States of Matter

CHAPTER 13

13.1 The Nature of Gases

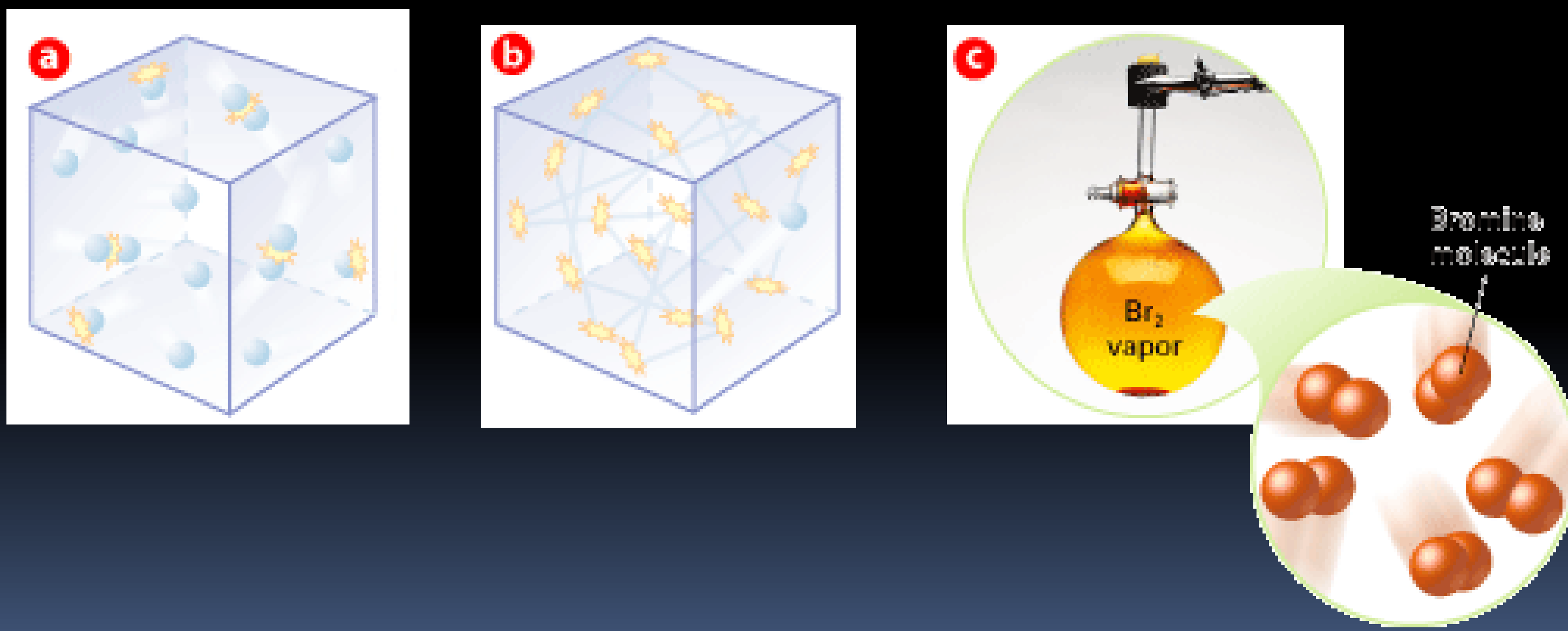
Connecting to Your World You are walking your dog in the woods. Suddenly your dog begins to bark and run toward what you think is a black cat. But before you realize that the "cat" is not a cat, the damage is done. The skunk has released its spray! Within seconds you smell that all-too-familiar foul odor. In this section, you will discover some general characteristics of gases that help explain how odors travel through the air, even on a windless day.

13.1 Nature of Gases

Kinetic Theory and a Model for Gases

- **kinetic energy-**
  - The energy an object has because of its motion.
- According to the kinetic theory,
  - all matter consists of tiny particles that are in constant motion.
  - The particles in a gas are considered to be small, hard spheres with an <u>insignificant</u> volume.
  - The motion of the particles in a gas is rapid, constant, and random.
  - All collisions between particles in a gas are perfectly elastic.

13.1 Nature of Gases



13.1 Nature of Gases

Gas Pressure

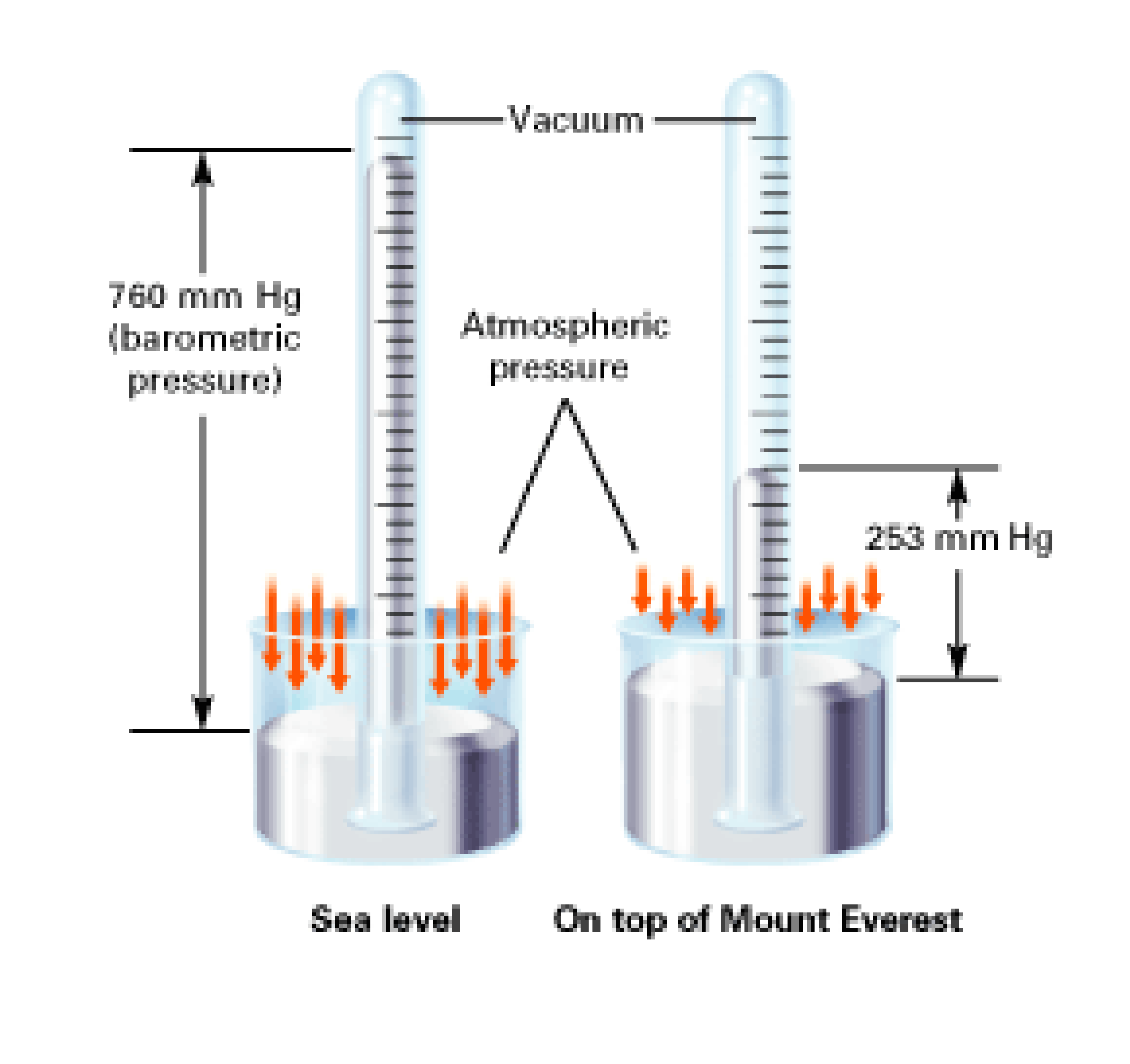
- Gas pressure-
  - results from the force exerted by a gas per unit surface area of an object.
  - result of simultaneous collisions of billions of rapidly moving particles in a gas with an object.

- Vacuum-
  - An empty space with no particles and no pressure

13.1 Nature of Gases

Gas Pressure

- Atmospheric pressure-
  - results from the collisions of atoms and molecules in air with objects.
  - Atmospheric pressure decreases as you climb a mountain
- barometer –
  - a device that is used to measure atmospheric pressure.


Vacuum
760 mm Hg
(barometric
pressure)
Atmospheric
pressure
253 mm Hg
Sea level
On top of Mount Everest

13.1 Nature of Gases

Gas Pressure

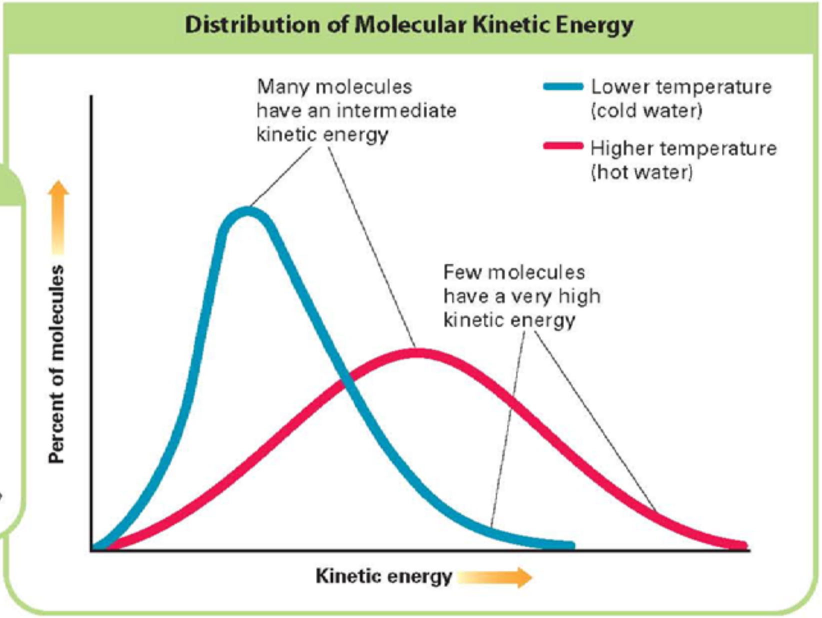
- The SI unit of pressure is the pascal (Pa).
  - It represents a very small amount of pressure.
  - normal atmospheric pressure is about 100,000 Pa, that is, 100 kilopascals (kPa).
- Two older units of pressure are still commonly used.
  - millimeters of mercury (mm Hg)
  - atmospheres.
  - 1 atm = 760 mm Hg = 101.3 kPa @ 25C

13.1 Nature of Gases

- **Standard Atmosphere-**
  - **Pressure required to support 760 mm Hg at 25C**

- **Kinetic Energy and Temperature**

Figure 13.3 Interpreting Graphs



INTERPRETING GRAPHS

a. Inferring Which point on each curve represents the average kinetic energy?
b. Analyzing Data Compare the shapes of the curves for cold water and hot water.
c. Predicting What would happen to the shape of the curve if the water temperature were even higher? Even lower?

13.1 Nature of Gases

Average Kinetic Energy and Kelvin Temperature

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

Section 13.2

THE NATURE OF LIQUIDS

13.2 The Nature of Liquids

Connecting to Your World The Kilauea volcano in Hawaii is the most active volcano in the world. It has been erupting for centuries. The hot lava oozes and flows, scorching everything in its path, occasionally overrunning nearby houses. When the lava cools, it solidifies into rock. The properties of liquids are related to intermolecular interactions. In this section you will learn about some of the properties of liquids.

13.2 The Nature of Liquids

Model for Liquids

- both the particles in gases and the particles in liquids have kinetic energy.
- This energy allows the particles in gases and liquids to flow past one another
- Substances that can flow are referred to as fluids.

13.2 The Nature of Liquids

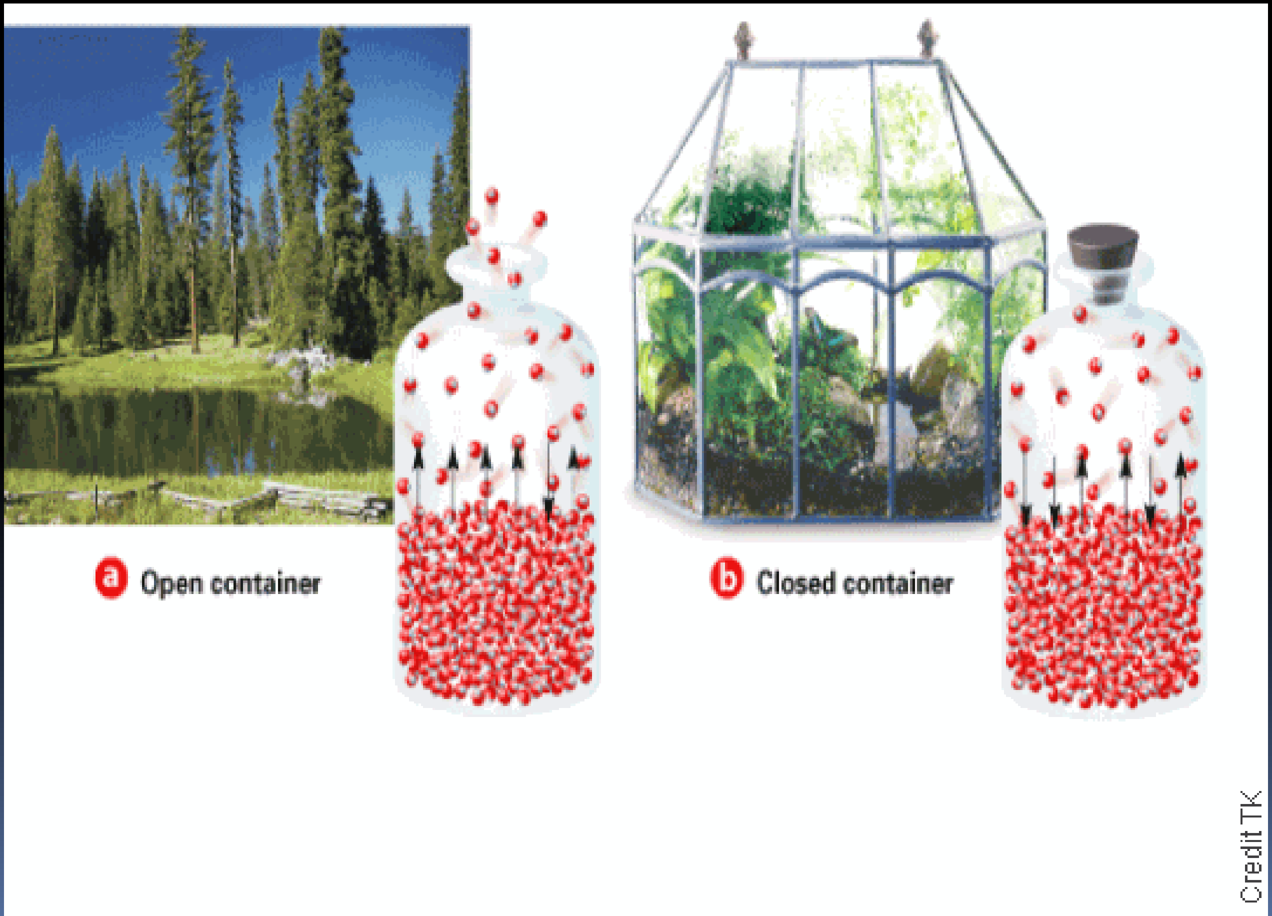
Model for Liquids

- The ability of gases and liquids to flow allows them to conform to the shape of their containers.

- **The interplay between particles in a liquid and the attractions among them determines the physical properties of liquids.**

13.2 The Nature of Liquids

- **Evaporation**



13.2 The Nature of Liquids

Evaporation

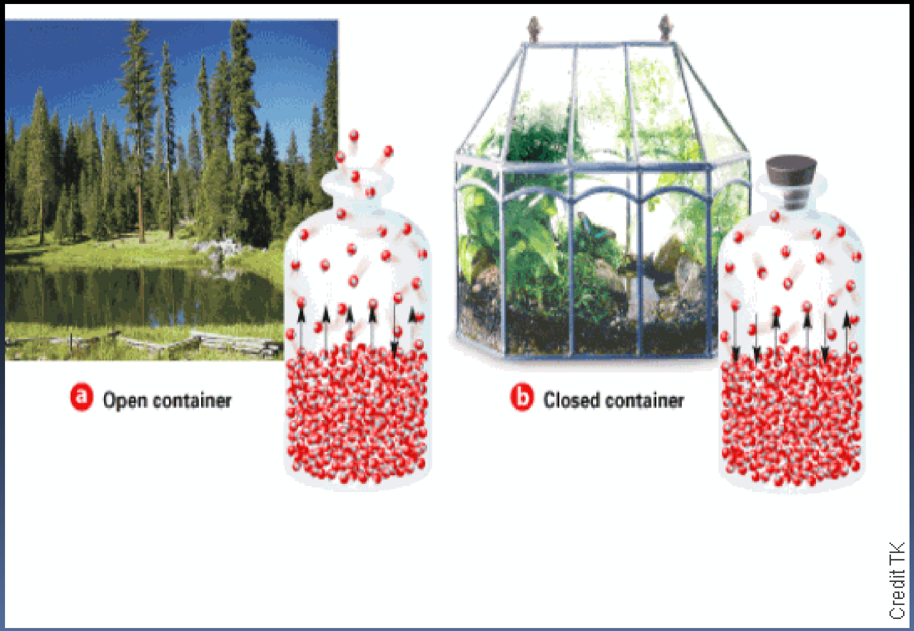
- **Vaporization-**
  - The conversion of a liquid to a gas or vapor
  - When such a conversion occurs at the surface of a liquid that is not boiling, the process is called **evaporation.**
  - Most of the molecules in a liquid don't have enough kinetic energy to overcome the attractive forces and escape into the gaseous state.

- **During evaporation, only those molecules with a certain minimum kinetic energy can escape from the surface of the liquid.**

13.2 The Nature of Liquids

Vapor Pressure

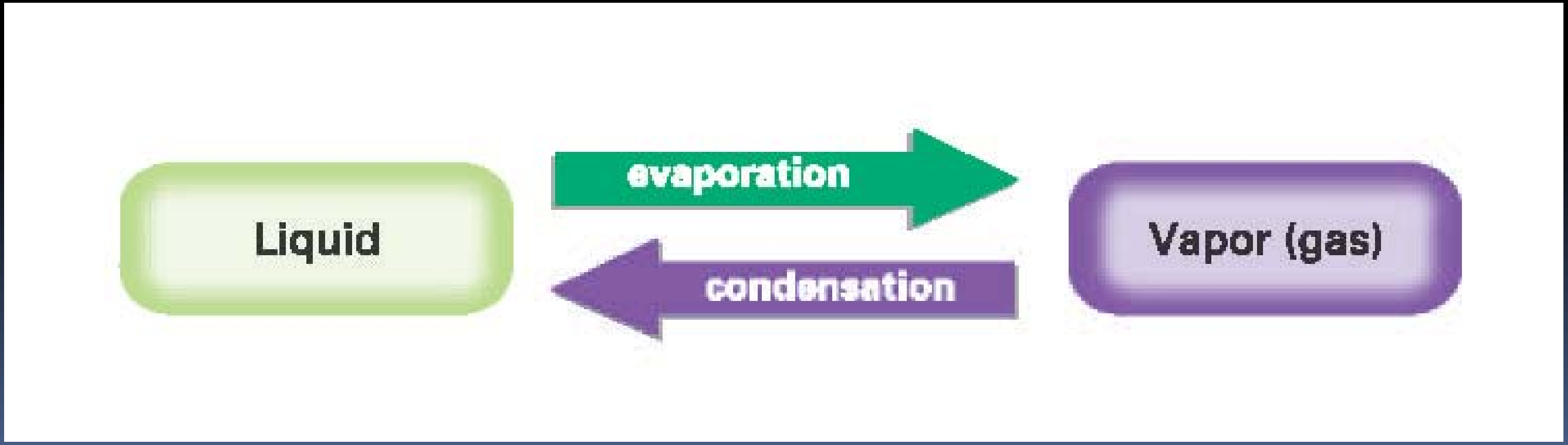
- **Vapor pressure**-
  - is a measure of the force exerted by a gas above a liquid.



13.2 The Nature of Liquids

Vapor Pressure

- **Equilibrium-**
  - **When the rate of evaporation of liquid equals the rate of condensation of vapor in a system**



13.2 The Nature of Liquids

Vapor Pressure and Temperature Change

- An increase in the temperature of a contained liquid increases the vapor pressure.
  - warmed liquid have increased kinetic energy.
  - more of the particles will have the minimum kinetic energy necessary to escape the surface of the liquid.

13.2 The Nature of Liquids

- Vapor Pressure and Temperature Change

Table 13.1

Vapor Pressure (in kPa) of Three Substances at Different Temperatures

	0°C	20°C	40°C	60°C	80°C	100°C
Water	0.61	2.33	7.37	19.92	47.34	101.33
Ethanol	1.63	5.85	18.04	47.02	108.34	225.75
Diethyl ether	24.70	58.96	122.80	230.65	399.11	647.87

13.2 The Nature of Liquids

Vapor Pressure Measurements

- Manometer-
  - The device used to measure vapor pressure of a liquid

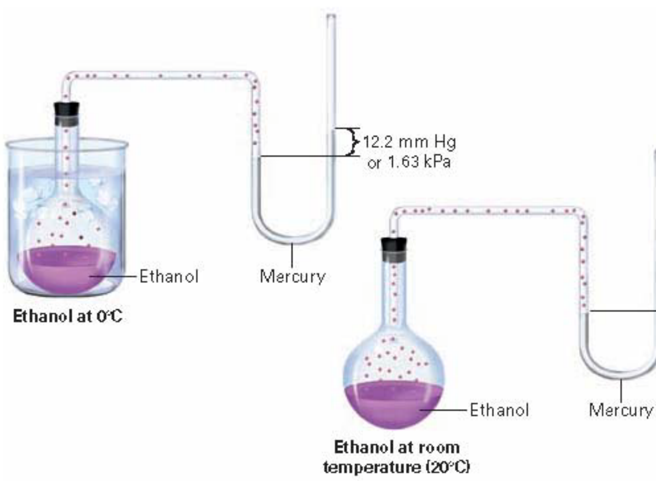


Figure 13.7 The vapor pressure of a contained liquid can be measured in a manometer. The vapor pressure is equal to the difference in height of the mercury in the two arms of the U-tube. **Calculating** ***What is the difference in vapor pressure between ethanol at 0°C and ethanol at 20°C?***

13.2 The Nature of Liquids

Boiling Point (listen)

- When heat is applied to a liquid in an open container:
  - rate of evaporation increases
  - greater number of particles at surface overcome the attractive forces keeping them in the liquid state.
  - average kinetic energy of the particles in the liquid increases
  - temperature of the liquid increases.
  - Bubbles of vapor form throughout the liquid, rise to the surface, and escape into the air.

13.2 The Nature of Liquids

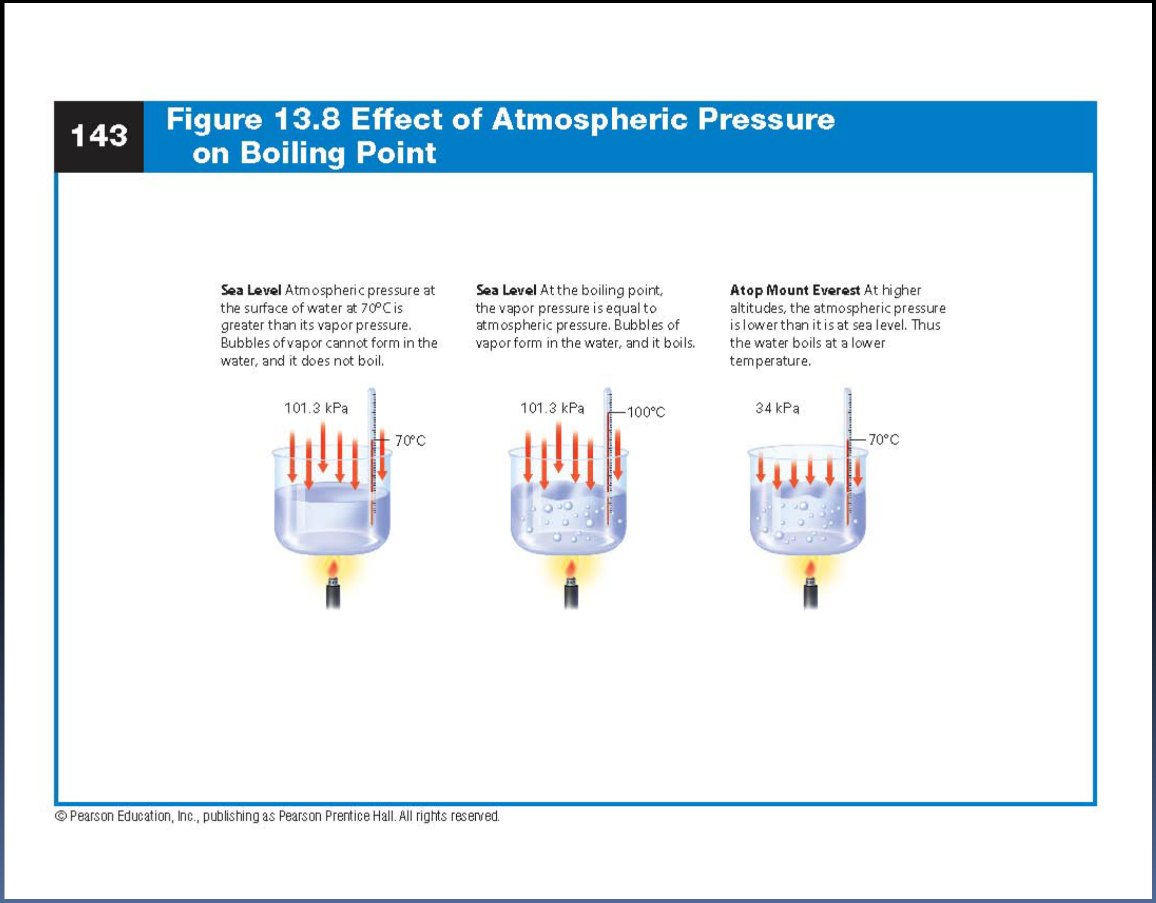
Boiling Point

- **When a liquid is heated to a temperature at which particles throughout the liquid have enough kinetic energy to vaporize, the liquid begins to boil.**

- Boiling Point (BP)-
  - The temperature at which the vapor pressure of the liquid is just equal to the external pressure on the liquid.

13.2 The Nature of Liquids

Boiling Point and Pressure Changes



13.2 The Nature of Liquids

144 **Figure 13.9 Interpreting Graphs**

INTERPRETING GRAPHS

a. Analyzing Data What is the boiling point of chloroform at 101.3 kPa?

b. Analyzing Data What is the vapor pressure of ethanol at 40°C?

c. Analyzing Data What would atmospheric pressure need to be for ethanoic acid to boil at 80°C?

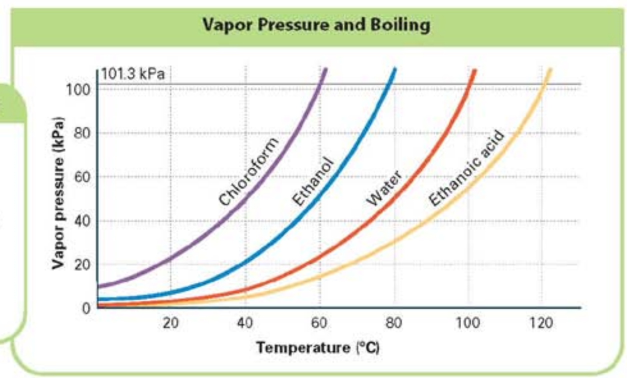


Table 13.2

The Normal Boiling Points of Several Substances	
Name and formula	**Boiling Point (°C)**
Carbon disulfide (CS_2)	46.0
Chloroform ($CHCl_3$)	61.7
Methanol (CH_4O)	64.7
Tetrachloromethane (CCl_4)	76.8
Ethanol (C_2H_6O)	78.5
Water (H_2O)	100.0

13.2 The Nature of Liquids

- **Things to remember:**
  - Boiling is a cooling process similar to evaporation.
  - particles with the highest kinetic energy escape first
  - the temperature of the boiling liquid never rises above its boiling point.
  - If heat is supplied at a greater rate, the liquid only boils faster.
  - The vapor produced is at the same temperature as that of the boiling liquid.

Section 13.3

THE NATURE OF SOLIDS

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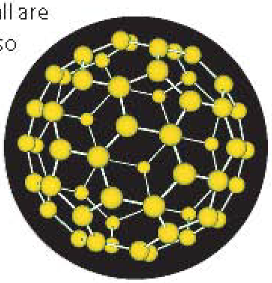
13.3 The Nature of Solids

Connecting to Your World In 1985, scientists discovered a new form of carbon. They called this form of carbon buckminsterfullerene, or buckyball for short. The molecules in buckyball are hollow spheres. The carbon atoms are arranged so that the pattern on the surface of the sphere resembles the surface of a soccer ball. In this section, you will learn how the arrangement of particles in solids determines some general properties of solids.



13.3 The Nature of Solids

A Model for Solids

- **The general properties of solids reflect the <u>orderly</u> arrangement of their particles and the <u>fixed</u> locations of their particles.**
- When you heat a solid, its particles vibrate more rapidly as their kinetic energy increases
- The **melting point** (mp) is the temperature at which a solid changes into a liquid.

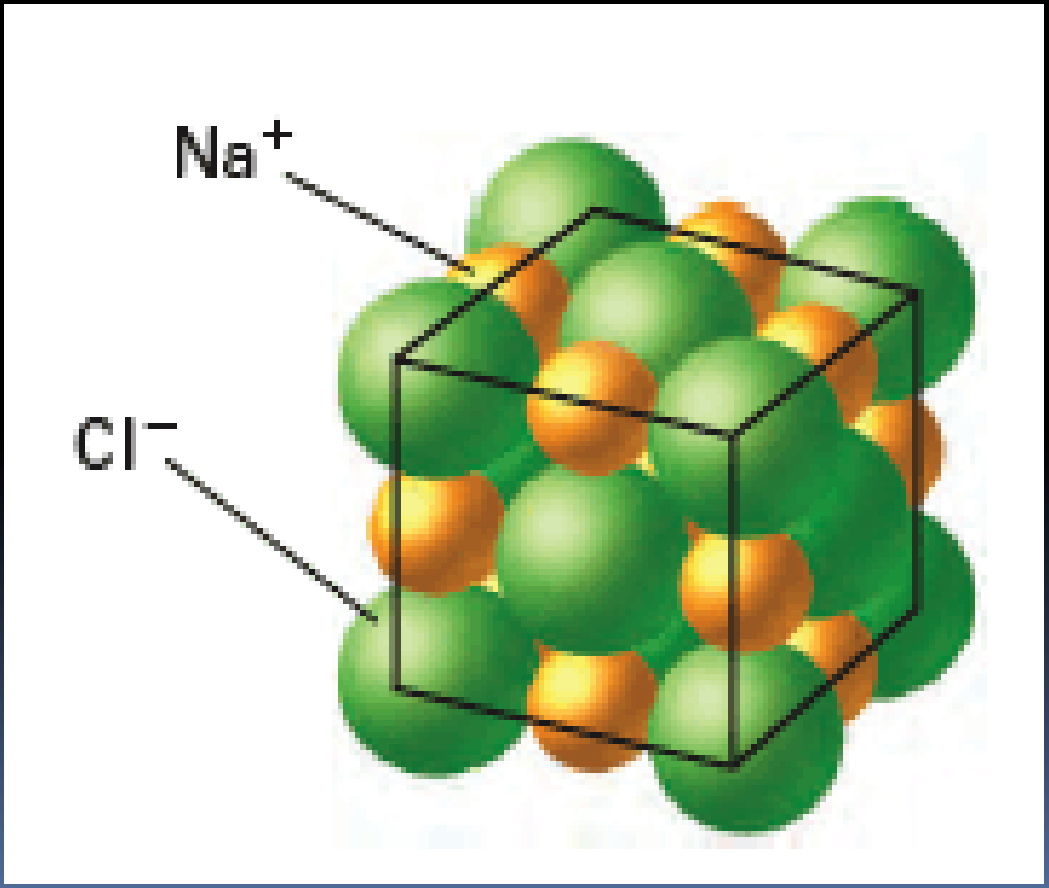
13.3 The Nature of Solids

Crystal Structure and Unit Cells

- Most solid substances are crystalline.
- In a **crystal** the particles are arranged in an orderly, repeating, three-dimensional pattern called a crystal lattice.
- **The shape of a crystal reflects the arrangement of the particles within the solid.**

13.3 The Nature of Solids

crystal lattice in sodium chloride.



13.3 The Nature of Solids

Crystal Systems

- A crystal has sides, or faces. The angles at which the faces of a crystal intersect are always the same for a given substance and are characteristic of that substance.
- Crystals are classified into seven groups, or crystal systems.

13.3 The Nature of Solids

- The edges are labeled a, b, and c.
- The angles are labeled α, β, and γ.
- The shape depends on the arrangement of the particles within it.

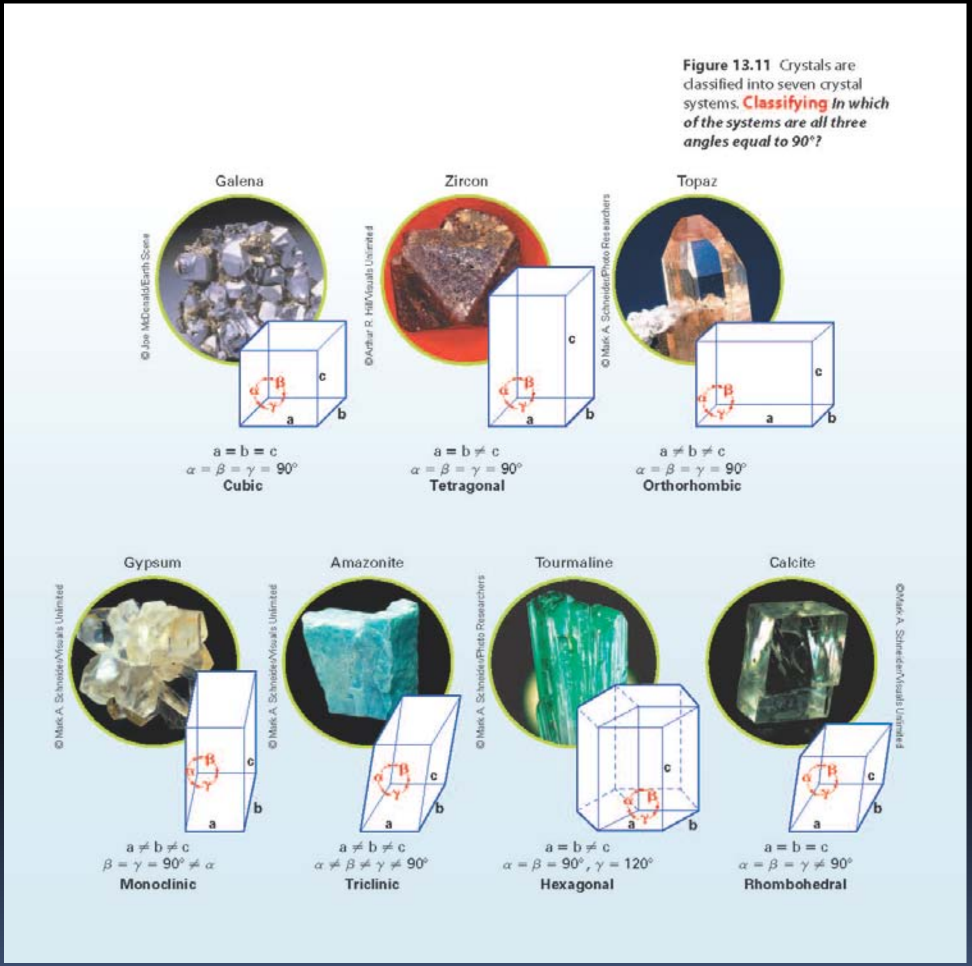


Figure 13.11 Crystals are classified into seven crystal systems. **Classifying** ***In which of the systems are all three angles equal to 90°?***

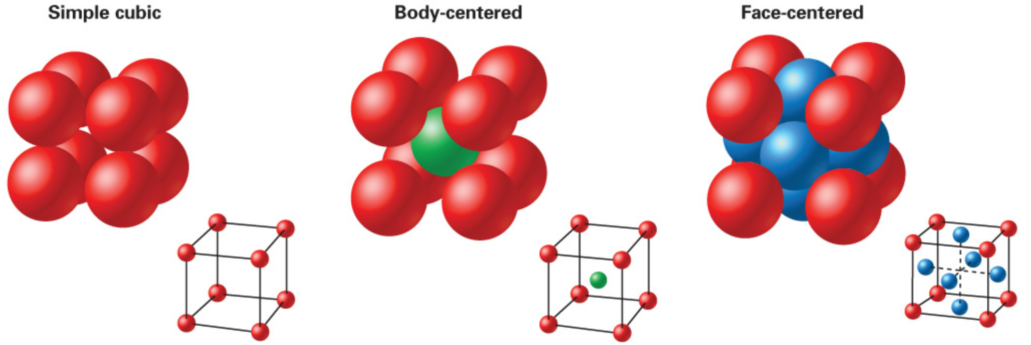
13.3 The Nature of Solids

Crystal Systems

- The smallest group of particles within a crystal that retains the geometric shape of the crystal is known as a **unit cell.**

- A **crystal lattice** is a repeating array of any one of fourteen kinds of unit cells.

Figure 13.12 The unit cell in a cubic crystal system may be simple cubic, body-centered cubic, or face-centered cubic. In the space-filling models and line drawings, the spheres represent atoms or ions.



In a simple cubic unit cell, the atoms or ions are arranged at the corners of an imaginary cube.

In a body-centered cubic unit cell, the atoms or ions are at the corners and in the center of an imaginary cube.

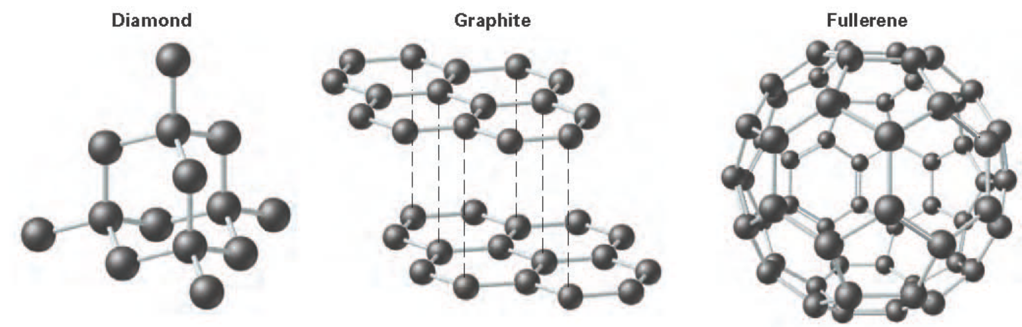
In a face-centered cubic unit cell, there are atoms or ions at the corners and in the center of each face of the imaginary cube.

13.3 The Nature of Solids

Allotropes

- Some solid substances can exist in more than one form.
  - Example-C

- 1985 – 3rd form discovered in
- Buckminsterfullerene, or buckyball.
- The 60 carbon atoms in molecules bonded to form a hollow sphere, or cage similar to soccer ball



In diamond, each carbon atom in the interior of the diamond is strongly bonded to four others. The array is rigid and compact.

In graphite, the carbon atoms are linked in widely spaced layers of hexagonal (six-sided) arrays.

In buckminsterfullerene, 60 carbon atoms form a hollow sphere. The carbons are arranged in pentagons and hexagons.

Figure 13.13 Diamond, graphite, and fullerenes are allotropes of carbon. **Classifying** ***Based on the arrangements of their atoms, explain why the properties of fullerenes are closer to those of diamond than of graphite?***

13.3 The Nature of Solids

Allotropes

- **Allotropes**-
  - two or more different molecular forms of the same element in the same physical state.
  - composed of atoms of the same element,
  - they have different properties because their structures are different.
- Only a few elements have allotropes.
  - C, P, S , O_2 , O_3, B and Sb

13.3 The Nature of Solids

Non-Crystalline Solids

- Not all solids are crystalline form
  - **<u>amorphous solid</u>** -lacks an ordered internal structure.
    - Examples-Rubber, plastic, asphalt , glass

- **<u>Glass</u>** has an irregular internal structures of glasses are intermediate between those of a crystalline solid and those of a free-flowing liquid.
  - does not melt at a definite temperature, softens when heated.
  - critical to the glassblower's art.

- When a crystalline solid is shattered, fragments tend to have the same surface angles as the original solid.
  - "Diamond cutting"

- By contrast, when an amorphous solid, such as glass, is shattered, the fragments have irregular angles and jagged edges.

Section 13.4

CHANGES OF STATE

13.4 Changes of State

Connecting to Your World Familiar weather events can remind you that water exists on Earth as a liquid, a solid, and a vapor. A spring shower brings liquid raindrops and a winter blizzard delivers solid snowflakes. On a humid summer day, you may be uncomfortable because there is a high concentration of water vapor in the air. As water cycles through the atmosphere, the oceans, and Earth's crust, it undergoes repeated changes of state. In this section, you will learn what conditions can control the state of a substance.

13.4 Changes of State

Sublimation-

- The change of a substance from a solid to a vapor without passing through the liquid state
  - occur because solids, like liquids, have a vapor pressure.
  - Examples –CO_2, Ice cubes, Air Fresheners, Freeze Dried Foods, I_2,
- **occurs in solids with vapor pressures that exceed atmospheric pressure at or near room temperature.**

13.4 Changes of State

- **Phase Diagrams-**
  - A single graph that represents the relationships among the solid, liquid, and vapor states (or phases) of a substance in a sealed container
  - gives the conditions of temperature and pressure at which a substance exists as solid, liquid, and gas (vapor).
- **The conditions of pressure and temperature at which two phases exist in equilibrium are indicated on a phase diagram by a line separating the phases.**
- The triple point-
  - the only set of conditions at which all three phases can exist in equilibrium with one another.

13.4 Changes of State

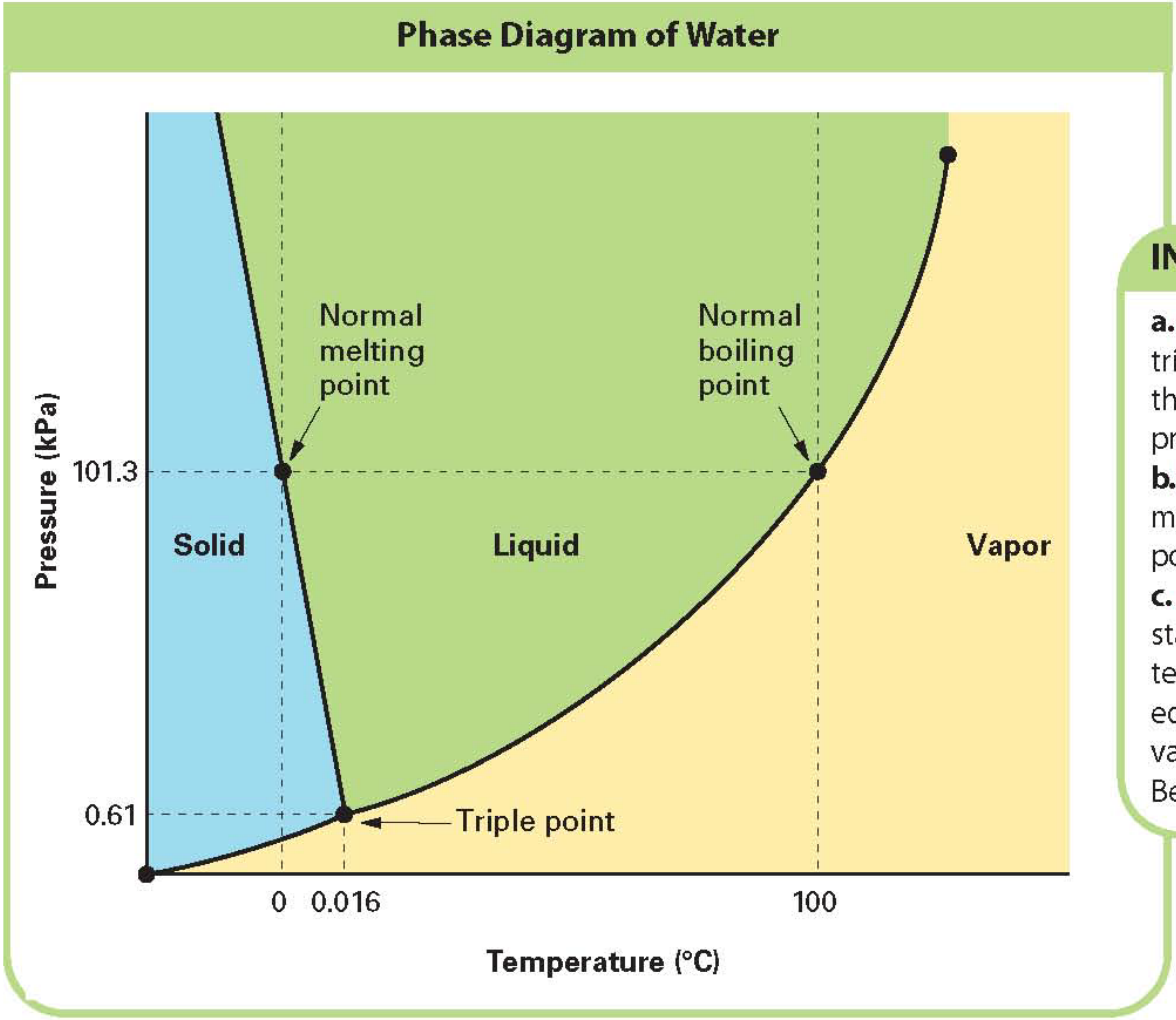


Figure 13.15 The phase diagram of water shows the relationship among pressure, temperature, and physical states of water.

INTERPRETING GRAPHS

a. Analyzing Data At the triple point of water, what are the values of temperature and pressure?

b. Inferring What states of matter are present at the triple point of water?

c. Analyzing Data Assuming standard pressure, at what temperature is there an equilibrium between water vapor and liquid water? Between liquid water and ice?

13.4 Changes of State

- phase simulation