STOICHIOMETRY

3.4 Avogadro's Number and the Mole

3.6 Quantitative Information from Balanced Equations

3.7 Limiting Reactants

The Mole

SI unit for amount of substance

The *mole (mol)* is the amount of a substance that contains as many objects as there are atoms in exactly 12.00 grams of Carbon-12

The Mole

1 mol = 6.02×10^{23}

6.02×10^{23} = Avogadro's number (N_A)

1 mol of H atoms = 6.02×10^{23} atoms

1 mol of Na^+ ions = 6.02×10^{23} ions

1 mol of CO_2 molec. = 6.02×10^{23} molec.

The Mole

1 mol of particles = 6.02×10^{23} particles

This is a conversion factor that allows us to convert between moles & number of particles (atoms, ions, molecules,….)

$$\frac{6.02 \times 10^{23}}{1 \text{ mol}} \equiv \frac{1 \text{ mol}}{6.02 \times 10^{23}}$$

The Mole

How many He atoms are in 1.61 mol He

$$1.61\ \cancel{\text{mol}} \times \frac{6.02 \times 10^{23}\ \text{atoms}}{\cancel{\text{mol}}} = 9.69 \times 10^{23}\ \text{atoms}$$

mol $\xrightarrow{N_A}$ atoms
molecules
apples

The Mole

How many mol are 9.69×10^{23} atoms of He

$$9.69 \times 10^{23}\ \cancel{\text{atoms}} \times \frac{\text{mol}}{6.02 \times 10^{23}\ \cancel{\text{atoms}}} = 1.61\ \text{mol}$$

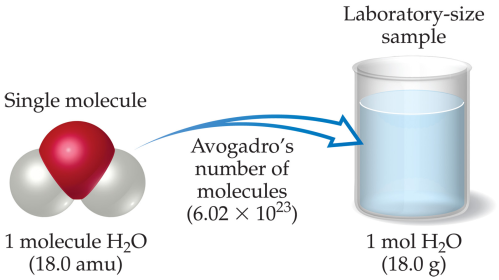
atoms
molecules
apples $\xrightarrow{\frac{1}{N_A}}$ mol

But How to Count Avogadro's Number?

Molar Mass ($\mathcal{M}$ = g/mol):

The mass of 1 mole of the substance in grams

The mass of 6.02×10^{23} units of the substance

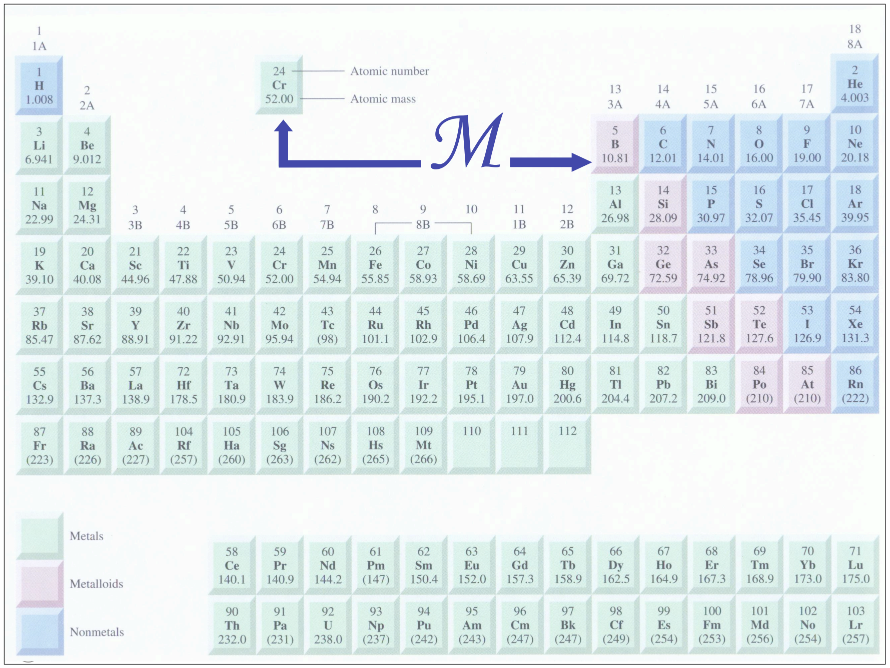


The mass of:

1 mol ^{12}C atoms = 12.00 g

6.02×10^{23} ^{12}C atoms = 12.00 g

$\mathcal{M}(^{12}C)$ = 12.00 g/mol



24
Cr
52.00 — Atomic number / Atomic mass

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (257)	105 **Ha** (260)	106 **Sg** (263)	107 **Ns** (262)	108 **Hs** (265)	109 **Mt** (266)	110	111	112						

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (147)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.0	91 **Pa** (231)	92 **U** 238.0	93 **Np** (237)	94 **Pu** (242)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (249)	99 **Es** (254)	100 **Fm** (253)	101 **Md** (256)	102 **No** (254)	103 **Lr** (257)

Metals
Metalloids
Nonmetals

Molar masses for molecules:

The sum of molar masses of all atoms in the molecule.

SO_2	1 S		32.07	g/mol
		+		
	2 O		2 (16.00)	g/mol
$\mathcal{M}$ (SO_2)			64.07	g/mol

1 molecule SO_2	1 S atom	2 O atoms
1 mol SO_2	1 mol S atom	2 mol O atoms

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23 g Na^+ = 1 mol Na^+ = 6.02 x 10^{23} Na^+ ions

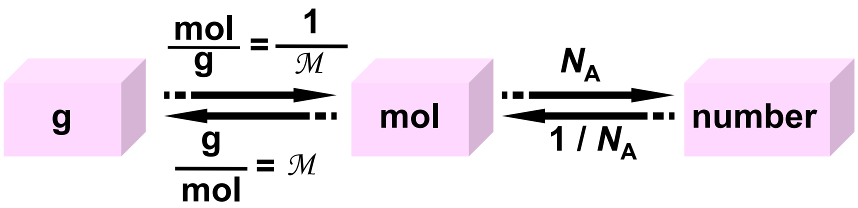
24 g Mg = 1 mol Mg = 6.02 x 10^{23} Mg atoms

1 g H = 1 mol H = 6.02 x 10^{23} H atoms

2 g H_2 = 1 mol H_2 = 6.02 x 10^{23} H_2 molecules

= 2 x 6.02 x 10^{23} H atoms

44 g CO_2 = 1 mol CO_2 = 6.02 x 10^{23} CO_2 molecules



$$\frac{\text{mol}}{\text{g}} = \frac{1}{\mathcal{M}}$$

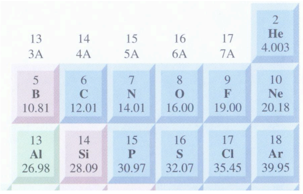
g ⇄ mol ⇄ number

N_A

$1 / N_A$

$$\frac{\text{g}}{\text{mol}} = \mathcal{M}$$

Which contains more atoms 4 g of ^4He or 16 g of ^{16}O ?



13 3A	14 4A	15 5A	16 6A	17 7A	2 **He** 4.003
5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95

4 g He = 1 mol He = 6.022 x 10^{23} He atoms

16 g O = 1 mol O = 6.022 x 10^{23} O atoms

Both contain the same number of atoms

How many moles of He atoms are in 6.46 g of He?

$$\text{g} \xrightarrow{\frac{1}{\mathcal{M}}} \text{mol}$$

$$6.46\ \cancel{\text{g}}\ \text{He} \times \frac{1\ \text{mol He}}{4.003\ \cancel{\text{g}}\ \text{He}} = 1.61\ \text{mol He}$$

Convert 1.61 mol of He to g

$$\text{mol} \xrightarrow{\mathcal{M}} \text{g}$$

How many He atoms are in 6.46 g of He?

$$\text{g} \xrightarrow{\frac{1}{\mathcal{M}}} \text{mol} \xrightarrow{N_A} \text{atoms}$$

$$6.46\ \cancel{\text{g He}} \times \frac{1\ \cancel{\text{mol He}}}{4.003\ \cancel{\text{g He}}} \times \frac{6.02 \times 10^{23}\ \text{He atoms}}{1\ \cancel{\text{mol He}}}$$

$$= 9.72 \times 10^{23}\ \text{He atoms}$$

How many H atoms are in 72.5 g of C_3H_8O

$$\text{g} \xrightarrow{\frac{1}{\mathcal{M}}} \begin{matrix}\text{mol}\\ C_3H_8O\end{matrix} \xrightarrow{8} \text{mol H} \xrightarrow{N_A} \text{H atoms}$$

1 C_3H_8O molecule ≡ 8 H atoms

1 mol C_3H_8O molecules ≡ 8 mol H atoms

$\mathcal{M}(C_3H_8O) = 3(12) + 8(1) + 1(16) = 60.\ \text{g/mol}$

$$72.5\ \cancel{\text{g}\ C_3H_8O} \times \frac{1\ \cancel{\text{mol}\ C_3H_8O}}{60.0\ \cancel{\text{g}\ C_3H_8O}} \times$$

$$\frac{8\ \cancel{\text{mol H atoms}}}{1\ \cancel{\text{mol}\ C_3H_8O}} \times \frac{6.022 \times 10^{23}\ \text{H atoms}}{1\ \cancel{\text{mol H atoms}}}$$

$$= 5.82 \times 10^{24}\ \text{H atoms}$$

How many water molecules present in 2.56 mL of water. d = 1.00 g/mL.

mL $\rightarrow$ g $\rightarrow$ mol $\rightarrow$ molecules

$$2.56\ \cancel{\text{mL H}_2\text{O}} \times \frac{1.00\ \cancel{\text{g H}_2\text{O}}}{\cancel{\text{mL H}_2\text{O}}} \times$$

$$\frac{1\ \cancel{\text{mol H}_2\text{O}}}{18.02\ \cancel{\text{g H}_2\text{O}}} \times \frac{6.022 \times 10^{23}\ \text{H}_2\text{O molec}}{\cancel{\text{mol H}_2\text{O}}}$$

$= 8.56 \times 10^{22}$ H_2O molec

Stoichiometry

The study of quantities of materials consumed and produced in chemical reactions.

$$2CH_3OH \ + \ 3O_2 \ \rightarrow \ 2CO_2 \ + \ 4H_2O$$

Reactants Products

2, 3, 2, 4: stoichiometric coefficients (mole ratios)

2 mol of CH_3OH reacts with 3 mol of O_2 to produce 2 mol of CO_2 and 4 mol of H_2O

$$2CH_3OH \ + \ 3O_2 \rightarrow 2CO_2 \ + \ 4H_2O$$

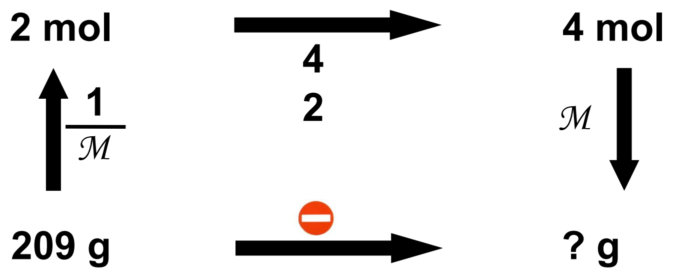
$$\frac{2\ \text{mol CH}_3\text{OH}}{2\ \text{mol CO}_2} \qquad \frac{3\ \text{mol O}_2}{2\ \text{mol CH}_3\text{OH}} \qquad \frac{2\ \text{mol CH}_3\text{OH}}{4\ \text{mol H}_2\text{O}}$$

How many moles of oxygen are required to burn 5.00 moles of methanol?

$$5.00\ \cancel{\text{mol CH}_3\text{OH}} \times \frac{3\ \text{mol O}_2}{2\ \cancel{\text{mol CH}_3\text{OH}}} = 7.50\ \text{mol O}_2$$

What mass of water is produced if 209 g of methanol is burned?

$$2CH_3OH \ + \ 3O_2 \ \rightarrow \ 2CO_2 \ + \ 4H_2O$$



g CH_3OH ➤ mol CH_3OH ➤ mol H_2O ➤ g H_2O

$$2CH_3OH \quad + \quad 3O_2 \quad \rightarrow \quad 2CO_2 \quad + \quad 4H_2O$$

g CH_3OH ➤ mol CH_3OH ➤ mol H_2O ➤ g H_2O

$$209\ \cancel{g\ CH_3OH} \times \frac{1\ \cancel{mol\ CH_3OH}}{32.0\ \cancel{g\ CH_3OH}} \times$$

$$\frac{4\ \cancel{mol\ H_2O}}{2\ \cancel{mol\ CH_3OH}} \times \frac{18.02\ g\ H_2O}{1\ \cancel{mol\ H_2O}}$$

$= 235$ g H_2O

What mass of O_2 required to produce 155 g CO_2?

$$2CH_3OH \quad + \quad 3O_2 \quad \rightarrow \quad 2CO_2 \quad + \quad 4H_2O$$

g CO_2 mol CO_2 mol O_2 g O_2

$$155\ \cancel{g\ CO_2} \times \frac{1\ \cancel{mol\ CO_2}}{44.0\ \cancel{g\ CO_2}} \times \frac{3\ \cancel{mol\ O_2}}{2\ \cancel{mol\ CO_2}} \times$$

$$\frac{32.0\ g\ O_2}{1\ \cancel{mol\ O_2}} = 169\ g\ O_2$$

6.50 grams of aluminum reacts with an excess of oxygen. How many grams of aluminum oxide are formed?

$$4Al \quad + \quad 3O_2 \quad \rightarrow \quad 2Al_2O_3$$

Answer = 12.3 g Al_2O_3 produced

Limiting & Excess Reactants

Limiting reactant: The reactant that is consumed first, limiting the amounts of products formed.

$$2NO \quad + \quad O_2 \quad \rightarrow \quad 2NO_2$$

2 mol	1 mol		2 mol
6 mol	3 mol		6 mol
6 mol	6 mol	3 react 3 excess	6 mol
Limiting reactant	Excess reactant		

If 124 g of Al are reacted with 601 g of Fe_2O_3, calculate the mass of Al_2O_3 formed.

$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$

g Al have ➡ mol Al ➡

mol Fe_2O_3 ➡ g Fe_2O_3 needed

OR

g Fe_2O_3 have ➡ mol Fe_2O_3

➡ mol Al ➡ g Al needed

$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$

124 g 601 g

g Al ➡ mol Al ➡ mol Fe_2O_3 needed ➡ g Fe_2O_3 needed

$$124\ \cancel{\text{g Al}} \times \frac{1\ \cancel{\text{mol Al}}}{27.0\ \cancel{\text{g Al}}} \times \frac{1\ \cancel{\text{mol } Fe_2O_3}}{2\ \cancel{\text{mol Al}}}$$

$$\times \frac{160.\ \text{g } Fe_2O_3}{1\ \cancel{\text{mol } Fe_2O_3}} = 367\ \text{g } Fe_2O_3 \text{ needed}$$

$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$

124 g 601 g

Start with 124 g Al ➡ need 367 g Fe_2O_3

Have more (601 g) Fe_2O_3

∴ Fe_2O_3 in EXCESS

Al is LIMITING REACTANT

Use LIMITING REACTANT to calculate amount of product that can form

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How many grams Al_2O_3 will form?

$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$

124 g

g Al ➡ mol Al ➡ mol Al_2O_3 ➡ g Al_2O_3 formed

$$124\ \cancel{\text{g Al}} \times \frac{1\ \cancel{\text{mol Al}}}{27.0\ \cancel{\text{g Al}}} \times \frac{1\ \cancel{\text{mol } Al_2O_3}}{2\ \cancel{\text{mol Al}}}$$

$$\times \frac{102\ \text{g } Al_2O_3}{1\ \cancel{\text{mol } Al_2O_3}} = 234\ \text{g } Al_2O_3$$

$2H_2 + O_2 \rightarrow 2H_2O$

If 5.00 g of H_2 and 5.00 g of O_2 were reacted, how many grams of H_2O will be produced and how many grams of each reactant will remain?

Answer = 5.63 g H_2O; 4.37 g H_2.

Reaction Yield

Theoretical Yield:

amount of product that would form if all limiting reagent reacted.

Actual Yield:

amount of product actually obtained from a reaction.

$$\% \text{ Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$

When 5.00 g of C_4H_{10} and 5.00 g of O_2 were reacted, the actual yield of CO_2 was 3.56 g. What is the % yield of CO_2?

$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

$$5.00 \cancel{\text{ g } C_4H_{10}} \times \frac{1 \cancel{\text{ mol } C_4H_{10}}}{58.1 \cancel{\text{ g } C_4H_{10}}} \times \frac{13 \cancel{\text{ mol } O_2}}{2 \cancel{\text{ mol } C_4H_{10}}}$$

$$\times \frac{32.0 \text{ g } O_2}{1 \cancel{\text{ mol } O_2}} = 17.9 \text{ g } O_2 \text{ needed}$$

Have only 5.00 g O_2

O_2 is LIMITING REACTANT

$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

Theoretical yield of CO_2:

$$5.00 \cancel{\text{ g } O_2} \times \frac{1 \cancel{\text{ mol } O_2}}{32.0 \cancel{\text{ g } O_2}} \times \frac{8 \cancel{\text{ mol } CO_2}}{13 \cancel{\text{ mol } O_2}}$$

$$\times \frac{44.0 \text{ g } CO_2}{1 \cancel{\text{ mol } CO_2}} = 4.23 \text{ g } CO_2$$

$$\% \text{ Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100$$

$$\% \text{ Yield} = \frac{3.56}{4.23} \times 100\% = 84.2\%$$

Reaction Yield

When 5.00 g of H_2 and 5.00 g of O_2 were reacted, the yield of H_2O was 87.9%. What is the actual yield of H_2O?

$$2H_2 + O_2 \rightarrow 2H_2O$$

Answer **= 4.95 g**