

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

CHOOSE an atom or molecule

EXPLORE solid, liquid, or gas

ADD or **REMOVE** heat from the system

OBSERVE the motion of the sample

States of Matter

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

VIEW a qualitative Lennard-Jones potential

VIEW a qualitative phase diagram

PUMP in additional atoms or molecules

PAUSE and step through the motion

States of Matter

Interaction Screen

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

The screenshot shows the PhET Interaction screen. At the top left, a callout box says "ZOOM in or out on the graph" with a magnifying glass icon. Below it, another callout box says "ADJUST parameters directly on the curve" with a green arrow pointing to the potential energy curve. To the right, a third callout box says "CHOOSE pairs of atoms to investigate or create a custom set" with a dot icon. At the bottom left, a fourth callout box says "DRAG the unpinned atom or the dot on the graph" with a green arrow pointing to the atom. The main interface includes a graph of Potential Energy vs. Distance Between Atoms, a list of atoms (Neon, Argon), adjustable parameters for Atom Diameter (σ) and Interaction Strength (ϵ), and a section for Forces (Hide Forces, Total Force, Attractive (van der Waals), Repulsive (electron overlap)). The bottom of the screen has a navigation bar with icons for States of Matter, States, Phase Changes, and Interaction, along with the PhET logo.

ZOOM in or out on the graph

ADJUST parameters directly on the curve

CHOOSE pairs of atoms to investigate or create a custom set

DRAG the unpinned atom or the dot on the graph

HIDE or show forces between atoms

Customization Options

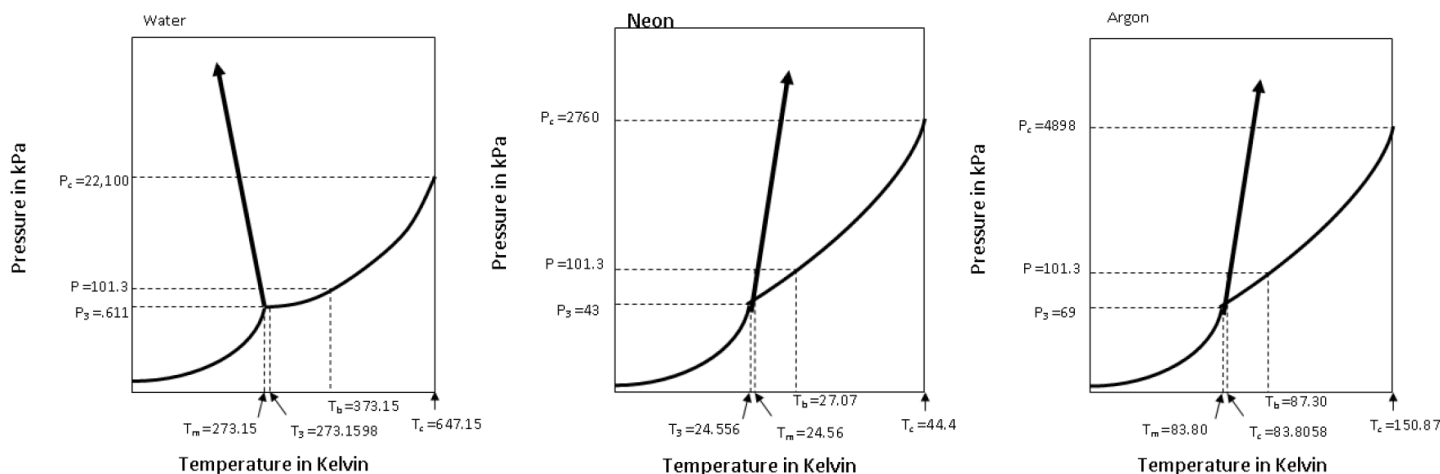
The following query parameters allow for customization of the simulation, and can be added by appending a '?' to the sim URL, and separating each query parameter with a '&'.

Query Parameter and Description	Examples
<code>defaultCelsius</code> - sets default temperature unit to Celsius (normally Kelvin)	<code>defaultCelsius</code>
<code>stickyBurners</code> - used to make the heat/cool slider position stick in place	<code>stickyBurners</code>
<code>colorProfile=projector</code> - changes the simulation colors for better contrast when projecting, also found in the PhET menu under Options > Projector Mode.	<code>colorProfile=projector</code>
<code>screens</code> - specifies which screens are included in the sim and their order. Each screen should be separated by a comma. For more information, visit the Help Center .	<code>screens=1</code> <code>screens=2,1</code>

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 Rouinfar, July 2022

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

Tm = melting point
Tb = boiling point

P3 = triple point
T3 = triple point

Pc = critical point
Tc = critical point

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.

Suggestions for Use

Clicker questions

- 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](#).