kinetic energy tensor is also calculated by this compute for use in the calculation of a pressure tensor. The formula for the components of the tensor is the same as the above formula, except that  $v^2$  is replaced by  $v_x * v_y$  for the xy component, etc.

The number of atoms contributing to the temperature is assumed to be constant for the duration of the run; use the *dynamic* option of the [compute\\_modify](#) command if this is not the case.

This compute subtracts out degrees-of-freedom due to fixes that constrain molecular motion, such as [fix shake](#) and [fix rigid](#). This means the temperature of groups of atoms that include these constraints will be computed correctly. If needed, the subtracted degrees-of-freedom can be altered using the *extra* option of the [compute\\_modify](#) command.

**Restrictions:** none

**Related commands:**

[compute temp](#), [compute temp/region](#), [compute pressure](#)

**Default:** none



## compute temp/ramp command

### Syntax:

```
compute ID group-ID temp/ramp vdim vlo vhi dim clo chi keyword value ...
```

- ID, group-ID are documented in [compute](#) command
- temp/ramp = style name of this compute command
- vdim = vx or vy or vz
- vlo,vhi = subtract velocities between vlo and vhi (velocity units)
- dim = x or y or z
- clo,chi = lower and upper bound of domain to subtract from (distance units)
- zero or more keyword/value pairs may be appended
- keyword = *units*

*units* value = *lattice* or *box*

### Examples:

```
temperature 2nd middle ramp vx 0 8 y 2 12 units lattice
```

### Description:

Define a computation that calculates the temperature of a group of atoms, after subtracting out an imposed velocity on the system before computing the kinetic energy. A compute of this style can be used by any command that computes a temperature, e.g. [thermo\\_modify](#), [fix temp/rescale](#), [fix npt](#), etc.

The meaning of the arguments for this command is the same as for the [velocity ramp](#) command which was presumably used to impose the velocity.

The *units* keyword determines the meaning of the distance units used for coordinates (c1,c2) and velocities (vlo,vhi). A *box* value selects standard distance units as defined by the [units](#) command, e.g. Angstroms for units = real or metal. A *lattice* value means the distance units are in lattice spacings; e.g. velocity = lattice spacings / tau. The [lattice](#) command must have been previously used to define the lattice spacing.

A 6-component kinetic energy tensor is also calculated by this compute for use in the calculation of a pressure tensor. The formula for the components of the tensor is the same as the above formula, except that  $v^2$  is replaced by  $v_x * v_y$  for the xy component, etc.

The number of atoms contributing to the temperature is assumed to be constant for the duration of the run; use the *dynamic* option of the [compute\\_modify](#) command if this is not the case.

This compute subtracts out degrees-of-freedom due to fixes that constrain molecular motion, such as [fix shake](#) and [fix rigid](#). This means the temperature of groups of atoms that include these constraints will be computed correctly. If needed, the subtracted degrees-of-freedom can be altered using the *extra* option of the [compute\\_modify](#) command.

**Restrictions:** none

**Related commands:**

compute temp, compute temp/region, compute temp/deform, compute pressure

**Default:**

The option default is units = lattice.

## compute temp/region command

### Syntax:

```
compute ID group-ID temp/region region-ID
```

- ID, group-ID are documented in [compute](#) command
- temp/region = style name of this compute command
- region-ID = ID of region to use for choosing atoms

### Examples:

```
temperature mine flow region boundary
```

### Description:

Define a computation that calculates the temperature of a group of atoms in a geometric region. This can be useful for thermostating one portion of the simulation box. E.g. a McDLT simulation where one side is cooled, and the other side is heated. A compute of this style can be used by any command that computes a temperature, e.g. [thermo\\_modify](#), [fix temp/rescale](#), etc.

Note that a *region*-style temperature can be used to thermostat with [fix temp/rescale](#) or [fix langevin](#), but should probably not be used with Nose/Hoover style fixes ([fix nvt](#), [fix npt](#), or [fix npb](#)), if the degrees-of-freedom included in the computed T varies with time.

The temperature is calculated by the formula  $KE = \text{dim}/2 N k T$ , where KE = total kinetic energy of the group of atoms (sum of  $1/2 m v^2$ ), dim = 2 or 3 = dimensionality of the simulation, N = number of atoms in both the group and region, k = Boltzmann constant, and T = temperature.

A 6-component kinetic energy tensor is also calculated by this compute for use in the computation of a pressure tensor. The formula for the components of the tensor is the same as the above formula, except that  $v^2$  is replaced by  $v_x * v_y$  for the xy component, etc.

The number of atoms contributing to the temperature is compute each time the temperature is evaluated since it is assumed atoms can enter/leave the region. Thus there is no need to use the *dynamic* option of the [compute\\_modify](#) command for this compute style.

Unlike other compute styles that calculate temperature, this compute does NOT currently subtract out degrees-of-freedom due to fixes that constrain molecular motion, such as [fix shake](#) and [fix rigid](#). If needed the subtracted degrees-of-freedom can be altered using the *extra* option of the [compute\\_modify](#) command.

**Restrictions:** none

### Related commands:

[compute temp](#), [compute pressure](#)

**Default:** none

## compute variable command

### Syntax:

```
compute ID group-ID variable name
```

- ID, group-ID are documented in [compute](#) command
- variable/atom = style name of this compute command
- name = variable name to invoke to compute a scalar quantity

### Examples:

```
compute 1 all variable myTemp
```

### Description:

Define a computation that calculates a formula that returns a scalar quantity. This quantity can be time averaged and output via the [fix ave/time](#) command. It could also be output via the [thermo\\_style custom](#) command, although it makes more sense to access the variable directly in this case.

The formula is defined by the [variable equal](#) command. A variable of style *equal* can access properties of the system, such as volume or temperature, and also reference individual atom attributes, such as its coordinates or velocity.

For example, these 3 commands would time average the system density (assuming the volume fluctuates) temperature and output the average value periodically to the file den.profile:

```
variable den equal div(atoms,vol)
compute density all variable den
fix 1 all ave/time 1 1000 density 0 den.profile
```

**Restrictions:** none

**Related commands:**

[fix ave/time](#), [variable](#)

**Default:** none

## compute variable/atom command

### Syntax:

```
compute ID group-ID variable/atom name
```

- ID, group-ID are documented in [compute](#) command
- variable/atom = style name of this compute command
- name = variable name to invoke for each atom

### Examples:

```
compute 1 flow variable/atom myVar
```

### Description:

Define a computation that calculates a formula for each atom in the group. The per-atom quantities can be output via the [dump custom](#) command or spatially averaged via the [fix ave/spatial](#) command.

The formula is defined by the [variable atom](#) command. A variable of style *atom* can access properties of the system, such as volume or temperature, and also reference individual atom attributes, such as its coordinates or velocity.

For example, these 3 commands would compute the xy kinetic energy of atoms in the flow group and include the values in dumped snapshots of the system.

```
variable xy atom mult(0.5,add(mult(vx[],vx[]),mult(vy[],vy[])))
compute ke flow variable/atom xy
dump 1 flow custom 1000 dump.flow tag type x y z c_ke
```

If the dump line were replaced by

```
fix 1 flow ave/spatial 100 1000 z lower 2.0 ke.profile compute ke
```

then the xy kinetic energy values would be averaged by z layer and the layer averages written periodically to the file ke.profile.

**Restrictions:** none

**Related commands:**

[dump custom](#), [fix ave/spatial](#)

**Default:** none

## create\_atoms command

### Syntax:

```
create_atoms type style args keyword values ...
```

- type = atom type (1–Ntypes) of atoms to create
- style = *box* or *region* or *single*

```
box args = none
region args = region-ID
region-ID = atoms will only be created if contained in the region
single args = x y z
x,y,z = coordinates of a single atom (distance units)
```

- zero or more keyword/value pairs may be appended
- keyword = *basis* or *units*

```
basis values = M itype
M = which basis atom
itype = atom type (1–N) to assign to this basis atom
units value = lattice or box
lattice = the geometry is defined in lattice units
box = the geometry is defined in simulation box units
```

### Examples:

```
create_atoms 1 box
create_atoms 3 region regsphere basis 2 3
create_atoms 3 single 0 0 5
```

### Description:

This command creates atoms on a lattice or a single atom as an alternative to reading in their coordinates via a [read\\_data](#) or [read\\_restart](#) command. A simulation box must already exist, which is typically created via the [create\\_box](#) command. Before using this command, a lattice must also be defined using the [lattice](#) command. The only exception is for the *single* style with units = box.

For the *box* style, the create\_atoms command fills the entire simulation box with atoms on the lattice. If your simulation box is periodic, you should insure its size is a multiple of the lattice spacings, to avoid unwanted atom overlaps at the box boundaries. If your box is periodic and a multiple of the lattice spacing in a particular dimension, LAMMPS is careful to put exactly one atom at the boundary (on either side of the box), not zero or two.

For the *region* style, the geometric volume is filled that is inside the simulation box and is also consistent with the region volume. See the [region](#) command for details. Note that a region can be specified so that its "volume" is either inside or outside a geometric boundary. Also note that if your region is the same size as a periodic simulation box (in some dimension), LAMMPS does not implement the same logic as with the *box* style, to insure exactly one atom at the boundary. if this is what you desire, you should either use the *box* style, or tweak the region size to get precisely the atoms you want.

For the *single* style, a single atom is added to the system at the specified coordinates. This can be useful for debugging purposes or to create a tiny system with a handful of atoms at specified positions.

The *basis* keyword specifies an atom type that will be assigned to specific basis atoms as they are created. See the [lattice](#) command for specifics on how basis atoms are defined for the unit cell of the lattice. By default, all created atoms are assigned the argument *type* as their atom type.

The *units* keyword determines the meaning of the distance units used to specify the coordinates of the one atom created by the *single* style. A *box* value selects standard distance units as defined by the [units](#) command, e.g. Angstroms for units = real or metal. A *lattice* value means the distance units are in lattice spacings.

Note that this command adds atoms to those that already exist. By using the `create_atoms` command multiple times, multiple sets of atoms can be added to the simulation. For example, interleaving `create_atoms` with [lattice](#) commands specifying different orientations, grain boundaries can be created. By using the `create_atoms` command in conjunction with the [delete\\_atoms](#) command, reasonably complex geometries can be created. The `create_atoms` command can also be used to add atoms to a system previously read in from a data or restart file. In all these cases, care should be taken to insure that new atoms do not overlap existing atoms inappropriately. The [delete\\_atoms](#) command can be used to handle overlaps.

Aside from their position and atom type, other properties of created atoms are set to 0.0, e.g. velocity, charge, etc. These properties can be changed via the [velocity](#) or [set](#) commands.

Atom IDs are assigned to created atoms in the following way. The collection of created atoms are assigned consecutive IDs that start immediately following the largest atom ID existing before the `create_atoms` command was invoked. When a simulation is performed on different numbers of processors, there is no guarantee a particular created atom will be assigned the same ID.

#### **Restrictions:**

An [atom\\_style](#) must be previously defined to use this command.

#### **Related commands:**

[lattice](#), [region](#), [create\\_box](#), [read\\_data](#), [read\\_restart](#)

**Default:** none

## create\_box command

### Syntax:

```
create_box N region-ID
```

- N = # of atom types to use in this simulation
- region-ID = ID of region to use as simulation domain

### Examples:

```
create_box 2 mybox
```

### Description:

This command creates a simulation box based on the specified region. Thus a [region](#) command must first be used to define a geometric domain.

The argument N is the number of atom types that will be used in the simulation.

If the region is not of style *prism*, then LAMMPS encloses the region (block, sphere, etc) with an axis-aligned (orthogonal) box which becomes the simulation domain.

If the region is of style *prism*, LAMMPS creates a non-orthogonal simulation domain shaped as a parallelepiped with triclinic symmetry. See the [region prism](#) command for a description of how the shape of the parallelepiped is defined. The parallelepiped has its "origin" at (xlo,ylo,zlo) and 3 edge vectors starting from its origin given by  $a = (xhi-xlo,0,0)$ ;  $b = (xy,yhi-ylo,0)$ ;  $c = (xz,yz,zhi-zlo)$ .

A prism region used with the create\_box command must have tilt factors (xy,xz,yz) that do not skew the box more than half the distance of the parallel box length. For example, if xlo = 2 and xhi = 12, then the x box length is 10 and the xy tilt factor must be between -5 and 5. Similarly, both xz and yz must be between  $-(xhi-xlo)/2$  and  $+(yhi-ylo)/2$ . Note that this is not a limitation, since if the maximum tilt factor is 5 (as in this example), then configurations with tilt = ..., -15, -5, 5, 15, 25, ... are all equivalent.

When a prism region is used, the simulation domain must be periodic in any dimensions with a non-zero tilt factor, as defined by the [boundary](#) command. I.e. if the xy tilt factor is non-zero, then both the x and y dimensions must be periodic. Similarly, x and z must be periodic if xz is non-zero and y and z must be periodic if yz is non-zero.

### Restrictions:

An [atom\\_style](#) and [region](#) must have been previously defined to use this command.

### Related commands:

[create\\_atoms](#), [region](#)

**Default:** none



## delete\_atoms command

### Syntax:

```
delete_atoms style args
```

- style = *group* or *region* or *overlap*

```
group args = group-ID
region args = region-ID
overlap args = distance type1 type2
    distance = delete atoms with neighbors within this cutoff (distance units)
    type1 = type of first atom in pair (optional)
    type2 = type of other atom in pair (optional)
```

### Examples:

```
delete_atoms group edge
delete_atoms region sphere
delete_atoms overlap 0.3
delete_atoms overlap 0.3 1 1
```

### Description:

Delete the specified atoms. This command can be used to carve out voids from a block of material or to delete created atoms that are too close to each other (e.g. at a grain boundary).

For style *group*, all atoms belonging to the group are deleted.

For style *region*, all atoms in the region volume are deleted.

For style *overlap*, pairs of atoms within the specified cutoff distance are searched for, and one of the 2 atoms is deleted. If no atom types are specified, an atom will always be deleted if the cutoff criterion is met. If a single atom type is specified, then one or both of the atoms in the pair must be of the specified type for a deletion to occur. If two atom types are specified, the two atoms in the pair must be of the specified types for a deletion to occur. For a given configuration of atoms, the only guarantee is that at the end of the deletion operation, enough deletions will have occurred that no atom pairs within the cutoff (and with the specified types) will remain. There is no guarantee that the minimum number of atoms will be deleted, or that the same atoms will be deleted when running on different numbers of processors.

After atoms are deleted, if the system is not molecular (no bonds), then atom IDs are re-assigned so that they run from 1 to the number of atoms in the system. This is not done for molecular systems, since it would foul up the bond connectivity that has already been assigned.

### Restrictions:

The *overlap* style requires inter-processor communication to acquire ghost atoms and setup a neighbor list. This means that your system must be ready to perform a simulation before using this command (force fields setup, atom masses set, etc).

If the [special\\_bonds](#) command is used with a setting of 0, then a pair of bonded atoms (1–2, 1–3, or 1–4) will not appear in the neighbor list, and thus will not be considered for deletion by the *overlap* style. You probably don't want to be deleting one atom in a bonded pair anyway.

**Related commands:**

[create\\_atoms](#)

**Default:** none

## delete\_bonds command

### Syntax:

```
delete_bonds group-ID style args keyword ...
```

- group-ID = group ID
- style = *multi* or *atom* or *bond* or *angle* or *dihedral* or *improper* or *stats*

```
multi args = none
atom args = an atom type
bond args = a bond type
angle args = an angle type
dihedral args = a dihedral type
improper args = an improper type
stats args = none
```

- zero or more keywords may be appended
- keyword = *undo* or *remove* or *special*

### Examples:

```
delete_bonds frozen multi remove
delete_bonds all atom 4 special
delete_bonds all stats
```

### Description:

Turn off (or on) molecular topology interactions, i.e. bonds, angles, dihedrals, impropers. This command is useful for deleting interactions that have been previously turned off by bond-breaking potentials. It is also useful for turning off topology interactions between frozen or rigid atoms. Pairwise interactions can be turned off via the [neigh\\_modify exclude](#) command. The [fix shake](#) command also effectively turns off certain bond and angle interactions.

For all styles, an interaction is only turned off (or on) if all the atoms involved are in the specified group. For style *multi* this is the only criterion applied – all types of bonds, angles, dihedrals, impropers in the group turned off.

For style *atom*, one or more of the atoms involved must also be of the specified type. For style *bond*, only bonds are candidates for turn-off, and the bond must be of the specified type. Styles *angle*, *dihedral*, and *improper* are treated similarly.

For style *bond*, you can set the type to 0 to delete bonds that have been previously broken; e.g. see the [bond\\_style quartic](#) command.

For style *stats* no interactions are turned off (or on); the status of all interactions in the specified group is simply reported. This is useful for diagnostic purposes if bonds have been turned off by a bond-breaking potential during a previous run.

The default behavior of the delete\_bonds command is to turn off interactions by toggling their type to a negative value. E.g. a bond\_type of 2 is set to -2. The neighbor list creation routines will not include such an interaction in their interaction lists. The default is also to not alter the list of 1-2, 1-3, 1-4 neighbors computed by the [special\\_bonds](#) command and used to weight pairwise force and energy calculations. This means that pairwise computations will proceed as if the bond (or angle, etc) were still turned on.

The keywords listed above can be appended to the argument list to alter the default behavior.

The *undo* keyword inverts the `delete_bonds` command so that the specified bonds, angles, etc are turned on if they are currently turned off. This means any negative value is toggled to positive. Note that the [fix shake](#) command also sets bond and angle types negative, so this option should not be used on those interactions.

The *remove* keyword is invoked at the end of the `delete_bonds` operation. It causes turned-off bonds (angles, etc) to be removed from each atom's data structure and then adjusts the global bond (angle, etc) counts accordingly. Removal is a permanent change; removed bonds cannot be turned back on via the *undo* keyword. Removal does not alter the pairwise 1-2, 1-3, 1-4 weighting list.

The *special* keyword is invoked at the end of the `delete_bonds` operation, after (optional) removal. It re-computes the pairwise 1-2, 1-3, 1-4 weighting list. The weighting list computation treats turned-off bonds the same as turned-on. Thus, turned-off bonds must be removed if you wish to change the weighting list.

Note that the choice of *remove* and *special* options affects how 1-2, 1-3, 1-4 pairwise interactions will be computed across bonds that have been modified by the `delete_bonds` command.

### Restrictions:

This command requires inter-processor communication to coordinate the deleting of bonds. This means that your system must be ready to perform a simulation before using this command (force fields setup, atom masses set, etc).

If deleted bonds (angles, etc) are removed but the 1-2, 1-3, 1-4 weighting list is not recomputed, this can cause a later [fix shake](#) command to fail due to an atom's bonds being inconsistent with the weighting list. This should only happen if the group used in the `fix` command includes both atoms in the bond, in which case you probably should be recomputing the weighting list.

### Related commands:

[neigh\\_modify](#) `exclude`, [special\\_bonds](#), [fix shake](#)

**Default:** none

## dielectric command

### Syntax:

```
dielectric value
```

- value = dielectric constant

### Examples:

```
dielectric 2.0
```

### Description:

Set the dielectric constant for Coulombic interactions (pairwise and long-range) to this value. The constant is unitless, since it is used to reduce the strength of the interactions. The value is used in the denominator of the formulas for Coulombic interactions – e.g. a value of 4.0 reduces the Coulombic interactions to 25% of their default strength. See the [pair\\_style](#) command for more details.

**Restrictions:** none

### Related commands:

[pair\\_style](#)

### Default:

```
dielectric 1.0
```

## dihedral\_style charmm command

### Syntax:

```
dihedral_style charmm
```

### Examples:

```
dihedral_style charmm  
dihedral_coeff 1 120.0 1 60 0.5
```

### Description:

The *charmm* dihedral style uses the potential

$$E = K[1 + \cos(n\phi - d)]$$

See ([MacKerell](#)) for a description of the CHARMM force field. This dihedral style can also be used for the AMBER force field (see the comment on weighting factors below). See ([Cornell](#)) for a description of the AMBER force field.

The following coefficients must be defined for each dihedral type via the [dihedral\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- K (energy)
- n (integer >= 0)
- d (integer value of degrees)
- weighting factor (0.0 to 1.0)

The weighting factor is applied to pairwise interaction between the 1st and 4th atoms in the dihedral. Note that this weighting factor is unrelated to the weighting factor specified by the [special\\_bonds](#) command which applies to all 1–4 interactions in the system.

For CHARMM force fields, the [special\\_bonds](#) 1–4 weighting factor should be set to 0.0. This is because the pair styles that contain "charmm" (e.g. [pair\\_style lj/charmm/coul/long](#)) define extra 1–4 interaction coefficients that are used by this dihedral style to compute those interactions explicitly. This means that if any of the weighting factors defined as dihedral coefficients (4th coeff above) are non-zero, then you must use a charmm pair style. Note that if you do not set the [special\\_bonds](#) 1–4 weighting factor to 0.0 (which is the default) then 1–4 interactions in dihedrals will be computed twice, once by the pair routine and once by the dihedral routine, which is probably not what you want.

For AMBER force fields, the [special\\_bonds](#) 1–4 weighting factor should be set to the AMBER defaults (1/2 and 5/6) and all the dihedral weighting factors (4th coeff above) should be set to 0.0. In this case, you can use any pair style you wish, since the dihedral does not need any 1–4 information.

### Restrictions:

This dihedral style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

**Related commands:**

[dihedral\\_coeff](#)

**Default:** none

---

**(Cornell)** Cornell, Cieplak, Bayly, Gould, Merz, Ferguson, Spellmeyer, Fox, Caldwell, Kollman, JACS 117, 5179–5197 (1995).

**(MacKerell)** MacKerell, Bashford, Bellott, Dunbrack, Evanseck, Field, Fischer, Gao, Guo, Ha, et al, J Phys Chem, 102, 3586 (1998).

## dihedral\_style class2 command

### Syntax:

```
dihedral_style class2
```

### Examples:

```
dihedral_style class2
dihedral_coeff 1 100 75 100 70 80 60
```

### Description:

The *class2* dihedral style uses the potential

$$\begin{aligned}
 E &= E_d + E_{mbt} + E_{ebt} + E_{at} + E_{aat} + E_{bb13} \\
 E_d &= \sum_{n=1}^3 K_n [1 - \cos(n\phi - \phi_n)] \\
 E_{mbt} &= (r_{jk} - r_2) [A_1 \cos(\phi) + A_2 \cos(2\phi) + A_3 \cos(3\phi)] \\
 E_{ebt} &= (r_{ij} - r_1) [B_1 \cos(\phi) + B_2 \cos(2\phi) + B_3 \cos(3\phi)] + \\
 &\quad (r_{kl} - r_3) [C_1 \cos(\phi) + C_2 \cos(2\phi) + C_3 \cos(3\phi)] \\
 E_{at} &= (\theta_{ijk} - \theta_1) [D_1 \cos(\phi) + D_2 \cos(2\phi) + D_3 \cos(3\phi)] + \\
 &\quad (\theta_{jkl} - \theta_2) [E_1 \cos(\phi) + E_2 \cos(2\phi) + E_3 \cos(3\phi)] \\
 E_{aat} &= M(\theta_{ijk} - \theta_1)(\theta_{jkl} - \theta_2) \cos(\phi) \\
 E_{bb13} &= N(r_{ij} - r_1)(r_{kl} - r_3)
 \end{aligned}$$

where  $E_d$  is the dihedral term,  $E_{mbt}$  is a middle-bond-torsion term,  $E_{ebt}$  is an end-bond-torsion term,  $E_{at}$  is an angle-torsion term,  $E_{aat}$  is an angle-angle-torsion term, and  $E_{bb13}$  is a bond-bond-13 term.

Theta1 and theta2 are equilibrium angles and r1 r2 r3 are equilibrium bond lengths.

See [\(Sun\)](#) for a description of the COMPASS class2 force field.

For this style, coefficients for the  $E_d$  formula can be specified in either the input script or data file. These are the 6 coefficients:

- K1 (energy)
- phi1 (degrees)
- K2 (energy)
- phi2 (degrees)
- K3 (energy)
- phi3 (degrees)

Coefficients for all the other formulas can only be specified in the data file.

For the  $E_{mbt}$  formula, the coefficients are listed under a "MiddleBondTorsion Coeffs" heading and each line lists 4 coefficients:



- A1 (energy/distance)
- A2 (energy/distance)
- A3 (energy/distance)
- r2 (distance)

For the Eebt formula, the coefficients are listed under a "EndBondTorsion Coeffs" heading and each line lists 8 coefficients:

- B1 (energy/distance)
- B2 (energy/distance)
- B3 (energy/distance)
- C1 (energy/distance)
- C2 (energy/distance)
- C3 (energy/distance)
- r1 (distance)
- r3 (distance)

For the Eat formula, the coefficients are listed under a "AngleTorsion Coeffs" heading and each line lists 8 coefficients:

- D1 (energy/radian)
- D2 (energy/radian)
- D3 (energy/radian)
- E1 (energy/radian)
- E2 (energy/radian)
- E3 (energy/radian)
- theta1 (degrees)
- theta2 (degrees)

Theta1 and theta2 are specified in degrees, but LAMMPS converts them to radians internally; hence the units of D and E are in energy/radian.

For the Eaat formula, the coefficients are listed under a "AngleAngleTorsion Coeffs" heading and each line lists 3 coefficients:

- M (energy/radian<sup>2</sup>)
- theta1 (degrees)
- theta2 (degrees)

Theta1 and theta2 are specified in degrees, but LAMMPS converts them to radians internally; hence the units of M are in energy/radian<sup>2</sup>.

For the Ebb13 formula, the coefficients are listed under a "BondBond13 Coeffs" heading and each line lists 3 coefficients:

- N (energy/distance<sup>2</sup>)
- r1 (distance)
- r3 (distance)

### Restrictions:

This dihedral style can only be used if LAMMPS was built with the "class2" package. See the [Making LAMMPS](#)

section for more info on packages.

**Related commands:**

[dihedral\\_coeff](#)

**Default:** none

---

(Sun) Sun, J Phys Chem B 102, 7338–7364 (1998).

## dihedral\_coeff command

### Syntax:

```
dihedral_coeff N args
```

- N = dihedral type (see asterisk form below)
- args = coefficients for one or more dihedral types

### Examples:

```
dihedral_coeff 1 80.0 1 3  
dihedral_coeff * 80.0 1 3 0.5  
dihedral_coeff 2* 80.0 1 3 0.5
```

### Description:

---

Specify the dihedral force field coefficients for one or more dihedral types. The number and meaning of the coefficients depends on the dihedral style. Dihedral coefficients can also be set in the data file read by the [read\\_data](#) command or in a restart file.

N can be specified in one of two ways. An explicit numeric value can be used, as in the 1st example above. Or a wild-card asterisk can be used to set the coefficients for multiple dihedral types. This takes the form "\*" or "\*n" or "n\*" or "m\*n". If N = the number of dihedral types, then an asterisk with no numeric values means all types from 1 to N. A leading asterisk means all types from 1 to n (inclusive). A trailing asterisk means all types from n to N (inclusive). A middle asterisk means all types from m to n (inclusive).

Note that using a dihedral\_coeff command can override a previous setting for the same dihedral type. For example, these commands set the coeffs for all dihedral types, then overwrite the coeffs for just dihedral type 2:

```
dihedral_coeff * 80.0 1 3  
dihedral_coeff 2 200.0 1 3
```

A line in a data file that specifies dihedral coefficients uses the exact same format as the arguments of the dihedral\_coeff command in an input script, except that wild-card asterisks should not be used since coefficients for all N types must be listed in the file. For example, under the "Dihedral Coeffs" section of a data file, the line that corresponds to the 1st example above would be listed as

```
1 80.0 1 3
```

---

Here is an alphabetic list of dihedral styles defined in LAMMPS. Click on the style to display the formula it computes and coefficients specified by the associated [dihedral\\_coeff](#) command:

- [dihedral\\_style none](#) – turn off dihedral interactions
- [dihedral\\_style hybrid](#) – define multiple styles of dihedral interactions
- [dihedral\\_style charmm](#) – CHARMM dihedral
- [dihedral\\_style class2](#) – COMPASS (class 2) dihedral
- [dihedral\\_style harmonic](#) – harmonic dihedral
- [dihedral\\_style helix](#) – helix dihedral
- [dihedral\\_style multi/harmonic](#) – multi-harmonic dihedral

**Restrictions:**

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

A dihedral style must be defined before any dihedral coefficients are set, either in the input script or in a data file.

**Related commands:**

[dihedral\\_style](#)

**Default:** none

## dihedral\_style harmonic command

### Syntax:

```
dihedral_style harmonic
```

### Examples:

```
dihedral_style harmonic  
dihedral_coeff 1 80.0 1 2
```

### Description:

The *harmonic* dihedral style uses the potential

$$E = K[1 + d \cos(n\phi)]$$

The following coefficients must be defined for each dihedral type via the [dihedral\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- K (energy)
- d (+1 or -1)
- n (integer >= 0)

### Restrictions:

This dihedral style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[dihedral\\_coeff](#)

**Default:** none

## dihedral\_style helix command

### Syntax:

```
dihedral_style helix
```

### Examples:

```
dihedral_style helix  
dihedral_coeff 1 80.0 100.0 40.0
```

### Description:

The *helix* dihedral style uses the potential

$$E = A[1 - \cos(\theta)] + B[1 + \cos(3\theta)] + C[1 + \cos(\theta + \frac{\pi}{4})]$$

This coarse-grain dihedral potential is described in [\(Guo\)](#). For dihedral angles in the helical region, the energy function is represented by a standard potential consisting of three minima, one corresponding to the trans (t) state and the other to gauche states (g+ and g-). The paper describes how the A,B,C parameters are chosen so as to balance secondary (largely driven by local interactions) and tertiary structure (driven by long-range interactions).

The following coefficients must be defined for each dihedral type via the [dihedral\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- A (energy)
- B (energy)
- C (energy)

### Restrictions:

This dihedral style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[dihedral\\_coeff](#)

**Default:** none

---

**(Guo)** Guo and Thirumalai, Journal of Molecular Biology, 263, 323–43 (1996).

## dihedral\_style hybrid command

### Syntax:

```
dihedral_style hybrid style1 style2 ...
```

- style1,style2 = list of one or more dihedral styles

### Examples:

```
dihedral_style hybrid harmonic helix
dihedral_coeff 1 harmonic 6.0 1 3
dihedral_coeff 2 helix 10 10 10
```

### Description:

The *hybrid* style enables the use of multiple dihedral styles in one simulation. An dihedral style is assigned to each dihedral type. For example, dipoles in a polymer flow (of dihedral type 1) could be computed with a *harmonic* potential and dipoles in the wall boundary (of dihedral type 2) could be computed with a *helix* potential. The assignment of dihedral type to style is made via the [dihedral\\_coeff](#) command or in the data file.

In the `dihedral_coeff` command, the first coefficient sets the dihedral style and the remaining coefficients are those appropriate to that style. In the example above, the 2 `dihedral_coeff` commands would set dipoles of dihedral type 1 to be computed with a *harmonic* potential with coefficients 80.0, 1.2 for K, d, n. Dihedral type 2 would be computed with a *helix* potential with coefficients 10.0, 10.0, 10.0 for A, B, C.

If the dihedral *class2* potential is one of the hybrid styles, it requires additional MiddleBondTorsion, EndBondTorsion, AngleTorsion, AngleAngleTorsion, and BondBond13 coefficients be specified in the data file. These lines must also have an additional "class2" argument added after the dihedral type. For dihedral types which are assigned to other hybrid styles, use the style name (e.g. "harmonic") appropriate to that style. The MiddleBondTorsion, etc coeffs for that dihedral type will then be ignored.

A dihedral style of *none* can be specified as an argument to `dihedral_style hybrid` and the corresponding `dihedral_coeff` commands, if you desire to turn off certain dihedral types.

### Restrictions:

This dihedral style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[dihedral\\_coeff](#)

**Default:** none

## dihedral\_style multi/harmonic command

### Syntax:

```
dihedral_style multi/harmonic
```

### Examples:

```
dihedral_style multi/harmonic  
dihedral_coeff 1 20 20 20 20 20
```

### Description:

The *multi/harmonic* dihedral style uses the potential

$$E = \sum_{n=1,5} A_n \cos^{n-1}(\phi)$$

The following coefficients must be defined for each dihedral type via the [dihedral\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- A1 (energy)
- A2 (energy)
- A3 (energy)
- A4 (energy)
- A5 (energy)

### Restrictions:

This dihedral style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[dihedral\\_coeff](#)

**Default:** none



## dihedral\_style none command

### Syntax:

```
dihedral_style none
```

### Examples:

```
dihedral_style none
```

### Description:

Using an dihedral style of none means dihedral forces are not computed, even if quadruplets of dihedral atoms were listed in the data file read by the [read\\_data](#) command.

**Restrictions:** none

**Related commands:** none

**Default:** none

## dihedral\_style opls command

### Syntax:

```
dihedral_style opls
```

### Examples:

```
dihedral_style opls  
dihedral_coeff 1 90.0 90.0 90.0 70.0
```

### Description:

The *opls* dihedral style uses the potential

$$E = \frac{1}{2}K_1[1 + \cos(\phi)] + \frac{1}{2}K_2[1 - \cos(2\phi)] + \frac{1}{2}K_3[1 + \cos(3\phi)] + \frac{1}{2}K_4[1 - \cos(4\phi)]$$

Note that the usual 1/2 factor is not included in the K values.

This dihedral potential is used in the OPLS force field and is described in [\(Watkins\)](#).

The following coefficients must be defined for each dihedral type via the [dihedral\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- K1 (energy)
- K2 (energy)
- K3 (energy)
- K4 (energy)

### Restrictions:

This dihedral style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[dihedral\\_coeff](#)

**Default:** none

---

**(Watkins)** Watkins and Jorgensen, J Phys Chem A, 105, 4118–4125 (2001).

## dihedral\_style command

### Syntax:

```
dihedral_style style
```

- style = *none* or *hybrid* or *charmm* or *class2* or *harmonic* or *helix* or *multi/harmonic* or *opls*

### Examples:

```
dihedral_style harmonic
dihedral_style multi/harmonic
dihedral_style hybrid harmonic charmm
```

### Description:

Set the formula(s) LAMMPS uses to compute dihedral interactions between quadruplets of atoms, which remain in force for the duration of the simulation. The list of dihedral quadruplets is read in by a [read\\_data](#) or [read\\_restart](#) command from a data or restart file.

Hybrid models where dihedrals are computed using different dihedral potentials can be setup using the *hybrid* dihedral style.

The coefficients associated with a dihedral style can be specified in a data or restart file or via the [dihedral\\_coeff](#) command.

All dihedral potentials store their coefficient data in binary restart files which means `dihedral_style` and [dihedral\\_coeff](#) commands do not need to be re-specified in an input script that restarts a simulation. See the [read\\_restart](#) command for details on how to do this. The one exception is that `dihedral_style hybrid` only stores the list of sub-styles in the restart file; dihedral coefficients need to be re-specified.

IMPORTANT NOTE: When both a dihedral and pair style is defined, the [special\\_bonds](#) command often needs to be used to turn off (or weight) the pairwise interaction that would otherwise exist between 4 bonded atoms.

In the formulas listed for each dihedral style, *phi* is the torsional angle defined by the quadruplet of atoms.

Here are some important points to take note of when defining the LAMMPS dihedral coefficients in the formulas that follow so that they are compatible with other force fields:

- The LAMMPS convention is that the trans position = 180 degrees, while in some force fields trans = 0 degrees.
- Some force fields reverse the sign convention on *d*.
- Some force fields divide/multiply *K* by the number of multiple torsions that contain the j–k bond in an i–j–k–l torsion.
- Some force fields let *n* be positive or negative which corresponds to *d* = 1 or –1 for the harmonic style.

---

Here is an alphabetic list of dihedral styles defined in LAMMPS. Click on the style to display the formula it computes and coefficients specified by the associated [dihedral\\_coeff](#) command:

- [dihedral\\_style none](#) – turn off dihedral interactions
- [dihedral\\_style hybrid](#) – define multiple styles of dihedral interactions

- [dihedral\\_style charmm](#) – CHARMM dihedral
  - [dihedral\\_style class2](#) – COMPASS (class 2) dihedral
  - [dihedral\\_style harmonic](#) – harmonic dihedral
  - [dihedral\\_style helix](#) – helix dihedral
  - [dihedral\\_style multi/harmonic](#) – multi-harmonic dihedral
  - [dihedral\\_style opl](#) – OPLS dihedral
- 

**Restrictions:**

Dihedral styles can only be set for atom styles that allow dihedrals to be defined.

Most dihedral styles are part of the "molecular" package. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info on packages. The doc pages for individual dihedral potentials tell if it is part of a package.

**Related commands:**

[dihedral\\_coeff](#)

**Default:**

dihedral\_style none

## dimension command

### Syntax:

```
dimension N
```

- $N = 2$  or  $3$

### Examples:

```
dimension 2
```

### Description:

Set the dimensionality of the simulation. By default LAMMPS runs 3d simulations. To run a 2d simulation, this command should be used prior to setting up a simulation box via the [create\\_box](#) or [read\\_data](#) commands. Restart files also store this setting.

See the discussion in [this section](#) for additional instructions on how to run 2d simulations.

### Restrictions:

This command must be used before the simulation box is defined by a [read\\_data](#) or [create\\_box](#) command.

### Related commands:

[fix enforce2d](#)

### Default:

```
dimension 3
```

## dipole command

### Syntax:

```
dipole I value
```

- I = atom type (see asterisk form below)
- value = dipole moment (dipole units)

### Examples:

```
dipole 1 1.0  
dipole 3 2.0  
dipole 3*5 0.0
```

### Description:

Set the dipole moment for all atoms of one or more atom types. This command is only used for atom styles that require dipole moments ([atom\\_style dipole](#)). A value of 0.0 should be used if the atom type has no dipole moment. Dipole values can also be set in the [read\\_data](#) data file. See the [units](#) command for a discussion of dipole units.

Currently, only [atom\\_style dipole](#) requires dipole moments be set.

I can be specified in one of two ways. An explicit numeric value can be used, as in the 1st example above. Or a wild-card asterisk can be used to set the dipole moment for multiple atom types. This takes the form "\*" or "\*n" or "n\*" or "m\*n". If N = the number of atom types, then an asterisk with no numeric values means all types from 1 to N. A leading asterisk means all types from 1 to n (inclusive). A trailing asterisk means all types from n to N (inclusive). A middle asterisk means all types from m to n (inclusive).

A line in a data file that specifies a dipole moment uses the same format as the arguments of the dipole command in an input script, except that no wild-card asterisk can be used. For example, under the "Dipoles" section of a data file, the line that corresponds to the 1st example above would be listed as

```
1 1.0
```

### Restrictions:

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

All dipoles moments must be defined before a simulation is run (if the atom style requires dipoles be set). They must also all be defined before a [set dipole](#) or [set dipole/random](#) command is used.

**Related commands:** none

**Default:** none

## displace\_atoms command

### Syntax:

displace\_atoms group-ID style args keyword value ...

- group-ID = ID of group of atoms to displace
- style = *move* or *ramp* or *random*

```
move args = delx dely delz
    delx,dely,delz = distance to displace in each dimension (distance units)
ramp args = ddim dlo dhi dim clo chi
    ddim = x or y or z
    dlo,dhi = displacement distance between dlo and dhi (distance units)
    dim = x or y or z
    clo,chi = lower and upper bound of domain to displace (distance units)
random args = dx dy dz seed
    dx,dy,dz = random displacement magnitude in each dimension (distance units)
    seed = random # seed (8 digits or less)
```

- zero or more keyword/value pairs may be appended

```
keyword = units
value = box or lattice
```

### Examples:

```
displace_atoms top move 0 -5 0 units box
displace_atoms flow ramp x 0.0 5.0 y 2.0 20.5
```

### Description:

Displace a group of atoms. This can be used to move atoms a large distance before beginning a simulation or to randomize atoms initially on a lattice. For example, in a shear simulation, an initial strain can be imposed on the system. Or two groups of atoms can be brought into closer proximity.

The *move* style displaces the group of atoms by the specified 3d distance.

The *ramp* style displaces atoms a variable amount in one dimension depending on the atom's coordinate in a (possibly) different dimension. For example, the second example command displaces atoms in the x-direction an amount between 0.0 and 5.0 distance units. Each atom's displacement depends on the fractional distance its y coordinate is between 2.0 and 20.5. Atoms with y-coordinates outside those bounds will be moved the minimum (0.0) or maximum (5.0) amount.

The *random* style independently moves each atom in the group by a random displacement, uniformly sampled from a value between  $-dx$  and  $+dx$  in the x dimension, and similarly for y and z. Random numbers are used in such a way that the displacement of a particular atom is the same, regardless of how many processors are being used.

Distance units for displacement are determined by the setting of *box* or *lattice* for the *units* keyword. *Box* means distance units as defined by the [units](#) command – e.g. Angstroms for *real* units. *Lattice* means distance units are in lattice spacings. The [lattice](#) command must have been previously used to define the lattice spacing.

---

Care should be taken not to move atoms on top of other atoms. After the move, atoms are remapped into the periodic simulation box if needed.

Atoms can be moved arbitrarily long distances by this command. If the simulation box is non-periodic, this can change its size or shape. This is not a problem, except that the mapping of processors to the simulation box is not changed by this command from its initial 3d configuration; see the [processors](#) command. Thus, if the box size or shape changes dramatically, the simulation may not be as well load-balanced (atoms per processor) as the initial mapping tried to achieve.

**Restrictions:**

This command requires inter-processor communication to migrate atoms once they have been displaced. This means that your system must be ready to perform a simulation before using this command (force fields are setup, atom masses are set, etc).

**Related commands:**

[lattice](#)

**Default:**

The option defaults are units = lattice.



## displace\_box command

### Syntax:

```
displace_box group-ID parameter args ... keyword value ...
```

- group-ID = ID of group of atoms to displace
- one or more parameter/arg pairs may be appended

```
parameter = x or y or z or xy or xz or yz
x, y, z args = style value(s)
style = final or delta or scale or volume
final values = lo hi
lo hi = box boundaries at end of run (distance units)
delta values = dlo dhi
dlo dhi = change in box boundaries at end of run (distance units)
scale values = factor
factor = multiplicative factor for change in box length at end of run
volume value = none = adjust this dim to preserve volume of system
xy, xz, yz args = style value
style = final or delta
final value = tilt
tilt = tilt factor at end of run (distance units)
delta value = dtilt
dtilt = change in tilt factor at end of run (distance units)
```

- zero or more keyword/value pairs may be appended
- keyword = *remap* or *units*

```
remap value = x or none
x = remap coords of atoms in group into deforming box
none = no remapping of coords
units value = lattice or box
lattice = distances are defined in lattice units
box = distances are defined in simulation box units
```

### Examples:

```
displace_box all xy final -2.0 z final 0.0 5.0 units box
displace_box all x scale 1.1 y volume z volume
```

### Description:

Change the volume and/or shape of the simulation box. Orthogonal simulation boxes have 3 adjustable parameters (x,y,z). Triclinic (non-orthogonal) simulation boxes have 6 adjustable parameters (x,y,z,xy,xz,yz). Any or all of them can be adjusted independently and simultaneously by this command. This fix can be used to expand or contract a box, or to apply a shear strain to a non-orthogonal box.

Any parameter varied by this command must refer to a periodic dimension – see the [boundary](#) command. For parameters "xy", "xz", and "yz" this means both affected dimensions must be periodic, e.g. x and y for "xy". Dimensions not varied by this command can be periodic or non-periodic.

The size and shape of the initial simulation box are specified by the [create\\_box](#) or [read\\_data](#) or [read\\_restart](#) command used to setup the simulation, or they are the values from the end of the previous run. The [create\\_box](#), [read\\_data](#), and [read\\_restart](#) commands also determine whether the simulation box is orthogonal or triclinic and their doc pages explain the meaning of the xy,xz,yz tilt factors. If the `displace_box` command changes the

xy,xz,yz tilt factors, then the simulation box must be triclinic, even if its initial tilt factors are 0.0.

---

For the *x*, *y*, and *z* parameters, this is the meaning of their styles and values.

For style *final*, the final *lo* and *hi* box boundaries of a dimension are specified. The values can be in lattice or box distance units. See the discussion of the *units* keyword below.

For style *delta*, plus or minus changes in the *lo*/*hi* box boundaries of a dimension are specified. The values can be in lattice or box distance units. See the discussion of the *units* keyword below.

For style *scale*, a multiplicative factor to apply to the box length of a dimension is specified. For example, if the initial box length is 10, and the factor is 1.1, then the final box length will be 11. A factor less than 1.0 means compression.

The *volume* style changes the specified dimension in such a way that the box volume remains constant while other box dimensions are changed explicitly via the styles discussed above. For example, "x scale 1.1 y scale 1.1 z volume" will shrink the *z* box length as the *x*,*y* box lengths increase, to keep the volume constant (product of *x*,*y*,*z* lengths). If "x scale 1.1 z volume" is specified and parameter *y* is unspecified, then the *z* box length will shrink as *x* increases to keep the product of *x*,*z* lengths constant. If "x scale 1.1 y volume z volume" is specified, then both the *y*,*z* box lengths will shrink as *x* increases to keep the volume constant (product of *x*,*y*,*z* lengths). In this case, the *y*,*z* box lengths shrink so as to keep their relative aspect ratio constant.

For solids or liquids, note that when one dimension of the box is expanded by this command, it may be physically undesirable to hold the other 2 box lengths constant (unspecified by this command) since that implies a density change. Using the *volume* style for those 2 dimensions to keep the box volume constant may make more physical sense, but may also not be correct for materials and potentials whose Poisson ratio is not 0.5.

For the *scale* and *volume* styles, the box length is expanded or compressed around its mid point.

---

For the *xy*, *xz*, and *yz* parameters, this is the meaning of their styles and values. Note that changing the tilt factors of a triclinic box does not change its volume.

For style *final*, the final tilt factor is specified. The value can be in lattice or box distance units. See the discussion of the *units* keyword below.

For style *delta*, a plus or minus change in the tilt factor is specified. The value can be in lattice or box distance units. See the discussion of the *units* keyword below.

All of these styles change the *xy*, *xz*, *yz* tilt factors. In LAMMPS, tilt factors (*xy*,*xz*,*yz*) for triclinic boxes are always bounded by half the distance of the parallel box length. For example, if *xlo* = 2 and *xhi* = 12, then the *x* box length is 10 and the *xy* tilt factor must be between -5 and 5. Similarly, both *xz* and *yz* must be between  $-(x_{hi}-x_{lo})/2$  and  $+(y_{hi}-y_{lo})/2$ . Note that this is not a limitation, since if the maximum tilt factor is 5 (as in this example), then configurations with tilt = ..., -15, -5, 5, 15, 25, ... are all equivalent. Any tilt factor specified by this command must be within these limits.

---

The *remap* keyword determines whether atom positions are re-mapped to the new box. If *remap* is set to *x* (the default), atoms in the *fix* group are re-mapped; otherwise they are not. If *remap* is set to *none*, then this remapping does not take place.

The *units* keyword determines the meaning of the distance units used to define various arguments. A *box* value selects standard distance units as defined by the *units* command, e.g. Angstroms for *units* = real or metal. A *lattice* value means the distance units are in lattice spacings. The *lattice* command must have been previously used to

define the lattice spacing.

---

The simulation box size or shape can be changed by arbitrarily large amounts by this command. This is not a problem, except that the mapping of processors to the simulation box is not changed by this command from its initial 3d configuration; see the [processors](#) command. Thus, if the box size or shape changes dramatically, the simulation may not be as well load-balanced (atoms per processor) as the initial mapping tried to achieve.

**Restrictions:**

Any box dimension varied by this fix must be periodic.

This command requires inter-processor communication to migrate atoms once they have moved. This means that your system must be ready to perform a simulation before using this command (force fields are setup, atom masses are set, etc).

**Related commands:**

[fix deform](#)

**Default:**

The option defaults are `remap = x` and `units = lattice`.

## dump command

### Syntax:

```
dump ID group-ID style N file args
```

- ID = user-assigned name for the dump
- group-ID = ID of the group of atoms to be dumped
- style = *atom* or *bond* or *dcd* or *xtc* or *xyz* or *custom*
- N = dump every this many timesteps
- file = name of file to write dump info to
- args = list of arguments for a particular style

```
atom args = none
bond args = none
dcd args = none
xtc args = precision (optional)
    precision = power-of-10 value from 10 to 1000000 (default = 1000)
xyz args = none
custom args = list of atom attributes
    possible attributes = tag, mol, type,
                        x, y, z, xs, ys, zs, xu, yu, zu, ix, iy, iz,
                        vx, vy, vz, fx, fy, fz,
                        q, mux, muy, muz,
                        quatw, quati, quatj, quatk, tqx, tqy, tqz,
                        epair, ebond, ke, etotal, centro,
                        sxx, syy, szz, sxy, sxz, syz,
                        c_ID, c_ID[N]

tag = atom ID
mol = molecule ID
type = atom type
x,y,z = unscaled atom coordinates
xs,ys,zs = scaled atom coordinates
xu,yu,zu = unwrapped atom coordinates
ix,iy,iz = box image that the atom is in
vx,vy,vz = atom velocities
fx,fy,fz = forces on atoms
q = atom charge
mux,muy,muz = orientation of dipolar atom
quatw,quati,quatj,quatk = quaternion components for aspherical particles
tqx,tqy,tqz = torque on aspherical particles
epair = per-atom pairwise energy
ebond = per-atom bond energy
ke = per-atom kinetic energy
etotal = per-atom total energy (ke + epair, not ebond)
centro = per-atom centro-symmetry parameter
sxx, syy, szz, sxy, sxz, syz = per-atom stress tensor components
c_ID = scalar per-atom quantity calculated by a compute identified by its ID
c_ID[N] = Nth per-atom vector quantity calculated by a compute identified by its ID
```

### Examples:

```
dump myDump all atom 100 dump.atom
dump 2 subgroup atom 50 dump.run.bin
dump 4a all custom 100 dump.myforce.* tag type x y vx fx
dump 4b flow custom 100 dump.%.myforce tag type epair sxx syy szz c_myF[3]
dump 1 all xtc 1000 file.xtc 100.0
```

## Description:

Dump a snapshot of atom quantities to one or more files every N timesteps in one of several styles. As described below, the filename determines the kind of output (text or binary or gzipped, one big file or one per timestep, one big file or one per processor). Only information for atoms in the specified group is dumped. The [dump\\_modify](#) command can also alter what atoms are included. Not all styles support all these options; see details below.

Note that because periodic boundary conditions are enforced only on timesteps when neighbor lists are rebuilt, the coordinates of an atom written to a dump file may be slightly outside the simulation box.

Also note that when LAMMPS is running in parallel, the atom information written to dump files (typically one line per atom) may be written in an indeterminate order. This is because data for a single snapshot is collected from multiple processors. This is always the case for the *atom*, *bond*, and *custom* styles. It is also the case for the *xyz* style if the dump group is not *all*. It is not the case for the *dcd* and *xtc* styles which always write atoms in sorted order. So does the *xyz* style if the dump group is *all*.

---

The *style* keyword determines what atom quantities are written to the file and in what format. Settings made via the [dump\\_modify](#) command can also alter the format of individual values and the file itself.

The *atom*, *bond*, and *custom* styles create files in a simple text format that is self-explanatory when viewing a dump file. Many of the LAMMPS [post-processing tools](#), including [Pizza.py](#), work with this format.

For style *atom*, atom coordinates are written to the file, along with the atom ID and atom type. By default, atom coords are written in a scaled format (from 0 to 1). I.e. an x value of 0.25 means the atom is at a location 1/4 of the distance from xlo to xhi of the box boundaries. The format can be changed to unscaled coords via the [dump\\_modify](#) settings. Image flags can also be added for each atom via [dump\\_modify](#).

For style *bond*, the bond topology between atoms is written, in the same format specified in data files read in by the [read\\_data](#) command. Both atoms in the bond must be in the dump group for the bond to be written. Any bonds that have been broken (see the [bond\\_style](#) command) by setting their bond type to 0 are not written. Bonds that have been turned off (see the [fix shake](#) or [delete\\_bonds](#) commands) by setting their bond type negative are written into the file.

Style *custom* allows you to specify a list of atom attributes to be written to the dump file for each atom. Possible attributes are listed above and will appear in the order specified. Be careful not to specify a quantity that is not defined for a particular simulation – such as *q* for atom style *bond*, since that atom style doesn't assign charges. Dumps occur at the very end of a timestep, so atom attributes will include effects due to fixes that are applied during the timestep. An explanation of some of the dump custom quantities is given below.

The *dcd* style writes DCD files, a standard atomic trajectory format used by the CHARMM, NAMD, and XPlor molecular dynamics packages. DCD files are binary and thus may not be portable to different machines. The dump group must be *all* for the *dcd* style.

The *xtc* style writes XTC files, a compressed trajectory format used by the GROMACS molecular dynamics package, and described [here](#). The precision used in XTC files can be specified; for example, a value of 100 means that coordinates are stored to 1/100 nanometer accuracy. XTC files are portable binary files written in the NFS XDR data format, so that any machine which supports XDR should be able to read them. The dump group must be *all* for the *xtc* style.

The *xyz* style writes XYZ files, which is a simple text-based coordinate format that many codes can read.

Note that DCD, XTC, and XYZ formatted files can be read directly by [VMD](#) (a popular molecular viewing

program). We are told VMD will also read LAMMPS *atom* style dump files since someone has added a LAMMPS format plug-in to VMD. It may require an initial snapshot from an XYZ formatted file to get started.

---

Dumps are performed on timesteps that are a multiple of N (including timestep 0) and on the last timestep of a minimization if the minimization converges. N can be changed between runs by using the [dump\\_modify](#) command (not allowed for *dcd* style).

The specified filename determines how the dump file(s) is written. The default is to write one large text file, which is opened when the dump command is invoked and closed when an [undump](#) command is used or when LAMMPS exits. For the *dcd* and *xtc* styles, this is a single large binary file.

Dump filenames can contain two wild-card characters. If a "\*" character appears in the filename, then one file per snapshot is written and the "\*" character is replaced with the timestep value. For example, tmp.dump.\* becomes tmp.dump.0, tmp.dump.10000, tmp.dump.20000, etc. This option is not available for the *dcd* and *xtc* styles.

If a "%" character appears in the filename, then one file is written for each processor and the "%" character is replaced with the processor ID from 0 to P-1. For example, tmp.dump.% becomes tmp.dump.0, tmp.dump.1, ... tmp.dump.P-1, etc. This creates smaller files and can be a fast mode of output on parallel machines that support parallel I/O for output. This option is not available for the *dcd*, *xtc*, and *xyz* styles.

Note that the "\*" and "%" characters can be used together to produce a large number of small dump files!

If the filename ends with ".bin", the dump file (or files, if "\*" or "%" is also used) is written in binary format. A binary dump file will be about the same size as a text version, but will typically write out much faster. Of course, when post-processing, you will need to convert it back to text format (see the [binary2txt tool](#)) or write your own code to read the binary file. The format of the binary file can be understood by looking at the tools/binary2txt.cpp file. This option is only available for the *atom* and *custom* styles.

If the filename ends with ".gz", the dump file (or files, if "\*" or "%" is also used) is written in gzipped format. A gzipped dump file will be about 3x smaller than the text version, but will also take longer to write. This option is not available for the *dcd* and *xtc* styles.

---

This section explains the atom quantities that can be specified as part of the *custom* style.

The *tag*, *mol*, *type*, *x*, *y*, *z*, *vx*, *vy*, *vz*, *fx*, *fy*, *fz*, *q* keywords are self-explanatory. *Tag* is the atom ID. *Mol* is the molecule ID, included in the data file for molecular systems. The *x*, *y*, *z* keywords write atom coordinates "unscaled", in the appropriate distance units (Angstroms, sigma, etc). Use *xs*, *ys*, *zs* if you want the coordinates "scaled" to the box size, so that each value is 0.0 to 1.0. Use *xu*, *yu*, *zu* if you want the coordinates "unwrapped" by the image flags for each atom. Unwrapped means that if the atom has passed thru a periodic boundary one or more times, the value is printed for what the coordinate would be if it had not been wrapped back into the periodic box. Note that using *xu*, *yu*, *zu* means that the coordinate values may be far outside the box size printed with the snapshot. The image flags can be printed directly using the *ix*, *iy*, *iz* keywords. The [dump\\_modify](#) command describes in more detail what is meant by scaled vs unscaled coordinates and the image flags.

The *mux*, *muy*, *muz* keywords are specific to dipolar systems defined with an atom style of *dipole*. They give the orientation of the atom's dipole.

The *quatw*, *quati*, *quatj*, *quatk*, *txx*, *txy*, *txz* keywords are specific to aspherical particles defined with an atom style of *ellipsoid*. The first 4 are the components of the quaternion that define the orientation of the particle. The final 3 give the rotational torque on the particle.

The *epair*, *ebond*, *ke*, *etotal*, *centro*, and *sxx*, etc keywords print the pairwise energy, bond energy, kinetic energy, total energy (pairwise + kinetic), centro-symmetry parameter, and components of the per-atom stress tensor for each atom. These quantities are calculated by computes that the dump defines, as if these commands had been issued:

```
compute dump-ID_epair/atom group-ID epair/atom
compute dump-ID_ebond/atom group-ID ebond/atom
compute dump-ID_ke/atom group-ID ke/atom
compute dump-ID_etotal/atom group-ID etotal/atom dump-ID_epair/atom
compute dump-ID_centro/atom group-ID centro/atom
compute dump-ID_stress/atom group-ID stress/atom
```

See the corresponding [compute](#) style commands for details on what is computed for each atom. Note that the ID of each new compute is the dump-ID with the compute style appended (with an underscore). The group for each new compute is the same as the dump group. Note that for *etotal*, an auxiliary compute for calculating the pairwise energy is created, since the [compute etotal/atom](#) command requires it as an extra argument.

**IMPORTANT NOTE:** The *etotal* keyword does NOT include contributions due to bonds, angles, etc that the atom is part of. The bond contribution can be computed separately via the *ebond* keyword. Currently, there is no way in LAMMPS to dump per-atom energy for angles, dihedrals, improper, or long-range interactions.

The *sxx*, *syy*, *szz*, *sxy*, *sxz*, *syx* keywords access the 6 components of the stress tensor calculated for each atom by the [compute stress/atom](#) style.

The *c\_ID* and *c\_ID[N]* keywords allow scalar or vector per-atom quantities calculated by a compute to be output. The ID in the keyword should be replaced by the actual ID of the compute that has been defined elsewhere in the input script. See the [compute](#) command for details. Note that scalar and vector quantities that are not calculated on a per-atom basis (e.g. global temperature or pressure) cannot be output in a dump. Rather, these quantities are output by the [thermo\\_style custom](#) command.

If *c\_ID* is used as a keyword, then the scalar per-atom quantity calculated by the compute is printed. If *c\_ID[N]* is used, then N in the range from 1–M will print the Nth component of the M-length per-atom vector calculated by the compute.

See [this section](#) for information on how to add new compute styles to LAMMPS that calculate per-atom quantities which could then be output with these keywords.

---

### Restrictions:

Scaled coordinates cannot be written to dump files when the simulation box is triclinic (non-orthogonal). Note that this is the default for dump style *atom*; the [dump\\_modify command](#) must be used to change it. The exception is DCD files which store the tilt factors for subsequent visualization by programs like [VMD](#).

To write gzipped dump files, you must compile LAMMPS with the `-DGZIP` option – see the [Making LAMMPS](#) section of the documentation.

The *bond* style is part of the "molecular" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

The *xtc* style is part of the "xtc" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info. This is because some machines may not support the lo-level XDR data format that XTC files are written with, which will result in a compile-time error when a lo-level include file is not found. Putting this style in a package makes it easy to exclude from a LAMMPS build for those machines.

Some pair potentials do not allow the calculation of per-atom energy and stress via the *epair*, *etotal*, *sxx*, etc keywords. One of these are the granular pair potentials. However, for those potentials, the [fix gran/diag](#) command can be used instead.

**Related commands:**

[dump\\_modify](#), [undump](#)

**Default:** none



## dump\_modify command

### Syntax:

dump\_modify dump-ID keyword values ...

- dump-ID = ID of dump to modify
- one or more keyword/value pairs may be appended
- keyword = *format* or *scale* or *image* or *header* or *flush* or *region* or *thresh*

```
format arg = C-style format string for one line of output
scale arg = yes or no
image arg = yes or no
flush arg = yes or no
every arg = N
    N = dump every this many timesteps
region arg = region-ID or "none"
thresh args = attribute operation value
    attribute = same attributes (x,fy,etotal,sxx,etc) used by dump custom style
    operation = "=" or ">=" or "==" or "!="
    value = numeric value to compare to
    these 3 args can be replaced by the word "none" to turn off threshholding
```

### Examples:

```
dump_modify 1 format "%d %d %20.15g %g %g" scale yes
dump_modify myDump image yes scale no flush yes
dump_modify 1 region mySphere thresh x <0.0 thresh epair >= 3.2
```

### Description:

Modify the parameters of a previously defined dump command. Not all parameters are relevant to all dump styles.

The text-based dump styles have a default C-style format string which simply specifies %d for integers and %g for real values. The *format* keyword can be used to override the default with a new C-style format string. Do not include a trailing "\n" newline character in the format string. This option has no effect on the *dcd* and *xtc* dump styles since they write binary files.

The *scale* and *image* keywords apply only to the dump *atom* style. A scale value of *yes* means atom coords are written in normalized units from 0.0 to 1.0 in each box dimension. A value of *no* means they are written in absolute distance units (e.g. Angstroms or sigma). If the image value is *yes*, 3 flags are appended to each atom's coords which are the absolute box image of the atom in each dimension. For example, an x image flag of -2 with a normalized coord of 0.5 means the atom is in the center of the box, but has passed thru the box boundary 2 times and is really 2 box lengths to the left of its current coordinate. Note that for dump style *custom* these values can be printed in the dump file by using the appropriate atom attributes in the dump command itself.

The *flush* option determines whether a flush operation is invoked after a dump snapshot is written to the dump file. A flush insures the output in that file is current (no buffering by the OS), even if LAMMPS halts before the simulation completes. Flushes cannot be performed with dump style *xtc*.

The *every* option changes the dump frequency originally specified by the [dump](#) command to a new value which must be > 0. The dump frequency cannot be changed for the dump *dcd* style.

The *region* keyword only applies to the dump *custom* style. If specified, only atoms in the region will be written to the dump file. Only one region can be applied as a filter (the last one specified). See the [region](#) command for more details. Note that a region can be defined as the "inside" or "outside" of a geometric shape, and it can be the "union" or "intersection" of a series of simpler regions.

The *thresh* keyword only applies to the dump *custom* style. Multiple thresholds can be specified. Specifying "none" turns off all threshold criteria. If thresholds are specified, only atoms whose attributes meet all the threshold criteria are written to the dump file. The possible attributes that can be tested for are the same as those that can be specified in the [dump custom](#) command. Note that different attributes can be output by the dump custom command than are used as threshold criteria by the dump\_modify command. E.g. you can output the coordinates and stress of atoms whose energy is above some threshold.

**Restrictions:** none

**Related commands:**

[dump](#), [undump](#)

**Default:**

The option defaults are format = %d and %g for each integer or floating point value, scale = yes, image = no, flush = yes (except for dump *xtc* style), region = none, and thresh = none.

## echo command

### Syntax:

```
echo style
```

- style = *none* or *screen* or *log* or *both*

### Examples:

```
echo both
echo log
```

### Description:

This command determines whether LAMMPS echoes each input script command to the screen and/or log file as it is read and processed. If an input script has errors, it can be useful to look at echoed output to see the last command processed.

**Restrictions:** none

**Related commands:** none

### Default:

```
echo log
```

## fix command

### Syntax:

```
fix ID group-ID style args
```

- ID = user-assigned name for the fix
- group-ID = ID of the group of atoms to apply the fix to
- style = one of a long list of possible style names (see below)
- args = arguments used by a particular style

### Examples:

```
fix 1 all nve
fix 3 all nvt 300.0 300.0 0.01
fix mine top setforce 0.0 NULL 0.0
```

### Description:

Set a fix that will be applied to a group of atoms. In LAMMPS, a "fix" is any operation that is applied to the system during timestepping or minimization. Examples include updating of atom positions and velocities due to time integration, controlling temperature, applying constraint forces to atoms, enforcing boundary conditions, computing diagnostics, etc. There are dozens of fixes defined in LAMMPS and new ones can be added – see [this section](#) for a discussion.

Each fix style has its own documentation page which describes its arguments and what it does, as listed below.

Fixes perform their operations at different stages of the timestep. If 2 or more fixes both operate at the same stage of the timestep, they are invoked in the order they were specified in the input script.

Fixes can be deleted with the [unfix](#) command. Note that this is the only way to turn off a fix; simply specifying a new fix with a similar style will not turn off the first one. For example, using a [fix nve](#) command for a second run after using a [fix nvt](#) command for the first run, will not cancel out the NVT time integration invoked by the "fix nvt" command. Thus two time integrators would be in place!

If you specify a new fix with the same ID and style as an existing fix, the old fix is deleted and the new one is created (presumably with new settings). This is the same as if an "unfix" command were first performed on the old fix, except that the new fix is kept in the same order relative to the existing fixes as the old one originally was. Note that this operation also wipes out any additional changes made to the old fix via the [fix\\_modify](#) command.

The [fix modify](#) command allows settings for some fixes to be reset. See the doc page for individual fixes for details.

Some fixes store an internal "state" which is written to binary restart files via the [restart](#) or [write\\_restart](#) commands. This allows the fix to continue on with its calculations in a restarted simulation. See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file. See the doc pages for individual fixes for info on which ones can be restarted.

Here is an alphabetic list of fix styles available in LAMMPS:

- [fix addforce](#) – add a force to each atom

- **fix aveforce** – add an averaged force to each atom
- **fix ave/atom** – compute per-atom time-averaged quantities
- **fix ave/spatial** – output per-atom quantities by layer
- **fix ave/time** – output time-averaged compute quantities
- **fix com** – compute a center-of-mass
- **fix deform** – change the simulation box size/shape
- **fix deposit** – add new atoms above a surface
- **fix drag** – drag atoms towards a defined coordinate
- **fix efield** – impose electric field on system
- **fix enforce2d** – zero out z-dimension velocity and force
- **fix freeze** – freeze atoms in a granular simulation
- **fix gran/diag** – compute granular diagnostics
- **fix gravity** – add gravity to atoms in a granular simulation
- **fix gyration** – compute radius of gyration
- **fix indent** – impose force due to an indenter
- **fix langevin** – Langevin temperature control
- **fix lineforce** – constrain atoms to move in a line
- **fix msd** – compute mean-squared displacement (i.e. diffusion coefficient)
- **fix momentum** – zero the linear and/or angular momentum of a group of atoms
- **fix npH** – constant NPH time integration via Nose/Hoover
- **fix npt** – constant NPT time integration via Nose/Hoover
- **fix npt/asphere** – NPT for aspherical particles
- **fix nve** – constant NVE time integration
- **fix nve/asphere** – NVT for aspherical particles
- **fix nve/dipole** – NVE for point dipolar particles
- **fix nve/gran** – NVE for granular particles
- **fix nve/limit** – NVE with limited step length
- **fix nve/noforce** – NVE without forces (v only)
- **fix nvt** – constant NVT time integration via Nose/Hoover
- **fix nvt/asphere** – NVT for aspherical particles
- **fix nvt/sllod** – NVT for NEMD with SLLOD equations
- **fix orient/fcc** – add grain boundary migration force
- **fix planeforce** – constrain atoms to move in a plane
- **fix poems** – constrain clusters of atoms to move as coupled rigid bodies
- **fix pour** – pour new atoms into a granular simulation domain
- **fix print** – print text and variables during a simulation
- **fix rdf** – compute radial distribution functions
- **fix recenter** – constrain the center-of-mass position of a group of atoms
- **fix rigid** – constrain one or more clusters of atoms to move as a rigid body
- **fix setforce** – set the force on each atom
- **fix shake** – SHAKE constraints on bonds and/or angles
- **fix spring** – apply harmonic spring force to group of atoms
- **fix spring/rg** – spring on radius of gyration of group of atoms
- **fix spring/self** – spring from each atom to its origin
- **fix temp/rescale** – temperature control by velocity rescaling
- **fix tmd** – guide a group of atoms to a new configuration
- **fix viscous** – viscous damping for granular simulations
- **fix wall/gran** – frictional wall(s) for granular simulations
- **fix wall/lj126** – Lennard-Jones 12–6 wall
- **fix wall/lj93** – Lennard-Jones 9–3 wall
- **fix wall/reflect** – reflecting wall(s)
- **fix wiggle** – oscillate walls and frozen atoms

**Restrictions:**

Some fix styles are part of specific packages. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info on packages. The doc pages for individual fixes tell if it is part of a package.

**Related commands:**

[unfix](#), [fix\\_modify](#)

**Default:** none

## fix addforce command

### Syntax:

```
fix ID group-ID addforce fx fy fz
```

- ID, group-ID are documented in [fix](#) command
- addforce = style name of this fix command
- fx,fy,fz = force component values (force units)

### Examples:

```
fix kick flow addforce 1.0 0.0 0.0
```

### Description:

Add fx,fy,fz to the corresponding component of force for each atom in the group. This command can be used to give an additional push to atoms in a simulation, such as for a simulation of Poiseuille flow in a channel.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command.

**Restrictions:** none

### Related commands:

[fix setforce](#), [fix aveforce](#)

**Default:** none

## fix ave/atom command

### Syntax:

```
fix ID group-ID ave/atom Nevery Nrepeat Nfreq compute-ID
```

- ID, group-ID are documented in [fix](#) command
- ave/atom = style name of this fix command
- Nevery = calculate property every this many timesteps
- Nrepeat = # of times to repeat the Nevery calculation before averaging
- Nfreq = timestep frequency at which the average value is calculated
- compute-ID = ID of per-atom compute that performs the calculation

### Examples:

```
fix 1 all ave/atom 1 100 100 myVx  
fix 1 all ave/atom 10 20 1000 my_epair
```

### Description:

Calculate one or more time-averaged per-atom quantities every few timesteps. The results of this calculation can be spatially averaged via the [fix ave/spatial](#) command or output to a file via the [dump custom](#) command.

The *compute-ID* specifies a [compute](#) which calculates the desired property. It must be a per-atom compute (one with the word "atom" in its style name) that calculates one or more values for each atom, as opposed to a global compute. The compute can be previously defined in the input script. Or it can be a compute defined by a [dump custom](#) command. Users can also write code for their own compute styles and [add them to LAMMPS](#).

The *Nevery*, *Nrepeat*, and *Nfreq* arguments specify how the property will be time-averaged. The final averaged value(s) are computed every *Nfreq* timesteps. The average is over *Nrepeat* values, computed in the preceeding time window every *Nevery* timesteps. Thus if *Nevery*=2, *Nrepeat*=6, and *Nfreq*=100, then the values on timesteps 90,92,94,96,98,100 will be used to compute the final average at timestep 100. Similar for timesteps 190,192,194,196,198,200 at timestep 200, etc.

If this fix is referenced by a [dump custom](#) or [fix ave/spatial](#) command, the time-averaged values can only be accessed every *Nfreq* timesteps.

If the compute calculates a single or multiple values per atom, then fix ave/atom will also calculate one or multiple time-averaged quantities per atom. This makes a difference in how the quantities are referenced in a [dump custom](#) command, e.g. c\_ID versus c\_ID[2].

Since the calculation is performed by the compute which stores its own "group" definition, the group specified for this fix is ignored. LAMMPS prints a warning if the fix group and compute group do not match.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).



**Restrictions:** none

**Related commands:**

[compute](#), [fix ave/spatial](#), [dump custom](#)

**Default:** none

## fix ave/spatial command

### Syntax:

```
fix ID group-ID ave/spatial Nevery Nfreq dim origin delta file style args keyword value ...
```

- ID, group-ID are documented in [fix](#) command
- ave/spatial = style name of this fix command
- Nevery = calculate property every this many timesteps
- Nfreq = write average property to file every this many steps
- dim = *x* or *y* or *z*
- origin = *lower* or *center* or *upper* or coordinate value (distance units)
- delta = thickness of spatial layers in dim (distance units)
- file = filename to write results to
- style = *density* or *compute*

*density* arg = *mass* or *number*

*mass* = compute mass density

*number* = compute number density

*compute* arg = compute-ID that stores or calculates per-atom quantities

- zero or more keyword/value pairs may be appended

keyword = *norm* or *units*

*norm* value = *all* or *sample*

*units* value = *box* or *lattice* or *reduced*

### Examples:

```
fix 1 all ave/spatial 10000 10000 z lower 2.0 centro.profile compute myCentro
fix 1 flow ave/spatial 100 1000 y 0.0 1.0 vel.profile compute Vx norm sample
fix 1 flow ave/spatial 100 1000 y 0.0 2.5 dens.profile density mass
```

### Description:

Calculate one or more instantaneous per-atom quantities every few timesteps, average them by layer in a chosen dimension and over a longer timescale, and print the results to a file. This can be used to spatially average per-atom properties such as velocity or energy or a quantity calculated by an equation you define; see the [variable atom](#) command.

The *density* styles means to simply count the number of atoms in each layer, either by mass or number. The *compute* style allows specification of a [compute](#) which will be invoked to calculate the desired property. The compute can be previously defined in the input script or it can be a compute defined by a [dump custom](#) command.

For the *compute* style, the fix ave/spatial command accesses the per-atom scalar or vector values stored by the compute. Thus it must be a "per-atom" compute with the word "atom" in its style name, rather than a "global" compute. See the [fix ave/time](#) command if you wish to time-average a global quantity calculated by a compute without the word atom in its style name, e.g. a compute that calculates a temperature or pressure.

Examples of useful computes to use are as follows. The [compute attribute/atom](#) command to select one or more atom attributes like vx or fz. The "compute variable/atom" style can be used to calculate any quantity for an atom that can be specified by a [variable atom](#) equation. Users can also write code for their own per-atom compute styles and [add them to LAMMPS](#). Note that the [dump custom](#) command can also be used to directly output

per-atom quantities calculated by a per-atom compute.

In all cases, the calculated property is averaged over atoms in each layer, where the layers are in a particular *dim* and have a thickness given by *delta*. Every *Nfreq* steps, when a property is calculated for the first time (after a previous write), the number of layers and the layer boundaries are computed. Thus if the simulation box changes size during a simulation, the number of layers and their boundaries may also change. Layers are defined relative to a specified *origin*, which may be the lower/upper edge of the box (in *dim*) or its center point, or a specified coordinate value. Starting at the origin, sufficient layers are created in both directions to completely cover the box. On subsequent timesteps every atom is mapped to one of the layers. Atoms beyond the lowermost/uppermost layer are counted in the first/last layer.

For orthogonal simulation boxes, the layers are "slices" aligned with the xyz coordinate axes. For non-orthogonal (triclinic) simulation boxes, the layers are "tilted slices" that align with the tilted faces of the box. See the [region prism](#) command for a discussion of the geometry of tilted boxes in LAMMPS. As described there, a tilted simulation box has edge vectors a,b,c. In that nomenclature, layers in the x dimension have faces with normals in the "b" cross "c" direction. Layers in y have faces normal to the "a" cross "c" direction. And layers in z have faces normal to the "a" cross "b" direction. Note that in order to define the thickness and position of these tilted layers in an unambiguous fashion, the *units* option must be set to *reduced*.

The *units* keyword determines the meaning of the distance units used for the layer thickness *delta* and for *origin* if it is a coordinate value. For orthogonal simulation boxes, any of the 3 options may be used. For non-orthogonal (triclinic) simulation boxes, only the *reduced* option may be used.

A *box* value selects standard distance units as defined by the [units](#) command, e.g. Angstroms for units = real or metal. A *lattice* value means the distance units are in lattice spacings. The [lattice](#) command must have been previously used to define the lattice spacing. A *reduced* value means normalized unitless values between 0 and 1, which represent the lower and upper faces of the simulation box respectively. Thus an *origin* value of 0.5 means the center of the box in any dimension. A *delta* value of 0.1 means 10 layers span the box in any dimension.

Consider a non-orthogonal box, with layers in the x dimension. No matter how the box is tilted, an *origin* of 0.0 means start layers at the lower "b" cross "c" plane of the simulation box and an *origin* of 1.0 means to start layers at the upper "b" cross "c" face of the box. A *delta* value of 0.1 means there will be 10 layers from 0.0 to 1.0, regardless of the current size or shape of the simulation box.

The *Nevery* and *Nfreq* arguments specify how the property calculated for each layer is time-averaged. The property is calculated once each *Nevery* timesteps. It is averaged and output every *Nfreq* timesteps. *Nfreq* must be a multiple of *Nevery*. In the 2nd example above, the property is calculated every 100 steps. After 10 calculations, the average result is written to the file, once every 1000 steps.

The *norm* keyword also affects how time-averaging is done. For an *all* setting, a layer quantity is summed over all atoms in all *Nfreq/Nevery* samples, as is the count of atoms in the layer. The printed value for the layer is Total-quantity / Total-count. In other words it is an average over the entire *Nfreq* timescale.

For a *sample* setting, the quantity is summed over atoms for only a single sample, as is the count, and a "average sample value" is computed, i.e. Sample-quantity / Sample-count. The printed value for the layer is the average of the M "average sample values", where M = *Nfreq/Nevery*. In other words it is an average of an average.

Each time info is written to the file, it is in the following format. A line with the timestep and number of layers is written. Then one line per layer is written, containing the layer ID (1-N), the coordinate of the center of the layer, the number of atoms in the layer, and one or more calculated values. The number of atoms and the value(s) are average quantities. If the value of the *units* keyword is *box* or *lattice*, the "coord" is printed in box units. If the value of the *units* keyword is *reduced*, the "coord" is printed in reduced units (0-1).

If the *density* keyword is used, or the *compute* keyword with a compute that calculates a single quantity per atom, then a single value will be printed for each layer. If the *compute* keyword is used with a compute that calculates N quantities per atom, then N values per line will be written, each of them averaged independently.

For the *compute* keyword, the calculation performed by the compute is on the group defined by the compute. However, only atoms in the fix group are included in the layer averaging. LAMMPS prints a warning if the fix group and compute group do not match.

Note that some computes perform costly calculations, involving use of or creation of neighbor lists. If the compute is invoked too often by fix ave/spatial, it can slow down a simulation.

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:**

[compute](#), [fix ave/time](#)

**Default:**

The option defaults are norm = all and units = lattice.

## fix ave/time command

### Syntax:

```
fix ID group-ID ave/time Nevery Nfreq compute-ID flag file
```

- ID, group-ID are documented in [fix](#) command
- ave/time = style name of this fix command
- Nevery = calculate property every this many timesteps
- Nfreq = write average property to file every this many steps
- compute-ID = ID of compute that performs the calculation
- flag = 0 for scalar quantity, 1 for vector quantity, 2 for both
- file = filename to write results to

### Examples:

```
fix 1 all ave/time 100 1000 myTemp 0 temp.stats
```

### Description:

Calculate one or more instantaneous quantities every few timesteps, average them over a longer timescale, and print the results to a file. This can be used to time-average any "compute" entity in LAMMPS such as a temperature or pressure.

The *compute-ID* specifies a [compute](#) which calculates the desired property. The compute must be a "global" compute that calculates one or more global properties rather than a "per-atom" compute. The compute can be previously defined in the input script. Or it can be a compute defined by [thermodynamic output](#) or other fixes such as [fix nvt](#) or [fix temp/rescale](#). Users can also write code for their own compute styles and [add them to LAMMPS](#).

In all these cases, the fix ave/time command uses the global scalar or vector calculated by the compute. See the [fix ave/spatial](#) command if you wish to average spatially, e.g. via a compute that calculates per-atom quantities.

The *Nevery* and *Nfreq* arguments specify how the property will be averaged. The property is calculated once each *Nevery* timesteps. It is averaged and output every *Nfreq* timesteps. *Nfreq* must be a multiple of *Nevery*. In the example above, the property is calculated every 100 steps. After 10 calculations, the average result is written to the file, once every 1000 steps.

The *flag* argument chooses whether the scalar and/or vector calculation of the compute is invoked. The former computes a single global value. The latter computes *N* global values, where *N* is defined by the compute, e.g. 6 pressure tensor components. In the vector case, each of the *N* values is averaged independently and *N* values are written to the file at each output.

Since the calculation is performed by the compute which stores its own "group" definition, the group specified for this fix is ignored. LAMMPS prints a warning if the fix group and compute group do not match.

If the compute calculates pressure, it will cause the force computations performed by LAMMPS (pair, bond, angle, etc) to calculate virial terms each *Nevery* timesteps. If this is more frequent than thermodynamic output, this adds extra cost to a simulation. However, if a constant pressure simulation is being run ([fix npt](#) or [fix nph](#)), LAMMPS is already calculating virial terms for the pressure every timestep.

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:**

[compute](#), [fix ave/spatial](#)

**Default:** none

## fix aveforce command

### Syntax:

```
fix ID group-ID aveforce fx fy fz
```

- ID, group-ID are documented in [fix](#) command
- aveforce = style name of this fix command
- fx,fy,fz = force component values (force units)

### Examples:

```
fix pressdown topwall aveforce 0.0 -1.0 0.0  
fix 2 bottomwall aveforce NULL -1.0 0.0
```

### Description:

Apply an additional external force to a group of atoms in such a way that every atom experiences the same force. This is useful for pushing on wall or boundary atoms so that the structure of the wall does not change over time.

The existing force is averaged for the group of atoms, component by component. The actual force on each atom is then set to the average value plus the component specified in this command. This means each atom in the group receives the same force.

If any of the arguments is specified as NULL then the forces in that dimension are not changed. Note that this is not the same as specifying a 0.0 value, since that sets all forces to the same average value without adding in any additional force.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command.

**Restrictions:** none

### Related commands:

[fix setforce](#), [fix addforce](#)

**Default:** none

## fix bond/swap command

### Syntax:

```
fix ID group-ID bond/swap fraction cutoff seed
```

- ID, group-ID are documented in [fix](#) command
- bond/swap = style name of this fix command
- fraction = fraction of group atoms to consider for swap
- cutoff = distance at which swapping will be considered (distance units)
- seed = random # seed (8 digits or less)

### Examples:

```
fix 1 all bond/swap 0.5 1.5 598934
```

### Description:

In a simulation of polymer chains, this command attempts to swap bonds between two different chains, effectively grafting the end of one chain onto another chain and vice versa. This is done via Monte Carlo rules using the Boltzmann acceptance criterion. Its purpose is to lower the energy of the system more rapidly than dynamics alone would do it, by enabling large conformational changes in a single timestep in a dense polymer melt. It is designed to be used for systems of [FENE](#) bead-spring polymer chains where each polymer is a linear chain of monomers, but LAMMPS does not enforce this requirement.

A schematic of the kinds of bond swaps that can occur is shown here:

On the left, the red chain and green chain have two monomers A1 and B1 close to each other, which are currently bonded to monomers A2 and B2 respectively within their own chains. The bond swap operation will attempt to delete the A1–A2 and B1–B2 bonds and replace them with A1–B2 and B1–A2 bonds. If the swap is energetically favorable, the two chains on the right are the result and each polymer chain has undergone a dramatic conformational change. These references provide more details on how the fix works and its application: [\(Sides\)](#) and [\(Sides\)](#).

The bond swapping operation is invoked each time neighbor lists are built during a simulation, since it potentially alters the list of which neighbors are considered for pairwise interaction. At each reneighboring step, each processor considers a random specified *fraction* of its atoms as potential swapping monomers for this timestep. Choosing a small *fraction* value can reduce the likelihood of an inverse swap happening soon after an initial swap.

For each monomer A1, its neighbors are examined for a potential B1 monomer. Both A1 and B1 must be in the fix group, their separation must be less than the specified *cutoff*, and the molecule IDs of A1 and B1 must be the same (see below). If a suitable partner is found, the energy change due to swapping the 2 bonds is computed. This includes changes in pairwise, bond, and angle energies (but not dihedral or improper energies) due to the altered connectivity of the 2 chains. If the energy decreases, the bond swap is accepted. If the energy increases it is accepted with probability  $\exp(-\Delta E/kT)$  where  $\Delta E$  is the increase in energy,  $k$  is the Boltzmann constant, and  $T$  is the current temperature of the system. Whether the swap is accepted or rejected, no other swaps are attempted by this processor on this timestep.

The criterion for matching molecule IDs is how bond swaps conserve chain length, and means you must setup



your simulation of polymer chains in a certain way, typically in the data file, read by the [read\\_data](#) comand. Consider a system of 6-mer chains. You have 3 choices. If the molecule IDs for each chain are set as 1,2,3,4,5,6 then swaps will conserve length and for a particular momoner there will be only one other monomer on another chain which is a potential swap partner. If the molecule IDs for each chain are set as 1,2,3,3,2,1 then swaps will conserve length but swaps can occur at either end of a chain; i.e. for a particular monomer there are 2 possible swap partners on another chain. In this scenario, swaps can also occur within one chain, i.e. its two ends swap with each other. The third choice is to give monomers on all chains the same molecule ID, e.g. 0. This will allow for a wide variety of swaps to occur, but will NOT conserve chain lengths.

**IMPORTANT NOTE:** If your simulation uses molecule IDs in the usual way, where all monomers on a chain have the same unique ID, then swaps will only occur within the same chain and will NOT conserve chain length. This is probably not what you want for this fix.

---

This fix computes a temperature each time it is invoked for use by the Boltzmann criterion. To do this, the fix creates its own compute of style "temp", as if this command had been issued:

```
compute fix-ID_temp all temp
```

See the [compute temp](#) command for details. Note that the ID of the new compute is the fix-ID with underscore + "temp" appended and the group for the new compute is "all", so that the temperature of the entire system is used.

Note that this is NOT the compute used by thermodynamic output (see the [thermo\\_style](#) command) with ID = *thermo\_temp*. This means you can change the attributes of this fix's temperature (e.g. its degrees-of-freedom) via the [compute\\_modify](#) command or print this temperature during thermodyanmic output via the [thermo\\_style custom](#) command using the appropriate compute-ID. It also means that changing attributes of *thermo\_temp* will have no effect on this fix.

---

#### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). Because the state of the random number generator is not saved in restart files, this means you cannot do "exact" restarts with this fix, where the simulation continues on the same as if no restart had taken place. However, in a statistical sense, a restarted simulation should produce the same behavior. Also note that each processor generates possible swaps independently of other processors. Thus if you repeat the same simulation on a different number of processors, the specific swaps performed will be different.

The [fix\\_modify temp](#) option is supported by this fix. You can use it to assign a [compute](#) you have defined to this fix which will be used to compute the temperature for the Boltzmann criterion.

Two statistical quantities stored by this fix can be printed as part of thermodynamic output via the keywords *f\_ID[N]* where ID is the fix-ID of this fix and *N* = 1,2. For *N*=1, the cummulative number of swaps performed by all processors is printed. For *N*=2, the cummulative number of swaps attempted (whether accepted or rejected) is printed. An attempt only occurs when swap partners meeting the criteria described above are found on a particular timestep. See the [thermo\\_style custom](#) command for details.

No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

#### **Restrictions:**

The setings of the "special\_bond" command must be 0,1,1 in order to use this fix, which is typical of FENE bead-spring chains. I.e. pairwise interactions between bonded atoms are turned off, but exist between atoms two

or three hops away along the chain length.

Currently, energy changes in dihedral and improper interactions due to a bond swap are not considered. Thus a simulation with this fix cannot use a dihedral or improper potential.

**Related commands:** none

**Default:** none

---

**(Sides)** Sides, Grest, Plimpton, J Chem Phys, 92, 5057 (1990).

**(Sides)** Sides, Grest, Plimpton, J Chem Phys, 92, 5057 (1990).

## fix com command

### Syntax:

```
fix ID group-ID com N file
```

- ID, group-ID are documented in [fix](#) command
- com = style name of this fix command
- N = compute center-of-mass every this many timesteps
- file = filename to write center-of-mass info to

### Examples:

```
fix 1 all com 100 com.out
```

### Description:

Compute the center-of-mass of the group of atoms every N steps, including all effects due to atoms passing thru periodic boundaries. Write the results to the specified file.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:** none

**Default:** none

## fix deform command

### Syntax:

fix ID group-ID deform N parameter args ... keyword value ...

- ID, group-ID are documented in [fix](#) command
- deform = style name of this fix command
- N = perform box deformation every this many timesteps
- one or more parameter/arg pairs may be appended

```
parameter = x or y or z or xy or xz or yz
x, y, z args = style value(s)
style = final or delta or scale or vel or erate or trate or volume
  final values = lo hi
    lo hi = box boundaries at end of run (distance units)
  delta values = dlo dhi
    dlo dhi = change in box boundaries at end of run (distance units)
  scale values = factor
    factor = multiplicative factor for change in box length at end of run
  vel value = V
    V = change box length at this velocity (distance/time units),
        effectively an engineering strain rate
  erate value = R
    R = engineering strain rate (1/time units)
  trate value = R
    R = true strain rate (1/time units)
  volume value = none = adjust this dim to preserve volume of system
xy, xz, yz args = style value
style = final or delta or vel or erate or trate
  final value = tilt
    tilt = tilt factor at end of run (distance units)
  delta value = dtilt
    dtilt = change in tilt factor at end of run (distance units)
  vel value = V
    V = change tilt factor at this velocity (distance/time units),
        effectively an engineering shear strain rate
  erate value = R
    R = engineering shear strain rate (1/time units)
  trate value = R
    R = true shear strain rate (1/time units)
```

- zero or more keyword/value pairs may be appended
- keyword = *remap* or *units*

```
remap value = x or v or none
  x = remap coords of atoms in group into deforming box
  v = remap velocities of all atoms when they cross periodic boundaries
  none = no remapping of x or v
units value = lattice or box
  lattice = distances are defined in lattice units
  box = distances are defined in simulation box units
```

### Examples:

```
fix 1 all deform 1 x final 0.0 9.0 z final 0.0 5.0 units box
fix 1 all deform 1 x trate 0.1 y volume z volume
fix 1 all deform 1 xy erate 0.001 remap v
fix 1 all deform 10 y delta 0.5 xz vel 1.0
```

## Description:

Change the volume and/or shape of the simulation box during a dynamics run. Orthogonal simulation boxes have 3 adjustable parameters (x,y,z). Triclinic (non-orthogonal) simulation boxes have 6 adjustable parameters (x,y,z,xy,xz,yz). Any or all of them can be adjusted independently and simultaneously by this command. This fix can be used to perform non-equilibrium MD (NEMD) simulations of a continuously strained system. See the [fix nvt/sllod](#) and [compute temp/deform](#) commands for more details.

Any parameter varied by this command must refer to a periodic dimension – see the [boundary](#) command. For parameters "xy", "xz", and "yz" this means both affected dimensions must be periodic, e.g. x and y for "xy". Dimensions not varied by this command can be periodic or non-periodic. Unspecified periodic dimensions can also be controlled by a [fix npt](#) or [fix nph](#) command.

The size and shape of the simulation box at the beginning of the simulation run were either specified by the [create\\_box](#) or [read\\_data](#) or [read\\_restart](#) command used to setup the simulation initially if it is the first run, or they are the values from the end of the previous run. The [create\\_box](#), [read\\_data](#), and [read\\_restart](#) commands specify whether the simulation box is orthogonal or non-orthogonal (triclinic) and explain the meaning of the xy,xz,yz tilt factors. If fix deform changes the xy,xz,yz tilt factors, then the simulation box must be triclinic, even if its initial tilt factors are 0.0.

As described below, the desired simulation box size and shape at the end of the run are determined by the parameters of the fix deform command. Every Nth timestep during the run, the simulation box is expanded, contracted, or tilted to ramped values between the initial and final values.

---

For the x, y, and z parameters, this is the meaning of their styles and values.

The *final*, *delta*, *scale*, *vel*, and *erate* styles all change the specified dimension of the box via "constant displacement" which is effectively a "constant engineering strain rate". This means the box dimension changes linearly with time from its initial to final value.

For style *final*, the final lo and hi box boundaries of a dimension are specified. The values can be in lattice or box distance units. See the discussion of the units keyword below.

For style *delta*, plus or minus changes in the lo/hi box boundaries of a dimension are specified. The values can be in lattice or box distance units. See the discussion of the units keyword below.

For style *scale*, a multiplicative factor to apply to the box length of a dimension is specified. For example, if the initial box length is 10, and the factor is 1.1, then the final box length will be 11. A factor less than 1.0 means compression.

For style *vel*, a velocity at which the box length changes is specified in units of distance/time. This is effectively a "constant engineering strain rate", where  $\text{rate} = V/L_0$  and  $L_0$  is the initial box length. The distance can be in lattice or box distance units. See the discussion of the units keyword below. For example, if the initial box length is 100 Angstroms, and V is 10 Angstroms/psec, then after 10 psec, the box length will have doubled. After 20 psec, it will have tripled.

The *erate* style changes a dimension of the the box at a "constant engineering strain rate". The units of the specified strain rate are 1/time. See the [units](#) command for the time units associated with different choices of simulation units, e.g. picoseconds for "metal" units). Tensile strain is unitless and is defined as  $\text{delta}/\text{length}_0$ , where  $\text{length}_0$  is the original box length and delta is the change relative to the original length. Thus if the *erate* R is 0.1 and time units are picoseconds, this means the box length will increase by 10% of its original length every picosecond. I.e. strain after 1 psec = 0.1, strain after 2 psec = 0.2, etc.  $R = -0.01$  means the box length will shrink

by 1% of its original length every picosecond. Note that for an "engineering" rate the change is based on the original box length, so running with  $R = 1$  for 10 picoseconds expands the box length by a factor of 10, not 1024 as it would with *trate*.

The *trate* style changes a dimension of the box at a "constant true strain rate". Note that this is not an "engineering strain rate", as the other styles are. Rather, for a "true" rate, the rate of change is constant, which means the box dimension changes non-linearly with time from its initial to final value. The units of the specified strain rate are 1/time. See the [units](#) command for the time units associated with different choices of simulation units, e.g. picoseconds for "metal" units). Tensile strain is unitless and is defined as  $\Delta/\text{length}_0$ , where  $\text{length}_0$  is the original box length and  $\Delta$  is the change relative to the original length. Thus if the *trate*  $R$  is 0.1 and time units are picoseconds, this means the box length will increase by 10% of its current length every picosecond. I.e. strain after 1 psec = 0.1, strain after 2 psec = 0.21, etc.  $R = 1$  or 2 means the box length will double or triple every picosecond.  $R = -0.01$  means the box length will shrink by 1% of its current length every picosecond. Note that for a "true" rate the change is continuous and based on the current length, so running with  $R = 1$  for 10 picoseconds does not expand the box length by a factor of 10 as it would with *erate*, but by a factor of 1024 since it doubles every picosecond.

Note that to change the volume (or cross-sectional area) of the simulation box at a constant rate, you can change multiple dimensions via *erate* or *trate*. E.g. to double the box volume every picosecond, you could set "x *trate* M", "y *trate* M", "z *trate* M", with  $M = \text{pow}(2, 1/3) - 1 = 1.26$ , since if each box dimension grows by 26%, the box volume doubles.

The *volume* style changes the specified dimension in such a way that the box volume remains constant while other box dimensions are changed explicitly via the styles discussed above. For example, "x scale 1.1 y scale 1.1 z volume" will shrink the z box length as the x,y box lengths increase, to keep the volume constant (product of x,y,z lengths). If "x scale 1.1 z volume" is specified and parameter y is unspecified, then the z box length will shrink as x increases to keep the product of x,z lengths constant. If "x scale 1.1 y volume z volume" is specified, then both the y,z box lengths will shrink as x increases to keep the volume constant (product of x,y,z lengths). In this case, the y,z box lengths shrink so as to keep their relative aspect ratio constant.

For solids or liquids, note that when one dimension of the box is expanded via fix deform (i.e. tensile strain), it may be physically undesirable to hold the other 2 box lengths constant (unspecified by fix deform) since that implies a density change. Using the *volume* style for those 2 dimensions to keep the box volume constant may make more physical sense, but may also not be correct for materials and potentials whose Poisson ratio is not 0.5. An alternative is to use [fix npt aniso](#) with zero applied pressure on those 2 dimensions, so that they respond to the tensile strain dynamically.

For the *scale*, *vel*, *erate*, *trate*, and *volume* styles, the box length is expanded or compressed around its mid point.

---

For the *xy*, *xz*, and *yz* parameters, this is the meaning of their styles and values. Note that changing the tilt factors of a triclinic box does not change its volume.

The *final*, *delta*, *vel*, and *erate* styles all change the shear strain at a "constant engineering shear strain rate". This means the tilt factor changes linearly with time from its initial to final value.

For style *final*, the final tilt factor is specified. The value can be in lattice or box distance units. See the discussion of the units keyword below.

For style *delta*, a plus or minus change in the tilt factor is specified. The value can be in lattice or box distance units. See the discussion of the units keyword below.

For style *vel*, a velocity at which the tilt factor changes is specified in units of distance/time. This is effectively an

"engineering shear strain rate", where  $\text{rate} = V/L_0$  and  $L_0$  is the initial box length perpendicular to the direction of shear. The distance can be in lattice or box distance units. See the discussion of the units keyword below. For example, if the initial tilt factor is 5 Angstroms, and the  $V$  is 10 Angstroms/psec, then after 1 psec, the tilt factor will be 15 Angstroms. After 2 psec, it will be 25 Angstroms.

The *erate* style changes a tilt factor at a "constant engineering shear strain rate". The units of the specified shear strain rate are 1/time. See the [units](#) command for the time units associated with different choices of simulation units, e.g. picoseconds for "metal" units). Shear strain is unitless and is defined as offset/length, where length is the box length perpendicular to the shear direction (e.g. y box length for xy deformation) and offset is the displacement distance in the shear direction (e.g. x direction for xy deformation) from the unstrained orientation. Thus if the *erate* R is 0.1 and time units are picoseconds, this means the shear strain will increase by 0.1 every picosecond. I.e. if the xy shear strain was initially 0.0, then strain after 1 psec = 0.1, strain after 2 psec = 0.2, etc. Thus the tilt factor would be 0.0 at time 0,  $0.1 \cdot y_{\text{box}}$  at 1 psec,  $0.2 \cdot y_{\text{box}}$  at 2 psec, etc, where  $y_{\text{box}}$  is the original y box length.  $R = 1$  or  $2$  means the tilt factor will increase by 1 or 2 every picosecond.  $R = -0.01$  means a decrease in shear strain by 0.01 every picosecond.

The *trate* style changes a tilt factor at a "constant true shear strain rate". Note that this is not an "engineering shear strain rate", as the other styles are. Rather, for a "true" rate, the rate of change is constant, which means the tilt factor changes non-linearly with time from its initial to final value. The units of the specified shear strain rate are 1/time. See the [units](#) command for the time units associated with different choices of simulation units, e.g. picoseconds for "metal" units). Shear strain is unitless and is defined as offset/length, where length is the box length perpendicular to the shear direction (e.g. y box length for xy deformation) and offset is the displacement distance in the shear direction (e.g. x direction for xy deformation) from the unstrained orientation. Thus if the *trate* R is 0.1 and time units are picoseconds, this means the shear strain or tilt factor will increase by 10% every picosecond. I.e. if the xy shear strain was initially 0.1, then strain after 1 psec = 0.11, strain after 2 psec = 0.121, etc.  $R = 1$  or  $2$  means the tilt factor will double or triple every picosecond.  $R = -0.01$  means the tilt factor will shrink by 1% every picosecond. Note that the change is continuous, so running with  $R = 1$  for 10 picoseconds does not change the tilt factor by a factor of 10, but by a factor of 1024 since it doubles every picosecond. Also note that the initial tilt factor must be non-zero to use the *trate* option.

Note that shear strain is defined as the tilt factor divided by the perpendicular box length. The *erate* and *trate* styles control the tilt factor, but assume the perpendicular box length remains constant. If this is not the case (e.g. it changes due to another fix deform parameter), then this effect on the shear strain is ignored.

All of these styles change the xy, xz, yz tilt factors during a simulation. In LAMMPS, tilt factors (xy,xz,yz) for triclinic boxes are always bounded by half the distance of the parallel box length. For example, if  $x_{\text{lo}} = 2$  and  $x_{\text{hi}} = 12$ , then the x box length is 10 and the xy tilt factor must be between  $-5$  and  $5$ . Similarly, both xz and yz must be between  $-(x_{\text{hi}} - x_{\text{lo}})/2$  and  $+(y_{\text{hi}} - y_{\text{lo}})/2$ . Note that this is not a limitation, since if the maximum tilt factor is 5 (as in this example), then configurations with tilt = ...,  $-15, -5, 5, 15, 25, \dots$  are all equivalent.

To obey this constraint and allow for large shear deformations to be applied via the xy, xz, or yz parameters, the following algorithm is used. If *prd* is the associated parallel box length (10 in the example above), then if the tilt factor exceeds the accepted range of  $-5$  to  $5$  during the simulation, then the box is re-shaped to the other limit (an equivalent box) and the simulation continues. Thus for this example, if the initial xy tilt factor was 0.0 and "xy final 100.0" was specified, then during the simulation the xy tilt factor would increase from 0.0 to 5.0, the box would be re-shaped so that the tilt factor becomes  $-5.0$ , the tilt factor would increase from  $-5.0$  to  $5.0$ , the box would be re-shaped again, etc. The re-shaping would occur 10 times and the final tilt factor at the end of the simulation would be 0.0. During each re-shaping event, atoms are remapped into the new box in the appropriate manner.

---

Each time the box size or shape is changed, the *remap* keyword determines whether atom positions are re-mapped to the new box. If *remap* is set to *x* (the default), atoms in the fix group are re-mapped; otherwise they

are not. If *remap* is set to *v*, then any atom in the fix group that crosses a periodic boundary will have a delta added to its velocity equal to the difference in velocities between the lo and hi boundaries. Note that this velocity difference can include tilt components, e.g. a delta in the x velocity when an atom crosses the y periodic boundary. If *remap* is set to *none*, then neither of these remappings take place.

**IMPORTANT NOTE:** When non-equilibrium MD (NEMD) simulations are performed using this fix, the option "remap v" should normally be used. This is because [fix nvt/sllod](#) adjusts the atom positions and velocities to provide a velocity profile that matches the changing box size/shape. Thus atom coordinates should NOT be remapped by fix deform, but velocities SHOULD be when atoms cross periodic boundaries, since that is consistent with maintaining the velocity profile already created by fix nvt/sllod. LAMMPS will warn you if the *remap* setting is not consistent with fix nvt/sllod.

**IMPORTANT NOTE:** If a [fix rigid](#) is defined for rigid bodies, and *remap* is set to *x*, then the center-of-mass coordinates of rigid bodies will be remapped to the changing simulation box. This will be done regardless of whether atoms in the rigid bodies are in the fix deform group or not. The velocity of the centers of mass are not remapped even if *remap* is set to *v*, since [fix nvt/sllod](#) does not currently do anything special for rigid particles. If you wish to perform a NEMD simulation of rigid particles, you can either thermostat them independently or include a background fluid and thermostat the fluid via [fix nvt/sllod](#).

The *units* keyword determines the meaning of the distance units used to define various arguments. A *box* value selects standard distance units as defined by the [units](#) command, e.g. Angstroms for units = real or metal. A *lattice* value means the distance units are in lattice spacings. The [lattice](#) command must have been previously used to define the lattice spacing. Note that the units choice also affects the *vel* style parameters since it is defined in terms of distance/time.

#### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command.

This fix can perform deformation over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

This fix is not invoked during [energy minimization](#).

#### **Restrictions:**

Any box dimension varied by this fix must be periodic.

#### **Related commands:**

[displace\\_box](#)

#### **Default:**

The option defaults are *remap* = x and *units* = lattice.



## fix deposit command

### Syntax:

```
fix ID group-ID deposit N type M seed keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- deposit = style name of this fix command
- N = # of atoms to insert
- type = atom type to assign to inserted atoms
- M = insert a single particle every M steps
- seed = random # seed
- one or more keyword/value pairs may be appended to args
- keyword = *region* or *global* or *local* or *near* or *attempt* or *rate* or *vx* or *vy* or *vz* or *units*

```
region value = region-ID
    region-ID = ID of region to use as insertion volume
global values = lo hi
    lo,hi = put new particle a distance lo-hi above all other particles (distance units)
local values = lo hi delta
    lo,hi = put new particle a distance lo-hi above any nearby particle beneath it (distance units)
    delta = lateral distance within which a neighbor is considered "nearby" (distance units)
near value = R
    R = only insert particle if further than R from existing particles (distance units)
attempt value = Q
    Q = attempt a single insertion up to Q times
rate value = V
    V = z velocity (y in 2d) at which insertion volume moves (velocity units)
vx values = vxlo vxhi
    vxlo,vxhi = range of x velocities for inserted particle (velocity units)
vy values = vylo vyhi
    vylo,vyhi = range of y velocities for inserted particle (velocity units)
vz values = vzlo vzhi
    vzlo,vzhi = range of z velocities for inserted particle (velocity units)
units value = lattice or box
    lattice = the geometry is defined in lattice units
    box = the geometry is defined in simulation box units
```

### Examples:

```
fix 3 all deposit 1000 2 100 29494 region myblock local 1.0 1.0 1.0 units box
fix 2 newatoms deposit 10000 1 500 12345 region disk near 2.0 vz -1.0 -0.8
```

### Description:

Insert a single particle into the simulation domain every M timesteps until N particles have been inserted. This is useful for simulating the deposition of particles onto a surface.

Inserted particles have the specified atom type and are assigned to two groups: the default group "all" and the group specified in the fix deposit command (which can also be "all").

If you are computing temperature values which include inserted particles, you will want to use the [compute\\_modify](#) dynamic option, which insures the current number of atoms is used as a normalizing factor each time temperature is computed.

Care must be taken that inserted particles are not too near existing particles, using the options described below. When inserting particles above a surface in a non-periodic box (see the [boundary](#) command), the possibility of a particle escaping the surface and flying upward should be considered, since the particle may be lost or the box size may grow infinitely large. A [fix wall/reflect](#) command can be used to prevent this behavior. Note that if a shrink-wrap boundary is used, it is OK to insert the new particle outside the box, however the box will immediately be expanded to include the new particle.

This command must use the *region* keyword to define an insertion volume. The specified region must have been previously defined with a [region](#) command. It must be defined with *side = in*.

Each timestep a particle is to be inserted, its coordinates are chosen as follows. A random position within the insertion volume is generated. If neither the *global* or *local* keyword is used, that is the trial position. If the *global* keyword is used, the random x,y values are used, but the z position of the new particle is set above the highest current atom in the simulation by a distance randomly chosen between lo/hi. (For a 2d simulation, this is done for the y position.) If the *local* keyword is used, the z position is set a distance between lo/hi above the highest current atom in the simulation that is "nearby" the chosen x,y position. In this context, "nearby" means the lateral distance (in x,y) between the new and old particles is less than the delta parameter.

Once a trial x,y,z location has been computed, the insertion is only performed if no current particle in the simulation is within a distance R of the new particle. If this test fails, a new random position within the insertion volume is chosen and another trial is made. Up to Q attempts are made. If an atom is not successfully deposited, LAMMPS prints a warning message.

The *rate* option moves the insertion volume in the z direction (3d) or y direction (2d). This enables particles to be inserted from a successively higher height over time. Note that this parameter is ignored if the *global* or *local* keywords are used, since those options choose a z-coordinate for insertion independently.

The vx, vy, and vz components of velocity for the inserted particle are set using the values specified for the vx, vy, and vz keywords. Note that normally, new particles should be assigned a negative vertical velocity so that they move towards the surface.

The *units* keyword determines the meaning of the distance units used for the other deposition parameters. A *box* value selects standard distance units as defined by the [units](#) command, e.g. Angstroms for units = real or metal. A *lattice* value means the distance units are in lattice spacings. The [lattice](#) command must have been previously used to define the lattice spacing. Note that the units choice affects all the keyword values that have units of distance or velocity.

#### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). This means you must be careful when restarting a deposition simulation, when the restart file was written in the middle of the deposition operation. Specifically, you should use a new fix deposit command in the input script for the restarted simulation that continues the operation. You will need to adjust the arguments of the original fix deposit command to do this.

Also note that because the state of the random number generator is not saved in restart files, you cannot do "exact" restarts with this fix, where the simulation continues on the same as if no restart had taken place. However, in a statistical sense, a restarted simulation should produce the same behavior if you adjust the fix deposit parameters appropriately.

None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:**

[fix\\_pour](#), [region](#)

**Default:**

The option defaults are  $\text{delta} = 0.0$ ,  $\text{near} = 0.0$ ,  $\text{attempt} = 10$ ,  $\text{rate} = 0.0$ ,  $\text{vx} = 0.0\ 0.0$ ,  $\text{vy} = 0.0\ 0.0$ ,  $\text{vz} = 0.0\ 0.0$ , and  $\text{units} = \text{lattice}$ .

## fix drag command

### Syntax:

```
fix ID group-ID drag x y z fmag delta
```

- ID, group-ID are documented in [fix](#) command
- drag = style name of this fix command
- x,y,z = coord to drag atoms towards
- fmag = magnitude of force to apply to each atom (force units)
- delta = cutoff distance inside of which force is not applied (distance units)

### Examples:

```
fix center small-molecule drag 0.0 10.0 0.0 5.0 2.0
```

### Description:

Apply a force to each atom in a group to drag it towards the point (x,y,z). The magnitude of the force is specified by fmag. If an atom is closer than a distance delta to the point, then the force is not applied.

Any of the x,y,z values can be specified as NULL which means do not include that dimension in the distance calculation or force application.

This command can be used to steer one or more atoms to a new location in the simulation.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

### Related commands:

[fix spring](#)

**Default:** none

## fix efield command

### Syntax:

```
fix ID group-ID efield ex ey ez
```

- ID, group-ID are documented in [fix](#) command
- efield = style name of this fix command
- ex,ey,ez = E-field component values (electric field units)

### Examples:

```
fix kick external-field efield 1.0 0.0 0.0
```

### Description:

Add a force  $F = qE$  to each charged atom in the group due to an external electric field being applied to the system.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

### Related commands:

[fix addforce](#)

**Default:** none

## fix enforce2d command

### Syntax:

```
fix ID group-ID enforce2d
```

- ID, group-ID are documented in [fix](#) command
- enforce2d = style name of this fix command

### Examples:

```
fix 5 all enforce2d
```

### Description:

Zero out the z-dimension velocity and force on each atom in the group. This is useful when running a 2d simulation to insure that atoms do not move from their initial z coordinate.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command.

**Restrictions:** none

**Related commands:** none

**Default:** none

## fix freeze command

### Syntax:

```
fix ID group-ID freeze
```

- ID, group-ID are documented in [fix](#) command
- freeze = style name of this fix command

### Examples:

```
fix 2 bottom freeze
```

### Description:

Zero out the force and torque on a granular particle. This is useful for preventing certain particles from moving in a simulation.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions:

This fix is part of the "granular" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

There can only be a single freeze fix defined. This is because other parts of the code (pair potentials, thermodynamics, etc) treat frozen particles differently and need to be able to reference a single group to which this fix is applied.

**Related commands:** none

[atom\\_style granular](#)

**Default:** none

## fix gran/diag command

### Syntax:

```
fix ID group-ID gran/diag nevery file layer
```

- ID, group-ID are documented in [fix](#) command
- gran/diag = style name of this fix command
- nevery = compute diagnostics every this many timesteps
- file = filename to store diagnostic info in
- layer = bin size in z-dimension (3d) or y-dimension (2d)

### Examples:

```
fix 1 all gran/diag 1000 tmp 0.9
```

### Description:

Compute aggregate density, velocity, and stress diagnostics for a group of granular atoms as a function of depth in the granular system. "Depth" means the z-dimension for a 3d simulation, and the y-dimension for a 2d simulation. The results are written to 3 files named file.den, file.vel, and file.str. The bins begin at the bottom of the system and extend upward with a thickness of *layer* for each bin. The quantities written to the file are averaged over all atoms in the bin.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions:

This fix is part of the "granular" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

### Related commands:

[atom\\_style granular](#)

**Default:** none



## fix gravity command

### Syntax:

```
fix ID group gravity style magnitude args
```

- ID, group are documented in [fix](#) command
- gravity = style name of this fix command
- magnitude = size of acceleration (force/mass units)
- style = *chute* or *spherical* or *gradient* or *vector*

```
chute args = angle
    angle = angle in +x away from -z or -y axis in 3d/2d (in degrees)
spherical args = phi theta
    phi = azimuthal angle from +x axis (in degrees)
    theta = angle from +z or +y axis in 3d/2d (in degrees)
gradient args = phi theta phi_grad theta_grad
    phi = azimuthal angle from +x axis (in degrees)
    theta = angle from +z or +y axis in 3d/2d (in degrees)
    phi_grad = rate of change of angle phi (full rotations per time unit)
    theta_grad = rate of change of angle theta (full rotations per time unit)
vector args = x y z
    x y z = vector direction to apply the acceleration
```

### Examples:

```
fix 1 all gravity 1.0 chute 24.0
fix 1 all gravity 1.0 spherical 0.0 -180.0
fix 1 all gravity 1.0 gradient 0.0 -180.0 0.0 0.1
fix 1 all gravity 100.0 vector 1 1 0
```

### Description:

Impose an additional acceleration on each particle in the group. This fix is typically used with granular systems to include a "gravity" term acting on the macroscopic particles. More generally, it can represent any kind of driving field, e.g. a pressure gradient inducing a Poisselle flow in a fluid. Note that this fix operates differently than the [fix addforce](#) command. The addforce fix adds the same force to each atom, independent of its mass. This command imparts the same acceleration to each atom (force/mass).

The *magnitude* of the acceleration is specified in force/mass units. For granular systems (LJ units) this is typically 1.0. See the [units](#) command for details.

Style *chute* is typically used for simulations of chute flow where the specified angle is the chute angle, with flow occurring in the +x direction. For 3d systems, the tilt is away from the z axis; for 2d systems, the tilt is away from the y axis.

Style *spherical* allows an arbitrary 3d direction to be specified for the acceleration vector. Phi and theta are defined in the usual spherical coordinates. Thus for acceleration acting in the -z direction, theta would be 180.0 (or -180.0). Theta = 90.0 and phi = -90.0 would mean acceleration acts in the -y direction. For 2d systems, *phi* is ignored and *theta* is an angle in the xy plane where theta = 0.0 is the y-axis.

Style *gradient* is the same as style *spherical* except that the direction of the acceleration vector is time dependent. The units of the gradient arguments are in full rotations per time unit. E.g. a timestep of 0.001 and a gradient of

0.1 means the acceleration vector would rotate thru 360 degrees every 10,000 timesteps. For the time-dependent case, the initial direction of the acceleration vector is  $\phi, \theta$  at the time the fix is specified. For 2d systems,  $\phi$  and  $\phi_{grad}$  are ignored.

Style *vector* imposes an acceleration in the vector direction given by (x,y,z). For 2d systems, the z component is ignored.

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:**

[atom\\_style granular](#), [fix addforce](#)

**Default:** none

## fix gyration command

### Syntax:

```
fix ID group-ID gyration N file
```

- ID, group-ID are documented in [fix](#) command
- gyration = style name of this fix command
- N = compute radius-of-gyration every this many timesteps
- file = filename to write gyration info to

### Examples:

```
fix 1 all gyration 100 molecule.out
```

### Description:

Compute the radius-of-gyration of the group of atoms every N steps, including all effects due to atoms passing thru periodic boundaries. Write the results to the specified file.

Rg is a measure of the size of the group of atoms, and is computed by this formula

$$R_g^2 = \frac{1}{M} \sum_i m_i (r_i - r_{cm})^2$$

where M is the total mass of the group and Rcm is the center-of-mass position of the group.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:** none

**Default:** none

## fix heat command

### Syntax:

```
fix ID group-ID heat N eflux
```

- ID, group-ID are documented in [fix](#) command
- heat = style name of this fix command
- N = add/subtract heat every this many timesteps
- eflux = rate of heat addition or subtraction (energy/time units)

### Examples:

```
fix 3 qin heat 1 1.0  
fix 4 qout heat 1 -1.0
```

### Description:

Add non-translational kinetic energy (heat) to a group of atoms such that their aggregate momentum is conserved. Two of these fixes can be used to establish a temperature gradient across a simulation domain by adding heat to one group of atoms (hot reservoir) and subtracting heat from another (cold reservoir). E.g. a simulation sampling from the McDLT ensemble. Note that the fix is applied to a group of atoms, not a geometric region, so that the same set of atoms is affected wherever they may move to.

Heat addition/subtraction is performed every N timesteps. The *eflux* parameter determines the change in aggregate energy of the entire group of atoms. Since eflux is in units of energy/time, this means a larger value of N will add/subtract a larger amount of energy each timestep the fix is invoked. If heat is subtracted from the system too aggressively so that the group's kinetic energy goes to zero, LAMMPS halts with an error message.

Fix heat is different from a thermostat such as [fix nvt](#) or [fix temp/rescale](#) in that energy is added/subtracted continually. Thus if there isn't another mechanism in place to counterbalance this effect, the entire system will heat or cool continuously. You can use multiple heat fixes so that the net energy change is 0.0 or use [fix viscous](#) to drain energy from the system.

This fix does not change the coordinates of its atoms; it only scales their velocities. Thus you must still use an integration fix (e.g. [fix nve](#)) on the affected atoms. This fix should not normally be used on atoms that have their temperature controlled by another fix – e.g. [fix nvt](#) or [fix langevin](#) fix.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

### Related commands:

[compute temp](#), [compute temp/region](#)

**Default:** none

## fix indent command

### Syntax:

```
fix ID group-ID indent k keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- indent = style name of this fix command
- k = force constant for indenter surface (force/distance^2 units)
- one or more keyword/value pairs may be appended
- keyword = *sphere* or *cylinder* or *vel* or *rstart* or *units*

```
sphere args = x y z R
  x,y,z = initial position of center of indenter
  R = sphere radius of indenter (distance units)
cylinder args = dim c1 c2 R
  dim = x or y or z = axis of cylinder
  c1,c2 = coords of cylinder axis in other 2 dimensions (distance units)
  R = cylinder radius of indenter (distance units)
vel args = vx vy vz
  vx,vy,vz = velocity of center of indenter (velocity units)
rstart value = R0
  R0 = sphere or cylinder radius at start of run (distance units)
  R is value at end of run, so indenter expands/contracts over time
units value = lattice or box
  lattice = the geometry is defined in lattice units
  box = the geometry is defined in simulation box units
```

### Examples:

```
fix 1 all indent 10.0 sphere 0.0 0.0 15.0 3.0 vel 0.0 0.0 -1.0
fix 2 flow indent 10.0 cylinder z 0.0 0.0 10.0 units box
```

### Description:

Insert an indenter within a simulation box. The indenter repels all atoms that touch it, so it can be used to push into a material or as an obstacle in a flow.

The indenter can either be spherical or cylindrical. You must set one of those 2 keywords.

A spherical indenter exerts a force of magnitude

$$F(r) = -k (r - R)^2$$

on each atom where  $k$  is the specified force constant,  $r$  is the distance from the atom to the center of the indenter, and  $R$  is the radius of the indenter. The force is repulsive and  $F(r) = 0$  for  $r > R$ .

A cylindrical indenter exerts the same force, except that  $r$  is the distance from the atom to the center axis of the cylinder. The cylinder extends infinitely along its axis.

If the *vel* keyword is specified, the center (or axis) of the spherical (or cylindrical) indenter will move during the simulation, based on its initial position (x,y,z) and the specified (vx,vy,vz). Note that if you do multiple runs, the initial position of the indenter (x,y,z) does not change, so it will continue to move at the specified velocity.

If the *rstart* keyword is specified, then the radius of the indenter is a time–dependent quantity. *R0* is the value assigned at the start of the run; *R* is the value at the end. At intermediate times, the radius is linearly interpolated between these two values. This option can be used, for example, to grow/shrink a void within the simulation box.

The *units* keyword determines the meaning of the distance units used to define the indenter. A *box* value selects standard distance units as defined by the [units](#) command, e.g. Angstroms for units = real or metal. A *lattice* value means the distance units are in lattice spacings. The [lattice](#) command must have been previously used to define the lattice spacing. Note that the units choice affects not only the indenter's physical geometry, but also its velocity and force constant since they are defined in terms of distance as well.

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#).

The [fix\\_modify energy](#) option is supported by this fix to add the energy of interaction between atoms and the indenter to the system's potential energy as part of [thermodynamic output](#). The energy of each particle interacting with the indenter is  $K/3 (r - R)^3$ .

The atom/indenter interaction energy can be printed as part of thermodynamic output via the keyword *f\_ID*, where *ID* is the fix–ID of this fix. See the [thermo\\_style custom](#) command for details.

This fix can adjust the indenter position and radius over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command. The *rstart* keyword does not change the indenter radius during an energy minimization; the indenter always has a radius of its final value *R* in that case.

**IMPORTANT NOTE:** If you want the atom/indenter interaction energy to be included in the total potential energy of the system (the quantity being minimized), you must enable the [fix\\_modify energy](#) option for this fix.

**Restrictions:** none

**Related commands:** none

**Default:**

The option defaults are *vel* = 0,0,0 and *units* = lattice.

## fix langevin command

### Syntax:

```
fix ID group-ID langevin Tstart Tstop damp seed keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- langevin = style name of this fix command
- Tstart,Tstop = desired temperature at start/end of run (temperature units)
- damp = damping parameter (time units)
- seed = random # seed to use for white noise (8 digits or less)
- zero or more keyword/value pairs may be appended

```
keyword = axes or scale or region
axes values = xflag yflag zflag
xflag,yflag,zflag = 0/1 to exclude/include a dimension in the thermostat
scale values = type ratio
type = atom type (1-N)
ratio = factor to scale the damping coefficient by
region values = region-ID
region-ID = ID of region to apply thermostat to
```

### Examples:

```
fix 3 boundary langevin 1.0 1.0 1000.0 699483
fix 1 all langevin 1.0 1.1 100.0 48279 axes 0 1 1
fix 3 boundary langevin 1.0 1.0 1000.0 699483 region boundary
```

### Description:

Apply a Langevin thermostat to a group of atoms which models an interaction with a background implicit solvent. Used with [fix nve](#), this command performs Brownian dynamics (BD), since the total force on each atom will have the form:

$$\mathbf{F} = \mathbf{F}_c + \mathbf{F}_f + \mathbf{F}_r$$

$\mathbf{F}_c$  is the conservative force computed via the usual inter-particle interactions ([pair\\_style](#), [bond\\_style](#), etc).

The  $\mathbf{F}_f$  and  $\mathbf{F}_r$  terms are added by this fix.  $\mathbf{F}_f = -\gamma \mathbf{v}$  and is a frictional drag or viscous damping term proportional to the particle's velocity. Gamma for each atom is computed as  $m/\text{damp}$ , where  $m$  is the mass of the particle and  $\text{damp}$  is the damping factor specified by the user.

$\mathbf{F}_r$  is a force due to solvent atoms at a temperature  $T$  randomly bumping into the particle. As derived from the fluctuation/dissipation theorem, its magnitude is proportional to  $\sqrt{T m / \text{dt damp}}$ , where  $T$  is the desired temperature,  $m$  is the mass of the particle,  $\text{dt}$  is the timestep size, and  $\text{damp}$  is the damping factor. Random numbers are used to randomize the direction and magnitude of this force.

The desired temperature at each timestep is a ramped value during the run from  $T_{\text{start}}$  to  $T_{\text{stop}}$ .

The *damp* parameter is specified in time units and determines how rapidly the temperature is relaxed. For example, a value of 100.0 means to relax the temperature in a timespan of (roughly) 100 time units (tau or fmsec or psec – see the [units](#) command). The damp factor can be thought of as inversely related to the viscosity of the



solvent. I.e. a small relaxation time implies a hi-viscosity solvent and vice versa. See the discussion about gamma and viscosity in the documentation for the [fix viscous](#) command for more details.

The random *# seed* should be a non-zero integer with 1 to 8 digits. A Marsaglia random number generator is used. Each processor uses the input seed to generate its own unique seed and its own stream of random numbers. Thus the dynamics of the system will not be identical on two runs on different numbers of processors.

The keyword *axes* can be used to specify which dimensions to add Ff and Fr to. A flag of 0 means skip that dimension; a flag of 1 means include that dimension. The default is 1 for all 3 dimensions.

The keyword *scale* allows the damp factor to be scaled up or down by the specified factor for atoms of that type. It can be used multiple times to adjust damp for several atom types. Note that specifying a ratio of 2 increase the relaxation time which is equivalent to the the solvent's viscosity acting on particles with 1/2 the diameter. This is the opposite effect of scale factors used by the [fix viscous](#) command, since the damp factor in *fix langevin* is inversely related to the gamma factor in *fix viscous*. Also note that the damping factor in *fix langevin* includes the particle mass in Ff, unlike *fix viscous*. Thus the mass and size of different atom types should be accounted for in the choice of ratio values.

The keyword *region* applies the fix only to atoms that are in the specified geometric region (and in the fix group). Since atoms can enter/leave a region, this test is performed each timestep.

As noted above, *fix langevin* does not update the coordinates or velocities of its atoms, only the forces. It is normally used with a [fix nve](#) that does the time integration. *Fix langevin* should not normally be used on atoms that also have their temperature controlled by another fix – e.g. a [nvt](#) or [temp/rescale](#) fix.

#### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). Because the state of the random number generator is not saved in restart files, this means you cannot do "exact" restarts with this fix, where the simulation continues on the same as if no restart had taken place. However, in a statistical sense, a restarted simulation should produce the same behavior.

None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command.

This fix can ramp its target temperature over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:**

[fix nvt](#), [fix temp/rescale](#), [fix viscous](#)

**Default:** none

## fix lineforce command

### Syntax:

```
fix ID group-ID lineforce x y z
```

- ID, group-ID are documented in [fix](#) command
- lineforce = style name of this fix command
- x y z = direction of line as a 3-vector

### Examples:

```
fix hold boundary lineforce 0.0 1.0 1.0
```

### Description:

Adjust the forces on each atom in the group so that it's motion will be along the linear direction specified by the vector (x,y,z). This is done by subtracting out components of force perpendicular to the line.

If the initial velocity of the atom is 0.0 (or along the line), then it should continue to move along the line thereafter.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command.

**Restrictions:** none

### Related commands:

[fix planeforce](#)

**Default:** none

## fix\_modify command

### Syntax:

```
fix_modify fix-ID keyword value ...
```

- fix-ID = ID of the fix to modify
- one or more keyword/value pairs may be appended
- keyword = *temp* or *press* or *energy*

```
temp value = compute ID that calculates a temperature
press value = compute ID that calculates a pressure
energy value = yes or no
```

### Examples:

```
fix_modify 3 temp myTemp press myPress
fix_modify 1 energy yes
```

### Description:

Modify one or more parameters of a previously defined fix. Only specific fix styles support specific parameters. See the doc pages for individual fix commands for info on which ones support which fix\_modify parameters.

The *temp* keyword is used to determine how a fix computes temperature. The specified compute ID must have been previously defined by the user via the [compute](#) command and it must be a style of compute that calculates a temperature. All fixes that compute temperatures define their own compute by default, as described in their documentation. Thus this option allows the user to override the default method for computing T.

The *press* keyword is used to determine how a fix computes pressure. The specified compute ID must have been previously defined by the user via the [compute](#) command and it must be a style of compute that calculates a pressure. All fixes that compute pressures define their own compute by default, as described in their documentation. Thus this option allows the user to override the default method for computing P.

For fixes that calculate a contribution to the potential energy of the system, the *energy* keyword will include that contribution in thermodynamic output of potential energy. See the [thermo\\_style](#) command for info on how potential energy is output. The contribution by itself can be printed by using the keyword f\_ID in the thermo\_style custom command, where ID is the fix-ID of the appropriate fix.

**Restrictions:** none

**Related commands:**

[fix](#), [temperature](#), [thermo\\_style](#)

**Default:**

The option defaults are temp = ID defined by fix, press = ID defined by fix, energy = no.

## fix momentum command

### Syntax:

```
fix ID group-ID momentum N keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- momentum = style name of this fix command
- N = adjust the momentum every this many timesteps one or more keyword/value pairs may be appended
- keyword = *linear* or *angular*

```
linear values = xflag yflag zflag  
               xflag,yflag,zflag = 0/1 to exclude/include each dimension  
angular values = none
```

### Examples:

```
fix 1 all momentum 1 linear 1 1 0  
fix 1 all momentum 100 linear 1 1 1 angular
```

### Description:

Zero the linear and/or angular momentum of the group of atoms every N timesteps by adjusting the velocities of the atoms. One (or both) of the *linear* or *angular* keywords must be specified.

If the *linear* keyword is used, the linear momentum is zeroed by subtracting the center-of-mass velocity of the group from each atom. This does not change the relative velocity of any pair of atoms. One or more dimensions can be excluded from this operation by setting the corresponding flag to 0.

If the *angular* keyword is used, the angular momentum is zeroed by subtracting a rotational component from each atom.

This command can be used to insure the entire collection of atoms (or a subset of them) does not drift or rotate during the simulation due to random perturbations (e.g. [fix langevin](#) thermostating).

Note that the [velocity](#) command can be used to create initial velocities with zero aggregate linear and/or angular momentum.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

### Related commands:

[fix recenter](#), [velocity](#)

**Default:** none

## fix msd command

### Syntax:

```
fix ID group-ID msd N file
```

- ID, group-ID are documented in [fix](#) command
- msd = style name of this fix command
- N = compute mean-squared displacement every this many timesteps
- file = filename to write mean-squared displacement info to

### Examples:

```
fix 1 all msd 100 diff.out
```

### Description:

Compute the mean-squared displacement (MSD) of the group of atoms every N steps, including all effects due to atoms passing thru periodic boundaries. The slope of the mean-squared displacement versus time is proportional to the diffusion coefficient of the diffusing atoms. The "origin" of the displacement for each atom is its position at the time the fix command was issued. Write the results to the specified file.

IMPORTANT NOTE: If an atom is part of a rigid body (see the [fix rigid](#) command), its periodic image flags are altered, and the computed MSD will not reflect its true displacement. See the [fix rigid](#) command for details. Thus, to compute the MSD of rigid bodies as they cross periodic boundaries, you will need to post-process a [dump file](#) containing coordinates of the atomss in the bodies.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

This fix writes the original coordinates of diffusing atoms to [binary restart files](#), so that the mean-squared displacement will be accurate in a restarted simulation. See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.

None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:** none

**Default:** none

## fix nph command

### Syntax:

```
fix ID group-ID nph p-style args keyword value ...
```

- ID, group-ID are documented in [fix](#) command
- nph = style name of this fix command
- p-style = xyz or xy or yz or xz or *aniso*

```
xyz args = Pstart Pstop Pdamp
          Pstart,Pstop = desired pressure at start/end of run (pressure units)
          Pdamp = pressure damping parameter (time units)
xy or yz or xz args = Px0 Px1 Py0 Py1 Pz0 Pz1 Pdamp
Px0,Px1,Py0,Py1,Pz0,Pz1 = desired pressure in x,y,z at
                          start/end (0/1) of run (pressure units)
Pdamp = pressure damping parameter (time units)
aniso args = Px0 Px1 Py0 Py1 Pz0 Pz1 Pdamp
Px0,Px1,Py0,Py1,Pz0,Pz1 = desired pressure in x,y,z at
                          start/end (0/1) of run (pressure units)
Pdamp = pressure damping parameter (time units)
```

- zero or more keyword/value pairs may be appended
- keyword = *drag* or *dilate*

```
drag value = drag factor added to barostat (0.0 = no drag)
dilate value = all or partial
```

### Examples:

```
fix 1 all nph xyz 0.0 0.0 1000.0
fix 2 all nph xz 5.0 5.0 NULL NULL 5.0 5.0 1000.0 drag 1.0
fix 2 all nph aniso 0.0 0.0 0.0 0.0 NULL NULL 1000.0
```

### Description:

Perform constant NPH integration to update positions and velocities each timestep for atoms in the group using a Nose/Hoover pressure barostat. P is pressure. This creates a system trajectory consistent with the isobaric ensemble. Unlike [fix npt](#), temperature will not be controlled if no other fix is used. Temperature can be controlled independently by using "[fix langevin](#) or [fix temp/rescale](#).

The atoms in the fix group are the only ones whose velocities and positions are updated by the velocity/position update portion of the NPT integration.

Regardless of what atoms are in the fix group, a global pressure is computed for all atoms. Similarly, when the size of the simulation box is changed, all atoms are re-scaled to new positions, unless the keyword *dilate* is specified with a value of *partial*, in which case only the atoms in the fix group are re-scaled. The latter can be useful for leaving the coordinates of atoms in a solid substrate unchanged and controlling the pressure of a surrounding fluid.

---

The pressure can be controlled in one of several styles, as specified by the *p-style* argument. In each case, the desired pressure at each timestep is a ramped value during the run from the starting value to the end value.

Style *xyz* means couple all dimensions together when pressure is computed (isotropic pressure), and dilate/contract the dimensions together.

Styles *xy* or *yz* or *xz* means that the 2 specified dimensions are coupled together, both for pressure computation and for dilation/contraction. The 3rd dimension dilates/contracts independently, using its pressure component as the driving force. These styles cannot be used for a 2d simulation.

For style *aniso*, all dimensions dilate/contract independently using their individual pressure components as the driving forces.

For any of the styles except *xyz*, any of the independent pressure components (e.g. *z* in *xy*, or any dimension in *aniso*) can have their target pressures (both start and stop values) specified as NULL. This means that no pressure control is applied to that dimension so that the box dimension remains unchanged. For a 2d simulation the *z* pressure components must be specified as NULL when using style *aniso*.

In some cases (e.g. for solids) the pressure (volume) and/or temperature of the system can oscillate undesirably when a Nose/Hoover barostat is applied. The optional *drag* keyword will damp these oscillations, although it alters the Nose/Hoover equations. A value of 0.0 (no drag) leaves the Nose/Hoover formalism unchanged. A non-zero value adds a drag term; the larger the value specified, the greater the damping effect. Performing a short run and monitoring the pressure is the best way to determine if the drag term is working. Typically a value between 0.2 to 2.0 is sufficient to damp oscillations after a few periods.

For all pressure styles, the simulation box stays rectangular in shape. Parinello–Rahman boundary conditions (tilted box) are not implemented in LAMMPS.

For all styles, the *Pdamp* parameter operates like the *Tdamp* parameter, determining the time scale on which pressure is relaxed. For example, a value of 1000.0 means to relax the pressure in a timespan of (roughly) 1000 time units (tau or fmsec or psec – see the [units](#) command).

---

This fix computes a temperature and pressure each timestep. To do this, the fix creates its own computes of style "temp" and "pressure", as if these commands had been issued:

```
compute fix-ID_temp group-ID temp
```

```
compute fix-ID_press group-ID pressure fix-ID_temp
```

See the [compute temp](#) and [compute pressure](#) commands for details. Note that the IDs of the new computes are the fix-ID with underscore + "temp" or "press" appended and the group for the new computes is the same as the fix group.

Note that these are NOT the computes used by thermodynamic output (see the [thermo\\_style](#) command) with ID = *thermo\_temp* and *thermo\_pressure*. This means you can change the attributes of this fix's temperature or pressure via the [compute\\_modify](#) command or print this temperature or pressure during thermodynamic output via the [thermo\\_style custom](#) command using the appropriate compute-ID. It also means that changing attributes of *thermo\_temp* or *thermo\_pressure* will have no effect on this fix.

### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

This fix writes the state of the Nose/Hoover barostat to [binary restart files](#). See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.



The `fix_modify temp` and `press` options are supported by this fix. You can use them to assign a `compute` you have defined to this fix which will be used in its thermostating or barostatting procedure. If you do this, note that the kinetic energy derived from the compute temperature should be consistent with the virial term computed using all atoms for the pressure. LAMMPS will warn you if you choose to compute temperature on a subset of atoms.

The `fix_modify energy` option is supported by this fix to add the energy change induced by Nose/Hoover barostatting to the system's potential energy as part of `thermodynamic output`.

The energy change can be printed as part of thermodynamic output via the keyword `f_ID`, where ID is the fix-ID of this fix. See the `thermo_style custom` command for details.

This fix can ramp its target pressure over multiple runs, using the `start` and `stop` keywords of the `run` command. See the `run` command for details of how to do this.

This fix is not invoked during `energy minimization`.

### Restrictions:

Any dimension being adjusted by this fix must be periodic. A dimension whose target pressures are specified as NULL can be non-periodic or periodic.

You should not use `fix nvt` with this fix. Instead, use `fix npt` if you want to control both temperature and pressure via Nose/Hoover.

### Related commands:

`fix nve`, `fix npt`, `fix_modify`

### Default:

The keyword defaults are `drag = 0.0` and `dilate = all`.

## fix npt command

### Syntax:

```
fix ID group-ID npt Tstart Tstop Tdamp p-style args keyword value ...
```

- ID, group-ID are documented in [fix](#) command
- npt = style name of this fix command
- Tstart,Tstop = desired temperature at start/end of run
- Tdamp = temperature damping parameter (time units)
- p-style = *xyz* or *xy* or *yz* or *xz* or *aniso*

```
xyz args = Pstart Pstop Pdamp
Pstart,Pstop = desired pressure at start/end of run (pressure units)
Pdamp = pressure damping parameter (time units)
xy or yz or xz or aniso args = Px_start Px_stop Py_start Py_stop Pz_start Pz_stop Pdamp
Px_start,Px_stop,... = desired pressure in x,y,z at start/end of run (pressure units)
Pdamp = pressure damping parameter (time units)
```

- zero or more keyword/value pairs may be appended
- keyword = *drag* or *dilate*

```
drag value = drag factor added to barostat/thermostat (0.0 = no drag)
dilate value = all or partial
```

### Examples:

```
fix 1 all npt 300.0 300.0 100.0 xyz 0.0 0.0 1000.0
fix 2 all npt 300.0 300.0 100.0 xz 5.0 5.0 NULL NULL 5.0 5.0 1000.0
fix 2 all npt 300.0 300.0 100.0 xz 5.0 5.0 NULL NULL 5.0 5.0 1000.0 drag 0.2
fix 2 water npt 300.0 300.0 100.0 aniso 0.0 0.0 0.0 0.0 NULL NULL 1000.0 dilate partial
```

### Description:

Perform constant NPT integration to update positions and velocities each timestep for atoms in the group using a Nose/Hoover temperature thermostat and Nose/Hoover pressure barostat. P is pressure; T is temperature. This creates a system trajectory consistent with the isothermal–isobaric ensemble.

The desired temperature at each timestep is a ramped value during the run from *Tstart* to *Tstop*. The *Tdamp* parameter is specified in time units and determines how rapidly the temperature is relaxed. For example, a value of 100.0 means to relax the temperature in a timespan of (roughly) 100 time units (tau or fmsec or psec – see the [units](#) command).

The atoms in the fix group are the only ones whose velocities and positions are updated by the velocity/position update portion of the NPT integration.

Regardless of what atoms are in the fix group, a global pressure is computed for all atoms. Similarly, when the size of the simulation box is changed, all atoms are re-scaled to new positions, unless the keyword *dilate* is specified with a value of *partial*, in which case only the atoms in the fix group are re-scaled. The latter can be useful for leaving the coordinates of atoms in a solid substrate unchanged and controlling the pressure of a surrounding fluid.

---

The pressure can be controlled in one of several styles, as specified by the *p-style* argument. In each case, the desired pressure at each timestep is a ramped value during the run from the starting value to the end value.

Style *xyz* means couple all dimensions together when pressure is computed (isotropic pressure), and dilate/contract the dimensions together.

Styles *xy* or *yz* or *xz* means that the 2 specified dimensions are coupled together, both for pressure computation and for dilation/contraction. The 3rd dimension dilates/contracts independently, using its pressure component as the driving force. These styles cannot be used for a 2d simulation.

For style *aniso*, all dimensions dilate/contract independently using their individual pressure components as the driving forces.

For any of the styles except *xyz*, any of the independent pressure components (e.g. *z* in *xy*, or any dimension in *aniso*) can have their target pressures (both start and stop values) specified as NULL. This means that no pressure control is applied to that dimension so that the box dimension remains unchanged. For a 2d simulation the *z* pressure components must be specified as NULL when using style *aniso*.

In some cases (e.g. for solids) the pressure (volume) and/or temperature of the system can oscillate undesirably when a Nose/Hoover barostat and thermostat is applied. The optional *drag* keyword will damp these oscillations, although it alters the Nose/Hoover equations. A value of 0.0 (no drag) leaves the Nose/Hoover formalism unchanged. A non-zero value adds a drag term; the larger the value specified, the greater the damping effect. Performing a short run and monitoring the pressure and temperature is the best way to determine if the drag term is working. Typically a value between 0.2 to 2.0 is sufficient to damp oscillations after a few periods.

For all pressure styles, the simulation box stays rectangular in shape. Parinello–Rahman boundary conditions (tilted box) are not yet implemented in LAMMPS.

For all styles, the *Pdamp* parameter operates like the *Tdamp* parameter, determining the time scale on which pressure is relaxed. For example, a value of 1000.0 means to relax the pressure in a timespan of (roughly) 1000 time units (tau or fmsec or psec – see the [units](#) command).

---

This fix computes a temperature and pressure each timestep. To do this, the fix creates its own computes of style "temp" and "pressure", as if these commands had been issued:

```
compute fix-ID_temp group-ID temp
compute fix-ID_press group-ID pressure fix-ID_temp
```

See the [compute temp](#) and [compute pressure](#) commands for details. Note that the IDs of the new computes are the fix-ID with underscore + "temp" or "press" appended and the group for the new computes is the same as the fix group.

Note that these are NOT the computes used by thermodynamic output (see the [thermo\\_style](#) command) with ID = *thermo\_temp* and *thermo\_pressure*. This means you can change the attributes of this fix's temperature or pressure via the [compute\\_modify](#) command or print this temperature or pressure during thermodynamic output via the [thermo\\_style custom](#) command using the appropriate compute-ID. It also means that changing attributes of *thermo\_temp* or *thermo\_pressure* will have no effect on this fix.

### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

This fix writes the state of the Nose/Hoover thermostat and barostat to [binary restart files](#). See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.

The `fix_modify temp` and `press` options are supported by this fix. You can use them to assign a `compute` you have defined to this fix which will be used in its thermostatting or barostatting procedure. If you do this, note that the kinetic energy derived from the compute temperature should be consistent with the virial term computed using all atoms for the pressure. LAMMPS will warn you if you choose to compute temperature on a subset of atoms.

The `fix_modify energy` option is supported by this fix to add the energy change induced by Nose/Hoover thermostatting and barostatting to the system's potential energy as part of `thermodynamic output`.

The energy change can be printed as part of thermodynamic output via the keyword `f_ID`, where ID is the fix-ID of this fix. See the `thermo_style custom` command for details.

This fix can ramp its target temperature and pressure over multiple runs, using the `start` and `stop` keywords of the `run` command. See the `run` command for details of how to do this.

This fix is not invoked during `energy minimization`.

### Restrictions:

Any dimension being adjusted by this fix must be periodic. A dimension whose target pressures are specified as NULL can be non-periodic or periodic.

The final Tstop cannot be 0.0 since it would make the target  $T = 0.0$  at some timestep during the simulation which is not allowed in the Nose/Hoover formulation.

### Related commands:

`fix nve`, `fix nvt`, `fix nph`, `fix_modify`

### Default:

The keyword defaults are `drag = 0.0` and `dilate = all`.

## fix npt/asphere command

### Syntax:

```
fix ID group-ID npt/asphere Tstart Tstop Tdamp p-style args keyword value ...
```

- ID, group-ID are documented in [fix](#) command
- npt/asphere = style name of this fix command
- Tstart,Tstop = desired temperature at start/end of run
- Tdamp = temperature damping parameter (time units)
- p-style = *xyz* or *xy* or *yz* or *xz* or *aniso*

```
xyz args = Pstart Pstop Pdamp
Pstart,Pstop = desired pressure at start/end of run (pressure units)
Pdamp = pressure damping parameter (time units)
xy or yz or xz or aniso args = Px_start Px_stop Py_start Py_stop Pz_start Pz_stop Pdamp
Px_start,Px_stop,... = desired pressure in x,y,z at start/end of run (pressure units)
Pdamp = pressure damping parameter (time units)
```

- zero or more keyword/value pairs may be appended
- keyword = *drag* or *dilate*

```
drag value = drag factor added to barostat/thermostat (0.0 = no drag)
dilate value = all or partial
```

### Examples:

```
fix 1 all npt/asphere 300.0 300.0 100.0 xyz 0.0 0.0 1000.0
fix 2 all npt/asphere 300.0 300.0 100.0 xz 5.0 5.0 NULL NULL 5.0 5.0 1000.0
fix 2 all npt/asphere 300.0 300.0 100.0 xz 5.0 5.0 NULL NULL 5.0 5.0 1000.0 drag 0.2
fix 2 water npt/asphere 300.0 300.0 100.0 aniso 0.0 0.0 0.0 0.0 NULL NULL 1000.0 dilate partial
```

### Description:

Perform constant NPT integration to update positions, velocities, and angular velocity each timestep for aspherical or ellipsoidal particles in the group using a Nose/Hoover temperature thermostat and Nose/Hoover pressure barostat. P is pressure; T is temperature. This creates a system trajectory consistent with the isothermal–isobaric ensemble.

The desired temperature at each timestep is a ramped value during the run from *Tstart* to *Tstop*. The *Tdamp* parameter is specified in time units and determines how rapidly the temperature is relaxed. For example, a value of 100.0 means to relax the temperature in a timespan of (roughly) 100 time units (tau or fmsec or psec – see the [units](#) command).

The particles in the fix group are the only ones whose velocities and positions are updated by the velocity/position update portion of the NPT integration.

Regardless of what particles are in the fix group, a global pressure is computed for all particles. Similarly, when the size of the simulation box is changed, all particles are re-scaled to new positions, unless the keyword *dilate* is specified with a value of *partial*, in which case only the particles in the fix group are re-scaled. The latter can be useful for leaving the coordinates of particles in a solid substrate unchanged and controlling the pressure of a surrounding fluid.

---

The pressure can be controlled in one of several styles, as specified by the *p-style* argument. In each case, the desired pressure at each timestep is a ramped value during the run from the starting value to the end value.

Style *xyz* means couple all dimensions together when pressure is computed (isotropic pressure), and dilate/contract the dimensions together.

Styles *xy* or *yz* or *xz* means that the 2 specified dimensions are coupled together, both for pressure computation and for dilation/contraction. The 3rd dimension dilates/contracts independently, using its pressure component as the driving force. These styles cannot be used for a 2d simulation.

For style *aniso*, all dimensions dilate/contract independently using their individual pressure components as the driving forces.

For any of the styles except *xyz*, any of the independent pressure components (e.g. *z* in *xy*, or any dimension in *aniso*) can have their target pressures (both start and stop values) specified as NULL. This means that no pressure control is applied to that dimension so that the box dimension remains unchanged. For a 2d simulation the *z* pressure components must be specified as NULL when using style *aniso*.

In some cases (e.g. for solids) the pressure (volume) and/or temperature of the system can oscillate undesirably when a Nose/Hoover barostat and thermostat is applied. The optional *drag* keyword will damp these oscillations, although it alters the Nose/Hoover equations. A value of 0.0 (no drag) leaves the Nose/Hoover formalism unchanged. A non-zero value adds a drag term; the larger the value specified, the greater the damping effect. Performing a short run and monitoring the pressure and temperature is the best way to determine if the drag term is working. Typically a value between 0.2 to 2.0 is sufficient to damp oscillations after a few periods.

For all pressure styles, the simulation box stays rectangular in shape. Parinello–Rahman boundary conditions (tilted box) are not yet implemented in LAMMPS.

For all styles, the *Pdamp* parameter operates like the *Tdamp* parameter, determining the time scale on which pressure is relaxed. For example, a value of 1000.0 means to relax the pressure in a timespan of (roughly) 1000 time units (tau or fmsec or psec – see the [units](#) command).

---

This fix computes a temperature and pressure each timestep. To do this, the fix creates its own computes of style "temp/asphere" and "pressure", as if these commands had been issued:

```
compute fix-ID_temp group-ID temp/asphere
compute fix-ID_press group-ID pressure fix-ID_temp
```

See the [compute temp/asphere](#) and [compute pressure](#) commands for details. Note that the IDs of the new computes are the fix-ID with underscore + "temp" or "press" appended and the group for the new computes is the same as the fix group.

Note that these are NOT the computes used by thermodynamic output (see the [thermo\\_style](#) command) with ID = *thermo\_temp* and *thermo\_press*. This means you can change the attributes of this fix's temperature or pressure via the [compute\\_modify](#) command or print this temperature or pressure during thermodynamic output via the [thermo\\_style custom](#) command using the appropriate compute-ID. It also means that changing attributes of *thermo\_temp* or *thermo\_press* will have no effect on this fix.

### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

This fix writes the state of the Nose/Hoover thermostat and barostat to [binary restart files](#). See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.

The [fix\\_modify](#) *temp* and *press* options are supported by this fix. You can use them to assign a [compute](#) you have defined to this fix which will be used in its thermostating or barostatting procedure. If you do this, note that the kinetic energy derived from the compute temperature should be consistent with the virial term computed using all atoms for the pressure. LAMMPS will warn you if you choose to compute temperature on a subset of atoms.

The [fix\\_modify](#) *energy* option is supported by this fix to add the energy change induced by Nose/Hoover thermostating and barostatting to the system's potential energy as part of [thermodynamic output](#).

The energy change can be printed as part of thermodynamic output via the keyword *f\_ID*, where ID is the fix-ID of this fix. See the [thermo\\_style custom](#) command for details.

This fix can ramp its target temperature and pressure over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

This fix is not invoked during [energy minimization](#).

### Restrictions:

This fix is part of the "asphere" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

Any dimension being adjusted by this fix must be periodic. A dimension whose target pressures are specified as NULL can be non-periodic or periodic.

The final Tstop cannot be 0.0 since it would make the target  $T = 0.0$  at some timestep during the simulation which is not allowed in the Nose/Hoover formulation.

### Related commands:

[fix npt](#), [fix nve\\_asphere](#), [fix\\_modify](#)

### Default:

The keyword defaults are *drag* = 0.0 and *dilate* = all.

## fix nve command

### Syntax:

```
fix ID group-ID nve
```

- ID, group-ID are documented in [fix](#) command
- nve = style name of this fix command

### Examples:

```
fix 1 all nve
```

### Description:

Perform constant NVE updates of position and velocity for atoms in the group each timestep. V is volume; E is energy. This creates a system trajectory consistent with the microcanonical ensemble.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

### Related commands:

[fix nvt](#), [fix npt](#)

**Default:** none



## fix nve/asphere command

### Syntax:

```
fix ID group-ID nve/asphere
```

- ID, group-ID are documented in [fix](#) command
- nve/asphere = style name of this fix command

### Examples:

```
fix 1 all nve/asphere
```

### Description:

Perform constant NVE updates of position, velocity, orientation, and angular velocity for aspherical or ellipsoidal particles in the group each timestep. V is volume; E is energy. This creates a system trajectory consistent with the microcanonical ensemble.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions:

This fix is part of the "asphere" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

### Related commands:

[fix nve](#)

**Default:** none

## fix nve/dipole command

### Syntax:

```
fix ID group-ID nve/dipole
```

- ID, group-ID are documented in [fix](#) command
- nve/dipole = style name of this fix command

### Examples:

```
fix 1 all nve/dipole
```

### Description:

Perform constant NVE updates of position, velocity, orientation, and angular velocity for particles with point dipole moments in the group each timestep. V is volume; E is energy. This creates a system trajectory consistent with the microcanonical ensemble.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions:

This fix is part of the "dipole" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

### Related commands:

[fix nve](#)

**Default:** none

## fix nve/gran command

### Syntax:

```
fix ID group-ID nve/gran
```

- ID, group-ID are documented in [fix](#) command
- nve/gran = style name of this fix command

### Examples:

```
fix 1 all nve/gran
```

### Description:

Perform constant NVE updates each timestep on a group of atoms of atom style granular. V is volume; E is energy. Granular atoms store rotational information as well as position and velocity, so this integrator updates translational and rotational degrees of freedom due to forces and torques.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions: none

This fix is part of the "granular" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

### Related commands:

[atom\\_style granular](#)

### Default: none

## fix nve/limit command

### Syntax:

```
fix ID group-ID nve/limit xmax
```

- ID, group-ID are documented in [fix](#) command
- nve = style name of this fix command
- xmax = maximum distance an atom can move in one timestep (distance units)

### Examples:

```
fix 1 all nve/limit 0.1
```

### Description:

Perform constant NVE updates of position and velocity for atoms in the group each timestep. A limit is imposed on the maximum distance an atom can move in one timestep. This is useful when starting a simulation with a configuration containing highly overlapped atoms. Normally this would generate huge forces which would blow atoms out of the simulation box, causing LAMMPS to stop with an error.

Using this fix can overcome that problem. Forces on atoms must still be computable (which typically means 2 atoms must have a separation distance  $> 0.0$ ). But large velocities generated by large forces are reset to a value that corresponds to a displacement of length  $xmax$  in a single timestep.  $xmax$  is specified in distance units; see the [units](#) command for details. The value of  $xmax$  should be consistent with the neighbor skin distance and the frequency of neighbor list re-building, so that pairwise interactions are not missed on successive timesteps as atoms move. See the [neighbor](#) and [neigh\\_modify](#) commands for details.

Note that if a velocity reset occurs the integrator will not conserve energy. On steps where no velocity resets occur, this integrator is exactly like the [fix nve](#) command. Since forces are unaltered, pressures computed by thermodynamic output will still be very large for overlapped configurations.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

### Related commands:

[fix nve](#), [fix nve/noforce](#), [pair\\_style soft](#)

**Default:** none

## fix nve/noforce command

### Syntax:

```
fix ID group-ID nve
```

- ID, group-ID are documented in [fix](#) command
- nve/noforce = style name of this fix command

### Examples:

```
fix 3 wall nve/noforce
```

### Description:

Perform updates of position, but not velocity for atoms in the group each timestep. In other words, the force on the atoms is ignored and their velocity is not updated. The atom velocities are used to update their positions.

This can be useful for wall atoms, when you set their velocities, and want the wall to move (or stay stationary) in a prescribed fashion.

This can also be accomplished via the [fix setforce](#) command, but with `fix nve/noforce`, the forces on the wall atoms are unchanged, and can thus be printed by the [dump](#) command or queried with an equal-style [variable](#) that uses the `fcm()` group function to compute the total force on the group of atoms.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

### Related commands:

[fix nve](#)

**Default:** none

## fix nvt command

### Syntax:

```
fix ID group-ID nvt Tstart Tstop Tdamp keyword value ...
```

- ID, group-ID are documented in [fix](#) command
- nvt = style name of this fix command
- Tstart,Tstop = desired temperature at start/end of run
- Tdamp = temperature damping parameter (time units)
- zero or more keyword/value pairs may be appended
- keyword = *drag*

*drag* value = drag factor added to thermostat (0.0 = no drag)

### Examples:

```
fix 1 all nvt 300.0 300.0 100.0
fix 1 all nvt 300.0 300.0 100.0 drag 0.2
```

### Description:

Perform constant NVT integration to update positions and velocities each timestep for atoms in the group using a Nose/Hoover temperature thermostat. V is volume; T is temperature. This creates a system trajectory consistent with the canonical ensemble.

The desired temperature at each timestep is a ramped value during the run from *Tstart* to *Tstop*. The *Tdamp* parameter is specified in time units and determines how rapidly the temperature is relaxed. For example, a value of 100.0 means to relax the temperature in a timespan of (roughly) 100 time units (tau or fmsec or psec – see the [units](#) command).

In some cases (e.g. for solids) the temperature of the system can oscillate undesirably when a Nose/Hoover thermostat is applied. The optional *drag* keyword will damp these oscillations, although it alters the Nose/Hoover equations. A value of 0.0 (no drag) leaves the Nose/Hoover formalism unchanged. A non-zero value adds a drag term; the larger the value specified, the greater the damping effect. Performing a short run and monitoring the temperature is the best way to determine if the drag term is working. Typically a value between 0.2 to 2.0 is sufficient to damp oscillations after a few periods.

This fix computes a temperature each timestep. To do this, the fix creates its own compute of style "temp", as if this command had been issued:

```
compute fix-ID_temp group-ID temp
```

See the [compute temp](#) command for details. Note that the ID of the new compute is the fix-ID with underscore + "temp" appended and the group for the new compute is the same as the fix group.

Note that this is NOT the compute used by thermodynamic output (see the [thermo\\_style](#) command) with ID = *thermo\_temp*. This means you can change the attributes of this fix's temperature (e.g. its degrees-of-freedom) via the [compute\\_modify](#) command or print this temperature during thermodynamic output via the [thermo\\_style custom](#) command using the appropriate compute-ID. It also means that changing attributes of *thermo\_temp* will have no effect on this fix.

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

This fix writes the state of the Nose/Hoover thermostat to [binary restart files](#). See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.

The [fix\\_modify temp](#) option is supported by this fix. You can use it to assign a [compute](#) you have defined to this fix which will be used in its thermostating procedure.

The [fix\\_modify energy](#) option is supported by this fix to add the energy change induced by Nose/Hoover thermostating to the system's potential energy as part of [thermodynamic output](#).

The energy change can be printed as part of thermodynamic output via the keyword `f_ID`, where ID is the fix-ID of this fix. See the [thermo\\_style custom](#) command for details.

This fix can ramp its target temperature over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

This fix is not invoked during [energy minimization](#).

**Restrictions:**

The final `Tstop` cannot be 0.0 since it would make the target  $T = 0.0$  at some timestep during the simulation which is not allowed in the Nose/Hoover formulation.

**Related commands:**

[fix nve](#), [fix npt](#), [fix temp/rescale](#), [fix langevin](#), [fix\\_modify](#), [temperature](#)

**Default:**

The keyword defaults are `drag = 0.0`.

## fix nvt/asphere command

### Syntax:

```
fix ID group-ID nvt/asphere Tstart Tstop Tdamp keyword value ...
```

- ID, group-ID are documented in [fix](#) command
- nvt/asphere = style name of this fix command
- Tstart,Tstop = desired temperature at start/end of run
- Tdamp = temperature damping parameter (time units)
- zero or more keyword/value pairs may be appended
- keyword = *drag*

*drag* value = drag factor added to thermostat (0.0 = no drag)

### Examples:

```
fix 1 all nvt/asphere 300.0 300.0 100.0
fix 1 all nvt/asphere 300.0 300.0 100.0 drag 0.2
```

### Description:

Perform constant NVT integration to update positions, velocities, and angular velocities each timestep for aspherical or ellipsoidal particles in the group using a Nose/Hoover temperature thermostat. V is volume; T is temperature. This creates a system trajectory consistent with the canonical ensemble.

The desired temperature at each timestep is a ramped value during the run from *Tstart* to *Tstop*. The *Tdamp* parameter is specified in time units and determines how rapidly the temperature is relaxed. For example, a value of 100.0 means to relax the temperature in a timespan of (roughly) 100 time units (tau or fmsec or psec – see the [units](#) command).

In some cases (e.g. for solids) the temperature of the system can oscillate undesirably when a Nose/Hoover thermostat is applied. The optional *drag* keyword will damp these oscillations, although it alters the Nose/Hoover equations. A value of 0.0 (no drag) leaves the Nose/Hoover formalism unchanged. A non-zero value adds a drag term; the larger the value specified, the greater the damping effect. Performing a short run and monitoring the temperature is the best way to determine if the drag term is working. Typically a value between 0.2 to 2.0 is sufficient to damp oscillations after a few periods.

This fix computes a temperature each timestep. To do this, the fix creates its own compute of style "temp/asphere", as if this command had been issued:

```
compute fix-ID_temp group-ID temp/asphere
```

See the [compute temp/asphere](#) command for details. Note that the ID of the new compute is the fix-ID with underscore + "temp" appended and the group for the new compute is the same as the fix group.

Note that this is NOT the compute used by thermodynamic output (see the [thermo\\_style](#) command) with ID = *thermo\_temp*. This means you can change the attributes of this fix's temperature (e.g. its degrees-of-freedom) via the [compute\\_modify](#) command or print this temperature during thermodynamic output via the [thermo\\_style custom](#) command using the appropriate compute-ID. It also means that changing attributes of *thermo\_temp* will have no effect on this fix.



### Restart, fix\_modify, thermo output, run start/stop, minimize info:

This fix writes the state of the Nose/Hoover thermostat to [binary restart files](#). See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.

The [fix\\_modify temp](#) option is supported by this fix. You can use it to assign a [compute](#) you have defined to this fix which will be used in its thermostating procedure.

The [fix\\_modify energy](#) option is supported by this fix to add the energy change induced by Nose/Hoover thermostating to the system's potential energy as part of [thermodynamic output](#).

The energy change can be printed as part of thermodynamic output via the keyword `f_ID`, where ID is the fix-ID of this fix. See the [thermo\\_style custom](#) command for details.

This fix can ramp its target temperature over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

This fix is not invoked during [energy minimization](#).

### Restrictions:

This fix is part of the "asphere" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

The final Tstop cannot be 0.0 since it would make the target  $T = 0.0$  at some timestep during the simulation which is not allowed in the Nose/Hoover formulation.

### Related commands:

[fix nvt](#), [fix nve\\_asphere](#), [fix npt\\_asphere](#), [fix\\_modify](#)

### Default:

The keyword defaults are `drag = 0.0`.

## fix nvt/sllod command

### Syntax:

```
fix ID group-ID nvt/sllod Tstart Tstop Tdamp keyword value ...
```

- ID, group-ID are documented in [fix](#) command
- nvt/sllod = style name of this fix command
- Tstart, Tstop = desired temperature at start/end of run
- Tdamp = temperature damping parameter (time units)
- zero or more keyword/value pairs may be appended
- keyword = *drag*

*drag* value = drag factor added to thermostat (0.0 = no drag)

### Examples:

```
fix 1 all nvt/sllod 300.0 300.0 100.0
fix 1 all nvt/sllod 300.0 300.0 100.0 drag 0.2
```

### Description:

Perform constant NVT integration to update positions and velocities each timestep for atoms in the group using a Nose/Hoover temperature thermostat. V is volume; T is temperature. This creates a system trajectory consistent with the canonical ensemble.

This thermostat is used for a simulation box that is changing size and/or shape, for example in a non-equilibrium MD (NEMD) simulation. The size/shape change is induced by use of the [fix deform](#) command, so each point in the simulation box can be thought of as having a "streaming" velocity. This position-dependent streaming velocity is subtracted from each atom's actual velocity to yield a thermal velocity which is used for temperature computation and thermostating. For example, if the box is being sheared in x, relative to y, then points at the bottom of the box (low y) have a small x velocity, while points at the top of the box (hi y) have a large x velocity. These velocities do not contribute to the thermal "temperature" of the atom.

IMPORTANT NOTE: [Fix deform](#) has an option for remapping either atom coordinates or velocities to the changing simulation box. To use fix nvt/sllod, fix deform should NOT remap atom positions, because fix nvt/sllod adjusts the atom positions and velocities to create a velocity profile that matches the changing box size/shape. Fix deform SHOULD remap atom velocities when atoms cross periodic boundaries since that is consistent with maintaining the velocity profile created by fix nvt/sllod. LAMMPS will give an error if this setting is not consistent.

The SLLOD equations of motion coupled to a Nose/Hoover thermostat are discussed in ([Tuckerman](#)) (eqs 4 and 5), which is what is implemented in LAMMPS in a velocity Verlet formulation.

The desired temperature at each timestep is a ramped value during the run from *Tstart* to *Tstop*. The *Tdamp* parameter is specified in time units and determines how rapidly the temperature is relaxed. For example, a value of 100.0 means to relax the temperature in a timespan of (roughly) 100 time units (tau or fmsec or psec – see the [units](#) command).

In some cases (e.g. for solids) the temperature of the system can oscillate undesirably when a Nose/Hoover thermostat is applied. The optional *drag* keyword will damp these oscillations, although it alters the Nose/Hoover

equations. A value of 0.0 (no drag) leaves the Nose/Hoover formalism unchanged. A non-zero value adds a drag term; the larger the value specified, the greater the damping effect. Performing a short run and monitoring the temperature is the best way to determine if the drag term is working. Typically a value between 0.2 to 2.0 is sufficient to damp oscillations after a few periods.

This fix computes a temperature each timestep. To do this, the fix creates its own compute of style "temp/deform", as if this command had been issued:

```
compute fix-ID_temp group-ID temp/deform
```

See the [compute temp/deform](#) command for details. Note that the ID of the new compute is the fix-ID with underscore + "temp" appended and the group for the new compute is the same as the fix group.

Note that this is NOT the compute used by thermodynamic output (see the [thermo\\_style](#) command) with ID = *thermo\_temp*. This means you can change the attributes of this fix's temperature (e.g. its degrees-of-freedom) via the [compute\\_modify](#) command or print this temperature during thermodynamic output via the [thermo\\_style custom](#) command using the appropriate compute-ID. It also means that changing attributes of *thermo\_temp* will have no effect on this fix.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

This fix writes the state of the Nose/Hoover thermostat to [binary restart files](#). See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.

The [fix\\_modify temp](#) option is supported by this fix. You can use it to assign a [compute](#) you have defined to this fix which will be used in its thermostating procedure.

The [fix\\_modify energy](#) option is supported by this fix to add the energy change induced by Nose/Hoover thermostating to the system's potential energy as part of [thermodynamic output](#).

The energy change can be printed as part of thermodynamic output via the keyword *f\_ID*, where ID is the fix-ID of this fix. See the [thermo\\_style custom](#) command for details.

This fix can ramp its target temperature over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

This fix is not invoked during [energy minimization](#).

### Restrictions:

The final Tstop cannot be 0.0 since it would make the target  $T = 0.0$  at some timestep during the simulation which is not allowed in the Nose/Hoover formulation.

### Related commands:

[fix nve](#), [fix npt](#), [fix npt](#), [fix temp/rescale](#), [fix langevin](#), [fix\\_modify](#), [temperature](#)

### Default:

The keyword defaults are *drag* = 0.0.

---

**(Tuckerman)** Tuckerman, Mundy, Balasubramanian, Klein, J Chem Phys, 106, 5615 (1997).

## fix orient/fcc command

```
fix ID group-ID orient/fcc nstats dir alat dE cutlo cuthi file0 file1
```

- ID, group-ID are documented in [fix](#) command
- nstats = print stats every this many steps, 0 = never
- dir = 0/1 for which crystal is used as reference
- alat = fcc cubic lattice constant (distance units)
- dE = energy added to each atom (energy units)
- cutlo,cuthi = values between 0.0 and 1.0, cutlo < cuthi
- file0,file1 = files that specify orientation of each grain

### Examples:

```
fix gb all orient/fcc 0 1 4.032008 0.001 0.25 0.75 xi.vec chi.vec
```

### Description:

The fix applies an orientation-dependent force to atoms near a planar grain boundary which can be used to induce grain boundary migration (in the direction perpendicular to the grain boundary plane). The motivation and explanation of this force and its application are described in ([Janssens](#)). The force is only applied to atoms in the fix group.

The basic idea is that atoms in one grain (on one side of the boundary) have a potential energy dE added to them. Atoms in the other grain have 0.0 potential energy added. Atoms near the boundary (whose neighbor environment is intermediate between the two grain orientations) have an energy between 0.0 and dE added. This creates an effective driving force to reduce the potential energy of atoms near the boundary by pushing them towards one of the grain orientations. For dir = 1 and dE > 0, the boundary will thus move so that the grain described by file0 grows and the grain described by file1 shrinks. Thus this fix is designed for simulations of two-grain systems, either with one grain boundary and free surfaces parallel to the boundary, or a system with periodic boundary conditions and two equal and opposite grain boundaries. In either case, the entire system can displace during the simulation, and such motion should be accounted for in measuring the grain boundary velocity.

The potential energy added to atom I is given by these formulas

$$\xi_i = \sum_{j=1}^{12} |\mathbf{r}_j - \mathbf{r}_j^I| \quad (1)$$

$$\xi_{IJ} = \sum_{j=1}^{12} |\mathbf{r}_j^J - \mathbf{r}_j^I| \quad (2)$$

$$\xi_{\text{low}} = \text{cutlo} \xi_{IJ} \quad (3)$$

$$\xi_{\text{high}} = \text{cuthi} \xi_{IJ} \quad (4)$$

$$\omega_i = \frac{\pi}{2} \frac{\xi_i - \xi_{\text{low}}}{\xi_{\text{high}} - \xi_{\text{low}}} \quad (5)$$

$$\begin{aligned} u_i &= 0 && \text{for } \xi_i < \xi_{\text{low}} \\ &= dE \frac{1 - \cos(2\omega_i)}{2} && \text{for } \xi_{\text{low}} < \xi_i < \xi_{\text{high}} \\ &= dE && \text{for } \xi_{\text{high}} < \xi_i \end{aligned} \quad (6)$$

which are fully explained in (Janssens). The order parameter  $\xi_i$  for atom I in equation (1) is a sum over the 12 nearest neighbors of atom I.  $\mathbf{r}_j$  is the vector from atom I to its neighbor J, and  $\mathbf{r}_j^I$  is a vector in the reference (perfect) crystal. That is, if  $\text{dir} = 0/1$ , then  $\mathbf{r}_j^I$  is a vector to an atom coord from file 0/1. Equation (2) gives the expected value of the order parameter  $\xi_{IJ}$  in the other grain.  $\text{hi}$  and  $\text{lo}$  cutoffs are defined in equations (3) and (4), using the input parameters *cutlo* and *cuthi* as thresholds to avoid adding grain boundary energy when the deviation in the order parameter from 0 or 1 is small (e.g. due to thermal fluctuations in a perfect crystal). The added potential energy  $U_i$  for atom I is given in equation (6) where it is interpolated between 0 and  $dE$  using the two threshold  $\xi_i$  values and the  $W_i$  value of equation (5).

The derivative of this energy expression gives the force on each atom which thus depends on the orientation of its neighbors relative to the 2 grain orientations. Only atoms near the grain boundary feel a net force which tends to drive them to one of the two grain orientations.

In equation (1), the reference vector used for each neighbor is the reference vector closest to the actual neighbor position. This means it is possible two different neighbors will use the same reference vector. In such cases, the atom in question is far from a perfect orientation and will likely receive the full  $dE$  addition, so the effect of duplicate reference vector usage is small.

The *dir* parameter determines which grain wants to grow at the expense of the other. A value of 0 means the first grain will shrink; a value of 1 means it will grow. This assumes that  $dE$  is positive. The reverse will be true if  $dE$  is negative.

The *alat* parameter is the cubic lattice constant for the fcc material and is only used to compute a cutoff distance of  $1.57 * \text{alat} / \sqrt{2}$  for finding the 12 nearest neighbors of each atom (which should be valid for an fcc crystal). A longer/shorter cutoff can be imposed by adjusting *alat*. If a particular atom has less than 12 neighbors within the cutoff, the order parameter of equation (1) is effectively multiplied by 12 divided by the actual number of neighbors within the cutoff.

The  $dE$  parameter is the maximum amount of additional energy added to each atom in the grain which wants to shrink.

The *cutlo* and *cuthi* parameters are used to reduce the force added to bulk atoms in each grain far away from the boundary. An atom in the bulk surrounded by neighbors at the ideal grain orientation would compute an order parameter of 0 or 1 and have no force added. However, thermal vibrations in the solid will cause the order parameters to be greater than 0 or less than 1. The cutoff parameters mask this effect, allowing forces to only be added to atoms with order-parameters between the cutoff values.

*File0* and *file1* are filenames for the two grains which each contain 6 vectors (6 lines with 3 values per line) which specify the grain orientations. Each vector is a displacement from a central atom (0,0,0) to a nearest neighbor atom in an fcc lattice at the proper orientation. The vector lengths should all be identical since an fcc lattice has a coordination number of 12. Only 6 are listed due to symmetry, so the list must include one from each pair of equal-and-opposite neighbors. A pair of orientation files for a Sigma=5 tilt boundary are show below.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#).

The [fix\\_modify energy](#) option is supported by this fix to add the potential energy of atom interactions with the grain boundary driving force to the system's potential energy as part of [thermodynamic output](#).

The atom/grain-boundary interaction energy can be printed as part of thermodynamic output via the keyword *f\_ID*, where ID is the fix-ID of this fix. See the [thermo\\_style custom](#) command for details.

No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions:

This fix should only be used with fcc lattices.

### Related commands:

[fix\\_modify](#)

**Default:** none

---

**(Janssens)** Janssens, Olmsted, Holm, Foiles, Plimpton, Derlet, Nature Materials, 5, 124–127 (2006).

---

For illustration purposes, here are example files that specify a Sigma=5 tilt boundary. This is for a lattice constant of 3.5706 Angs.

file0:

```

0.798410432046075    1.785300000000000    1.596820864092150
-0.798410432046075    1.785300000000000    -1.596820864092150
2.395231296138225    0.000000000000000    0.798410432046075
0.798410432046075    0.000000000000000    -2.395231296138225
1.596820864092150    1.785300000000000    -0.798410432046075
1.596820864092150    -1.785300000000000    -0.798410432046075

```

file1:

```

-0.798410432046075    1.785300000000000    1.596820864092150
0.798410432046075    1.785300000000000    -1.596820864092150

```

0.798410432046075	0.0000000000000000	2.395231296138225
2.395231296138225	0.0000000000000000	-0.798410432046075
1.596820864092150	1.7853000000000000	0.798410432046075
1.596820864092150	-1.7853000000000000	0.798410432046075



## fix planeforce command

### Syntax:

```
fix ID group-ID planeforce x y z
```

- ID, group-ID are documented in [fix](#) command
- lineforce = style name of this fix command
- x y z = 3-vector that is normal to the plane

### Examples:

```
fix hold boundary planeforce 1.0 0.0 0.0
```

### Description:

Adjust the forces on each atom in the group so that it's motion will be in the plane specified by the normal vector (x,y,z). This is done by subtracting out components of force perpendicular to the plane.

If the initial velocity of the atom is 0.0 (or in the plane), then it should continue to move in the plane thereafter.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command.

**Restrictions:** none

### Related commands:

[fix lineforce](#)

**Default:** none

## fix poems

Syntax:

```
fix ID group-ID poems keyword values
```

- ID, group-ID are documented in [fix](#) command
- poems = style name of this fix command
- keyword = *group* or *file* or *molecule*

```
group values = list of group IDs
molecule values = none
file values = filename
```

### Examples:

```
fix 3 fluid poems group clump1 clump2 clump3
fix 3 fluid poems file cluster.list
```

### Description:

Treats one or more sets of atoms as coupled rigid bodies. This means that each timestep the total force and torque on each rigid body is computed and the coordinates and velocities of the atoms are updated so that the collection of bodies move as a coupled set. This can be useful for treating a large biomolecule as a collection of connected, coarse-grained particles.

The coupling, associated motion constraints, and time integration is performed by the software package [Parallelizable Open source Efficient Multibody Software \(POEMS\)](#) which computes the constrained rigid-body motion of articulated (jointed) multibody systems ([Anderson](#)). POEMS was written and is distributed by Prof Kurt Anderson, his graduate student Rudranarayan Mukherjee, and other members of his group at Rensselaer Polytechnic Institute (RPI). Rudranarayan developed the LAMMPS/POEMS interface. For copyright information on POEMS and other details, please refer to the documents in the poems directory distributed with LAMMPS.

This fix updates the positions and velocities of the rigid atoms with a constant-energy time integration, so you should not update the same atoms via other fixes (e.g. nve, nvt, npt, temp/rescale, langevin).

Each body must have a non-degenerate inertia tensor, which means it must contain at least 3 non-collinear atoms. Which atoms are in which bodies can be defined via several options.

For option *group*, each of the listed groups is treated as a rigid body. Note that only atoms that are also in the fix group are included in each rigid body.

For option *molecule*, each set of atoms in the group with a different molecule ID is treated as a rigid body.

For option *file*, sets of atoms are read from the specified file and each set is treated as a rigid body. Each line of the file specifies a rigid body in the following format:

```
ID type atom1-ID atom2-ID atom3-ID ...
```

ID as an integer from 1 to M (the number of rigid bodies). Type is any integer; it is not used by the fix poems command. The remaining arguments are IDs of atoms in the rigid body, each typically from 1 to N (the number of

atoms in the system). Only atoms that are also in the fix group are included in each rigid body. Blank lines and lines that begin with '#' are skipped.

A connection between a pair of rigid bodies is inferred if one atom is common to both bodies. The POEMS solver treats that atom as a spherical joint with 3 degrees of freedom. Currently, a collection of bodies can only be connected by joints as a linear chain. The entire collection of rigid bodies can represent one or more chains. Other connection topologies (tree, ring) are not allowed, but will be added later. Note that if no joints exist, it is more efficient to use the [fix rigid](#) command to simulate the system.

When the poems fix is defined, it will print out statistics on the total # of clusters, bodies, joints, atoms involved. A cluster in this context means a set of rigid bodies connected by joints.

For computational efficiency, you should turn off pairwise and bond interactions within each rigid body, as they no longer contribute to the motion. The "neigh\_modify exclude" and "delete\_bonds" commands can be used to do this if each rigid body is a group.

For computational efficiency, you should only define one fix poems which includes all the desired rigid bodies. LAMMPS will allow multiple poems fixes to be defined, but it is more expensive.

The degrees-of-freedom removed by coupled rigid bodies are accounted for in temperature and pressure computations. Similarly, the rigid body contribution to the pressure virial is also accounted for. The latter is only correct if forces within the bodies have been turned off, and there is only a single fix poems defined.

#### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

#### **Restrictions:**

This fix is part of the "poems" package. It is only enabled if LAMMPS was built with that package, which also requires the POEMS library be built and linked with LAMMPS. See the [Making LAMMPS](#) section for more info.

#### **Related commands:**

[fix rigid](#), [delete\\_bonds](#), [neigh\\_modify](#) exclude

**Default:** none

---

(**Anderson**) Anderson, Mukherjee, Critchley, Ziegler, and Lipton "POEMS: Parallelizable Open-source Efficient Multibody Software ", Engineering With Computers (2006). ([link to paper](#))

## fix pour command

### Syntax:

```
fix ID group-ID pour N type seed keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- pour = style name of this fix command
- N = # of atoms to insert
- type = atom type to assign to inserted atoms
- seed = random # seed
- one or more keyword/value pairs may be appended to args
- keyword = *region* or *diam* or *dens* or *vol* or *rate* or *vel*

```
region value = region-ID
  region-ID = ID of region to use as insertion volume
diam values = lo hi
  lo,hi = range of diameters for inserted particles (distance units)
dens values = lo hi
  lo,hi = range of densities for inserted particles
vol values = fraction Nattempt
  fraction = desired volume fraction for filling insertion volume
  Nattempt = max # of insertion attempts per atom
rate value = V
  V = z velocity (3d) or y velocity (2d) at which
    insertion volume moves (velocity units)
vel values (3d) = vxlo vxhi vylo vyhi vz
vel values (2d) = vxlo vxhi vy
  vxlo,vxhi = range of x velocities for inserted particles (velocity units)
  vylo,vyhi = range of y velocities for inserted particles (velocity units)
  vz = z velocity (3d) assigned to inserted particles (velocity units)
  vy = y velocity (2d) assigned to inserted particles (velocity units)
```

### Examples:

```
fix 3 all pour 1000 2 29494 region myblock
fix 2 all pour 10000 1 19985583 region disk vol 0.33 100 rate 1.0 diam 0.9 1.1
```

### Description:

Insert particles into a granular run every few timesteps within a specified region until N particles have been inserted. This is useful for simulating the pouring of particles into a container under the influence of gravity.

Inserted particles are assigned the specified atom type and are assigned to two groups: the default group "all" and the group specified in the fix pour command (which can also be "all").

This command must use the *region* keyword to define an insertion volume. The specified region must have been previously defined with a [region](#) command. It must be of type *block* or a z-axis *cylinder* and must be defined with side = *in*. The cylinder style of region can only be used with 3d simulations.

Each timestep particles are inserted, they are placed randomly inside the insertion volume so as to mimic a stream of poured particles. The larger the volume, the more particles that can be inserted at any one timestep. Particles are inserted again after enough time has elapsed that the previously inserted particles fall out of the insertion volume under the influence of gravity. Insertions continue every so many timesteps until the desired # of particles

has been inserted.

All other keywords are optional with defaults as shown below. The *diam*, *dens*, and *vel* options enable inserted particles to have a range of diameters or densities or xy velocities. The specific values for a particular inserted particle will be chosen randomly and uniformly between the specified bounds. The *vz* or *vy* value for option *vel* assigns a z-velocity (3d) or y-velocity (2d) to each inserted particle.

The *vol* option specifies what volume fraction of the insertion volume will be filled with particles. The higher the value, the more particles are inserted each timestep. Since inserted particles cannot overlap, the maximum volume fraction should be no higher than about 0.6. Each timestep particles are inserted, LAMMPS will make up to a total of *M* tries to insert the new particles without overlaps, where  $M = \# \text{ of inserted particles} * N_{\text{attempt}}$ . If LAMMPS is unsuccessful at completing all insertions, it prints a warning.

The *rate* option moves the insertion volume in the z direction (3d) or y direction (2d). This enables pouring particles from a successively higher height over time.

#### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). This means you must be careful when restarting a pouring simulation, when the restart file was written in the middle of the pouring operation. Specifically, you should use a new fix pour command in the input script for the restarted simulation that continues the operation. You will need to adjust the arguments of the original fix pour command to do this.

Also note that because the state of the random number generator is not saved in restart files, you cannot do "exact" restarts with this fix, where the simulation continues on the same as if no restart had taken place. However, in a statistical sense, a restarted simulation should produce the same behavior if you adjust the fix pour parameters appropriately.

None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

#### **Restrictions:**

This fix is part of the "granular" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

For 3d simulations, a gravity fix in the  $-z$  direction must be defined for use in conjunction with this fix. For 2d simulations, gravity must be defined in the  $-y$  direction.

#### **Related commands:**

[fix\\_deposit](#), [fix\\_gravity](#), [region](#)

#### **Default:**

The option defaults are *diam* = 1.0 1.0, *dens* = 1.0 1.0, *vol* = 0.25 50, *rate* = 0.0, *vel* = 0.0 0.0 0.0 0.0 0.0.

## fix print command

### Syntax:

```
fix ID group-ID print N string
```

- ID, group-ID are documented in [fix](#) command
- print = style name of this fix command
- N = print every N steps
- string = text string to print with optional variable names

### Examples:

```
fix extra all print 100 "Coords of marker atom = $x $y $z"
```

### Description:

Print a text string to the screen and logfile every N steps during a simulation run. This can be used for diagnostic purposes or even as a debugging tool to monitor some quantity during a run. The text string must be a single argument, so it should be enclosed in double quotes if it is more than one word. If it contains variables it must be enclosed in double quotes to insure they are not evaluated when the input script is read, but will instead be evaluated when the string is printed.

See the [variable](#) command for a description of *equal* style variables which are the most useful ones to use with the fix print command, since they are evaluated afresh each timestep that the fix print line is output. Equal-style variables can calculate complex formulas involving atom and group properties, mathematical operations, other variables, etc.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions:

If *equal*-style variables are used which contain [thermo\\_style custom](#) keywords for energy such as `pe`, `eng`, `evdwl`, `ebond`, etc, then they will only be up-to-date on timesteps where thermodynamics are computed. For example, if you output thermodynamics every 100 steps, but issue a fix print command with `N = 2` that contains such a variable, the printed value will only be current on timesteps that are a multiple of 100. This is because the potential functions in LAMMPS (`pairwise`, `bond`, etc) only compute energies on timesteps when thermodynamic output is being performed.

### Related commands:

[variable](#), [print](#)

**Default:** none

## fix rdf command

### Syntax:

```
fix ID group-ID rdf N file Nbin itype1 jtype1 itype2 jtype2 ...
```

- ID, group-ID are documented in [fix](#) command
- rdf = style name of this fix command
- N = compute radial distribution function (RDF) every this many timesteps
- file = filename to write radial distribution function info to
- Nbin = number of RDF bins
- itypeN = central atom type for RDF pair N
- jtypeN = distribution atom type for RDF pair N

### Examples:

```
fix 1 all rdf 500 rdf.out 100 1 1
fix 1 fluid rdf 10000 rdf.out 100 1 1 1 2 2 1 2 2
```

### Description:

Compute the radial distribution function (RDF), also known as  $g(r)$ , and coordination number every N steps. The RDF for each specified atom type pair is histogrammed in Nbin bins from distance 0 to  $R_c$ , where  $R_c$  = the maximum force cutoff for any pair of atom types. An atom pair only contributes to the RDF if

- both atoms are in the fix group
- the distance between them is within the maximum force cutoff
- their interaction is stored in the neighbor list

Bonded atoms (1–2, 1–3, 1–4 interactions within a molecular topology) with a pairwise weighting factor of 0.0 are not included in the RDF; pairs with a non-zero weighting factor are included. The weighting factor is set by the [special\\_bonds](#) command.

The RDF statistics for each timestep are written to the specified file, as are the RDF values averaged over all timesteps.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions:

The RDF is not computed for distances longer than the force cutoff, since processors (in parallel) don't know atom coordinates for atoms further away than that distance. If you want an RDF for larger  $r$ , you'll need to post-process a dump file.

### Related commands:

pair\_style

**Default:** none



## fix recenter command

### Syntax:

```
fix ID group-ID recenter x y z keyword value ...
```

- ID, group-ID are documented in [fix](#) command
- recenter = style name of this fix command
- x,y,z = constrain center-of-mass to these coords (distance units), any coord can also be NULL or INIT (see below)
- zero or more keyword/value pairs may be appended
- keyword = *shift* or *units*

```
shift value = group-ID
group-ID = group of atoms whose coords are shifted
units value = box or lattice or fraction
```

### Examples:

```
fix 1 all recenter 0.0 0.5 0.0
fix 1 all recenter INIT INIT NULL
fix 1 all recenter INIT 0.0 0.0 units box
```

### Description:

Constrain the center-of-mass position of a group of atoms by adjusting the coordinates of the atoms every timestep. This is simply a small shift that does not alter the dynamics of the system or change the relative coordinates of any pair of atoms in the group. This can be used to insure the entire collection of atoms (or a portion of them) do not drift during the simulation due to random perturbations (e.g. [fix langevin](#) thermostating).

Distance units for the x,y,z values are determined by the setting of the *units* keyword, as discussed below. One or more x,y,z values can also be specified as NULL, which means exclude that dimension from this operation. Or it can be specified as INIT which means to constrain the center-of-mass to its initial value at the beginning of the run.

The center-of-mass (COM) is computed for the group specified by the fix. If the current COM is different than the specified x,y,z, then a group of atoms has their coordinates shifted by the difference. By default the shifted group is also the group specified by the fix. A different group can be shifted by using the *shift* keyword. For example, the COM could be computed on a protein to keep it in the center of the simulation box. But the entire system (protein + water) could be shifted.

If the *units* keyword is set to *box*, then the distance units of x,y,z are defined by the [units](#) command – e.g. Angstroms for *real* units. A *lattice* value means the distance units are in lattice spacings. The [lattice](#) command must have been previously used to define the lattice spacing. A *fraction* value means a fractional distance between the lo/hi box boundaries, e.g. 0.5 = middle of the box. The default is to use lattice units.

Note that the [velocity](#) command can be used to create velocities with zero aggregate linear and/or angular momentum.

**IMPORTANT NOTE:** This fix performs its operations at the same point in the timestep as other time integration fixes, such as [fix nve](#), [fix nvt](#), or [fix npt](#). Thus fix recenter should normally be the last such fix specified in the

input script, since the adjustments it makes to atom coordinates should come after the changes made by time integration. LAMMPS will warn you if your fixes are not ordered this way.

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:**

This fix should not be used with an x,y,z setting that causes a large shift in the system on the 1st timestep, due to the requested COM being very different from the initial COM. This could cause atoms to be lost, especially in parallel. Instead, use the [displace\\_atoms](#) command, which can be used to move atoms a large distance.

**Related commands:**

[fix momentum](#), [velocity](#)

**Default:**

The option defaults are *adjust* = fix group-ID, and *units* = lattice.

## fix rigid

### Syntax:

```
fix ID group-ID rigid keyword values
```

- ID, group-ID are documented in [fix](#) command
- rigid = style name of this fix command
- keyword = *single* or *molecule* or *group*

```
single values = none  
molecule values = none  
group values = list of group IDs
```

### Examples:

```
fix 1 clump rigid single  
fix 1 polychains rigid molecule  
fix 2 fluid rigid group clump1 clump2 clump3
```

### Description:

Treat one or more sets of atoms as an independent rigid body. This means that each timestep the total force and torque on each rigid body is computed and the coordinates and velocities of the atoms in each body are updated so that they move as a rigid body. This can be useful for freezing one or more portions of a large biomolecule, or for simulating a system of colloidal particles.

This fix updates the positions and velocities of the rigid atoms with a constant-energy time integration, so you should not update the same atoms via other fixes (e.g. nve, nvt, npt).

Each body must have two or more atoms. Which atoms are in which bodies can be defined via several options.

For option *single* the entire group of atoms is treated as one rigid body.

For option *molecule*, each set of atoms in the group with a different molecule ID is treated as a rigid body.

For option *group*, each of the listed groups is treated as a separate rigid body. Note that only atoms that are also in the fix group are included in each rigid body.

For computational efficiency, you should also turn off pairwise and bond interactions within each rigid body, as they no longer contribute to the motion. The [neigh\\_modify exclude](#) and [delete\\_bonds](#) commands are used to do this.

For computational efficiency, you should define one fix rigid which includes all the desired rigid bodies. LAMMPS will allow multiple rigid fixes to be defined, but it is more expensive.

The degrees-of-freedom removed by rigid bodies are accounted for in temperature and pressure computations. Similarly, the rigid body contribution to the pressure virial is also accounted for. The latter is only correct if forces within the bodies have been turned off, and there is only a single fix rigid defined. For each linear rigid body of three or more atoms, one degree-of-freedom must be subtracted using a [compute\\_modify](#) command (i.e. for a simulation of 10 such rigid bodies, use "compute\_modify thermo\_temp extra 13", after the thermo\_style

command, where 3 is the default setting and an additional 10 degrees-of-freedom are subtracted).

Note that this fix uses constant-energy integration, so you may need to impose additional constraints to control the temperature of an ensemble of rigid bodies. You can use [fix langevin](#) for this purpose to treat the system as effectively immersed in an implicit solvent, i.e. a Brownian dynamics model. Or you can thermostat additional atoms of an explicit solvent directly.

**IMPORTANT NOTE:** The periodic image flags of atoms in rigid bodies are modified when the center-of-mass of the rigid body moves across a periodic boundary. They are not incremented/decremented as they would be for non-rigid atoms. This change does not affect dynamics, but means that any diagnostic computation based on the atomic image flag values must be adjusted accordingly. For example, the [fix msd](#) will not compute the expected mean-squared displacement for such atoms, and the image flag values written to a [dump file](#) will be different than they would be if the atoms were not in a rigid body.

#### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

#### **Restrictions:**

This fix performs an MPI\_Allreduce each timestep that is proportional in length to the number of rigid bodies. Hence it will not scale well in parallel if large numbers of rigid bodies are simulated.

If the atoms in a single rigid body initially straddle a periodic boundary, the input data file must define the image flags for each atom correctly, so that LAMMPS can "unwrap" the atoms into a valid rigid body.

You should not use this fix if you just want to hold group of atoms stationary. A better way to do this is to not include those atoms in your time integration fix. E.g. use "fix 1 mobile nve" instead of "fix 1 all nve", where "mobile" is the group of atoms that you want to move.

#### **Related commands:**

[delete\\_bonds](#), [neigh\\_modify](#) exclude

**Default:** none

## fix setforce command

### Syntax:

```
fix ID group-ID setforce fx fy fz
```

- ID, group-ID are documented in [fix](#) command
- setforce = style name of this fix command
- fx,fy,fz = force component values

### Examples:

```
fix freeze indenter setforce 0.0 0.0 0.0  
fix 2 edge setforce NULL 0.0 0.0
```

### Description:

Set each component of force on each atom in the group to the specified values fx,fy,fz. This erases all previously computed forces on the atom, though additional fixes could add new forces. This command can be used to freeze certain atoms in the simulation by zeroing their force, assuming their initial velocity zero.

Any of the fx,fy,fz values can be specified as NULL which means do not alter the force component in that dimension.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix.

The total vector force on the group of atoms before it is reset is stored by the fix and its components can be printed as part of thermodynamic output via the keywords `f_ID[N]` where ID is the fix-ID of this fix and N = 1,2,3. See the [thermo\\_style custom](#) command for details. Note that the fix stores the total force on the group of atoms, but the printed value may be normalized by the total number of atoms in the simulation depending on the [thermo\\_modify norm](#) option being used.

No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command.

**Restrictions:** none

### Related commands:

[fix addforce](#), [fix aveforce](#)

**Default:** none

## fix shake command

### Syntax:

```
fix ID group-ID shake tol iter N keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- shake = style name of this fix command
- tol = accuracy tolerance of SHAKE solution
- iter = max # of iterations in each SHAKE solution
- N = print SHAKE statistics every this many timesteps (0 = never)
- one or more keyword/value pairs are appended
- keyword = *b* or *a* or *t* or *m*

```
b values = one or more bond types
a values = one or more angle types
t values = one or more atom types
m value = one or more mass values
```

### Examples:

```
fix 1 sub shake 0.0001 20 10 b 4 19 a 3 5 2
fix 1 sub shake 0.0001 20 10 t 5 6 m 1.0 a 31
```

### Description:

Apply bond and angle constraints to specified bonds and angles in the simulation. This typically enables a longer timestep.

Each timestep the specified bonds and angles are reset to their equilibrium lengths and angular values via the well-known SHAKE algorithm. This is done by applying an additional constraint force so that the new positions preserve the desired atom separations. The equations for the additional force are solved via an iterative method that typically converges to an accurate solution in a few iterations. The desired tolerance (e.g.  $1.0\text{e-}4 = 1$  part in 10000) and maximum # of iterations are specified as arguments. Setting the N argument will print statistics to the screen and log file about regarding the lengths of bonds and angles that are being constrained. Small delta values mean SHAKE is doing a good job.

In LAMMPS, only small clusters of atoms can be constrained. This is so the constraint calculation for a cluster can be performed by a single processor, to enable good parallel performance. A cluster is defined as a central atom connected to others in the cluster by constrained bonds. LAMMPS allows for the following kinds of clusters to be constrained: one central atom bonded to 1 or 2 or 3 atoms, or one central atom bonded to 2 others and the angle between the 3 atoms also constrained. This means water molecules or CH<sub>2</sub> or CH<sub>3</sub> groups may be constrained, but not all the C–C backbone bonds of a long polymer chain.

The *b* keyword lists bond types that will be constrained. The *t* keyword lists atom types. All bonds connected to an atom of the specified type will be constrained. The *m* keyword lists atom masses. All bonds connected to atoms of the specified masses will be constrained (within a fudge factor of MASSDELTA specified in fix\_shake.cpp). The *a* keyword lists angle types. If both bonds in the angle are constrained then the angle will also be constrained if its type is in the list.

For all keywords, a particular bond is only constrained if both atoms in the bond are in the group specified with

the SHAKE fix.

The degrees-of-freedom removed by SHAKE bonds and angles are accounted for in temperature and pressure computations. Similarly, the SHAKE contribution to the pressure virial is also accounted for.

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:**

For computational efficiency, there can only be one shake fix defined in a simulation.

If you use a tolerance that is too large or a max-iteration count that is too small, the constraints will not be enforced very strongly, which can lead to poor energy conservation. You can test for this in your system by running a constant NVE simulation with a particular set of SHAKE parameters and monitoring the energy versus time.

**Related commands:** none

**Default:** none

## fix spring command

### Syntax:

```
fix ID group-ID spring keyword values
```

- ID, group-ID are documented in [fix](#) command
- spring = style name of this fix command
- keyword = *tether* or *couple*

```
tether values = K x y z R0
  K = spring constant (force/distance units)
  x,y,z = point to which spring is tethered
  R0 = equilibrium distance from tether point (distance units)
couple values = group-ID2 K x y z R0
  group-ID2 = 2nd group to couple to fix group with a spring
  K = spring constant (force/distance units)
  x,y,z = direction of spring
  R0 = equilibrium distance of spring (distance units)
```

### Examples:

```
fix pull ligand spring tether 50.0 0.0 0.0 0.0 0.0
fix pull ligand spring tether 50.0 0.0 0.0 0.0 5.0
fix pull ligand spring tether 50.0 NULL NULL 2.0 3.0
fix 5 bilayer1 spring couple bilayer2 100.0 NULL NULL 10.0 0.0
fix longitudinal pore spring couple ion 100.0 NULL NULL -20.0 0.0
fix radial pore spring couple ion 100.0 0.0 0.0 NULL 5.0
```

### Description:

Apply a spring force to a group of atoms or between two groups of atoms. This is useful for applying an umbrella force to a small molecule or lightly tethering a large group of atoms (e.g. all the solvent or a large molecule) to the center of the simulation box so that it doesn't wander away over the course of a long simulation. It can also be used to hold the centers of mass of two groups of atoms at a given distance or orientation with respect to each other.

The *tether* style attaches a spring between a fixed point  $x,y,z$  and the center of mass of the fix group of atoms. The equilibrium position of the spring is  $R0$ . At each timestep the distance  $R$  from the center of mass of the group of atoms to the tethering point is computed, taking account of wrap-around in a periodic simulation box. A restoring force of magnitude  $K (R - R0) M_i / M$  is applied to each atom in the group where  $K$  is the spring constant,  $M_i$  is the mass of the atom, and  $M$  is the total mass of all atoms in the group. Note that  $K$  thus represents the total force on the group of atoms, not a per-atom force.

The *couple* style links two groups of atoms together. The first group is the fix group; the second is specified by group-ID2. The groups are coupled together by a spring that is at equilibrium when the two groups are displaced by a vector  $x,y,z$  with respect to each other and at a distance  $R0$  from that displacement. Note that  $x,y,z$  is the equilibrium displacement of group-ID2 relative to the fix group. Thus (1,1,0) is a different spring than (-1,-1,0). When the relative positions and distance between the two groups are not in equilibrium, the same spring force described above is applied to atoms in each of the two groups.

For both the *tether* and *couple* styles, any of the  $x,y,z$  values can be specified as NULL which means do not include that dimension in the distance calculation or force application.



The first example above pulls the ligand towards the point (0,0,0). The second example holds the ligand near the surface of a sphere of radius 5 around the point (0,0,0). The third example holds the ligand a distance 3 away from the  $z=2$  plane (on either side).

The fourth example holds 2 bilayers a distance 10 apart in  $z$ . For the last two examples, imagine a pore (a slab of atoms with a cylindrical hole cut out) oriented with the pore axis along  $z$ , and an ion moving within the pore. The fifth example holds the ion a distance of  $-20$  below the  $z = 0$  center plane of the pore (umbrella sampling). The last example holds the ion a distance 5 away from the pore axis (assuming the center-of-mass of the pore in  $x,y$  is the pore axis).

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:**

[fix drag](#), [fix spring/self](#), [fix spring/rg](#)

**Default:** none

## fix spring/rg command

### Syntax:

```
fix ID group-ID spring/rg K RG0
```

- ID, group-ID are documented in [fix](#) command
- spring/rg = style name of this fix command
- K = harmonic force constant (force/distance units)
- RG0 = target radius of gyration to constrain to (distance units)

if RG0 = NULL, use the current RG as the target value

### Examples:

```
fix 1 protein spring/rg 5.0 10.0
fix 2 micelle spring/rg 5.0 NULL
```

### Description:

Apply a harmonic restraining force to atoms in the group to affect their central moment about the center of mass (radius of gyration). This fix is useful to encourage a protein or polymer to fold/unfold and also when sampling along the radius of gyration as a reaction coordinate (i.e. for protein folding).

The radius of gyration is defined as RG in the first formula. The energy of the constraint and associated force on each atom is given by the second and third formulas, when the group is at a different RG than the target value RG0.

$$R_G^2 = \frac{1}{M} \sum_i^N m_i \left( x_i - \frac{1}{M} \sum_j^N m_j x_j \right)^2$$

$$E = K (R_G - R_{G0})^2$$

$$F_i = 2K \frac{m_i}{M} \left( 1 - \frac{R_{G0}}{R_G} \right) \left( x_i - \frac{1}{M} \sum_j^N m_j x_j \right)$$

The (xi – center-of-mass) term is computed taking into account periodic boundary conditions, m\_i is the mass of the atom, and M is the mass of the entire group. Note that K is thus a force constant for the aggregate force on the group of atoms, not a per-atom force.

If RG0 is specified as NULL, then the RG of the group is computed at the time the fix is specified, and that value is used as the target.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy](#)

minimization.

**Restrictions:** none

**Related commands:**

[fix spring](#), [fix spring/self](#)

**Default:** none

## fix spring/self command

### Syntax:

```
fix ID group-ID spring/self K
```

- ID, group-ID are documented in [fix](#) command
- spring/self = style name of this fix command
- K = spring constant (force/distance units)

### Examples:

```
fix tether boundary-atoms spring/self 10.0
```

### Description:

Apply a spring force independently to each atom in the group to tether it to its initial position. The initial position for each atom is its location at the time the fix command was issued. At each timestep, the magnitude of the force on each atom is  $-Kr$ , where  $r$  is the displacement of the atom from its current position to its initial position.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

This fix writes the original coordinates of tethered atoms to [binary restart files](#), so that the spring effect will be the same in a restarted simulation. See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.

None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

### Related commands:

[fix drag](#), [fix spring](#)

**Default:** none

## fix temp/rescale command

### Syntax:

```
fix ID group-ID temp/rescale N Tstart Tstop window fraction keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- temp/rescale = style name of this fix command
- N = perform rescaling every N steps
- Tstart,Tstop = desired temperature at start/end of run (temperature units)
- window = only rescale if temperature is outside this window (temperature units)
- fraction = rescale to target temperature by this fraction
- zero or more keyword/value pairs may be appended
- keyword = *region* or *partial*

```
region values = region-ID
    region-ID = ID of region to apply rescaling to
partial values = xflag yflag zflag
    xflag,yflag,zflag = 0/1 if the velocity component should not or should be rescaled
```

### Examples:

```
fix 3 flow temp/rescale 100 1.0 1.1 0.02 0.5
fix 3 boundary temp/rescale 1 1.0 1.5 0.05 1.0 region edge
fix 3 boundary temp/rescale 1 1.0 1.5 0.05 1.0 partial 0 1 1
```

### Description:

Reset the temperature of a group of atoms by explicitly rescaling their velocities.

Rescaling is performed every N timesteps. The target temperature is a ramped value between the *Tstart* and *Tstop* temperatures at the beginning and end of the run.

Rescaling is only performed if the difference between the current and desired temperatures is greater than the *window* value. The amount of rescaling that is applied is a *fraction* (from 0.0 to 1.0) of the difference between the actual and desired temperature. E.g. if *fraction* = 1.0, the temperature is reset to exactly the desired value.

The keyword *region* applies the fix only to atoms that are in the specified geometric region (and in the fix group). Since atoms can enter/leave a region, this test is performed each timestep.

The keyword *partial* rescales only the specified velocity components. A compute of style temp/partial is used to compute the current temperature of just those components (see below).

The *region* and *partial* keywords cannot currently be used together.

A temp/rescale fix does not update the coordinates of its atoms. It is normally used with a fix of style *nve* that does that. A temp/rescale fix should not normally be used on atoms that also have their temperature controlled by another fix – e.g. a [nvt](#) or [langevin](#) fix.

This fix computes a temperature each timestep. To do this, the fix creates its own compute of style "temp" or "temp/region" or "temp/partial", as if one of these commands had been issued:

```
compute fix-ID_temp group-ID temp
compute fix-ID_temp group-ID temp/region region-ID
compute fix-ID_temp group-ID temp/partial xflag yflag zflag
```

Which is used depends on whether the *region* or *partial* keywords were specified with the fix. See the [compute temp](#), [compute temp/region](#), and [compute temp/partial](#) commands for details. Note that the ID of the new compute is the fix-ID with underscore + "temp" appended and the group for the new compute is the same as the fix group.

Note that this is NOT the compute used by thermodynamic output (see the [thermo\\_style](#) command) with ID = *thermo\_temp*. This means you can change the attributes of this fix's temperature (e.g. its degrees-of-freedom) via the [compute\\_modify](#) command or print this temperature during thermodynamic output via the [thermo\\_style custom](#) command using the appropriate compute-ID. It also means that changing attributes of *thermo\_temp* will have no effect on this fix.

#### **Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#).

The [fix\\_modify temp](#) option is supported by this fix. You can use it to assign a [compute](#) you have defined to this fix which will be used in its thermostating procedure. For consistency, if using the keyword *region*, the compute you assign should also be of style [temp/region](#).

The [fix\\_modify energy](#) option is supported by this fix to add the energy change implied by a velocity rescaling to the system's potential energy as part of [thermodynamic output](#). Note that because this fix is invoked every N steps and thermodynamic info is printed every M steps, that unless M is a multiple of N, the energy contribution will not be for the current timestep.

The energy change can be printed as part of thermodynamic output via the keyword *f\_ID*, where ID is the fix-ID of this fix. See the [thermo\\_style custom](#) command for details.

This fix can ramp its target temperature over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:**

[fix langevin](#), [fix nvt](#), [fix\\_modify](#)

**Default:** none

## fix tmd command

### Syntax:

```
fix ID group-ID tmd rho_final file1 N file2
```

- ID, group-ID are documented in [fix](#) command
- tmd = style name of this fix command
- rho\_final = desired value of rho at the end of the run (distance units)
- file1 = filename to read target structure from
- N = dump TMD statistics every this many timesteps, 0 = no dump
- file2 = filename to write TMD statistics to (only needed if N > 0)

### Examples:

```
fix 1 all nve
fix 2 tmdatoms tmd 1.0 target_file 100 tmd_dump_file
```

### Description:

Perform targeted molecular dynamics (TMD) on a group of atoms. A holonomic constraint is used to force the atoms to move towards (or away from) the target configuration. The parameter "rho" is monotonically decreased (or increased) from its initial value to rho\_final at the end of the run.

Rho has distance units and is a measure of the root-mean-squared distance (RMSD) between the current configuration of the atoms in the group and the target coordinates listed in file1. Thus a value of rho\_final = 0.0 means move the atoms all the way to the final structure during the course of the run.

The format of the target file1 is as follows:

```
0.0 25.0 xlo xhi
0.0 25.0 ylo yhi
0.0 25.0 zlo zhi
125      24.97311    1.69005      23.46956  0  0  -1
126      1.94691     2.79640     1.92799   1  0  0
127      0.15906     3.46099     0.79121   1  0  0
...
```

The first 3 lines may or may not be needed, depending on the format of the atoms to follow. If image flags are included with the atoms, the 1st 3 lo/hi lines must appear in the file. If image flags are not included, the 1st 3 lines should not appear. The 3 lines contain the simulation box dimensions for the atom coordinates, in the same format as in a LAMMPS data file (see the [read\\_data](#) command).

The remaining lines each contain an atom ID and its target x,y,z coordinates. The atom lines (all or none of them) can optionally be followed by 3 integer values: nx,ny,nz. For periodic dimensions, they specify which image of the box the atom is considered to be in, i.e. a value of N (positive or negative) means add N times the box length to the coordinate to get the true value.

The atom lines can be listed in any order, but every atom in the group must be listed in the file. Atoms not in the fix group may also be listed; they will be ignored.

TMD statistics are written to file2 every N timesteps, unless N is specified as 0, which means no statistics.

The atoms in the fix tmd group should be integrated (via a fix nve, nvt, npt) along with other atoms in the system.

Restarts can be used with a fix tmd command. For example, imagine a 10000 timestep run with a rho\_initial = 11 and a rho\_final = 1. If a restart file was written after 2000 time steps, then the configuration in the file would have a rho value of 9. A new 8000 time step run could be performed with the same rho\_final = 1 to complete the conformational change at the same transition rate. Note that for restarted runs, the name of the TMD statistics file should be changed to prevent it being overwritten.

For more information about TMD, see [\(Schlitter1\)](#) and [\(Schlitter2\)](#).

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command.

This fix can ramp its rho parameter over multiple runs, using the *start* and *stop* keywords of the [run](#) command. See the [run](#) command for details of how to do this.

This fix is not invoked during [energy minimization](#).

**Restrictions:**

All TMD fixes must be listed in the input script after all integrator fixes (nve, nvt, npt) are applied. This ensures that atoms are moved before their positions are corrected to comply with the constraint.

Atoms that have a TMD fix applied should not be part of a group to which a SHAKE fix is applied. This is because LAMMPS assumes there are not multiple competing holonomic constraints applied to the same atoms.

**Related commands:** none

**Default:** none

---

**(Schlitter1)** Schlitter, Swegat, Mulders, "Distance-type reaction coordinates for modelling activated processes", J Molecular Modeling, 7, 171–177 (2001).

**(Schlitter2)** Schlitter and Klahn, "The free energy of a reaction coordinate at multiple constraints: a concise formulation", Molecular Physics, 101, 3439–3443 (2003).



## fix viscous command

### Syntax:

```
fix ID group-ID viscous gamma keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- viscous = style name of this fix command
- gamma = damping coefficient (force/velocity units)
- zero or more keyword/value pairs can be appended
- keyword = *b* or *a* or *t* or *m*
- zero or more keyword/value pairs may be appended

```
keyword = scale  
scale values = type ratio  
type = atom type (1-N)  
ratio = factor to scale the damping coefficient by
```

### Examples:

```
fix 1 flow viscous 0.1  
fix 1 damp viscous 0.5 scale 3 2.5
```

### Description:

Add a viscous damping force to atoms in the group that is proportional to the velocity of the atom. The added force can be thought of as a frictional interaction with implicit solvent. In granular simulations this can be useful for draining the kinetic energy from the system in a controlled fashion. If used without additional thermostating (to add kinetic energy to the system), it has the effect of slowly (or rapidly) freezing the system; hence it is a simple energy minimization technique.

The damping force  $F$  is given by  $F = -\text{gamma} * \text{velocity}$ . The larger the coefficient, the faster the kinetic energy is reduced. If the optional keyword *scale* is used, gamma can scaled up or down by the specified factor for atoms of that type. It can be used multiple times to adjust gamma for several atom types.

In a Brownian dynamics context,  $\text{gamma} = kT / mD$ , where  $k$  = Boltzmann's constant,  $T$  = temperature,  $m$  = particle mass, and  $D$  = particle diffusion coefficient.  $D$  can be written as  $kT / (6 \pi \eta d)$ , where  $\eta$  = viscosity of the frictional fluid and  $d$  = diameter of particle. This means  $\text{gamma} = 6 \pi \eta d$ , and thus is proportional to the viscosity of the fluid and the particle diameter.

In the current implementation, rather than have the user specify a viscosity (in centiPoise or some other units), gamma is specified directly in force/velocity units. If needed, gamma can be adjusted for atoms of different sizes (i.e. sigma) by using the *scale* keyword.

Note that Brownian dynamics models also typically include a randomized force term to thermostat the system at a chosen temperature. The [fix langevin](#) command adds both a viscous damping term and this random force to each atom; hence if using *fix langevin* you do not typically need to use *fix viscous*.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this

fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:**

[fix langevin](#)

**Default:** none

## fix wall/gran command

### Syntax:

```
fix ID group-ID wall/gran wallstyle args keyword values ...
```

- ID, group-ID are documented in [fix](#) command
- wall/gran = style name of this fix command
- style = *xplane* or *yplane* or *zplane* or *zcylinder*
- args = list of arguments for a particular style

```
xplane or yplane or zplane args = lo hi gamma xmu
    lo, hi = position of lower and upper plane (either can be NULL)
    gamman = damping coeff for normal direction collisions with wall
    xmu = friction coeff for the wall
zcylinder args = radius gamma xmu
    radius = cylinder radius (distance units)
    gamman = damping coeff for normal direction collisions with wall
    xmu = friction coeff for the wall
```

- zero or more keyword/value pairs may be appended to args

```
keyword = wiggle
values = dim amplitude period
    dim = x or y or z
    amplitude = size of oscillation (distance units)
    period = time of oscillation (time units)
```

### Examples:

```
fix 1 all wall/gran xplane -10.0 10.0 50.0 0.5
fix 2 all wall/gran zcylinder 15.0 50.0 0.5 wiggle z 3.0 2.0
fix 1 all wall/gran zplane 0.0 NULL 100.0 0.5
```

### Description:

Bound the simulation domain of a granular system with a frictional wall. All particles in the group interact with the wall when they are close enough to touch it.

The *wallstyle* can be planar or cylindrical. The 3 planar options specify a pair of walls in a dimension. Wall positions are given by *lo* and *hi*. Either of the values can be specified as NULL if a single wall is desired. For a *zcylinder* wallstyle, the cylinder's axis is at  $x = y = 0.0$ , and the radius of the cylinder is specified. For all wallstyles, a damping and friction coefficient for particle–wall interactions are also specified.

Optionally, a wall can be oscillated, similar to the oscillations of frozen particles specified by the [fix\\_wiggle](#) command. This is useful in packing simulations of granular particles. If the keyword *wiggle* is appended to the argument list, then a dimension for the motion, as well as its *amplitude* and *period* is specified. Each timestep, the position of the wall in the appropriate *dim* is set according to this equation:

$$\text{position} = \text{pos0} + A - A \cos(\omega * \text{delta})$$

where *pos0* is the position at the time the fix was specified, *A* is the *amplitude*,  $\omega$  is  $2 \text{ PI} / \text{period}$ , and *delta* is the elapsed time since the fix was specified. The velocity of the wall is also set to the derivative of this expression.

**Restart, fix\_modify, thermo output, run start/stop, minimize info:**

This fix writes the shear friction state of atoms interacting with the wall to [binary restart files](#), so that a simulation can continue correctly if granular potentials with shear "history" effects are being used. See the [read\\_restart](#) command for info on how to re-specify a fix in an input script that reads a restart file, so that the operation of the fix continues in an uninterrupted fashion.

None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:**

This fix is part of the "granular" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

Any dimension (xyz) that has a granular wall must be non-periodic.

A zcylinder wall can only be oscillated in the z dimension.

**Related commands:**

[fix\\_wiggle](#)

**Default:** none

## fix wall/lj126 command

### Syntax:

```
fix ID group-ID wall/lj126 style coord epsilon sigma cutoff
```

- ID, group-ID are documented in [fix](#) command
- wall/lj126 = style name of this fix command
- style = *xlo* or *xhi* or *ylo* or *yhi* or *zlo* or *zhi*
- coord = position of wall
- epsilon = Lennard-Jones epsilon for wall-particle interaction
- sigma = Lennard-Jones sigma for wall-particle interaction
- cutoff = distance from wall at which wall-particle interaction is cut off

### Examples:

```
fix wallhi all wall/lj126 xhi 10.0 1.0 1.0 1.12
```

### Description:

Bound the simulation domain with a Lennard-Jones wall that encloses the atoms. The energy  $E$  of a wall-particle interactions is given by the 12-6 potential

$$E = 4\epsilon \left[ \left( \frac{\sigma}{r} \right)^{12} - \left( \frac{\sigma}{r} \right)^6 \right] \quad r < r_c$$

where  $r$  is the distance from the particle to the wall *coord*, and epsilon and sigma are the usual LJ parameters.  $r_c$  is the cutoff value specified in the command. This interaction provides a harder, more repulsive interaction with the wall than the softer 9-3 potential provided by the [fix wall/lj93](#) command.

The wall potential is shifted so that the energy of a wall-particle interaction is 0.0 at the cutoff distance.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#).

The [fix\\_modify energy](#) option is supported by this fix to add the energy of interaction between atoms and the wall to the system's potential energy as part of [thermodynamic output](#).

The atom/wall interaction energy can be printed as part of thermodynamic output via the keyword `f_ID`, where ID is the fix-ID of this fix. See the [thermo\\_style custom](#) command for details.

No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command.

**IMPORTANT NOTE:** If you want the atom/wall interaction energy to be included in the total potential energy of the system (the quantity being minimized), you **MUST** enable the [fix\\_modify energy](#) option for this fix.

**Restrictions:**

Any dimension (xyz) that has a LJ 12/6 wall must be non-periodic.

**Related commands:**

[fix wall/reflect](#), [fix wall/lj93](#)

**Default:** none

## fix wall/lj93 command

### Syntax:

```
fix ID group-ID wall/lj93 style coord epsilon sigma cutoff
```

- ID, group-ID are documented in [fix](#) command
- wall/lj93 = style name of this fix command
- style = *xlo* or *xhi* or *ylo* or *yhi* or *zlo* or *zhi*
- coord = position of wall
- epsilon = Lennard–Jones epsilon for wall–particle interaction
- sigma = Lennard–Jones sigma for wall–particle interaction
- cutoff = distance from wall at which wall–particle interaction is cut off

### Examples:

```
fix wallhi all wall/lj93 xhi 10.0 1.0 1.0 2.5
```

### Description:

Bound the simulation domain with a Lennard–Jones wall that encloses the atoms. The energy  $E$  of a wall–particle interactions is given by the 9–3 potential

$$E = \epsilon \left[ \frac{2}{15} \left( \frac{\sigma}{r} \right)^9 - \left( \frac{\sigma}{r} \right)^3 \right] \quad r < r_c$$

where  $r$  is the distance from the particle to the wall *coord*, and epsilon and sigma are the usual LJ parameters.  $R_c$  is the cutoff value specified in the command. This interaction is derived by integrating over a 3d half–lattice of Lennard–Jones 12–6 particles. A harder, more repulsive wall interaction can be computed by using the [fix wall/lj126](#) command.

The wall potential is shifted so that the energy of a wall–particle interaction is 0.0 at the cutoff distance.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#).

The [fix\\_modify energy](#) option is supported by this fix to add the energy of interaction between atoms and the wall to the system's potential energy as part of [thermodynamic output](#).

The atom/wall interaction energy can be printed as part of thermodynamic output via the keyword `f_ID`, where ID is the fix-ID of this fix. See the [thermo\\_style custom](#) command for details.

No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command.

The forces due to this fix are imposed during an energy minimization, invoked by the [minimize](#) command.

IMPORTANT NOTE: If you want the atom/wall interaction energy to be included in the total potential energy of the system (the quantity being minimized), you MUST enable the [fix\\_modify energy](#) option for this fix.

**Restrictions:**

Any dimension (xyz) that has a LJ 9/3 wall must be non-periodic.

**Related commands:**

[fix wall/reflect](#), [fix wall/lj126](#)

**Default:** none



## fix wall/reflect command

### Syntax:

```
fix ID group-ID wall/reflect keyword ...
```

- ID, group-ID are documented in [fix](#) command
- wall/reflect = style name of this fix command
- one or more keyword/value pairs may be appended
- keyword = *xlo* or *xhi* or *ylo* or *yhi* or *zlo* or *zhi*

### Examples:

```
fix xwalls all wall/reflect xlo xhi
fix walls all wall/reflect xlo ylo zlo xhi yhi zhi
```

### Description:

Bound the simulation with one or more walls which reflect particles when they attempt to move thru them.

Reflection means that if an atom moves outside the box on a timestep by a distance delta (e.g. due to [fix nve](#)), then it is put back inside the box by the same delta and the sign of the corresponding component of its velocity is flipped.

IMPORTANT NOTE: This fix performs its operations at the same point in the timestep as other time integration fixes, such as [fix nve](#), [fix nvt](#), or [fix npt](#). Thus fix wall/reflect should normally be the last such fix specified in the input script, since the adjustments it makes to atom coordinates should come after the changes made by time integration. LAMMPS will warn you if your fixes are not ordered this way.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

### Restrictions:

Any dimension (xyz) that has a reflecting wall must be non-periodic.

A reflecting wall cannot be used with rigid bodies such as those defined by a "fix rigid" command. This is because the wall/reflect displaces atoms directly rather than exerts a force on them. For rigid bodies, use a soft wall instead, such as [fix wall/lj93](#).

### Related commands:

[fix wall/lj93](#) command

**Default:** none

## fix wiggle command

### Syntax:

fix ID group-ID wiggle dim amplitude period

- ID, group-ID are documented in [fix](#) command
- wiggle = style name of this fix command
- dim = *x* or *y* or *z*
- amplitude = size of oscillation (distance units)
- period = time of oscillation (time units)

### Examples:

```
fix 1 frozen wiggle 3.0 0.5
```

### Description:

Move a group of atoms in a sinusoidal oscillation. This is useful in granular simulations when boundary atoms are wiggled to induce packing of the dynamic atoms. The dimension *dim* of movement is specified as is the *amplitude* and *period* of the oscillations. Each timestep the *dim* coordinate of each atom is set to

$$\text{coord} = \text{coord0} + A - A \cos (\omega * \text{delta})$$

where *coord0* is the coordinate at the time the fix was specified, *A* is the *amplitude*,  $\omega$  is  $2 \text{ PI} / \text{period}$ , and *delta* is the elapsed time since the fix was specified. The velocity of the atom is set to the derivative of this expression.

### Restart, fix\_modify, thermo output, run start/stop, minimize info:

No information about this fix is written to [binary restart files](#). None of the [fix\\_modify](#) options are relevant to this fix. No quantities calculated by this fix can be output by the [thermo\\_style custom](#) command. No parameter of this fix can be used with the *start/stop* keywords of the [run](#) command. This fix is not invoked during [energy minimization](#).

**Restrictions:** none

**Related commands:** none

**Default:** none

## group command

### Syntax:

```
group ID style args
```

- ID = user-defined name of the group
- style = *region* or *type* or *id* or *molecule* or *subtract* or *union* or *intersect*

```

region args = region-ID
type or id or molecule
  args = one or more atom types, atom IDs, or molecule IDs
  args = logical value
    logical = "" or ">=" or "==" or "!="
    value = an atom type or atom ID or molecule ID (depending on style)
  args = logical value1 value2
    logical = ""
    value1,value2 = atom types or atom IDs or molecule IDs
                    (depending on style)
subtract args = two or more group IDs
union args = one or more group IDs
intersect args = two or more group IDs

```

### Examples:

```

group edge region regstrip
group water type 3 4
group sub id <= 150
group polyA molecule 50 250
group boundary subtract all a2 a3
group boundary union lower upper
group boundary intersect upper flow

```

### Description:

Identify a collection of atoms as belonging to a group. The group ID can then be used in other commands such as `fix`, `velocity`, `dump`, or `temperature` to act on the atoms together.

If the group ID already exists, the group command adds the specified atoms to the group.

The *region* style puts all atoms in the region volume into the group. Note that this is a static one-time assignment. The atoms remain assigned (or not assigned) to the group even in they later move out of the region volume.

The *type*, *id*, and *molecule* styles put all atoms with the specified atom types, atom IDs, or molecule IDs into the group. These 3 styles can have their arguments specified in one of two formats. The 1st format is a list of values (types or IDs). For example, the 2nd command in the examples above puts all atoms of type 3 or 4 into the group named *water*. The 2nd format is a *logical* followed by one or two values (type or ID). The 7 valid logicals are listed above. All the logicals except take a single argument. The 3rd example above adds all atoms with IDs from 1 to 150 to the group named *sub*. The logical means "between" and takes 2 arguments. The 4th example above adds all atoms belonging to molecules with IDs from 50 to 250 (inclusive) to the group named *polyA*.

The *subtract* style takes a list of two or more existing group names as arguments. All atoms that belong to the 1st group, but not to any of the other groups are added to the specified group.

The *union* style takes a list of one or more existing group names as arguments. All atoms that belong to any of the listed groups are added to the specified group.

The *intersect* style takes a list of two or more existing group names as arguments. Atoms that belong to every one of the listed groups are added to the specified group.

A group with the ID *all* is predefined. All atoms belong to this group.

**Restrictions:**

There can be no more than 32 defined groups, including "all".

**Related commands:**

region, fix, velocity, dump, temperature

**Default:**

All atoms belong to the "all" group.

## hmc command

### Syntax:

```
hmc N M temp compute-ID seed1 seed2
```

- N = total # of timesteps to run MD
- M = perform Monte Carlo test every this many steps
- temp = temperature to create velocities at
- compute-ID = ID of the compute that will measure temperature at each MC stage
- seed1 = random # seed for Boltzmann factor in Monte Carlo test
- seed2 = random # seed used to generate velocities

### Examples:

```
hmc 100000 20 300.0 thermo_temp 679383 58728  
hmc 1000 10 1.0 myTemp 679383 58728
```

### Description:

Run a hybrid Monte Carlo (HMC) simulation in the following manner. Every M steps a new set of velocities are generated and assigned to all atoms at the specified temperature, sampling from a Gaussian distribution. Dynamics is run for M steps and the initial energy of the system (potential + kinetic) is compared to the final energy. If the final energy is lower, the final state (coordinates) of the system is accepted. If the final energy is higher, the final state is accepted via the Boltzmann criterion, or it is rejected. If the final state is rejected, the initial coordinates of the atoms (M steps previously) are restored. This procedure is repeated every M steps until N total steps have elapsed.

The specified compute-ID is used to compute the temperature of the system when generating a velocity distribution and at the beginning and end of each short dynamics run. Note that a compute with ID *thermo\_temp* is created and used by [thermodynamic output](#), so it can also be used here.

Statistics on the acceptance ratio for the HMC moves are printed at the end of the run.

### Restrictions:

HMC is derived for simulations performed with constant NVE time integration ([fix nve](#) command). You should not use other thermostats or constraints on your system. LAMMPS does not check that this is the case.

Thermodynamics must be computed and printed out at least every Mth step when using the hmc command.

### Related commands:

[temper](#)

**Default:** none

## if command

### Syntax:

```
if value1 operator value2 then command1 else command2
```

- value1 = 1st value
- operator = "" or ">=" or "==" or "!="
- value2 = 2nd value
- then = required word
- command1 = command to execute if condition is met
- else = optional word
- command2 = command to execute if condition is not met (optional argument)

### Examples:

```
if ${steps} > 1000 then exit
if $x <= $y then "print X is smaller = $x" else "print Y is smaller = $y"
if ${eng} > 0.0 then "timestep 0.005"
if ${eng} > ${eng_previous} then "jump file1" else "jump file2"
```

### Description:

This command provides an in-then-else test capability within an input script. Two values are numerically compared to each other and the result is TRUE or FALSE. Note that as in the examples above, either of the values can be variables, as defined by the [variable](#) command, so that when they are evaluated when substituted for in the if command, a user-defined computation will be performed which can depend on the current state of the simulation.

If the result of the if test is TRUE, then command1 is executed. This can be any valid LAMMPS input script command. If the command is more than 1 word, it should be enclosed in double quotes, so that it will be treated as a single argument, as in the examples above.

The if command can contain an optional "else" clause. If it does and the result of the if test is FALSE, then command2 is executed.

Note that if either command1 or command2 is a bogus LAMMPS command, such as "exit" in the first example, then executing the command will cause LAMMPS to halt.

**Restrictions:** none

**Related commands:**

[variable](#)

**Default:** none

## improper\_style class2 command

### Syntax:

```
improper_style class2
```

### Examples:

```
improper_style class2
improper_coeff 1 100.0 0
```

### Description:

The *class2* improper style uses the potential

$$\begin{aligned}
 E &= E_i + E_{aa} \\
 E_i &= K \left[ \frac{\chi_{ijkl} + \chi_{kjli} + \chi_{ljik}}{3} - \chi_0 \right]^2 \\
 E_{aa} &= M_1(\theta_{ijk} - \theta_1)(\theta_{kjl} - \theta_3) + \\
 &\quad M_2(\theta_{ijk} - \theta_1)(\theta_{ijl} - \theta_2) + \\
 &\quad M_3(\theta_{ijl} - \theta_2)(\theta_{kjl} - \theta_3)
 \end{aligned}$$

where  $E_i$  is the improper term and  $E_{aa}$  is an angle–angle term. The 3  $\chi$  terms in  $E_i$  are an average over 3 out-of-plane angles.

The 4 atoms in an improper quadruplet (listed in the data file read by the [read\\_data](#) command) are ordered I,J,K,L.  $\chi_{IJKL}$  refers to the angle between the plane of I,J,K and the plane of J,K,L, and the bond JK lies in both planes. Similarly for  $\chi_{KJLI}$  and  $\chi_{LJIK}$ . Note that atom J appears in the common bonds (JI, JK, JL) of all 3  $\chi$  terms. Thus J (the 2nd atom in the quadruplet) is the atom of symmetry in the 3  $\chi$  angles.

The subscripts on the various theta's refer to different combinations of 3 atoms (I,J,K,L) used to form a particular angle. E.g.  $\theta_{IJL}$  is the angle formed by atoms I,J,L with J in the middle.  $\theta_1$ ,  $\theta_2$ ,  $\theta_3$  are the equilibrium positions of those angles. Again, atom J (the 2nd atom in the quadruplet) is the atom of symmetry in the theta angles, since it is always the center atom.

Since atom J is the atom of symmetry, normally the bonds J–I, J–K, J–L would exist for an improper to be defined between the 4 atoms, but this is not required.

See [\(Sun\)](#) for a description of the COMPASS *class2* force field.

The following coefficients must be defined for each improper type via the [improper\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

For this style, coefficients for the  $E_i$  formula can be specified in either the input script or data file. These are the 2 coefficients:

- K (energy/radian<sup>2</sup>)
- $\chi_0$  (degrees)

X0 is specified in degrees, but LAMMPS converts it to radians internally; hence the units of K are in energy/radian<sup>2</sup>.

Coefficients for the Eaa formula can only be specified in the data file. For the Eaa formula, the coefficients are listed under a "AngleAngle Coeffs" heading and each line lists 6 coefficients:

- M1 (energy/distance)
- M2 (energy/distance)
- M3 (energy/distance)
- theta1 (degrees)
- theta2 (degrees)
- theta3 (degrees)

The theta values are specified in degrees, but LAMMPS converts them to radians internally; hence the units of M are in energy/radian<sup>2</sup>.

**Restrictions:**

This improper style can only be used if LAMMPS was built with the "class2" package. See the [Making LAMMPS](#) section for more info on packages.

**Related commands:**

[improper\\_coeff](#)

**Default:** none

---

(Sun) Sun, J Phys Chem B 102, 7338–7364 (1998).



## improper\_coeff command

### Syntax:

```
improper_coeff N args
```

- N = improper type (see asterisk form below)
- args = coefficients for one or more improper types

### Examples:

```
improper_coeff 1 300.0 0.0
improper_coeff * 80.2 -1 2
improper_coeff *4 80.2 -1 2
```

### Description:

Specify the improper force field coefficients for one or more improper types. The number and meaning of the coefficients depends on the improper style. Improper coefficients can also be set in the data file read by the [read\\_data](#) command or in a restart file.

N can be specified in one of two ways. An explicit numeric value can be used, as in the 1st example above. Or a wild-card asterisk can be used to set the coefficients for multiple improper types. This takes the form "\*" or "\*n" or "n\*" or "m\*n". If N = the number of improper types, then an asterisk with no numeric values means all types from 1 to N. A leading asterisk means all types from 1 to n (inclusive). A trailing asterisk means all types from n to N (inclusive). A middle asterisk means all types from m to n (inclusive).

Note that using an improper\_coeff command can override a previous setting for the same improper type. For example, these commands set the coeffs for all improper types, then overwrite the coeffs for just improper type 2:

```
improper_coeff * 300.0 0.0
improper_coeff 2 50.0 0.0
```

A line in a data file that specifies improper coefficients uses the exact same format as the arguments of the improper\_coeff command in an input script, except that wild-card asterisks should not be used since coefficients for all N types must be listed in the file. For example, under the "Improper Coeffs" section of a data file, the line that corresponds to the 1st example above would be listed as

```
1 300.0 0.0
```

---

Here is an alphabetic list of improper styles defined in LAMMPS. Click on the style to display the formula it computes and coefficients specified by the associated [improper\\_coeff](#) command:

- [improper\\_style none](#) – turn off improper interactions
- [improper\\_style hybrid](#) – define multiple styles of improper interactions
- [improper\\_style class2](#) – COMPASS (class 2) improper
- [improper\\_style cvff](#) – CVFF improper
- [improper\\_style harmonic](#) – harmonic improper

---

### Restrictions:

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

An improper style must be defined before any improper coefficients are set, either in the input script or in a data file.

**Related commands:**

[improper\\_style](#)

**Default:** none

## improper\_style cvff command

### Syntax:

```
improper_style cvff
```

### Examples:

```
improper_style cvff  
improper_coeff 1 80.0 -1 4
```

### Description:

The *cvff* improper style uses the potential

$$E = K[1 + d \cos(n\phi)]$$

where phi is the Wilson out-of-plane angle.

If the 4 atoms in an improper quadruplet (listed in the data file read by the [read\\_data](#) command) are ordered I,J,K,L then the Wilson angle is between the plane of I,J,K and the plane of J,K,L. This is essentially a dihedral angle, which is why the formula for this improper style is the same as for [dihedral\\_style harmonic](#). Alternatively, you can think of atoms J,K,L as being in a plane, and atom I above the plane, and the Wilson angle as a measure of how far out-of-plane I is with respect to the other 3 atoms.

Note that defining 4 atoms to interact in this way, does not mean that bonds necessarily exist between I-J, J-K, or K-L, as they would in a linear dihedral. Normally, the bonds I-J, I-K, I-L would exist for an improper to be defined between the 4 atoms.

The following coefficients must be defined for each improper type via the [improper\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- K (energy)
- d (+1 or -1)
- n (0,1,2,3,4,6)

### Restrictions:

This improper style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[improper\\_coeff](#)

**Default:** none

## improper\_style harmonic command

### Syntax:

```
improper_style harmonic
```

### Examples:

```
improper_style harmonic  
improper_coeff 1 100.0 0
```

### Description:

The *harmonic* improper style uses the potential

$$E = K(\chi - \chi_0)^2$$

where  $\chi$  is the improper angle,  $\chi_0$  is its equilibrium value, and  $K$  is a prefactor. Note that the usual 1/2 factor is included in  $K$ .

If the 4 atoms in an improper quadruplet (listed in the data file read by the [read\\_data](#) command) are ordered I,J,K,L then  $\chi$  is the angle between the plane of I,J,K and the plane of J,K,L. Alternatively, you can think of atoms J,K,L as being in a plane, and atom I above the plane, and  $\chi$  as a measure of how far out-of-plane I is with respect to the other 3 atoms.

Note that defining 4 atoms to interact in this way, does not mean that bonds necessarily exist between I-J, J-K, or K-L, as they would in a linear dihedral. Normally, the bonds I-J, I-K, I-L would exist for an improper to be defined between the 4 atoms.

The following coefficients must be defined for each improper type via the [improper\\_coeff](#) command as in the example above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- $K$  (energy/radian<sup>2</sup>)
- $\chi_0$  (degrees)

$\chi_0$  is specified in degrees, but LAMMPS converts it to radians internally; hence the units of  $K$  are in energy/radian<sup>2</sup>.

### Restrictions:

This improper style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[improper\\_coeff](#)

**Default:** none

## improper\_style hybrid command

### Syntax:

```
improper_style hybrid style1 style2 ...
```

- style1,style2 = list of one or more improper styles

### Examples:

```
improper_style hybrid harmonic helix
improper_coeff 1 harmonic 120.0 30
improper_coeff 2 cvff 20.0 -1 2
```

### Description:

The *hybrid* style enables the use of multiple improper styles in one simulation. An improper style is assigned to each improper type. For example, impropers in a polymer flow (of improper type 1) could be computed with a *harmonic* potential and impropers in the wall boundary (of improper type 2) could be computed with a *cvff* potential. The assignment of improper type to style is made via the [improper\\_coeff](#) command or in the data file.

In the `improper_coeff` command, the first coefficient sets the improper style and the remaining coefficients are those appropriate to that style. In the example above, the 2 `improper_coeff` commands would set impropers of improper type 1 to be computed with a *harmonic* potential with coefficients 120.0, 30 for K, X0. Improper type 2 would be computed with a *cvff* potential with coefficients 20.0, -1, 2 for K, d, n.

If the improper *class2* potential is one of the hybrid styles, it requires additional AngleAngle coefficients be specified in the data file. These lines must also have an additional "class2" argument added after the improper type. For improper types which are assigned to other hybrid styles, use the style name (e.g. "harmonic") appropriate to that style. The AngleAngle coeffs for that improper type will then be ignored.

An improper style of *none* can be specified as an argument to `improper_style hybrid` and the corresponding `improper_coeff` commands, if you desire to turn off certain improper types.

### Restrictions:

This improper style can only be used if LAMMPS was built with the "molecular" package (which it is by default). See the [Making LAMMPS](#) section for more info on packages.

### Related commands:

[improper\\_coeff](#)

**Default:** none

## improper\_style none command

### Syntax:

```
improper_style none
```

### Examples:

```
improper_style none
```

### Description:

Using an improper style of none means improper forces are not computed, even if quadruplets of improper atoms were listed in the data file read by the [read\\_data](#) command.

**Restrictions:** none

**Related commands:** none

**Default:** none

## improper\_style command

### Syntax:

```
improper_style style
```

- style = *none* or *hybrid* or *class2* or *cvff* or *harmonic*

### Examples:

```
improper_style harmonic  
improper_style cvff  
improper_style hybrid cvff harmonic
```

### Description:

Set the formula(s) LAMMPS uses to compute improper interactions between quadruplets of atoms, which remain in force for the duration of the simulation. The list of improper quadruplets is read in by a [read\\_data](#) or [read\\_restart](#) command from a data or restart file. Note that the ordering of the 4 atoms in an improper quadruplet determines the definition of the improper angle used in the formula for each style. See the doc pages of individual styles for details.

Hybrid models where impropers are computed using different improper potentials can be setup using the *hybrid* improper style.

The coefficients associated with an improper style can be specified in a data or restart file or via the [improper\\_coeff](#) command.

All improper potentials store their coefficient data in binary restart files which means [improper\\_style](#) and [improper\\_coeff](#) commands do not need to be re-specified in an input script that restarts a simulation. See the [read\\_restart](#) command for details on how to do this. The one exception is that [improper\\_style hybrid](#) only stores the list of sub-styles in the restart file; improper coefficients need to be re-specified.

IMPORTANT NOTE: When both an improper and pair style is defined, the [special\\_bonds](#) command often needs to be used to turn off (or weight) the pairwise interaction that would otherwise exist between a group of 4 bonded atoms.

---

Here is an alphabetic list of improper styles defined in LAMMPS. Click on the style to display the formula it computes and coefficients specified by the associated [improper\\_coeff](#) command:

- [improper\\_style none](#) – turn off improper interactions
- [improper\\_style hybrid](#) – define multiple styles of improper interactions
- [improper\\_style class2](#) – COMPASS (class 2) improper
- [improper\\_style cvff](#) – CVFF improper
- [improper\\_style harmonic](#) – harmonic improper

---

### Restrictions:

Improper styles can only be set for atom\_style choices that allow impropers to be defined.

Most improper styles are part of the "molecular" package. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info on packages. The doc pages for individual improper potentials tell if it is part of a package.

**Related commands:**

[improper\\_coeff](#)

**Default:**

```
improper_style none
```



## include command

### Syntax:

```
include file
```

- file = filename of new input script to switch to

### Examples:

```
include newfile  
include in.run2
```

### Description:

This command opens a new input script file and begins reading LAMMPS commands from that file. When the new file is finished, the original file is returned to. Include files can be nested as deeply as desired. If input script A includes script B, and B includes A, then LAMMPS could run for a long time.

If the filename is a variable (see the [variable](#) command), different processor partitions can run different input scripts.

**Restrictions:** none

### Related commands:

[variable](#), [jump](#)

**Default:** none

## jump command

### Syntax:

```
jump file label
```

- file = filename of new input script to switch to
- label = optional label within file to jump to

### Examples:

```
jump newfile  
jump in.run2 runloop
```

### Description:

This command closes the current input script file, opens the file with the specified name, and begins reading LAMMPS commands from that file. The original file is not returned to, although by using multiple jump commands it is possible to chain from file to file or back to the original file.

Optionally, if a 2nd argument is used, it is treated as a label and the new file is scanned (without executing commands) until the label is found, and commands are executed from that point forward. This can be used to loop over a portion of the input script, as in this example. These commands perform 10 runs, each of 10000 steps, and create 10 dump files named file.1, file.2, etc. The [next](#) command is used to exit the loop after 10 iterations. When the "a" variable has been incremented for the 10th time, it will cause the next jump command to be skipped.

```
variable a loop 10  
label loop  
dump 1 all atom 100 file.$a  
run 10000  
undump 1  
next a  
jump in.lj loop
```

If the jump *file* argument is a variable, the jump command can be used to cause different processor partitions to run different input scripts. In this example, LAMMPS is run on 40 processors, with 4 partitions of 10 procs each. An in.file containing the example variable and jump command will cause each partition to run a different simulation.

```
mpirun -np 40 lmp_ibm -partition 4x10 -in in.file  
  
variable f world script.1 script.2 script.3 script.4  
jump $f
```

### Restrictions:

If you jump to a file and it does not contain the specified label, LAMMPS will come to the end of the file and exit.

### Related commands:

[variable](#), [include](#), [label](#), [next](#)

**Default:** none

## kspace\_modify command

### Syntax:

```
kspace_modify keyword value ...
```

- one or more keyword/value pairs may be listed
- keyword = *mesh* or *order* or *gewald* or *slab*

```
mesh value = x y z
  x,y,z = PPPM FFT grid size in each dimension
order value = N
  N = grid extent of Gaussian for PPPM mapping of each charge
gewald value = r
  r = PPPM G-ewald parameter
slab value = volfactor
  volfactor = ratio of the total extended volume used in the
              2d approximation compared with the volume of the simulation domain
```

### Examples:

```
kspace_modify mesh 24 24 30 order 6
kspace_modify slab 3.0
```

### Description:

Set parameters used by the kspace solvers defined by the [kspace\\_style](#) command. Not all parameters are relevant to all kspace styles.

The *mesh* keyword sets the 3d FFT grid size for kspace style ppm. Each dimension must be factorizable into powers of 2, 3, and 5. When this option is not set, the PPPM solver chooses its own grid size, consistent with the user-specified accuracy and pairwise cutoff. Values for x,y,z of 0,0,0 unset the option.

The *order* keyword determines how many grid spacings an atom's charge extends when it is mapped to the FFT grid in kspace style ppm. The default for this parameter is 5, which means each charge spans 5 grid cells in each dimension.

The *gewald* keyword sets the value of the PPPM G-ewald parameter. Without this setting, LAMMPS chooses the parameter automatically as a function of cutoff, precision, grid spacing, etc. This means it can vary from one simulation to the next which may not be desirable for matching a KSpace solver to a pre-tabulated pairwise potential. This setting can also be useful if PPPM fails to choose a good grid spacing and G-ewald parameter automatically. If the value is set to 0.0, LAMMPS will choose the G-ewald parameter automatically.

The *slab* keyword allows an Ewald or PPPM solver to be used for a systems that are periodic in x,y but non-periodic in z – a [boundary](#) setting of "boundary p p f". This is done by treating the system as if it were periodic in z, but inserting empty volume between atom slabs and removing dipole inter-slab interactions so that slab-slab interactions are effectively turned off. The volfactor value sets the ratio of the extended dimension in z divided by the actual dimension in z. The recommended value is 3.0. A larger value is inefficient; a smaller value introduces unwanted slab-slab interactions. The use of fixed boundaries in z means that the user must prevent particle migration beyond the initial z-bounds, typically by providing a wall-style fix.

**Restrictions:** none

**Related commands:**

[kspace\\_style](#), [boundary](#)

**Default:**

The option defaults are `mesh = 0 0 0`, `order = 5`, `gewald = 0.0`, and `slab = 1.0`.

## kspace\_style command

### Syntax:

```
kspace_style style value
```

- style = *none* or *ewald* or *pppm*

```
none value = none
ewald value = precision
precision = desired accuracy
pppm value = precision
precision = desired accuracy
pppm/tip4p value = precision
precision = desired accuracy
```

### Examples:

```
kspace_style ppm 1.0e-4
kspace_style none
```

### Description:

Define a K-space solver for LAMMPS to use each timestep to compute long-range Coulombic interactions. When such a solver is used in conjunction with an appropriate pair style, the cutoff for Coulombic interactions is effectively infinite; each charge in the system interacts with charges in an infinite array of periodic images of the simulation domain.

The *ewald* style performs a standard Ewald summation as described in any solid-state physics text.

The *pppm* style invokes a particle-particle particle-mesh solver ([Hockney](#)) which maps atom charge to a 3d mesh, uses 3d FFTs to solve Poisson's equation on the mesh, then interpolates electric fields on the mesh points back to the atoms. It is closely related to the particle-mesh Ewald technique (PME) ([Darden](#)) used in AMBER and CHARMM. The cost of traditional Ewald summation scales as  $N^{3/2}$  where  $N$  is the number of atoms in the system. The PPPM solver scales as  $N \log(N)$  due to the FFTs, so it is almost always a faster choice ([Pollock](#)).

The *pppm/tip4p* style is identical to the *pppm* style except that it adds a charge at the massless 4th site in each TIP4P water molecule. It should be used with [pair styles](#) with a *long/tip4p* in their style name.

When a kspace style is used, a pair style that includes the short-range correction to the pairwise Coulombic forces must also be selected. These styles are ones that have a *coul/long* in their style name.

A precision value of 1.0e-4 means one part in 10000. This setting is used in conjunction with the pairwise cutoff to determine the number of K-space vectors for style *ewald* or the FFT grid size for style *pppm*.

### Restrictions:

A simulation must be 3d and periodic in all dimensions to use an Ewald or PPPM solver. The only exception is if the slab option is set with [kspace\\_modify](#), in which case the xy dimensions must be periodic and the z dimension must be non-periodic.

Kspace styles are part of the "kspace" package. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

When using a long-range pairwise TIP4P potential, you must use kspace style *pppm/tip4p* and vice versa.

**Related commands:**

[kspace\\_modify](#), [pair\\_style](#) lj/cut/coul/long, [pair\\_style](#) lj/charmm/coul/long

**Default:**

```
kspace_style none
```

---

**(Darden)** Darden, York, Pedersen, J Chem Phys, 98, 10089 (1993).

**(Hockney)** Hockney and Eastwood, Computer Simulation Using Particles, Adam Hilger, NY (1989).

**(Pollock)** Pollock and Glosli, Comp Phys Comm, 95, 93 (1996).

## label command

### Syntax:

```
label ID
```

- ID = string used as label name

### Examples:

```
label xyz  
label loop
```

### Description:

Label this line of the input script with the chosen ID. Unless a [jump](#) command was used previously, this does nothing. But if a [jump](#) command was used with a label argument to begin invoking this script file, then all command lines in the script prior to this line will be ignored. I.e. execution of the script will begin at this line. This is useful for looping over a section of the input script as discussed in the [jump](#) command.

**Restrictions:** none

**Related commands:** none

**Default:** none



## lattice command

### Syntax:

```
lattice style scale keyword values ...
```

- style = *none* or *sc* or *bcc* or *fcc* or *diamond* or *sq* or *sq2* or *hex* or *custom*
- scale = scale factor between lattice and simulation box

```
for style none:
    scale is not specified (nor any optional args)
for all other styles:
    scale = reduced density rho* (for LJ units)
    scale = lattice constant in Angstroms (for real or metal units)
```

- zero or more keyword/value pairs may be appended
- keyword = *origin* or *orient* or *spacing* or *a1* or *a2* or *a3* or *basis*

```
origin values = x y z
    x,y,z = fractions of a unit cell (0 <= x,y,z <1)
orient values = dim i j k
    dim = x or y or z
    i,j,k = integer lattice directions
spacing values = dx dy dz
    dx,dy,dz = lattice spacings in the x,y,z box directions
a1,a2,a3 values = x y z
    x,y,z = primitive vector components that define unit cell
basis values = x y z
    x,y,z = fractional coords of a basis atom (0 <= x,y,z <1)
```

### Examples:

```
lattice fcc 3.52
lattice hex 0.85
lattice sq 0.8 origin 0.0 0.5 0.0 orient x 1 1 0 orient y -1 1 0
lattice custom 3.52 a1 1.0 0.0 0.0 a2 0.5 1.0 0.0 a3 0.0 0.0 0.5 &          basis 0.0 0.0
lattice none
```

### Description:

Define a lattice for use by other commands. In LAMMPS, a lattice is simply a set of points in space, determined by a unit cell with basis atoms, that is replicated infinitely in all dimensions. The arguments of the lattice command can be used to define a wide variety of crystallographic lattices.

A lattice is used by LAMMPS in two ways. First, the [create\\_atoms](#) command creates atoms on the lattice points inside the simulation box. Note that the [create\\_atoms](#) command allows different atom types to be assigned to different basis atoms of the lattice. Second, the lattice spacing in the x,y,z dimensions implied by the lattice, can be used by other commands as distance units (e.g. [create\\_box](#), [region](#) and [velocity](#)), which are often convenient to use when the underlying problem geometry is atoms on a lattice.

The lattice style must be consistent with the dimension of the simulation – see the [dimension](#) command. Styles *sc* or *bcc* or *fcc* or *diamond* are for 3d problems. Styles *sq* or *sq2* or *hex* are for 2d problems. Style *custom* can be used for either 2d or 3d problems.

A lattice consists of a unit cell, a set of basis atoms within that cell, and a set of transformation parameters (scale, origin, orient) that map the unit cell into the simulation box. The vectors  $a_1, a_2, a_3$  are the edge vectors of the unit cell. This is the nomenclature for "primitive" vectors in solid-state crystallography, but in LAMMPS the unit cell they determine does not have to be a "primitive cell" of minimum volume.

---

Lattices of style *sc*, *fcc*, *bcc*, and *diamond* are 3d lattices that define a cubic unit cell with edge length = 1.0. This means  $a_1 = 1.0\ 0.0\ 0.0$ ,  $a_2 = 0.0\ 1.0\ 0.0$ , and  $a_3 = 0.0\ 0.0\ 1.0$ . The placement of the basis atoms within the unit cell are described in any solid-state physics text. A *sc* lattice has 1 basis atom at the lower-left-bottom corner of the cube. A *bcc* lattice has 2 basis atoms, one at the corner and one at the center of the cube. A *fcc* lattice has 4 basis atoms, one at the corner and 3 at the cube face centers. A *diamond* lattice has 8 basis atoms.

Lattices of style *sq* and *sq2* are 2d lattices that define a square unit cell with edge length = 1.0. This means  $a_1 = 1.0\ 0.0\ 0.0$  and  $a_2 = 0.0\ 1.0\ 0.0$ . A *sq* lattice has 1 basis atom at the lower-left corner of the square. A *sq2* lattice has 2 basis atoms, one at the corner and one at the center of the square. A *hex* style is also a 2d lattice, but the unit cell is rectangular, with  $a_1 = 1.0\ 0.0\ 0.0$  and  $a_2 = 0.0\ \sqrt{3.0}\ 0.0$ . It has 2 basis atoms, one at the corner and one at the center of the rectangle.

A lattice of style *custom* allows you to specify  $a_1$ ,  $a_2$ ,  $a_3$ , and a list of basis atoms to put in the unit cell. By default,  $a_1, a_2, a_3$  are 3 orthogonal unit vectors (edges of a unit cube). But you can specify them to be of any length and non-orthogonal to each other, so that they describe a tilted parallelepiped. Via the *basis* keyword you add atoms, one at a time, to the unit cell. Its arguments are fractional coordinates ( $0.0 \leq x, y, z < 1.0$ ), so that a value of 0.5 means a position half-way across the unit cell in that dimension.

---

This sub-section discusses the arguments that determine how the idealized unit cell is transformed into a lattice of points within the simulation box.

The *scale* argument determines how the size of the unit cell will be scaled when mapping it into the simulation box. I.e. it determines a multiplicative factor to apply to the unit cell, to convert it to a lattice of the desired size and distance units in the simulation box. The meaning of the *scale* argument depends on the [units](#) being used in your simulation.

For unit style *real* or *metal*, the scale argument is in Angstroms. For example, if the unit cell is a unit cube with edge length 1.0, setting *scale* = 3.52 would create a cubic lattice with a spacing of 3.52 Angstroms.

For unit style *lj*, the scale argument is the Lennard-Jones reduced density, typically written as  $\rho^*$ . LAMMPS converts this value into the multiplicative factor via the formula " $\text{factor}^{\text{dim}} = \rho / \rho^*$ ", where  $\rho = N/V$  with  $V$  = the volume of the lattice unit cell and  $N$  = the number of basis atoms in the unit cell (described below), and  $\text{dim} = 2$  or  $3$  for the dimensionality of the simulation. Effectively, this means that if LJ particles of size  $\sigma = 1.0$  are used in the simulation, the lattice of particles will be at the desired reduced density.

The *origin* option specifies how the unit cell will be shifted or translated when mapping it into the simulation box. The  $x, y, z$  values are fractional values ( $0.0 \leq x, y, z < 1.0$ ) meaning shift the lattice by a fraction of the lattice spacing in each dimension. The meaning of "lattice spacing" is discussed below.

The *orient* option specifies how the unit cell will be rotated when mapping it into the simulation box. The *dim* argument is one of the 3 coordinate axes in the simulation box. The other 3 arguments are the crystallographic direction in the lattice that you want to orient along that axis, specified as integers. E.g. "*orient* x 2 1 0" means the  $x$ -axis in the simulation box will be the [210] lattice direction. The 3 lattice directions you specify must be mutually orthogonal and obey the right-hand rule, i.e. ( $X \text{ cross } Y$ ) points in the  $Z$  direction. Note that this description is really only valid for orthogonal lattices. if you are using the more general lattice style *custom* with non-orthogonal  $a_1, a_2, a_3$  vectors, then think of the 3 *orient* options as creating a 3x3 rotation matrix which is applied to  $a_1, a_2, a_3$  to rotate the original unit cell to a new orientation in the simulation box.

---

Several LAMMPS commands have the option to use distance units that are inferred from "lattice spacing" in the x,y,z box directions. E.g. the [region](#) command can create a block of size 10x20x20, where 10 means 10 lattice spacings in the x direction.

The *spacing* option sets the 3 lattice spacings directly. All must be non-zero (use 1.0 for dz in a 2d simulation). The specified values are multiplied by the multiplicative factor described above that is associated with the scale factor. Thus a spacing of 1.0 means one unit cell independent of the scale factor. This option can be useful if the spacings LAMMPS computes are inconvenient to use in subsequent commands, which can be the case for non-orthogonal or rotated lattices.

If the *spacing* option is not specified, the lattice spacings are computed by LAMMPS in the following way. A unit cell of the lattice is mapped into the simulation box (scaled, shifted, rotated), so that it now has (perhaps) a modified shape and orientation. The lattice spacing in X is defined as the difference between the min/max extent of the x coordinates of the 8 corner points of the modified unit cell. Similarly, the Y and Z lattice spacings are defined as the difference in the min/max of the y and z coordinates.

Note that if the unit cell is orthogonal with axis-aligned edges (not rotated via the *orient* keyword), then the lattice spacings in each dimension are simply the scale factor (described above) multiplied by the length of  $a_1, a_2, a_3$ . Thus a *hex* style lattice with a scale factor of 3.0 Angstroms, would have a lattice spacing of 3.0 in x and  $3 \times \sqrt{3}$  in y.

**IMPORTANT NOTE:** For non-orthogonal unit cells and/or when a rotation is applied via the *orient* keyword, then the lattice spacings may be less intuitive. In particular, in these cases, there is no guarantee that the lattice spacing is an integer multiple of the periodicity of the lattice in that direction. Thus, if you create an orthogonal periodic simulation box whose size in a dimension is a multiple of the lattice spacing, and then fill it with atoms via the [create\\_atoms](#) command, you will NOT necessarily create a periodic system. I.e. atoms may overlap incorrectly at the faces of the simulation box.

Regardless of these issues, the values of the lattice spacings LAMMPS calculates are printed out, so their effect in commands that use the spacings should be decipherable.

---

The command "lattice none" can be used to turn off a previous lattice definition. Any command that attempts to use the lattice directly ([create\\_atoms](#)) or associated lattice spacings will then generate an error. No additional arguments need be used with "lattice none".

---

### Restrictions:

The *a1, a2, a3, basis* keywords can only be used with style *custom*.

### Related commands:

[dimension](#), [create\\_atoms](#), [region](#)

### Default:

```
lattice none
```

For other lattice styles, the option defaults are *origin* = 0.0 0.0 0.0, *orient* = x 1 0 0, *orient* = y 0 1 0, *orient* = z 0 0 1, *a1* = 1.0 0.0 0.0, *a2* = 0.0 1.0 0.0, and *a3* = 0.0 0.0 1.0.

## log command

### Syntax:

```
log file
```

- file = name of new logfile

### Examples:

```
log log.equil
```

### Description:

This command closes the current LAMMPS log file, opens a new file with the specified name, and begins logging information to it. If the specified file name is *none*, then no new log file is opened.

If multiple processor partitions are being used, the file name should be a variable, so that different processors do not attempt to write to the same log file.

The file "log.lammps" is the default log file for a LAMMPS run. The name of the initial log file can also be set by the command-line switch `-log`. See [this section](#) for details.

**Restrictions:** none

**Related commands:** none

### Default:

The default LAMMPS log file is named log.lammps

## mass command

### Syntax:

```
mass I value
```

- I = atom type (see asterik form below)
- value = mass

### Examples:

```
mass 1 1.0
mass * 62.5
mass 2* 62.5
```

### Description:

Set the mass for all atoms of one or more atom types. Mass values can also be set in the [read\\_data](#) data file. See the [units](#) command for what mass units to use.

Most atom styles require masses to be specified. One exception is [atom\\_style granular](#), where masses are defined for individual atoms, not types. [Pair\\_style eam](#) defines the masses of atom types in the EAM potential file.

I can be specified in one of two ways. An explicit numeric value can be used, as in the 1st example above. Or a wild-card asterik can be used to set the mass for multiple atom types. This takes the form "\*" or "\*n" or "n\*" or "m\*n". If N = the number of atom types, then an asterik with no numeric values means all types from 1 to N. A leading asterik means all types from 1 to n (inclusive). A trailing asterik means all types from n to N (inclusive). A middle asterik means all types from m to n (inclusive).

A line in a data file that specifies mass uses the same format as the arguments of the mass command in an input script, except that no wild-card asterik can be used. For example, under the "Masses" section of a data file, the line that corresponds to the 1st example above would be listed as

```
1 1.0
```

### Restrictions:

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

All masses must be defined before a simulation is run (if the atom style requires masses be set). They must also all be defined before a [velocity](#) or [fix shake](#) command is used.

**Related commands:** none

**Default:** none

## min\_modify command

### Syntax:

min\_modify keyword values ...

- one or more keyword/value pairs may be listed

```
keyword = linestyle or dmin or dmax or lineiter  
  linestyle value = secant or scan  
  dmin value = min  
    min = minimum distance for line search to move (distance units)  
  dmax value = max  
    max = maximum distance for line search to move (distance units)  
  lineiter value = N  
    N = max number of iterations in a line search
```

### Examples:

```
min_modify linestyle scan dmin 0.001 dmax 0.2  
min_modify lineiter 5
```

### Description:

This command sets parameters that affect the minimization algorithms. The various settings may effect the convergence rate and overall number of force evaluations required by a minimization, so users can experiment with these parameters to tune their minimizations.

The *linestyle* sets the algorithm used for 1d line searches at each outer iteration of the minimizer. The *secant* style uses two successive force/energy evaluations to create a parabola and pick its minimum as an estimate of the next iteration's 1d minimum. The *scan* style starts its 1d search at *dmin* and doubles the distance along the line at which the energy is computed until the minimum is passed. It continues only as far as *dmax*. Normally, the *secant* method should find more accurate 1d minimums in less iterations, but the *scan* method can be more robust.

The *dmin* and *dmax* settings are both used by the *scan* line search as described above. For the *secant* line search, only the *dmin* value is used to pick an initial point to begin the secant approximation.

The *lineiter* setting is used by the *secant* algorithm to limit its iterations. The smaller the setting, the more inaccurate the line search becomes. Nonlinear conjugate gradient is not thought to require high-accuracy line searches in order to converge efficiently.

**Restrictions:** none

**Related commands:**

[min\\_style](#), [minimize](#)

**Default:**

The option defaults are *linestyle* = *secant*, *dmin* = 1.0e-5, *dmax* = 0.1, and *lineiter* = 10.

## min\_style command

### Syntax:

```
min_style style
```

- style = *cg* or *cg/fr* or *sd*

### Examples:

```
min_style cg  
min_style sd
```

### Description:

Choose a minimization algorithm to use when a [minimize](#) command is performed.

Style *cg* is the Polak–Ribiere (PR) version of the conjugate gradient (CG) algorithm. At each iteration the force gradient is combined with the previous iteration information to compute a new search direction perpendicular (conjugate) to previous search directions. The PR variant affects how the direction is chosen and how the CG method is restarted when it ceases to make progress. The PR variant is thought to be the most effective CG choice.

Style *cg/fr* is the Fletcher–Reeves version of the conjugate gradient algorithm.

Style *sd* is a steepest descent algorithm. At each iteration, the downhill direction corresponding to the force vector (negative gradient of energy) is searched along by a 1d line search. Typically, steepest descent will not converge as quickly as CG, but may be more robust in some situations.

**Restrictions:** none

**Related commands:**

[min\\_modify](#), [minimize](#)

**Default:**

```
min_style cg
```

## minimize command

### Syntax:

```
minimize tolerance maxiter maxeval
```

- tolerance = stopping tolerance
- maxiter = max iterations of minimizer
- maxeval = max number of total force/energy evaluations

### Examples:

```
minimize 1.0e-4 100 1000
```

### Description:

Perform an energy minimization of the system, by adjusting each atom's atomic coordinates. The algorithm used is set by the [min\\_style](#) command. Minimize commands can be interspersed with [run](#) commands to alternate between relaxation and dynamics. The minimizers are implemented in a robust fashion that should allow for systems with highly overlapped atoms (large energies and forces) to still be minimized by pushing the atoms off of each other.

Following the minimization a statistical summary is printed that includes the energy change and convergence criteria information.

A minimization involves an outer iteration loop which sets the search direction along which coordinates are changed. An inner iteration is then performed using a line search algorithm. The line search typically evaluates forces and energies several times to set new coordinates. The minimization stops if any of several criteria are met:

- the change in energy between outer iterations is less than the tolerance
- the number of outer iterations exceeds maxiter
- the number of force evaluations exceeds maxeval
- the 3N dimensional force vector goes (nearly) to zero

For the first criterion, the specified tolerance is unitless; it is met when the ratio of the energy delta to the energy magnitude is equal to the tolerance (e.g. one part in  $10^4$  in the example above).

During a minimization, the outer iteration count is treated as a timestep. Output is triggered by this timestep, e.g. thermodynamic output or dump and restart files.

For optimal convergence, a [pair style](#) that goes smoothly to 0.0 at the cutoff distance for both energy and force should typically be used though this is not required. Examples include *pair/lj/charmm/coul/charmm* and *pair/lj/charmm/coul/long*. If a *soft* potential is used the Astop value is used for the prefactor (no time dependence).

Only some fixes (typically those that apply force constraints) are invoked during minimization. See the doc pages for individual [fix](#) commands to see which ones are relevant.

**IMPORTANT NOTE:** Some fixes which are invoked during minimization have an associated potential energy. For that energy to be included in the total potential energy of the system (the quantity being minimized), you



MUST enable the [fix\\_modify energy](#) option for that fix. The doc pages for individual [fix](#) commands specify if this should be done.

### Restrictions:

Features that are not yet implemented are listed here, in case someone knows how they could be coded:

It is an error to use [fix shake](#) with minimization because it turns off bonds that should be included in the potential energy of the system. The effect of a fix shake can be approximated during a minimization by using stiff spring constants for the bonds and/or angles that would normally be constrained by the SHAKE algorithm.

[Fix rigid](#) is also not supported by minimization. It is not an error to have it defined, but the energy minimization will not keep the defined body(s) rigid during the minimization. Note that if bonds, angles, etc internal to a rigid body have been turned off (e.g. via [neigh\\_modify exclude](#)), they will not contribute to the potential energy which is probably not what is desired.

The volume of the simulation domain is not allowed to change during a minimization. Ideally we would allow a fix such as *npt* to impose an external pressure that would be included in the minimization (i.e. allow the box dimensions to change), but this has not yet been implemented.

### Related commands:

[min\\_modify](#), [min\\_style](#), [run\\_style](#)

**Default:** none

## neigh\_modify command

### Syntax:

neigh\_modify keyword values ...

- one or more keyword/value pairs may be listed

```
keyword = delay or every or check or exclude or page or one
delay value = N
    N = delay building until this many steps since last build
every value = M
    M = build neighbor list every this many steps
check value = yes or no
    yes = only build if some atom has moved half the skin distance or more
    no = always build on 1st step that every and delay are satisfied
exclude values:
    type M N
        M,N = exclude if one atom in pair is type M, other is type N
    group group1-ID group2-ID
        group1-ID,group2-ID = exclude if one atom is in 1st group, other in 2nd
    molecule group-ID
        groupname = exclude if both atoms are in the same molecule and in the same group
    none
        delete all exclude settings
page value = N
    N = number of pairs stored in a single neighbor page
one value = N
    N = max number of neighbors of one atom
```

### Examples:

```
neigh_modify every 2 delay 10 check yes page 100000
neigh_modify exclude type 2 3
neigh_modify exclude group frozen frozen check no
neigh_modify exclude group residuel chain3
neigh_modify exclude molecule rigid
```

### Description:

This command sets parameters that affect the pairwise neighbor list.

The *every*, *delay*, and *check* options affect how often the list is built as a simulation runs. The *delay* setting means never build a new list until at least N steps after the previous build. The *every* setting means build the list every M steps (after the delay has passed). If the *check* setting is *no*, the list is built on the 1st step that satisfies the *delay* and *every* settings. If the *check* setting is *yes*, then the list is only built on a particular step if some atom has moved more than half the skin distance (specified in the [neighbor](#) command) since the last build.

When the rRESPA integrator is used (see the [run\\_style](#) command), the *every* and *delay* parameters refer to the longest (outermost) timestep.

The *exclude* option turns off pairwise interactions between certain pairs of atoms, by not including them in the neighbor list. These are sample scenarios where this is useful:

- In crack simulations, pairwise interactions can be shut off between 2 slabs of atoms to effectively create a crack.
- When a large collection of atoms is treated as frozen, interactions between those atoms can be turned off to save needless computation. E.g. Using the [fix setforce](#) command to freeze a wall or portion of a bio-molecule.
- When one or more rigid bodies are specified, interactions within each body can be turned off to save needless computation. See the [fix rigid](#) command for more details.

The *exclude type* option turns off the pairwise interaction if one atom is of type M and the other of type N. M can equal N. The *exclude group* option turns off the interaction if one atom is in the first group and the other is the second. Group1-ID can equal group2-ID. The *exclude molecule* option turns off the interaction if both atoms are in the specified group and in the same molecule, as determined by their molecule ID.

Each of the exclude options can be specified multiple times. The *exclude type* option is the most efficient option to use; it requires only a single check, no matter how many times it has been specified. The other exclude options are more expensive if specified multiple times; they require one check for each time they have been specified.

Note that the exclude options only affect pairwise interactions; see the [delete\\_bonds](#) command for information on turning off bond interactions.

The *page* and *one* options affect how memory is allocated for the neighbor lists. For most simulations the default settings for these options are fine, but if a very large problem is being run or a very long cutoff is being used, these parameters can be tuned. The indices of neighboring atoms are stored in "pages", which are allocated one after another as they fill up. The size of each page is set by the *page* value. A new page is allocated when the next atom's neighbors could potentially overflow the list. This threshold is set by the *one* value which tells LAMMPS the maximum number of neighbor's one atom can have.

### Restrictions:

If the "delay" setting is non-zero, then it must be a multiple of the "every" setting.

The exclude molecule option can only be used with atom styles that define molecule IDs.

### Related commands:

[neighbor](#), [delete\\_bonds](#)

### Default:

The option defaults are delay = 10, every = 1, check = yes, exclude = none, page = 10000, and one = 2000.

## neighbor command

### Syntax:

```
neighbor skin style
```

- *skin* = extra distance beyond force cutoff (distance units)
- *style* = *bin* or *nsq* or *multi*

### Examples:

```
neighbor 0.3 bin  
neighbor 2.0 nsq
```

### Description:

This command sets parameters that affect the building of the pairwise neighbor list. All atom pairs within a cutoff distance equal to the their force cutoff plus the *skin* distance are stored in the list. Typically, the larger the skin distance, the less often neighbor lists need to be built, but more pairs must be checked for possible force interactions every timestep. The default value for *skin* depends on the choice of units for the simulation (see below).

The *style* value selects what algorithm is used to build the list. The *bin* style creates the list by binning which is an operation that scales linearly with  $N/P$ , the number of atoms per processor where  $N$  = total number of atoms and  $P$  = number of processors. It is almost always faster than the *nsq* style which scales as  $(N/P)^2$ . For unsolvated small molecules in a non-periodic box, the *nsq* choice can sometimes be faster. Either style should give the same answers.

The *multi* style is a modified binning algorithm that is useful for systems with a wide range of cutoff distances, e.g. due to different size particles. For the *bin* style, the bin size is set to 1/2 of the largest cutoff distance between any pair of atom types and a single set of bins is defined to search over for all atom types. This can be inefficient if one pair of types has a very long cutoff, but other type pairs have a much shorter cutoff. For style *multi* the bin size is set to 1/2 of the shortest cutoff distance and multiple sets of bins are defined to search over for different atom types. This imposes some extra setup overhead, but the searches themselves may be much faster for the short-cutoff cases.

The [neigh\\_modify](#) command has additional options that control how often neighbor lists are built and which pairs are stored in the list.

When a run is finished, counts of the number of neighbors stored in the pairwise list and the number of times neighbor lists were built are printed to the screen and log file. See [this section](#) for details.

**Restrictions:** none

### Related commands:

[neigh\\_modify](#), [units](#)

### Default:

```
0.3 bin      for lj units (0.3 sigma)
```

2.0 bin      for real or metal units (2.0 Angstroms)

## newton command

### Syntax:

```
newton flag  
newton flag1 flag2
```

- flag = *on* or *off* for both pairwise and bonded interactions
- flag1 = *on* or *off* for pairwise interactions
- flag2 = *on* or *off* for bonded interactions

### Examples:

```
newton off  
newton on off
```

### Description:

This command turns Newton's 3rd law *on* or *off* for pairwise and bonded interactions. For most problems, setting Newton's 3rd law to *on* means a modest savings in computation at the cost of two times more communication. Whether this is faster depends on problem size, force cutoff lengths, a machine's compute/communication ratio, and how many processors are being used.

Setting the pairwise newton flag to *off* means that if two interacting atoms are on different processors, both processors compute their interaction and the resulting force information is not communicated. Similarly, for bonded interactions, newton *off* means that if a bond, angle, dihedral, or improper interaction contains atoms on 2 or more processors, the interaction is computed by each processor.

LAMMPS should produce the same answers for any newton flag settings, except for round-off issues.

With [run\\_style respa](#) and only bonded interactions (bond, angle, etc) computed in the innermost timestep, it may be faster to turn newton *off* for bonded interactions, to avoid extra communication in the innermost loop.

### Restrictions:

The newton bond setting cannot be changed after the simulation box is defined by a [read\\_data](#) or [create\\_box](#) command.

### Related commands:

[run\\_style respa](#)

### Default:

```
newton on
```

## next command

### Syntax:

```
next variables
```

- variables = one or more variable names

### Examples:

```
next x
next a t x myTemp
```

### Description:

This command is used with variables defined by the [variable](#) command. It assigns the next value to the variable from the list of values defined for that variable by the [variable](#) command. Thus when that variable is subsequently substituted for in an input script command, the new value is used.

See the [variable](#) command for info on how to define and use different kinds of variables in LAMMPS input scripts. If a variable name is a single lower-case character from "a" to "z", it can be used in an input script command as \$a or \$z. If it is multiple letters, it can be used as \${myTemp}.

If multiple variables are used as arguments to the *next* command, then all must be of the same variable style: *index*, *loop*, *universe*, or *uloop*. An exception is that *universe*- and *uloop*-style variables can be mixed in the same *next* command. *Atom*- or *equal*- or *world*-style variables cannot be incremented by a next command. All the variables specified are incremented by one value from their respective lists.

When any of the variables in the next command has no more values, a flag is set that causes the input script to skip the next [jump](#) command encountered. This enables a loop containing a next command to exit.

When the next command is used with *index*- or *loop*-style variables, the next value is assigned to the variable for all processors. When the next command is used with *universe*- or *uloop*-style variables, the next value is assigned to whichever processor partition executes the command first. All processors in the partition are assigned the same value. Running LAMMPS on multiple partitions of processors via the "-partition" command-line switch is described in [this section](#) of the manual. *Universe*- and *uloop*-style variables are incremented using the files "tmp.lammps.variable" and "tmp.lammps.variable.lock" which you will see in your directory during such a LAMMPS run.

Here is an example of running a series of simulations using the next command with an *index*-style variable. If this input script is named in.polymer, 8 simulations would be run using data files from directories run1 thru run8.

```
variable d index run1 run2 run3 run4 run5 run6 run7 run8
shell cd $d
read_data data.polymer
run 10000
shell cd ..
clear
next d
jump in.polymer
```

If the variable "d" were of style *universe*, and the same in.polymer input script were run on 3 partitions of processors, then the first 3 simulations would begin, one on each set of processors. Whichever partition finished first, it would assign variable "d" the 4th value and run another simulation, and so forth until all 8 simulations were finished.

Jump and next commands can also be nested to enable multi-level loops. For example, this script will run 15 simulations in a double loop.

```
variable i loop 3
variable j loop 5
clear
...
read_data data.polymer.$i$j
print Running simulation $i.$j
run 10000
next j
jump in.script
next i
jump in.script
```

**Restrictions:** none

**Related commands:**

[jump](#), [include](#), [shell](#), [variable](#),

**Default:** none



## orient command

### Syntax:

```
orient dim i j k
```

- dim =  $x$  or  $y$  or  $z$
- $i,j,k$  = orientation of lattice that is along box direction dim

### Examples:

```
orient x 1 1 0
orient y -1 1 0
orient z 0 0 1
```

### Description:

Specify the orientation of a cubic lattice along simulation box directions  $x$  or  $y$  or  $z$ . These 3 basis vectors are used when the [create\\_atoms](#) command generates a lattice of atoms.

The 3 basis vectors B1, B2, B3 must be mutually orthogonal and form a right-handed system such that B1 cross B2 is in the direction of B3.

The basis vectors should be specified in an irreducible form (smallest possible integers), though LAMMPS does not check for this.

**Restrictions:** none

### Related commands:

[origin](#), [create\\_atoms](#)

### Default:

```
orient x 1 0 0
orient y 0 1 0
orient z 0 0 1
```

## origin command

### Syntax:

```
origin x y z
```

- x,y,z = origin of a lattice

### Examples:

```
origin 0.0 0.5 0.5
```

### Description:

Set the origin of the lattice defined by the [lattice](#) command. The lattice is used by the [create\\_atoms](#) command to create new atoms and by other commands that use a lattice spacing as a distance measure. This command offsets the origin of the lattice from the (0,0,0) coordinate of the simulation box by some fraction of a lattice spacing in each dimension.

The specified values are in lattice coordinates from 0.0 to 1.0, so that a value of 0.5 means the lattice is displaced 1/2 a cubic cell.

**Restrictions:** none

Related commands:

[lattice](#), [orient](#)

### Default:

```
origin 0 0 0
```

## pair\_style airebo command

### Syntax:

```
pair_style airebo cutoff LJ_flag TORSION_flag
```

- cutoff = LJ cutoff (sigma scale factor)
- LJ\_flag = 0/1 to turn off/on the LJ term in AIREBO (optional)
- TORSION\_flag = 0/1 to turn off/on the torsion term in AIREBO (optional)

### Examples:

```
pair_style airebo 3.0
pair_style airebo 2.5 1 0
pair_coeff * * ../potentials/CH.airebo H C
```

### Description:

The *airebo* pair style computes the Adaptive Intermolecular Reactive Empirical Bond Order (AIREBO) Potential of [Stuart](#) for a system of carbon and/or hydrogen atoms. The potential consists of three terms:

$$E = \frac{1}{2} \sum_i \sum_{j \neq i} \left[ E_{ij}^{REBO} + E_{ij}^{LJ} + \sum_{k \neq i, j} \sum_{l \neq i, j, k} E_{ijkl}^{TORSION} \right]$$

By default, all three terms are included. If the two optional flag arguments to the `pair_style` command are included, the LJ and torsional terms can be turned off. Note that both or neither of the flags must be included.

The detailed formulas for this potential are given in [Stuart](#); here we provide only a brief description.

The  $E_{REBO}$  term has the same functional form as the hydrocarbon REBO potential developed in [Brenner](#). The coefficients for  $E_{REBO}$  in AIREBO are essentially the same as Brenner's potential, but a few fitted spline values are slightly different. For most cases the  $E_{REBO}$  term in AIREBO will produce the same energies, forces and statistical averages as the original REBO potential from which it was derived. The  $E_{REBO}$  term in the AIREBO potential gives the model its reactive capabilities and only describes short-ranged C–C, C–H and H–H interactions ( $r < 2$  Angstroms). These interactions have strong coordination-dependence through a bond order parameter, which adjusts the attraction between the LJ atoms based on the position of other nearby atoms and thus has 3- and 4-body dependence.

The  $E_{LJ}$  term adds longer-ranged interactions ( $2 < r < \text{cutoff}$ ) using a form similar to the standard [Lennard Jones potential](#). The  $E_{LJ}$  term in AIREBO contains a series of switching functions so that the short-ranged LJ repulsion ( $1/r^{12}$ ) does not interfere with the energetics captured by the  $E_{REBO}$  term. The extent of the  $E_{LJ}$  interactions is determined by the *cutoff* argument to the `pair_style` command which is a scale factor. For each type pair (C–C, C–H, H–H) the cutoff is obtained by multiplying the scale factor by the sigma value defined in the potential file for that type pair. In the standard AIREBO potential,  $\sigma_{CC} = 3.4$  Angstroms, so with a scale factor of 3.0 (the argument in `pair_style`), the resulting  $E_{LJ}$  cutoff would be 10.2 Angstroms.

The  $E_{TORSION}$  term is an explicit 4-body potential that describes various diheadral angle preferences in hydrocarbon configurations.

Only a single `pair_coeff` command is used with the *airebo* style which specifies an AIREBO potential file with parameters for C and H. These are mapped to LAMMPS atom types by specifying N additional arguments after the filename in the `pair_coeff` command, where N is the number of LAMMPS atom types:

- filename
- N element names = mapping of AIREBO elements to atom types

As an example, if your LAMMPS simulation has 4 atoms types and you want the 1st 3 to be C, and the 4th to be H, you would use the following `pair_coeff` command:

```
pair_coeff * * CH.airebo C C C H
```

The 1st 2 arguments must be `* *` so as to span all LAMMPS atom types. The first three C arguments map LAMMPS atom types 1,2,3 to the C element in the AIREBO file. The final H argument maps LAMMPS atom type 4 to the H element in the SW file. If a mapping value is specified as NULL, the mapping is not performed. This can be used when a *airebo* potential is used as part of the *hybrid* pair style. The NULL values are placeholders for atom types that will be used with other potentials.

The parameters/coefficients for the AIREBO potentials are listed in the CH.airebo file to agree with the original (Stuart) paper. Thus the parameters are specific to this potential and the way it was fit, so modifying the file should be done cautiously. Also note that the E\_LJ and E\_TORSION terms in AIREBO are intended to be used with the E\_REBO term and not as stand-alone potentials. Thus we don't suggest you use `pair_style airebo` with the E\_REBO term turned off.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

This pair style does not support the `pair_modify` mix, shift, table, and tail options.

This pair style does not calculate per-atom energy and stress, as used by the `compute epair/atom`, `compute stress/atom`, and `dump custom` commands.

This pair style does not write its information to [binary restart files](#), since it is stored in potential files. Thus, you need to re-specify the `pair_style` and `pair_coeff` commands in an input script that reads a restart file.

### Restrictions:

This pair style is part of the "manybody" package. It is only enabled if LAMMPS was built with that package (which it is by default). See the [Making LAMMPS](#) section for more info.

This pair potential requires the `newton` setting to be "on" for pair interactions.

The CH.airebo potential file provided with LAMMPS (see the potentials directory) is parameterized for metal [units](#). You can use the AIREBO potential with any LAMMPS units, but you would need to create your own AIREBO potential file with coefficients listed in the appropriate units if your simulation doesn't use "metal" units.

### Related commands:

[pair\\_coeff](#)

**Default:** none

---

**(Stuart)** Stuart, Tutein, Harrison, J Chem Phys, 112, 6472–6486 (2000).

**(Brenner)** Brenner, Shenderova, Harrison, Stuart, Ni, Sinnott, J Physics: Condensed Matter, 14, 783–802 (2002).

## pair\_style buck command

## pair\_style buck/coul/cut command

## pair\_style buck/coul/long command

### Syntax:

pair\_style style args

- style = *buck* or *buck/coul/cut* or *buck/coul/long*
- args = list of arguments for a particular style

*buck* args = cutoff  
     cutoff = global cutoff for Buckingham interactions (distance units)  
*buck/coul/cut* args = cutoff (cutoff2)  
     cutoff = global cutoff for Buckingham (and Coulombic if only 1 arg) (distance units)  
     cutoff2 = global cutoff for Coulombic (optional) (distance units)  
*buck/coul/long* args = cutoff (cutoff2)  
     cutoff = global cutoff for Buckingham (and Coulombic if only 1 arg) (distance units)  
     cutoff2 = global cutoff for Coulombic (optional) (distance units)

### Examples:

```
pair_style buck 2.5
pair_coeff * * 100.0 1.5 200.0
pair_coeff * * 100.0 1.5 200.0 3.0

pair_style buck/coul/cut 10.0
pair_style buck/coul/cut 10.0 8.0
pair_coeff * * 100.0 1.5 200.0
pair_coeff 1 1 100.0 1.5 200.0 9.0
pair_coeff 1 1 100.0 1.5 200.0 9.0 8.0

pair_style buck/coul/long 10.0
pair_style buck/coul/long 10.0 8.0
pair_coeff * * 100.0 1.5 200.0
pair_coeff 1 1 100.0 1.5 200.0 9.0
```

### Description:

The *buck* style computes a Buckingham potential (exp/6 instead of Lennard–Jones 12/6) given by

$$E = Ae^{-r/\rho} - \frac{C}{r^6} \quad r < r_c$$

Rc is the cutoff.

The *buck/coul/cut* and *buck/coul/long* styles add a Coulombic term as described for the [lj/cut](#) pair styles.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- A (energy units)
- rho (distance units)
- C (energy–distance<sup>6</sup> units)
- cutoff (distance units)
- cutoff2 (distance units)

The latter 2 coefficients are optional. If not specified, the global LJ and Coulombic cutoffs are used. If only one cutoff is specified, it is used as the cutoff for both LJ and Coulombic interactions for this type pair. If both coefficients are specified, they are used as the LJ and Coulombic cutoffs for this type pair. You cannot specify 2 cutoffs for style *buck*, since it has no Coulombic terms.

The second coefficient, rho, must be greater than zero.

For *buck/coul/long* only the LJ cutoff can be specified since a Coulombic cutoff cannot be specified for an individual I,J type pair. All type pairs use the same global Coulombic cutoff specified in the `pair_style` command.

---

#### **Mixing, shift, table, tail correction, per–atom energy/stress, and restart info:**

None of the Buckingham pair styles support mixing. Thus, coefficients for all I,J pairs must be specified explicitly.

All of the Buckingham pair styles support the `pair_modify` shift option for the energy of the `exp()` and `1/r6` portion of the pair interaction.

The *buck/coul/long* pair style does not support the `pair_modify` table option since a tabulation capability has not yet been added to this potential.

None of the Buckingham pair styles support the `pair_modify` tail option for adding long–range tail corrections to energy and pressure.

All of the Buckinham pair styles can calculate per–atom energy and stress, as used by the `compute epair/atom`, `compute stress/atom`, and `dump custom` commands.

All of the Buckinham pair styles write their information to `binary restart files`, so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

#### **Restrictions:**

The *buck/coul/long* style is part of the "kspace" package. It is only enabled if LAMMPS was built with that package (which it is by default). See the [Making LAMMPS](#) section for more info.

#### **Related commands:**

[pair\\_coeff](#)

**Default:** none

**pair\_style lj/charmm/coul/charmm command****pair\_style lj/charmm/coul/charmm/implicit command****pair\_style lj/charmm/coul/long command****pair\_style lj/charmm/coul/long/opt command****Syntax:**

```
pair_style style args
```

- style = *lj/charmm/coul/charmm* or *lj/charmm/coul/charmm/implicit* or *lj/charmm/coul/long* or *lj/charmm/coul/long/opt*
- args = list of arguments for a particular style

```
lj/charmm/coul/charmm args = inner outer (inner2) (outer2)
    inner, outer = global switching cutoffs for Lennard Jones (and Coulombic if only 2 args)
    inner2, outer2 = global switching cutoffs for Coulombic (optional)
lj/charmm/coul/charmm/implicit args = inner outer (inner2) (outer2)
    inner, outer = global switching cutoffs for LJ (and Coulombic if only 2 args)
    inner2, outer2 = global switching cutoffs for Coulombic (optional)
lj/charmm/coul/long args = inner outer (cutoff)
    inner, outer = global switching cutoffs for LJ (and Coulombic if only 2 args)
    cutoff = global cutoff for Coulombic (optional, outer is Coulombic cutoff if only 2 args)
```

**Examples:**

```
pair_style lj/charmm/coul/charmm 8.0 10.0
pair_style lj/charmm/coul/charmm 8.0 10.0 7.0 9.0
pair_coeff * * 100.0 2.0
pair_coeff 1 1 100.0 2.0 150.0 3.5

pair_style lj/charmm/coul/charmm/implicit 8.0 10.0
pair_style lj/charmm/coul/charmm/implicit 8.0 10.0 7.0 9.0
pair_coeff * * 100.0 2.0
pair_coeff 1 1 100.0 2.0 150.0 3.5

pair_style lj/charmm/coul/long 8.0 10.0
pair_style lj/charmm/coul/long/opt 8.0 10.0
pair_style lj/charmm/coul/long 8.0 10.0 9.0
pair_coeff * * 100.0 2.0
pair_coeff 1 1 100.0 2.0 150.0 3.5
```

**Description:**

The *lj/charmm* styles compute LJ and Coulombic interactions with an additional switching function  $S(r)$  that ramps the energy and force smoothly to zero between an inner and outer cuoff. It is a widely used potential in the [CHARMM](#) MD code. See [\(MacKerell\)](#) for a description of the CHARMM force field.



$$\begin{aligned}
E &= LJ(r) & r < r_{\text{in}} \\
&= S(r) * LJ(r) & r_{\text{in}} < r < r_{\text{out}} \\
&= 0 & r > r_{\text{out}} \\
E &= C(r) & r < r_{\text{in}} \\
&= S(r) * C(r) & r_{\text{in}} < r < r_{\text{out}} \\
&= 0 & r > r_{\text{out}} \\
LJ(r) &= 4\epsilon \left[ \left( \frac{\sigma}{r} \right)^{12} - \left( \frac{\sigma}{r} \right)^6 \right] \\
C(r) &= \frac{C q_i q_j}{\epsilon r} \\
S(r) &= \frac{[r_{\text{out}}^2 - r^2]^2 [r_{\text{out}}^2 + 2r^2 - 3r_{\text{in}}^2]}{[r_{\text{out}}^2 - r_{\text{in}}^2]^3}
\end{aligned}$$

Both the LJ and Coulombic terms require an inner and outer cutoff. They can be the same for both formulas or different depending on whether 2 or 4 arguments are used in the `pair_style` command. In each case, the inner cutoff distance must be less than the outer cutoff. It is typical to make the difference between the 2 cutoffs about 1.0 Angstrom.

Style `lj/charmm/coul/charmm/implicit` computes the same formulas as style `lj/charmm/coul/charmm` except that an additional  $1/r$  term is included in the Coulombic formula. The Coulombic energy thus varies as  $1/r^2$ . This is effectively a distance-dependent dielectric term which is a simple model for an implicit solvent with additional screening. It is designed for use in a simulation of an unsolvated biomolecule (no explicit water molecules).

Style `lj/charmm/coul/long` computes the same formulas as style `lj/charmm/coul/charmm` except that an additional damping factor is applied to the Coulombic term, as in the discussion for pair style `lj/cut/coul/long`. Only one Coulombic cutoff is specified for `lj/charmm/coul/long`; if only 2 arguments are used in the `pair_style` command, then the outer LJ cutoff is used as the single Coulombic cutoff.

Style `lj/charmm/coul/long/opt` is an optimized version of style `lj/charmm/coul/long` that should give identical answers. Depending on system size and the processor you are running on, it may be 5–25% faster (for the pairwise portion of the run time).

The following coefficients must be defined for each pair of atom types via the `pair_coeff` command as in the examples above, or in the data file or restart files read by the `read_data` or `read_restart` commands, or by mixing as described below:

- epsilon (energy units)
- sigma (distance units)
- epsilon\_14 (energy units)
- sigma\_14 (distance units)

Note that sigma is defined in the LJ formula as the zero-crossing distance for the potential, not as the energy minimum at  $2^{1/6}$  sigma.

The latter 2 coefficients are optional. If they are specified, they are used in the LJ formula between 2 atoms of these types which are also first and fourth atoms in any dihedral. No cutoffs are specified because this CHARMM force field does not allow varying cutoffs for individual atom pairs; all pairs use the global cutoff(s) specified in the `pair_style` command.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs  $I, J$  and  $I \neq J$ , the `epsilon`, `sigma`, `epsilon_14`, and `sigma_14` coefficients for all of the `lj/charmm` pair styles can be mixed. They are always mixed with the value *arithmetic*. See the "pair\_modify" command for details.

None of the `lj/charmm` pair styles support the `pair_modify` shift option, since the Lennard-Jones portion of the pair interaction is smoothed to 0.0 at the cutoff.

The `lj/charmm/coul/long` and `lj/charmm/coul/long/opt` pair styles support the `pair_modify` table option since they can tabulate the short-range portion of the long-range Coulombic interaction.

None of the `lj/charmm` pair styles support the `pair_modify` tail option for adding long-range tail corrections to energy and pressure, since the Lennard-Jones portion of the pair interaction is smoothed to 0.0 at the cutoff.

All of the `lj/charmm` pair styles can calculate per-atom energy and stress, as used by the `compute epair/atom`, `compute stress/atom`, and `dump custom` commands.

All of the `lj/charmm` pair styles write their information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

---

### Restrictions:

The `lj/charmm/coul/charmm` and `lj/charmm/coul/charmm/implicit` styles are part of the "molecule" package. The `lj/charmm/coul/long` style is part of the "kspace" package. The `lj/charmm/coul/long/opt` style is part of the "opt" package and also requires the "kspace" package. They are only enabled if LAMMPS was built with those package(s) (molecule and kspace are by default). See the [Making LAMMPS](#) section for more info.

On some 64-bit machines, compiling with `-O3` appears to break the Coulombic tabling option used by the `lj/charmm/coul/long` style. See the "Additional build tips" section of the Making LAMMPS documentation pages for workarounds on this issue.

### Related commands:

[pair\\_coeff](#)

**Default:** none

---

(**MacKerell**) MacKerell, Bashford, Bellott, Dunbrack, Evanseck, Field, Fischer, Gao, Guo, Ha, et al, J Phys Chem, 102, 3586 (1998).

## pair\_style lj/class2 command

## pair\_style lj/class2/coul/cut command

## pair\_style lj/class2/coul/long command

### Syntax:

pair\_style style args

- style = *lj/class2* or *lj/class2/coul/cut* or *lj/class2/coul/long*
- args = list of arguments for a particular style

```
lj/class2 args = cutoff
    cutoff = global cutoff for class 2 interactions (distance units)
lj/class2/coul/cut args = cutoff (cutoff2)
    cutoff = global cutoff for class 2 (and Coulombic if only 1 arg) (distance units)
    cutoff2 = global cutoff for Coulombic (optional) (distance units)
lj/class2/coul/long args = cutoff (cutoff2)
    cutoff = global cutoff for class 2 (and Coulombic if only 1 arg) (distance units)
    cutoff2 = global cutoff for Coulombic (optional) (distance units)
```

### Examples:

```
pair_style lj/class2 10.0
pair_coeff * * 100.0 2.5
pair_coeff 1 2* 100.0 2.5 9.0
```

```
pair_style lj/class2/coul/cut 10.0
pair_style lj/class2/coul/cut 10.0 8.0
pair_coeff * * 100.0 3.0
pair_coeff 1 1 100.0 3.5 9.0
pair_coeff 1 1 100.0 3.5 9.0 9.0
```

```
pair_style lj/class2/coul/long 10.0
pair_style lj/class2/coul/long 10.0 8.0
pair_coeff * * 100.0 3.0
pair_coeff 1 1 100.0 3.5 9.0
```

### Description:

The *lj/class2* styles compute a 6/9 Lennard–Jones potential given by

$$E = \epsilon \left[ 2 \left( \frac{\sigma}{r} \right)^9 - 3 \left( \frac{\sigma}{r} \right)^6 \right] \quad r < r_c$$

Rc is the cutoff.

The *lj/class2/coul/cut* and *lj/class2/coul/long* styles add a Coulombic term as described for the [lj/cut](#) pair styles.

See [\(Sun\)](#) for a description of the COMPASS class2 force field.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands, or by mixing as described below:

- epsilon (energy units)
- sigma (distance units)
- cutoff1 (distance units)
- cutoff2 (distance units)

The latter 2 coefficients are optional. If not specified, the global class 2 and Coulombic cutoffs are used. If only one cutoff is specified, it is used as the cutoff for both class 2 and Coulombic interactions for this type pair. If both coefficients are specified, they are used as the class 2 and Coulombic cutoffs for this type pair. You cannot specify 2 cutoffs for style *lj/class2*, since it has no Coulombic terms.

For *lj/class2/coul/long* only the class 2 cutoff can be specified since a Coulombic cutoff cannot be specified for an individual I,J type pair. All type pairs use the same global Coulombic cutoff specified in the *pair\_style* command.

: line

If the *pair\_coeff* command is not used to define coefficients for a particular  $I \neq J$  type pair, the mixing rule for epsilon and sigma for all class2 potentials is to use the *sixthpower* formulas documented by the [pair\\_modify](#) command. The [pair\\_modify mix](#) setting is thus ignored for class2 potentials for epsilon and sigma. However it is still followed for mixing the cutoff distance.

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs I,J and  $I \neq J$ , the epsilon and sigma coefficients and cutoff distance for all of the *lj/class2* pair styles can be mixed. Epsilon and sigma are always mixed with the value *sixthpower*. The cutoff distance is mixed by whatever option is set by the *pair\_modify* command (default = geometric). See the "pair\_modify" command for details.

All of the *lj/class2* pair styles support the [pair\\_modify](#) shift option for the energy of the Lennard–Jones portion of the pair interaction.

The *lj/class2/coul/long* pair style does not support the [pair\\_modify](#) table option since a tabulation capability has not yet been added to this potential.

All of the *lj/class2* pair styles support the [pair\\_modify](#) tail option for adding a long-range tail correction to the energy and pressure of the Lennard–Jones portion of the pair interaction.

All of the *lj/class2* pair styles can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

All of the *lj/class2* pair styles write their information to [binary restart files](#), so *pair\_style* and *pair\_coeff* commands do not need to be specified in an input script that reads a restart file.

### Restrictions:

All of these pair styles are part of the "class2" package. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

### Related commands:

[pair\\_coeff](#)

**Default:** none

---

**(Sun)** Sun, J Phys Chem B 102, 7338–7364 (1998).

## pair\_coeff command

### Syntax:

```
pair_coeff I J args
```

- I,J = atom types (see asterik form below)
- args = coefficients for one or more pairs of atom types

### Examples:

```
pair_coeff 1 2 1.0 1.0 2.5
pair_coeff 2 * 1.0 1.0
pair_coeff 3* 1*2 1.0 1.0 2.5
pair_coeff * * 1.0 1.0
pair_coeff * * nialhjea 1 1 2
pair_coeff * 3 morse.table ENTRY1
pair_coeff 1 2 lj/cut 1.0 1.0 2.5 (for pair_style hybrid)
```

### Description:

Specify the pairwise force field coefficients for one or more pairs of atom types. The number and meaning of the coefficients depends on the pair style. Pair coefficients can also be set in the data file read by the [read\\_data](#) command or in a restart file.

I and J can be specified in one of two ways. Explicit numeric values can be used for each, as in the 1st example above.  $I \leq J$  is required. LAMMPS sets the coefficients for the symmetric J,I interaction to the same values.

A wild-card asterik can be used in place of or in conjunction with the I,J arguments to set the coefficients for multiple pairs of atom types. This takes the form "\*" or "\*n" or "n\*" or "m\*n". If N = the number of atom types, then an asterik with no numeric values means all types from 1 to N. A leading asterik means all types from 1 to n (inclusive). A trailing asterik means all types from n to N (inclusive). A middle asterik means all types from m to n (inclusive). Note that only type pairs with  $I \leq J$  are considered; if asteriks imply type pairs where  $J < I$ , they are ignored.

Note that a pair\_coeff command can override a previous setting for the same I,J pair. For example, these commands set the coeffs for all I,J pairs, then overwrite the coeffs for just the I,J = 2,3 pair:

```
pair_coeff * * 1.0 1.0 2.5
pair_coeff 2 3 2.0 1.0 1.12
```

A line in a data file that specifies pair coefficients uses the exact same format as the arguments of the pair\_coeff command in an input script, with the exception of the I,J type arguments. In each line of the "Pair Coeffs" section of a data file, only a single type I is specified, which sets the coefficients for type I interacting with type I. This is because the section has exactly N lines, where N = the number of atom types. For this reason, the wild-card asterik should also not be used as part of the I argument. Thus in a data file, the line corresponding to the 1st example above would be listed as

```
2 1.0 1.0 2.5
```

For many potentials, if coefficients for type pairs with  $I \neq J$  are not set explicitly by a pair\_coeff command, the values are inferred from the I,I and J,J settings by mixing rules; see the [pair\\_modify](#) command for a discussion.

Details on this option as it pertains to individual potentials are described on the doc page for the potential.

---

Here is an alphabetic list of pair styles defined in LAMMPS. Click on the style to display the formula it computes, arguments specified in the pair\_style command, and coefficients specified by the associated [pair\\_coeff](#) command:

- [pair\\_style airebo](#) – AI-REBO potential
  - [pair\\_style buck](#) – Buckingham potential
  - [pair\\_style buck/coul/cut](#) – Buckinhhham with cutoff Coulomb
  - [pair\\_style buck/coul/long](#) – Buckingham with long-range Coulomb
  - [pair\\_style colloid](#) – integrated colloidal potential
  - [pair\\_style dpd](#) – dissipative particle dynamics (DPD)
  - [pair\\_style eam](#) – embedded atom method (EAM)
  - [pair\\_style eam/alloy](#) – alloy EAM
  - [pair\\_style eam/fs](#) – Finnis–Sinclair EAM
  - [pair\\_style gayberne](#) – Gay–Berne ellipsoidal potential
  - [pair\\_style gran/hertzian](#) – granular potential with Hertizain interactions
  - [pair\\_style gran/history](#) – granular potential with history effects
  - [pair\\_style gran/no\\_history](#) – granular potential without history effects
  - [pair\\_style lj/charmm/coul/charmm](#) – CHARMM potential with cutoff Coulomb
  - [pair\\_style lj/charmm/coul/charmm/implicit](#) – CHARMM for implicit solvent
  - [pair\\_style lj/charmm/coul/long](#) – CHARMM with long-range Coulomb
  - [pair\\_style lj/class2](#) – COMPASS (class 2) force field with no Coulomb
  - [pair\\_style lj/class2/coul/cut](#) – COMPASS with cutoff Coulomb
  - [pair\\_style lj/class2/coul/long](#) – COMPASS with long-range Coulomb
  - [pair\\_style lj/cut](#) – cutoff Lennard–Jones potential with no Coulomb
  - [pair\\_style lj/cut/coul/cut](#) – LJ with cutoff Coulomb
  - [pair\\_style lj/cut/coul/debye](#) – LJ with Debye damping added to Coulomb
  - [pair\\_style lj/cut/coul/long](#) – LJ with long-range Coulomb
  - [pair\\_style lj/cut/coul/long/tip4p](#) – LJ with long-range Coulomb for TIP4P water
  - [pair\\_style lj/expand](#) – Lennard–Jones for variable size particles
  - [pair\\_style lj/smooth](#) – smoothed Lennard–Jones potential
  - [pair\\_style meam](#) – modified embedded atom method (MEAM)
  - [pair\\_style morse](#) – Morse potential
  - [pair\\_style soft](#) – Soft (cosine) potential
  - [pair\\_style sw](#) – Stillinger–Weber 3–body potential
  - [pair\\_style table](#) – tabulated pair potential
  - [pair\\_style tersoff](#) – Tersoff 3–body potential
  - [pair\\_style yukawa](#) – Yukawa potential
- 

#### Restrictions:

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

#### Related commands:

[pair\\_style](#), [pair\\_modify](#), [read\\_data](#), [read\\_restart](#), [pair\\_write](#)

**Default:** none

## pair\_style colloid command

### Syntax:

```
pair_style colloid cutoff
```

- cutoff = global cutoff for colloidal interactions (distance units)

### Examples:

```
pair_style colloid 10.0
pair_coeff * * 25 1.0 10.0 10.0
pair_coeff 1 1 144 1.0 0.0 0.0 3.0
pair_coeff 1 2 75.398 1.0 0.0 10.0 9.0
pair_coeff 2 2 39.478 1.0 10.0 10.0 25.0
```

### Description:

Style *colloid* computes pairwise interactions between large colloidal particles and small solvent particles using 3 formulas. A colloidal particle has a size > sigma; a solvent particle is the usual Lennard–Jones particle of size sigma.

The colloid–colloid interaction energy is given by

$$U_A = -\frac{A}{6} \left[ \frac{2a_1a_2}{r^2 - (a_1 + a_2)^2} + \frac{2a_1a_2}{r^2 - (a_1 - a_2)^2} + \ln \left( \frac{r^2 - (a_1 + a_2)^2}{r^2 - (a_1 - a_2)^2} \right) \right]$$

$$U_R = \frac{A}{37800} \frac{\sigma^6}{r} \left[ \frac{r^2 - 7r(a_1 + a_2) + 6(a_1^2 + 7a_1a_2 + a_2^2)}{(r - a_1 - a_2)^7} + \frac{r^2 + 7r(a_1 + a_2) + 6(a_1^2 + 7a_1a_2 + a_2^2)}{(r + a_1 + a_2)^7} - \frac{r^2 + 7r(a_1 - a_2) + 6(a_1^2 - 7a_1a_2 + a_2^2)}{(r + a_1 - a_2)^7} - \frac{r^2 - 7r(a_1 - a_2) + 6(a_1^2 - 7a_1a_2 + a_2^2)}{(r - a_1 + a_2)^7} \right]$$

$$U = U_A + U_R, \quad r < r_c$$

A is the Hamaker constant, a1 and a2 are the radii of the two colloidal particles, and Rc is the cutoff. This equation results from describing each colloidal particle as an integrated collection of Lennard–Jones particles of size sigma and is derived in (Everaers).

The colloid–solvent interaction energy is given by



$$U = \frac{2 a^3 \sigma^3 A}{9 (a^2 - r^2)^3} \left[ 1 - \frac{(5 a^6 + 45 a^4 r^2 + 63 a^2 r^4 + 15 r^6) \sigma^6}{15 (a - r)^6 (a + r)^6} \right], \quad r < r_c$$

A is the Hamaker constant, a is the radius of the colloidal particle, and Rc is the cutoff. This formula is derived from the colloid–colloid interaction, letting one of the particle sizes go to zero.

The solvent–solvent interaction energy is given by the usual Lennard–Jones formula

$$U = \frac{A}{36} \left[ \left( \frac{\sigma}{r} \right)^{12} - \left( \frac{\sigma}{r} \right)^6 \right], \quad r < r_c$$

which results from letting both particle sizes go to zero.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands, or by mixing as described below:

- A (energy units)
- sigma (distance units)
- d1 (distance units)
- d2 (distance units)
- cutoff (distance units)

A is the energy prefactor and should typically be set as follows:

- A\_cc = colloid/colloid = 4 pi^2 = 39.5
- A\_ss = solvent/solvent = 144 (assuming epsilon = 1, so that 144/36 = 4)
- A\_cs = colloid/solvent = sqrt(A\_cc\*A\_ss)

Sigma is the size of the solvent particle or the constituent particles integrated over in the colloidal particle and should typically be set as follows:

- Sigma\_cc = colloid/colloid = 1.0
- Sigma\_ss = solvent/solvent = 1.0 or whatever size the solvent particle is
- Sigma\_cs = colloid/solvent = arithmetic mixing between colloid sigma and solvent sigma

Thus typically Sigma\_cs = 1.0, unless the solvent particle's size != 1.0.

D1 and d2 are particle diameters, so that d1 = 2\*a1 and d2 = 2\*a2 in the formulas above. Both d1 and d2 must be values >= 0. If d1 > 0 and d2 > 0, then the pair interacts via the colloid–colloid formula above. If d1 = 0 and d2 = 0, then the pair interacts via the solvent–solvent formula. I.e. a d value of 0 is a Lennard–Jones particle of size sigma. If either d1 = 0 or d2 = 0 and the other is larger, then the pair interacts via the colloid–solvent formula.

Note that the diameter of a particular particle type may appear in multiple [pair\\_coeff](#) commands, as it interacts with other particle types. You should insure the particle diameter is specified consistently each time it appears.

The last coefficient is optional. If not specified, the global cutoff specified in the [pair\\_style](#) command is used. However, you typically want different cutoffs for interactions between different particle sizes. E.g. if colloidal particles of diameter 10 are used with solvent particles of diameter 1, then a solvent–solvent cutoff of 2.5 would correspond to a colloid–colloid cutoff of 25. A good rule–of–thumb is to use a colloid–solvent cutoff that is half

the big diameter + 4 times the small diameter. I.e.  $9 = 5 + 4$  for the colloid–solvent cutoff in this case.

---

### Mixing, shift, table, tail correction, per–atom energy/stress, and restart info:

For atom type pairs  $I, J$  and  $I \neq J$ , the  $A$ ,  $\sigma$ ,  $d1$ , and  $d2$  coefficients and cutoff distance for this pair style can be mixed.  $A$  is an energy value mixed like a LJ epsilon.  $D1$  and  $d2$  are distance values and are mixed like  $\sigma$ . The default mix value is *geometric*. See the "pair\_modify" command for details.

This pair style supports the [pair\\_modify](#) shift option for the energy of the pair interaction.

The [pair\\_modify](#) table option is not relevant for this pair style.

This pair style does not support the [pair\\_modify](#) tail option for adding long–range tail corrections to energy and pressure.

This pair style can calculate per–atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style writes its information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

---

### Restrictions:

This style is part of the "colloid" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

### Related commands:

[pair\\_coeff](#)

**Default:** none

---

(**Everaers**) Everaers, Ejtehadi, Phys Rev E, 67, 041710 (2003).

## pair\_style dipole/cut command

### Syntax:

```
pair_style dipole/cut cutoff (cutoff2)
```

- cutoff = global cutoff LJ (and Coulombic if only 1 arg) (distance units)
- cutoff2 = global cutoff for Coulombic (optional) (distance units)

### Examples:

```
pair_style dipole/cut 10.0
pair_coeff * * 1.0 1.0
pair_coeff 2 3 1.0 1.0 2.5 4.0
```

### Description:

Style *dipole/cut* computes interactions between pairs of particles that each have a charge and/or a point dipole moment. In addition to the usual Lennard–Jones interaction between the particles (Elj) the charge–charge (Eqq), charge–dipole (Eqp), and dipole–dipole (Epp) interactions are computed by these formulas for the energy (E), force (F), and torque (T) between particles I and J.

$$\begin{aligned}
 E_{qq} &= \frac{q_i q_j}{r} \\
 E_{qp} &= \frac{q}{r^3} (\vec{p} \cdot \vec{r}) \\
 E_{pp} &= \frac{1}{r^3} (\vec{p}_i \cdot \vec{p}_j) - \frac{3}{r^5} (\vec{p}_i \cdot \vec{r})(\vec{p}_j \cdot \vec{r})
 \end{aligned}$$

$$\begin{aligned}
 F_{qq} &= \frac{q_i q_j}{r^3} \vec{r} \\
 F_{qp} &= -\frac{q}{r^3} \vec{p} + \frac{3q}{r^5} (\vec{p} \cdot \vec{r}) \vec{r} \\
 F_{pp} &= \frac{3}{r^5} (\vec{p}_i \cdot \vec{p}_j) \vec{r} - \frac{15}{r^7} (\vec{p}_i \cdot \vec{r})(\vec{p}_j \cdot \vec{r}) \vec{r} + \frac{3}{r^5} [(\vec{p}_j \cdot \vec{r}) \vec{p}_i + (\vec{p}_i \cdot \vec{r}) \vec{p}_j]
 \end{aligned}$$

$$\begin{aligned}
 T_{pq} = T_{ij} &= \frac{q_j}{r^3} (\vec{p}_i \times \vec{r}) \\
 T_{qp} = T_{ji} &= -\frac{q_i}{r^3} (\vec{p}_j \times \vec{r}) \\
 T_{pp} = T_{ij} &= -\frac{1}{r^3} (\vec{p}_i \times \vec{p}_j) + \frac{3}{r^5} (\vec{p}_j \cdot \vec{r})(\vec{p}_i \times \vec{r}) \\
 T_{pp} = T_{ji} &= -\frac{1}{r^3} (\vec{p}_j \times \vec{p}_i) + \frac{3}{r^5} (\vec{p}_i \cdot \vec{r})(\vec{p}_j \times \vec{r})
 \end{aligned}$$

where  $q_i$  and  $q_j$  are the charges on the two particles,  $\vec{p}_i$  and  $\vec{p}_j$  are the dipole moment vectors of the two particles,  $r$  is their separation distance, and the vector  $\vec{r} = \vec{R}_i - \vec{R}_j$  is the separation vector between the two particles. Note that

$E_{qq}$  and  $F_{qq}$  are simply Coulombic energy and force,  $F_{ij} = -F_{ji}$  as symmetric forces, and  $T_{ij} \neq -T_{ji}$  since the torques do not act symmetrically. These formulas are discussed in (Allen) and in (Toukmaji).

If one cutoff is specified in the `pair_style` command, it is used for both the LJ and Coulombic (q,p) terms. If two cutoffs are specified, they are used as cutoffs for the LJ and Coulombic (q,p) terms respectively.

Use of this pair style requires the use of the `fix nve/dipole` command to integrate rotation of the dipole moments. Additionally, `atom_style dipole` should be used since it defines the point dipoles and their rotational state. The magnitude of the dipole moment for each type of particle can be defined by the `dipole` command or in the "Dipoles" section of the data file read in by the `read_data` command. Their initial orientation can be defined by the `set dipole` command or in the "Atoms" section of the data file.

The following coefficients must be defined for each pair of atoms types via the `pair_coeff` command as in the examples above, or in the data file or restart files read by the `read_data` or `read_restart` commands, or by mixing as described below:

- epsilon (energy units)
- sigma (distance units)
- cutoff1 (distance units)
- cutoff2 (distance units)

The latter 2 coefficients are optional. If not specified, the global LJ and Coulombic cutoffs specified in the `pair_style` command are used. If only one cutoff is specified, it is used as the cutoff for both LJ and Coulombic interactions for this type pair. If both coefficients are specified, they are used as the LJ and Coulombic cutoffs for this type pair.

---

#### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs  $I, J$  and  $I \neq J$ , the epsilon and sigma coefficients and cutoff distances for this pair style can be mixed. The default mix value is *geometric*. See the "pair\_modify" command for details.

For atom type pairs  $I, J$  and  $I \neq J$ , the A, sigma, d1, and d2 coefficients and cutoff distance for this pair style can be mixed. A is an energy value mixed like a LJ epsilon. D1 and d2 are distance values and are mixed like sigma. The default mix value is *geometric*. See the "pair\_modify" command for details.

This pair style supports the `pair_modify` shift option for the energy of the Lennard-Jones portion of the pair interaction.

The `pair_modify` table option is not relevant for this pair style.

This pair style does not support the `pair_modify` tail option for adding long-range tail corrections to energy and pressure.

This pair style can calculate per-atom energy and stress, as used by the `compute epair/atom`, `compute stress/atom`, and `dump custom` commands.

This pair style writes its information to `binary restart files`, so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

#### Restrictions:

This style is part of the "dipole" package. It is only enabled if LAMMPS was built with that package. See the

[Making LAMMPS](#) section for more info.

**Related commands:**

[pair\\_coeff](#), [fix nve/dipole](#), [compute temp/dipole](#)

**Default:** none

---

(**Allen**) Allen and Tildesley, Computer Simulation of Liquids, Clarendon Press, Oxford, 1987.

(**Toukmaji**) Toukmaji, Sagui, Board, and Darden, J Chem Phys, 113, 10913 (2000).

## pair\_style dpd command

### Syntax:

```
pair_style dpd T cutoff seed
```

- T = temperature (temperature units)
- cutoff = global cutoff for DPD interactions (distance units)
- seed = random # seed (integer > 0 and < 900000000)

### Examples:

```
pair_style dpd 1.0 2.5 34387
pair_coeff * * 3.0 1.0
pair_coeff 1 1 3.0 1.0 1.0
```

### Description:

Style *dpd* computes a force field for dissipative particle dynamics (DPD) following the exposition in (Groot). The force on atom I due to atom J is given as a sum of 3 terms

$$\begin{aligned}
 \vec{f} &= (F^C + F^D + F^R)\hat{r}_{ij} & r < r_c \\
 F^C &= Aw(r) \\
 F^D &= -\gamma w^2(r)(\hat{r}_{ij} \bullet \vec{v}_{ij}) \\
 F^R &= \sigma w(r)\alpha(\Delta t)^{-1/2} \\
 w(r) &= 1 - r/r_c
 \end{aligned}$$

where  $F^C$  is a conservative force,  $F^D$  is a dissipative force, and  $F^R$  is a random force.  $\hat{r}_{ij}$  is a unit vector in the direction  $\mathbf{R}_i - \mathbf{R}_j$ ,  $\mathbf{V}_{ij}$  is the vector difference in velocities of the two atoms =  $\mathbf{V}_i - \mathbf{V}_j$ ,  $\alpha$  is a Gaussian random number with zero mean and unit variance,  $\Delta t$  is the timestep size, and  $w(r)$  is a weighting factor that varies between 0 and 1.  $r_c$  is the cutoff.  $\sigma$  is set equal to  $\sqrt{2 T \gamma}$ , where  $T$  is a parameter in the *pair\_style* command.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- A (force units)
- gamma (force/velocity units)
- cutoff (distance units)

The last coefficient is optional. If not specified, the global DPD cutoff is used. Note that  $\sigma$  is set equal to  $\sqrt{2 T \gamma}$ , where  $T$  is the temperature set by the [pair\\_style](#) command so it does not need to be specified.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

This pair style does not support mixing. Thus, coefficients for all I,J pairs must be specified explicitly.

This pair style does not support the [pair\\_modify](#) shift option for the energy of the pair interaction.

The [pair\\_modify](#) table option is not relevant for this pair style.

This pair style does not support the [pair\\_modify](#) tail option for adding long-range tail corrections to energy and pressure.

This pair style can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands. However, only the first term with the A coefficient (conservative force) is used for these computations. The drag force and random force terms are not.

This pair style writes its information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file. Note that the user-specified random number seed is stored in the restart file, so when a simulation is restarted, each processor will re-initialize its random number generator the same way it did initially. This means the random forces will be random, but will not be the same as they would have been if the original simulation had continued past the restart time.

---

**Restrictions:**

This style is part of the "dpd" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

The default frequency for rebuilding neighbor lists is every 10 steps (see the [neigh\\_modify](#) command). This may be too infrequent for DPD simulations since particles move rapidly and can overlap by large amounts. If this setting yields a non-zero number of "dangerous" reneighborings (printed at the end of a simulation), you should experiment with forcing reneighborings more often and see if system energies/trajectories change.

**Related commands:**

[pair\\_coeff](#)

**Default:** none

---

(Groot) Groot and Warren, J Chem Phys, 107, 4423–35 (1997).

**pair\_style eam command****pair\_style eam/opt command****pair\_style eam/alloy command****pair\_style eam/alloy/opt command****pair\_style eam/fs command****pair\_style eam/fs/opt command****Syntax:**

```
pair_style style
```

- style = *eam* or *eam/alloy* or *eam/fs* or *eam/opt* or *eam/alloy/opt* or *eam/fs/opt*

**Examples:**

```
pair_style eam
pair_style eam/opt
pair_coeff * * cuu3
pair_coeff 1*3 1*3 niu3.eam
```

```
pair_style eam/alloy
pair_style eam/alloy/opt
pair_coeff * * ../potentials/nialhjea.eam.alloy Ni Al Ni Ni
```

```
pair_style eam/fs
pair_style eam/fs/opt
pair_coeff * * nialhjea.eam.fs Ni Al Ni Ni
```

**Description:**

Style *eam* computes pairwise interactions for metals and metal alloys using embedded–atom method (EAM) potentials ([Daw](#)). The total energy  $E_i$  of an atom  $I$  is given by

$$E_i = F_\alpha \left( \sum_{j \neq i} \rho_\alpha(r_{ij}) \right) + \frac{1}{2} \sum_{j \neq i} \phi_{\alpha\beta}(r_{ij})$$

where  $F$  is the embedding energy which is a function of the atomic electron density  $\rho$ ,  $\phi$  is a pair potential interaction, and  $\alpha$  and  $\beta$  are the element types of atoms  $I$  and  $J$ . The multi–body nature of the EAM potential is a result of the embedding energy term. Both summations in the formula are over all neighbors  $J$  of atom  $I$  within the cutoff distance.

Style *eam/opt* is an optimized version of style *eam* that should give identical answers. Depending on system size and the processor you are running on, it may be 5–25% faster (for the pairwise portion of the run time).



The cutoff distance and the tabulated values of the functionals  $F$ ,  $\rho$ , and  $\phi$  are listed in one or more files which are specified by the `pair_coeff` command. These are ASCII text files in a DYNAMO-style format which is described below. DYNAMO is a serial MD code. Several DYNAMO potential files for different metals are included in the "potentials" directory of the LAMMPS distribution. All of these files are parameterized in terms of LAMMPS [metal units](#).

**IMPORTANT NOTE:** The *eam* style reads single-element EAM potentials in the DYNAMO *funcfl* format. Either single element or alloy systems can be modeled using multiple *funcfl* files and style *eam*. For the alloy case LAMMPS mixes the single-element potentials to produce alloy potentials, the same way that DYNAMO does. Alternatively, a single DYNAMO *setfl* file or Finnis/Sinclair EAM file can be used by LAMMPS to model alloy systems by invoking the *eam/alloy* or *eam/fs* styles as described below. These files require no mixing since they specify alloy interactions explicitly.

For style *eam*, potential values are read from a file that is in the DYNAMO single-element *funcfl* format. If the DYNAMO file was created by a Fortran program, it cannot have "D" values in it for exponents. C only recognizes "e" or "E" for scientific notation.

Note that unlike for other potentials, cutoffs for EAM potentials are not set in the `pair_style` or `pair_coeff` command; they are specified in the EAM potential files themselves.

For style *eam* a potential file must be assigned to each I,I pair of atom types by using one or more `pair_coeff` commands, each with a single argument:

- filename

Thus the following command

```
pair_coeff *2 1*2 cuu3.eam
```

will read the `cuu3` potential file and use the tabulated Cu values for  $F$ ,  $\phi$ ,  $\rho$  that it contains for type pairs 1,1 and 2,2 (type pairs 1,2 and 2,1 are ignored). In effect, this makes atom types 1 and 2 in LAMMPS be Cu atoms. Different single-element files can be assigned to different atom types to model an alloy system. The mixing to create alloy potentials for type pairs with  $I \neq J$  is done automatically the same way that the serial DYNAMO code originally did it; you do not need to specify coefficients for these type pairs.

*Funcfl* files in the *potentials* directory of the LAMMPS distribution have an ".eam" suffix. A DYNAMO single-element *funcfl* file is formatted as follows:

- line 1: comment (ignored)
- line 2: atomic number, mass, lattice constant, lattice type (e.g. FCC)
- line 3:  $N_{\rho}$ ,  $dr_{\rho}$ ,  $N_r$ ,  $dr$ , cutoff

On line 2, all values but the mass are ignored by LAMMPS. The mass is in mass [units](#) (e.g. mass number or grams/mole for metal units). The cubic lattice constant is in Angstroms. On line 3,  $N_{\rho}$  and  $N_r$  are the number of tabulated values in the subsequent arrays,  $dr_{\rho}$  and  $dr$  are the spacing in density and distance space for the values in those arrays, and the specified cutoff becomes the pairwise cutoff used by LAMMPS for the potential. The units of  $dr$  are Angstroms; I'm not sure of the units for  $dr_{\rho}$  – some measure of electron density.

Following the 3 header lines are 3 arrays of tabulated values:

- embedding function  $F(\rho)$  ( $N_{\rho}$  values)
- effective charge function  $Z(r)$  ( $N_r$  values)
- density function  $\rho(r)$  ( $N_r$  values)

The values for each array can be listed as multiple values per line, so long as each array starts on a new line. For example, the individual  $Z(r)$  values are for  $r = 0, dr, 2*dr, \dots (Nr-1)*dr$ .

The units for the embedding function  $F$  are eV. The units for the density function  $\rho$  are the same as for  $drho$  (see above, electron density). The units for the effective charge  $Z$  are "atomic charge" or  $\sqrt{\text{Hartree} * \text{Bohr-radii}}$ . For 2 interacting atoms  $i,j$  this is used by LAMMPS to compute the pair potential term in the EAM energy expression as  $r*\phi_i$ , in units of eV–Angstroms, via the formula

$$r*\phi_i = 27.2 * 0.529 * Z_i * Z_j$$

where 1 Hartree = 27.2 eV and 1 Bohr = 0.529 Angstroms.

---

Style *eam/alloy* computes pairwise interactions using the same formula as style *eam*. However the associated `pair_coeff` command reads a DYNAMO *setfl* file instead of a *funcfl* file. *Setfl* files can be used to model a single–element or alloy system. In the alloy case, as explained above, *setfl* files contain explicit tabulated values for alloy interactions. Thus they allow more generality than *funcfl* files for modeling alloys.

Style *eam/alloy/opt* is an optimized version of style *eam/alloy* that should give identical answers. Depending on system size and the processor you are running on, it may be 5–25% faster (for the pairwise portion of the run time).

For style *eam/alloy*, potential values are read from a file that is in the DYNAMO multi–element *setfl* format, except that element names (Ni, Cu, etc) are added to one of the lines in the file. If the DYNAMO file was created by a Fortran program, it cannot have "D" values in it for exponents. C only recognizes "e" or "E" for scientific notation.

Only a single `pair_coeff` command is used with the *eam/alloy* style which specifies a DYNAMO *setfl* file, which contains information for  $M$  elements. These are mapped to LAMMPS atom types by specifying  $N$  additional arguments after the filename in the `pair_coeff` command, where  $N$  is the number of LAMMPS atom types:

- filename
- $N$  element names = mapping of *setfl* elements to atom types

As an example, the `potentials/nialhjea.setfl` file has tabulated EAM values for 3 elements and their alloy interactions: Ni, Al, and H. If your LAMMPS simulation has 4 atom types and you want the 1st 3 to be Ni, and the 4th to be Al, you would use the following `pair_coeff` command:

```
pair_coeff * * nialhjea.eam.alloy Ni Ni Ni Al
```

The 1st 2 arguments must be `**` so as to span all LAMMPS atom types. The first three Ni arguments map LAMMPS atom types 1,2,3 to the Ni element in the *setfl* file. The final Al argument maps LAMMPS atom type 4 to the Al element in the *setfl* file. Note that there is no requirement that your simulation use all the elements specified by the *setfl* file.

If a mapping value is specified as NULL, the mapping is not performed. This can be used when an *eam/alloy* potential is used as part of the *hybrid* pair style. The NULL values are placeholders for atom types that will be used with other potentials.

*Setfl* files in the *potentials* directory of the LAMMPS distribution have an ".eam.alloy" suffix. A DYNAMO multi–element *setfl* file is formatted as follows:

- lines 1,2,3 = comments (ignored)
- line 4: Nelements Element1 Element2 ... ElementN

- line 5: Nrho, drho, Nr, dr, cutoff

In a DYNAMO *setfl* file, line 4 only lists Nelements = the # of elements in the *setfl* file. For LAMMPS, the element name (Ni, Cu, etc) of each element must be added to the line, in the order the elements appear in the file.

The meaning and units of the values in line 5 is the same as for the *funcfl* file described above. Note that the cutoff (in Angstroms) is a global value, valid for all pairwise interactions for all element pairings.

Following the 5 header lines are Nelements sections, one for each element, each with the following format:

- line 1 = atomic number, mass, lattice constant, lattice type (e.g. FCC)
- embedding function F(rho) (Nrho values)
- density function rho(r) (Nr values)

As with the *funcfl* files, only the mass (g/cm<sup>3</sup>) is used by LAMMPS from the 1st line. The cubic lattice constant is in Angstroms. The F and rho arrays are unique to a single element and have the same format and units as in a *funcfl* file.

Following the Nelements sections, Nr values for each pair potential phi(r) array are listed for all i,j element pairs in the same format as other arrays. Since these interactions are symmetric (i,j = j,i) only phi arrays with i >= j are listed, in the following order: i,j = (1,1), (2,1), (2,2), (3,1), (3,2), (3,3), (4,1), ..., (Nelements, Nelements). Unlike the effective charge array Z(r) in *funcfl* files, the tabulated values for each phi function are listed in *setfl* files directly as r\*phi (in units of eV-Angstroms), since they are for atom pairs.

Style *eam/fs* computes pairwise interactions for metals and metal alloys using a generalized form of EAM potentials due to Finnis and Sinclair ([Finnis](#)). The total energy  $E_i$  of an atom  $I$  is given by

$$E_i = F_\alpha \left( \sum_{j \neq i} \rho_{\alpha\beta}(r_{ij}) \right) + \frac{1}{2} \sum_{j \neq i} \phi_{\alpha\beta}(r_{ij})$$

This has the same form as the EAM formula above, except that rho is now a functional specific to the atomic types of both atoms  $I$  and  $J$ , so that different elements can contribute differently to the total electron density at an atomic site depending on the identity of the element at that atomic site.

Style *eam/fs/opt* is an optimized version of style *eam/fs* that should give identical answers. Depending on system size and the processor you are running on, it may be 5–25% faster (for the pairwise portion of the run time).

The associated [pair\\_coeff](#) command for style *eam/fs* reads a DYNAMO *setfl* file that has been extended to include additional rho\_alpha\_beta arrays of tabulated values. A discussion of how FS EAM differs from conventional EAM alloy potentials is given in ([Ackland1](#)). An example of such a potential is the same author's Fe-P FS potential ([Ackland2](#)). Note that while FS potentials always specify the embedding energy with a square root dependence on the total density, the implementation in LAMMPS does not require that; the user can tabulate any functional form desired in the FS potential files.

For style *eam/fs*, the form of the pair\_coeff command is exactly the same as for style *eam/alloy*, e.g.

```
pair_coeff * * nialhjea.eam.fs Ni Ni Ni Al
```

where there are N additional arguments after the filename, where N is the number of LAMMPS atom types. The N values determine the mapping of LAMMPS atom types to EAM elements in the file, as described above for style *eam/alloy*. As with *eam/alloy*, if a mapping value is NULL, the mapping is not performed. This can be used

when an *eam/fs* potential is used as part of the *hybrid* pair style. The NULL values are used as placeholders for atom types that will be used with other potentials.

FS EAM files include more information than the DYNAMO *setfl* format files read by *eam/alloy*, in that *i,j* density functionals for all pairs of elements are included as needed by the Finnis/Sinclair formulation of the EAM.

FS EAM files in the *potentials* directory of the LAMMPS distribution have an ".eam.fs" suffix. They are formatted as follows:

- lines 1,2,3 = comments (ignored)
- line 4: Nelements Element1 Element2 ... ElementN
- line 5: Nrho, drho, Nr, dr, cutoff

The 5–line header section is identical to an EAM *setfl* file.

Following the header are Nelements sections, one for each element I, each with the following format:

- line 1 = atomic number, mass, lattice constant, lattice type (e.g. FCC)
- embedding function F(rho) (Nrho values)
- density function rho(r) for element I at element 1 (Nr values)
- density function rho(r) for element I at element 2
- ...
- density function rho(r) for element I at element Nelement

The units of these quantities in line 1 are the same as for *setfl* files. Note that the rho(r) arrays in Finnis/Sinclair can be asymmetric ( $i,j \neq j,i$ ) so there are Nelements<sup>2</sup> of them listed in the file.

Following the Nelements sections, Nr values for each pair potential phi(r) array are listed in the same manner ( $r \cdot \phi$ , units of eV–Angstroms) as in EAM *setfl* files. Note that in Finnis/Sinclair, the phi(r) arrays are still symmetric, so only phi arrays for  $i \geq j$  are listed.

---

### Mixing, shift, table, tail correction, per–atom energy/stress, and restart info:

For atom type pairs *I,J* and  $I \neq J$ , where types *I* and *J* correspond to two different element types, mixing is performed by LAMMPS as described above with the individual styles. You never need to specify a *pair\_coeff* command with  $I \neq J$  arguments for the eam styles.

This pair style does not support the [pair\\_modify](#) shift, table, and tail options.

All of the eam pair styles can calculate per–atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands. These quantities include the contribution from the embedding term in the EAM formulas.

The eam pair styles do not write their information to [binary restart files](#), since it is stored in potential files. Thus, you need to re–specify the *pair\_style* and *pair\_coeff* commands in an input script that reads a restart file.

---

### Restrictions:

All of these styles except those ending in *opt* are part of the "manybody" package. They are only enabled if LAMMPS was built with that package (which it is by default). The styles ending in *opt* are part of the "opt" package and also require the "manybody" package. They are only enabled if LAMMPS was built with those packages. See the [Making LAMMPS](#) section for more info.

**Related commands:**

[pair\\_coeff](#)

Here are several WWW sites that discuss EAM potentials stored in either the original DYNAMO or other formats:

<http://www.ims.uconn.edu/centers/simul/pot>  
<http://cst-www.nrl.navy.mil/ccm6/ap>  
<http://enpub.fulton.asu.edu/cms/potentials/main/main.htm>

In principle, these potentials could be used with LAMMPS, though the alternate formats would need to be converted to the DYNAMO format used by LAMMPS and described above.

**Default:** none

---

**(Ackland1)** Ackland, Condensed Matter (2005).

**(Ackland2)** Ackland, Mendelev, Srolovitz, Han and Barashev, Journal of Physics: Condensed Matter, 16, S2629 (2004).

**(Daw)** Daw, Baskes, Phys Rev Lett, 50, 1285 (1983). Daw, Baskes, Phys Rev B, 29, 6443 (1984).

**(Finnis)** Finnis, Sinclair, Philosophical Magazine A, 50, 45 (1984).

## pair\_style gayberne command

### Syntax:

```
pair_style gayberne gamma epsilon mu cutoff
```

- gamma = shift for potential minimum (typically 1)
- epsilon = exponent for eta orientation-dependent energy function
- mu = exponent for chi orientation-dependent energy function
- cutoff = global cutoff for interactions (distance units)

### Examples:

```
pair_style gayberne 1.0 1.0 1.0 10.0
pair_coeff * * 1.0 1.7 1.7 3.4 3.4 1.0 1.0 1.0
```

### Description:

Style *gayberne* computes a Gay–Berne anisotropic LJ interaction ([Beradi](#)) between pairs of ellipsoidal particles or an ellipsoidal and spherical particle via the formulas

$$U(\mathbf{A}_1, \mathbf{A}_2, \mathbf{r}_{12}) = U_r(\mathbf{A}_1, \mathbf{A}_2, \mathbf{r}_{12}, \gamma) \cdot \eta_{12}(\mathbf{A}_1, \mathbf{A}_2, v) \cdot \chi_{12}(\mathbf{A}_1, \mathbf{A}_2, \mathbf{r}_{12}, \mu)$$

$$U_r = 4\epsilon(\varrho^{12} - \varrho^6)$$

$$\varrho = \frac{\sigma}{h_{12} + \gamma\sigma}$$

where  $\mathbf{A}_1$  and  $\mathbf{A}_2$  are the transformation matrices from the simulation box frame to the body frame and  $\mathbf{r}_{12}$  is the center to center vector between the particles.  $U_r$  controls the shifted distance dependent interaction based on the distance of closest approach of the two particles ( $h_{12}$ ) and the user-specified shift parameter  $\gamma$ . When both particles are spherical, the formula reduces to the usual Lennard–Jones interaction (see details below for when Gay–Berne treats a particle as "spherical").

For large uniform molecules it has been shown that the energy parameters are approximately representable in terms of local contact curvatures ([Everaers](#)):

$$\epsilon_a = \sigma \cdot \frac{a}{b \cdot c}; \epsilon_b = \sigma \cdot \frac{b}{a \cdot c}; \epsilon_c = \sigma \cdot \frac{c}{a \cdot b}$$

The variable names utilized as potential parameters are for the most part taken from ([Everaers](#)) in order to be consistent with its RE-squared potential fix. Details on the epsilon and mu parameters are given [here](#). Use of this pair style requires the NVE, NVT, or NPT fixes with the *asphere* extension (e.g. [fix nve/asphere](#)) in order to integrate particle rotation. Additionally, [atom\\_style ellipsoid](#) should be used since it defines the rotational state of the ellipsoidal particles.

More details of the Gay–Berne formulation are given in the references listed below and in [this document](#).

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands, or by mixing as described below:

- epsilon = well depth (energy units)
- sigma = minimum effective particle radii (distance units)
- epsilon\_i\_a = relative well depth of type I for side-to-side interactions
- epsilon\_i\_b = relative well depth of type I for face-to-face interactions
- epsilon\_i\_c = relative well depth of type I for end-to-end interactions
- epsilon\_j\_a = relative well depth of type J for side-to-side interactions
- epsilon\_j\_b = relative well depth of type J for face-to-face interactions
- epsilon\_j\_c = relative well depth of type J for end-to-end interactions
- cutoff (distance units)

The last coefficient is optional. If not specified, the global cutoff specified in the [pair\\_style](#) command is used.

The epsilon\_i and epsilon\_j coefficients are actually defined for atom types, not for pairs of atom types. Thus, in a series of [pair\\_coeff](#) commands, they only need to be specified once for each atom type.

Specifically, if any of epsilon\_i\_a, epsilon\_i\_b, epsilon\_i\_c are non-zero, the three values are assigned to atom type I. If all the epsilon\_i values are zero, they are ignored. If any of epsilon\_j\_a, epsilon\_j\_b, epsilon\_j\_c are non-zero, the three values are assigned to atom type J. If all three epsilon\_i values are zero, they are ignored. Thus the typical way to define the epsilon\_i and epsilon\_j coefficients is to list their values in "[pair\\_coeff](#) I J" commands when I = J, but set them to 0.0 when I != J. If you do list them when I != J, you should insure they are consistent with their values in other [pair\\_coeff](#) commands.

Note that if this potential is being used as a sub-style of [pair\\_style hybrid](#), and there is no "[pair\\_coeff](#) I I" setting made for Gay-Berne for a particular type I (because I-I interactions are computed by another hybrid pair potential), then you still need to insure the epsilon a,b,c coefficients are assigned to that type in a "[pair\\_coeff](#) I J" command.

**IMPORTANT NOTE:** If the epsilon a,b,c for an atom type are all 1.0, and if the shape of the particle is spherical (see the [shape](#) command), meaning the 3 diameters are all the same, then the particle is treated as "spherical" by the Gay-Berne potential. This is significant because if two "spherical" particles interact, then the simple Lennard-Jones formula is used to compute their interaction energy/force using epsilon and sigma, which is much cheaper to compute than the full Gay-Berne formula. Thus you should insure epsilon a,b,c are set to 1.0 for spherical particle types and use epsilon and sigma to specify its interaction with other spherical particles.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs I,J and I != J, the epsilon and sigma coefficients and cutoff distance for this pair style can be mixed. The default mix value is *geometric*. See the "[pair\\_modify](#)" command for details.

This pair styles supports the [pair\\_modify](#) shift option for the energy of the Lennard-Jones portion of the pair interaction, but only for sphere-sphere interactions. There is no shifting performed for ellipsoidal interactions due to the anisotropic dependence of the interaction.

The [pair\\_modify](#) table option is not relevant for this pair style.

This pair style does not support the [pair\\_modify](#) tail option for adding long-range tail corrections to energy and pressure.

This pair style does not calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style writes its information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

---

**Restrictions:**

This style is part of the "asphere" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

The Gay-Berne potential does not become isotropic as  $r$  increases ([Everaers](#)). The distance-of-closest-approach approximation used by LAMMPS becomes less accurate when high-aspect ratio ellipsoids are used.

**Related commands:**

[pair\\_coeff](#), [fix nve/asphere](#), [compute temp/asphere](#)

**Default:** none

---

**(Everaers)** Everaers and Ejtehadi, Phys Rev E, 67, 041710 (2003).

**(Berardi)** Berardi, Fava, Zannoni, Chem Phys Lett, 297, 8–14 (1998).

**(Perram)** Perram and Rasmussen, Phys Rev E, 54, 6565–6572 (1996).

**(Allen)** Allen and Germano, Mol Phys 104, 3225–3235 (2006).



## pair\_style gran/hertzian command

## pair\_style gran/history command

## pair\_style gran/no\_history command

### Syntax:

```
pair_style style Kn gamma_n xmu dampflag
```

- style = *gran/hertzian* or *gran/history* or *gran/no\_history*
- Kn = spring constant for particle repulsion

(mg/d units where m is mass, g is the gravitational constant, d is diameter of a particle)

- gamma\_n = damping coefficient for normal direction collisions (sqrt(g/d) units)
- xmu = static yield criterion
- dampflag = flag (0/1) for whether to (no/yes) include tangential damping

### Examples:

```
pair_style gran/history 200000.0 0.5 1.0 1
```

### Description:

The *gran* styles use the following formula ([Silbert](#)) for frictional force between two granular particles that are a distance  $r$  apart when  $r$  is less than the contact distance  $d$ .

$$F = f(\delta/d) (k_n \delta \mathbf{n}_{ij} - m_{\text{eff}} \gamma_n \mathbf{v}_n) + f(\delta/d) (-k_t \delta \Delta \mathbf{s}_t - m_{\text{eff}} \gamma_t \mathbf{v}_t)$$

The 1st term is a normal force and the 2nd term is a tangential force. The other quantities are as follows:

- delta =  $d - r$
- $f(x) = 1$  for Hookean contacts used in pair styles *history* and *no\_history*
- $f(x) = \text{sqrt}(x)$  for pair style *hertzian*
- Kn = elastic constant for normal contact
- Kt = elastic constant for tangential contact = 2/7 of Kn
- gamma\_n = viscoelastic constants for normal contact
- gamma\_t = viscoelastic constants for tangential contact = 1/2 of gamma\_n
- m\_eff =  $M_i M_j / (M_i + M_j)$  = effective mass of 2 particles of mass  $M_i$  and  $M_j$
- Delta St = tangential displacement vector between the 2 spherical particles which is truncated to satisfy a frictional yield criterion
- n = a unit vector along the line connecting the centers of the 2 particles
- Vn = normal component of the relative velocity of the 2 particles
- Vt = tangential component of the relative velocity of the 2 particles

The Kn and gamma\_n coefficients are set as parameters to the pair\_style command. Xmu is also specified which is the upper limit of the tangential force through the Coulomb criterion  $F_t = xmu * F_n$ . The tangential force between 2 particles grows according to a tangential spring and dash-pot model until  $F_t/F_n = xmu$  and then is held

at  $F_t = F_n * x_{mu}$  until the particles lose contact.

For granular styles there are no individual atom type coefficients that can be set via the [pair\\_coeff](#) command. All global settings are made via the `pair_style` command.

See the citation below for more discussion of granular potentials.

---

**Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:**

The [pair\\_modify](#) mix, shift, table, and tail options are not relevant for granular pair styles.

This pair style does not calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style writes its information to [binary restart files](#), so a `pair_style` commands does not need to be specified in an input script that reads a restart file.

---

**Restrictions:** none

All the granular pair styles are part of the "granular" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

**Related commands:**

[pair\\_coeff](#)

**Default:** none

---

**(Silbert)** Silbert, Ertas, Grest, Halsey, Levine, Plimpton, Phys Rev E, 64, p 051302 (2001).

## pair\_style hybrid command

### Syntax:

```
pair_style hybrid style1 style2 ...
```

- style1,style2 = list of one or more pair styles

### Examples:

```
pair_style hybrid lj/charmm/coul/long 10.0 eam
pair_coeff 1*2 1*2 eam niu3
pair_coeff 3 3 lj/cut/coul/cut 1.0 1.0
pair_coeff 1*2 3 lj/cut 0.5 1.2
```

### Description:

The *hybrid* style enables the use of multiple pair styles in one simulation. A pair style can be assigned to each pair of atom types via the [pair\\_coeff](#) command.

For example, a metal on a LJ surface could be computed where the metal atoms interact with each other via a *eam* potential, the surface atoms interact with each other via a *lj/cut* potential, and the metal/surface interaction is also via a *lj/cut* potential.

All pair styles that will be used must be listed in the `pair_style hybrid` command (in any order). The name of each sub-style is followed by its arguments, as illustrated in the example above.

In the `pair_coeff` command, the first coefficient sets the pair style and the remaining coefficients are those appropriate to that style. For example, consider a simulation with 3 atom types: types 1 and 2 are Ni atoms, type 3 are LJ atoms with charges. The following commands would set up a hybrid simulation:

```
pair_style hybrid eam/alloy lj/cut/coul/cut 10.0 lj/cut 8.0
pair_coeff * * eam/alloy nialhjea 1 1 0
pair_coeff 3 3 lj/cut/coul/cut 1.0 1.0
pair_coeff 1*2 3 lj/cut 0.8 1.1
```

If the `pair_coeff` command for a sub-style requires the use of `* *` as atom type arguments (e.g. the *eam/alloy* example above), then it will also include trailing arguments which map atom types to elements in the potential. These mapping arguments should be specified as 0 if the sub-style is not being applied to certain atom types.

Note that you may also need to use an [atom\\_style](#) hybrid command in your input script, if atoms in the simulation will have attributes from several atom styles, due to using multiple pair potentials.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

Any pair potential settings made via the [pair\\_modify](#) command are passed along to all sub-styles of the hybrid potential.

For atom type pairs  $I, J$  and  $I \neq J$ , if the sub-style assigned to  $I, I$  and  $J, J$  is the same, and if the sub-style allows for mixing, then the coefficients for  $I, J$  can be mixed. The default mix value is *geometric*. See the "pair\_modify" command for details. See the doc page for the sub-style to see if allows for mixing.

The hybrid pair style supports the [pair\\_modify](#) shift, table, and tail options for an I,J pair interaction, if the associated sub-style supports it.

The hybrid pair style can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands, if all its sub-styles can perform per-atom calculations.

For the hybrid pair style, the list of sub-styles and their respective settings are written to [binary restart files](#), so a pair\_style command does not need to be specified in an input script that reads a restart file. However, the coefficient information is not stored in the restart file. Thus, pair\_coeff commands do need to be specified in the restart input script.

### Restrictions:

A pair style of *none* can be specified as an argument to pair\_style hybrid and the corresponding pair\_coeff commands, if you desire to turn off pairwise interactions between certain pairs of atom types.

When using a long-range Coulombic solver (via the [kspace\\_style](#) command) with pair\_style hybrid, one or more sub-styles will be of the "long" variety. E.g. *lj/cut/coul/long* or *buck/coul/long*. It is OK to have more than one sub-style with a "long" component, but you must insure that the short-range Coulombic cutoff used by each of these pair styles is consistent. Else the long-range Coulombic solve will be inconsistent.

### Related commands:

[pair\\_coeff](#)

**Default:** none

**pair\_style lj/cut command****pair\_style lj/cut/opt command****pair\_style lj/cut/coul/cut command****pair\_style lj/cut/coul/debye command****pair\_style lj/cut/coul/long command****pair\_style lj/cut/coul/long/tip4p command****Syntax:**

```
pair_style style args
```

- style = *lj/cut* or *lj/cut/opt* or *lj/cut/coul/cut* or *lj/cut/coul/debye* or *lj/cut/coul/long* or *lj/cut/coul/long/tip4p*
- args = list of arguments for a particular style

```
lj/cut args = cutoff
  cutoff = global cutoff for Lennard Jones interactions (distance units)
lj/cut/opt args = cutoff
  cutoff = global cutoff for Lennard Jones interactions (distance units)
lj/cut/coul/cut args = cutoff (cutoff2)
  cutoff = global cutoff for LJ (and Coulombic if only 1 arg) (distance units)
  cutoff2 = global cutoff for Coulombic (optional) (distance units)
lj/cut/coul/debye args = kappa cutoff (cutoff2)
  kappa = Debye length (inverse distance units)
  cutoff = global cutoff for LJ (and Coulombic if only 1 arg) (distance units)
  cutoff2 = global cutoff for Coulombic (optional) (distance units)
lj/cut/coul/long args = cutoff (cutoff2)
  cutoff = global cutoff for LJ (and Coulombic if only 1 arg) (distance units)
  cutoff2 = global cutoff for Coulombic (optional) (distance units)
lj/cut/coul/long/tip4p args = otype htype btype atype qdist cutoff (cutoff2)
  otype,htype = atom types for TIP4P O and H
  btype,atype = bond and angle types for TIP4P waters
  qdist = distance from O atom to massless charge (distance units)
  cutoff = global cutoff for LJ (and Coulombic if only 1 arg) (distance units)
  cutoff2 = global cutoff for Coulombic (optional) (distance units)
```

**Examples:**

```
pair_style lj/cut 2.5
pair_style lj/cut/opt 2.5
pair_coeff * * 1 1
pair_coeff 1 1 1 1.1 2.8

pair_style lj/cut/coul/cut 10.0
pair_style lj/cut/coul/cut 10.0 8.0
pair_coeff * * 100.0 3.0
pair_coeff 1 1 100.0 3.5 9.0
pair_coeff 1 1 100.0 3.5 9.0 9.0

pair_style lj/cut/coul/debye 1.5 3.0
pair_style lj/cut/coul/debye 1.5 2.5 5.0
```

```

pair_coeff * * 1.0 1.0
pair_coeff 1 1 1.0 1.5 2.5
pair_coeff 1 1 1.0 1.5 2.5 5.0

pair_style lj/cut/coul/long 10.0
pair_style lj/cut/coul/long 10.0 8.0
pair_coeff * * 100.0 3.0
pair_coeff 1 1 100.0 3.5 9.0

pair_style lj/cut/coul/long/tip4p 1 2 7 8 0.3 12.0
pair_style lj/cut/coul/long/tip4p 1 2 7 8 0.3 12.0 10.0
pair_coeff * * 100.0 3.0
pair_coeff 1 1 100.0 3.5 9.0

```

### Description:

The *lj/cut* styles compute the standard 6/12 Lennard–Jones potential, given by

$$E = 4\epsilon \left[ \left( \frac{\sigma}{r} \right)^{12} - \left( \frac{\sigma}{r} \right)^6 \right] \quad r < r_c$$

Rc is the cutoff.

Style *lj/cut/opt* is an optimized version of style *lj/cut* that should give identical answers. Depending on system size and the processor you are running on, it may be 5–25% faster (for the pairwise portion of the run time).

Style *lj/cut/coul/cut* adds a Coulombic pairwise interaction given by

$$E = \frac{Cq_iq_j}{\epsilon r} \quad r < r_c$$

where C is an energy–conversion constant, Qi and Qj are the charges on the 2 atoms, and epsilon is the dielectric constant which can be set by the [dielectric](#) command. If one cutoff is specified in the *pair\_style* command, it is used for both the LJ and Coulombic terms. If two cutoffs are specified, they are used as cutoffs for the LJ and Coulombic terms respectively.

Style *lj/cut/coul/debye* adds an additional exp() damping factor to the Coulombic term, given by

$$E = \frac{Cq_iq_j}{\epsilon r} \exp(-\kappa r) \quad r < r_c$$

where kappa is the Debye length. This potential is another way to mimic the screening effect of a polar solvent.

Style *lj/cut/coul/long* computes the same Coulombic interactions as style *lj/cut/coul/cut* except that an additional damping factor is applied to the Coulombic term so it can be used in conjunction with the [kspace\\_style](#) command and its *ewald* or *pppm* option. The Coulombic cutoff specified for this style means that pairwise interactions within this distance are computed directly; interactions outside that distance are computed in K-space.

Style *lj/cut/coul/long/tip4p* implements the TIP4P water model of ([Jorgensen](#)), which introduces a massless site located a short distance away from the oxygen atom along the bisector of the HOH angle. The atomic types of the

oxygen and hydrogen atoms, the bond and angle types for OH and HOH interactions, and the distance to the massless charge site are specified as `pair_style` arguments.

**IMPORTANT NOTE:** For each TIP4P water molecule in your system, the atom IDs for the O and 2 H atoms must be consecutive, with the O atom first. This is to enable LAMMPS to "find" the 2 H atoms associated with each O atom. For example, if the atom ID of an O atom in a TIP4P water molecule is 500, then its 2 H atoms must have IDs 501 and 502.

See the [howto section](#) for more information on how to use the TIP4P pair style.

The following coefficients must be defined for each pair of atoms types via the `pair_coeff` command as in the examples above, or in the data file or restart files read by the `read_data` or `read_restart` commands, or by mixing as described below:

- epsilon (energy units)
- sigma (distance units)
- cutoff1 (distance units)
- cutoff2 (distance units)

Note that sigma is defined in the LJ formula as the zero-crossing distance for the potential, not as the energy minimum at  $2^{1/6}$  sigma.

The latter 2 coefficients are optional. If not specified, the global LJ and Coulombic cutoffs specified in the `pair_style` command are used. If only one cutoff is specified, it is used as the cutoff for both LJ and Coulombic interactions for this type pair. If both coefficients are specified, they are used as the LJ and Coulombic cutoffs for this type pair. You cannot specify 2 cutoffs for style `lj/cut`, since it has no Coulombic terms.

For `lj/cut/coul/long` and `lj/cut/coul/long/tip4p` only the LJ cutoff can be specified since a Coulombic cutoff cannot be specified for an individual I,J type pair. All type pairs use the same global Coulombic cutoff specified in the `pair_style` command.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs I,J and  $I \neq J$ , the epsilon and sigma coefficients and cutoff distance for all of the `lj/cut` pair styles can be mixed. The default mix value is *geometric*. See the "pair\_modify" command for details.

All of the `lj/cut` pair styles support the `pair_modify` shift option for the energy of the Lennard-Jones portion of the pair interaction.

The `lj/cut/coul/long` and `lj/cut/coul/long/tip4p` pair styles support the `pair_modify` table option since they can tabulate the short-range portion of the long-range Coulombic interaction.

All of the `lj/cut` pair styles support the `pair_modify` tail option for adding a long-range tail correction to the energy and pressure of the Lennard-Jones portion of the pair interaction.

All of the `lj/cut` pair styles can calculate per-atom energy and stress, as used by the `compute epair/atom`, `compute stress/atom`, and `dump custom` commands.

All of the `lj/cut` pair styles write their information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

---

### Restrictions:

The *lj/cut/coul/long* and *lj/cut/coul/long/tip4p* styles are part of the "kspace" package. They are only enabled if LAMMPS was built with that package (which it is by default). The *lj/cut/opt* style is part of the "opt" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

On some 64-bit machines, compiling with `-O3` appears to break the Coulombic tabling option used by the *lj/cut/coul/long* style. See the "Additional build tips" section of the Making LAMMPS documentation pages for workarounds on this issue.

**Related commands:**

[pair\\_coeff](#)

**Default:** none

---

**(Jorgensen)** Jorgensen, Chandrasekhar, Madura, Impey, Klein, J Chem Phys, 79, 926 (1983).



## pair\_style lj/expand command

### Syntax:

```
pair_style lj/expand cutoff
```

- cutoff = global cutoff for lj/expand interactions (distance units)

### Examples:

```
pair_style lj/expand 2.5
pair_coeff * * 1.0 1.0 0.5
pair_coeff 1 1 1.0 1.0 -0.2 2.0
```

### Description:

Style *lj/expand* computes a LJ interaction with a distance shifted by delta which can be useful when particles are of different sizes, since it is different that using different sigma values in a standard LJ formula:

$$E = 4\epsilon \left[ \left( \frac{\sigma}{r - \Delta} \right)^{12} - \left( \frac{\sigma}{r - \Delta} \right)^6 \right] \quad r < r_c + \Delta$$

Rc is the cutoff which does not include the delta distance. I.e. the actual force cutoff is the sum of cutoff + delta.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands, or by mixing as described below:

- epsilon (energy units)
- sigma (distance units)
- delta (distance units)
- cutoff (distance units)

The delta values can be positive or negative. The last coefficient is optional. If not specified, the global LJ cutoff is used.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs I,J and I != J, the epsilon, sigma, and shift coefficients and cutoff distance for this pair style can be mixed. Shift is always mixed via an *arithmetic* rule. The other coefficients are mixed according to the `pair_modify mix` value. The default mix value is *geometric*. See the "pair\_modify" command for details.

This pair style supports the [pair\\_modify](#) shift option for the energy of the pair interaction.

The [pair\\_modify](#) table option is not relevant for this pair style.

This pair style supports the [pair\\_modify](#) tail option for adding a long-range tail correction to the energy and pressure of the pair interaction.

This pair style can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style writes its information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

---

**Restrictions:** none

**Related commands:**

[pair\\_coeff](#)

**Default:** none

## pair\_style lj/smooth command

### Syntax:

```
pair_style lj/smooth Rin cutoff
```

- Rin = global inner cutoff beyond which force smoothing will be applied (distance units)
- cutoff = global cutoff for lj/smooth interactions (distance units)

### Examples:

```
pair_style lj/smooth 8.0 10.0
pair_coeff * * 10.0 1.5
pair_coeff 1 1 20.0 1.3 7.0 9.0
```

### Description:

Style *lj/smooth* computes a LJ interaction with a force smoothing applied between the inner and outer cutoff.

$$E = 4\epsilon \left[ \left( \frac{\sigma}{r} \right)^{12} - \left( \frac{\sigma}{r} \right)^6 \right] \quad r < r_{in}$$

$$F = C_1 + C_2(r - r_{in}) + C_3(r - r_{in})^2 + C_4(r - r_{in})^3 \quad r_{in} < r < r_c$$

The polynomial coefficients C1, C2, C3, C4 are computed by LAMMPS to cause the force to vary smoothly from Rin to Rc. At Rin the force and its 1st derivative will match the unsmoothed LJ formula. At Rc the force and its 1st derivative will be 0.0.

IMPORTANT NOTE: this force smoothing causes the energy to be discontinuous both in its values and 1st derivative. This can lead to poor energy conservation and may require the use of a thermostat. Plot the energy and force resulting from this formula via the [pair\\_write](#) command to see the effect.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands, or by mixing as described below:

- epsilon (energy units)
- sigma (distance units)
- Rin (distance units)
- cutoff (distance units)

The last 2 coefficients are optional. If not specified, the global Rin and cutoff are used. Rin cannot be 0.0. If Rin = cutoff, then no force smoothing is performed for this type pair; the standard LJ formula is used.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs I,J and I != J, the epsilon, sigma, Rin coefficients and the cutoff distance for this pair style can be mixed. Rin is a cutoff value and is mixed like the cutoff. The other coefficients are mixed according to the `pair_modify mix` option. The default mix value is *geometric*. See the "pair\_modify" command for details.

This pair style supports the [pair\\_modify](#) shift option for the energy of the pair interaction.

The [pair\\_modify](#) table option is not relevant for this pair style.

This pair style does not support the [pair\\_modify](#) tail option for adding long-range tail corrections to energy and pressure, since the energy of the pair interaction is smoothed to 0.0 at the cutoff.

This pair style can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style writes its information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

---

**Restrictions:** none

**Related commands:**

[pair\\_coeff](#)

**Default:** none

## pair\_style meam command

### Syntax:

```
pair_style meam
```

### Examples:

```
pair_style meam
pair_coeff * * ../potentials/library.meam Si ../potentials/si.meam Si
pair_coeff * * ../potentials/library.meam Ni Al NULL Ni Al Ni Ni
```

### Description:

Style *meam* computes pairwise interactions for a variety of materials using modified embedded-atom method (MEAM) potentials ([Baskes](#)). Conceptually, it is an extension to the original [EAM potentials](#) which adds angular forces. It is thus suitable for modeling metals and alloys with fcc, bcc, hcp and diamond cubic structures, as well as covalently bonded materials like silicon and carbon.

In the MEAM formulation, the total energy  $E$  of a system of atoms is given by:

$$E = \sum_i \left\{ F_i(\bar{\rho}_i) + \frac{1}{2} \sum_{i \neq j} \phi_{ij}(r_{ij}) \right\}$$

where  $F$  is the embedding energy which is a function of the atomic electron density  $\rho$ , and  $\phi$  is a pair potential interaction. The pair interaction is summed over all neighbors  $J$  of atom  $I$  within the cutoff distance. As with EAM, the multi-body nature of the MEAM potential is a result of the embedding energy term. Details of the computation of the embedding and pair energies, as implemented in LAMMPS, are given in ([Gullet](#)) and references therein.

The various parameters in the MEAM formulas are listed in two files which are specified by the [pair\\_coeff](#) command. These are ASCII text files in a format consistent with other MD codes that implement MEAM potentials, such as the serial DYNAMO code and Warp. Several MEAM potential files with parameters for different materials are included in the "potentials" directory of the LAMMPS distribution with a ".meam" suffix. All of these are parameterized in terms of LAMMPS [metal units](#).

Note that unlike for other potentials, cutoffs for MEAM potentials are not set in the `pair_style` or `pair_coeff` command; they are specified in the MEAM potential files themselves.

Only a single `pair_coeff` command is used with the *meam* style which specifies two MEAM files and the element(s) to extract information for. The MEAM elements are mapped to LAMMPS atom types by specifying  $N$  additional arguments after the 2nd filename in the `pair_coeff` command, where  $N$  is the number of LAMMPS atom types:

- MEAM library file
- Elem1, Elem2, ...
- MEAM parameter file
- $N$  element names = mapping of MEAM elements to atom types

As an example, the potentials/library.meam file has generic MEAM settings for a variety of elements. The potentials/sic.meam file has specific parameter settings for a Si and C alloy system. If your LAMMPS simulation has 4 atoms types and you want the 1st 3 to be Si, and the 4th to be C, you would use the following pair\_coeff command:

```
pair_coeff * * library.meam Si C sic.meam Si Si Si C
```

The 1st 2 arguments must be \* \* so as to span all LAMMPS atom types. The two filenames are for the library and parameter file respectively. The Si and C arguments (between the file names) are the two elements for which info will be extracted from the library file. The first three trailing Si arguments map LAMMPS atom types 1,2,3 to the MEAM Si element. The final C argument maps LAMMPS atom type 4 to the MEAM C element.

If the 2nd filename is specified as NULL, no parameter file is read, which simply means the generic parameters in the library file are used. Use of the NULL specification for the parameter file is discouraged for systems with more than a single element type (e.g. alloys), since the parameter file is expected to set element interaction terms that are not captured by the information in the library file.

If a mapping value is specified as NULL, the mapping is not performed. This can be used when a *meam* potential is used as part of the *hybrid* pair style. The NULL values are placeholders for atom types that will be used with other potentials.

The MEAM library file provided with LAMMPS has the name potentials/library.meam. It is the "meamf" file used by other MD codes. Aside from blank and comment lines (start with #) which can appear anywhere, it is formatted as a series of entries, each of which has 19 parameters and can span multiple lines:

```
elt, lat, z, ielement, atwt, alpha, b0, b1, b2, b3, alat, esub, asub, t0, t1, t2, t3, rozero, ibar
```

The "elt" and "lat" parameters are text strings, such as elt = Si or Cu and lat = dia or fcc. Because the library file is used by Fortran MD codes, these strings may be enclosed in single quotes, but this is not required. The other numeric parameters match values in the formulas above. The value of the "elt" string is what is used in the pair\_coeff command to identify which settings from the library file you wish to read in. There can be multiple entries in the library file with the same "elt" value; LAMMPS reads the 1st matching entry it finds and ignores the rest.

If used, the MEAM parameter file contains settings that override or complement the library file settings. Examples of such parameter files are in the potentials directory with a ".meam" suffix. Their format is the same as is read by other Fortran MD codes. Aside from blank and comment lines (start with #) which can appear anywhere, each line has one of the following forms. Each line can also have a trailing comment (starting with #) which is ignored.

```
keyword = value
keyword(I) = value
keyword(I,J) = value
keyword(I,J,K) = value
```

The recognized keywords are as follows:

```
Ec, alpha, rho0, delta, lattce, attrac, repuls, nn2, Cmin, Cmax, rc, delr, augt1, gsmooth_factor, re
```

where

```
rc          = cutoff radius for cutoff function; default = 4.0
delr        = length of smoothing distance for cutoff function; default = 0.1
rho0(I)     = relative density for element I (overwrites value
```

```

        read from meamf file)
Ec(I,J)      = cohesive energy of reference structure for I-J mixture
delta(I,J)   = heat of formation for I-J alloy; if Ec_IJ is input as
              zero, then LAMMPS sets Ec_IJ = (Ec_II + Ec_JJ)/2 - delta_IJ
alpha(I,J)   = alpha parameter for pair potential between I and J (can
              be computed from bulk modulus of reference structure
re(I,J)      = equilibrium distance between I and J in the reference
              structure
Cmax(I,J,K)  = Cmax screening parameter when I-J pair is screened
              by K (I<=J); default = 2.8
Cmin(I,J,K)  = Cmin screening parameter when I-J pair is screened
              by K (I<=J); default = 2.0
lattce(I,J)  = lattice structure of I-J reference structure:
              dia = diamond (interlaced fcc for alloy)
              fcc = face centered cubic
              bcc = body centered cubic
              dim = dimer
              B1  = rock salt (NaCl structure)
gsmooth_factor = factor determining the length of the G-function smoothing
              region; only significant for ibar=0 or ibar=4.
              99.0 = short smoothing region, sharp step
              0.5  = long smoothing region, smooth step
              default = 99.0
augtl        = integer flag for whether to augment t1 parameter by
              3/5*t3 to account for old vs. new meam formulations;
              0 = don't augment t1
              1 = augment t1
              default = 1

```

Rc, delr, re are in distance units (Angstroms in the case of metal units). Ec and delta are in energy units (eV in the case of metal units).

Each keyword represents a quantity which is either a scalar, vector, 2d array, or 3d array and must be specified with the correct corresponding array syntax. The indices I,J,K each run from 1 to N where N is the number of MEAM elements being used.

Thus these lines

```

rho0(2) = 2.25
alpha(1,2) = 4.37

```

set rho0 for the 2nd element to the value 2.25 and set alpha for the alloy interaction between elements 1 and 2 to 4.37.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs I,J and  $I \neq J$ , where types I and J correspond to two different element types, mixing is performed by LAMMPS with user-specifiable parameters as described above. You never need to specify a pair\_coeff command with  $I \neq J$  arguments for this style.

This pair style does not support the [pair\\_modify](#) shift, table, and tail options.

This pair style does not calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style does not write its information to [binary restart files](#), since it is stored in potential files. Thus, you need to re-specify the pair\_style and pair\_coeff commands in an input script that reads a restart file.

---

**Restrictions:**

This style is part of the "meam" package. It is only enabled if LAMMPS was built with that package, which also requires the MEAM library be built and linked with LAMMPS. See the [Making LAMMPS](#) section for more info.

**Related commands:**

[pair\\_coeff](#), [pair\\_style eam](#)

**Default:** none

---

**(Baskes)** Baskes, Phys Rev B, 46, 2727–2742 (1992).

**(Gullet)** Gullet, Wagner, Slepoy, SANDIA Report 2003–8782 (2003). This report may be accessed on–line via [this link](#).



## pair\_modify command

### Syntax:

```
pair_modify keyword value ...
```

- one or more keyword/value pairs may be listed
- keyword = *shift* or *mix* or *table* or *tabinner* or *tail*

```
mix value = geometric or arithmetic or sixthpower
shift value = yes or no
table value = N
    2^N = # of values in table
tabinner value = cutoff
    cutoff = inner cutoff at which to begin table (distance units)
tail value = yes or no
```

### Examples:

```
pair_modify shift yes mix geometric
pair_modify tail yes
pair_modify table 12
```

### Description:

Modify the parameters of the currently defined pair style. Not all parameters are relevant to all pair styles.

The *mix* keyword affects pair coefficients for interactions between atoms of type I and J, when  $I \neq J$  and the coefficients are not explicitly set in the input script. Note that coefficients for  $I = J$  must be set explicitly, either in the input script via the "pair\_coeff" command or in the "Pair Coeffs" section of the [data file](#). For some pair styles it is not necessary to specify coefficients when  $I \neq J$ , since a "mixing" rule will create them from the I,I and J,J settings. The pair\_modify *mix* value determines what formulas are used to compute the mixed coefficients. In each case, the cutoff distance is mixed the same way as sigma.

Note that not all pair styles support mixing. Also, some mix options are not available for certain pair styles. See the doc page for individual pair styles for those restrictions. Note also that the [pair\\_coeff](#) command also can be used to directly set coefficients for a specific  $I \neq J$  pairing, in which case no mixing is performed.

*mix geometric*

```
epsilon_ij = sqrt(epsilon_i * epsilon_j)
sigma_ij = sqrt(sigma_i * sigma_j)
```

*mix arithmetic*

```
epsilon_ij = sqrt(epsilon_i * epsilon_j)
sigma_ij = (sigma_i + sigma_j) / 2
```

*mix sixthpower*

```
epsilon_ij = (2 * sqrt(epsilon_i*epsilon_j) * sigma_i^3 * sigma_j^3) /
    (sigma_i^6 + sigma_j^6)
sigma_ij = ((sigma_i**6 + sigma_j**6) / 2) ^ (1/6)
```

The *shift* keyword determines whether a Lennard–Jones potential is shifted at its cutoff to 0.0. If so, this adds an energy term to each pairwise interaction which will be included in the thermodynamic output, but does not affect pair forces or atom trajectories. See the doc page for individual pair styles to see which ones support this option.

The *table* keyword applies to pair styles with a long–range Coulombic term; see the doc page for individual styles to see which potentials support this option. If *N* is non–zero, a table of length  $2^N$  is pre–computed for forces and energies, which can shrink their computational cost by up to a factor of 2. The table is indexed via a bit–mapping technique (Wolff) and a linear interpolation is performed between adjacent table values. In our experiments with different table styles (lookup, linear, spline), this method typically gave the best performance in terms of speed and accuracy.

The choice of table length is a tradeoff in accuracy versus speed. A larger *N* yields more accurate force computations, but requires more memory which can slow down the computation due to cache misses. A reasonable value of *N* is between 8 and 16. The default value of 12 (table of length 4096) gives approximately the same accuracy as the no–table (*N* = 0) option. For *N* = 0, forces and energies are computed directly, using a polynomial fit for the needed *erfc()* function evaluation, which is what earlier versions of LAMMPS did. Values greater than 16 typically slow down the simulation and will not improve accuracy; values from 1 to 8 give unreliable results.

The *tabinner* keyword sets an inner cutoff above which the pairwise computation is done by table lookup (if tables are invoked). The smaller this value is set, the less accurate the table becomes (for a given number of table values), which can require use of larger tables. The default cutoff value is  $\sqrt{2.0}$  distance units which means nearly all pairwise interactions are computed via table lookup for simulations with "real" units, but some close pairs may be computed directly (non–table) for simulations with "lj" units.

When the *tail* keyword is set to *yes*, certain pair styles will add a long–range VanderWaals tail "correction" to the energy and pressure. See the doc page for individual styles to see which support this option. These corrections are included in the calculation and printing of thermodynamic quantities (see the *thermo\_style* command). Their effect will also be included in constant NPT or NPH simulations where the pressure influences the simulation box dimensions (e.g. the *fix npt* and *fix nph* commands). The formulas used for the long–range corrections come from equation 5 of (Sun).

Several assumptions are inherent in using tail corrections, including the following:

- The simulated system is a 3d bulk homogeneous liquid. This option should not be used for systems that are non–liquid, 2d, have a slab geometry (only 2d periodic), or inhomogeneous.
- *G(r)*, the radial distribution function (rdf), is unity beyond the cutoff, so a fairly large cutoff should be used (i.e. 2.5 sigma for an LJ fluid), and it is probably a good idea to verify this assumption by checking the rdf. The rdf is not exactly unity beyond the cutoff for each pair of interaction types, so the tail correction is necessarily an approximation.
- Thermophysical properties obtained from calculations with this option enabled will not be thermodynamically consistent with the truncated force–field that was used. In other words, atoms do not feel any LJ pair interactions beyond the cutoff, but the energy and pressure reported by the simulation include an estimated contribution from those interactions.

**Restrictions:** none

You cannot use *shift yes* with *tail yes*, since those are conflicting options. You cannot use *tail yes* with 2d simulations.

**Related commands:**

[pair\\_style](#), [pair\\_coeff](#), [thermo\\_style](#)

**Default:**

The option defaults are mix = geometric, shift = no, table = 12, tabinner = sqrt(2.0), tail = no.

Note that some pair styles perform mixing, but only a certain style of mixing. See the doc pages for individual pair styles for details.

---

**(Wolff)** Wolff and Rudd, Comp Phys Comm, 120, 200–32 (1999).

**(Sun)** Sun, J Phys Chem B, 102, 7338–7364 (1998).

## pair\_style morse command

## pair\_style morse/opt command

### Syntax:

```
pair_style morse cutoff
```

- cutoff = global cutoff for Morse interactions (distance units)

### Examples:

```
pair_style morse 2.5
pair_style morse/opt 2.5
pair_coeff * * 100.0 2.0 1.5
pair_coeff 1 1 100.0 2.0 1.5 3.0
```

### Description:

Style *morse* computes pairwise interactions with the formula

$$E = D_0 \left[ e^{-2\alpha(r-r_0)} - 2e^{-\alpha(r-r_0)} \right] \quad r < r_c$$

Rc is the cutoff.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- D0 (energy units)
- alpha (1/distance units)
- r0 (distance units)
- cutoff (distance units)

The last coefficient is optional. If not specified, the global morse cutoff is used.

Style *morse/opt* is an optimized version of style *morse* that should give identical answers. Depending on system size and the processor you are running on, it may be 5–25% faster (for the pairwise portion of the run time).

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

None of the Morse pair styles support mixing. Thus, coefficients for all I,J pairs must be specified explicitly.

All of the Morse pair styles support the [pair\\_modify](#) shift option for the energy of the pair interaction.

The [pair\\_modify](#) table options is not relevant for the Morse pair styles.

None of the Morse pair styles support the [pair\\_modify](#) tail option for adding long-range tail corrections to energy and pressure.

All of the Morse pair styles can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

All of the Morse pair styles write their information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

---

#### **Restrictions:**

The *morse/opt* style is part of the "opt" package. It is only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info.

#### **Related commands:**

[pair\\_coeff](#)

**Default:** none

## pair\_style none command

### Syntax:

```
pair_style none
```

### Examples:

```
pair_style none
```

### Description:

Using a pair style of none means pair forces are not computed.

With this choice, the force cutoff is 0.0, which means that only atoms within the neighbor skin distance (see the [neighbor](#) command) are communicated between processors. You must insure the skin distance is large enough to acquire atoms needed for computing bonds, angles, etc.

A pair style of *none* will also prevent pairwise neighbor lists from being built. However if the [neighbor](#) style is *bin*, data structures for binning are still allocated. If the neighbor skin distance is small, then these data structures can consume a large amount of memory. So you should either set the neighbor style to *nsq* or set the skin distance to a larger value.

**Restrictions:** none

**Related commands:** none

**Default:** none

## pair\_style soft command

### Syntax:

```
pair_style soft cutoff
```

- cutoff = global cutoff for soft interactions (distance units)

### Examples:

```
pair_style soft 2.5
pair_coeff * * 0.0 60.0
pair_coeff 1 1 0.0 60.0 3.0
```

### Description:

Style *soft* computes pairwise interactions with the formula

$$E = A \left[ 1 + \cos \left( \frac{\pi r}{r_c} \right) \right] \quad r < r_c$$

It is useful for pushing apart overlapping atoms, since it does not blow up as  $r$  goes to 0.  $A$  is a pre-factor that varies in time from the start to the end of the run. The [run](#) command documents how to make the ramping take place across multiple runs.  $R_c$  is the cutoff. See the [fix nve/limit](#) command for another way to push apart overlapping atoms.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands, or by mixing as described below:

- Astart (energy units)
- Astop (energy units)
- cutoff (distance units)

Astart and Astop are the values of the prefactor at the start and end of the next run. At intermediate times the value of  $A$  will be ramped between these 2 values. Note that before performing a 2nd run, you will want to adjust the values of Astart and Astop for all type pairs, or switch to a new pair style.

The last coefficient is optional. If not specified, the global soft cutoff is used.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs  $I, J$  and  $I \neq J$ , the Astart, Astop coefficients and cutoff distance for this pair style can be mixed. Astart and Astop are always mixed via a *geometric* rule. The cutoff is mixed according to the `pair_modify mix` value. The default mix value is *geometric*. See the "pair\_modify" command for details.

This pair styles does not support the [pair\\_modify](#) shift option, since the pair interaction is goes to 0.0 at the cutoff.

The [pair\\_modify](#) table and tail options are not relevant for this pair style.

This pair style can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style writes its information to [binary restart files](#), so `pair_style` and `pair_coeff` commands do not need to be specified in an input script that reads a restart file.

---

**Restrictions:** none

**Related commands:**

[pair\\_coeff](#), [fix nve/limit](#)

**Default:** none



## pair\_style command

### Syntax:

```
pair_style style args
```

- style = one of the following
  - ◆ *none*, *hybrid*, *airebo*, *buck*, *buck/coul/cut*, *buck/coul/long*,
  - ◆ *dpd*, *eam*, *eam/alloy* or *eam/fs*, *gran/hertzian*,
  - ◆ *gran/history*, *gran/no\_history*, *lj/charmm/coul/charmm*,
  - ◆ *lj/charmm/coul/charmm/implicit* or *lj/charmm/coul/long*,
  - ◆ *lj/class2*, *lj/class2/coul/cut* or *lj/class2/coul/long*, *lj/cut*,
  - ◆ *lj/cut/coul/cut* or *lj/cut/coul/debye*, *lj/cut/coul/long*,
  - ◆ *lj/cut/coul/long/tip4p*, *lj/expand*, *lj/smooth*, *meam*, *morse*,
  - ◆ *soft*, *sw*, *table*, *tersoff*, *yukawa*
- args = arguments used by a particular style

### Examples:

```
pair_style lj/cut 2.5
pair_style eam/alloy
pair_style hybrid lj/charmm/coul/long 10.0 eam
pair_style table linear 1000
pair_style none
```

### Description:

Set the formula(s) LAMMPS uses to compute pairwise interactions. In LAMMPS, pair potentials are defined between pairs of atoms that are within a cutoff distance and the set of active interactions typically changes over time. See the [bond\\_style](#) command to define potentials between pairs of bonded atoms, which typically remain in place for the duration of a simulation.

In LAMMPS, pairwise force fields encompass a variety of interactions, some of which include many-body effects, e.g. EAM, Stillinger–Weber, Tersoff, REBO potentials. They are still classified as "pairwise" potentials because the set of interacting atoms changes with time (unlike molecular bonds) and thus a neighbor list is used to find nearby interacting atoms.

Hybrid models where specified pairs of atom types interact via different pair potentials can be setup using the *hybrid* pair style.

The coefficients associated with a pair style are typically set for each pair of atom types, and are specified by the [pair\\_coeff](#) command or read from a file by the [read\\_data](#) or [read\\_restart](#) commands.

The [pair\\_modify](#) command sets options for mixing of type I–J interaction coefficients and adding energy offsets or tail corrections to Lennard–Jones potentials. Details on these options as they pertain to individual potentials are described on the doc page for the potential. Likewise, info on whether the potential information is stored in a [restart file](#) or whether the potential supports calculation of per-atom energy and stress by the [compute epair/atom](#) and [compute stress/atom](#) commands is given on the potential doc page.

In the formulas listed for each pair style,  $E$  is the energy of a pairwise interaction between two atoms separated by a distance  $r$ . The force between the atoms is the negative derivative of this expression.

If the `pair_style` command has a cutoff argument, it sets global cutoffs for all pairs of atom types. The distance(s) can be smaller or larger than the dimensions of the simulation box.

Typically, the global cutoff value can be overridden for a specific pair of atom types by the `pair_coeff` command. The pair style settings (including global cutoffs) can be changed by a subsequent `pair_style` command using the same style. This will reset the cutoffs for all atom type pairs, including those previously set explicitly by a `pair_coeff` command. The exceptions to this are that `pair_style table` and `hybrid` settings cannot be reset. A new `pair_style` command for these styles will wipe out all previously specified `pair_coeff` values.

---

Here is an alphabetic list of pair styles defined in LAMMPS. Click on the style to display the formula it computes, arguments specified in the `pair_style` command, and coefficients specified by the associated `pair_coeff` command:

- [pair\\_style none](#) – turn off pairwise interactions
- [pair\\_style hybrid](#) – define multiple styles of pairwise interactions
- [pair\\_style airebo](#) – AI-REBO potential
- [pair\\_style buck](#) – Buckingham potential
- [pair\\_style buck/coul/cut](#) – Buckinhham with cutoff Coulomb
- [pair\\_style buck/coul/long](#) – Buckingham with long-range Coulomb
- [pair\\_style colloid](#) – integrated colloidal potential
- [pair\\_style dpd](#) – dissipative particle dynamics (DPD)
- [pair\\_style eam](#) – embedded atom method (EAM)
- [pair\\_style eam/alloy](#) – alloy EAM
- [pair\\_style eam/fs](#) – Finnis–Sinclair EAM
- [pair\\_style gayberne](#) – Gay–Berne ellipsoidal potential
- [pair\\_style gran/hertzian](#) – granular potential with Hertizain interactions
- [pair\\_style gran/history](#) – granular potential with history effects
- [pair\\_style gran/no\\_history](#) – granular potential without history effects
- [pair\\_style lj/charmm/coul/charmm](#) – CHARMM potential with cutoff Coulomb
- [pair\\_style lj/charmm/coul/charmm/implicit](#) – CHARMM for implicit solvent
- [pair\\_style lj/charmm/coul/long](#) – CHARMM with long-range Coulomb
- [pair\\_style lj/class2](#) – COMPASS (class 2) force field with no Coulomb
- [pair\\_style lj/class2/coul/cut](#) – COMPASS with cutoff Coulomb
- [pair\\_style lj/class2/coul/long](#) – COMPASS with long-range Coulomb
- [pair\\_style lj/cut](#) – cutoff Lennard–Jones potential with no Coulomb
- [pair\\_style lj/cut/coul/cut](#) – LJ with cutoff Coulomb
- [pair\\_style lj/cut/coul/debye](#) – LJ with Debye damping added to Coulomb
- [pair\\_style lj/cut/coul/long](#) – LJ with long-range Coulomb
- [pair\\_style lj/cut/coul/long/tip4p](#) – LJ with long-range Coulomb for TIP4P water
- [pair\\_style lj/expand](#) – Lennard–Jones for variable size particles
- [pair\\_style lj/smooth](#) – smoothed Lennard–Jones potential
- [pair\\_style meam](#) – modified embedded atom method (MEAM)
- [pair\\_style morse](#) – Morse potential
- [pair\\_style soft](#) – Soft (cosine) potential
- [pair\\_style sw](#) – Stillinger–Weber 3–body potential
- [pair\\_style table](#) – tabulated pair potential
- [pair\\_style tersoff](#) – Tersoff 3–body potential
- [pair\\_style yukawa](#) – Yukawa potential

---

**Restrictions:**

This command must be used before any coefficients are set by the [pair\\_coeff](#), [read\\_data](#), or [read\\_restart](#) commands.

Some pair styles are part of specific packages. They are only enabled if LAMMPS was built with that package. See the [Making LAMMPS](#) section for more info on packages. The doc pages for individual pair potentials tell if it is part of a package.

**Related commands:**

[pair\\_coeff](#), [read\\_data](#), [pair\\_modify](#), [kspace\\_style](#), [dielectric](#), [pair\\_write](#)

**Default:**

`pair_style none`

## pair\_style sw command

### Syntax:

```
pair_style sw
```

### Examples:

```
pair_style sw
pair_coeff * * si.sw Si
pair_coeff * * SiC.sw Si C Si
```

### Description:

The *sw* style computes a 3-body [Stillinger–Weber](#) potential for the energy  $E$  of a system of atoms as

$$\begin{aligned}
 E &= \sum_i \sum_{j>i} \phi_2(r_{ij}) + \sum_i \sum_{j \neq i} \sum_{k>j} \phi_3(r_{ij}, r_{ik}, \theta_{ijk}) \\
 \phi_2(r) &= A \epsilon \left[ B \left( \frac{\sigma}{r} \right)^p - \left( \frac{\sigma}{r} \right)^q \right] \exp \left( \frac{\sigma}{r - a\sigma} \right) \\
 \phi_3(r, s, \theta) &= \lambda \epsilon [\cos \theta - \cos \theta_0]^2 \exp \left( \frac{\gamma \sigma}{r - a\sigma} \right) \exp \left( \frac{\gamma \sigma}{s - a\sigma} \right)
 \end{aligned}$$

where  $\phi_2$  is a two-body term and  $\phi_3$  is a three-body term. The summations in the formula are over all neighbors  $J$  and  $K$  of atom  $I$  within a cutoff distance  $= a \cdot \sigma$ .

Only a single `pair_coeff` command is used with the *sw* style which specifies a Stillinger–Weber potential file with parameters for all needed elements. These are mapped to LAMMPS atom types by specifying  $N$  additional arguments after the filename in the `pair_coeff` command, where  $N$  is the number of LAMMPS atom types:

- filename
- $N$  element names = mapping of SW elements to atom types

As an example, imagine the `SiC.sw` file has Stillinger–Weber values for Si and C. If your LAMMPS simulation has 4 atom types and you want the 1st 3 to be Si, and the 4th to be C, you would use the following `pair_coeff` command:

```
pair_coeff * * SiC.sw Si Si Si C
```

The 1st 2 arguments must be `**` so as to span all LAMMPS atom types. The first three `Si` arguments map LAMMPS atom types 1,2,3 to the Si element in the SW file. The final `C` argument maps LAMMPS atom type 4 to the C element in the SW file. If a mapping value is specified as `NULL`, the mapping is not performed. This can be used when a *sw* potential is used as part of the *hybrid* pair style. The `NULL` values are placeholders for atom types that will be used with other potentials.

Stillinger–Weber files in the *potentials* directory of the LAMMPS distribution have a ".sw" suffix. Lines that are not blank or comments (starting with #) define parameters for a triplet of elements. The parameters in a single entry correspond to the two-body and three-body coefficients in the formula above:

- element 1 (the center atom in a 3–body interaction)
- element 2
- element 3
- epsilon (energy units)
- sigma (distance units)
- a
- lambda
- gamma
- costheta0
- A
- B
- p
- q

The A, B, p, and q parameters are used only for two–body interactions. The lambda, gamma, and costheta0 parameters are used only for three–body interactions. The epsilon, sigma and a parameters are used for both two–body and three–body interactions. The non–annotated parameters are unitless.

The Stillinger–Weber potential file must contain entries for all the elements listed in the pair\_coeff command. It can also contain entries for additional elements not being used in a particular simulation; LAMMPS ignores those entries.

For a single–element simulation, only a single entry is required (e.g. SiSiSi). For a two–element simulation, the file must contain 8 entries (for SiSiSi, SiSiC, SiCSi, SiCC, CSiSi, CSiC, CCSi, CCC), that specify SW parameters for all permutations of the two elements interacting in three–body configurations. Thus for 3 elements, 27 entries would be required, etc.

As annotated above, the first element in the entry is the center atom in a three–body interaction. Thus an entry for SiCC means a Si atom with 2 C atoms as neighbors. By symmetry, three–body parameters for SiCSi and SiSiC entries should be the same. The parameters used for the two–body interaction come from the entry where the 2nd element is repeated. Thus the two–body parameters for Si interacting with C, comes from the SiCC entry. Again by symmetry, the two–body parameters in the SiCC and CSiSi entries should thus be the same. The parameters used for a particular three–body interaction come from the entry with the corresponding three elements. The parameters used only for two–body interactions (A, B, p, and q) in entries whose 2nd and 3rd element are different (e.g. SiCSi) are not used for anything and can be set to 0.0 if desired.

---

### **Mixing, shift, table, tail correction, per–atom energy/stress, and restart info:**

For atom type pairs I,J and I != J, where types I and J correspond to two different element types, mixing is performed by LAMMPS as described above from values in the potential file.

This pair style does not support the [pair\\_modify](#) shift, table, and tail options.

This pair style does not calculate per–atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style does not write its information to [binary restart files](#), since it is stored in potential files. Thus, you need to re–specify the pair\_style and pair\_coeff commands in an input script that reads a restart file.

---

### **Restrictions:**

This pair style is part of the "manybody" package. It is only enabled if LAMMPS was built with that package (which it is by default). See the [Making LAMMPS](#) section for more info.

This pair style requires the [newton](#) setting to be "on" for pair interactions.

The Stillinger–Weber potential files provided with LAMMPS (see the potentials directory) are parameterized for metal [units](#). You can use the SW potential with any LAMMPS units, but you would need to create your own SW potential file with coefficients listed in the appropriate units if your simulation doesn't use "metal" units.

**Related commands:**

[pair\\_coeff](#)

**Default:** none

---

**(Stillinger)** Stillinger and Weber, Phys Rev B, 31, 5262 (1985).

## pair\_style table command

### Syntax:

```
pair_style table style N
```

- style = *lookup* or *linear* or *spline* or *bitmap* = method of interpolation
- N = use N values in *lookup*, *linear*, *spline* tables
- N = use  $2^N$  values in *bitmap* tables

### Examples:

```
pair_style table linear 1000
pair_style table bitmap 12
pair_coeff * 3 morse.table ENTRY1
pair_coeff * 3 morse.table ENTRY1 7.0
```

### Description:

Style *table* creates interpolation tables of length  $N$  from pair potential and force values listed in a file(s) as a function of distance. The files are read by the [pair\\_coeff](#) command.

The interpolation tables are created by fitting cubic splines to the file values and interpolating energy and force values at each of  $N$  distances. During a simulation, these tables are used to interpolate energy and force values as needed. The interpolation is done in one of 4 styles: *lookup*, *linear*, *spline*, or *bitmap*.

For the *lookup* style, the distance between 2 atoms is used to find the nearest table entry, which is the energy or force.

For the *linear* style, the distance is used to find 2 surrounding table values from which an energy or force is computed by linear interpolation.

For the *spline* style, a cubic spline coefficients are computed and stored each of the  $N$  values in the table. The pair distance is used to find the appropriate set of coefficients which are used to evaluate a cubic polynomial which computes the energy or force.

For the *bitmap* style, the  $N$  means to create interpolation tables that are  $2^N$  in length. The pair distance is used to index into the table via a fast bit-mapping technique ([Wolff](#)) and a linear interpolation is performed between adjacent table values.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands:

- filename
- keyword
- cutoff (distance units)

The filename specifies a file containing tabulated energy and force values. The keyword specifies a section of the file. The cutoff is an optional coefficient. If not specified, the outer cutoff in the table itself (see below) will be used to build an interpolation table that extend to the largest tabulated distance. If specified, only file values up to the cutoff are used to create the interpolation table.

The format of a tabulated file is as follows (without the parenthesized comments):

```
# Morse potential for Fe      (one or more comment or blank lines)

MORSE_FE                      (keyword is first text on line)
N 500 R 1.0 10.0              (N, R, RSQ, BITMAP, FPRIME parameters)
                               (blank)
1 1.0 25.5 102.34             (index, r, energy, force)
2 1.02 23.4 98.5
...
500 10.0 0.001 0.003
```

A section begins with a non-blank line whose 1st character is not a "#"; blank lines or lines starting with "#" can be used as comments between sections. The first line begins with a keyword which identifies the section. The line can contain additional text, but the initial text must match the argument specified in the `pair_coeff` command. The next line lists (in any order) one or more parameters for the table. Each parameter is a keyword followed by one or more numeric values.

The parameter "N" is required; its value is the number of table entries that follow. All other parameters are optional. If "R" or "RSQ" or "BITMAP" does not appear, then the distances in each line of the table are used as-is to perform spline interpolation. In this case, the table values can be spaced in *r* uniformly or however you wish to position table values in regions of large gradients.

If used, the parameters "R" or "RSQ" are followed by 2 values *rlo* and *rhi*. If specified, the distance associated with each energy and force value is computed from these 2 values (at high accuracy), rather than using the (low-accuracy) value listed in each line of the table. For "R", distances uniformly spaced between *rlo* and *rhi* are computed; for "RSQ", squared distances uniformly spaced between *rlo*\**rlo* and *rhi*\**rhi* are computed.

If used, the parameter "BITMAP" is also followed by 2 values *rlo* and *rhi*. These values, along with the "N" value determine the ordering of the N lines that follow and what distance is associated with each. This ordering is complex, so it is not documented here, since this file is typically produced by the `pair_write` command with its *bitmap* option. When the table is in BITMAP format, the "N" parameter in the file must be equal to  $2^M$  where M is the value specified in the `pair_style` command. Also, a cutoff parameter cannot be used as an optional 3rd argument in the `pair_coeff` command; the entire table extent as specified in the file must be used.

If used, the parameter "FPRIME" is followed by 2 values *fplo* and *fphi* which are the derivative of the force at the innermost and outermost distances listed in the table. These values are needed by the spline construction routines. If not specified by the "FPRIME" parameter, they are estimated (less accurately) by the first 2 and last 2 force values in the table. This parameter is not used by BITMAP tables.

Following a blank line, the next N lines list the tabulated values. On each line, the 1st value is the index from 1 to N, the 2nd value is *r* (in distance units), the 3rd value is the energy (in energy units), and the 4th is the force (in force units). The *r* values must increase from one line to the next (unless the BITMAP parameter is specified).

Note that one file can contain many sections, each with a tabulated potential. LAMMPS reads the file section by section until it finds one that matches the specified keyword.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

This pair style does not support mixing. Thus, coefficients for all I,J pairs must be specified explicitly.

The `pair_modify` shift, table, and tail options are not relevant for this pair style.



This pair style can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style writes the settings for the "pair\_style table" command to [binary restart files](#), so a pair\_style command does not need to be specified in an input script that reads a restart file. However, the coefficient information is not stored in the restart file, since it is tabulated in the potential files. Thus, pair\_coeff commands do need to be specified in the restart input script.

---

**Restrictions:** none

**Related commands:**

[pair\\_coeff](#)

**Default:** none

---

(**Wolff**) Wolff and Rudd, Comp Phys Comm, 120, 200–32 (1999).

## pair\_style tersoff command

### Syntax:

```
pair_style tersoff
```

### Examples:

```
pair_style tersoff
pair_coeff * * si.tersoff Si
pair_coeff * * SiC.tersoff Si C Si
```

### Description:

The *tersoff* style computes a 3-body Tersoff potential for the energy  $E$  of a system of atoms as

$$\begin{aligned}
 E &= \frac{1}{2} \sum_i \sum_{j \neq i} V_{ij} \\
 V_{ij} &= f_C(r_{ij}) [f_R(r_{ij}) + b_{ij} f_A(r_{ij})] \\
 f_C(r) &= \begin{cases} 1 & : r < R - D \\ \frac{1}{2} - \frac{1}{2} \sin\left(\frac{\pi}{2} \frac{r-R}{D}\right) & : R - D < r < R + D \\ 0 & : r > R + D \end{cases} \\
 f_R(r) &= A \exp(-\lambda_1 r) \\
 f_A(r) &= -B \exp(-\lambda_2 r) \\
 b_{ij} &= (1 + \beta^n \zeta_{ij}^n)^{-\frac{1}{2n}} \\
 \zeta_{ij} &= \sum_{k \neq i, j} f_C(r_{ik}) g(\theta_{ijk}) \exp[\lambda_3^3 (r_{ij} - r_{ik})^3] \\
 g(\theta) &= 1 + \frac{c^2}{d^2} - \frac{c^2}{[d^2 + (\cos \theta - \cos \theta_0)^2]}
 \end{aligned}$$

where  $f_R$  is a two-body term and  $f_A$  includes three-body interactions. The summations in the formula are over all neighbors  $J$  and  $K$  of atom  $I$  within a cutoff distance  $= R + D$ .

Only a single `pair_coeff` command is used with the *tersoff* style which specifies a Tersoff potential file with parameters for all needed elements. These are mapped to LAMMPS atom types by specifying  $N$  additional arguments after the filename in the `pair_coeff` command, where  $N$  is the number of LAMMPS atom types:

- filename
- $N$  element names = mapping of Tersoff elements to atom types

As an example, imagine the `SiC.tersoff` file has Tersoff values for Si and C. If your LAMMPS simulation has 4 atoms types and you want the 1st 3 to be Si, and the 4th to be C, you would use the following `pair_coeff` command:

```
pair_coeff * * SiC.tersoff Si Si Si C
```

The 1st 2 arguments must be \* \* so as to span all LAMMPS atom types. The first three Si arguments map LAMMPS atom types 1,2,3 to the Si element in the Tersoff file. The final C argument maps LAMMPS atom type 4 to the C element in the Tersoff file. If a mapping value is specified as NULL, the mapping is not performed. This can be used when a *tersoff* potential is used as part of the *hybrid* pair style. The NULL values are placeholders for atom types that will be used with other potentials.

Tersoff files in the *potentials* directory of the LAMMPS distribution have a ".tersoff" suffix. Lines that are not blank or comments (starting with #) define parameters for a triplet of elements. The parameters in a single entry correspond to coefficients in the formula above:

- element 1 (the center atom in a 3–body interaction)
- element 2 (the atom bonded to the center atom)
- element 3 (the atom influencing the 1–2 bond in a bond–order sense)
- lambda3 (1/distance units)
- c
- d
- costheta0 (can be a value < -1 or > 1)
- n
- beta
- lambda2 (1/distance units)
- B (energy units)
- R (distance units)
- D (distance units)
- lambda1 (1/distance units)
- A (energy units)

The n, beta, lambda2, B, lambda1, and A parameters are only used for two–body interactions. The lambda3, c, d, and costheta0 parameters are only used for three–body interactions. The R and D parameters are used for both two–body and three–body interactions. The non–annotated parameters are unitless.

The Tersoff potential file must contain entries for all the elements listed in the pair\_coeff command. It can also contain entries for additional elements not being used in a particular simulation; LAMMPS ignores those entries.

For a single–element simulation, only a single entry is required (e.g. SiSiSi). For a two–element simulation, the file must contain 8 entries (for SiSiSi, SiSiC, SiCSi, SiCC, CSiSi, CSiC, CCSi, CCC), that specify Tersoff parameters for all permutations of the two elements interacting in three–body configurations. Thus for 3 elements, 27 entries would be required, etc.

As annotated above, the first element in the entry is the center atom in a three–body interaction and it is bonded to the 2nd atom and the bond is influenced by the 3rd atom. Thus an entry for SiCC means Si bonded to a C with another C atom influencing the bond. Thus three–body parameters for SiCSi and SiSiC entries will not, in general, be the same. The parameters used for the two–body interaction come from the entry where the 2nd element is repeated. Thus the two–body parameters for Si interacting with C, comes from the SiCC entry. By symmetry, the twobody parameters in the SiCC and CSiSi entries should thus be the same. The parameters used for a particular three–body interaction come from the entry with the corresponding three elements. The parameters used only for two–body interactions (n, beta, lambda2, B, lambda1, and A) in entries whose 2nd and 3rd element are different (e.g. SiCSi) are not used for anything and can be set to 0.0 if desired.

---

#### Mixing, shift, table, tail correction, per–atom energy/stress, and restart info:

For atom type pairs I,J and I != J, where types I and J correspond to two different element types, mixing is performed by LAMMPS as described above from values in the potential file.

This pair style does not support the [pair\\_modify](#) shift, table, and tail options.

This pair style does not calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style does not write its information to [binary restart files](#), since it is stored in potential files. Thus, you need to re-specify the `pair_style` and `pair_coeff` commands in an input script that reads a restart file.

---

**Restrictions:**

This pair style is part of the "manybody" package. It is only enabled if LAMMPS was built with that package (which it is by default). See the [Making LAMMPS](#) section for more info.

This pair style requires the [newton](#) setting to be "on" for pair interactions.

The Tersoff potential files provided with LAMMPS (see the potentials directory) are parameterized for metal [units](#). You can use the Tersoff potential with any LAMMPS units, but you would need to create your own Tersoff potential file with coefficients listed in the appropriate units if your simulation doesn't use "metal" units.

**Related commands:**

[pair\\_coeff](#)

**Default:** none

---

**(Tersoff)** Tersoff, Phys Rev B, 37, 6991 (1988).

## pair\_write command

### Syntax:

```
pair_write itype jtype N style inner outer file keyword Qi Qj
```

- itype,jtype = 2 atom types
- N = # of values
- style = *r* or *rsq* or *bitmap*
- inner,outer = inner and outer cutoff (distance units)
- file = name of file to write values to
- keyword = section name in file for this set of tabulated values
- Qi,Qj = 2 atom charges (charge units) (optional)

### Examples:

```
pair_write 1 3 500 r 1.0 10.0 table.txt LJ
pair_write 1 1 1000 rsq 2.0 8.0 table.txt Yukawa_1_1 -0.5 0.5
```

### Description:

Write energy and force values to a file as a function of distance for the currently defined pair potential. This is useful for plotting the potential function or otherwise debugging its values. If the file already exists, the table of values is appended to the end of the file to allow multiple tables of energy and force to be included in one file.

The energy and force values are computed at distances from inner to outer for 2 interacting atoms of type itype and jtype, using the appropriate [pair\\_coeff](#) coefficients. If the style is *r*, then N distances are used, evenly spaced in r; if the style is *rsq*, N distances are used, evenly spaced in  $r^2$ .

For example, for N = 7, style = *r*, inner = 1.0, and outer = 4.0, values are computed at r = 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0.

If the style is *bitmap*, then  $2^N$  values are written to the file in a format and order consistent with how they are read in by the [pair\\_coeff](#) command for pair style *table*. For reasonable accuracy in a bitmapped table, choose  $N \geq 12$ , an *inner* value that is smaller than the distance of closest approach of 2 atoms, and an *outer* value  $\leq$  cutoff of the potential.

If the pair potential is computed between charged atoms, the charges of the pair of interacting atoms can optionally be specified. If not specified, values of  $Q_i = Q_j = 1.0$  are used.

The file is written in the format used as input for the [pair\\_style table](#) option with *keyword* as the section name. Each line written to the file lists an index number (1–N), a distance (in distance units), an energy (in energy units), and a force (in force units).

### Restrictions:

All force field coefficients for pair and other kinds of interactions must be set before this command can be invoked.

Due to how the pairwise force is computed, an inner value  $> 0.0$  must be specified even if the potential has a finite

value at  $r = 0.0$ .

**Related commands:**

[pair\\_style](#), [pair\\_coeff](#)

**Default:** none

## pair\_style yukawa command

### Syntax:

```
pair_style yukawa kappa cutoff
```

- kappa = screening length (inverse distance units)
- cutoff = global cutoff for Yukawa interactions (distance units)

### Examples:

```
pair_style yukawa 2.0 2.5
pair_coeff 1 1 100.0 2.3
pair_coeff * * 100.0
```

### Description:

Style *yukawa* computes pairwise interactions with the formula

$$E = A \frac{e^{-\kappa r}}{r} \quad r < r_c$$

Rc is the cutoff.

The following coefficients must be defined for each pair of atoms types via the [pair\\_coeff](#) command as in the examples above, or in the data file or restart files read by the [read\\_data](#) or [read\\_restart](#) commands, or by mixing as described below:

- A (energy units)
- cutoff (distance units)

The last coefficient is optional. If not specified, the global yukawa cutoff is used.

---

### Mixing, shift, table, tail correction, per-atom energy/stress, and restart info:

For atom type pairs I,J and I != J, the A coefficient and cutoff distance for this pair style can be mixed. A is an energy value mixed like a LJ epsilon. The default mix value is *geometric*. See the "pair\_modify" command for details.

This pair style supports the [pair\\_modify](#) shift option for the energy of the pair interaction.

The [pair\\_modify](#) table option is not relevant for this pair style.

This pair style does not support the [pair\\_modify](#) tail option for adding long-range tail corrections to energy and pressure.

This pair style can calculate per-atom energy and stress, as used by the [compute epair/atom](#), [compute stress/atom](#), and [dump custom](#) commands.

This pair style writes its information to [binary restart files](#), so pair\_style and pair\_coeff commands do not need to be specified in an input script that reads a restart file.

---

**Restrictions:** none

**Related commands:**

[pair\\_coeff](#)

**Default:** none



## print command

### Syntax:

```
print args
```

- args = a line of text and variables names to print out

### Examples:

```
print The system volume is now $v
```

### Description:

Print the list of arguments as a line of text to the screen and/or logfile. If variables are included in the arguments, they will be evaluated and their current values printed. Note that if variables are included, the print string should not be enclosed in double quotes, else it will prevent the variables from being evaluated.

If you want the print command to be executed multiple times (with changing variable values), there are 3 options. First, consider using the [fix print](#) command, which will invoke a print periodically during a simulation. Second, the print command can be used as an argument to the *every* option of the [run](#) command. Third, the print command could appear in a section of the input script that is looped over (see the [jump](#) command).

See the [variable](#) command for a description of *equal* style variables which are typically the most useful ones to use with the print command. Equal-style variables can calculate complex formulas involving atom and group properties, mathematical operations, other variables, etc.

**Restrictions:** none

**Related commands:**

[fix print](#), [variable](#)

**Default:** none

## processors command

### Syntax:

```
processors Px Py Pz
```

- Px,Py,Pz = # of processors in each dimension of a 3d grid

### Examples:

```
processors 2 4 4
```

### Description:

Specify how processors are mapped as a 3d logical grid to the global simulation box.

When this command has not been specified, LAMMPS will choose Px, Py, Pz based on the dimensions of the global simulation box so as to minimize the surface/volume ratio of each processor's sub-domain.

Since LAMMPS does not load-balance by changing the grid of 3d processors on-the-fly, this command should be used to override the LAMMPS default if it is known to be sub-optimal for a particular problem. For example, a problem where the atom's extent will change dramatically over the course of the simulation.

The product of Px, Py, Pz must equal P, the total # of processors LAMMPS is running on. If multiple partitions are being used then P is the number of processors in this partition; see [this section](#) for an explanation of the `-partition` command-line switch.

If P is large and prime, a grid such as 1 x P x 1 will be required, which may incur extra communication costs.

### Restrictions:

This command cannot be used after the simulation box is defined by a [read\\_data](#) or [create\\_box](#) command. It can be used before a restart file is read to change the 3d processor grid from what is specified in the restart file.

**Related commands:** none

### Default:

LAMMPS chooses Px, Py, Pz

## read\_data command

### Syntax:

```
read_data file
```

- file = name of data file to read in

### Examples:

```
read_data data.lj
read_data ../run7/data.polymer.gz
```

### Description:

Read in a data file containing information LAMMPS needs to run a simulation. The file can be ASCII text or a gzipped text file (detected by a .gz suffix). This is one of 3 ways to specify initial atom coordinates; see the [read\\_restart](#) and [create\\_atoms](#) commands for alternative methods.

The structure of the data file is important, though many settings and sections are optional or can come in any order. See the examples directory for sample data files for different problems.

A data file has a header and a body. The header appears first. The first line of the header is always skipped; it typically contains a description of the file. Then lines are read one at a time. Lines can have a trailing comment starting with '#' that is ignored. If the line is blank (only whitespace after comment is deleted), it is skipped. If the line contains a header keyword, the corresponding value(s) is read from the line. If it doesn't contain a header keyword, the line begins the body of the file.

The body of the file contains zero or more sections. The first line of a section has only a keyword. The next line is skipped. The remaining lines of the section contain values. The number of lines depends on the section keyword as described below. Zero or more blank lines can be used between sections. Sections can appear in any order, with a few exceptions as noted below.

The formatting of individual lines in the data file (indentation, spacing between words and numbers) is not important except that header and section keywords (e.g. atoms, xlo xhi, Masses, Bond Coeffs) must be capitalized as shown and can't have extra white space between their words – e.g. two spaces or a tab between "Bond" and "Coeffs" is not valid.

---

These are the recognized header keywords. Header lines can come in any order. The value(s) are read from the beginning of the line. Thus the keyword *atoms* should be in a line like "1000 atoms"; the keyword *ylo yhi* should be in a line like "-10.0 10.0 ylo yhi"; the keyword *xy xz yz* should be in a line like "0.0 5.0 6.0 xy xz yz". All these settings have a default value of 0, except the lo/hi box size defaults are -0.5 and 0.5. A line need only appear if the value is different than the default.

- *atoms* = # of atoms in system
- *bonds* = # of bonds in system
- *angles* = # of angles in system
- *dihedrals* = # of dihedrals in system
- *impropers* = # of impropers in system
- *atom types* = # of atom types in system

- *bond types* = # of bond types in system
- *angle types* = # of angle types in system
- *dihedral types* = # of dihedral types in system
- *improper types* = # of improper types in system
- *xlo xhi* = simulation box boundaries in x dimension
- *ylo yhi* = simulation box boundaries in y dimension
- *zlo zhi* = simulation box boundaries in z dimension
- *xy xz yz* = simulation box tilt factors for triclinic domain

The initial simulation box size is determined by the lo/hi settings. In any dimension, the system may be periodic or non-periodic; see the [boundary](#) command.

If the *xy xz yz* line does not appear, then LAMMPS will set up an axis-aligned (orthogonal) simulation box. If the line does appear, LAMMPS creates a non-orthogonal simulation domain shaped as a parallelepiped with triclinic symmetry. See the [region prism](#) command for a description of how the extent of the parallelepiped is defined. The parallelepiped has its "origin" at (*xlo*,*ylo*,*zlo*) and 3 edge vectors starting from the origin given by  $a = (xhi-xlo, 0, 0)$ ;  $b = (xy, yhi-ylo, 0)$ ;  $c = (xz, yz, zhi-zlo)$ . Note that if your simulation will tilt the box, e.g. via the [fix deform](#) command, the simulation box must be triclinic, even if the tilt factors are initially 0.0.

The tilt factors (*xy*,*xz*,*yz*) can not skew the box more than half the distance of the parallel box length. For example, if *xlo* = 2 and *xhi* = 12, then the x box length is 10 and the *xy* tilt factor must be between -5 and 5. Similarly, both *xz* and *yz* must be between  $-(xhi-xlo)/2$  and  $+(yhi-ylo)/2$ . Note that this is not a limitation, since if the maximum tilt factor is 5 (as in this example), then configurations with tilt = ..., -15, -5, 5, 15, 25, ... are all equivalent.

When a triclinic system is used, the simulation domain must be periodic in any dimensions with a non-zero tilt factor, as defined by the [boundary](#) command. I.e. if the *xy* tilt factor is non-zero, then both the x and y dimensions must be periodic. Similarly, x and z must be periodic if *xz* is non-zero and y and z must be periodic if *yz* is non-zero.

For 2d simulations, the *zlo zhi* values should be set to bound the z coords for atoms that appear in the file; the default of -0.5 0.5 is valid if all z coords are 0.0. For 2d triclinic simulations, the *xz* and *yz* tilt factors must be 0.0.

If the system is non-periodic (in a dimension), then all atoms in the data file should have coordinates (in that dimension) between the lo and hi values. Furthermore, if running in parallel, the lo/hi values should be just a bit smaller/larger than the min/max extent of atoms. For example, if your atoms extend from 0 to 50, you should not specify the box bounds as -10000 and 10000. Since LAMMPS uses the specified box size to layout the 3d grid of processors, this will be sub-optimal and may cause a parallel simulation to lose atoms when LAMMPS shrink-wraps the box to the atoms.

If the system is periodic (in a dimension), then atom coordinates can be outside the bounds; they will be remapped (in a periodic sense) back inside the box.

---

These are the section keywords for the body of the file.

- *Atoms, Velocities, Masses, Shapes, Dipoles* = atom-property sections
- *Bonds, Angles, Dihedrals, Improvers* = molecular topology sections
- *Pair Coeffs, Bond Coeffs, Angle Coeffs, Dihedral Coeffs, Improper Coeffs* = force field sections
- *BondBond Coeffs, BondAngle Coeffs, MiddleBondTorsion Coeffs, EndBondTorsion Coeffs, AngleTorsion Coeffs, AngleAngleTorsion Coeffs, BondBond13 Coeffs, AngleAngle Coeffs* = class 2 force field sections

Each section is listed below in alphabetic order. The format of each section is described including the number of lines it must contain and rules (if any) for where it can appear in the data file.

Any individual line in the various sections can have a trailing comment starting with "#" for annotation purposes. E.g. in the *Atoms* section:

```
10 1 17 -1.0 10.0 5.0 6.0 # salt ion
```

---

*Angle Coeffs* section:

- one line per angle type
- line syntax: ID coeffs

```
ID = angle type (1-N)
coeffs = list of coeffs
```

- example:

```
6 70 108.5 0 0
```

The number and meaning of the coefficients are specific to the defined angle style. See the [angle\\_style](#) and [angle\\_coeff](#) commands for details. Coefficients can also be set via the [angle\\_coeff](#) command in the input script.

---

*AngleAngle Coeffs* section:

- one line per improper type
- line syntax: ID coeffs

```
ID = improper type (1-N)
coeffs = list of coeffs (see improper\_coeff)
```

---

*AngleAngleTorsion Coeffs* section:

- one line per dihedral type
- line syntax: ID coeffs

```
ID = dihedral type (1-N)
coeffs = list of coeffs (see dihedral\_coeff)
```

---

*Angles* section:

- one line per angle
- line syntax: ID type atom1 atom2 atom3

```
ID = number of angle (1-Nangles)
type = angle type (1-Nangletype)
atom1,atom2,atom3 = IDs of 1st,2nd,3rd atoms in angle
```

example:

```
2 2 17 29 430
```

The 3 atoms are ordered linearly within the angle. Thus the central atom (around which the angle is computed) is the atom2 in the list. E.g. H,O,H for a water molecule. The *Angles* section must appear after the *Atoms* section. All values in this section must be integers (1, not 1.0).

---

*AngleTorsion Coeffs* section:

- one line per dihedral type
- line syntax: ID coeffs

```
ID = dihedral type (1-N)
coeffs = list of coeffs (see dihedral\_coeff)
```

---

*Atoms* section:

- one line per atom
- line syntax: depends on atom style

An *Atoms* section must appear in the data file if `natoms > 0` in the header section. The atoms can be listed in any order. These are the line formats for each [atom style](#) in LAMMPS:

angle	atom-ID molecule-ID atom-type x y z
atomic	atom-ID atom-type x y z
bond	atom-ID molecule-ID atom-type x y z
charge	atom-ID atom-type q x y z
dipole	atom-ID atom-type q x y z mux muy muz
dpd	atom-ID atom-type x y z
ellipsoid	atom-ID atom-type x y z quatw quati quatj quatk
full	atom-ID molecule-ID atom-type q x y z
granular	atom-ID atom-type diameter density x y z
molecular	atom-ID molecule-ID atom-type x y z
hybrid	atom-ID atom-type x y z sub-style1 sub-style2 ...

where the keywords have these meanings:

- atom-ID = integer ID of atom
- molecule-ID = integer ID of molecule the atom belongs to
- type-ID = type of atom (1-Ntype)
- q = charge on atom
- diameter = diameter of atom
- density = density of atom
- x,y,z = coordinates of atom
- mux,muy,muz = direction of dipole moment of atom
- quatw,quati,quatj,quatk = quaternion components for orientation of atom

The units for these quantities depend on the unit style; see the [units](#) command for details.

For 2d simulations specify z as 0.0, or a value within the `zlo zhi` setting in the data file header.

The atom-ID is used to identify the atom throughout the simulation and in dump files. Normally, it is a unique value from 1 to `Natoms` for each atom. Unique values larger than `Natoms` can be used, but they will cause extra memory to be allocated on each processor, if an atom map array is used (see the [atom\\_modify](#) command). If an atom map array is not used (e.g. an atomic system with no bonds), velocities are not assigned in the data file, and you don't care if unique atom IDs appear in dump files, then the atom-IDs can all be set to 0.

The molecule ID is a 2nd identifier attached to an atom. Normally, it is a number from 1 to N, identifying which molecule the atom belongs to. It can be 0 if it is an unbonded atom or if you don't care to keep track of molecule assignments.

The values *quatw*, *quati*, *quatj*, and *quatk* set the orientation of the atom as a quaternion (4-vector). Note that the [shape](#) command or "Shapes" section of the data file specifies the aspect ratios of an ellipsoidal particle, which is oriented by default with its x-axis along the simulation box's x-axis, and similarly for y and z. If this body is rotated (via the right-hand rule) by an angle  $\theta$  around a unit vector (a,b,c), then the quaternion that represents its new orientation is given by  $(\cos(\theta/2), a*\sin(\theta/2), b*\sin(\theta/2), c*\sin(\theta/2))$ . These 4 components are *quatw*, *quati*, *quatj*, and *quatk* as specified above. LAMMPS normalizes each atom's quaternion in case (a,b,c) was not a unit vector.

For atom\_style hybrid, following the 5 initial values (ID,type,x,y,z), specific values for each sub-style must be listed. The order of the sub-styles is the same as they were listed in the [atom\\_style](#) command. The sub-style specific values are those that are not the 5 standard ones (ID,type,x,y,z). For example, for the "charge" sub-style, a "q" value would appear. For the "full" sub-style, a "molecule-ID" and "q" would appear. These are listed in the same order they appear as listed above.

Thus if

```
atom_style hybrid charge granular
```

were used in the input script, each atom line would have these fields:

```
atom-ID atom-type x y z q diameter density
```

Atom lines (all lines or none of them) can optionally list 3 final integer values: nx,ny,nz. For periodic dimensions, they specify which image of the box the atom is considered to be in. An image of 0 means the box as defined. A value of 2 means add 2 box lengths to get the true value. A value of -1 means subtract 1 box length to get the true value. LAMMPS updates these flags as atoms cross periodic boundaries during the simulation. The flags can be output with atom snapshots via the [dump](#) command. If nx,ny,nz values are not set in the data file, LAMMPS initializes them to 0.

Atom velocities and other atom quantities not defined above are set to 0.0 when the *Atoms* section is read. They may later be set by a *Velocities* section in the data file or by a [velocity](#) or [set](#) command in the input script.

---

*Bond Coeffs* section:

- one line per bond type
- line syntax: ID coeffs

```
ID = bond type (1-N)
coeffs = list of coeffs
```

- example:

```
4 250 1.49
```

The number and meaning of the coefficients are specific to the defined bond style. See the [bond\\_style](#) and [bond\\_coeff](#) commands for details. Coefficients can also be set via the [bond\\_coeff](#) command in the input script.

---

*BondAngle Coeffs* section:

- one line per angle type

- line syntax: ID coeffs

```
ID = angle type (1-N)
coeffs = list of coeffs (see class 2 section of angle\_coeff)
```

---

*BondBond Coeffs* section:

- one line per angle type
- line syntax: ID coeffs

```
ID = angle type (1-N)
coeffs = list of coeffs (see class 2 section of angle\_coeff)
```

---

*BondBond13 Coeffs* section:

- one line per dihedral type
- line syntax: ID coeffs

```
ID = dihedral type (1-N)
coeffs = list of coeffs (see class 2 section of dihedral\_coeff)
```

---

*Bonds* section:

- one line per bond
- line syntax: ID type atom1 atom2

```
ID = bond number (1-Nbonds)
type = bond type (1-Nbondtype)
atom1,atom2 = IDs of 1st,2nd atoms in bond
```

- example:

```
12 3 17 29
```

The *Bonds* section must appear after the *Atoms* section. All values in this section must be integers (1, not 1.0).

---

*Dihedral Coeffs* section:

- one line per dihedral type
- line syntax: ID coeffs

```
ID = dihedral type (1-N)
coeffs = list of coeffs
```

- example:

```
3 0.6 1 0 1
```

The number and meaning of the coefficients are specific to the defined dihedral style. See the [dihedral\\_style](#) and [dihedral\\_coeff](#) commands for details. Coefficients can also be set via the [dihedral\\_coeff](#) command in the input script.

---

*Dihedrals* section:

- one line per dihedral
- line syntax: ID type atom1 atom2 atom3 atom4



```
ID = number of dihedral (1-Ndihedrals)
type = dihedral type (1-Ndihedraltypes)
atom1,atom2,atom3,atom4 = IDs of 1st,2nd,3rd,4th atoms in dihedral
```

- example:

```
12 4 17 29 30 21
```

The 4 atoms are ordered linearly within the dihedral. The *Dihedrals* section must appear after the *Atoms* section. All values in this section must be integers (1, not 1.0).

---

*Dipoles* section:

- one line per atom type line syntax: ID dipole-moment

```
ID = atom type (1-N)
dipole-moment = value of dipole moment
```

- example:

```
2 0.5
```

This defines the dipole moment of each atom type (which can be 0.0 for some types). This can also be set via the [dipole](#) command in the input script.

---

*EndBondTorsion Coeffs* section:

- one line per dihedral type
- line syntax: ID coeffs

```
ID = dihedral type (1-N)
coeffs = list of coeffs (see class 2 section of dihedral\_coeff)
```

---

*Improper Coeffs* section:

- one line per improper type
- line syntax: ID coeffs

```
ID = improper type (1-N)
coeffs = list of coeffs
```

- example:

```
2 20 0.0548311
```

The number and meaning of the coefficients are specific to the defined improper style. See the [improper\\_style](#) and [improper\\_coeff](#) commands for details. Coefficients can also be set via the [improper\\_coeff](#) command in the input script.

---

*Impropers* section:

- one line per improper
- line syntax: ID type atom1 atom2 atom3 atom4

```
ID = number of improper (1-Nimpropers)
type = improper type (1-Nimpropertypes)
atom1,atom2,atom3,atom4 = IDs of 1st,2nd,3rd,4th atoms in improper
```

- example:

```
12 3 17 29 13 100
```

The ordering of the 4 atoms determines the definition of the improper angle used in the formula for each [improper style](#). See the doc pages for individual styles for details.

The *Impropers* section must appear after the *Atoms* section. All values in this section must be integers (1, not 1.0).

---

*Masses* section:

- one line per atom type
- line syntax: ID mass

```
ID = atom type (1-N)
mass = mass value
```

- example:

```
3 1.01
```

This defines the mass of each atom type. This can also be set via the [mass](#) command in the input script. This section should not be used for atom styles that define a mass for individual atoms – e.g. atom style granular.

---

*MiddleBondTorsion Coeffs* section:

- one line per dihedral type
- line syntax: ID coeffs

```
ID = dihedral type (1-N)
coeffs = list of coeffs (see class 2 section of dihedral\_coeff)
```

---

*Pair Coeffs* section:

- one line per atom type
- line syntax: ID coeffs

```
ID = atom type (1-N)
coeffs = list of coeffs
```

- example:

```
3 0.022 2.35197 0.022 2.35197
```

The number and meaning of the coefficients are specific to the defined pair style. See the [pair\\_style](#) and [pair\\_coeff](#) commands for details. Coefficients can also be set via the [pair\\_coeff](#) command in the input script.

---

*Shapes* section:

- one line per atom type
- line syntax: ID x y z

```
ID = atom type (1-N)
x = x diameter
y = y diameter
z = z diameter
```

- example:

```
3 2.0 1.0 1.0
```

This defines the shape of each atom type. This can also be set via the [shape](#) command in the input script. This section should only be used for atom styles that define a shape, e.g. atom style dipole or ellipsoid.

---

*Velocities* section:

- one line per atom
- line syntax: depends on atom style

all styles except those listed	atom-ID vx vy vz
dipole	atom-ID vx vy vz wx wy wz
ellipsoid	atom-ID vx vy vz lx ly lz
granular	atom-ID vx vy vz wx wy wz

where the keywords have these meanings:

- vx,vy,vz = translational velocity of atom
- lx,ly,lz = angular momentum of aspherical atom
- wx,wy,wz = angular velocity of granular atom

The velocity lines can appear in any order. This section can only be used after an *Atoms* section. This is because the *Atoms* section must have assigned a unique atom ID to each atom so that velocities can be assigned to them.

Vx,vy,vz are in [units](#) of velocity. Lx, ly, lz are in units of angular momentum (distance–velocity–mass). Wx,Wy,Wz are in units of angular velocity (radians/time).

Translational velocities can also be set by the [velocity](#) command in the input script.

---

### Restrictions:

To read gzipped data files, you must compile LAMMPS with the `-DGZIP` option – see the [Making LAMMPS](#) section of the documentation.

### Related commands:

[read\\_restart](#), [create\\_atoms](#)

**Default:** none

## read\_restart command

### Syntax:

```
read_restart file
```

- file = name of binary restart file to read in

### Examples:

```
read_restart save.10000
read_restart restart.*
read_restart poly.*.%
```

### Description:

Read in a previously saved simulation from a restart file. This allows continuation of a previous run. Information about what is stored in a restart file is given below.

Restart files are saved in binary format to enable exact restarts, meaning that the trajectories of a restarted run will precisely match those produced by the original run had it continued on. Several things can prevent exact restarts due to round-off effects, in which case the trajectories in the 2 runs will slowly diverge. These include running on a different number of processors or changing certain settings such as those set by the [newton](#) or [processors](#) commands. LAMMPS will issue a WARNING in these cases. Certain fixes will also not restart exactly, though they should provide statistically similar results. These include [fix shake](#) and [fix langevin](#). If a restarted run is immediately different than the run which produced the restart file, it could be a LAMMPS bug, so consider [reporting it](#) if you think the behavior is wrong.

Because restart files are binary, they may not be portable to other machines. They can be converted to ASCII data files using the [restart2data tool](#) in the tools sub-directory of the LAMMPS distribution.

Similar to how restart files are written (see the [write\\_restart](#) and [restart](#) commands), the restart filename can contain two wild-card characters. If a "\*" appears in the filename, the directory is searched for all filenames that match the pattern where "\*" is replaced with a timestep value. The file with the largest timestep value is read in. Thus, this effectively means, read the latest restart file. It's useful if you want your script to continue a run from where it left off. See the [run](#) command and its "upto" option for how to specify the run command so it doesn't need to be changed either.

If a "%" character appears in the restart filename, LAMMPS expects a set of multiple files to exist. The [restart](#) and [write\\_restart](#) commands explain how such sets are created. Read\_restart will first read a filename where "%" is replaced by "base". This file tells LAMMPS how many processors created the set. Read\_restart then reads the additional files. For example, if the restart file was specified as save.% when it was written, then read\_restart reads the files save.base, save.0, save.1, ... save.P-1, where P is the number of processors that created the restart file. Note that only a single processor reads all the files, so the input does not use parallel I/O. The number of processors which created the set can be different the number of processors in the current LAMMPS simulation.

---

A restart file stores the following information about a simulation: units and atom style, simulation box size and shape and boundary settings, group definitions, atom type settings such as mass and particle shape, individual atoms and their group assignments and molecular topology attributes, force field styles and coefficients, and [special\\_bonds](#) settings. This means that commands for these quantities do not need to be re-specified in the input

script that reads the restart file, though you can redefine settings after the restart file is read.

One exception is that some pair styles do not store their info in restart files. The doc pages for individual pair styles note if this is the case. This is also true of `bond_style hybrid` (and `angle_style`, `dihedral_style`, `improper_style hybrid`).

Information about `kpace_style` settings are not stored in the restart file. Hence if you wish to use an Ewald or PPPM solver, these commands must be re-issued after the restart file is read.

The list of `fixes` used for a simulation is not stored in the restart file. This means the new input script should specify all fixes it will use. Note that some fixes store an internal "state" which is written to the restart file. This allows the fix to continue on with its calculations in a restarted simulation. To re-enable such a fix, the fix command in the new input script must use the same fix-ID and group-ID as was used in the input script that wrote the restart file. If a match is found, LAMMPS prints a message indicating that the fix is being re-enabled. If no match is found before the first run or minimization is performed by the new script, the "state" information for the saved fix is discarded. See the doc pages for individual fixes for info on which ones can be restarted in this manner.

Bond interactions (angle, etc) that have been turned off by the `fix shake` or `delete_bonds` command will be written to a restart file as if they are turned on. This means they will need to be turned off again in a new run after the restart file is read.

Bonds that are broken (e.g. by a bond-breaking potential) are written to the restart file as broken bonds with a type of 0. Thus these bonds will still be broken when the restart file is read.

**IMPORTANT NOTE:** No other information is stored in the restart file. This means that an input script that reads a restart file should specify settings for quantities like `timestep size`, `thermodynamic` and `dump` output, `geometric regions`, etc.

**Restrictions:** none

**Related commands:**

`read_data`, `write_restart`, `restart`

**Default:** none

## region command

### Syntax:

region ID style args keyword value ...

- ID = user-assigned name for the region
- style = *block* or *cylinder* or *prism* or *sphere* or *union* or *intersect*

```

block args = xlo xhi ylo yhi zlo zhi
             xlo,xhi,ylo,yhi,zlo,zhi = bounds of block in all
             dimensions (distance units)
cylinder args = dim c1 c2 radius lo hi
             dim = x or y or z = axis of cylinder
             c1,c2 = coords of cylinder axis in other 2 dimensions (distance units)
             radius = cylinder radius (distance units)
             lo,hi = bounds of cylinder in dim (distance units)
prism args = xlo xhi ylo yhi zlo zhi xy xz yz
             xlo,xhi,ylo,yhi,zlo,zhi = bounds of untilted prism (distance units)
             xy = distance to tilt y in x direction (distance units)
             xz = distance to tilt z in x direction (distance units)
             yz = distance to tilt z in y direction (distance units)
sphere args = x y z radius
             x,y,z = center of sphere (distance units)
             radius = radius of sphere (distance units)
union args = N reg-ID1 reg-ID2 ...
             N = # of regions to follow, must be 2 or greater
             reg-ID1,reg-ID2, ... = IDs of regions to join together
intersect args = N reg-ID1 reg-ID2 ...
             N = # of regions to follow, must be 2 or greater
             reg-ID1,reg-ID2, ... = IDs of regions to intersect

```

- zero or more keyword/value pairs may be appended
- keyword = *side* or *units*

```

side value = in or out
             in = the region is inside the specified geometry
             out = the region is outside the specified geometry
units value = lattice or box
             lattice = the geometry is defined in lattice units
             box = the geometry is defined in simulation box units

```

### Examples:

```

region 1 block -3.0 5.0 INF 10.0 INF INF
region 2 sphere 0.0 0.0 0.0 5 side out
region void cylinder y 2 3 5 -5.0 INF units box
region 1 prism 0 10 0 10 0 10 2 0 0
region outside union 4 side1 side2 side3 side4

```

### Description:

This command defines a geometric region of space. Various other commands use regions. For example, the region can be filled with atoms via the [create\\_atoms](#) command. Or the atoms in the region can be identified as a group via the [group](#) command, or deleted via the [delete\\_atoms](#) command.

The lo/hi values for *block* or *cylinder* or *prism* styles can be specified as EDGE or INF. EDGE means they extend all the way to the global simulation box boundary. Note that this is the current box boundary; if the box changes size during a simulation the region does not. INF means a large negative or positive number (1.0e20), so it should encompass the simulation box even if it changes size. If a region is defined before the simulation box has been created (via [create\\_box](#) or [read\\_data](#) or [read\\_restart](#) commands), then an EDGE or INF parameter cannot be used.

For style *cylinder*, the c1,c2 params are coordinates in the 2 other dimensions besides the cylinder axis dimension. For dim = x,  $c1/c2 = y/z$ ; for dim = y,  $c1/c2 = x/z$ ; for dim = z,  $c1/c2 = x/y$ . Thus the third example above specifies a cylinder with its axis in the y-direction located at x = 2.0 and z = 3.0, with a radius of 5.0, and extending in the y-direction from -5.0 to the upper box boundary.

For style *prism*, a parallelepiped is defined (it's too hard to spell parallelepiped in an input script!). Think of the parallelepiped as initially an axis-aligned orthogonal box with the same xyz lo/hi parameters as region style *block* would define. Then, while holding the (xlo,ylo,zlo) corner point fixed, the box is "skewed" or "tilted" in 3 directions. First, for the lower xy face of the box, the xy factor is how far the upper y edge is shifted in the x direction. The lower xy face is now a parallelogram. A plus or minus value for xy can be specified; 0.0 means no tilt. Then, the upper xy face of the box is translated in the x and y directions by xz and yz. This results in a parallelepiped whose "origin" is at (xlo,ylo,zlo) with 3 edge vectors starting from its origin given by  $a = (xhi-xlo,0,0)$ ;  $b = (xy,yhi-ylo,0)$ ;  $c = (xz,yz,zhi-zlo)$ .

A prism region used with the [create\\_box](#) command must have tilt factors (xy,xz,yz) that do not skew the box more than half the distance of the parallel box length. For example, if xlo = 2 and xhi = 12, then the x box length is 10 and the xy tilt factor must be between -5 and 5. Similarly, both xz and yz must be between  $-(xhi-xlo)/2$  and  $+(yhi-ylo)/2$ . Note that this is not a limitation, since if the maximum tilt factor is 5 (as in this example), then configurations with tilt = ..., -15, -5, 5, 15, 25, ... are all equivalent.

The *union* style creates a region consisting of the volume of all the listed regions combined. The *intersect* style creates a region consisting of the volume that is common to all the listed regions.

The *side* keyword determines whether the region is considered to be inside or outside of the specified geometry. Using this keyword in conjunction with *union* and *intersect* regions, complex geometries can be built up. For example, if the interior of two spheres were each defined as regions, and a *union* style with *side* = out was constructed listing the region-IDs of the 2 spheres, the resulting region would be all the volume in the simulation box that was outside both of the spheres.

The *units* keyword determines the meaning of the distance units used to define the region. A *box* value selects standard distance units as defined by the [units](#) command, e.g. Angstroms for units = real or metal. A *lattice* value means the distance units are in lattice spacings. The [lattice](#) command must have been previously used to define the lattice spacing.

### Restrictions:

A prism cannot be of 0.0 thickness in any dimension; use a small z thickness for 2d simulations. For 2d simulations, the xz and yz parameters must be 0.0.

### Related commands:

[lattice](#), [create\\_atoms](#), [delete\\_atoms](#), [group](#)

### Default:

The option defaults are side = in and units = lattice.

## replicate command

### Syntax:

```
replicate nx ny nz
```

- nx,ny,nz = replication factors in each dimension

### Examples:

```
replicate 2 3 2
```

### Description:

Replicate the current simulation one or more times in each dimension. For example, replication factors of 2,2,2 will create a simulation with 8x as many atoms by doubling the simulation domain in each dimension. A replication factor of 1 in a dimension leaves the simulation domain unchanged.

All properties of the atoms are replicated, including their velocities, which may or may not be desirable. New atom IDs (tags) are assigned to new atoms, as are molecule IDs. Bonds and other topology interactions are created between pairs of new atoms as well as between old and new atoms. This is done by using the image flag for each atom to "unwrap" it out of the periodic box before replicating it. This means that molecular bonds you specify in the original data file that span the periodic box should be between two atoms with image flags that differ by 1. This will allow them to be unwrapped appropriately.

This command operates similar to the replicate tool in the tools sub-directory of the LAMMPS distribution which creates new data files from old ones.

### Restrictions:

A 2d simulation cannot be replicated in the z dimension.

If a simulation is non-periodic in a dimension, care should be used when replicating it in that dimension, as it may put atoms nearly on top of each other.

If the current simulation was read in from a restart file (before a run is performed), there can have been no fix information stored in the file for individual atoms. Similarly, no fixes can be defined at the time the replicate command is used that require vectors of atom information to be stored. This is because the replicate command does not know how to replicate that information for new atoms it creates.

**Related commands:** none

**Default:** none



## reset\_timestep command

### Syntax:

```
reset_timestep N
```

- N = timestep number

### Examples:

```
reset_timestep 0  
reset_timestep 4000000
```

### Description:

Set the timestep counter to the specified value. This command normally comes after the timestep has been set by reading it in from a file or a previous simulation advanced the timestep.

The [read\\_data](#) and [create\\_box](#) commands set the timestep to 0; the [read\\_restart](#) command sets the timestep to the value it had when the restart file was written.

**Restrictions:** none

**Related commands:** none

**Default:** none

## restart command

### Syntax:

```
restart 0
restart N root
restart N file1 file2
```

- N = write a restart file every this many timesteps
- root = filename to which timestep # is appended
- file1,file2 = two full filenames, toggle between them when writing file

### Examples:

```
restart 0
restart 1000 poly.restart
restart 1000 restart.*.equil
restart 10000 poly.%.1 poly.%.2
```

### Description:

Write out a binary restart file every so many timesteps as a run proceeds. A value of 0 means do not write out restart files. Using one filename as an argument will create a series of filenames which include the timestep in the filename. Using two filenames will produce only 2 restart files. LAMMPS will toggle between the 2 names as it writes successive restart files.

Similar to [dump](#) files, the restart filename(s) can contain two wild-card characters. If a "\*" appears in the filename, it is replaced with the current timestep value. This is only recognized when a single filename is used (not when toggling back and forth). Thus, the 3rd example above creates restart files as follows: restart.1000.equil, restart.2000.equil, etc. If a single filename is used with no "\*", then the timestep value is appended. E.g. the 2nd example above creates restart files as follows: poly.restart.1000, poly.restart.2000, etc.

If a "%" character appears in the restart filename(s), then one file is written for each processor and the "%" character is replaced with the processor ID from 0 to P-1. An additional file with the "%" replaced by "base" is also written, which contains global information. For example, the files written on step 1000 for filename restart.% would be restart.base.1000, restart.0.1000, restart.1.1000, ..., restart.P-1.1000. This creates smaller files and can be a fast mode of output on parallel machines that support parallel I/O for output.

Restart files are written on timesteps that are a multiple of N but not on the first timestep of a run or minimization. A restart file is not written on the last timestep of a run unless it is a multiple of N. A restart file is written on the last timestep of a minimization if  $N > 0$  and the minimization converges.

See the [read\\_restart](#) command for information about what is stored in a restart file.

Restart files can be read by a [read\\_restart](#) command to restart a simulation from a particular state. Because the file is binary (to enable exact restarts), it may not be readable on another machine. In this case, the [restart2data program](#) in the tools directory can be used to convert a restart file to an ASCII data file. Both the read\_restart command and restart2data tool can read in a restart file that was written with the "%" character so that multiple files were created.

**Restrictions:** none

**Related commands:**

[write\\_restart](#), [read\\_restart](#)

**Default:**

```
restart 0
```

## run command

### Syntax:

```
run N keyword values ...
```

- N = # of timesteps
- zero or more keyword/value pairs may be appended
- keyword = *upto* or *start* or *stop* or *pre* or *post* or *every*

```
upto value = none
start value = N1
  N1 = timestep at which 1st run started
stop value = N2
  N2 = timestep at which last run will end
pre value = no or yes
post value = no or yes
every values = M command
  M = break the run into M-timestep segments and invoke command between them
  command = a single LAMMPS command (enclosed in double quotes if multiple words)
  NULL means no command will be invoked
```

### Examples:

```
run 10000
run 1000000 upto
run 100 start 0 stop 1000
run 1000 pre no post yes
run 100000 start 0 stop 1000000 every 1000 "print Protein Rg = $r"
run 100000 every 1000 NULL
```

### Description:

Run or continue dynamics for a specified number of timesteps.

When the [run style](#) is *respa*, N refers to outer loop (largest) timesteps.

A value of N = 0 is acceptable; only the thermodynamics of the system are computed and printed without taking a timestep.

The *upto* keyword means to perform a run starting at the current timestep up to the specified timestep. E.g. if the current timestep is 10,000 and "run 100000 upto" is used, then an additional 90,000 timesteps will be run. This can be useful for very long runs on a machine that allocates chunks of time and terminate your job when time is exceeded. If you need to restart your script multiple times (reading in the last restart file), you can keep restarting your script with the same run command until the simulation finally completes.

The *start* or *stop* keywords can be used if multiple runs are being performed and you want a [fix](#) command that changes some value over time (e.g. temperature) to make the change across the entire set of runs and not just a single run. See the doc page for individual fixes to see which ones can be used with the *start/stop* keywords. The [pair\\_style soft](#) potential also changes its pair potential coefficients in this manner.

For example, consider this fix followed by 10 run commands:

```
fix          1 all nvt 200.0 300.0 1.0
```

```
run          1000 start 0 stop 10000
run          1000 start 0 stop 10000
...
run          1000 start 0 stop 10000
```

The NVT fix ramps the target temperature from 200.0 to 300.0 during a run. If the run commands did not have the start/stop keywords (just "run 1000"), then the temperature would ramp from 200.0 to 300.0 during the 1000 steps of each run. With the start/stop keywords, the ramping takes place over the 10000 steps of all runs together.

The *pre* and *post* keywords can be used to streamline the setup, clean-up, and associated output to the screen that happens before and after a run. This can be useful if you wish to do many short runs in succession (e.g. LAMMPS is being called as a library which is doing other computations between successive short LAMMPS runs).

By default (pre and post = yes), LAMMPS creates neighbor lists, computes forces, and imposes fix constraints before every run. And after every run it gathers and prints timings statistics. If a run is just a continuation of a previous run (i.e. no settings are changed), the initial computation is not necessary; the old neighbor list is still valid as are the forces. So if *pre* is specified as "no" then the initial setup is skipped, except for printing thermodynamic info.

**IMPORTANT NOTE:** If your input script changes settings between 2 runs (e.g. adds a [fix](#) or [dump](#) or [compute](#) or changes a [neighbor](#) list parameter), then the initial setup must be performed. LAMMPS does not check for this, but it would be an error to use the *pre* option in this case.

If *post* is specified as "no", the full timing summary is skipped; only a one-line summary timing is printed. Note that if *pre* is set to "no" for the 1st run LAMMPS performs, then it is overridden, since the initial setup computations must be done.

The *every* option provides a means of interleaving LAMMPS runs with a command. This can be a short-hand abbreviation to avoid listing a long series of runs in your input script. Or it can be useful for invoking a command that wraps some other code (e.g. as a library) to perform a computation periodically during a long LAMMPS run. See [this section](#) of the documentation for ideas about how to couple LAMMPS to other codes.

N total steps are simulated, in shorter runs of M steps each. After each M-length run, the command is invoked. If the command is specified as NULL, no command is invoked. Thus these lines:

```
variable q equal x[100]
run 6000 every 2000 "print Coord = $q"
```

are the equivalent of:

```
variable q equal x[100]
run 2000
print Coord = $q
run 2000
print Coord = $q
run 2000
print Coord = $q
```

which does 3 runs of 2000 steps and prints the x-coordinate of a particular atom between runs. Note that the command can contain [variables](#) of style *equal* which will be evaluated each time the command is invoked.

If the *pre* and *post* options are set to "no" when *every* is used, then the 1st run will do the full setup and the last run will print the full timing summary, but these operations will be skipped for intermediate runs.

**Restrictions:** none

**Related commands:**

[minimize](#), [run\\_style](#), [temper](#)

**Default:**

The option defaults are start = the current timestep, stop = current timestep + N, pre = yes, and post = yes.

## run\_style command

### Syntax:

```
run_style style args
```

- style = *verlet* or *respa*

```
verlet args = none
respa args = N n1 n2 ... keyword values ...
N = # of levels of rRESPA
n1, n2, ... = loop factor between rRESPA levels (N-1 values)
zero or more keyword/value pairings may be appended to the loop factors
keyword = bond or angle or dihedral or improper or
pair or inner or middle or outer or kspace
bond value = M
M = which level (1-N) to compute bond forces in
angle value = M
M = which level (1-N) to compute angle forces in
dihedral value = M
M = which level (1-N) to compute dihedral forces in
improper value = M
M = which level (1-N) to compute improper forces in
pair value = M
M = which level (1-N) to compute pair forces in
inner values = M cut1 cut2
M = which level (1-N) to compute pair inner forces in
cut1 = inner cutoff between pair inner and
      pair middle or outer (distance units)
cut2 = outer cutoff between pair inner and
      pair middle or outer (distance units)
middle values = M cut1 cut2
M = which level (1-N) to compute pair middle forces in
cut1 = inner cutoff between pair middle and pair outer (distance units)
cut2 = outer cutoff between pair middle and pair outer (distance units)
outer value = M
M = which level (1-N) to compute pair outer forces in
kspace value = M
M = which level (1-N) to compute kspace forces in
```

### Examples:

```
run_style verlet
run_style respa 4 2 2 2 bond 1 dihedral 2 pair 3 kspace 4
run_style respa 4 2 2 2 bond 1 dihedral 2 inner 3 5.0 6.0 outer 4 kspace 4
```

### Description:

Choose the style of time integrator used for molecular dynamics simulations performed by LAMMPS.

The *verlet* style is a velocity–Verlet integrator.

The *respa* style implements the rRESPA multi–timescale integrator ([Tuckerman](#)) with N hierarchical levels, where level 1 is the innermost loop (shortest timestep) and level N is the outermost loop (largest timestep). The loop factor arguments specify what the looping factor is between levels. N1 specifies the number of iterations of level 1 for a single iteration of level 2, N2 is the iterations of level 2 per iteration of level 3, etc. N–1 looping

parameters must be specified.

The `timestep` command sets the timestep for the outermost rRESPA level. Thus if the example command above for a 4-level rRESPA had an outer timestep of 4.0 fmsec, the inner timestep would be 8x smaller or 0.5 fmsec. All other LAMMPS commands that specify number of timesteps (e.g. `neigh_modify` parameters, `dump` every N timesteps, etc) refer to the outermost timesteps.

The rRESPA keywords enable you to specify at what level of the hierarchy various forces will be computed. If not specified, the defaults are that bond forces are computed at level 1 (innermost loop), angle forces are computed where bond forces are, dihedral forces are computed where angle forces are, improper forces are computed where dihedral forces are, pair forces are computed at the outermost level, and kspace forces are computed where pair forces are. The inner, middle, outer forces have no defaults.

The *inner* and *middle* keywords take additional arguments for cutoffs that are used by the force computations. If the 2 cutoffs for *inner* are 5.0 and 6.0, this means that all pairs up to 6.0 apart are computed by the inner force. Those between 5.0 and 6.0 have their force go ramped to 0.0 so the overlap with the next regime (middle or outer) is smooth. The next regime (middle or outer) will compute forces for all pairs from 5.0 outward, with those from 5.0 to 6.0 having their value ramped in an inverse manner.

When using rRESPA (or for any MD simulation) care must be taken to choose a timestep size(s) that insures the Hamiltonian for the chosen ensemble is conserved. For the constant NVE ensemble, total energy must be conserved. Unfortunately, it is difficult to know *a priori* how well energy will be conserved, and a fairly long test simulation (~10 ps) is usually necessary in order to verify that no long-term drift in energy occurs with the trial set of parameters.

With that caveat, a few rules-of-thumb may be useful in selecting *respa* settings. The following applies mostly to biomolecular simulations using the CHARMM or a similar all-atom force field, but the concepts are adaptable to other problems. Without SHAKE, bonds involving hydrogen atoms exhibit high-frequency vibrations and require a timestep on the order of 0.5 fmsec in order to conserve energy. The relatively inexpensive force computations for the bonds, angles, impropers, and dihedrals can be computed on this innermost 0.5 fmsec step. The outermost timestep cannot be greater than 4.0 fmsec without risking energy drift. Smooth switching of forces between the levels of the rRESPA hierarchy is also necessary to avoid drift, and a 1–2 angstrom "healing distance" (the distance between the outer and inner cutoffs) works reasonably well. We thus recommend the following settings for use of the *respa* style without SHAKE in biomolecular simulations:

```
timestep 4.0
run_style respa 4 2 2 2 inner 2 4.5 6.0 middle 3 8.0 10.0 outer 4
```

With these settings, users can expect good energy conservation and roughly a 2.5 fold speedup over the *verlet* style with a 0.5 fmsec timestep.

If SHAKE is used with the *respa* style, time reversibility is lost, but substantially longer time steps can be achieved. For biomolecular simulations using the CHARMM or similar all-atom force field, bonds involving hydrogen atoms exhibit high frequency vibrations and require a time step on the order of 0.5 fmsec in order to conserve energy. These high frequency modes also limit the outer time step sizes since the modes are coupled. It is therefore desirable to use SHAKE with *respa* in order to freeze out these high frequency motions and increase the size of the time steps in the *respa* hierarchy. The following settings can be used for biomolecular simulations with SHAKE and rRESPA:

```
fix          2 all shake 0.000001 500 0 m 1.0 a 1
timestep     4.0
run_style     respa 2 2 inner 1 4.0 5.0 outer 2
```



With these settings, users can expect good energy conservation and roughly a 1.5 fold speedup over the *verlet* style with SHAKE and a 2.0 fmsec timestep.

For non-biomolecular simulations, the *respa* style can be advantageous if there is a clear separation of time scales – fast and slow modes in the simulation. Even a LJ system can benefit from rRESPA if the interactions are divided by the inner, middle and outer keywords. A 2-fold or more speedup can be obtained while maintaining good energy conservation. In real units, for a pure LJ fluid at liquid density, with a sigma of 3.0 angstroms, and epsilon of 0.1 Kcal/mol, the following settings seem to work well:

```
timestep 36.0  
run_style respa 3 3 4 inner 1 3.0 4.0 middle 2 6.0 7.0 outer 3
```

**Restrictions:** none

Whenever using rRESPA, the user should experiment with trade-offs in speed and accuracy for their system, and verify that they are conserving energy to adequate precision.

**Related commands:**

[timestep](#), [run](#)

**Default:**

```
run_style verlet
```

---

**(Tuckerman)** Tuckerman, Berne and Martyna, J Chem Phys, 97, p 1990 (1992).

## set command

### Syntax:

```
set style ID keyword value ...
```

- style = *atom* or *group* or *region*
- ID = atom ID or group ID or region ID
- one or more keyword/value pairs may be appended
- keyword = *type* or *type/fraction* or *mol* or *x* or *y* or *z* or *vx* or *vy* or *vz* or *charge* or *dipole* or *dipole/random* or *quat/random* or *bond* or *angle* or *dihedral* or *improper*

```
type value = atom type
type/fraction values = type fraction seed
type = new atom type
fraction = fraction of selected atoms to set to new atom type
seed = random # seed (8 digits or less)
mol value = molecule ID
x,y,z value = atom coordinate (distance units)
vx,vy,vz value = velocity component (velocity units)
charge value = atomic charge (charge units)
dipole values = x y z
x,y,z = orientation of dipole moment vector
dipole/random value = seed
seed = random # seed (8 digits or less) for dipole moment orientations
quat values = a b c theta
a,b,c = unit vector to rotate particle around via right-hand rule
theta = rotation angle in degrees
quat/random value = seed
seed = random # seed (8 digits or less) for quaternion orientations
bond value = bond type for all bonds between selected atoms
angle value = angle type for all angles between selected atoms
dihedral value = dihedral type for all dihedrals between selected atoms
improper value = improper type for all impropers between selected atoms
```

### Examples:

```
set group solvent type 2
set group solvent type/fraction 2 0.5 12393
set group edge bond 4
set region half charge 0.5
set atom 100 x 0.5 vx 1.0
set atom 1492 type 3
```

### Description:

Set one or more properties of one or more atoms. Since atom properties are initially assigned by the [read\\_data](#), [read\\_restart](#) or [create\\_atoms](#) commands, this command changes those assignments. This can be useful for overriding the default values assigned by the [create\\_atoms](#) command (e.g. charge = 0.0). It can be useful for altering pairwise and molecular force interactions, since force-field coefficients are defined in terms of types. It can be used to change the labeling of atoms by atom type when they are output in [dump](#) files. It can be useful for debugging purposes; i.e. positioning an atom at a precise location to compute subsequent forces or energy.

The style *atom* selects a single atom. The style *group* selects the entire group of atoms. The style *region* selects all atoms in the geometric region. The associated ID for each of these styles is either the unique atom ID (typically a

number from 1 to  $N$  = the number of atoms in the simulation), the group ID, or the region ID. See the [group](#) and [region](#) commands for details of how to specify a group or region.

---

Keyword *type* sets the atom type for all selected atoms. The specified value must be from 1 to *ntypes*, where *ntypes* was set by the [create\\_box](#) command or the *atom types* field in the header of the data file read by the [read\\_data](#) command.

Keyword *type/fraction* sets the atom type for a fraction of the selected atoms. The actual number of atoms changed is not guaranteed to be exactly the requested fraction, but should be statistically close. Random numbers are used in such a way that a particular atom is changed or not changed, regardless of how many processors are being used.

Keyword *mol* sets the molecule ID for all selected atoms. The [atom style](#) being used must support the use of molecule IDs.

Keywords *x*, *y*, *z*, *vx*, *vy*, *vz*, and *charge* set the coordinates, velocity, or charge of all selected atoms. For *charge*, the [atom style](#) being used must support the use of atomic charge.

Keyword *dipole* uses the specified *x,y,z* values as components of a vector to set as the orientation of the dipole moment vectors of the selected atoms. The magnitude of the dipole moment for each atom is set by the [dipole](#) command.

Keyword *dipole/random* randomizes the orientation of the dipole moment vectors of the selected atoms. The magnitude of the dipole moment for each atom is set by the [dipole](#) command. For 2d systems, the *z* component of the orientation is set to 0.0. Random numbers are used in such a way that the orientation of a particular atom is the same, regardless of how many processors are being used.

Keyword *quat* uses the specified values to create a quaternion (4-vector) that represents the orientation of the selected atoms. Note that the [shape](#) command is used to specify the aspect ratios of an ellipsoidal particle, which is oriented by default with its *x*-axis along the simulation box's *x*-axis, and similarly for *y* and *z*. If this body is rotated (via the right-hand rule) by an angle *theta* around a unit rotation vector (*a,b,c*), then the quaternion that represents its new orientation is given by  $(\cos(\theta/2), a*\sin(\theta/2), b*\sin(\theta/2), c*\sin(\theta/2))$ . The *theta* and *a,b,c* values are the arguments to the *quat* keyword. LAMMPS normalizes the quaternion in case (*a,b,c*) was not specified as a unit vector. For 2d systems, the *a,b,c* values are ignored, since a rotation vector of (0,0,1) is the only valid choice.

Keyword *quat/random* randomizes the orientation of the quaternion of the selected atoms. Random numbers are used in such a way that the orientation of a particular atom is the same, regardless of how many processors are being used. For 2d systems, only orientations in the *xy* plane are generated.

For the *dipole* and *quat* keywords, the [atom style](#) being used must support the use of dipoles or quaternions.

Keywords *bond*, *angle*, *dihedral*, and *improper*, set the bond type (angle type, etc) of all bonds (angles, etc) of selected atoms to the specified value from 1 to *nbondtypes* (*nangletypes*, etc). All atoms in a particular bond (angle, etc) must be selected atoms in order for the change to be made. The value of *nbondtype* (*nangletypes*, etc) was set by the *bond types* (*angle types*, etc) field in the header of the data file read by the [read\\_data](#) command.

### Restrictions:

You cannot set an atom attribute (e.g. *mol* or *q*) if the [atom\\_style](#) does not have that attribute.

This command requires inter-processor communication to coordinate the setting of bond types (angle types, etc).

This means that your system must be ready to perform a simulation before using one of these keywords (force fields set, atom mass set, etc). This is not necessary for other keywords.

Using the *region* style with the bond (angle, etc) keywords can give unpredictable results if there are bonds (angles, etc) that straddle periodic boundaries. This is because the region may only extend up to the boundary and partner atoms in the bond (angle, etc) may have coordinates outside the simulation box if they are ghost atoms.

**Related commands:**

[create\\_box](#), [create\\_atoms](#), [read\\_data](#)

**Default:** none

## shape command

### Syntax:

```
mass I x y z
```

- I = atom type (see asterik form below)
- x = x diameter
- y = y diameter
- z = z diameter

### Examples:

```
shape 1 1.0 1.0 1.0
shape * 3.0 1.0 1.0
shape 2* 3.0 1.0 1.0
```

### Description:

Set the shape for all atoms of one or more atom types. Shape values can also be set in the [read\\_data](#) data file. See the [units](#) command for what distance units to use.

Currently, only [atom\\_style dipole](#) and [atom\\_style ellipsoid](#) require that shapes be set.

Dipoles use the atom shape to compute a moment of inertia for rotational energy. Only the 1st component of the shape is used since the particles are assumed to be spherical. The value of the first component should be the same as the Lennard–Jones sigma value defined in the dipole pair potential, i.e. in [pair\\_style dipole](#).

Ellipsoids use the atom shape to compute a generalized inertia tensor. For example, a shape setting of 3.0 1.0 1.0 defines a particle 3x longer in x than in y or z and with a circular cross-section in yz. Ellipsoids that are spherical can be defined by setting all 3 shape components the same.

The I index can be specified in one of two ways. An explicit numeric value can be used, as in the 1st example above. Or a wild-card asterik can be used to set the mass for multiple atom types. This takes the form "\*" or "\*n" or "n\*" or "m\*n". If N = the number of atom types, then an asterik with no numeric values means all types from 1 to N. A leading asterik means all types from 1 to n (inclusive). A trailing asterik means all types from n to N (inclusive). A middle asterik means all types from m to n (inclusive).

A line in a data file that specifies shape uses the same format as the arguments of the shape command in an input script, except that no wild-card asterik can be used. For example, under the "Shapes" section of a data file, the line that corresponds to the 1st example above would be listed as

```
1 1.0 1.0 1.0
```

### Restrictions:

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

All shapes must be defined before a simulation is run (if the atom style requires shapes be set).

**Related commands:** none

**Default:** none

## shell command

### Syntax:

```
shell style args
```

- style = *cd* or *mkdir* or *mv* or *rm* or *rmdir*

```
cd arg = dir
    dir = directory to change to
mkdir args = dir1 dir2 ...
    dir1,dir2 = one or more directories to create
mv args = old new
    old = old filename
    new = new filename
rm args = file1 file2 ...
    file1,file2 = one or more filenames to delete
rmdir args = dir1 dir2 ...
    dir1,dir2 = one or more directories to delete
```

### Examples:

```
shell cd sub1
shell cd ..
shell mkdir tmp1 tmp2 tmp3
shell rmdir tmp1
shell mv log.lammps hold/log.1
shell rm TMP/file1 TMP/file2
```

### Description:

Execute a shell command. Only a few simple file-based shell commands are supported, in Unix-style syntax. With the exception of *cd*, all commands are executed by only a single processor, so that files/directories are not being manipulated by multiple processors.

The *cd* style executes the Unix "cd" command to change the working directory. All subsequent LAMMPS commands that read/write files will use the new directory. All processors execute this command.

The *mkdir* style executes the Unix "mkdir" command to create one or more directories.

The *mv* style executes the Unix "mv" command to rename a file and/or move it to a new directory.

The *rm* style executes the Unix "rm" command to remove one or more files.

The *rmdir* style executes the Unix "rmdir" command to remove one or more directories. A directory must be empty to be successfully removed.

### Restrictions:

LAMMPS does not detect errors or print warnings when any of these Unix commands execute. E.g. if the specified directory does not exist, executing the *cd* command will silently not do anything.

**Related commands:** none

**Default:** none



## special\_bonds command

### Syntax:

```
special_bonds style
special_bonds c1 c2 c3
special_bonds c1 c2 c3 c4 c5 c6
```

- *style* = *charmm* or *amber*
- *c1,c2,c3,c4,c5,c6* = numeric coefficients from 0.0 to 1.0

### Examples:

```
special_bonds charmm
special_bonds amber
special_bonds 0.0 0.0 1.0
special_bonds 0.0 0.0 1.0 0.0 0.0 0.5
```

### Description:

Set the weighting coefficients for the pairwise force and energy contributions from atom pairs that are also bonded to each other directly or indirectly. The 1st coefficient is the weighting factor on 1–2 atom pairs, which are those directly bonded to each other. The 2nd coefficient is the weighting factor on 1–3 atom pairs which are those separated by 2 bonds (e.g. the 2 H atoms in a water molecule). The 3rd coefficient is the weighting factor on 1–4 atom pairs which are separated by 3 bonds (e.g. the 1st and 4th atoms in a dihedral interaction).

Note that for purposes of computing weighted pairwise interactions, 1–3 and 1–4 interactions are not defined from the list of angles or dihedrals used by the simulation. Rather, they are inferred topologically by the set of bonds defined when atoms are read in from a file ([read\\_data](#) or [read\\_restart](#)). Thus the set of 1–2,1–3,1–4 interactions is the same whether angle potentials are computed or not, and remains the same even if bonds are constrained, or turned off, or removed during a simulation. The only exception is if the [delete\\_bonds](#) command is used with the *special* option that recomputes the 1–2,1–3,1–4 topologies; see the command for more details.

The *charmm* style sets all 3 coefficients to 0.0, which is the default for the CHARMM force field. In pair styles *lj/charmm/coul/charmm* and *lj/charmm/coul/long* the 1–4 coefficients are defined explicitly, and these pair-wise contributions are computed in the charmm dihedral style – see the [pair\\_coeff](#) and [dihedral\\_style](#) commands for more information.

The *amber* style sets the 3 coefficients to 0.0 0.0 0.5 for LJ interactions and to 0.0 0.0 0.833 for Coulombic interactions, which is the default for a particular version of the AMBER force field, where the last value is 5/6.

A *special\_bonds* command with 3 coefficients sets the 1–2, 1–3, and 1–4 coefficients for both LJ and Coulombic terms to those values.

A *special\_bonds* command with 6 coefficients sets the 1–2, 1–3, and 1–4 LJ coefficients to the first 3 values and the Coulombic coefficients to the last 3 values.

**Restrictions:** none

**Related commands:**

`delete_bonds`

**Default:**

`special_bonds 0.0 0.0 0.0`

## temper command

### Syntax:

```
temper N M temp fix-ID seed1 seed2 index
```

- $N$  = total # of timesteps to run
- $M$  = attempt a tempering swap every this many steps
- $temp$  = initial temperature for this ensemble
- $fix-ID$  = ID of the fix that will control temperature during the run
- $seed1$  = random # seed used to decide on adjacent temperature to partner with
- $seed2$  = random # seed for Boltzmann factor in Metropolis swap
- $index$  = which temperature (0 to  $N-1$ ) I am simulating (optional)

### Examples:

```
temper 100000 100 $t tempfix 0 58728
temper 40000 100 $t tempfix 0 32285 $w
```

### Description:

Run a parallel tempering (replica exchange) simulation of multiple ensembles of a system on multiple partitions of processors. The processor partitions are defined using the `-partition` command-line switch (see [this section](#)). Each ensemble's temperature is typically controlled at a different value by a fix with ID *fix-ID* that controls temperature. Possible fix styles are [nvt](#), [npt](#), and [temp/rescale](#). The desired temperature is specified by *temp*, which is typically a variable previously set in the input script, so that each partition is assigned a different temperature. See the [variable](#) command for more details. For example,

```
variable t world 300.0 310.0 320.0 330.0
```

As the tempering simulation runs for  $N$  timesteps, a swap between adjacent ensembles will be attempted every  $M$  timesteps. If *seed1* is 0, then the swap attempts will alternate between odd and even pairings. If *seed1* is non-zero then it is used as a seed in a random number generator to randomly choose an odd or even pairing each time. Each attempted swap of temperatures is either accepted or rejected based on a Boltzmann-weighted Metropolis criterion which uses *seed2* in the random number generator.

The last argument *index* is optional and is used when restarting a tempering run from a set of restart files (one for each replica) which had previously swapped to new temperatures. The *index* value (from 0 to  $N-1$ , where  $N$  is the # of replicas) identifies which temperature the replica was simulating on the timestep the restart files were written. Obviously, this argument must be a variable so that each partition has the correct value. Set the variable to the  $N$  values listed in the log file for the previous run for the replica temperatures at that timestep. For example if the log file listed

```
500000 2 4 0 1 3
```

then a setting of

```
variable w proc 2 4 0 1 3
```

would be used to restart the run with a tempering command like the example above with `$w` as the last argument.

**Restrictions:** none

**Related commands:**

[variable](#)

**Default:** none

## thermo command

### Syntax:

```
thermo N
```

- N = output thermodynamics every N timesteps

### Examples:

```
thermo 100
```

### Description:

Compute and print thermodynamic info (e.g. temperature, energy, pressure) on timesteps that are a multiple of N and at the beginning and end of a simulation. A value of 0 will only print thermodynamics at the beginning and end.

The content and format of what is printed is controlled by the [thermo\\_style](#) and [thermo\\_modify](#) commands.

**Restrictions:** none

### Related commands:

[thermo\\_style](#), [thermo\\_modify](#)

### Default:

```
thermo 0
```

## thermo\_modify command

### Syntax:

```
thermo_modify keyword value ...
```

- one or more keyword/value pairs may be listed
- keyword = *lost* or *norm* or *flush* or *line* or *format* or *temp* or *press* or *drot* or *grot*

```
lost value = error or warn or ignore
norm value = yes or no
flush value = yes or no
line value = one or multi
format values = int string or float string or M string
    M = integer from 1 to N, where N = # of quantities being printed
    string = C-style format string
window value = N
    N = number of previous print-outs to average over
temp value = compute ID that calculates a temperature
press value = compute ID that calculates a pressure
drot value = compute ID that calculates rotational energy for dipolar atoms
grot value = compute ID that calculates rotational energy for granular atoms
```

### Examples:

```
thermo_modify lost ignore flush yes
thermo_modify temp myTemp format 3 %15.8g
thermo_modify line multi format float %g
```

### Description:

Set options for how thermodynamic information is computed and printed by LAMMPS.

**IMPORTANT NOTE:** These options apply to the currently defined thermo style. When you specify a [thermo\\_style](#) command, all thermodynamic settings are restored to their default values, including those previously set by a thermo\_modify command. Thus if your input script specifies a thermo\_style command, you should use the thermo\_modify command after it.

The *lost* keyword determines whether LAMMPS checks for lost atoms each time it computes thermodynamics and what it does if atoms are lost. If the value is *ignore*, LAMMPS does not check for lost atoms. If the value is *error* or *warn*, LAMMPS checks and either issues an error or warning. The code will exit with an error and continue with a warning. This can be a useful debugging option.

The *norm* keyword determines whether the thermodynamic print-out is normalized by the number of atoms or is the total summed across all atoms. Different unit styles have different defaults for this setting.

The *flush* keyword invokes a flush operation after thermodynamic info is written to the log file. This insures the output in that file is current (no buffering by the OS), even if LAMMPS halts before the simulation completes.

The *line* keyword determines whether thermodynamics will be printed as a series of numeric values on one line or in a multi-line format with 3 quantities with text strings per line and a dashed-line header containing the timestep and CPU time. This modify option overrides the *one* and *multi* thermo\_style settings.

The *format* keyword sets the numeric format of individual printed quantities. The *int* and *float* keywords set the format for all integer or floating-point quantities printed. The setting with a numeric value (e.g. format 5 % 10.4g) sets the format of the Mth value printed in each output line, the 5th column of output in this case. If the format for a specific column has been set, it will take precedent over the *int* or *float* setting.

The *window* keyword sets the number of previous thermodynamic screen outputs over which [thermo\\_style custom](#) ave quantities are averaged when printed.

The *temp* keyword is used to determine how thermodynamic temperature is calculated, which is used by all thermo quantities that require a temperature ("temp", "press", "ke", "etotal", "enthalpy", "pxx etc", "tave", "pave"). The specified compute ID must have been previously defined by the user via the [compute](#) command and it must be a style of compute that calculates a temperature. As described in the [thermo\\_style](#) command, thermo output uses a default compute for temperature with ID = *thermo\_temp*. This option allows the user to override the default.

The *press* keyword is used to determine how thermodynamic pressure is calculated, which is used by all thermo quantities that require a pressure ("press", "enthalpy", "pxx etc", "pave"). The specified compute ID must have been previously defined by the user via the [compute](#) command and it must be a style of compute that calculates a pressure. As described in the [thermo\\_style](#) command, thermo output uses a default compute for pressure with ID = *thermo\_pressure*. This option allows the user to override the default.

The *drot* keyword is used to determine how rotational energy is calculated for dipolar atoms, which is used by the thermo\_style keyword *drot*. The specified compute ID must have been previously defined by the user via the [compute](#) command. As described in the [thermo\\_style](#) command, thermo output has a default compute for this calculation with ID = *thermo\_rotate\_dipole*. This option allows the user to override the default.

The *grot* keyword is used to determine how rotational energy is calculated for granular atoms, which is used by the thermo\_style keyword *grot*. The specified compute ID must have been previously defined by the user via the [compute](#) command. As described in the [thermo\\_style](#) command, thermo output has a default compute for this calculation with ID = *thermo\_rotate\_gran*. This option allows the user to override the default.

**Restrictions:** none

**Related commands:**

[thermo](#), [thermo\\_style](#)

**Default:**

The option defaults are lost = error, norm = yes for unit style of *lj*, norm = no for unit style of *real* and *metal*, flush = no, window = 10, temp/press/drot/grot = compute IDs defined by thermo\_style.

The defaults for the line and format options depend on the thermo style. For styles "one", "granular", and "custom" the line and format defaults are "one", "%8d", and "%12.8g". For style "multi", the line and format defaults are "multi", "%8d", and "%14.4f".

## thermo\_style command

### Syntax:

```
thermo_style style args
```

- style = *one* or *multi* or *granular* or *custom*
- args = list of arguments for a particular style

```
one args = none
multi args = none
granular args = none
custom args = list of attributes
    possible attributes = step, atoms, cpu, temp, press,
                        pe, ke, etotal, enthalpy,
                        evdwl, ecoul, epair, ebond, eangle, edihed, eimp,
                        emol, elong, etail,
                        vol, lx, ly, lz, xlo, xhi, ylo, yhi, zlo, zhi,
                        pxx, pyy, pzz, pxy, pxz, pyz
                        drot, grot,
                        tave, pave, eave, peave,
                        c_ID, c_ID[n], f_ID, f_ID[n], v_name

step = timestep
atoms = # of atoms
cpu = elapsed CPU time
temp = temperature
press = pressure
pe = total potential energy
ke = kinetic energy
etotal = total energy (pe + ke)
enthalpy = enthalpy (pe + press*vol)
evdwl = VanderWaal pairwise energy
ecoul = Coulombic pairwise energy
epair = pairwise energy (evdwl + ecoul + elong + etail)
ebond = bond energy
eangle = angle energy
edihed = dihedral energy
eimp = improper energy
emol = molecular energy (ebond + eangle + edihed + eimp)
elong = long-range kspace energy
etail = VanderWaal energy long-range tail correction
vol = volume
lx,ly,lz = box lengths in x,y,z
xlo,xhi,ylo,yhi,zlo,zhi = box boundaries
pxx,pyy,pzz,pxy,pxz,pyz = 6 components of pressure tensor
drot = rotational energy of dipolar atoms
grot = rotational energy of granular atoms
tave, pave, eave, peave = time-averaged temp, press, etotal, pe
c_ID = scalar quantity calculated by a compute identified by its ID
c_ID[N] = Nth vector quantity calculated by a compute identified by its ID
f_ID = scalar quantity calculated by a fix identified by its ID
f_ID[N] = Nth vector quantity calculated by a fix identified by its ID
v_name = current value of a variable identified by the variable name
```

### Examples:

```
thermo_style multi
thermo_style custom step temp pe etotal press vol
thermo_style custom step temp etotal c_myTemp v_abc
```



## Description:

Set the style and content for printing thermodynamic data to the screen and log file.

Style *one* prints a one-line summary of thermodynamic info that is the equivalent of "thermo\_style custom step temp epair emol etotal press". The line contains only numeric values.

Style *multi* prints a multiple-line listing of thermodynamic info that is the equivalent of "thermo\_style custom etotal ke temp pe ebond eangle edihed eimp evdwl ecoul elong press". The listing contains numeric values and a string ID for each quantity.

Style *granular* is used with [atom style granular](#) and prints a one-line numeric summary that is the equivalent of "thermo\_style custom step atoms ke grot".

Style *custom* is the most general setting and allows you to specify which of the keywords listed above you want printed on each thermodynamic timestep. Note that the keywords `c_ID`, `f_ID`, `v_name` are references to [computes](#), [fixes](#), and [variables](#) that have been defined elsewhere in the input script or can even be new styles which users have added to LAMMPS (see the [Section\\_modify](#) section of the documentation). Thus the *custom* style provides a flexible means of outputting essentially any desired quantity as a simulation proceeds.

All styles except *custom* have *vol* appended to their list of outputs if the simulation box volume changes during the simulation.

Options invoked by the [thermo\\_modify](#) command can be used to set the one- or multi-line format of the print-out, the normalization of energy quantities (total or per-atom), and the numeric precision of each printed value.

IMPORTANT NOTE: When you specify a "thermo\_style [command](#), all [thermodynamic settings are restored to their default values, including those previously set by a :thermo\\_modify](#) command. Thus if your input script specifies a thermo\_style command, you should use the thermo\_modify command after it.

---

Several of the thermodynamic quantities require a temperature to be computed: "temp", "press", "ke", "etotal", "enthalpy", "pxx etc", "tave", "pave". By default this is done by using the "thermo\_temp" compute which is created by LAMMPS as if this command had been issued:

```
compute thermo_temp all temp
```

See the [compute temp](#) command for details. Note that the ID of this compute is *thermo\_temp* and the group is *all*. You can change the attributes of this temperature (e.g. its degrees-of-freedom) via the [compute\\_modify](#) command. Alternatively, you can directly assign a new compute (that calculates temperature) which you have defined, to be used for calculating any thermodynamic quantity that requires a temperature. This is done via the [thermo\\_modify](#) command.

Several of the thermodynamic quantities require a pressure to be computed: "press", "enthalpy", "pxx etc", "pave". By default this is done by using the "thermo\_pressure" compute which is created by LAMMPS as if this command had been issued:

```
compute thermo_pressure all pressure thermo_temp
```

See the [compute pressure](#) command for details. Note that the ID of this compute is *thermo\_pressure* and the group is *all*. You can change the attributes of this pressure via the [compute\\_modify](#) command. Alternatively, you can directly assign a new compute (that calculates pressure) which you have defined, to be used for calculating any thermodynamic quantity that requires a pressure. This is done via the [thermo\\_modify](#) command.

The *drot* keyword requires a rotational energy to be computed for point dipole particles. To do this, a compute of style "rotate/dipole" is created, as if this command had been issued:

```
compute thermo_rotate_dipole all rotate/dipole
```

See the [compute rotate/dipole](#) command for details. Note that the ID of the new compute is *thermo\_rotate\_dipole* and the group is *all*. You can change the attributes of this computation via the [compute\\_modify](#) command. Alternatively, you can directly assign a new compute which you have defined, to be used for *drot*. This is done via the [thermo\\_modify](#) command. For example, this could be useful if you wish to exclude certain particles from the computation.

The *grot* keyword requires a rotational energy to be computed for granular particles. To do this, a compute of style "rotate/gran" is created, as if this command had been issued:

```
compute thermo_rotate_gran all rotate/gran
```

See the [compute rotate/gran](#) command for details. Note that the ID of the new compute is *thermo\_rotate\_gran* and the group is *all*. You can change the attributes of this computation via the [compute\\_modify](#) command. Alternatively, you can directly assign a new compute which you have defined, to be used for *grot*. This is done via the [thermo\\_modify](#) command. For example, this could be useful if you wish to exclude frozen particles from the computation.

---

The potential energy of the system *pe* will include contributions from fixes if the [fix\\_modify thermo](#) option was set for each fix. For example, the [fix wall/lj93](#) fix will contribute the energy of atoms interacting with the wall.

A long-range tail correction *etail* for the VanderWaal pairwise energy will be non-zero only if the [pair\\_modify tail](#) option is turned on. The *etail* contribution is included in *evdwl*, *pe*, and *etotal*, and the corresponding tail correction to the pressure is included in *press* and *pxx*, *pyy*, etc.

The time-averaged keywords *tave*, *pave*, *eave*, *peave* are averaged over the last N thermodynamic outputs to the screen (not the last N timesteps), where N is the value set by the *window* option of the [thermo\\_modify](#) command (N = 10 by default).

---

The *c\_ID* and *c\_ID[N]* keywords allow scalar or vector quantities calculated by a compute to be output. The ID in the keyword should be replaced by the actual ID of the compute that has been defined elsewhere in the input script. See the [compute](#) command for details. Note that only global scalar or vector quantities calculated by a compute can be output as thermodynamic data; per-atom quantities calculated by a compute are output by the [dump custom](#) command.

If *c\_ID* is used as a keyword, then the scalar quantity calculated by the compute is printed. If *c\_ID[N]* is used, then N in the range from 1–M will print the Nth component of the M-length vector calculated by the compute. See the doc pages for individual compute styles for info on what these quantities are.

The *f\_ID* and *f\_ID[N]* keywords allow scalar or vector quantities calculated by a fix to be output. The ID in the keyword should be replaced by the actual ID of the fix that has been defined elsewhere in the input script.

If *f\_ID* is used as a keyword, then the scalar quantity calculated by the fix is printed. If *f\_ID[N]* is used, then N in the range from 1–M will print the Nth component of the M-length vector calculated by the fix. See the doc pages for individual fix styles for info on what these quantities are. For fixes that compute a contribution to the potential energy of the system, the scalar quantity *f\_ID* is typically that quantity.

The *v\_name* keyword allow the current value of a variable to be output. The name in the keyword should be

replaced by the actual name of the variable that has been defined elsewhere in the input script. See the [variable](#) command for details. Equal-style variables can calculate complex formulas involving atom and group properties, mathematical operations, other variables, etc. This keyword enables them to be evaluated and their value printed periodically during a simulation.

See [this section](#) for information on how to add new compute and fix styles as well as variable options to LAMMPS that calculate quantities that could then be output with these keywords as part of thermodynamic information.

---

#### **Restrictions:**

This command must come after the simulation box is defined by a [read\\_data](#), [read\\_restart](#), or [create\\_box](#) command.

#### **Related commands:**

[thermo](#), [thermo\\_modify](#), [fix\\_modify](#), [temperature](#)

#### **Default:**

```
thermo_style one
```

## timestep command

### Syntax:

```
timestep dt
```

- dt = timestep size (time units)

### Examples:

```
timestep 2.0  
timestep 0.003
```

### Description:

Set the timestep size for subsequent molecular dynamics simulations. See the [units](#) command for a discussion of time units. Note that using the units command also sets the timestep to its default value in the chosen units.

When the run style is *respa*, dt is the timestep for the outer loop (largest) timestep.

**Restrictions:** none

**Related commands:**

[run](#), [run\\_style](#) respa, [units](#)

### Default:

```
timestep = 0.005 tau for units = lj  
timestep = 1.0 fmsec for units = real  
timestep = 0.001 psec for units = metal
```

## uncompute command

### Syntax:

```
uncompute compute-ID
```

- compute-ID = ID of a previously defined compute

### Examples:

```
uncompute 2  
uncompute lower-boundary
```

### Description:

Delete a compute that was previously defined with a [compute](#) command. This also wipes out any additional changes made to the compute via the [compute\\_modify](#) command.

**Restrictions:** none

**Related commands:**

[compute](#)

**Default:** none

## undump command

### Syntax:

```
undump dump-ID
```

- dump-ID = ID of previously defined dump

### Examples:

```
undump mine  
undump 2
```

### Description:

Turn off a previously defined dump so that it is no longer active. This closes the file associated with the dump.

**Restrictions:** none

### Related commands:

[dump](#)

**Default:** none

## unfix command

### Syntax:

```
unfix fix-ID
```

- fix-ID = ID of a previously defined fix

### Examples:

```
unfix 2  
unfix lower-boundary
```

### Description:

Delete a fix that was previously defined with a [fix](#) command. This also wipes out any additional changes made to the fix via the [fix\\_modify](#) command.

**Restrictions:** none

### Related commands:

[fix](#)

**Default:** none

## units command

### Syntax:

```
units style
```

- style = *lj* or *real* or *metal*

### Examples:

```
units metal  
units lj
```

### Description:

This command sets the style of units used for a simulation. It determines the units of all quantities specified in the input script and data file, as well as quantities output to the screen, log file, and dump files. Typically, this command is used at the very beginning of an input script.

For real and metallic units, LAMMPS uses physical constants from [www.physics.nist.gov](http://www.physics.nist.gov). For the definition of Kcal in real units, LAMMPS uses the thermochemical calorie = 4.184 J.

For style *lj*, all quantities are unitless:

- distance = sigma
- time = tau
- mass = one
- energy = epsilon
- velocity = sigma/tau
- force = epsilon/sigma
- temperature = reduced LJ temperature
- pressure = reduced LJ pressure
- charge = reduced LJ charge
- dipole = reduced LJ dipole moment
- electric field = force/charge

For style *real*, these are the units:

- distance = Angstroms
- time = femtoseconds
- mass = grams/mole
- energy = Kcal/mole
- velocity = Angstroms/femtosecond
- force = Kcal/mole–Angstrom
- temperature = degrees K
- pressure = atmospheres
- charge = multiple of electron charge (+1.0 is a proton)
- dipole = charge\*Angstroms
- electric field = volts/Angstrom



For style *metal*, these are the units:

- distance = Angstroms
- time = picoseconds
- mass = grams/mole
- energy = eV
- velocity = Angstroms/picosecond
- force = eV/Angstrom
- temperature = degrees K
- pressure = bars
- charge = multiple of electron charge (+1.0 is a proton)
- dipole = charge\*Angstroms
- electric field = volts/Angstrom

This command also sets the timestep size and neighbor skin distance to default values for each style. For style *lj* these are  $dt = 0.005$  tau and  $skin = 0.3$  sigma. For style *real* these are  $dt = 1.0$  fmsec and  $skin = 2.0$  Angstroms. For style *metal* these are  $dt = 0.001$  psec and  $skin = 2.0$  Angstroms.

**Restrictions:**

This command cannot be used after the simulation box is defined by a [read\\_data](#) or [create\\_box](#) command.

**Related commands:** none

**Default:**

```
units lj
```

## variable command

### Syntax:

variable name style args ...

- name = name of variable to define
- style = *index* or *loop* or *world* or *universe* or *uloop* or *equal* or *atom*

*index* args = one or more strings  
*loop* args = N = integer size of loop  
*world* args = one string for each partition of processors  
*universe* args = one or more strings  
*uloop* args = N = integer size of loop  
*equal* or *atom* args = one equation containing numbers, thermo keywords, math functions, group  
 numbers = 0.0, -5.4, 2.8e-4, etc  
 thermo keywords = vol, ke, press, etc from [thermo\\_style](#)  
 math functions = add(x,y), sub(x,y), mult(x,y), div(x,y),  
                   neg(x), pow(x,y), exp(x), ln(x), sqrt(x)  
 group functions = mass(group), charge(group),  
                   xcm(group,dim), vcm(group,dim), fcm(group,dim),  
                   bound(group,xmin), gyration(group)  
 atom vectors for *equal* = mass[N], x[N], y[N], z[N],  
                           vx[N], vy[N], vz[N],  
                           fx[N], fy[N], fz[N]  
 atom vectors for *atom* = mass[], x[], y[], z[],  
                           vx[], vy[], vz[],  
                           fx[], fy[], fz[]  
 compute references = c\_ID[0], c\_ID[N]  
 other variables = v\_abc, v\_x, etc

### Examples:

```
variable x index run1 run2 run3 run4 run5 run6 run7 run8
variable LoopVar loop $n
variable beta equal div(temp,3.0)
variable b1 equal add(x[234],mult(0.5,vol))
variable b equal div(xcm(mol1,x),2.0)
variable b equal c_myTemp[0]
variable b atom div(mult(x,y),vol)
variable temp world 300.0 310.0 320.0 $Tfinal
variable x universe 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
variable x uloop 15
```

### Description:

This command assigns one or more strings to a variable name. Variables can be used in several ways in LAMMPS. A variable can be referenced elsewhere in an input script. For variable styles that store multiple strings, the [next](#) command can be used to increment which string is assigned to the variable. Variables can be evaluated to produce a numeric value which can be output either directly (see the [print](#), [fix print](#), and [run every](#) commands) or as part of thermodynamic output (see the [thermo\\_style](#) command), fix output (see the [fix ave/spatial](#) and [compute variable/atom](#) commands), or dump output (see the [dump custom](#) and [compute variable/atom](#) commands).

In the discussion that follows, the "name" of the variable is the arbitrary string that is the 1st argument in the variable command. The "string" is one or more of the subsequent arguments. The "string" can be simple text as in

the 1st example above, it can contain other variables as in the 2nd example, or it can be an equation as in the 3rd example. The "value" is the numeric quantity resulting from evaluation of the string. Note that the same string can generate different values when it is evaluated at different times during a simulation.

**IMPORTANT NOTE:** When a variable command is encountered in the input script and the variable name has already been specified, the command is ignored. This means variables can NOT be re-defined in an input script (with 2 exceptions, read further). This is to allow an input script to be processed multiple times without resetting the variables; see the [jump](#) or [include](#) commands. It also means that using a command-line switch `-var` will override a corresponding variable setting in the input script.

There are two exceptions to this rule. First, variables of style *equal* ARE redefined each time the command is encountered. This allow them to be reset, e.g. in a loop. This means an *equal*-style variable will re-define a command-line switch `-var` setting, so use an *index*-style variable for these settings instead, as in `bench/in.lj`.

Second, as described below, if a variable is iterated on to the end of its list of strings via the [next](#) command, it is removed from the list of active variables, and is thus available to be re-defined in a subsequent variable command.

---

[This section](#) of the manual explains how occurrences of a variable name in an input script line are replaced by the variable's string. The variable name can be referenced as `$x` if the name "x" is a single character, or as `${LoopVar}` if the name "LoopVar" is one or more characters.

As described below, for variable styles *index*, *loop*, *universe*, and *uloop*, which string is assigned to a variable can be incremented via the [next](#) command. When there are no more strings to assign, the variable is "exhausted" and a flag is set that causes the next [jump](#) command encountered in the input script to be skipped. This enables the construction of simple loops in the input script that are iterated over and exited from.

---

For the *index* style, one or more strings are specified. Initially, the 1st string is assigned to the variable. Each time a [next](#) command is used with the variable name, the next string is assigned. All processors assign the same string to the variable.

*Index* style variables with a single string value can also be set by using the command-line switch `-var`; see [this section](#) for details.

The *loop* style is identical to the *index* style except that the strings are the integers from 1 to N. This allows generation of a long list of runs (e.g. 1000) without having to list N strings in the input script. Initially, the string "1" is assigned to the variable. Each time a [next](#) command is used with the variable name, the next string ("2", "3", etc) is assigned. All processors assign the same string to the variable.

For the *world* style, one or more strings are specified. There must be one string for each processor partition or "world". See [this section](#) of the manual for information on running LAMMPS with multiple partitions via the `-partition` command-line switch. This variable command assigns one string to each world. All processors in the world are assigned the same string. The next command cannot be used with *equal* style variables, since there is only one value per world. This style of variable is useful when you wish to run different simulations on different partitions, or when performing a parallel tempering simulation (see the [temper](#) command), to assign different temperatures to different partitions.

For the *universe* style, one or more strings are specified. There must be at least as many strings as there are processor partitions or "worlds". See [this page](#) for information on running LAMMPS with multiple partitions via the `-partition` command-line switch. This variable command initially assigns one string to each world. When a [next](#) command is encountered using this variable, the first processor partition to encounter it, is assigned the next available string. This continues until all the variable strings are consumed. Thus, this command can be used to run

50 simulations on 8 processor partitions. The simulations will be run one after the other on whatever partition becomes available, until they are all finished. *Universe* style variables are incremented using the files "tmp.lammps.variable" and "tmp.lammps.variable.lock" which you will see in your directory during such a LAMMPS run.

The *uloop* style is identical to the *universe* style except that the strings are the integers from 1 to N. This allows generation of long list of runs (e.g. 1000) without having to list N strings in the input script.

For the *equal* and *atom* styles, a single string is specified which represents an equation that will be evaluated afresh each time the variable is used. For *equal* style variables this equation computes a scalar quantity, which becomes the value of the variable whenever it is evaluated. For *atom* style variables it computes a quantity for each atom, which is used by the "compute variable/atom" command and its associated output.

Note that *equal* and *atom* variables can produce different values at different stages of the input script or at different times during a run. For example, if an *equal* variable is used in a [fix print](#) command, different values could be printed each timestep it was invoked.

The next command cannot be used with *equal* or *atom* style variables, since there is only one string.

The equation for an *equal* or *atom* variable can contain a variety of quantities. The syntax for each kind of quantity is simple, but multiple quantities can be nested and combined in various ways to build up formulas of arbitrary complexity. For example, this is a valid (though strange) variable equation:

```
variable x equal div(add(pe,c_MyTemp[0]),pow(vol,div(1,3)))
```

Specifically, an equation can contain numbers, thermo keywords, math functions, group functions, atom vectors, compute references, and other variables. There is one difference between *equal* and *atom* variables; the syntax of Atom vector references is different.

Number	0.2, 1.0e20, -15.4, etc
Thermo keywords	vol, pe, ebond, etc
Math functions	add(x,y), sub(x,y), mult(x,y), div(x,y), neg(x), pow(x,y), exp(x), ln(x), sqrt(x)
Group functions	mass(ID), charge(ID), xcm(ID,dim), vcm(ID,dim), fcm(ID,dim) bound(ID,dir), gyration(ID)
Atom vectors for <i>equal</i>	mass[N], x[N], y[N], z[N], vx[N], vy[N], vz[N], fx[N], fy[N], fz[N]
Atom vectors for <i>atom</i>	mass[], x[], y[], z[], vx[], vy[], vz[], fx[], fy[], fz[]
Compute references	c_ID[0], c_ID[N]
Other variables	v_abc, v_x, etc

The thermo keywords allowed in the equation are those defined by the "thermo\_style custom" command. Note that many thermodynamic quantities are only computable after the first simulation has begun. Likewise, many thermodynamic quantities (such as energies) are only computed on timesteps when thermodynamic output is being performed. If the variable equation these quantities at other times, out-of-date or invalid values may be used.

Math functions take one or two arguments, each of which may be an equation containing any of the quantities defined above. This allows equations to be nested, as in the examples above.

Group functions take one or two arguments. The first argument is the group-ID. The *dim* argument is *x* or *y* or *z*. The *dir* argument is *xmin*, *xmax*, *ymin*, *ymax*, *zmin*, or *zmax*. The group functions mass() and charge() are the total mass and charge of the group of atoms. Xcm() and vcm() return components of the position and velocity of the center of mass of the group. Fcm() returns a component of the total force on the group of atoms. Bound() returns

the min/max of a particular coordinate for all atoms in the group. `Gyration()` computes the radius-of-gyration of the group of atoms. See the [fix gyration](#) command for the formula.

For *equal* style variables, atom vectors take a single integer argument from 1–N, which is the desired atom-ID, e.g. `x[243]`. For *atom* style variables, atom vectors take no argument. Since *atom* style variables compute one value per atom, a reference like `x[]` means the x-coord of each atom will be used when evaluating the variable.

Compute references access scalar or vector quantities calculated by a [compute](#). The ID in the reference should be replaced by the actual ID of the compute defined elsewhere in the input script. See the [compute](#) command for details. Note that per-atom quantities calculated by a compute cannot be accessed this way, but only global scalar or vector quantities.

If `c_ID[0]` is used as a keyword, then the scalar quantity calculated by the compute is printed. If `c_ID[N]` is used, then N in the range from 1–M will print the Mth component of the N-length vector calculated by the compute.

The current values of other variables can be accessed by prepending a "v\_" to the variable name. This will cause the other variable to be evaluated. Note that if you do something circular like this:

```
variable a equal v_b
variable b equal v_a
print $a
```

then LAMMPS will run for a while when the print statement is invoked.

Note that there is a subtle difference between using a variable in a *equal* or *atom* style equation in the form `$x` versus `v_x`.

In the former case, as with any other input script command, the variable's value is substituted for immediately when the line is read from the input script. Thus if the current simulation box volume was 1000.0, then these lines:

```
variable x equal vol
variable y equal mult($x,2)
```

would associate the equation string "mult(1000.0,2)" with variable y.

By contrast, these lines:

```
variable x equal vol
variable y equal mult(v_x,2)
```

would associate the equation string "mult(v\_x,2)" with variable y.

Thus if the variable y were evaluated periodically during a run where the box volume changed, the resulting value would always be 2000.0 for the first case, but would change dynamically for the second case.

---

### Restrictions:

The use of atom vectors in *equal* style variables requires the atom style to use a global mapping in order to look up the vector indices. Only atom styles with molecular information create global maps unless the [atom\\_modify map](#) command is used.

All *universe*- and *uloop*-style variables must have the same number of values.

**Related commands:**

[next](#), [jump](#), [include](#), [temper](#), [fix print](#), [print](#)

**Default:** none

## velocity command

### Syntax:

velocity group-ID style args keyword value ...

- group-ID = ID of group of atoms whose velocity will be changed
- style = *create* or *set* or *scale* or *ramp* or *zero*

```
create args = temp seed
    temp = temperature value (temperature units)
    seed = random # seed (8 digits or less)
set args = vx vy vz
    vx,vy,vz = velocity value or NULL (velocity units)
scale arg = temp
    temp = temperature value (temperature units)
ramp args = vdim vlo vhi dim clo chi
    vdim = vx or vy or vz
    vlo,vhi = lower and upper velocity value (velocity units)
    dim = x or y or z
    clo,chi = lower and upper coordinate bound (distance units)
zero arg = linear or angular
    linear = zero the linear momentum
    angular = zero the angular momentum
```

- zero or more keyword/value pairs may be appended
- keyword = *dist* or *sum* or *mom* or *rot* or *temp* or *loop* or *units*

```
dist value = uniform or gaussian
sum value = no or yes
mom value = no or yes
rot value = no or yes
temp value = temperature ID
loop value = all or local or geom
units value = box or lattice
```

### Examples:

```
velocity all create 300.0 4928459 rot yes dist gaussian
velocity border set NULL 4.0 3.0 sum yes units box
velocity flow scale 300.0
velocity flow ramp lattice vx 0.0 5.0 y 5 20 temp mytemp
velocity all zero linear
```

### Description:

Set or change the velocities of a group of atoms in one of several styles. For each style, there are required arguments and optional keyword/value parameters. Not all options are used by each style. Each option has a default as listed below.

The *create* style generates an ensemble of velocities using a random number generator with the specified seed as the specified temperature.

The *set* style sets the velocities of all atoms in the group to the specified values. If any component is specified as NULL, then it is not set.

The *scale* style computes the current temperature of the group of atoms and then rescales the velocities to the specified temperature.

The *ramp* style is similar to that used by the [temperature](#) ramp command. Velocities ramped uniformly from *vlo* to *vhi* are applied to dimension *vx*, or *vy*, or *vz*. The value assigned to a particular atom depends on its relative coordinate value (in *dim*) from *clo* to *chi*. For the example above, an atom with *y*-coordinate of 10 (1/4 of the way from 5 to 20), would be assigned a *x*-velocity of 1.25 (1/4 of the way from 0.0 to 5.0). Atoms outside the coordinate bounds (less than 5 or greater than 20 in this case), are assigned velocities equal to *vlo* or *vhi* (0.0 or 5.0 in this case).

The *zero* style adjusts the velocities of the group of atoms so that the aggregate linear or angular momentum is zero. No other changes are made to the velocities of the atoms.

All temperatures specified in the velocity command are in temperature units; see the [units](#) command. The units of velocities and coordinates depend on whether the *units* keyword is set to *box* or *lattice*, as discussed below.

For all styles, no atoms are assigned *z*-component velocities if the simulation is 2d; see the [dimension](#) command.

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The keyword/value option pairs are used in the following ways by the various styles.

The *dist* option is used by *create*. The ensemble of generated velocities can be a *uniform* distribution from some minimum to maximum value, scaled to produce the requested temperature. Or it can be a *gaussian* distribution with a mean of 0.0 and a sigma scaled to produce the requested temperature.

The *sum* option is used by all styles, except *zero*. The new velocities will be added to the existing ones if *sum* = yes, or will replace them if *sum* = no.

The *mom* and *rot* options are used by *create*. If *mom* = yes, the linear momentum of the newly created ensemble of velocities is zeroed; if *rot* = yes, the angular momentum is zeroed.

The *temp* option is used by *create* and *scale* to specify a user-defined way of computing temperature. If this option is not used, *create* and *scale* compute temperature with the style "full" for the group of atoms whose velocity is being altered. See the [temperature](#) command for details. If the computed temperature should have degrees-of-freedom removed due to fix constraints (e.g. SHAKE or rigid-body constraints), then the appropriate fix command must be specified before the velocity command is issued.

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The *loop* option is used by *create* in the following ways.

If *loop* = all, then each processor loops over all atoms in the simulation to create velocities, but only stores velocities for atoms it owns. This can be a slow loop for a large simulation. If atoms were read from a data file, the velocity assigned to a particular atom will be the same, regardless of how many processors are being used. This will not be the case if atoms were created using the [create\\_atoms](#) command, since atom IDs will likely be assigned to atoms differently.

If *loop* = local, then each processor loops over only its atoms to produce velocities. The random number seed is adjusted to give a different set of velocities on each processor. This is a fast loop, but the velocity assigned to a particular atom will depend on which processor owns it. Thus the results will always be different when a simulation is run on a different number of processors.

If *loop* = geom, then each processor loops over only its atoms. For each atom a unique random number seed is created, based on the atom's xyz coordinates. A velocity is generated using that seed. This is a fast loop and will always give the same set of velocities, independent of how many processors are used. However, the generated



velocities may be more correlated than if the *all* or *local* options are used.

Note that the *loop geom* option will not necessarily assign identical velocities for two simulations run on different machines. This is because the computations based on xyz coordinates are sensitive to tiny differences in the double-precision value for a coordinate as stored on a particular machine.

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The *units* option is used by *set* and *ramp*. If *units* = *box*, the velocities and coordinates specified in the velocity command are in the standard units described by the [units](#) command (e.g. Angstroms/fmsec for real units). If *units* = *lattice*, velocities are in units of lattice spacings per time (e.g. spacings/fmsec) and coordinates are in lattice spacings. The [lattice](#) command must have been previously used to define the lattice spacing.

**Restrictions:** none

**Related commands:**

[fix shake](#), [lattice](#)

**Default:**

The option defaults are *dist* = *uniform*, *sum* = *no*, *mom* = *yes*, *rot* = *no*, *temp* = *full style on group-ID*, *loop* = *all*, and *units* = *lattice*.

## write\_restart command

### Syntax:

```
write_restart file
```

- file = name of file to write restart information to

### Examples:

```
write_restart restart.equil  
write_restart poly.%.*
```

### Description:

Write a binary restart file of the current state of the simulation. See the [read\\_restart](#) command for information about what is stored in a restart file.

During a long simulation, the [restart](#) command is typically used to dump restart files periodically. The `write_restart` command is useful after a minimization or whenever you wish to write out a single current restart file.

Similar to [dump](#) files, the restart filename can contain two wild-card characters. If a "\*" appears in the filename, it is replaced with the current timestep value. If a "%" character appears in the filename, then one file is written by each processor and the "%" character is replaced with the processor ID from 0 to P-1. An additional file with the "%" replaced by "base" is also written, which contains global information. For example, the files written for filename `restart.%` would be `restart.base`, `restart.0`, `restart.1`, ... `restart.P-1`. This creates smaller files and can be a fast mode of output on parallel machines that support parallel I/O for output.

Restart files can be read by a [read\\_restart](#) command to restart a simulation from a particular state. Because the file is binary (to enable exact restarts), it may not be readable on another machine. In this case, the `restart2data` program in the `tools` directory can be used to convert a restart file to an ASCII data file. Both the `read_restart` command and `restart2data` tool can read in a restart file that was written with the "%" character so that multiple files were created.

### Restrictions:

This command requires inter-processor communication to migrate atoms before the restart file is written. This means that your system must be ready to perform a simulation before using this command (force fields setup, atom masses set, etc).

### Related commands:

[restart](#), [read\\_restart](#)

**Default:** none