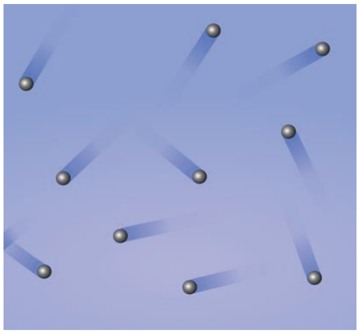
Warm-Up | Gas Laws

Understanding Kinetic-Molecular Theory

Postulates of kinetic-molecular theory:



- A gas is composed of small [particles] that are in continuous, random motion.
- The particles in a gas occupy a volume that is extremely small compared with the container. Particle volume is therefore considered to be negligible.
- The particles in a gas do not impose any [forces] on one another. Collisions between particles are perfectly elastic.
- The average kinetic energy of particles in a gas is proportional to the absolute [temperature] of the gas.

Lesson Objectives

By the end of this lesson, you should be able to:

- State Boyle's law, Charles's law, and Gay-Lussac's law, and apply these laws to calculate the relationships among [volume], temperature, and pressure.
- Derive the [combined] gas law from Boyle's law, Charles's law, and Gay-Lussac's law.
- Define partial pressure.
- Apply Dalton's law of partial pressures to describe the composition of [gases].

Science Practice: Make a table to compare the various gas laws.

Warm-Up | Gas Laws

Words to Know

Fill in this table as you work through the lesson. You may also use the glossary to help you.

Boyle's law	the law that states that the pressure and volume of a fixed quantity of a gas are inversely proportional under constant temperature conditions
Charles's law	the law that states that the volume and absolute temperature of a fixed quantity of a gas are directly proportional under constant pressure conditions
combined gas law	the law that combines Boyle's law, Charles's law, and Gay-Lussac's law, and states that for a fixed quantity of a gas, the pressure varies inversely with volume, while the temperature varies directly with pressure and with volume
Dalton's law	the law that states that the total pressure exerted by a mixture of gases is the sum of the individual partial pressures of the gases in the mixture
Gay-Lussac's law	the law that states that the pressure and absolute temperature of a fixed quantity of a gas are directly proportional under constant volume conditions
partial pressure	an individual gas's contribution to the total pressure exerted by a mix of gases

Instruction | Gas Laws

Slide 1

Lesson Question

What is the relationship among pressure, temperature, and volume of a gas?

Slide 2

Boyle's Law

Boyle's law states that the pressure and volume of a fixed quantity of a gas are inversely proportional under constant temperature conditions.

Volume decreases → pressure increases

Volume increases → pressure decreases

- $PV = k$
  - $k =$ constant
- $P_1V_1 = P_2V_2$

V_1, P_1

V_2, P_2

Instruction | Gas Laws

Slide 2

Applying Boyle's Law

A syringe contains argon gas at a pressure of 1.0 atm and 298 K. The volume of the gas is 40.0 mL. What happens to the pressure of the gas if the plunger on the syringe is depressed to the 20.0 mL mark? Assume temperature does not change.

- Write and rearrange the equation to solve for the required variable.

$$P_1V_1 = P_2V_2$$

$$\frac{P_1V_1}{V_2} = \boxed{P_2}$$

- Insert the given values and solve.

$$\frac{1.0 \text{ atm} \times 40.0 \text{ mL}}{20.0 \text{ mL}} = \boxed{2.0} \text{ atm}$$

Slide 6

Charles's Law

Charles's law states that the [volume] and absolute temperature of a fixed quantity of gas are [directly] proportional under constant pressure conditions.

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

- Temperature increases → volume increases
- Temperature [decreases] → volume decreases

$V = kT$

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

Gas law calculations must always use absolute temperature (kelvin temperature).

Instruction | Gas Laws

Slide 6

Applying Charles's Law

A syringe is filled with argon gas at a pressure of 1.0 atm and at room temperature (22°C). The volume of the argon gas under these conditions is 20.0 mL. What happens to the volume of the argon gas when you heat the syringe to 100°C?

- Write the equation and solve for the required variable.

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

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

- Convert temperature to kelvin.

$°C + 273.15 = ?\ \text{kelvin}$

$T_1 = 22°C + 273.15$

$= \boxed{295}\ \text{K}$

$T_2 = 100°C + 273.15$

$= \boxed{373}\ \text{K}$

- Substitute the given values and solve.

$$\frac{20.0\ \text{mL} \times 373\ \text{K}}{295\ \text{K}} = V_2$$

$$= \boxed{25.3}\ \text{mL}$$

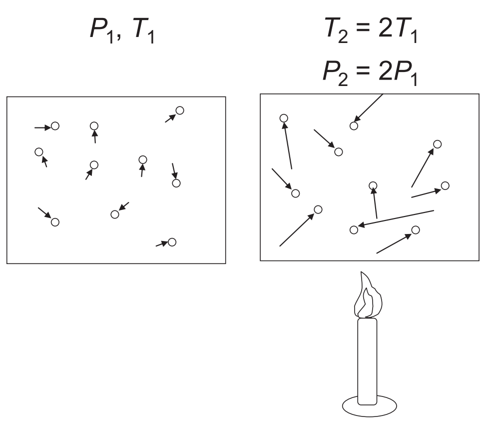
Slide 10

Gay-Lussac's Law

Gay-Lussac's law states that the pressure and absolute temperature of a fixed quantity of gas are directly proportional under constant volume conditions.

- Temperature increases → pressure increases
- Temperature decreases → pressure decreases
- $P = kT$

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



Instruction | Gas Laws

Slide 10

Applying Gay-Lussac's Law

A syringe is filled with argon gas at a pressure of 1.0 atm and at room temperature (22°C). The volume of the argon gas under these conditions is 20.0 mL. How much pressure would you have to apply to keep the volume of the gas constant as the temperature increases to 100°C?

- Write the equation and rearrange to find the desired variable.

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

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

- Convert temperature to kelvin.

$°C + 273.15 = ?\ \text{kelvin}$

$T_1 = 22°C + 273.15 = $ 295 K

$T_2 = 100°C + 273.15 = $ 373 K

- Substitute the given values and solve.

$$\frac{1.0\ \text{atm} \times 373\ \text{K}}{295\ \text{K}} = P_2$$

$= $ 1.3 atm

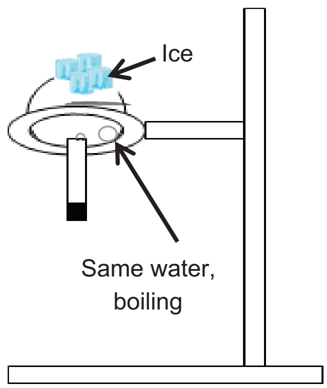
Instruction | Gas Laws

Slide

10

Gay-Lussac's Law in Action

Water **boils** on ice because:



- the volume is constant.
- the temperature has been decreased.
- the **pressure** of gas above the water decreases in response to the temperature decrease.
- the **vapor** pressure of the water now equals the pressure of gas above the water, which causes boiling.

14

Combined Gas Law

Boyle's Law

$P_1V_1 = P_2V_2$

Charles's Law

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

Gay-Lussac's Law

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

Combined gas law

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

Combined gas law states that for a fixed quantity of a gas, the pressure varies **inversely** with volume, while the temperature varies directly with pressure and with **volume**.

Slide 14

Applying the Combined Gas Law

A raft inflated to a volume of 39.2 L at 22°C with a pressure of 0.98 atm is taken on a trip down a river. During lunch, the rafters pull the raft onshore and leave it in the sun while they eat. The temperature inside the raft increases to 97°C at a pressure of 1.2 atm and the raft bursts. What was the volume of the raft the moment before it burst?

- Write the equation and rearrange to solve for the desired variable.

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

$$\boxed{\frac{T_2}{P_2}} \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \boxed{\frac{T_2}{P_2}}$$

$$\frac{T_2P_1V_1}{P_2T_1} = V_2$$

- Convert the temperature to kelvin.

$T_1 = 22°\text{C} + 273.15 = \boxed{295}$ K

$T_2 = 97°\text{C} + 273.15 = \boxed{370}$ K

- Substitute the given values and solve.

$$\frac{370\text{K} \times .98 \text{ atm} \times 39.2\text{L}}{1.2 \text{ atm} \times 295\text{K}} = V_2$$

$V_2 = \boxed{40}$ L

Instruction | Gas Laws

Slide 17

Real-World Application of the Combined Gas Law

Inside a home hot-water tank:

- the water is heated.
- the pressure and volume **increase** inside the tank.
- the overflow **valve** provides a way to release the increased pressure.
- the **water** is allowed to back up in cold-water pipes to take care of increased volume.

Joule–Thomson Effect

When spraying a gas from an aerosol can:

- the pressure of gas decreases as it goes from being **compressed** in the container to being released into the atmosphere.
- the **kinetic** energies of gas molecules decrease.
- the gas **temperature** decreases as it is sprayed.

Instruction | Gas Laws

Slide 20

Partial Pressure

Partial pressure is the fraction of the total pressure exerted by a mix of gases that is contributed by an individual gas.

- It refers to pressure of one gas in a mixture of gases.
- It considers the pressure of a single gas as if it occupied the container by itself.

N_2 (g): 78.08 percent, ~593 torr

O_2 (g): 20.95 percent, ~159 torr

Ar (g): 0.93 percent, ~7 torr

Air mixture: 100 percent, 760 torr

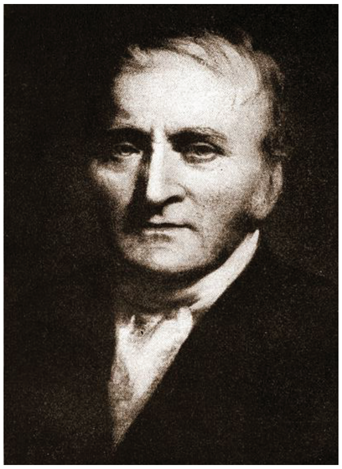
The sum of the partial pressures equals the total pressure of the mixture.

Dalton's Law

Dalton's law states that the total pressure exerted by a mixture of gases is the sum of the individual partial pressures of the gases in the mixture.

$$P_T = P_1 + P_2 + P_3 + \ldots + P_n$$

$$\frac{P_a}{P_T} = \frac{n_a}{n_T} \rightarrow P_a = \left(\frac{n_a}{n_T}\right) P_T$$



Slide 20

Applying Dalton's Law of Partial Pressures

A gas cylinder contains 1.0 mol He and 4.0 mol Ar gas at a total pressure of 1.6 atm. What is the partial pressure of each gas?

- Write the equation and rearrange to solve for the desired variable.

$$\frac{P_a}{P_T} = \frac{N_a}{N_T}$$

$$P_a = \left(\frac{N_a}{N_T}\right) P_T$$

- Substitute the given values and solve.

$$P_{He} = \left(\frac{1.0 \text{ mol}}{5.0 \text{ mol}}\right) 1.6 \text{ atm} = \boxed{0.3} \text{ atm He}$$

$$P_{Ar} = \left(\frac{4.0 \text{ mol}}{5.0 \text{ mol}}\right) 1.6 \text{ atm} = \boxed{1.3} \text{ atm Ar}$$

Summary | Gas Laws

Lesson Question

What is the relationship among pressure, temperature, and volume of a gas?

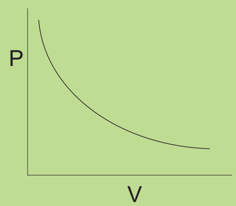
Answer

(Sample answer) Boyle's law, Charles's law, Gay-Lussac's law, and the combined gas law express the relationship between pressure, temperature, and volume of a gas. Each of these laws assumes that the quantity of gas is constant.

Slide 2

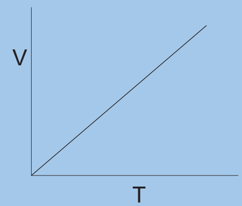
Three Gas Laws

Boyle's law



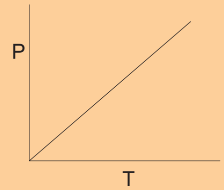
$P_1 \boxed{V_1} = P_2V_2$

Charles's law



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

Gay-Lussac's law

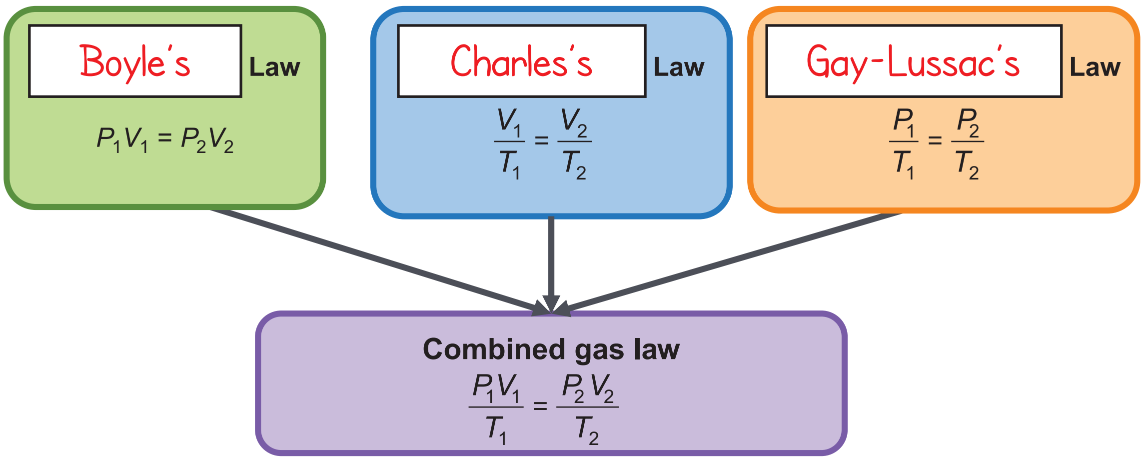


$\frac{P_1}{T_1} = \frac{\boxed{P_2}}{T_2}$

Summary | Gas Laws

Slide 2

Combined Gas Law



Dalton's Law of Partial Pressures

The total pressure of a mixture of gases is equal to the sum of the partial pressures of the individual gases:

$$P_T = P_1 + P_2 + P_3 + \ldots + P_n$$

Each partial pressure can be determined from the mole fraction of that gas in the mixture:

$$\frac{P_a}{P_T} = \frac{n_a}{n_T} \quad \Rightarrow \quad P_a = \left(\frac{n_a}{n_T}\right)P_T$$

Summary | Gas Laws

Use this space to write any questions or thoughts about this lesson.