THE BIG IDEA

Changes of phase usually involve a transfer of energy.

The four possible forms of matter—solid, liquid, gas, and plasma—are called phases. Matter can change from one phase to another. The phase of matter depends on its temperature and the pressure that is exerted upon it.

23.1 Evaporation

Evaporation is a process that cools the liquid left behind.

23.1 Evaporation

Water in an open container will eventually evaporate. The liquid that disappears becomes water vapor in the air.

Evaporation is a change of phase from liquid to gas that takes place at the surface of a liquid.

23.1 Evaporation

Molecules in the liquid phase continuously move about in all directions and bump into one another at different speeds.

Some of the molecules gain kinetic energy while others lose kinetic energy.

Molecules at the surface of the liquid that gain kinetic energy may have enough energy to break free of the liquid.

They now comprise a *vapor,* molecules in the gaseous phase.

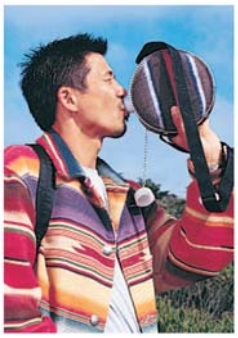
23.1 Evaporation

The increased kinetic energy of molecules bumped free of the liquid comes from molecules remaining in the liquid.

The average kinetic energy of the molecules remaining behind in the liquid is lowered.

23.1 Evaporation

The cloth covering on the sides of the canteen promotes cooling when it is wet. As the faster-moving water molecules leave the cloth, the temperature of the cloth decreases.



23.1 Evaporation

When the human body overheats, sweat glands produce perspiration.

As the sweat evaporates, it cools us and helps us maintain a stable body temperature.

23.1 Evaporation

Pigs lack sweat glands. They wallow in mud to cool themselves.

23.1 Evaporation

CONCEPT CHECK

How does evaporation affect a liquid's temperature?

23.2 Condensation

Condensation warms the area where the liquid forms.

23.2 Condensation

Condensation is the changing of a gas to a liquid.

Droplets form on a cold soda can when water vapor molecules collide with the slower-moving molecules of the cold can surface.

The vapor molecules give up so much kinetic energy that they can't stay in the gaseous phase. They condense.

23.2 Condensation

Condensation also occurs when gas molecules are captured by liquids.

In their random motion, gas molecules may hit a liquid and lose kinetic energy.

The attractive forces exerted on them by the liquid may hold them. Gas molecules become liquid molecules.

23.2 Condensation

Kinetic energy lost by condensing gas molecules warms the surface they strike.

A steam burn is more damaging than a burn from boiling water because steam gives up energy when it condenses.

23.2 Condensation

Heat is given up by steam when it condenses inside the radiator.

23.2 Condensation

Relative Humidity

At any given temperature and pressure, there is a limit to the amount of water vapor in the air.

When any substance contains the maximum amount of another substance, the first substance is said to be **saturated.**

23.2 Condensation

The ratio between how much water vapor is in the air and the maximum amount that *could* be in the air at the same temperature is called the **relative humidity**.

Relative humidity is *not* a measure of how much water vapor is in the air.

In summer, with a low relative humidity, there may be more water vapor in the air than in winter with high relative humidity.

23.2 Condensation

At a relative humidity of 100%, the air is saturated.

More water vapor is required to saturate high-temperature air than low-temperature air.

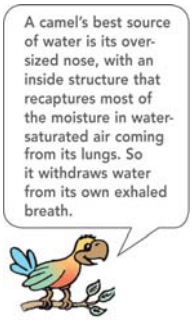
The warm air of tropical regions is capable of containing much more moisture than cold Arctic air.

23.2 Condensation

For saturation, there must be water vapor molecules in the air undergoing condensation.

When slow-moving molecules collide, some stick together—they condense.

The faster the water molecules move, the less able they are to condense to form droplets.



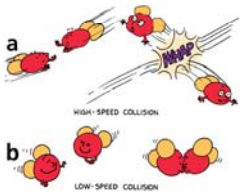
23.2 Condensation

a. At high speeds, molecules of water vapor bounce apart and remain a gas.

23.2 Condensation

a. At high speeds, molecules of water vapor bounce apart and remain a gas.

b. At lower speeds, molecules of water vapor are more likely to stick together and form a liquid.



23.2 Condensation

Temperature is a measure of *average* kinetic energy.

There are always some molecules moving faster than average, and some moving slower.

Even at high temperature, there will be enough slow molecules to cause condensation—provided there is enough water vapor.

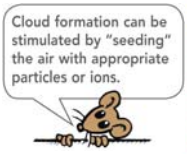
23.2 Condensation

Fog and Clouds

Warm air rises. As it rises, it expands. As it expands, it cools.

As it cools, water vapor molecules begin sticking together after colliding, rather than bouncing off one another.

If there are larger and slower-moving particles or ions present, water vapor condenses upon these particles, and makes a cloud.



23.2 Condensation

Fog is basically a cloud that forms near the ground.

Fog occurs in areas where moist air near the ground cools.

Some of the water vapor condenses out of the air as it cools, making fog.

A key feature of fog and cloud formation is a slowing down of water vapor molecules in air.

23.2 Condensation

think!

Is it correct to say that relative humidity is a measure of the amount of water vapor in the air at a particular temperature?

23 Change of Phase
Conceptual Physics

23.2 Condensation

think!

Is it correct to say that relative humidity is a measure of the amount of water vapor in the air at a particular temperature?

Answer:

No. Humidity is a measure of the amount of water vapor *per volume of air,* whatever the temperature. Relative humidity, on the other hand, is the amount of vapor in the air compared with the amount for saturation at a particular temperature. Relative humidity is a ratio, expressed as a percent.

23 Change of Phase
Conceptual Physics

23.2 Condensation

CONCEPT CHECK

How does condensation affect temperature?

23 Change of Phase
Conceptual Physics

23.3 Evaporation and Condensation Rates

The molecules and energy leaving a liquid's surface by evaporation can be counteracted by as many molecules and as much energy returning by condensation.

23 Change of Phase
Conceptual Physics

23.3 Evaporation and Condensation Rates

When you emerge from a shower into a dry room, you often feel chilly because evaporation is taking place quickly.

If you stay in the shower stall, moisture from the air condenses on your skin, counteracting the cooling of evaporation.

If as much moisture condenses as evaporates, you will feel no change in body temperature.

23 Change of Phase
Conceptual Physics

23.3 Evaporation and Condensation Rates

If you leave a covered dish of water for several days, no apparent evaporation takes place.

Much activity is taking place at the molecular level.

Evaporation *and* condensation occur continuously at equal rates so the water level doesn't change.

23.3 Evaporation and Condensation Rates

Evaporation and condensation normally take place at the same time.

- If evaporation exceeds condensation, the liquid is cooled.
- If condensation exceeds evaporation, the liquid is warmed.

23.3 Evaporation and Condensation Rates

CONCEPT CHECK

How can evaporation and condensation take place at the same time?

23.4 Boiling

Increasing the pressure on the surface of a liquid raises the boiling point of the liquid.

23.4 Boiling

Evaporation takes place at the surface of a liquid.

A change of phase from liquid to gas can also take place beneath the surface of a liquid, causing bubbles.

The bubbles are buoyed upward to the surface, where they escape into the surrounding air.

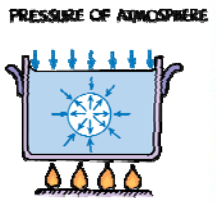
The change of phase from liquid to gas beneath a liquid's surface is called **boiling.**

23.4 Boiling

The pressure of the vapor within the bubbles in a boiling liquid is great enough to resist the pressure of the surrounding water.

Unless the vapor pressure is great enough, the surrounding pressures will collapse any bubbles that may form.

Below the boiling point, the vapor pressure is not great enough. Bubbles do not form until the boiling point is reached.



23.4 Boiling

As the atmospheric pressure is increased, the molecules in the vapor must move faster to exert increased pressure to counteract the additional atmospheric pressure.

At lowered pressure (as at high altitudes) boiling point decreases.

Boiling depends not only on temperature but on pressure also.

23.4 Boiling

High Pressure

A pressure cooker has a tight-fitting lid that does not allow vapor to escape until it reaches a certain pressure.

As the vapor builds up inside the sealed pressure cooker, pressure on the surface of the liquid is increased, which prevents boiling.

Increased pressure forces the water to reach a higher temperature before boiling can occur.

The increased temperature of the water cooks the food faster.

23.4 Boiling

Low Pressure

It is important to note that it is the high temperature of the water that cooks the food, not the boiling process itself.

At high altitudes, water boils at a lower temperature. In Denver, water boils at 95°C, instead of the 100°C of sea level.

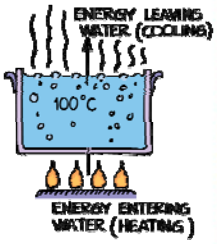
If you try to cook food in boiling water of a lower temperature, you must wait a longer time for proper cooking.

23.4 Boiling

Boiling, like evaporation, is a process that cools the liquid.

When 100°C water at atmospheric pressure is boiling, heat is taken away as fast as it is added.

If cooling did not take place, continued application of heat to boiling water would result in a continued increase in temperature.



23.4 Boiling

think!

Since boiling is a cooling process, would it be a good idea to cool your hot and sticky hands by dipping them into boiling water? Explain.

23.4 Boiling

think!

Since boiling is a cooling process, would it be a good idea to cool your hot and sticky hands by dipping them into boiling water? Explain.

Answer:

No, no, no! When we say boiling is a cooling process, we mean that the *water* (not your hands!) is being cooled. A dip in 100°C water would be most uncomfortable for your hands!

23.4 Boiling

CONCEPT CHECK

What is the effect of pressure on the boiling temperature of a liquid?

23.5 Freezing

In general, dissolving anything in a liquid lowers the liquid's freezing temperature.

23.5 Freezing

When energy is continually withdrawn from a liquid, molecular motion slows.

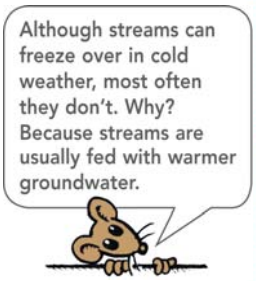
Eventually, the forces of attraction between the molecules cause them to get closer to one another.

The molecules then vibrate about fixed positions and form a solid.

23.5 Freezing

When energy is extracted from water at a temperature of 0°C and at atmospheric pressure, ice is formed.

The change in phase from liquid to solid is called **freezing.**



23.5 Freezing

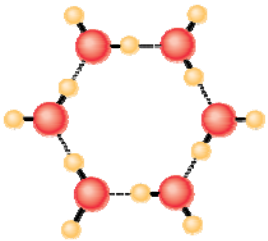
If sugar or salt is dissolved in the water, the freezing temperature will be lowered.

The molecules or ions get in the way of water molecules that otherwise would join into a six-sided ice-crystal structure.

Antifreeze is a practical application of this process.

23.5 Freezing

Pure ice crystals have an open structure. When other kinds of molecules or ions are introduced, crystal formation is interrupted, and the freezing temperature is lowered.



23.5 Freezing

CONCEPT CHECK

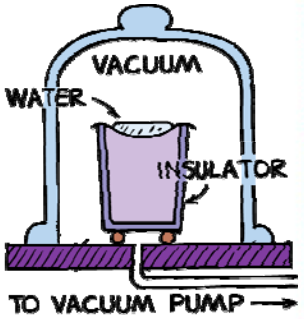
What effect does dissolving anything in a liquid have on the liquid's freezing temperature?

23.6 Boiling and Freezing at the Same Time

Lowering the pressure can cause boiling and freezing to take place at the same time!

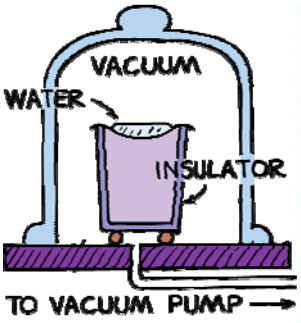
23.6 Boiling and Freezing at the Same Time

A dish of water at room temperature is placed in a vacuum jar. A gram or two of water is placed in a dish that is insulated from the base by a polystyrene cup.



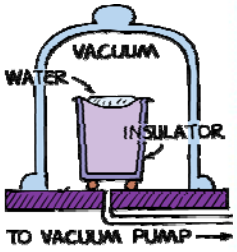
23.6 Boiling and Freezing at the Same Time

- If the pressure in the jar is slowly reduced, the water will start to boil.
- The boiling process takes higher-energy molecules away from the water left in the dish, which cools to a lower temperature.



23.6 Boiling and Freezing at the Same Time

- As the pressure is further reduced, more and more of the faster remaining slow-moving molecules boil away.
- Continued boiling results in a lowering of temperature until the freezing point of approximately 0°C is reached.
- Cooling by boiling causes ice to form over the bubbling water.



23.6 Boiling and Freezing at the Same Time

If drops of coffee are sprayed into a vacuum chamber, they, too, will boil until they freeze.

Even after they are frozen, the water molecules will continue to evaporate until little crystals of coffee solids are left.

This is how freeze-dried coffee is made. The low temperature of this process tends to keep the chemical structure of coffee solids from changing.

23.6 Boiling and Freezing at the Same Time

CONCEPT CHECK

What can cause boiling and freezing to take place at the same time?

23.7 Regelation

Regelation can occur only in substances that expand when they freeze.

23.7 Regelation

The open-structured crystals of ice can be crushed by the application of pressure.

Ice normally melts at 0°C, but pressure lowers the melting point.

The crystals are simply crushed to the liquid phase.

At twice standard atmospheric pressure, the melting point is lowered to -0.007°C.

23.7 Regelation

When the pressure is removed, refreezing occurs.

The phenomenon of melting under pressure and freezing again when the pressure is reduced is called **regelation**.

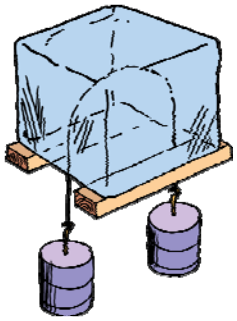
It is one of the properties of water that make it different from other substances.

23.7 Regelation

You can see regelation if you suspend a fine wire that supports heavy weights over an ice block.

The wire will cut through the ice, but its track will refill with ice.

The wire and weights fall to the floor, leaving the ice in a single solid piece!



23.7 Regelation

To make a snowball, you use regelation.

When you compress the snow with your hands, you cause a slight melting, which helps to bind the snow into a ball.

Making snowballs is difficult in very cold weather, because the pressure you can apply may not be enough to melt the snow.

23.7 Regelation

CONCEPT CHECK **Why do so few substances undergo regelation?**

23.8 Energy and Changes of Phase

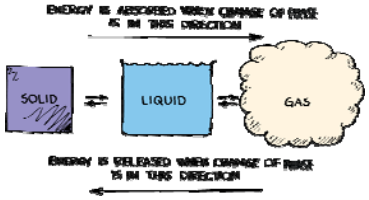
Energy must be put into a substance to change its phase from solid to liquid to gas. Conversely, energy must be extracted from a substance to change its phase from gas to liquid to solid.

23.8 Energy and Changes of Phase

If you heat a solid sufficiently, it will melt and become a liquid.

If you heat the liquid, it will vaporize and become a gas.

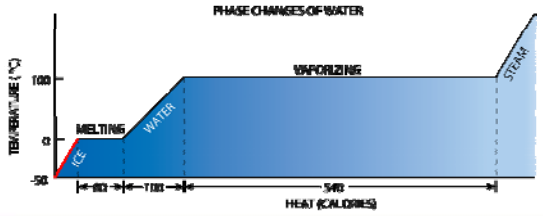
The change in the internal energy of a substance causes the change of phase.



23.8 Energy and Changes of Phase

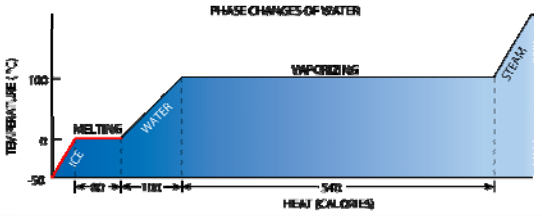
Examples of Phase Changes

Suppose we have a 1-gram piece of ice at a temperature of -50°C in a closed container, and it is put on a stove to heat.



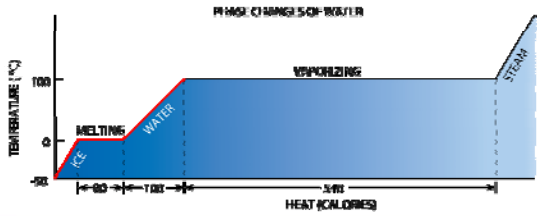
23.8 Energy and Changes of Phase

- A thermometer in the container reveals a slow increase in temperature up to 0°C.
- Once it reaches 0°C, the temperature of the ice remains at 0°C even though heat input continues.
- Rather than getting warmer, the ice melts.



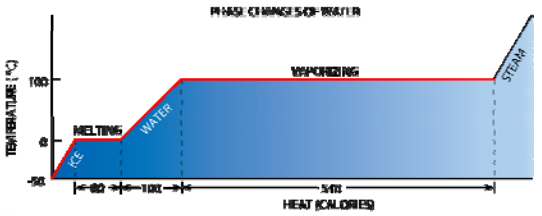
23.8 Energy and Changes of Phase

- In order for the whole gram of ice to melt, 80 calories (335 joules) of heat energy must be absorbed by the ice.
- Not until all the ice melts does the temperature again begin to rise.



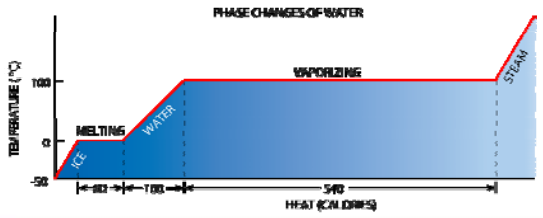
23.8 Energy and Changes of Phase

- Each additional calorie absorbed by the gram of water increases its temperature by 1°C until it reaches its boiling temperature, 100°C.



23.8 Energy and Changes of Phase

- The temperature remains constant while water is boiled away. The water absorbs 540 calories (2255 joules) of heat to vaporize the gram.
- When all the water has become steam at 100°C, the temperature begins to rise once more.



23.8 Energy and Changes of Phase

Reversibility of Phase Changes

The phase change sequence is reversible.

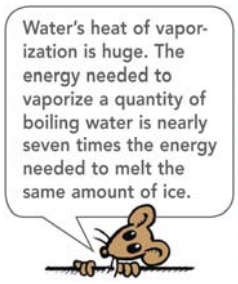
- When the molecules in a gram of steam condense to form water, they liberate 540 calories (2255 joules) of heat.
- When the water is cooled from 100°C to 0°C, 100 additional calories are liberated to the environment.
- When ice water fuses to become solid ice, 80 more calories (335 joules) of energy are released by the water.

23.8 Energy and Changes of Phase

The 540 calories (2255 joules) required to vaporize a gram of water is a relatively large amount of energy.

It is much more than is required to change a gram of ice at absolute zero to boiling water at 100°C.

Although the molecules in steam and boiling water at 100°C have the same average kinetic energy, steam has more potential energy.



23.8 Energy and Changes of Phase

In steam, the molecules are free of each other and are not bound together in the liquid.

A vast amount of energy can be released during condensation.

23.8 Energy and Changes of Phase

Under some conditions hot water will freeze faster than warm water. This occurs for water hotter than 80°C.

Cooling rates by rapid evaporation are very high. Each gram of water draws 540 calories from the water left behind.

This is an enormous quantity of energy compared to cooling by thermal conduction.

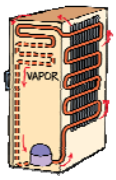
23.8 Energy and Changes of Phase

When a car is washed on a cold day, hot water will freeze more readily than warm water because of the energy that the rapidly evaporating water takes with it.

23.8 Energy and Changes of Phase

Applications of Phase Changes

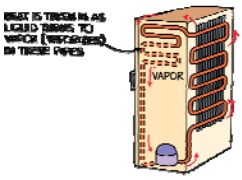
A refrigerator's cooling cycle uses the changes of phase of the refrigeration fluid (not water).



23.8 Energy and Changes of Phase

Applications of Phase Changes

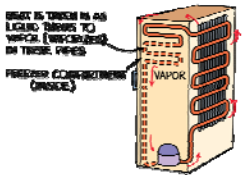
- Liquid is pumped into the cooling unit, where it is forced through a tiny opening to evaporate.



23.8 Energy and Changes of Phase

Applications of Phase Changes

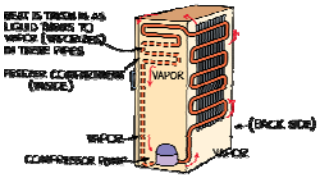
- It draws heat from the things stored in the food compartment.



23.8 Energy and Changes of Phase

Applications of Phase Changes

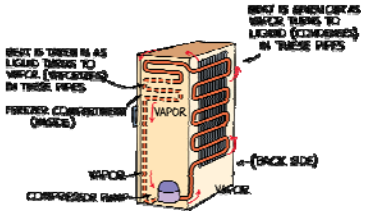
- The gas then goes to coils located outside the cooling unit.



23.8 Energy and Changes of Phase

Applications of Phase Changes

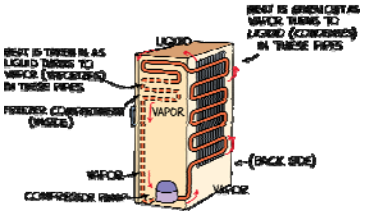
- As the gas condenses in the coils, heat is given off.



23.8 Energy and Changes of Phase

Applications of Phase Changes

- The liquid returns to the cooling unit, and the cycle continues.



23.8 Energy and Changes of Phase

A motor pumps the fluid through the system, where it enters the cyclic processes of vaporization and condensation.

Place your hand near the condensation coils of a refrigerator and you will feel the heat that has been extracted from the inside.

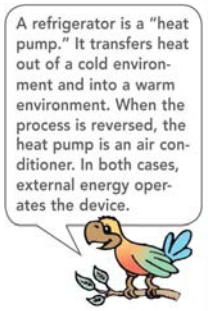
23.8 Energy and Changes of Phase

An air conditioner employs the same principles.

It simply pumps heat from one part of the unit to another.

When the roles of vaporization and condensation are reversed, the air conditioner becomes a heater.

A device that moves heat is called a **heat pump.**



23.8 Energy and Changes of Phase

Some people judge the hotness of a clothes iron by touching it briefly with a finger.

This is also a way to burn the finger—unless it is first moistened.

Energy that ordinarily would go into burning the finger goes, instead, into changing the phase of the moisture on it.

23.8 Energy and Changes of Phase

- A solid absorbs energy when it melts.
- A liquid absorbs energy when it vaporizes.
- A gas emits energy when it liquefies.
- A liquid releases energy when it solidifies.

23.8 Energy and Changes of Phase

think!

How much energy is released when a gram of steam at 100°C condenses to water at 100°C?

23.8 Energy and Changes of Phase

think!

How much energy is released when a gram of steam at 100°C condenses to water at 100°C?

Answer:

One gram of steam at 100°C releases 540 calories of energy when it condenses to become water at the same temperature.

23.8 Energy and Changes of Phase

think!

When H_2O in the vapor phase condenses, is the surrounding air warmed or cooled?

23 Change of Phase
Conceptual Physics

23.8 Energy and Changes of Phase

think!

When H_2O in the vapor phase condenses, is the surrounding air warmed or cooled?

Answer:

The surrounding air is warmed because the change of phase is from vapor to liquid, which releases energy.

23 Change of Phase
Conceptual Physics

23.8 Energy and Changes of Phase

CONCEPT CHECK **How is energy related to phase changes?**

23 Change of Phase
Conceptual Physics

Assessment Questions

1. When evaporation occurs, the molecules left behind in the water
   a. are more energetic.
   b. have increased average speeds.
   c. result in lowered temperature and decreased energy.
   d. have a higher temperature and are less energetic.

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Conceptual Physics

Assessment Questions

1. When evaporation occurs, the molecules left behind in the water
   a. are more energetic.
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   c. result in lowered temperature and decreased energy.
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Answer: C

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Conceptual Physics

Assessment Questions

2. When relatively slow-moving molecules condense from the air, the temperature of the remaining air tends to
   a. remain unchanged.
   b. decrease.
   c. increase.
   d. spread out uniformly.

Assessment Questions

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   a. remain unchanged.
   b. decrease.
   c. increase.
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Answer: C

Assessment Questions

3. Put a saucer of water on your table. A process that then occurs is
   a. evaporation.
   b. condensation.
   c. both of these
   d. neither of these

Assessment Questions

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   a. evaporation.
   b. condensation.
   c. both of these
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Answer: C

Assessment Questions

4. The process of boiling water tends to
   a. warm the water.
   b. cool the water.
   c. both warm and cool the water at the same time.
   d. have no effect on the water's temperature.

Assessment Questions

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   a. warm the water.
   b. cool the water.
   c. both warm and cool the water at the same time.
   d. have no effect on the water's temperature.

Answer: B

Assessment Questions

5. When salt is introduced to water, the temperature at which freezing takes place is
   a. unaffected.
   b. lowered.
   c. increased.
   d. dependent on the shape of ice crystals.

Assessment Questions

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   a. unaffected.
   b. lowered.
   c. increased.
   d. dependent on the shape of ice crystals.

Answer: B

Assessment Questions

6. Boiling and freezing occur when water is subjected to
   a. decreased temperatures.
   b. decreased atmospheric pressure.
   c. increased temperatures.
   d. increased atmospheric pressure.

Assessment Questions

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   a. decreased temperatures.
   b. decreased atmospheric pressure.
   c. increased temperatures.
   d. increased atmospheric pressure.

Answer: B

Assessment Questions

7. Regelation occurs due to water's
   a. high specific heat.
   b. open-structured ice crystals.
   c. high rate of expansion.
   d. slight tendency to freeze when temperature is lowered.

Assessment Questions

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   a. high specific heat.
   b. open-structured ice crystals.
   c. high rate of expansion.
   d. slight tendency to freeze when temperature is lowered.

Answer: B

Assessment Questions

8. When water changes to steam, energy is
   a. absorbed by the water.
   b. released by the water.
   c. conserved as the phase change occurs.
   d. changed to a different form.

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   a. absorbed by the water.
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Answer: A