Gas Laws

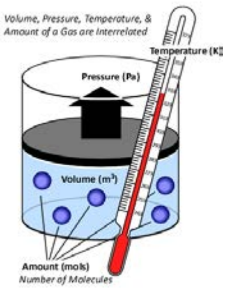
1. Describe the properties of gas particles and explain how the kinetic energy of gas particles is related to temperature.
2. Students will be able to state and use the Ideal Gas Law, Boyle's law, Charles' law, Gay-Lussac's law, Avogadro's Law and the Combined gas law to solve problems involving the temperature, volume and pressure of a contained gas.

Ideal Gases

In Chemistry, we will consider ALL GASES to be **ideal**.

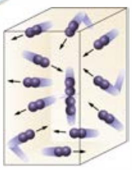
What is an ideal gas?

An ideal gas is any gas that meets the **<u>5 basic assumptions</u>** of **kinetic molecular** *theory* stating how the particles of any **gas** move.



5 Basic Assumptions

1. Gas particles do not **attract** or **repel** each other.
2. Gas particles are much **smaller** than the distances between them.



> Almost all the volume is **empty space**.

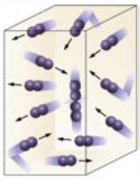
> Explains why gases are easy to compress.

5 Basic Assumptions

3. Gas particles are in **constant random** motion.
4. Particles move in **straight lines** until collision.

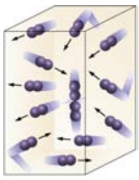
> Explains why gases **fill** any container.

> No **kinetic** energy is lost when gas particles collide with each other or the walls of the container.



5 Basic Assumptions

5. All gases have the **same** average kinetic energy at a given **temperature**.



Real Gases

Most real gases behave ideally. High temperatures and low pressures support ideal gas behavior. However, at low temps and high pressure gases behave oddly.

Gases *are* subject to attractive and repulsive forces and do exchange energy.

Smaller gas particles move faster than larger particles at the same temperature.

Gases and Energy

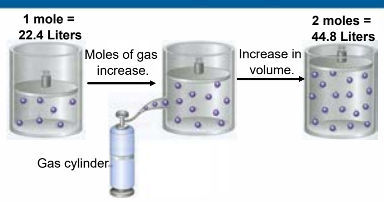
- When gases are heated, kinetic energy **increases**.
- When a gas has **more** kinetic energy, its particles push collide more with the surroundings.

Gases and Energy

- If the container *can* expand, the gas **volume** will increase.
  - > A rubber balloon
- If the container *cannot* expand, gas **pressure** will increase.
  - > A rigid container, like a glass jar

Avogadro's Law

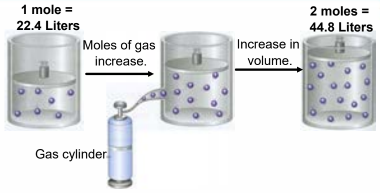
$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$



- Under the same sets of physical conditions, all gases behave the same way.
- Two different gases of **equal volume** at the **same** pressure and temperature have equal numbers of **particles** and therefore **moles,** regardless of the identity of either gas.

Avogadro's Law

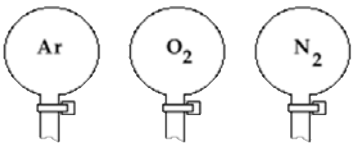
$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$



- First, if you add more gas, volume of the gas increases.
  - Example.... take a deep breath!
- Second, 1 mole of ANY gas at standard temperature and pressure contains 22.4 L of gas.

Avogadro's Law

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



	Ar	O_2	N_2
Volume:	22.4 L	22.4 L	22.4 L
Mass:	40 g	32 g	28 g
Quantity:	1 mol	1 mol	1 mol
Pressure:	1 atm	1 atm	1 atm
Temperature:	273 K	273 K	273 K

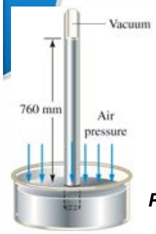
Gas Laws

4 Variables

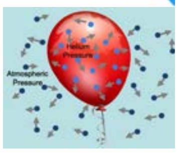
Dalton's Law of Partial Pressures

Vapor Pressure

4 VARIABLES



1. **Pressure** (**P**)



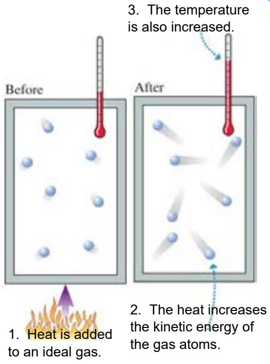
- Created by molecules of gas **colliding** with the walls of the container.
- Systeme Internationale Unit, or **SI** unit, is the pascal, Pa.
- **101.3** kPa = **1.000** atmosphere = **760.0** mmHg or torr

Practice: Convert 1.4 atmospheres of pressure to kPa.

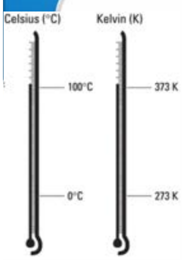
4 VARIABLES

2. **Temperature** (**T**)

- A measure of the **kinetic** energy of gas particles.
- Temperature is **directly** proportional to kinetic energy.



4 VARIABLES



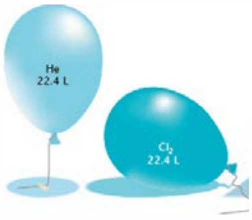
- **SI Unit** is **Kelvin** (K).
- All calculations in this unit are in *KELVIN*.
- To convert from Celsius, **K = °C + 273.15**
- Standard Temperature = **273.15 K** = **0°C**.
- 0 K is called "**absolute** zero", the temperature at which the motion of particles theoretically stop.

Practice: Convert 33.0°C to Kelvin.

4 VARIABLES

3. **Volume** (**V**)

- The 3-D space enclosed by the container's **walls.**
- **SI unit** is **liters** (L)
- At STP, there are **22.4 L** of a gas per one mole of that gas.



4 VARIABLES

4. **Moles** (**n**)

- The **amount** of gas present in **moles.**
- If the amount is given in grams, we will **convert** it to moles.
- 1 mole is the standard at STP

1 mole of oxygen gas has a mass of 32.00 grams and occupies 22.4 Liters (a balloon whose diameter is 35.cm).

STP

Standard
Temperature
Pressure

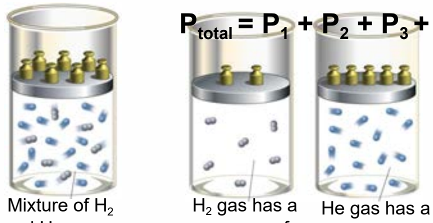
Temperature: 0℃ = 273.15K

Pressure: 101.3 kPa = 1.000 atm = 760.0 mmHg = 760.0 torr

Dalton's Law of Partial Pressure

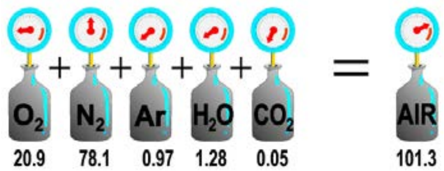
In a **mixture** of gases, the **total** pressure exerted by the mixture of gases is equal to the **sum** of the partial pressure of each gas.

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



Dalton's Law of Partial Pressure

Example - Air contains N_2, O_2, H_2O, Ar CO_2, the sum of which makes up the air pressure around us at any time.



At sea level, the air pressure is 101.3 kPa, but air is not a pure gas, it is mixture of the above gases.

Dalton's Law of Partial Pressure

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

Example

A sealed room contains a mixture of air and sulfur hexafluoride gas, SF_6, at a total pressure of 105.4 kPa. The air pressure in the room is 101.3 kPa. What is the partial pressure of the sulfur hexafluoride?

Molar Volume of a Gas - Vapor Pressure

One of the best ways to collect a gas in a reaction is over water.

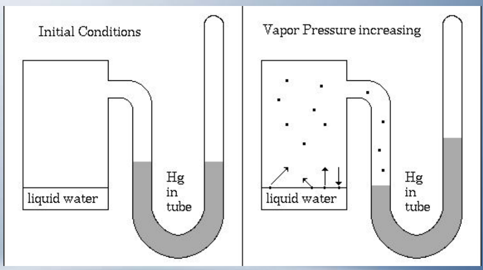
We can use Dalton's law to calculate the Pressure of a specific gas collected over water.

The "total" pressure is the atmospheric pressure.

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

Dalton's Law of Partial Pressures and Vapor Pressure

Vapor Pressure: the equilibrium pressure of a vapor above its liquid. It is the pressure of the vapor resulting from evaporation of a liquid above a sample of the liquid in a closed container. (This can also be true for a solid).



Vapor Pressure

Collecting a Gas over water

After collecting the gas, you can adjust the water level in the container so that the pressure inside and outside the container are the same. Because of this, if we know the atmospheric pressure, we also know the pressure of the gas inside the container.

The gases inside the bottle are:

- the gas being collected
- water vapor that has escaped from the surface of the water that sits under the gas

.

Dalton's Law of Partial Pressures tells us that the total pressure in the container must be the sum of the pressures of the gas we collected and the water vapor.

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

P_T in this case is the atmospheric pressure!

Molar Volume of a Gas

The vapor pressure of water (or any other substance) is dependent on the temperature.

TABLE 12.1
The Vapor Pressure of Water

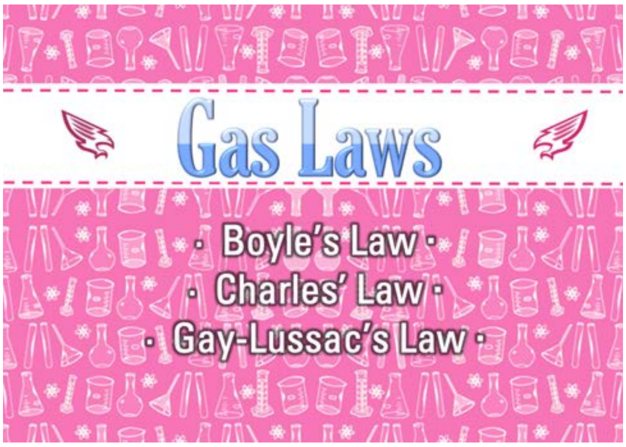
Temperature (°C)	Vapor Pressure (torr)	Temperature (°C)	Vapor Pressure (torr)
20	17.5	29	30.0
21	18.7	30	31.8
22	19.8	40	55.3
23	21.1	50	92.5
24	22.4	60	149.4
25	23.8	70	233.7
26	25.2	80	355.1
27	26.7	90	525.8
28	28.3	100	760.0

Next

Molar Volume of a Gas

Example: 60.0L of nitrogen gas is collected over water at 40.0 °C, when the atmospheric pressure is 760.0mmHg.

a) What is the partial pressure of the nitrogen?

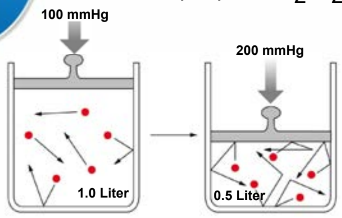


Boyle's Law

Boyle's Law demo

The relationship between pressure and volume when the **temperature** is held ***constant***.

$$P_1V_1 = P_2V_2$$



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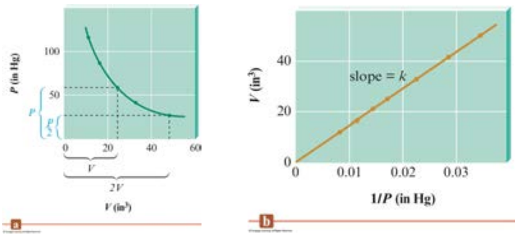


Boyle's Law

$$P_1V_1 = P_2V_2$$

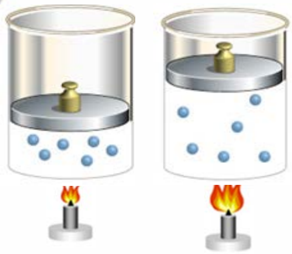
Example 1

A high altitude balloon contains 30.1 L of helium gas at 103 kPa. What is the volume when the balloon rises to an altitude where the pressure is only 25.4 kPa?

CHARLES' LAW

The relationship between volume and temperature when the **pressure** is held ***constant***.

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



CHARLES' LAW

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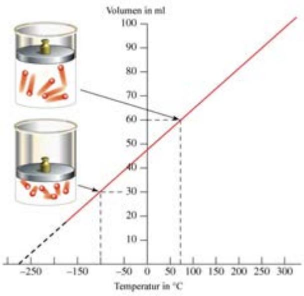


CHARLES' LAW

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

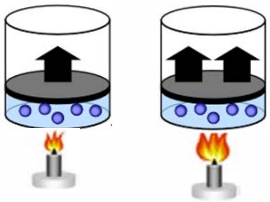
Example 1

A balloon inflated in a room at 24°C has a volume of 4.0 L. The balloon is then heated to a temperature of 58°C. What is the new volume if the pressure is held constant?

Gay-Lussac's Law

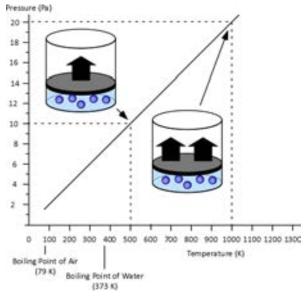
The relationship between pressure and temperature when the **volume** is held ***constant***.

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



Gay-Lussac's Law

The relationship between pressure and temperature when the **volume** is held ***constant***.



Gay-Lussac's Law

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

Example 1

The gas left in a used aerosol can is at a pressure of 103 kPa at 25°C. If this can is thrown into a fire, what is the pressure of the gas when its temperature reaches 928°C?

Combined Gas Law

States the relationship among pressure, volume and temperature of a <u>gas</u> under **two** *sets of conditions*.

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

- We ***MUST use Kelvin*** for temperature

Combined Gas Law

We can use PV = nRT to solve most gas problems.

In a gas sample, R will ALWAYS = PV/nT. So, if any component changes, there will be a responding change in all other factors, if possible.

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

Combined Gas Law

When the conditions surrounding a gas change, we will employ the combined gas law.

What do you do if a factor is not mentioned in a question?

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

- We ***MUST use Kelvin*** for temperature

Combined Gas Law

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

Example

A gas at 155 kPa and 25°C occupies a container with an initial volume of 1.00 L. By changing the volume, the pressure of the gas increases to 605 kPa as the temperature is raised to 125°C. What is the new volume?

variables

	initial (1)	final (2)
P		
V		
T		

Gas Laws

IDEAL GAS LAW

Ideal Gas Law

Measures of Ideal gases have these relationships.

PV ~ nT

We use the ideal gas constant, ***R***, to create the following equality.

PV = nRT

Ideal Gas Law

PV = nRT

Pressure (P) - units are atm, mmHg, torr, or kPa

Volume (V) - unit is liter

Moles (n)

Temperature (T) - unit is Kelvin

Ideal Gas Constant (R) - depends on pressure unit.

Ideal Gas Law

What is R?

PV = nRT

R is the **Ideal Gas Constant.**

There are ideal gas constants for pressure in **kPa**, **atm**, **torr**, and **mmHg.**

Pressure in **kPa**

$8.314 \frac{L\ kPa}{mol\ K}$

Pressure in **atm**

$0.08206 \frac{L\ atm}{mol\ K}$

Pressure in **torr or mmHg**

$62.36 \frac{L\ kPa}{mol\ K}$

Ideal Gas Law

How to calculate R?

$$PV = nRT$$

@ STP, $R = \frac{22.4\,L \times 101.3\,kPa}{273\,K \times 1\,mole} = 8.31$

You can do this for all pressure units in a pinch!

pressure in **kPa**

$R = 8.31 \frac{L \cdot kPa}{K \cdot mol}$

pressure in **atm**

$R = 0.0821 \frac{L \cdot atm}{K \cdot mol}$

pressure in **torr** *or* **mmHg**

$R = 62.4 \frac{L \cdot \text{torr or mmHg}}{K \cdot mol}$

Ideal Gas Law

$$PV = nRT$$

Example 1

When the temperature of a hollow sphere containing 685 L of helium gas is 621 K, the pressure of the gas is 1.89 x 10^3 kPa. How many moles of the helium does the sphere contain? What mass is this?

Ideal Gas Law

$$PV = nRT$$

Example 2

Determine the volume occupied by 2.34 grams of carbon dioxide gas at STP.