

## A Model of Matter: Part 6 Melting

Last week, we concluded our discussion of evaporation by asking about another **change of state** (what the NYS Core Curricula call “**phase change**”). Let’s look into **melting**...

Fill a beaker with crushed ice. Add water until the glass is full.

What do you predict the temperature of the water will be

- after adding the water to the crushed ice?
- after half the crush ice has melted?
- immediately after all ice has melted?

Does the **liquid water** temperature increase, decrease, or remain the same? Why?

Let’s do a thought experiment that investigates these issues...

### Change of state task: melting

A thermometer is suspended in the center of a beaker of water. The water is frozen. The thermometer frozen in ice is left outside for several hours. The outside temperature is  $-10^{\circ}\text{F}$ . Then the beaker, thermometer, and ice are placed in a warm-water bath (a large container of water with its temperature maintained at  $70^{\circ}\text{F}$ ). The thermometer scale range is  $-20^{\circ}\text{F}$  to  $100^{\circ}\text{F}$ .



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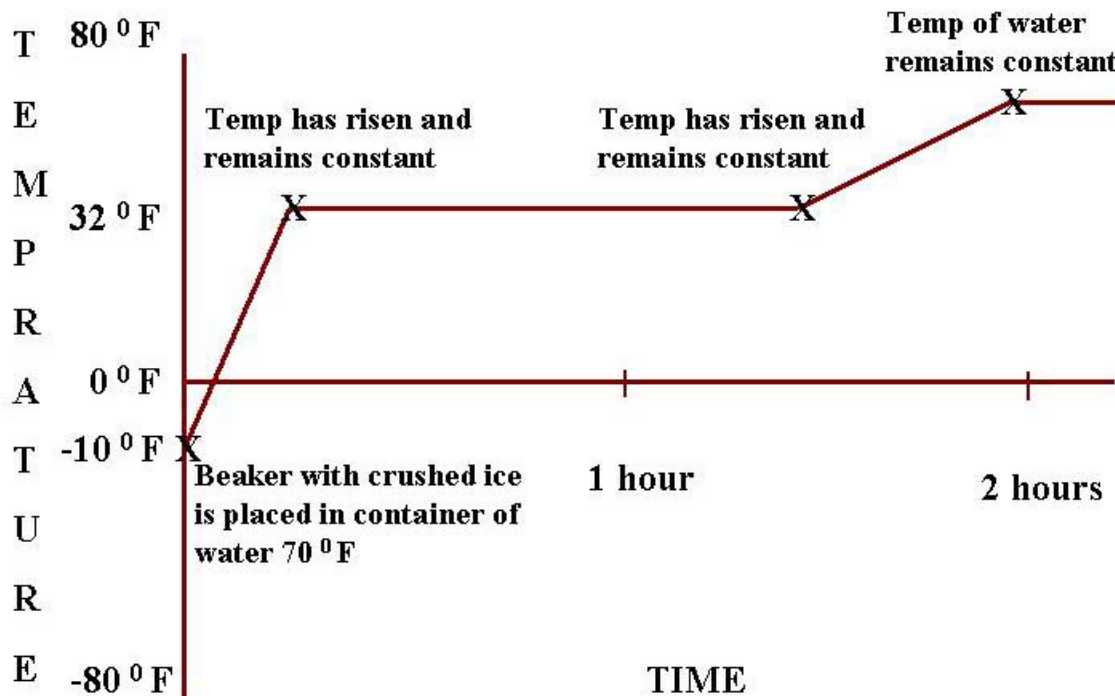
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After two hours in the  $70^{\circ}$  warm-water bath, all the ice has melted and temperature of water inside the beaker has risen to  $70^{\circ}$  F.

If you periodically record the temperature of water in the beaker over the two hours, what do you notice has happened? Obviously, the water temperature increases, but when and why?

Temperature vs time graph from the time the beaker of ice is placed in the warm-water bath



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If you look at the graph, you see that at  $t_0$  (the instant that the beaker filled with ice was carefully placed in the warm-water bath), the temperature of the ice is  $-10^\circ\text{F}$ . The temperature increases to  $32^\circ\text{F}$  and stays at  $32^\circ\text{F}$  until all the ice has melted. Then the temperature of the water gradually increases to  $70^\circ\text{F}$  and stays at that temperature as long as the water in the beaker is in the warm-water bath at a temperature of  $70^\circ\text{F}$ . We observe that the water temperature in the beaker will increase to its melting point until all the ice has melted. The temperature of water in the beaker then increases to equal the temperature of its surroundings.

If we consider our model of matter (tiny particles in motion), what changes occur in the motion of  $\text{H}_2\text{O}$  molecules in the beaker over the two-hour period? Why do these changes take place?

### 1. The temperature of ice first rises from $-10^\circ\text{F}$ to $32^\circ\text{F}$

There is a lot happening here:

- Ice is a solid with a shape independent of its container. The water molecules in the ice have strong inter-molecular forces (hydrogen bonds) locking them together in a solid, crystallized structure. Because of the strength of the inter-molecular forces holding the molecules together, the molecules cannot move about independently, so ice is a solid.
- Even though the water molecules cannot move independently, the **atoms** (two hydrogen, one oxygen) in each molecule of water can move back and forth in position and thus vibrate.

Here is a website that has great illustrations of the vibrational movement of the atoms in a water molecule: <http://www.lsbu.ac.uk/water/vibrj.html>

- Vibration is one of three forms of motion of water molecules. Individual molecules of water can move about from place to place, a kind of movement called translational motion. A molecule of water can also turn just as the Earth rotates on its axis; that's rotational motion. In ice, the molecules are held in place; they cannot move from one place to another or rotate. The only motion possible in solid ice is the vibration of the atoms in each molecule.
- Because atoms in the water molecules of ice have a vibrational movement, they possess **kinetic energy**. If you remember from *A Model of Matter: Part 3*, atoms have mass, and when they are in motion, they have kinetic energy.
- The **temperature** of a sample is a measure of the average **kinetic energy** of its molecules or atoms.

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Let's get back to our beaker of water. As heat from the water is conducted through the glass of the beaker into the ice, the *rate at which the atoms in the water molecules are vibrating increases*. As the ice warms from  $-10^{\circ}\text{F}$  to  $32^{\circ}\text{F}$ , its average **kinetic energy** increases. (If **temperature** is a measure of average **kinetic energy**, then an increase in **temperature** is evidence of an increase in **kinetic energy**.)

## 2. The ice melts from $-10^{\circ}\text{F}$ to $32^{\circ}\text{F}$

From  $-10^{\circ}\text{F}$  to  $32^{\circ}\text{F}$ , the vibrational motion *increases*, and at  $32^{\circ}\text{F}$  this vibrational motion becomes so intense that the forces holding the molecules in the crystalline structure of ice are overcome. As these forces holding the molecules together are overwhelmed by the vibrational energy, the ice melts into liquid water.

Breaking the forces (hydrogen bonds) holding the molecules together requires a lot of energy. Even as some of the ice turns to water, most of the **heat energy** goes to separating the water molecules from each other, increasing their potential energy (energy of position), not to changing the motion of the molecules. The **kinetic energy** of the molecules does not change, so the temperature of the ice-water mixture remains steady at  $32^{\circ}\text{F}$  as all the ice melts.

## 3. The temperature of the water in the beaker increases

Heat energy continues to be conducted through the glass to what's in the beaker (it's liquid water, now). As the liquid water warms from  $32^{\circ}\text{F}$  to  $70^{\circ}\text{F}$ , we know the average **kinetic energy** of molecules *increases*. Molecular movement is of a new type now: the freed molecules in liquid water rotate *and* move from place to place as the atoms vibrate.

## 4. The temperature of the water remains constant at $70^{\circ}\text{F}$

When the sample of water is at the same temperature as the surrounding warm-water bath, the system is in thermal equilibrium: there is no net heat transfer, and neither water sample experiences any further temperature change.

By using our model of matter, we have explained our observations of

- temperature (increasing, remaining the same, increasing again, then maintaining a constant temperature), and
- change of state (solid to liquid).

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## Coming up

We have explained what happens to frozen water using our model of matter (tiny particles in motion). But how well does this model work for different substances? Consider this:

- Could we ever use a thermometer filled with water instead of mercury?
- What are the benefits and limitations?
- What other liquid(s) can be used in a thermometer?
- How can we explain the choice of liquid using our model of matter?

### What do the New York State standards say?

In the Elementary Core Curriculum, Standard 3, The Physical Setting,

Major Understandings state:

- 3.1c Objects have properties that can be observed, described and/or measured: length, width, volume, size, shape, mass or weight, temperature, flexibility, reflectiveness of light.
- 3.2b Temperature can affect the state of matter of a substance.

In the Intermediate Core Curriculum, Standard 3, The Physical Setting,

Major Understandings state:

- 3.1a Substances have characteristic properties. Some of these properties include color, odor, phase at room temperature, density, solubility, heat and electrical conductivity, hardness, and boiling and freezing points.
- 3.1d The motion of particles helps to explain the phases (states) of matter as well as changes from one phase to another. The phase in which matter exists depends on the attractive forces among particles.
- 3.3b Atoms and molecules are perpetually in motion. The greater the temperature, the greater the motion.

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