

States Screen

Heat or cool atoms and molecules and watch as they change between solid, liquid and gas phases.

VIEW the temperature in K or °C

OBSERVE the motion of the sample

CHOOSE an atom or molecule

EXPLORE solid, liquid, or gas

ADD or **REMOVE** heat from the system

Phase Changes Screen

Explore how the system behaves as the atoms and molecules are heated, cooled, compressed, or more particles are added.

COMPRESS the sample

PUMP in additional atoms or molecules

PAUSE and step through the motion

VIEW a qualitative Lennard-Jones potential

VIEW a qualitative phase diagram

Interaction Screen

Investigate how the relationship between attractive and repulsive forces govern the interaction between atoms.

The screenshot displays the PhET Interaction screen. At the top left, a callout box labeled 'ZOOM in or out on the graph' points to a zoom icon. Below it, another callout labeled 'ADJUST parameters directly on the curve' points to a red curve on a graph of Potential Energy vs. Distance Between Atoms. The graph shows a minimum energy point with parameters σ and ϵ indicated. A third callout labeled 'DRAG the unpinned atom or the dot on the graph' points to a 3D model of two atoms. On the right, a control panel labeled 'Atoms' allows selecting 'Neon' and 'Argon', and adjusting 'Atom Diameter (σ)' and 'Interaction Strength (ϵ)'. Below this, a 'Forces' panel has checkboxes for 'Hide Forces' and 'Total Force', and arrows for 'Attractive (van der Waals)', 'Repulsive (electron overlap)', and 'Total Force'. A fourth callout labeled 'CHOOSE pairs of atoms to investigate or create a custom set' points to the atom selection area. A fifth callout labeled 'HIDE or show forces between atoms' points to the 'Hide Forces' checkbox. At the bottom, there are playback controls (Slow Motion, Normal, Play/Pause, Stop) and a PhET logo.

Customization Options

- The simulation colors can be changed for better contrast when projecting by clicking on the PhET menu and selecting Options > Projector Mode. Alternatively, append `?colorProfile=projector` to the end of the simulation URL.

Model Simplifications

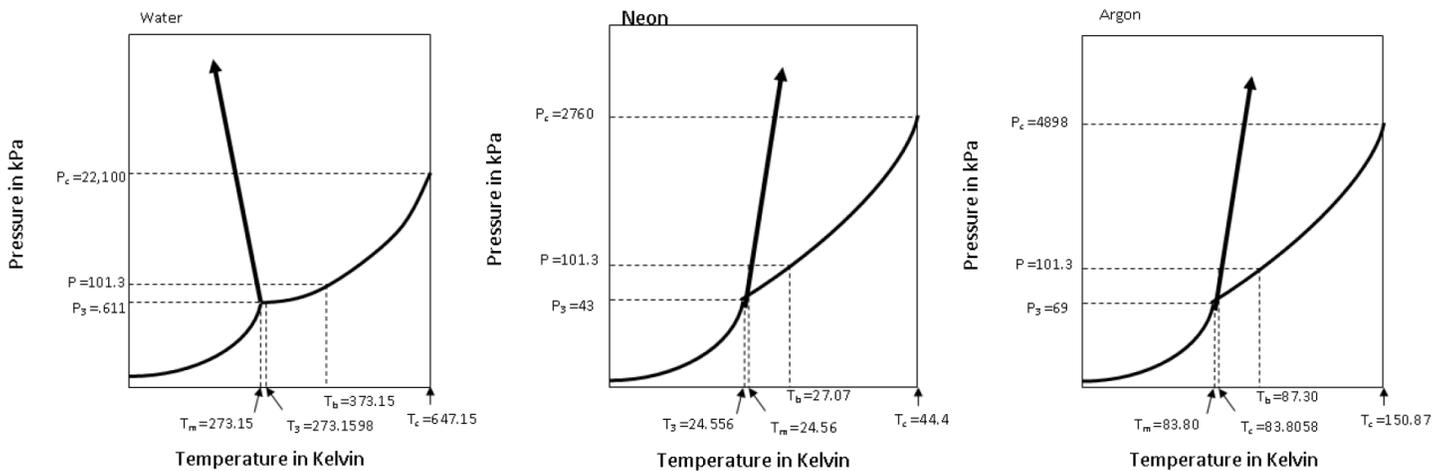
- The model works best when there are at least (roughly) 15 particles in the container. It is possible to create situations where there are only a few particles in the container and, in these situations, students may observe some odd behaviors. One example is occasional visible changes to the velocity of individual particles. If students observe such things, they should be told that this is due to the limitations of the model, and doesn't represent "real world" phenomena.
- The number of particles that can be pumped into the system is limited. The indicator bars on the bicycle pump display how many additional particles can be pumped into the system.
- This simulation is intended for studying equilibrium states. As such, adding/removing heat, adjusting the volume, and pumping in additional particles is purposely kept slow so that the system can generally equilibrate as the changes are made. (Faster changes to the system, if allowed, would produce a greater variety of system states.)
- Latent heat is not addressed or supported by the model in this simulation.
- The temperature of the system is calculated from the velocities of the particles, and may change as more particles are pumped into the system.
- The pressure in the system is derived from the momentum transfers between the particles and the container walls. As a result, the pressure at 0 K will be zero.
- It is possible to reach absolute zero in the simulation, but the rate of temperature change slows down substantially as 0 K is approached. This is intentional, since it is very difficult to make a system of

molecules this cold. True absolute zero is impossible to achieve, so this should be thought of as rounding down from anything below 0.5 K.

- For solid water, we wanted to show that there is space between the molecules. The correct structure of solid water requires a 3D view, but with minor compromises, we were able to show the situation qualitatively in 2D. Additionally, the solid water particles vibrate more than expected. A resource for the most common visual for ice structure can be found [here](#).
- Some amount of gravity is simulated, but it is minimal - just enough to keep the solid forms of the substances on the floor of the container. For this reason, substances in their liquid form don't always spread out along the bottom of the container, like water does in a glass. The liquid phase is still visually distinct from the other phases in terms of inter-molecular spacing and velocity.
- While plasma is a state of matter, we have deliberately chosen not to model it in this simulation.
- For younger students, it may be important to explain that the hand and the container are not at all to scale, since in the real world they too are made of atoms and molecules.

Phase Diagrams

The sim is not designed to be used as a comprehensive tool for learning about phase diagrams, instead the focus is on phases of matter. The phase diagram axes do not have scales, but are meant to give students a general idea about understanding phase diagrams. The small number of particles shown and the simplicity of the underlying models makes it difficult to map accurately the exact phase to the correct regions of the phase diagram. However, we felt there would be some benefit to students being exposed to a simplified phase diagram. (Phase diagrams for water, neon, and argon are illustrated below.) In the sim, the diagram marker remains on the coexistence line between liquid/gas or solid/gas (and is extrapolated into the critical region). If this approximation does not fit your specific learning goals, and you are concerned this might cause confusion, you can encourage your students to keep the phase diagram closed.



Legend T_m = melting point P_3 = triple point P_c = critical point
 T_b = boiling point T_3 = triple point T_c = critical point

Suggestions for Use

Clicker questions

Rouinfar, November 2021

- Provide screenshots of solid, liquid, and gaseous water. Ask students to determine which screenshot best describes liquid water.
- Provide screenshots of neon and oxygen at 15 K, 30 K, and 45 K. Ask students to determine which substance has the weakest and strongest intermolecular forces.

Sample Challenge Prompts

- Draw a picture of each substance as a solid, liquid, and gas. Explain the differences and similarities between each state.
- Draw a picture of each substance as a solid. Describe how solid water compares to the other substances, and explain why ice floats on water.
- Describe a procedure to change the phase of one of the substances.
- Explain how a change in temperature affects the pressure inside a container.
- Predict what happens to the speed of the atoms and the amount of space between them if (a) heat is added to the system, (b) heat is removed from the system, or (c) the volume of the container is reduced.
- Describe how attractive and repulsive forces influence the attraction between two atoms.
- Explain the relationship between the attractive forces between atoms and the potential energy graph for the atom pair.

See all published activities for States of Matter [here](#).

For more tips on using PhET sims with your students, see [Tips for Using PhET](#).