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13 States of Matter

Big idea KINETIC THEORY

13.1 The Nature of Gases

For students using the Foundation edition, assign problems 1–19.

Essential Understanding Temperature and pressure affect gases much more than they affect any other state of matter.

Lesson Summary

Kinetic Theory and a Model for Gases The kinetic theory refers to the constant motion of particles in matter and, for gases, makes three assumptions.

- Particles in a gas are hard spheres and are so small that their volume is insignificant.
- Particles in a gas move constantly, rapidly, and randomly.
- When particles in a gas collide, neither particle loses any of its kinetic energy.

Gas Pressure The kinetic theory can be used to explain gas pressure.

- Gas pressure is the result of the simultaneous collisions of billions of gas particles with an object.
- The pressure air exerts on Earth is called atmospheric pressure, which is measured with a barometer.
- Units for measuring gas pressure include pascals (Pa), millimeters of mercury (mm Hg), and atmospheres (atm).

Kinetic Energy and Temperature Temperature is a measure of the average kinetic energy of the particles in a collection of atoms or molecules.

- An increase in the average kinetic energy of particles results in an increase in temperature.
- Particles are no longer moving at a theoretical temperature known as absolute zero (0K, −273.15°C).
- The Kelvin temperature of a substance is directly proportional to the kinetic energy of its particles.

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BUILD Math Skills

Converting Between Units of Pressure Three of the most common units of pressure are atmospheres (atm), millimeters of mercury (mm Hg) and pascals (Pa). Atmospheres relate to the pressure exerted by our atmosphere. A device called a barometer uses the difference between heights of mercury in two different tubes to measure pressure. Pascals are the SI unit for pressure, where 1 Pa = 1 N/m^2. It is important to remember that there are 1000 Pa in 1 kilopascal (kPa).

The relationship between these units is:

$$1 \text{ atm} = 760 \text{ mm Hg} = 101.3 \text{ kPa}$$

When converting between units:

- Start with the pressure in the given units.
- Always put the units you begin with on the bottom of the ratio by which you are going to multiply.
- Put the units you want to end with on the top of the ratio.
- You will multiply all the numbers that fall on top and divide by all the numbers that fall on the bottom.

Sample Problem Determine the number of kilopascals (kPa) present in 0.53 m of Hg.

Start with the given units.

$$0.53 \text{ m of Hg}$$

Hint: Remember, you may need more than one ratio to get to the desired units.

Now you want to convert from meters to millimeters, so you can use the equivalents. The conversion is: 1×10^{-3} m = 1 mm, so *mm* will go on the top since it is the desired unit.

$$0.53 \text{ m of Hg} \times \frac{1 \text{ mm}}{1 \times 10^{-3} \text{ m}} \rightarrow$$

$$0.53 \cancel{\text{m}} \text{ of Hg} \times \frac{1 \text{ mm}}{1 \times 10^{-3} \cancel{\text{m}}}$$

Next, you want to convert from mm of Hg to kilopascals, so you will use the ratio of 760 mm of Hg = 101.3 kPa.

$$0.53 \text{ m of Hg} \times \frac{1 \text{ mm}}{1 \times 10^{-3} \text{ m}} \times \frac{101.3 \text{ kPa}}{760 \text{ mm of Hg}} \rightarrow$$

$$0.53 \cancel{\text{m}} \text{ of Hg} \times \frac{1 \text{ mm}}{1 \times 10^{-3} \cancel{\text{m}}} \times \frac{101.3 \text{ kPa}}{760 \cancel{\text{mm}} \text{ of Hg}}$$

Finally, multiply all the numbers on top and divide by all the numbers on the bottom to get the equivalent kPa.

$$\frac{(0.53 \times 101.3)}{(1 \times 10^{-3} \times 760)} = 70.64 \text{ kPa}$$

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Now it's your turn to practice converting between different units of pressure.

1. Determine how many mm of Hg are equal to 5.3 atm of pressure.

   4,028 mm of Hg

2. Determine how many atmospheres of pressure are equal to 65.78 kPa.

   0.649 atm

3. If you have 2.86 atm of pressure, is that more or less than 2000 mm of Hg?

   more (2173.6 mm of Hg)

4. What is the pressure in both mm of Hg and atmospheres if you are given 5678.32 Pa?

   42.601 mm of Hg and 0.056 atm

After reading Lesson 13.1, answer the following questions.

Kinetic Theory and a Model for Gases

5. The energy an object has because of its motion is called *kinetic energy*.

6. Circle the letter of each sentence that is true about the assumptions of the kinetic theory concerning gases.

   (a.) A gas is composed of particles with insignificant volume that are relatively far apart.

   b. Strong attractive forces exist between particles of a gas.

   c. Gases tend to collect near the bottom of a container.

   (d.) The paths of uninterrupted travel of particles in a gas are relatively short because the particles are constantly colliding with each other or with other objects.

7. Is the following statement true or false? According to the kinetic theory, collisions between particles in a gas are perfectly elastic because kinetic energy is transferred without loss from one particle to another, and the total kinetic energy remains constant.

   true

Gas Pressure

8. Gas pressure results from the force exerted by a gas per *unit surface area of an object*.

9. Simultaneous collisions of billions of particles in a gas with an object result in *gas pressure*.

10. What force holds the particles of air in Earth's atmosphere? *gravity*

11. What kind of pressure is measured with a barometer? *atmospheric pressure*

12. Look at Figure 13.2. What accounts for the difference in height of the two columns of mercury shown in the figure?

    The mercury column on the left is shown at sea level; the one on the right is shown at an altitude of 9000 m. Because atmospheric pressure decreases as altitude increases, the column on the right is lower than the one on the left.

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13. Circle the letter next to every name of a unit of pressure.

(**a.**) mm Hg
b. standard
(**c.**) pascal
(**d.**) kPa
(**e.**) atm
f. degree

14. Standard temperature and pressure (STP) are defined as

a temperature of 0°C and a pressure of 101.3 kPa, or 1 atm.

Kinetic Energy and Temperature

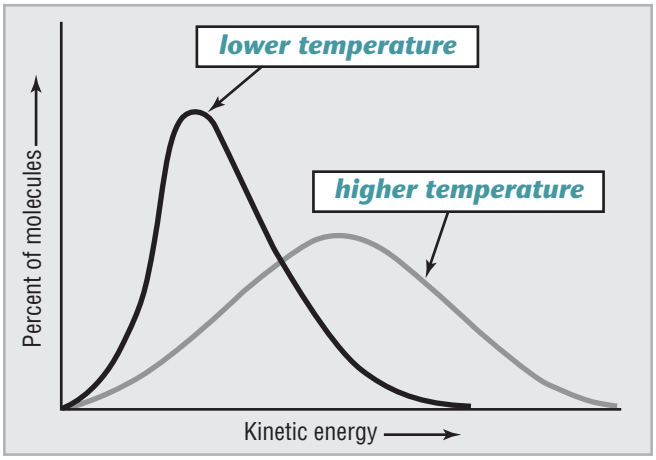
15. What happens to the temperature of a substance when the average kinetic energy of its particles increases?

The temperature of the substance increases.

16. Is the following statement true or false? All the particles in a substance at a given temperature have the same kinetic energy. ***false***

17. The temperature 0 K, or –273.15°C, is called ***absolute*** zero. Theoretically, particles of matter at this temperature would have no ***kinetic energy/motion***.

18. On the graph below, write the labels *lower temperature* and *higher temperature* to identify the curve that depicts the kinetic energy distribution of particles in a liquid at a lower temperature and at a higher temperature.



19. Circle the letter of the temperature scale that correctly completes this sentence. Temperature on the _____ scale is directly proportional to the average kinetic energy of the particles of a substance.

a. Celsius
(**b.**) Kelvin
c. Fahrenheit
d. Centigrade

Name _____ Class _____ Date _____

13.2 The Nature of Liquids

For students using the Foundation edition, assign problems 1–4, 6–16.

Essential Understanding The properties and physical changes of liquids are the result of the particle motion and the attraction between particles in a liquid.

Lesson Summary

A Model for Liquids The properties of liquids are the result of both the disruption caused by particle motion and the attraction between particles in a liquid.

- Liquids flow because their particles can slide by each other.
- Liquids have a definite volume because of the attraction between their particles.
- Particles are close together in a liquid, so a change in pressure has little effect on a liquid.

Evaporation Evaporation is the change of a liquid to a gas at the surface of a liquid that is not boiling.

- The kinetic energy of a particle at the surface of a liquid determines whether or not the particle evaporates.
- Evaporation increases when the temperature of the liquid increases.
- Evaporation is a cooling process because the higher-energy particles in the liquid are the particles that evaporate.

Vapor Pressure Vapor pressure is the force exerted by a gas above a liquid in a closed container.

- In a closed container containing a liquid, gas particles eventually condense at the same rate as liquid particles vaporize.
- In a closed system, when vapor pressure is constant, a dynamic equilibrium has been reached.
- Increasing the temperature of a contained liquid increases its vapor pressure.

Boiling Point Boiling point is the temperature at which particles throughout a liquid have enough energy to vaporize.

- At the boiling point of a liquid, vapor pressure equals the external pressure on the liquid.
- Boiling point is affected by external pressure; as external pressure decreases, boiling point decreases.
- The normal boiling point of a liquid is the temperature at which the liquid boils when the external pressure is 101.3 kPa.

After reading Lesson 13.2, answer the following questions.

A Model for Liquids

1. Is the following sentence true or false? The kinetic theory states that there are no attractions between the particles of a liquid. ***false*** _____

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2. Circle the letter next to each sentence that is true about the particles of a liquid.

   a. Most of the particles in a liquid have enough kinetic energy to escape into a gaseous state.

   b. Liquids are much denser than gases because intermolecular forces reduce the amount of space between the particles in a liquid.

   c. Increasing pressure on a liquid has almost no effect on its volume.

   d. Liquid particles are free to slide past one another.

Evaporation

3. The conversion of a liquid to a gas or vapor is called ***vaporization***.

4. When vaporization occurs at the surface of a liquid that is not boiling, the process is called ***evaporation***.

5. As a liquid evaporates, why do only some of the particles break away from the surface of the liquid? Why does the liquid evaporate faster if the temperature is increased?

   Most of the molecules do not have enough kinetic energy to overcome the attractive forces. As the temperature is increased, the average kinetic energy increases and more particles have enough kinetic energy to overcome the forces keeping them in the liquid state.

6. Is the following sentence true or false? Evaporation is a cooling process because the particles in a liquid with the highest kinetic energy tend to escape first, leaving the remaining particles with a lower average kinetic energy and, thus, a lower temperature. ***true***

Questions 7–10 refer to either container A or container B below. Think of each container as a system involving both liquid water and water vapor.

(a) (b)

7. From which of the containers are water molecules able to escape? ***b***

8. In which container can a dynamic equilibrium be established between water molecules in the liquid state and water molecules in the vapor state? ***a***

9. In which container will the water level remain constant? ***a***

10. From which container is it possible for all of the liquid water to disappear through evaporation? ***b***

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11. What causes the chill you may feel after stepping out of a swimming pool on a warm, windy day?

Wind causes water on the skin to evaporate, which is a cooling process.

Vapor Pressure

12. Circle the letter next to each sentence that is true about vapor pressure.

(a.) Vapor pressure exists when particles of a liquid in a closed, partly filled container vaporize and collide with the walls of the container.

(b.) After a time in a closed, partly filled container, a liquid will evaporate and its vapor will condense at equal rates.

c. Look at Figure 13.6b. Condensation on the inside of the terrarium indicates that there is no liquid-vapor equilibrium in the sealed terrarium.

(d.) When the temperature of a contained liquid increases, its vapor pressure increases.

13. Look at Figure 13.7. How does the vapor pressure of the ethanol in the manometer change when the temperature is increased from 0°C to 20°C? Circle the letter of the correct answer.

a. The vapor pressure decreases by more than 4 kPa.

b. The vapor pressure remains constant.

(c.) The vapor pressure increases by more than 4 kPa.

d. There is no way to detect a change in vapor pressure with a manometer.

Boiling Point

14. The boiling point of a liquid is the temperature at which the vapor pressure of the liquid is just equal to the *external pressure*.

15. Look at Figure 13.8. Why does the boiling point decrease as altitude increases?

At higher altitudes, atmospheric pressure is lower than it is at sea level. Because boiling occurs when vapor pressure is equal to atmospheric pressure, a liquid boils at a lower temperature.

16. Use Figure 13.9. At approximately what temperature would ethanol boil atop Mount Everest, where the atmospheric pressure is 34 kPa? Circle the letter next to the best estimate.

(a.) 50°C **b.** 100°C **c.** 0°C **d.** 85°C

17. Is the following sentence true or false? After a liquid reaches its boiling point, its temperature continues to rise until all the liquid vaporizes. *false*

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13.3 The Nature of Solids

For students using the Foundation edition, assign problems 1–4, 6–12, 14.

Essential Understanding The properties of solids are related to their structure.

Lesson Summary

A Model for Solids The properties of solids reflect the arrangement and fixed locations of their particles.

- Particles in a solid vibrate in place and do not move past each other.
- At its melting point, the particles in a solid overcome the attraction between them, and they start to flow.
- For any substance, freezing point is the same temperature as the melting point, and equilibrium between liquid and solid exist at this temperature.

Crystal Structure and Unit Cells The shape of a crystal reflects the arrangements of the particles in the solid.

- Based on their shape, crystals are classified into seven crystal systems.
- Solid substances that can exist in more than one form are allotropes.
- Solids that have no crystal form are amorphous solids.

After reading Lesson 13.3, answer the following questions.

A Model for Solids

1. Is the following sentence true or false? Although particles in solids have kinetic energy, the motion of particles in solids is restricted to vibrations about fixed points. ***true***

2. A solid melts when ***the organization of its particles breaks down***.

3. Is the following sentence true or false? The temperature at which the liquid and solid states of a substance are in equilibrium is the same as the melting point *and* the freezing point of the substance. ***true***

Crystal Structure and Unit Cells

4. How are particles arranged in a crystal?

   They are arranged in an orderly, repeating, three-dimensional pattern.

5. What type of solid has a relatively low melting point?

   A molecular solid has a relatively low melting point.

6. Do all solids melt when heated? Explain.

   No; some solids, such as wood, decompose.

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7. Circle the letter next to each sentence that is true about solids.

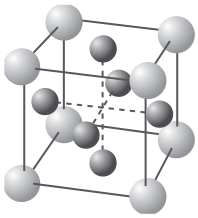
a. Most solid substances are not crystalline.

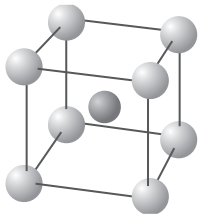
b. All crystals have sides, or faces, that intersect at angles that are characteristic for a given substance.

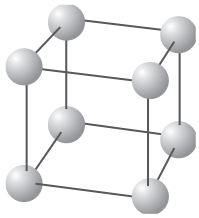
c. There are seven groups, or crystal systems, into which all crystals can be classified.

d. The orderly array of sodium ions and chloride ions gives crystals of table salt their regular shape.

Identify the unit cell in each figure below as *simple cubic, body-centered cubic*, or *face-centered cubic.*







8. *face-centered cubic* **9.** *body-centered cubic* **10.** *simple cubic*

11. Is the following sentence true or false? Some solid substances can exist in more than one form. Give an example to support your answer.

True. The element carbon has at least three solid forms: graphite, diamond, and buckminsterfullerene.

12. Two or more different molecular forms of the same element in the same physical state are called *allotropes*.

13. What is an amorphous solid?

An amorphous solid lacks an ordered internal structure.

14. Circle the letter next to each solid that is an amorphous solid.

a. table salt

b. rubber

c. plastic

d. glass

15. How does glass differ from a crystalline solid?

The internal structure of glass is intermediate between free-flowing liquid and crystalline solid. Glass does not have a definite melting point, but softens when heated. Glass breaks into irregular, jagged pieces when shattered.

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13.4 Changes of State

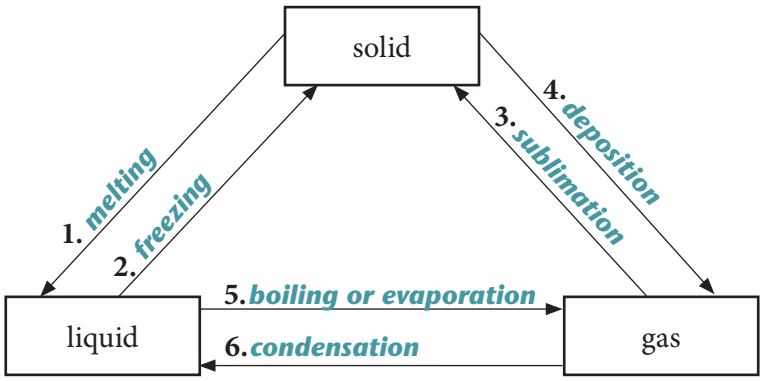
For students using the Foundation edition, assign problems 1–6.

Essential Understanding Changes of state depend on changes in energy of the particles involved.

Reading Strategy

Concept Map A concept map helps you organize concepts using visual relationships and linking words. Mapping out these connections helps you think about how information fits together.

As you read Lesson 13.4, use the concept map below. On each arrow, fill in the appropriate change of state.



EXTENSION **Give a real-life example of each change of state shown in the concept map.**

Sample answers: 1. ice changing to liquid water, 2. molten steel solidifying, 3. dry ice changing to carbon dioxide gas, 4. formation of frost from water vapor in the air, 5. a wet cloth drying, 6. dew forming on grass

Lesson Summary

Sublimation Sublimation is the change of state from a solid to a vapor without passing through the liquid state.

- Sublimation occurs when the solid has a vapor pressure that is greater than atmospheric pressure at or near room temperature.
- The process that is the opposite of sublimation is deposition.
- There are useful applications for sublimation such as separating mixtures and purifying compounds.

Phase Diagrams A phase diagram relates the solid, liquid, and gas states of a particular substance to the temperature and the pressure at which the states exist in equilibrium.

- The triple point on the diagram is the set of temperature and pressure at which all three states exist in dynamic equilibrium.
- A phase diagram can be used to show how a change in temperature or pressure might affect the state of a substance.

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After reading Lesson 13.4, answer the following questions.

Sublimation

1. The process by which wet laundry dries on an outdoor clothesline in winter is called ***sublimation***.
2. Is the following sentence true or false? Solids have vapor pressure because some particles near the surface of a solid substance have enough kinetic energy to escape directly into the vapor phase. ***true***

Phase Diagrams

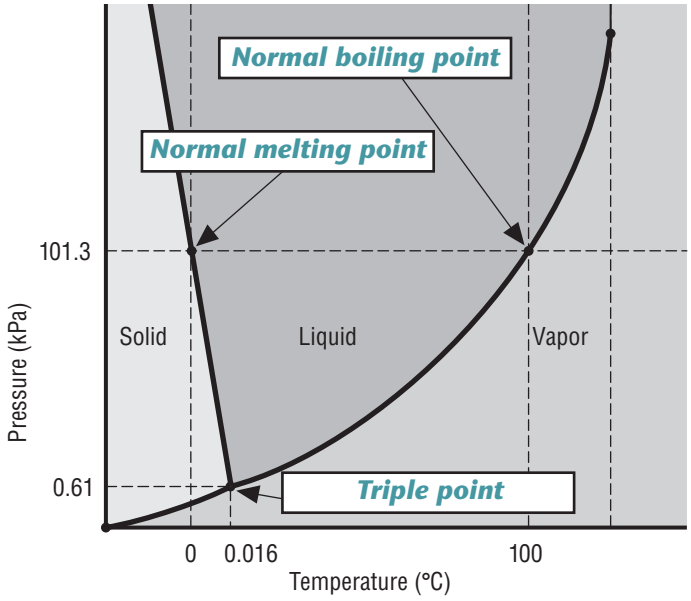
3. What does a phase diagram show?

   A phase diagram shows the temperature and pressure conditions at which a substance exists in the solid, liquid, and vapor phases.

4. What is the triple point of a substance?

   The triple point represents the only conditions of temperature and pressure at which three phases of a substance can exist in equilibrium.

5. In the phase diagram for water shown below, label the melting point and boiling point at normal atmospheric pressure, and the triple point.



6. Use the phase diagram above to answer the following question. Why is a laboratory required to produce the conditions necessary for observing water at the triple point?

   From the diagram, the triple point of water is at a pressure of 0.61 kPa, far below atmospheric pressure. Laboratory equipment is necessary to achieve pressures this low.

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Guided Practice Problems

Answer the following questions about Practice Problem 2.

The pressure at the top of Mount Everest is 33.7 kPa. Is that pressure greater than or less than 0.25 atm?

Analyze

Step 1. To convert kPa to atm, what conversion factor do you need to use?

$\frac{1\ atm}{101.3\ kPa}$

Step 2. Why can you use an estimate to solve this problem?

Because "greater than or less than" questions don't require an exact answer. An estimate will probably be sufficient to produce the correct answer.

Calculate

Step 3. Write the expression needed to find the answer.

$33.7\ \cancel{kPa} \times \frac{1\ atm}{101.3\ \cancel{kPa}} = \frac{33.7}{101.3}\ atm$

Step 4. Which common fraction is this number close to?

$\frac{33.7}{101.3}$ atm is close to $\frac{33}{99}$ atm or $\frac{1}{3}$ atm.

Step 5. What is this fraction written as a decimal? Is this number greater than or less than 0.25?

0.333 is greater than 0.25.

Evaluate

Step 6. Are you confident your estimate gave a correct answer to this problem?

Because the estimate is more than 30% greater than 0.25, you can be confident that the difference isn't due to rounding.

Extra Practice

What pressure, in atmospheres, does a gas exert at 152 mm Hg?

$152\ \cancel{mm\ Hg} \times \frac{1\ atm}{760\ \cancel{mm\ Hg}} = 0.200\ atm$

What is this pressure in kilopascals?

$0.200\ \cancel{atm} \times \frac{101.3\ kPa}{1\ \cancel{atm}} = 20.3\ kPa$

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Apply the Big idea

Ahmed's yard is covered with snow. Use the kinetic theory to explain the changes that occur in the snow when the air temperature increases above the freezing point of water.

Sample answer: As air temperature increases, the particles in the air move faster. Collisions of fast-moving air particles in the snow increase movement of water molecules in the snow. As this motion increases, the water molecules start moving fast enough to break the attraction between particles, and the water melts. As the water molecules continue gaining energy, some of the molecules move fast enough to evaporate, becoming a gas.

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13 Self-Check Activity

For Questions 1–11, complete each statement by writing the correct word or words. If you need help, you can go online.

13.1 The Nature of Gases

1. The ***kinetic theory*** makes three assumptions about the volume, the motion, and the collisions of gas particles.

2. When many particles in a gas simultaneously collide with an object, ***gas pressure*** results.

3. The ***Kelvin*** temperature of a substance is directly proportional to the average kinetic energy of the particles of the substance.

13.2 The Nature of Liquids

4. The ***physical properties*** of liquids depend on both the disruption of the particles in the liquid and the attraction between the particles.

5. During ***evaporation***, particles with enough energy escape at the surface of a liquid.

6. When a closed system has constant vapor pressure, a(n) ***dynamic equilibrium*** exists between the liquid and its vapor.

7. When the particles throughout a liquid have enough energy to vaporize, ***boiling*** occurs.

13.3 The Nature of Solids

8. The arrangement and location of its particles affect the ***general properties*** of a solid.

9. A crystalline solid has a certain arrangement of particles, which is reflected in its ***shape***.

13.4 Changes of State

10. When the vapor pressure of a solid equals or exceeds atmospheric pressure at room temperature, ***sublimation*** occurs.

11. A(n) ***phase diagram*** relates the solid, liquid, and gas states of a substance to temperature and pressure.

If You Have Trouble With…											
Question	1	2	3	4	5	6	7	8	9	10	11
See Page	420	421	424	425	426	427	428	431	432	436	438

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Review Vocabulary

For each set of vocabulary terms, write a sentence that includes all the terms and explains the relationship among them. *Accept any answer students can justify. Sample answers provided.*

1. vaporization, evaporation, sublimation

Both evaporation and vaporization involve changing from a liquid to its vapor, and sublimation also involves forming a vapor, this time from a solid.

2. boiling point, normal boiling point

The normal boiling point of a liquid is its boiling point when the pressure is 101.3°C.

3. atmospheric pressure, barometer, pascal (Pa), standard atmosphere (atm)

Atmospheric pressure is caused by the collision of air particles with Earth; it is measured by using a barometer, and has units of pascals (Pa) or standard atmospheres (atm).

4. phase diagram, triple point, melting point, boiling point

A phase diagram includes information, such as the triple point of a substance, and can be used to find the melting point or the boiling point of the substance at a specified pressure.

5. kinetic energy, gas pressure, vacuum

Gases create gas pressure because of the kinetic energy of their particles as they collide with an object; but when there is a vacuum, there are no gas particles and, thus, no gas pressure.