GAS LAWS

- were derived by experiment long before kinetic theory, but agree with the kinetic picture!

Boyle's Law:

$$PV = \text{constant}$$

True at constant temperature

$$P_1V_1 = \text{constant} \qquad P_2V_2 = \text{constant}$$

$$\boxed{P_1V_1 = P_2V_2}$$

True at constant temperature

Charles's Law:

$$\frac{V}{T} = \text{constant}$$

True at constant pressure, and using ABSOLUTE temperature

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

True at constant pressure, and using ABSOLUTE temperature

Combined gas law: $$\frac{PV}{T} = \text{constant}$$

Must use ABSOLUTE temperature units!

$$\boxed{\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}}$$

Must use ABSOLUTE temperature units!

amount (moles) of gas must be constant!

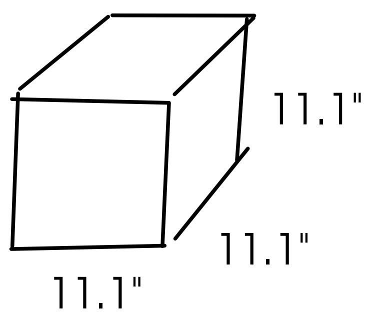
Avogadro's law:

- a mole of any gas at the same conditions has the same volume.

1 mol gas molecules @ 0°C and 1 atm

volume = 22.4 L

"STP"
Standard Temperature and Pressure



= 22.4 L

Ideal gas law:

$$\frac{PV}{T} = \text{constant}$$

... but this constant actually depends on the amount of gas!

$$= n \times \text{"}R\text{"}$$

The ideal gas constant.

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

... combining these together ...

$$\frac{PV}{T} = nR$$

$$\boxed{PV = nRT}$$

P = pressure atm

V = volume L

T = ABSOLUTE temperature K

R = ideal gas constant

n = number of moles of gas molecules

A balloon is taken from a room where the temperature is 27.0 C to a freezer where the temperature is -5.0 C. If the balloon has a volume of 3.5 L in the 27.0 C room, what is the volume of the balloon in the freezer. Assume pressure is constant.

$$\frac{\cancel{P_1}V_1}{T_1} = \frac{\cancel{P_2}V_2}{T_2} \xrightarrow{P\text{ constant}} \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$V_1 = 3.5\text{ L}$

$T_1 = 27.0°C = 300.2\text{ K}$

$V_2 = ?$

$T_2 = -5.0°C = 268.2\text{ K}$

$$\frac{3.5\text{ L}}{300.2\text{ K}} = \frac{V_2}{268.2\text{ K}}$$

$$\boxed{3.1\text{ L} = V_2}$$

2.25 L of nitrogen gas is trapped in a piston at 25.0 C and 1.00 atm pressure. If the piston is pushed in so that the gas's volume is 1.00 L while the temperature increases to 31.0 C, what is the pressure of the gas in the piston?

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

$P_1 = 1.00\text{ atm}$ $V_1 = 2.25\text{ L}$

$T_1 = 25.0°C = 298.2\text{ K}$

$P_2 = ?$ $V_2 = 1.00\text{ L}$

$T_2 = 31.0°C = 304.2\text{ K}$

$$\frac{(1.00\text{ atm})(2.25\text{ L})}{298.2\text{ K}} = \frac{P_2(1.00\text{ L})}{304.2\text{ K}}$$

$$\boxed{2.30\text{ atm} = P_2}$$

Calculate the mass of 22650* L of oxygen gas at 25.0 C and 1.18 atm pressure.

$\leftarrow O_2$

*Volume of a 10'x10'x8' room

O_2: 32.00 g O_2 = mol O_2

1) Use PV=nRT to find the moles of oxygen gas
2) Convert moles oxygen to mass using formula weight.

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

$P = 1.18\,\text{atm}$

$V = 22650\,\text{L}$

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

$T = 25.0\,^\circ\text{C} = 298.2\,\text{K}$

1. $$n_{O_2} = \frac{(1.18\,\text{atm})(22650\,\text{L})}{\left(0.08206\,\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}\right)(298.2\,\text{K})} = 1092.222357\,\text{mol}\ O_2$$

2. $$1092.222357\,\text{mol}\ O_2 \times \frac{32.00\,\text{g}\ O_2}{\text{mol}\ O_2} = \boxed{35\bar{0}00\,\text{g}\ O_2}$$

35.0 kg
~77 lb

CHEMICAL CALCULATIONS WITH THE GAS LAWS

$\boxed{FW_{NaHCO_3} = 84.007\ g/mol}$

$$H_2SO_4(aq) + 2NaHCO_3(s) \rightarrow 2H_2O(l) + 2CO_2(g) + Na_2SO_4(aq)$$

Given 25.0 g of sodium bicarbonate and sufficient sulfuric acid, what volume of carbon dioxide gas would be produced at 25.0 C and 0.950 atm pressure?

1) Convert 25.0 grams sodium bicarbonate to moles. Use FORMULA WEIGHT.
2) Convert moles sodium bicarbonate to moles carbon dioxide. Use CHEMICAL EQUATION.
3) Convert moles carbon dioxide to volume. Use IDEAL GAS EQUATION.

1 $84.007\ g\ NaHCO_3 = mol\ NaHCO_3$ 2 $2\ mol\ NaHCO_3 = 2\ mol\ CO_2$

$$25.0\ g\ NaHCO_3 \times \underbrace{\frac{mol\ NaHCO_3}{84.007\ g\ NaHCO_3}}_{1} \times \underbrace{\frac{2\ mol\ CO_2}{2\ mol\ NaHCO_3}}_{2} = 0.2975942481\ mol\ CO_2$$

3 $PV = nRT$

$V = \frac{nRT}{P}$

$n = 0.2975942481\ mol\ CO_2$ $P = 0.950\ atm$

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

$T = 25.0°C = 298.2\ K$

$$V = \frac{(0.2975942481\ mol\ CO_2)(0.08206\ \frac{L\cdot atm}{mol\cdot K})(298.2\ K)}{0.950\ atm} =$$

$= \boxed{7.67\ L\ CO_2}$ @ 25.0°C, 0.950 atm

What volume would the gas in the last example problem have at STP?

(0°C, 1 atm)

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

$P_1 = 0.950$ atm
$V_1 = 7.67$ L
$T_1 = 298.2$ K

$P_2 = 1$ atm
$V_2 = ?$
$T_2 = 273.2$ K

$$\frac{(0.950\text{ atm})(7.67\text{ L})}{298.2\text{ K}} = \frac{(1\text{ atm})V_2}{273.2\text{ K}}$$

$$V_2 = \boxed{6.67\text{ L } CO_2} \text{ @ STP}$$

Alternate solution: Use PV=nRT to calculate the new volume.

$25\bar{0}0$ L of chlorine gas at 25.0 C and 1.00 atm are used to make hydrochloric acid. How many grams of hydrochloric acid could be produced if all the chlorine reacts?

$$H_2 + Cl_2 \rightarrow 2\,HCl$$

1 - Convert 2500 L chlorine gas to moles. Use IDEAL GAS LAW, PV=nRT
2 - Convert moles chlorine gas to moles HCl. Use CHEMICAL EQUATION
3 - Convert moles HCl to mass HCl. Use FORMULA WEIGHT.

(1) $PV = nRT$

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

$P = 1.00$ atm

$V = 25\bar{0}0$ L

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

$T = 25.0°C = 298.2$ K

$$n_{Cl_2} = \frac{(1.00 \text{ atm})(25\bar{0}0 \text{ L})}{\left(0.08206 \frac{L\text{-}atm}{mol \cdot K}\right)(298.2 \text{ K})} = 102.1646983 \text{ mol } Cl_2$$

(2) mol Cl_2 = 2 mol HCl

(3) HCl - H: 1 x 1.008
Cl: 1 x 35.45
36.458 g HCl = mol HCl

$$102.1646983 \text{ mol } Cl_2 \times \frac{2 \text{ mol HCl}}{\text{mol } Cl_2} \times \frac{36.458 \text{ g HCl}}{\text{mol HCl}} = \boxed{7450 \text{ g HCl}}$$

$2\,HCl + Na_2CO_3 \rightarrow CO_2 + H_2O + 2\,NaCl$

If 48.90 mL of 0.250 M HCl solution reacts with sodium carbonate to produce 50.0 mL of carbon dioxide gas at 290.2 K, what is the pressure of the carbon dioxide gas?

1 - Convert 48.90 mL of 0.250 M HCl to moles. Use MOLARITY.
2 - Convert moles HCl to moles carbon dioxide gas. Use CHEMICAL EQUATION.
3 - Convert moles carbon dioxide gas to pressure. Use IDEAL GAS LAW

① 0.250 mol HCl = L mL = 10^{-3} L ② 2 mol HCl = mol CO_2

$$48.90\ \text{mL} \times \frac{10^{-3}\ \text{L}}{\text{mL}} \times \underbrace{\frac{0.250\ \text{mol HCl}}{\text{L}}}_{1} \times \underbrace{\frac{\text{mol } CO_2}{2\ \text{mol HCl}}}_{2} = 0.006125\ \text{mol } CO_2$$

③ $PV = nRT$

$P = \dfrac{nRT}{V}$

$n = 0.006125\ \text{mol } CO_2$ $T = 290.2\ \text{K}$

$R = 0.08206\ \dfrac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}$ $V = 50.0\ \text{mL} = 0.0500\ \text{L}$

$$P = \frac{(0.006125\ \text{mol } CO_2)\left(0.08206\ \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}\right)(290.2\ \text{K})}{0.0500\ \text{L}}$$

$$= \boxed{2.91\ \text{atm}}$$