

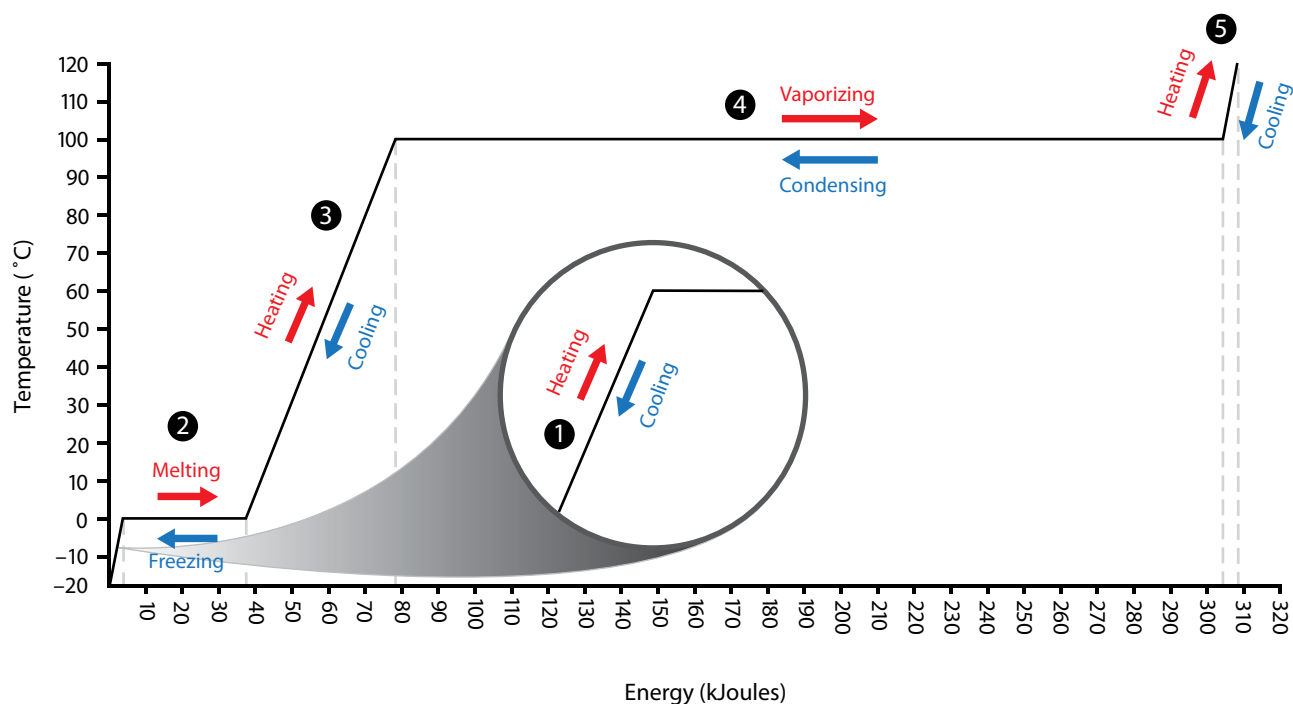
Additional Teacher Background

Chapter 2, Lesson 5, p. 130

Heating/Cooling curve

Throughout chapter 2, students have seen that adding energy (heating) increases the rate of melting and evaporation. They have also seen that removing energy (cooling) increases the rate of condensation and freezing. There are other interesting phenomena related to state changes that are not as easily explored in a classroom setting. One has to do with the relative amount of energy it takes to cause a substance to change from one state to another. Another is that the temperature of a substance remains constant during state changes.

Both these factors can be displayed on a graph showing the change in temperature while water is heated or cooled. This type of graph is called a heating curve. (You may sometimes see it called a phase diagram but a phase diagram is technically different.) The graph shows the energy added or removed on the x-axis and the corresponding temperature change on the y-axis. The units of energy are in kilojoules. The actual number of kilojoules required for the different state changes is not as important as seeing that some changes require much more or less energy than others. The graph is easiest to interpret if you look at the different steps separately and then all together.



Step 1: Adding energy increases the temperature of ice from $-20\text{ }^{\circ}\text{C}$ to $0\text{ }^{\circ}\text{C}$.

This takes a relatively small amount of energy because the energy goes into vibrating the molecules and not to break the bonds holding the molecules together. The molecules which are vibrating in fixed positions in the ice at $-20\text{ }^{\circ}\text{C}$ are made to vibrate somewhat faster at $0\text{ }^{\circ}\text{C}$.

Step 2: Adding energy causes the ice to change state by melting to liquid water with no change in temperature.

This process takes about 8 times as much energy as step 1. It makes sense that more energy is required because energy is being used to overcome the attractive forces holding the molecules in the crystal structure. The temperature does not change during this process because right at the melting point, the energy used in bond breaking does not increase the speed of the molecules, it just breaks the bond. The kinetic energy added is converted to potential energy which does not change the temperature.

Step 3: Adding energy increases the temperature of the water from $0\text{ }^{\circ}\text{C}$ to $100\text{ }^{\circ}\text{C}$.

This process takes about 25% more energy than step 2. So it takes more energy to raise the temperature of water from $0\text{ }^{\circ}\text{C}$ to $100\text{ }^{\circ}\text{C}$ than it does to melt the same amount of ice to liquid water. To melt ice, energy is added which causes the molecules to vibrate until the orderly arrangement of water molecules in the crystal collapses. But as liquid water, the water molecules are still attracted to each other and are still close together (in fact they are closer together in liquid water than in ice) but are able to slide past one another.

Once the ice has turned to liquid water, the energy added must still work against the attractions of the water molecules to raise the temperature of the water. This is why water has such a high specific heat which is the amount of energy required to raise 1 gram of a substance by $1\text{ }^{\circ}\text{C}$. Therefore raising liquid water from $0\text{ }^{\circ}\text{C}$ to $100\text{ }^{\circ}\text{C}$ takes a lot of energy.

Step 4: Adding energy causes the water to change state by vaporizing to become water vapor at the boiling point with no change in temperature.

This process takes nearly 5 times the amount of energy of step 3. Boiling takes more energy than the other processes because it is the only process in which the attractions between water molecules are completely overcome and water molecules are separated by relatively large distances. The temperature does not change during this process because right at the boiling point, the energy used in bond breaking does not increase the speed of the molecules, it just breaks the bond. The kinetic energy added is converted to potential energy which does not change the temperature.

Step 5: Adding energy causes the temperature of the water vapor to increase from 100 °C to 120 °C.

This process takes less energy than any of the other steps. Water molecules in the vapor phase are already far apart and do not feel significant attractions from one another. When energy is added to them, their motion readily increases.

Looking at the graph as a cooling curve

The entire graph can also be looked at as a cooling curve if you look at it in reverse.

Step 5: Removing energy (cooling) causes the temperature of water vapor to decrease from 120 °C to 100 °C.

It is exactly the same amount of energy removed that was added to cause the temperature to increase from 100 °C to 120 °C.

Step 4: Removing energy causes the water to change state by condensing to become liquid water at the boiling point with no change in temperature.

The temperature does not change during this phase change. This is because right at the condensation point, the energy removed allows the molecules to “bond” but does not change their speed.
Step 3: Removing energy from the liquid water causes its temperature to decrease from 100 °C to 0 °C.

It is exactly the same amount of energy removed that was added to cause the temperature to increase from 0 °C to 100 °C.

Step 2: Removing energy from water at 0 °C causes liquid water to change state by freezing to solid ice.

The temperature does not change during this process because right at the freezing point, the energy removed allows to molecules to form bonds but does not change their speed.

Step 1: Removing energy from ice causes the temperature of the ice to decrease from 0 °C to -20 °C.

It is exactly the same amount of energy removed as was added to cause the temperature to increase from -20 °C to 0 °C.