Chapter 14: The Behavior of Gases

14.1 Properties of Gases

Compressibility

- **Compressibility** is a measure of how much the volume of matter decreases under pressure. When a person collides with an inflated airbag, the compression of the gas absorbs the energy of the impact.

Compressibility

- Gases are easily compressed because of the space between the particles in a gas.
  - The distance between particles in a gas is much greater than the distance between particles in a liquid or solid.
  - Under pressure, the particles in a gas are forced closer together.

Two devices are used to measure pressure

- **barometer** - measures atmospheric pressure
- **Manometer** – measures gas pressure inside a container

Example Manometer Problems

- Pressure must be in mm Hg to solve!
- A soccer ball is attached to an open-ended manometer. The mercury level in the manometer is 10 mm higher on the side attached to the ball. Atmospheric pressure has been determined to be 770 mm Hg. What is the gas pressure in the ball?

Example Manometer Problems

- A balloon is attached to an open-ended manometer. The mercury level in the u-tube is 15 mm higher on the open end of the tube. The atmospheric pressure is 1.12 atm. What is the gas pressure in the balloon?

Factors Affecting Gas Pressure

- The amount of gas, volume, and temperature are factors that affect gas pressure.

Factors Affecting Gas Pressure

- Four variables are generally used to describe a gas. The variables and their common units are
  - pressure (*P*) in kilopascals
  - volume (*V*) in liters
  - temperature (*T*) in kelvins
  - the number of moles (*n*).

Factors Affecting Gas Pressure

- Collisions of particles with the inside walls of the raft result in the pressure that is exerted by the enclosed gas. Increasing the number of particles increases the number of collisions, which is why the gas pressure increases.

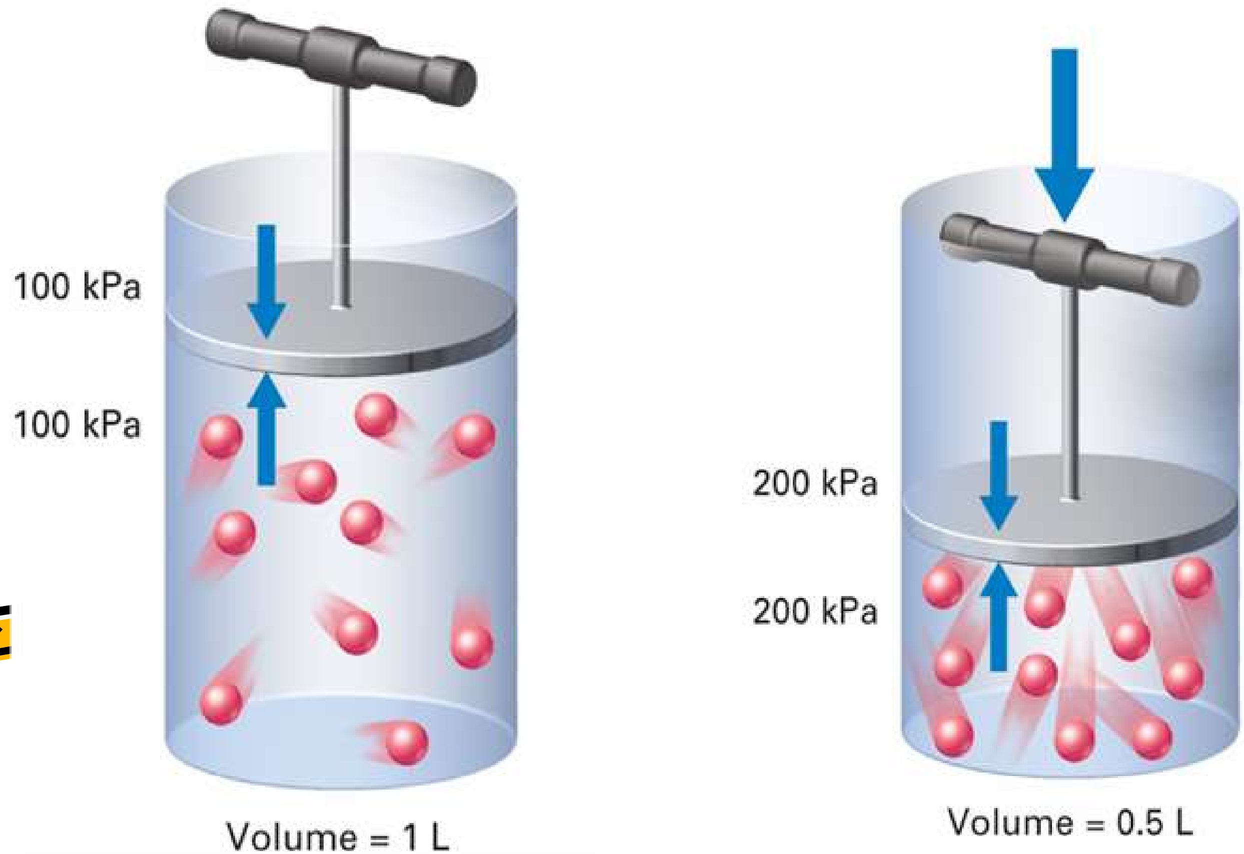
Factors Affecting Gas Pressure

– Volume

- You can raise the pressure exerted by a contained gas by reducing its volume. The more a gas is compressed, the greater is the pressure that the gas exerts inside the container.

Factors Affecting Gas Pressure

- When the volume of the container is halved, the pressure the gas exerts is doubled.

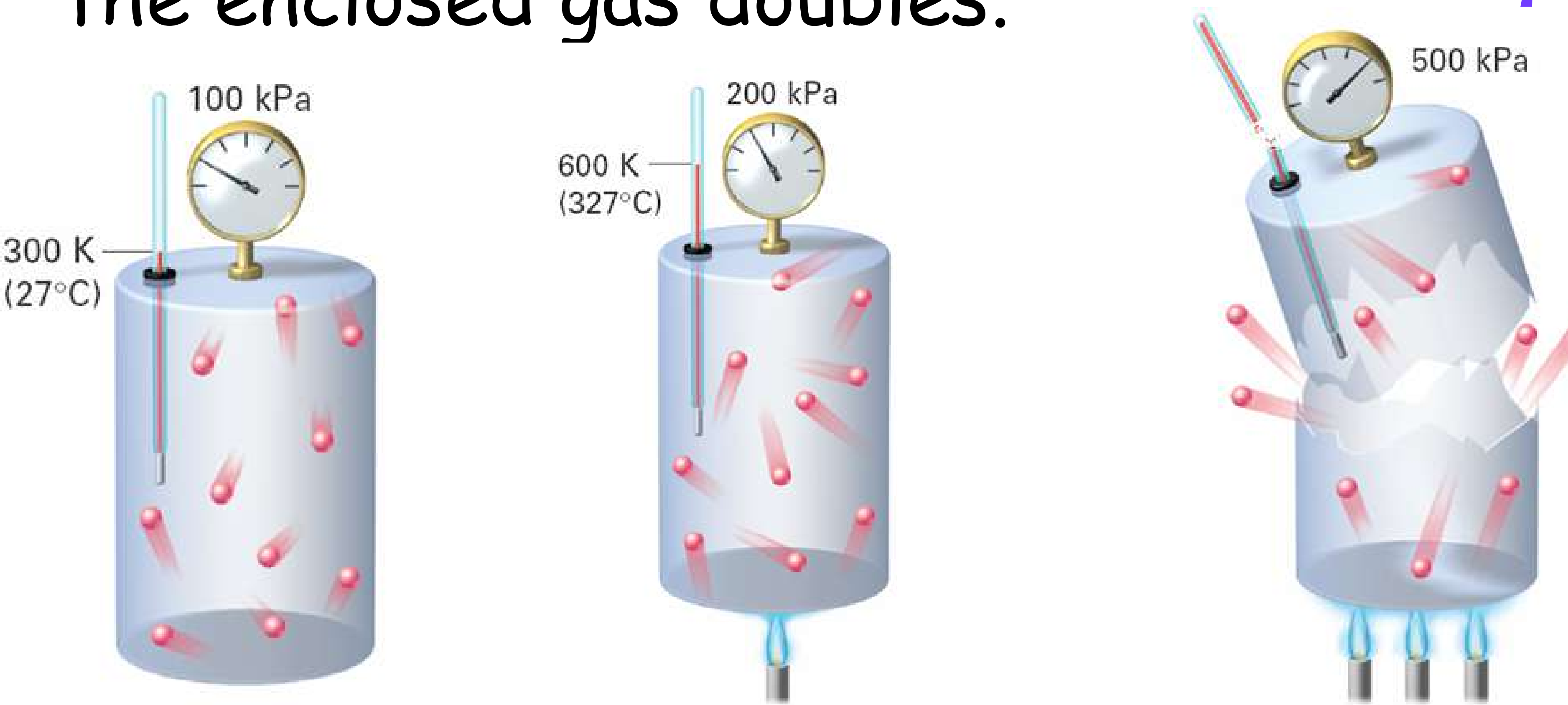


Temperature

- An increase in the temperature of an enclosed gas causes an increase in its pressure.
  - As a gas is heated, the average kinetic energy of the particles in the gas increases. Faster-moving particles strike the walls of their container with more energy.

Factors Affecting Gas Pressure

- When the Kelvin temperature of the enclosed gas doubles, the pressure of the enclosed gas doubles.



14.1 Section Quiz.

– 1. Compared to liquids and solids, gases are easily compressed because the particles in a gas

a) attract each other.

b) are spaced relatively far apart.

c) are very small.

d) repel each other.

14.1 Section Quiz.

– 2. Gas pressure is affected by

a) temperature, volume, and the amount of the gas.

b) temperature, volume, and the molar mass of the gas.

c) phase diagram, volume, and the size of the container.

d) temperature, phase diagram, and the mass of the gas container.

14.1 Section Quiz.

– 3. For gases, the SI units for volume (*V*), pressure (*P*), and temperature (*T*) are, respectively,

a) liters, kilopascals, and °C.

b) liters, kilopascals, and kelvins.

c) cm^3, kilopascals, and kelvins.

d) liters, atmospheres, and °C.

14.2 The Gas Laws

Boyle's Law: Pressure and Volume

- **Boyle's law** states that for a given mass of gas at constant temperature, the volume of the gas varies inversely with pressure.

$$P_1 \times V_1 = P_2 \times V_2$$

Sample Problem 14.1

Using Boyle's Law

A balloon contains 30.0 L of helium gas at 103 kPa. What is the volume of the helium when the balloon rises to an altitude where the pressure is only 25.0 kPa? (Assume that the temperature remains constant.)

for Sample Problem 14.1

8. A gas with a volume of 4.00 L at a pressure of 205 kPa is allowed to expand to a volume of 12.0 L. What is the pressure in the container if the temperature remains constant?

Practice

- 1) Helium has a pressure of 3.54 atm with a volume of 23.1 L. The new pressure is 1.87 atm, what is the volume?
- 2) Argon has a pressure of 34.6 atm. It is transferred to a new tank with a volume of 456 L and pressure of 2.94 atm. What was the volume of the original container?

Charles's Law: Temperature and Volume

- **Charles's law** states that the volume of a fixed mass of gas is directly proportional to its Kelvin temperature if the pressure is kept constant.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Sample Problem 14.2

Using Charles's Law

A balloon inflated in a room at 24°C has a volume of 4.00 L. The balloon is then heated to a temperature of 58°C. What is the new volume if the pressure remains constant?

for Sample Problem 14.2

10. Exactly 5.00 L of air at −50.0°C is warmed to 100.0°C. What is the new volume if the pressure remains constant?

Practice

- 1) A sample of oxygen gas has a volume of 4.55 L at 25°C. Calculate volume when the temp is raised to 45°C.
- 2) A sample of hydrogen is collected at 34°C and heated to 68°C. At 68°C the volume is 26.0 L. What was the volume at 34°C?

Gay-Lussac's Law: Pressure and Temperature

- Gay-Lussac's law **states that the pressure of a gas is directly proportional to the Kelvin temperature if the volume remains constant.**

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Sample Problem 14.3

Using Gay-Lussac's Law

Aerosol cans carry warnings on their labels that say not to incinerate (burn) them or store the cans above a certain temperature. This problem will show why it is dangerous to dispose of aerosol cans in a fire. The gas in a used aerosol can is at a pressure of 103 kPa at 25°C. If the can is thrown onto a fire, what will the pressure be when the temperature reaches 928°C?

for Sample Problem 14.3

12. The pressure in a car tire is 198 kPa at 27°C. After a long drive, the pressure is 225 kPa. What is the temperature of the air in the tire? Assume that the volume is constant.

Practice

- 1) The pressure of a gas in a tank is 3.2 atm at 22°C. If temp rises to 60°C, what will the pressure be?
- 2) A gas has a pressure of 125 kPa at 30°C. If the pressure increases to 201 kPa, what is the new temp?

The Combined Gas Law

- **The** combined gas law **describes the relationship among the pressure, temperature, and volume of an enclosed gas.**

The Combined Gas Law

- The combined gas law allows you to do calculations for situations in which only the amount of gas is constant.

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

Sample Problem 14.4

Using the Combined Gas Law

The volume of a gas-filled balloon is 30.0 L at 313 K and 153 kPa pressure. What would the volume be at standard temperature and pressure (STP)?

for Sample Problem 14.4

14. A 5.00-L air sample has a pressure of 107 kPa at a temperature of −50.0°C. If the temperature is raised to 102°C and the volume expands to 7.00 L, what will the new pressure be?

Practice

- 1) Helium at 23°C with a volume of 5.60 L at 2.45 atm is changed to a pressure of 8.75 atm and cooled to 15°C. What is the volume?

Practice

- 2) Helium at 28°C and a volume of 3.80 L at a pressure of 3.15 atm expands to a volume of 9.50 L and is heated to 43°C. Calculate the new pressure.

Gas Laws continued

- **<u>Avogadro's Principle</u>** – equal volumes of gases at the same temperature and pressure contain equal numbers of particles – regardless of particle size
- 1000 large Kr particles will occupy the same volume as 1000 small He particles
- **Molar volume** - 1 mol of any gas at standard temperature ($0^{\circ}C$)and pressure (1 atm) occupies 22.4L.

Example Problems

- Calculate the volume that 0.881 mol of Ne gas will occupy at STP.
- How many moles of chlorine gas will be contained in a 4 L flask at STP?
- Calculate the volume that 2.0 kg of methane gas (CH_4) will occupy at STP.
- How many grams of N_2 will it take to fill up a 2 L flask at STP?

14.2 Section Quiz.

– 1. If the volume of a gas in a container were reduced to one fifth the original volume at constant temperature, the pressure of the gas in the new volume would be

a) one and one fifth times the original pressure.

b) one fifth of the original pressure.

c) four fifths of the original pressure.

d) five times the original pressure.

14.2 Section Quiz.

– 2. A balloon appears slightly smaller when it is moved from the mountains to the seashore at constant temperature. The best gas law to explain this observation would be

a) Gay-Lussacs's Law.

b) Graham's Law.

c) Boyle's Law.

d) Charles's Law.

14.2 Section Quiz.

– 3. At 46°C and 89 kPa pressure, a gas occupies a volume of 0.600 L. How many liters will it occupy at 0°C and 20.8 kPa?

a) 0.600 L

b) 2.58 L

c) 0.140 L

d) 2.20 L

14.3 Ideal Gases

Ideal Gas Law

- **The gas law that includes all four variables—*P*, *V*, *T*, and *n*—is called the** ideal gas law.
- **The** ideal gas constant (*R*) **has the value 8.31 (L·kPa)/(K·mol).**

$$P \times V = n \times R \times T \text{ or } PV = nRT$$

Sample Problem 14.5

Using the Ideal Gas Law to Find the Amount of a Gas

A deep underground cavern contains 2.24×10^6 L of methane gas (CH_4) at a pressure of 1.50×10^3 kPa and a temperature of 315 K. How many kilograms of CH_4 does the cavern contain?

for Sample Problem 14.5

24. A child's lungs can hold 2.20 L. How many grams of air do her lungs hold at a pressure of 102 kPa and a body temperature of 37°C? Use a molar mass of 29 g for air, which is about 20% O_2 (32 g/mol) and 80% N_2 (28 g/mol).

Practice

- 1) A 2.50 mol sample of nitrogen gas has a volume of 5.50 L at 27°C. Calculate pressure.
- 2) A 5.00 mol sample of oxygen gas has a pressure of 110 kPa at 22°C. Calculate volume.

Practice

- 3) What volume is occupied by 0.250 mol CO_2 at 25°C and 80.5 kPa?
- 4) A 1.5 mol sample of radon has a volume of 21.0 L at 33°C. What is the pressure?

Practice

- 5) A sample of neon has a volume of 3.45 L at 25°C and 90 kPa. Calculate moles.
- 6) A 25 g sample of argon has a volume of 9.00 L at 875 mmHg. What is the temp in °C?

Practice Problems

- How many grams of gas are present in a sample that has a molar mass of 70.0 g/mol and occupies a 2.00-L container at 117 kPa and 35.1°C?

Applications of the ideal gas law

- Since density is mass divided by volume, the ideal gas equation can be rearranged to solve for molar mass or density

$$M = \frac{DRT}{P} \qquad D = \frac{MP}{RT}$$

Practice Problems

- Calculate the molar mass of a gas kept at 1.00 atm pressure and a temperature of 22.0°C with a density of 1.25 g/L.

Practice

- The density of a gas was measured at 1.50 atm and 27°C and found to be 1.95 g/L. Calculate the molar mass of the gas.

Practice Problems

- Calculate the density of chlorine gas at 22.0°C and 1.00 atm pressure.
- What is the density of a gas with a molar mass of 26.1 g/mol at 1.02 atm pressure and 25.0°C?

Gas Stoichiometry

- Ammonia is synthesized from hydrogen and nitrogen gases. If 5.00 L of nitrogen reacts completely at 3.00 atm and 298 K, how many grams of ammonia are produced?

Gas Stoichiometry

- When iron rusts, it undergoes a reaction with oxygen to form iron (III) oxide. Calculate the volume of oxygen gas at standard pressure and 298 K that will react with 52.0 g iron.

Gas Stoichiometry

- When solid calcium carbonate is heated, it decomposes to form solid calcium oxide and carbon dioxide gas. How many liters of carbon dioxide will be produced at 298 K and 1 atm if 2.38 kg of calcium carbonate reacts completely?

Ideal Gases and Real Gases

– Real gases differ most from an ideal gas at low temperatures and high pressures.

14.3 Section Quiz.

– 1. An aerosol spray can with a volume of 325 mL contains 3.00 g of propane (C_3H_8) as a propellant. What is the pressure in atm of the gas in the can at 28°C?

a) 524 kPa

b) $2.31\ 10^4$ kPa

c) 475 kPa

d) 0.524 kPa

14.3 Section Quiz.

– 2. Find the volume of a gas in liters if 2.95 mol has a pressure of 77.0 kPa at a temperature of 52°C.

a) 22.4 L

b) 16.6 L

c) 103 L

d) 50.2 L

14.3 Section Quiz.

– 3. An ideal gas differs from a real gas in that the molecules of an ideal gas

a) have no attraction for one another.

b) have a significant volume.

c) have a molar mass of zero.

d) have no kinetic energy.

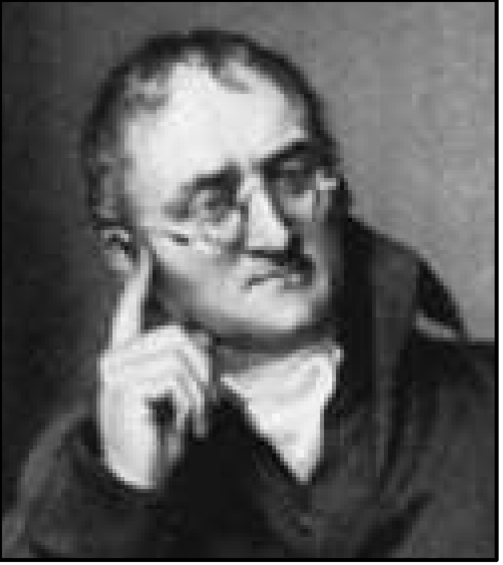
14.4 Gases: Mixtures and Movements

Dalton's Law

- The contribution each gas in a mixture makes to the total pressure is called the **partial pressure** exerted by that gas.

Table 14.1

Composition of Dry Air		
Component	**Volume (%)**	**Partial pressure (kPa)**
Nitrogen	78.08	79.11
Oxygen	20.95	21.22
Carbon dioxide	0.04	0.04
Argon and others	0.93	0.95
Total	100.00	101.32



Dalton's Law

- In a mixture of gases, the total pressure is the sum of the partial pressures of the gases.

$$P_{\text{total}} = P_1 + P_2 + P_3 + \ldots$$

Sample Problem 14.6

Using Dalton's Law of Partial Pressures

Air contains oxygen, nitrogen, carbon dioxide, and trace amounts of other gases. What is the partial pressure of oxygen (P_{O_2}) at 101.30 kPa of total pressure if the partial pressures of nitrogen, carbon dioxide, and other gases are 79.10 kPa, 0.040 kPa, and 0.94 kPa, respectively?

for Sample Problem 14.6

32. A gas mixture containing oxygen, nitrogen, and carbon dioxide has a total pressure of 32.9 kPa. If $P_{O_2} = 6.6$ kPa and $P_{N_2} = 23.0$ kPa, what is P_{CO_2}?

Example

- A person using an oxygen mask is breathing air with 33% O_2. What is the partial pressure of the O_2 when the air pressure in the mask is 110 kPa?

Gases collected by water displacement

- Since water vapor exerts vapor pressure, Dalton's Law can be used to calculate the pressure of a gas collected over water:

$$P_{atm} = P_{gas} + P_{H2O}$$

Gases Collected by Water Displacement

- The vapor pressure of water varies with temperature. The values of P_{H2O} at various temperatures can be found in a standard reference table.

Water Vapor Pressure Table

Temperature (°C)	Pressure (mmHg)	Temperature (°C)	Pressure (mmHg)	Temperature (°C)	Pressure (mmHg)
0.0	4.6	19.5	17.0	27.0	26.7
5.0	6.5	20.0	17.5	28.0	28.3
10.0	9.2	20.5	18.1	29.0	30.0
12.5	10.9	21.0	18.6	30.0	31.8
15.0	12.8	21.5	19.2	35.0	42.2
15.5	13.2	22.0	19.8	40.0	55.3
16.0	13.6	22.5	20.4	50.0	92.5
16.5	14.1	23.0	21.1	60.0	149.4
17.0	14.5	23.5	21.7	70.0	233.7
17.5	15.0	24.0	22.4	80.0	355.1
18.0	15.5	24.5	23.1	90.0	525.8
18.5	16.0	25.0	23.8	95.0	633.9
19.9	16.5	26.0	25.2	100.0	760.0

Example

- Oxygen gas from the decomposition of potassium chlorate, $KClO_3$, was collected by water displacement. The barometric pressure and temperature during the experiment were 731.0 mm Hg and 20.0°C. What was the partial pressure of the oxygen collected? The vapor pressure of water at 20°C is 17.5 mm Hg.

Example

- Some hydrogen gas is collected over water at 20.0°C. The partial pressure of the hydrogen is 742.5 mm Hg. What is the barometric pressure at the time the gas is collected?

Example

- A sample of nitrogen gas is collected over water at a temperature of 23.0°C. What is the pressure of the nitrogen gas if atmospheric pressure is 785 mm Hg?

Graham's Law

- **Diffusion** is the tendency of molecules to move toward areas of lower concentration until the concentration is uniform throughout.

Graham's Law

- During **effusion**, a gas escapes through a tiny hole in its container.
  - Gases of lower molar mass diffuse and effuse faster than gases of higher molar mass.

Graham's Law

- Thomas Graham's Contribution
  - **Graham's law of effusion** states that the rate of effusion of a gas is inversely proportional to the square root of the gas's molar mass. This law can also be applied to the diffusion of gases.

Graham's Law

- Because the rate of effusion is related only to a particle's speed, Graham's law can be written as follows for two gases, A and B.

$$\frac{\text{Rate}_A}{\text{Rate}_B} = \sqrt{\frac{\text{molar mass}_B}{\text{molar mass}_A}}$$

Example

- Ammonia has a molar mass of 17.0 g/mol and hydrogen chloride has a molar mass of 36.5 g/mol. What is the ratio of their diffusion rates? Which gas diffuses faster?

Example

- Compare the rates of effusion of hydrogen and oxygen.
- Compare the rate of effusion of carbon dioxide with that of hydrogen chloride.

Example

- An unknown gas effuses at a rate 1.5 times faster than tetrafluorethylene (C_2F_4). What is the molar mass of the unknown gas?

Example

- A sample of hydrogen effuses through a porous container about 9 times faster than an unknown gas. Estimate the molar mass of the unknown gas.

Example

- If a molecule of neon gas travels at an average of 400. m/s at a given temperature, estimate the average speed of a molecule of butane gas, C_4H_{10}, at the same temperature.

14.4 Section Quiz.

– 1. What is the partial pressure of oxygen in a diving tank containing oxygen and helium if the total pressure is 800 kPa and the partial pressure of helium is 600 kPa?

a) 200 kPa

b) 0.75 kPa

c) 1.40 10^4 kPa

d) 1.33 kPa

14.4 Section Quiz.

– 2. A mixture of three gases exerts a pressure of 448 kPa, and the gases are present in the mole ratio 1 : 2 : 5. What are the individual gas pressures?

a) 44 kPa, 88 kPa, and 316 kPa

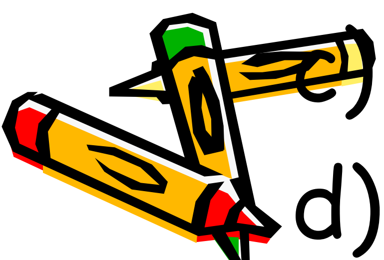
b) 52 kPa, 104 kPa, and 292 kPa

c) 56 kPa, 112 kPa, and 280 kPa

d) 84 kPa, 168 kPa, and 196 kPa

14.4 Section Quiz.

- 3. Choose the correct words for the spaces. Graham's Law says that the rate of diffusion of a gas is ______________ proportional to the square root of its ______________ mass.
  - a) directly, atomic
  - b) inversely, atomic
  - c) inversely, molar
  - d) directly, molar



Mixed Review

1) What is the volume occupied by 1.24 mol of a gas at 35°C if the pressure is 96.2 kPa?
2) A gas with a volume of 4.0 L at 90.0 kPa expands until the pressure drops to 20.0 kPa. What is the new volume?

Mixed Review

3) A 3.50 L gas sample at 20°C and a pressure of 86.7 kPa expands to a volume of 8.00 L. The final pressure is 56.7 kPa. What is the final temperature in °C?

4) Determine the total pressure of a mixture with partial pressures of 20.0 kPa, 46.7 kPa and 26.7 kPa.

Mixed Review

5) The pressure in a sealed plastic container is 108 kPa at 41°C. What is the pressure when the temperature drops to 22°C?

6) If a sample of gas occupies 6.80 L at 325°C, what will its volume be at 25°C?

Mixed Review

7) If 4.50 g of methane gas (CH_4) is in a 2.00 L container at 35°C, what is the pressure in the container?

8) A gas at 155 kPa and 25°C has an initial volume of 1.00 L. What will the volume be at STP?