Gases

Variables for gases

- Number of moles (n): Just like always
- Volume (V): Just like always
- Temperature (T): Just like always
- Pressure (P): Ah-ha! Something new!

Pressure – a new variable

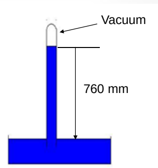
- Pressure is defined to be force applied over an area:

$$P = \frac{force}{area}$$

- Force is in units of kg m s^{-2}. Area is in units of m^2. This gives pressure units (SI) of kg m^{-1} s^{-2}.
- This unit is also called the Pascal (Pa).

Barometers – another pressure unit

- In the 1500s Evangelista Torricelli invented the barometer.
- Showed the idea to a couple of friends in France named Pascal, hence the unit.



Other units of pressure

- Atmospheres (atm)
- mmHg (or torr, for *torr*icelli)
- psi (pounds per square inch)
- Relationships:
  1 atm = 760 mmHg (torr) = 101325 Pa

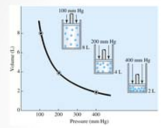
Gas Laws

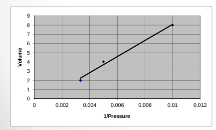
- Gas Laws are empirical laws that describe what happens with a gas under certain conditions.
- Based on observation
- We will look at several gas laws and an overall law.

Boyle's Law

- Popularized by Robert Boyle in the 1600's
- Boyle's Law looks at the relationship between pressure and volume of a gas under constant temperature and number of moles.

Boyle's Law





- This is an example of Boyle's experimental set up.
- Boyle found this relationship.
- If we look at the data differently we see the trend.

Boyle's Law

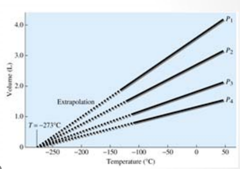
- Seeing something graphically can help us to understand what is happening.
- Seeing it mathematically allows us to use it.
- Boyle's Law, mathematically is expressed as

or $V \propto \frac{1}{P}$

$PV = C$ or $P_1V_1 = P_2V_2$

Charles' Law (Amontson's Law)

- This law explores the relationship between the volume and the temperature of a gas.
- The pressure and the number of moles of gas is constant.
- This is the basis of the absolute temperature scale.



Charles' Law

- Mathematically the law can be expressed as:

$$V \propto T$$

$$\frac{V}{T} = C$$

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

One must remember that when using any gas law the temperature ***must*** be in Kelvin!

Gay-Lussac's Law

- Gay-Lussac investigated the relationship betweeen the temperature of a gas and the pressure.
- Look at the two laws we've seen so far.
  - What do you expect the relationship to be?
- Gay-Lussac found that the pressure of a gas is directly proportional to the Kelvin temperature.

Gay-Lussac's Law

- Mathematically this can be expressed as:

$$P \propto T$$

- We can also express it as:

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

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Avogadro's Law

- Avogadro determined the relationship between the volume of a gas and the number of molecules present.
- He said that if two gases are at the same pressure and temperature, equal volumes will contain the same number of molecules.
- Mathematically this can be expressed as: $V \propto n$

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STP (Standard Temperature and Pressure)

- When comparing gases, as in using Avogadro's Law, we usually compare them at Standard Temperature and Pressure (STP).
- This is defined as 0°C (273.15 K) and 1 atm (760 mmHg).
- At STP 1 mole of any gas occupies 22.414 L
  - This is ONLY at STP. At other T and P the volume will be different.
  - This can be used as a conversion factor in later problems.

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The Combined Gas Law

- We can combine Boyle's, Charles' and Gay-Lussac's Laws into one law. If we do this we get:

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

- The stipulation here is that the number of moles of gas is constant.
- We can use this to convert a gas to STP from another set of conditions.

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Gay-Lussac's Other Law

- Gay-Lussac looked at Avogadro's Law and chemical reactions in the gas phase and derived another law.
- When gases react, they do so such that the volumes that react are simple whole number ratios that are the same as the stoichiometric ratios.

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Gay-Lussac's Other Law

$$N_{2(g)} + 3\,H_{2\,(g)} \rightarrow 2\,NH_{3\,(g)}$$

1 L 3 L 2 L

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The Ideal Gas Law

- If we combine all of the gas laws together, we get:

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

- The constant, R, is called the ideal gas constant.
- It's value depends on the units used.

R, the ideal gas constant

- R = 0.08206 L atm mol^{-1} K^{-1}
  = 62.363 L mmHg mol^{-1} K^{-1}
  = 8.314 L kPa mol^{-1} K^{-1}
  = 8.314 J mol^{-1} K^{-1}
- You only need to know one of the values, and then convert the pressure to that unit.

The Ideal Gas Law

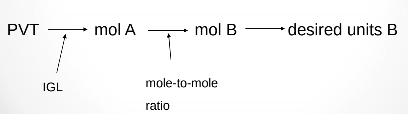
- The Ideal Gas Law can be used to find the number of moles of gas in a sample. You must be given the pressure, volume and temperature of the gas.

$$n = \frac{PV}{RT}$$

- The number of moles can be used to do stoichiometric calculations.

Gas Laws and Stoichiometry

- The volume, temperature and pressure of a gas tells us how many moles of that gas are present.
- The rest of the calculation is the same as before.



Equations derived from the Ideal Gas Law

$$PV = nRT$$
$$mPV = mnRT$$
$$\frac{mP}{n} = \frac{mRT}{V}$$
$$MP = dRT$$

This equation show us that the density of a gas is related to it's molar mass. If we can measure the density, pressure and temperature, we can determine the molar mass.

Dalton's Law of Partial Pressures

- When two or more gases are in the same container they act as if they are the only gas in the container.
- This means that each gas exerts its own pressure (partial pressure) on the container.
- The total pressure in the container will be the sum of the individual partial pressures.

$$P_T = P_1 + P_2 + \cdots + P_n = \sum_{i=1}^{n} P_i$$

Mole fractions and partial pressures

- The mole fraction (X) of a gas is defined as the number of moles of one of the gases divided by the total number of moles of gas.

$$X_i = \frac{n_i}{n_t}$$

Mole fractions continued

- Remember that the number of moles of gas is proportional to the pressure of the gas (Ideal Gas Law). We can then restate the formula for the mole fraction of a gas as:

$$X_i = \frac{P_i}{P_T} \quad \text{or} \quad P_i = X_i P_T$$