Ideal Gas & Gas Stoichiometry

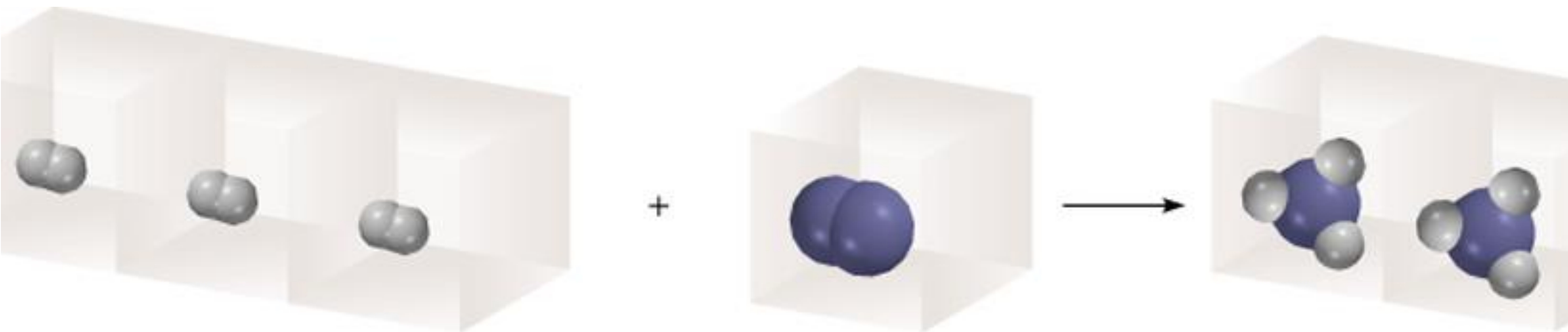
Avogadro's Law

$V \alpha$ number of moles (n)

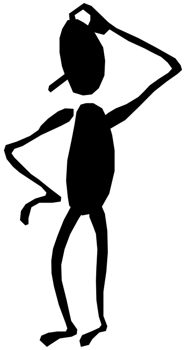
V = constant x n

$V_1/n_1 = V_2/n_2$

Constant temperature
Constant pressure



$3H_2\,(g)$	+	$N_2\,(g)$	$\longrightarrow$	$2NH_3\,(g)$
3 molecules	+	1 molecule	$\longrightarrow$	2 molecules
3 moles	+	1 mole	$\longrightarrow$	2 moles
3 volumes	+	1 volume	$\longrightarrow$	2 volumes



Ammonia burns in oxygen to form nitric oxide (NO) and water vapor. How many volumes of NO are obtained from one volume of ammonia at the same temperature and pressure?

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$$

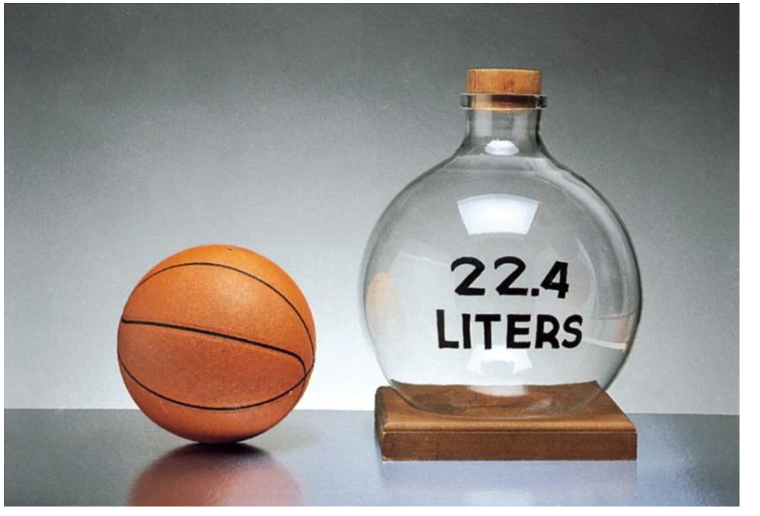
1 mole NH_3 ⟶ 1 mole NO

At constant *T* and *P*

1 volume NH_3 ⟶ 1 volume NO

The conditions 0 ^{0}C and 1 atm are called **standard temperature and pressure (STP).**

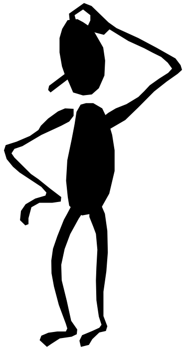
Experiments show that at STP, 1 mole of an ideal gas occupies 22.414 L.



$$PV = nRT$$

$$R = \frac{PV}{nT} = \frac{(1\ \text{atm})(22.414\text{L})}{(1\ \text{mol})(273.15\ \text{K})}$$

R = 0.082057 L • atm / (mol • K)



What is the volume (in liters) occupied by 49.8 g of HCl at STP?

$T = 0\ ^0\text{C} = 273.15\ \text{K}$

$P = 1\ atm$

$n = 49.8\ \text{g} \times \dfrac{1\ \text{mol HCl}}{36.45\ \text{g HCl}} = 1.37\ \text{mol}$

$PV = nRT$

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

$$V = \frac{1.37\ \text{mol} \times 0.0821\ \dfrac{\text{L}\bullet\text{atm}}{\text{mol}\bullet\text{K}} \times 273.15\ \text{K}}{1\ \text{atm}}$$

$V = 30.6\ \text{L}$

Density (d) Calculations

$$d = \frac{m}{V} = \frac{P\mathcal{M}}{RT}$$

m is the mass of the gas in g

$\mathcal{M}$ is the molar mass of the gas

Molar Mass ($\mathcal{M}$) of a Gaseous Substance

$$\mathcal{M} = \frac{dRT}{P}$$

d is the density of the gas in g/L

Ideal Gas Equation

Boyle's law: $V \propto \frac{1}{P}$ (at constant n and T)

Charles' law: $V \propto T$ (at constant n and P)

Avogadro's law: $V \propto n$ (at constant P and T)

$$V \propto \frac{nT}{P}$$

$$V = \text{constant} \times \frac{nT}{P} = R\frac{nT}{P}$$

R is the **gas constant**

$$PV = nRT$$

Determine Pressure:

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

Determine the pressure in atm exerted by 12.0 grams of sulfur dioxide gas at 22. ^{0} C in a 750.0 ml vessel.

1. Change all units:

$$n\ SO_2 = 12.0 \text{ grams of } SO_2 \left| \frac{1 \text{ mole } SO_2}{64.0 \text{ g}} \right| = 0.188 \text{ moles } SO_2$$

T= 22 + 273 = 295 K

V= 0.750 L

2. Plug into equation

$$P = \frac{(0.188 \text{ moles})(0.0821)(295\ K)}{0.750\ L} =$$

6.07 atm

Determine Volume:

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

Determine the volume occupied by 5.00 grams of sulfur dioxide at 10.^{0}C exerting a pressure of 12.5 Kpa.

1. Change all units:

$n\ SO_2 = 5.00 \text{ grams of } SO_2 \times \frac{1 \text{ mole } SO_2}{64.0 \text{ g}} = 0.0781 \text{ moles } SO_2$

T= 10. + 273 = 285 K

$P = 12.5 \times \frac{1 \text{ atm}}{101.3 \text{KPa}} = 0.123 \text{ atm}$

2. Plug into equation

$$V = \frac{(0.0781 \text{ moles})(0.0821)(285 \text{ K})}{0.123 \text{ atm}} =$$

14.8 L

Determine Temperature:

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

Determine the temperature in Celsius of a 2.50 liter vessel that contains 14.00 grams of sulfur dioxide and exerts a pressure of 255.2 Kpa.

1. Change all units:

$$n\ SO_2 = 14.00 \text{ grams of } SO_2 \left| \frac{1 \text{ mole } SO_2}{64.0 \text{ g}} \right| = 0.219 \text{ moles } SO_2$$

P = 255.2 / 101.3 KpPa= 2.52 atm

2. Plug into equation

$$T = \frac{(2.52\ \text{atm})(2.50\ \text{L})}{(0.0821)(0.219\ \text{moles})} =$$

350. K

77. celsius

Determine sample size:

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

Determine the mass of a sample of sulfur dioxide in a 750.0 milliliter vessel that exerts a pressure of 875 mmHg at 10.^{0}C.

1. Change all units:

P 875 mmHg = $\frac{1\ \text{atm}}{760\ \text{mmHg}}$ = 1.15 atm

T= 10.+ 273 = 283 K

750.0 ml = 0.7500 L

2. Plug into equation

$$n = \frac{(1.15\ \text{atm})(0.7500\ \text{L})}{(0.0821)(283\ \text{K})} =$$

0.0371 moles

3. Solve for grams n X mm

0.0371 moles SO_2 $\frac{64.0\ \text{g}\ SO_2}{1\ \text{mole}}$ =

2.38 g SO_2

Determine the Gas in a vessel:

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

A label has fallen off a **550.0 milliliter** vessel that exerts a pressure of **775 mmHg at 20.^{0}C.** The empty cylinder has a mass of **987.00 grams.** The cylinder with the gas in it has a mass of **988.49** grams.. Determine the MM of the gas.

1. Change all units:

P 775 mmHg $= \frac{1 \text{ atm}}{760 \text{ mmHg}} =$ 1.02 atm

T= 20.+ 273 = 293 K

550.0 ml = 0.5500 L

2. Plug into equation

$$n = \frac{(1.02 \text{ atm})(0.550 \text{ L})}{(0.0821)(293 \text{ K})} =$$

0.0233 moles

3. Solve for MM by dividing grams of sample by moles

$\frac{1.49 \text{ g}}{0.0233 \text{ mole}}$ =

63.9 g/mole

Could the gas be sulfur dioxide?

Gas Stoichiometry

Gases are affected by temperature and pressure and must be handled differently.

Gases are affected the same way therefore in a chemical reaction in which the reactants and products are gases the volumes the molar volume of a gas may be used as a conversion factor

Gas Stoichiometry

- Many chemical reactions involve gases as a reactant or a product
- **Gas Stoichiometry –** the procedure for calculating the volume of gases as products or reactants
- Gases also have a molar volume (L/mol) rather than concentration.
- This is the conversion factor used to convert (litres of gas) to (moles of gas)
- The Ideal Gas Law ($PV = nRT$) may also be required to:

    A) find the number of moles of reactant

    B) Find the V, P, or T of the product

STP = 22.4L/mol

Molar Volume

- Molar volume is the **same** for all gases at the same temperature and pressure
- Remember, all gases have the same physical properties!
  - At STP, molar volume = 22.4 L/mol (101.325 kPa and 0^{o}C)

This can be used as a conversion factor just like molar mass!

At STP, one mole of gas has a volume of 22.4 L, which is approximately the volume of 11 "empty" 2 L pop bottles.

Example # 1

- What volume of ammonia gas can be produced at 22.0ºC and 787 mmHg given 25.0 milliliters of each reagent?

- First write the balanced equation!

- $N_2 (g) + 3 H_2 (g) \rightarrow 2 NH_3 (g)$

- Note: the coefficients represent equivalent volumes of the gases at the same temperature and pressure.

- Next determine the limiting reagent:

$$25.0 \text{ mL } N_2 \times \frac{2 \ NH_3}{1 \ N2} = 50.0 \text{ mls } NH_3 (g)$$

$$25.0 \text{ ml } H_2 \times \frac{2 \ NH_3}{3 \ H2} = 16.7 \text{ mls } NH_3 (g)$$

How much leftover ???

Example #2

- Hydrogen gas is produced when sodium metal is added to water. What mass of sodium is necessary to produce 20.0L of hydrogen at STP?
- Remember: 22.4L/mol for STP

$$2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$$

m = ?	V = 20.0L
22.99g/mol	22.4L/mol

$$20.0\,\cancel{L} \times \frac{1\,\cancel{mol}}{22.4\,\cancel{L}} \times \frac{2mol\ Na}{1\ mol\ H} \times \frac{22.99g}{1\,\cancel{mol}\ Na} = 41.1\ g\ Na_{(s)}$$

****Remember – molar volume is the conversion factor for gases just like molar mass is the conversion factor in gravimetric stoichiometry**

Example #3

- If 300.0g of propane burns in a gas barbecue, what volume of oxygen measured at STP is required for the reaction?
- Remember: 1 mol of any gas occupies 22.4 L at STP

$C_3H_{8(g)}$	+	$5O_{2(g)}$	→	$3CO_{2(g)}$	+	$4H_2O_{(g)}$
m = 300g		m = ?				
44.11g/mol		22.4L/mol				

$$300.0\ \text{g} \times \frac{1\ \text{mol}}{44.11\ \text{g}} \times \frac{5\ \text{mol}\ O_2}{1\ \text{mol}\ C_3H_8} \times \frac{22.4\ \text{L}}{1\ \text{mol}} = 762\ \text{L}\ O_{2(g)}$$

****Remember – molar volume is the conversion factor for gases just like molar mass is the conversion factor in gravimetric stoichiometry**

Gas Stoichiometry Summary

1. Write a balanced chemical equation and list the measurements, unknown quantity symbol, and conversion factors for the measured and required substances.
2. Convert the measured quantity to a chemical amount using the appropriate conversion factor
3. Calculate the chemical amount of the required substance using the mole ratio from the balanced chemical equation.
4. Convert the calculated chemical amount to the final quantity requested using the appropriate conversion factor.

Given Volume Going To Grams Non- STP

1. Solve PV= nRT for moles A

   n_A= PV/ RT

2. Solve Stoich Expression for Grams B

Moles A	# Moles B	MM B
	# Moles A	1 Mole B

Example

If the conditions are not STP , the molar volume cannot be used! You must use the ideal gas law to find the gas values using moles determined from stoichiometry

- 5.50×10^3 liters of ammonia formed at 450kPa and 80.°C. How many grams of hydrogen were required?

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

	H_2	NH_3
	m = X Grams	V= 5.50 x 103 l
	M = 2.02 g/mol	P = 450kPA
	T = 353.13K	

$$n = PV/RT = \frac{(4.44 atm)(5.50 \times 10^3 \text{ liters})}{(0.0821 \, ^{atm \bullet L}/_{mol \bullet K})(4.44 atm)}$$

$= \rightarrow 6.70 \times 10^4$ moles $\mathbf{NH_{3(g)}}$

$$6.70 \times 10^4 \text{ moles } \mathbf{NH_{3(g)}} \left| \frac{3\ H_2}{2\ NH_3} \right| \frac{2.02 \text{ grams}}{1 \text{ mole } H_2} \right| = 203 \text{ kilograms} H_{2(g)}$$

Example

If the conditions are not STP , the molar volume cannot be used! You must use the ideal gas law to find the gas values using moles determined from stoichiometry

- What volume of ammonia at 450kPa and 80°C can be obtained from the complete reaction of 7.5kg of hydrogen with nitrogen?

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

For H_2: m = 7500g, M = 2.02 g/mol

For NH_3: m = ?, P = 450kPA, T = 353.13K

$$7500 \text{ g} \times \frac{1 \text{ mol}}{2.02 \text{ g}} \times \frac{2 \text{ } NH_3}{3 \text{ } H_2} = 2475.2475 \text{ mol } NH_{3(g)}$$

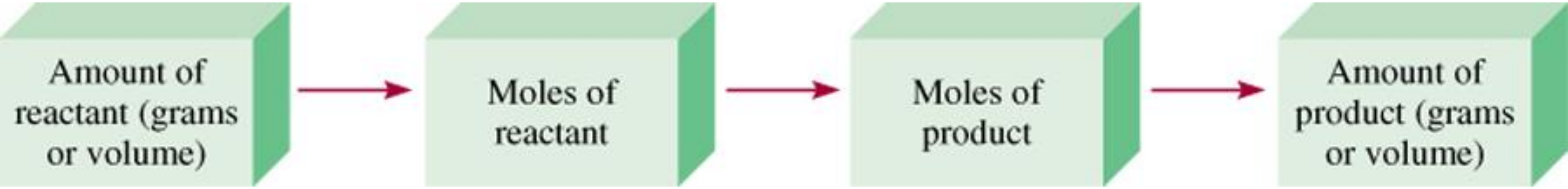
$$PV = nRT \rightarrow V = \frac{nRT}{P} = \frac{(2475.2475 \text{ mol})(0.0821 \frac{atm \cdot L}{mol \cdot K})(353.15 \text{K})}{(4.44 \text{atm})}$$

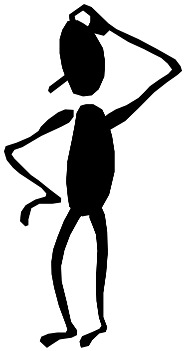
$$= 16150.10\text{L} \rightarrow \mathbf{1.6 \times 10^4 \text{ L of } NH_{3(g)}}$$

Given Grams going to Volume of a gas non- STP

- 1. Solve stoich expression to change grams of material A to moles of gas B
- $$\text{Grams A} \times \frac{1 \text{ Mol A}}{\text{MM A}} \times \frac{\# \text{ moles B}}{\# \text{moles A}} = \text{Moles B}$$
- 2. Solve PV=nRT for V_B $$V_B = \frac{n_B RT}{P}$$

Gas Stoichiometry





What is the volume of CO_2 produced at 37^0 C and 1.00 atm when 5.60 g of glucose are used up in the reaction:

$$C_6H_{12}O_6\ (s) + 6O_2\ (g) \longrightarrow 6CO_2\ (g) + 6H_2O\ (l)$$

$$\text{g } C_6H_{12}O_6 \longrightarrow \text{mol } C_6H_{12}O_6 \longrightarrow \text{mol } CO_2 \longrightarrow V\ CO_2$$

$$5.60 \text{ g } C_6H_{12}O_6 \times \frac{1 \text{ mol } C_6H_{12}O_6}{180 \text{ g } C_6H_{12}O_6} \times \frac{6 \text{ mol } CO_2}{1 \text{ mol } C_6H_{12}O_6} = 0.187 \text{ mol } CO_2$$

$$V = \frac{nRT}{P} = \frac{0.187 \text{ mol} \times 0.0821 \frac{\text{L}\bullet\text{atm}}{\text{mol}\bullet\text{K}} \times 310.15 \text{ K}}{1.00 \text{ atm}} = 4.76 \text{ L}$$

Your Turn To Try

Gas Stoichiometry #1

If reactants and products are at the same conditions of temperature and pressure, then mole ratios of *gases* are also volume ratios.

3 $H_2(g)$ + $N_2(g)$ → 2$NH_3(g)$

3 moles H_2 + 1 mole N_2 → 2 moles NH_3

3 liters H_2 + 1 liter N_2 → 2 liters NH_3

Gas Stoichiometry #2

How many liters of ammonia can be produced when 12 liters of hydrogen react with an excess of nitrogen?

$$\underline{3}\ H_2(g) + N_2(g) \rightarrow \underline{2}\ NH_3(g)$$

$$\frac{12\ \cancel{L\ H_2}}{} \times \frac{2\ L\ NH_3}{3\ \cancel{L\ H_2}} = 8.0\ L\ NH_3$$

Gas Stoichiometry #3 At STP

How many liters of oxygen gas, at STP, can be collected from the complete decomposition of 50.0 grams of potassium chlorate?

$$2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g)$$

50.0 g $KClO_3$	1 mol $KClO_3$	3 mol O_2	22.4 L O_2
	122.55 g $KClO_3$	2 mol $KClO_3$	1 mol O_2

= 13.7 L O_2

Gas Stoichiometry #4

How many liters of oxygen gas, at 37.0°C and 0.930 atmospheres, can be collected from the complete decomposition of 50.0 grams of potassium chlorate?

$$2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g)$$

$$\frac{50.0\ \text{g KClO}_3}{} \times \frac{1\ \text{mol KClO}_3}{122.55\ \text{g KClO}_3} \times \frac{3\ \text{mol O}_2}{2\ \text{mol KClO}_3} = 0.612\ \text{mol O}_2$$

$$V = \frac{nRT}{P} = \frac{(0.612\ \text{mol})(0.0821\ \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(310\ \text{K})}{0.930\ \text{atm}} = 16.7\ \text{L}$$

Gas Stoichiometry #5

15.5 liters of oxygen gas was collected at 37.0°C and 0.930 atmosphere when potassium chlorate decomposed. How many grams were used?

$$2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g)$$

$$n = \frac{PV}{RT} = \frac{(15.0\ L)\ 0.930\ atm}{(0.0821\ \frac{L \cdot atm}{mol \cdot K})\ (310K)} = 0.548\ mol\ O_2$$

$$0.548\ moles\ O_2 \left|\ \frac{2\ mol\ KClO_3}{3\ mol\ O_2}\ \right|\ \frac{122.55\ g\ KClO_3}{1\ mol\ KClO_3} = 44.8\ grams$$