Gases

Chapter 12
Properties of Gases

5 important gas properties:

1) Gases have an indefinite shape
2) Gases have low densities
3) Gases can compress
4) Gases can expand
5) Gases mix completely with other gases in the same container.
Detailed Gas Properties

1) Gases have an indefinite shape:
When a container is completely filled with gas, gas takes the shape of the container.

2) Gases have low densities:
Air density: about 0.001 g/mL
Water density: 1.0 g/mL for water.
Air is about 1000 times less dense than water.
3) Gases can compress:

Volume of a gas decreases when the container volume is decreased.

If the volume is reduced enough, the gas will liquefy.

4) Gases can expand:

Volume of a gas increases when the container volume is increased.

A gas constantly expands to fill a sealed container.
5) Gases mix completely with other gases in the same container:

Air is an example of a mixture of gases.

Think of automobiles, they emit nitrogen oxide gases into the atmosphere, which mix with the other atmospheric gases.

A mixture of gases in a sealed container will mix to form a homogeneous mixture.
6) Gas pressure is the result of constantly moving gas molecules striking the inside surface of their container.

As the collision of molecules with the sides of the container increases, pressure increases.

The higher the temperature, the faster gas molecules move.
Atmospheric Pressure

Air molecules in the environment cause atmospheric pressure.

Torricelli invented barometer in 1643 to measure atmospheric pressure.

Atmospheric pressure (standard pressure) is 29.9 inches of mercury or 760 torr at sea level.
Gas Pressure Conversions

Question: The barometric pressure is 27.5 in. Hg. What is the barometric pressure in atmospheres?

\[
27.5 \text{ in. Hg} \times \frac{1 \text{ atm}}{29.9 \text{ in Hg}} = 0.920 \text{ atm}
\]
Variables Affecting Gas Pressure

There are three variables that affect gas pressure:

1) The *volume* of the container.

2) The *temperature* of the gas.

3) The *number of molecules* of gas in the container.
Volume and Pressure

- When container volume decreases, pressure increases.

*Why?* Because, the gas molecules can collide with the container more often.

- When container volume increases, pressure decreases.

*Why?* Because, the gas molecules can collide with the container less often.
Absolute Zero

Theoretical *temperature* at which a gas would have zero volume and no pressure.

0 K = -273.15 °C = -459 °F

Kelvin T = Celsius T + 273.15

All gas law problems use Kelvin temperature.
Temperature (T) and Pressure (P)

- When $T \downarrow$, $P \downarrow$
  
  Why? Because, gas molecules move slower and collide with the container less often.

- When $T \uparrow$, $P \uparrow$

  Why? Because, gas molecules move faster and collide with the container more often.
Molecules and Pressure

- When the number of molecules decreases, pressure decreases.
  Why? Because there are fewer gas molecule collisions with the side of the container.

- When the number of molecules increases, pressure increases.
  Why? Because, there are more gas molecule collisions with the side of the container.
Boyle’s Law states that the volume of a gas is inversely proportional to the pressure at constant temperature.

Inversely proportional: two variables have a reciprocal relationship.

Mathematically: \[ V \alpha \frac{1}{P} \].
Cont’d…Boyle’s Law

Introducing a proportionality constant, \( k \), Boyle’s law is written as:

\[ V = k \times \frac{1}{P}. \]

Rearranging the equation above:

\[ PV = k \]

Sample of gas initially has at \( P_1 \) and \( V_1 \) conditions. Change the conditions of the sample to \( P_2 \) and \( V_2 \).

Because the product of pressure and volume is constant, the equations above can be rearranged as shown below:

\[ P_1 V_1 = k = P_2 V_2 \]
How Do We Apply Boyle’s Law

- To find the new pressure after a change in volume:
  \[ V_1 \times \frac{P_1}{P_2} = V_2 \]

- To find the new volume after a change in pressure:
  \[ P_1 \times \frac{V_1}{V_2} = P_2 \]
Boyle’s Law Problem

**Problem:** A 1.50 L sample of methane gas exerts a pressure of 1650 mm Hg. What is the final pressure if the volume changes to 7.00L?

\[ P_1 \times \frac{V_1}{V_2} = P_2 \]

\[ 1650 \text{ mm Hg} \times \frac{1.50 \text{ L}}{7.00 \text{ L}} = 354 \text{ mm Hg} \]

The volume increased and the pressure decreased as expected.
Gas Laws: Charles’ Law (1783)

The volume of a gas is directly proportional to the temperature in Kelvin.

\[ V \propto T \text{ at constant pressure} \]
Charles’ Law uses a proportionality constant, \( k \).

\[ V = kT \quad \text{or} \quad \frac{V}{T} = k \]

Sample of gas initially has at \( V_1 \) and \( T_1 \) conditions. Change the conditions of the sample to \( V_2 \) and \( T_2 \). Since the ratio of volume to temperature is constant:

\[ \frac{V_1}{T_1} = k = \frac{V_2}{T_2} \]
Applying Charles’ Law

- To find the new volume after a change in temperature:

\[ V_1 \times \frac{T_2}{T_1} = V_2 \]

- To find the new temperature after a change in volume:

\[ T_1 \times \frac{V_2}{V_1} = T_2 \]
**Charles’ Law Problem**

**Problem:** A 275 L helium balloon is heated from 20°C to 40°C. What is the final volume at constant P?

Must convert the temp from °C to K:

- \(20°C + 273 = 293\ \text{K}\)
- \(40°C + 273 = 313\ \text{K}\)

\[
V_1 \times \frac{T_2}{T_1} = V_2
\]

\[
275\ \text{L} \times \frac{313\ \text{K}}{293\ \text{K}} = 294\ \text{L}
\]
Gay-Lussac discovered that the pressure of a gas is **directly proportional** to the temperature in Kelvin.

\[ P \propto T \text{ at constant volume.} \]
Cont’d... Gay-Lussac’s Law

Write Gay-Lussac’s Law as an equation using a proportionality constant, $k$.

$$P = k \frac{T}{1} \quad \text{or} \quad \frac{P}{T} = k$$

Sample of gas initially has at $P_1$ and $T_1$ conditions. Change the conditions of the sample to $P_2$ and $T_2$. Since the ratio of pressure to temperature is constant:

$$\frac{P_1}{T_1} = k = \frac{P_2}{T_2}$$
Applying Gay-Lussac’s Law

➢ To find the new volume after a change in temperature:

\[ P_1 \times \frac{T_2}{T_1} = P_2 \]

➢ To find the new temperature after a change in volume:

\[ T_1 \times \frac{P_2}{P_1} = T_2 \]
Problem: A steel container of nitrous oxide at 15.0 atm is cooled from 25°C to –40°C. What is the final volume at constant V?

Must convert the temp from °C to K:

25°C + 273 = 298 K
–40°C + 273 = 233 K

\[ P_1 \times \frac{T_2}{T_1} = P_2 \]

\[ 15.0 \text{ atm} \times \frac{298 \text{ K}}{233 \text{ K}} = 11.7 \text{ atm} \]
Combined Gas Law

In the gas laws, Boyle’s, Charles’s, and Gay-Lussac’s, always one of the variables assumed to be remaining constant.

Experimentally, all three variables (temperature, pressure, and volume) found to be usually changing. As a result, all three laws are combined, to obtain the combined gas law:

\[
\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}
\]
Applying The Combined Gas Law

- To find a new volume when P and T change:

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

- To find a new pressure when V and T change:

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

- To find a new temperature when P and V change:

\[ T_2 = T_1 \times \frac{P_2}{P_1} \times \frac{V_2}{V_1} \]
Combined Gas Law Problem

**Problem:** In a combined gas law problem, there are three variables: P, V, and T.

Apply the combined gas law to 10.0L of carbon dioxide gas at 300 K and 1.00 atm. If the volume and Kelvin temperature double, what is the new pressure?
Cont’d... Combined Gas Law Problem

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

\[ P_2 = 1.00 \text{ atm} \times \frac{10.0 \text{ L}}{20.0 \text{ L}} \times \frac{600 \text{ K}}{300 \text{ K}} \]

\[ P_2 = 1.00 \text{ atm} \]
Vapor Pressure

Vapor pressure is the pressure exerted by the gaseous vapor above a liquid when the rates of evaporation and condensation are equal.

As temperature increases, vapor pressure increases.
Gas Laws: Dalton’s Law

Dalton’s law of partial pressures: The total pressure of a gaseous mixture is equal to the sum of the individual pressures of each gas.

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

The pressure exerted by each gas in a mixture is called partial pressure, \( P_n \).
Dalton’s Law Problem

Problem: An atmospheric sample contains nitrogen, oxygen, and argon. If the partial pressure of nitrogen is 587 mm Hg, oxygen is 158 mm Hg, and argon is 7 mm Hg, what is the barometric pressure?

\[ P_{\text{total}} = P_{\text{nitrogen}} + P_{\text{oxygen}} + P_{\text{argon}} \]

\[ P_{\text{total}} = 587 \text{ mm Hg} + 158 \text{ mm Hg} + 7 \text{ mm Hg} \]

\[ P_{\text{total}} = 752 \text{ mm Hg} \]
Ideal Gas Behavior

An ideal gas behaves in a predictable and consistent way.

Ideal gases have the following properties:
1) Gases are made up of very tiny molecules
2) Gases molecules demonstrate rapid motion in straight lines and in random directions
3) Gas molecules have no attraction for one another.
4) Gas molecules undergo elastic collisions
5) The average kinetic energy of gas molecules is proportional to the Kelvin temperature.
Ideal Gas Law

Pressure of a gas is inversely proportional to volume and directly proportional to temperature and the number of molecules (or moles).

By introducing a proportionality constant, \( R \), ideal gas law equation can be obtained by rearranging equation show below:

\[
P = \frac{RnT}{V}.
\]
Ideal Gas Law

Ideal gas law equation:

\[ PV = nRT \]

\( R \) is **the ideal gas constant**

\[ R = 0.0821 \text{ atm} \cdot \text{L/mol} \cdot \text{K} \]
Problem: How many moles of hydrogen gas occupy 0.500 L at STP?

At STP, \( T = 273 \text{ K} \) and \( P = 1 \text{ atm} \). Rearrange the ideal gas equation to solve for moles:

\[
\frac{PV}{RT} = \frac{(1 \text{ atm})(0.500 \text{ L})}{(0.0821 \text{ atm} \cdot \text{L/mol} \cdot \text{K})(273 \text{ K})}
\]

\[ n = 0.0223 \text{ moles} \]
Review

- Gases have variable shape and volume.

- The pressure of a gas is directly proportional to the temperature and the number of moles present.

- The pressure of a gas is inversely proportional to the volume it occupies.

- Molar volume is the volume one mole of ideal gas, 22.414 L at standard conditions.
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Cont’d... Review

- Boyle’s Law is: $P_1 V_1 = P_2 V_2$

- Charles’ Law is: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

- Gay-Lussac’s Law is: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

- The combined gas law is: $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$
Cont’d…Review

- Dalton’s Law of partial pressures is:

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

- The Ideal Gas Law is: \( PV = nRT \)

\[ R \text{ is the ideal gas constant: } 0.0821 \text{ atm} \cdot \text{L/mol} \cdot \text{K} \]