Chapter 9

The Gaseous State

Chapter 9 Topics

1. The Behavior of Gases
2. Factors that Affect the Properties of Gases
3. The Ideal Gas Law
4. Kinetic-molecular Theory of Gases
5. Gases and Chemical Reactions

Gases in Our Atmosphere

TABLE 9.1 Volume Percent of Gases in the Atmosphere

Gas	Volume Percent	Gas	Volume Percent	Gas	Volume Percen
N_2	78.09	CH_4	0.00015	O_3	0.000002
O_2	20.94	Kr	0.0001	NH_3	0.000001
Ar	0.93	H_2	0.00005	NO_2	0.0000001
CO_2	0.032	N_2O	0.000025	SO_2	0.00000002
Ne	0.0018	CO	0.00001	H_2O	Varies
He	0.00052	Xe	0.000008		

9.1 The Behavior of Gases

- One way that we can describe gases is by their density.
- All gases have a relatively low densities in comparison to liquids and solids, due to the large amount of empty space between molecules.

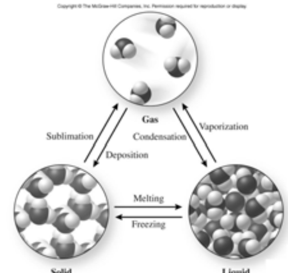

Figure 1.24

Density

- Because of their low densities, gases exist above the Earth and bubble up through liquids.

Figure 9.13

Behavior of Gases at the Molecular Level

- Gases consist of particles (atoms or molecules) that are relatively far apart.
- Gas particles move about rapidly.
  - An average O_2 molecule moves at a velocity of 980 mi/hr at room temperature.
- Gas particles have little effect on one another unless they collide. When they collide, they do not stick to one another.
- Gases expand to fill their containers.

Temperature and Density

- All gases expand when heated.
  - Why? Because the resulting temperature increase causes an increase in the kinetic energy of the gas molecules, making them move faster, collide harder, and spread out.
- Which gas has the greatest density?

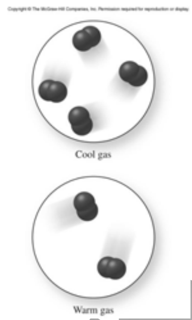

Figure 9.3

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Why does a hot air balloon rise in the atmosphere?

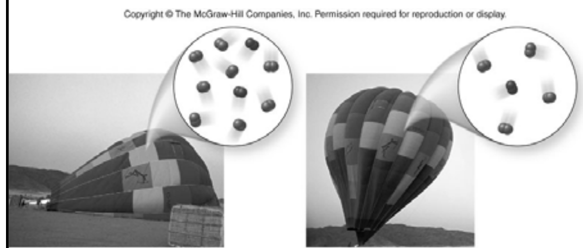

Figure 9.4

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Pressure

- Changes in pressure and amount of gas can affect the properties of a gas.
- What happens to volume and pressure when air molecules are added to the <u>tire</u>?
- What happens to density?

Figure 9.5

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Pressure

- What causes the balloon to be inflated?

Figure 9.1

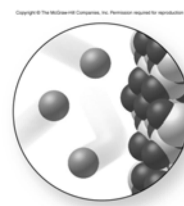

Figure 9.7

<u>anim</u>

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Pressure

- Pressure (P) is the amount of force applied per unit area:

$$\text{Pressure (P)} = \frac{\text{force}}{\text{area}}$$

- We can describe the pressure exerted by gas particles by:

$$\text{Pressure (P)} = \frac{\text{force of gas particles}}{\text{area of container}}$$

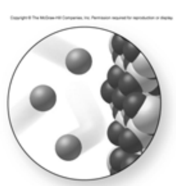

Figure 9.7

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Pressure

Figure p. 320 margin

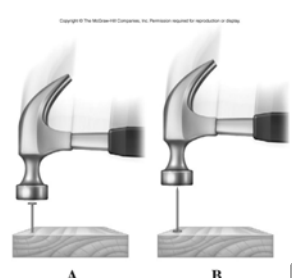

Figure 9.8

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Which gas has the greater pressure?
(assume they are at the same temperature)

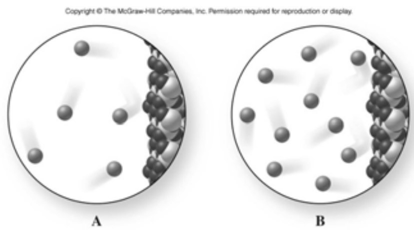

Figure 9.9

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Pressure

- Why does the can crush when the air is removed from the inside?

Figure 9.10

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Measuring Pressure (Units)

- psi
  - pounds per square inch
  - lb/in^2
- Atmospheric pressure is commonly measured with a barometer.
  - inches of Hg
  - mmHg
  - torr
  - atm

1 atm = 760 mmHg
1 atm = 760 torr

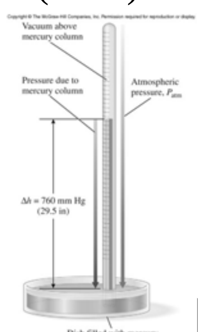

Figure 9.11

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9.2 Factors that Affect the Properties of Gases

- Volume and Pressure
  - As a weather balloon ascends to higher altitudes of lower pressures, its volume increases.
  - As bubbles rise in water from greater pressures to lower pressures, they increase in size.

Figure 9.12

Figure 9.13

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Volume and Pressure

- How are volume and pressure related?

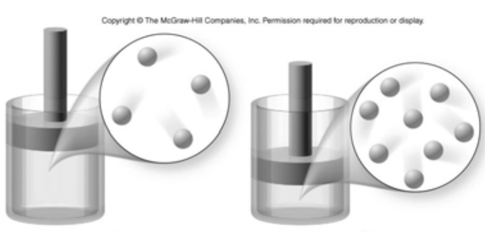

Figure 9.14

Boyle

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Graph of Volume vs. Pressure

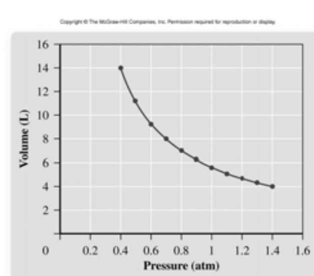

Figure 9.15

Boyle

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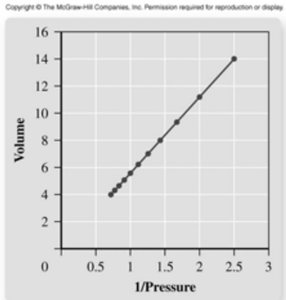
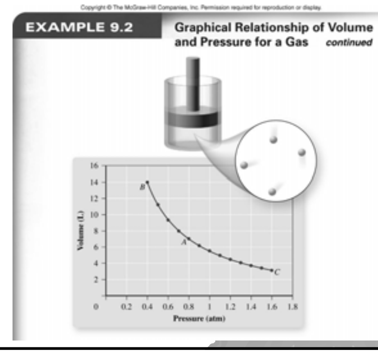
Graph of Volume vs. 1/Pressure shows that they are inversely related.



V = (constant)× 1/P

Figure 9.16

What happens to pressure when the volume is doubled?



Boyle's Law

- $P \propto 1/V$
- PV = constant
- P = constant × $1/V$
- V = constant × $1/P$

- $P_1V_1 = P_2V_2$

Boyle's Law

- $P_1V_1 = P_2V_2$

- If the pressure of a 2.0-L sample of gas is decreased from 1.2 atm to 0.25 atm at constant temperature, what is the new volume?

Volume and Temperature

- What is the relationship between volume and temperature (at constant pressure)?

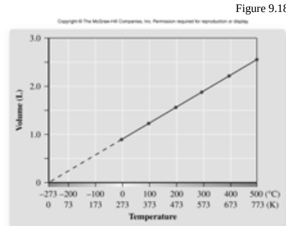
Figure 9.17

balloons

Charles's Law

- $V \propto T$
- V/T = constant
- V = constant × T
- T = constant × V

Figure 9.18



- Temperature must be in units of Kelvin. Why?

at constant pressure

Charles

Charles's Law

- If a balloon filled with air has a volume of 15.0 L at 25°C, what is its volume at –100°C? Assume constant pressure.

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Group Work

- What new temperature is required to reduce the volume of a balloon from 20.0 L (at 28°C) to 12.0 L.
- Report your answer in both Kelvin and °C.

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Combined Gas Law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Pressure Effect 1

Pressure Effect 2

Pressure Effect 3

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Gay-Lussac's Law of Combining Volumes (1808)

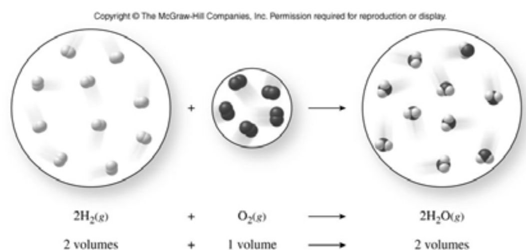

Figure 9.19

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Avogadro's Hypothesis

- Why did the blimp deflate?

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Avogadro's Hypothesis

- $V \propto n$
- V/n = constant

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

At constant temperature and pressure

n and T

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Including Moles in the Gas Law

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

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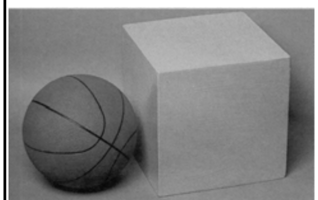
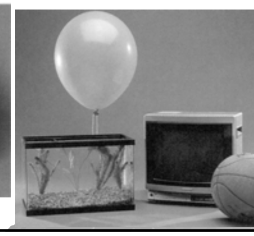
Molar Volume at STP

- We can show that 22.414 L of any gas at 0°C and 1 atm contain 6.02×10^{23} gas molecules.





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9.3 The Ideal Gas Law

$$\text{constant} = \frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

$$\text{constant } (R) = \frac{PV}{nT}$$

$$PV = nRT$$

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The Ideal Gas Law

$$R = \frac{PV}{nT}$$

$$R = \frac{(1 \text{ atm})(22.414 \text{ L})}{(1.000 \text{ mol})(273.15 \text{ K})}$$

$$R = 0.08206 \frac{\text{L atm}}{\text{mol K}}$$

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The Ideal Gas Law

- The ideal gas law allows us to calculate pressure, volume, moles, or temperature, when three out of the four variables are known.
- If the identity of the gas is known, molar mass can be used to convert between moles and grams.

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The Ideal Gas Law

- What mass of oxygen gas will occupy a 6.0-liter container, at a pressure of 700 torr and at a temperature of 25°C?

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The Ideal Gas Law

- What mass of oxygen gas will occupy a 6.0-liter container, at a pressure of 700 torr and at a temperature of 25°C?

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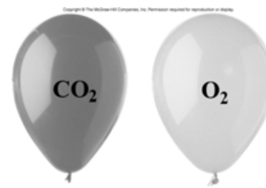
Gas Properties

a) Which balloon has the greatest number of gas molecules?
b) Which balloon has the greatest number of moles of gas?
c) Which balloon has the greatest mass?
d) Which balloon has the greatest density?



Question 9.60

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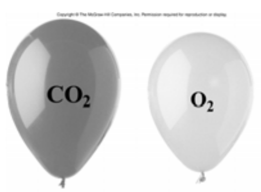
Gas Properties

- If the O_2 balloon had been filled to a smaller volume, which of the following quantities would change for the O_2 gas?
  - number of molecules
  - moles
  - mass
  - density



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Dalton's Law of Partial Pressures

- Dalton's Law of Partial Pressures
  - Gases in a mixture behave independently and exert the same pressure they would exert if they were in a container alone.

$$P_{total} = P_A + P_B + P_C + \ \ldots$$

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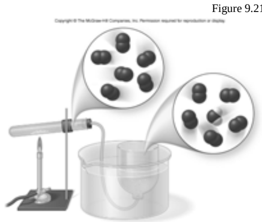
Dalton's Law of Partial Pressures

- When a gas is collected above a liquid, such as water, the liquid's vapor adds to the gas and to the total pressure.
- $P_{total} = P_{gas} + P_{H2O\ vapor}$
- $P_{gas} = P_{total} - P_{H2O\ vapor}$
- $P_{H2O\ vapor}$ is a constant at a specific temperature, so we can just look up its value.

Figure 9.21



$2KBrO_3(l) \rightarrow 2KBr(s) + 3O_2(g)$

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TABLE 9.2 Vapor Pressure of Water at Various Temperatures

Temperature (°C)	Vapor Pressure (torr)	Temperature (°C)	Vapor Pressure (torr)
0	4.6	28	28.3
5	6.5	29	30.0
10	9.2	30	31.8
15	12.8	35	42.2
16	13.6	40	55.3
17	14.5	45	71.9
18	15.5	50	92.5
19	16.5	60	149.4
20	17.5	70	233.7
21	18.6	80	355.1
22	19.8	90	525.8
23	21.1	100	760.0
24	22.4	110	1074.6
25	23.8	150	3570.5
26	25.2	200	11,659.2
27	26.7	300	64,432.8

9.4 Kinetic-Molecular Theory of Gases

- Postulates of KMT
  1. Gases are composed of small and widely separated particles (molecules or atoms).
     - In a normal gas, less than 0.1% of the space is due to the volume of the gas particles. The rest is empty space.
  2. Particles of a gas behave independently of one another.
  3. Each particle of a gas is in rapid, straight-line motion, until it collides with another molecule or with its container.
  4. The average kinetic energy of gas particles depends only on the absolute temperature: $KE_{ave} \propto T_{Kelvin}$
     - This means that all gases have the same average *KE* when at the same temperature.

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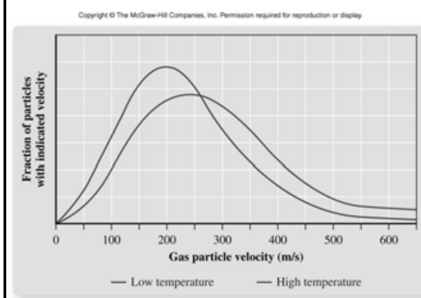
Kinetic Energy, Molecular Velocity, and Temperature



For a particular gas, KE is related to molecular velocity:

$KE_{ave}=½m(v_{ave})^2$

Gas Simulation

Figure 9.22

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Kinetic Energy, Molecular Velocity, and Temperature

- Ar, CO_2, and H_2 all at the same temperature
  a) Which of these gases has the greatest average KE?
  b) Which has the greatest average velocity?

m, T, v

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Diffusion

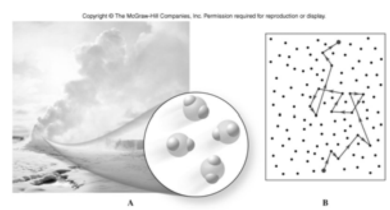

Figure 9.23

$$m_1v_1^2 = m_2v_2^2$$

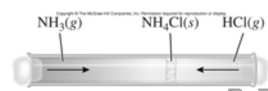

Figure 9.24

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Effusion

- A helium balloon loses volume more quickly than an "air" balloon because helium effuses through the balloon's pores more quickly.

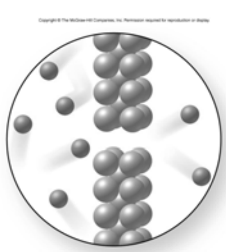

Figure 9.25

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Kinetic Energy, Molecular Velocity, and Temperature

- Ar, CO_2, and H_2 all at the same temperature
  a) Which of these gases diffuses at the greatest rate?
  b) Which of these gases effuses at the greatest rate?

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