Mass Relationship

Periodic Table

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 **H** 1.01																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											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** 39.1	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** 72.61	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** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.29
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	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac^** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (264)	108 **Hs** (265)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

*	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	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** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

Molar Calculations

The Mole and Molar Mass

- **The mole (mol)** is the amount of a substance that contains the same number of entities as there are atoms in exactly **12 g** of **carbon-12**.

➢ 1 mole of glucose molecule ($C_6H_{12}O_6$) contains 6 moles of C atoms, 12 moles of H atoms, and 6 moles of O atoms.

- One mole (1 mol) contains $\mathbf{6.022 \times 10^{23}}$ entities. This constant value is known as **Avogadro's Number** (***N***).

- **The molar mass** of a substance is the mass of one mole of the substance in grams.

➢ Atomic mass of Na = 22.99 amu. Molar mass of Na = 22.99 g

Sample Problem 3.1

Silver (Ag, Z = 47) is used in jewelry and tableware but no longer in U.S. coins. How many grams of Ag are in 0.0342 mol of Ag?

SOLUTION

$$0.0342\ \cancel{\text{mol Ag}} \times \frac{107.9\text{ g Ag}}{1\ \cancel{\text{mol Ag}}}$$

$$= \boxed{3.69\text{ g Ag}}$$

Sample Problem 3.3

Iron (Fe, Z = 26) is the main component of steel and is therefore the most important metal in society. How many Fe atoms are in 95.8 g of Fe?

SOLUTION

$$95.8\,\cancel{g\,Fe} \times \frac{1\ \cancel{mol\ Fe}}{55.85\ \cancel{g\ Fe}} \times \frac{6.022\times10^{23}\ \text{Fe atoms}}{1\ \cancel{mol\ Fe}}$$

$$= \boxed{1.03\times10^{24}\ \text{Fe atoms}}$$

Sample Problem 3.5

Ammonium carbonate, or $(NH_4)_2CO_3$, a white solid that decomposes on warming, is a component of baking powder.

a) How many *formula units* are in 41.6 g of ammonium carbonate?

b) How many O atoms are in this sample?

SOLUTION

(a) Molar mass $(NH_4)_2CO_3 = 2(14 + 4 \times 1) + 12 + 3 \times 16$ g

$= 96$ g.

$$41.6\,\cancel{g\,(NH_4)_2}CO_3 \times \frac{1\,\text{mol}\,\cancel{(NH_4)_2}CO_3}{96\,\cancel{g\,(NH_4)_2CO_3}} \times \frac{6.022 \times 10^{23}\ \text{For. Unit.}}{1\,\text{mol}\,\cancel{(NH_4)_2}CO_3}$$

$$= \boxed{2.61 \times 10^{23}\ \text{for. units}}$$

(b) $$\frac{3\ \text{Oxy atoms}}{1\ \text{For. Unit}\ \cancel{(NH_4)_2}CO_3} \times (2.61 \times 10^{23})\,(NH_4)_2\cancel{CO_3\ \text{units}}$$

$$= \boxed{7.83 \times 10^{23}\ \text{O atoms}}$$

Mass Percent

Sample Problem 3.6

Ammonium nitrate, or NH_4NO_3, is a common fertilizer. What is the mass percent of each element in ammonium nitrate?

SOLUTION

Molar mass $NH_4NO_3 = (14 + 4\times1 + 14 + 3\times16)$ g

$= 80$ g

Mass of N atoms in $NH_4NO_3 = 2\times14$ g $= 28$g.

Mass of H atoms " " $= 4\times1$ g $= 4$g

Mass of O atoms " " $= 3\times16$g $= 48$g.

% mass N $= \dfrac{28\cancel{g}}{80\cancel{g}} \times 100\% = 35\%$

% mass H $= \dfrac{4g}{80g} \times 100\% = 5\%$

% mass O $= \dfrac{48g}{80g} \times 100\% = 60\%$

100%

Molecular Formula and Empirical Formula

Molecular and Empirical Formulas

- **The molecular formula** shows the ***actual*** number of atoms of each element in a molecule.

- **The empirical formula** is the simplest formula for a molecule — it shows the ***lowest whole number of moles*** and gives the ***relative*** number of atoms of each element present.

➢ The **molecular formula** for glucose is $\mathbf{C_6H_{12}O_6}$ while its **empirical formula** is $\mathbf{CH_2O}$.

➢ The **molecular formula** for hydrogen peroxide is $\mathbf{H_2O_2}$ while its **empirical formula** is **HO**.

Sample Problem 3.8

A sample of an unknown compound contains 0.21 mol of zinc, 0.14 mol of phosphorus, and 0.56 mol of oxygen. What is its empirical formula?

SOLUTION

$$Zn : P : O = 0.21 \text{ mol} : 0.14 \text{ mol} : 0.56 \text{ mol}$$

$$= \frac{0.21 \text{ mol}}{0.14 \text{ mol}} : \frac{0.14 \text{ mol}}{0.14 \text{ mol}} : \frac{0.56 \text{ mol}}{0.14 \text{ mol}}$$

$$= (1.5 : 1 : 4)2$$

$$= 3 : 2 : 8$$

$$\boxed{Zn_3P_2O_8}$$

Sample Problem 3.9

Analysis of a sample of an ionic compound yields 2.82 g of Na, 4.35 g of Cl, and 7.83 g of O. What is the empirical formula?

SOLUTION

$$Na : Cl : O = 2.82\,g : 4.35\,g : 7.83\,g$$

$$= 2.82\,\cancel{g} \times \frac{1\,mol\,Na}{23\,\cancel{g\,Na}} : 4.35\,\cancel{g} \times \frac{1\,mol\,Cl}{35.5\,\cancel{g\,Cl}} : 7.83\,\cancel{g} \times \frac{1\,mol\,O}{16\,\cancel{g\,O}}$$

$$= \frac{0.12\,mol}{0.12} : \frac{0.12\,mol}{0.12} : \frac{0.49\,mol}{0.12}$$

$$= 1 : 1 : 4$$

$$\boxed{NaClO_4}$$

Sample Problem 3.10

Elemental analysis of lactic acid (Molar Mass = 90.08 g/mol) shows that this compound contains 40.0 mass % C, 6.71 mass % H, and 53.3 mass % O. Determine the empirical formula and the molecular formula for lactic acid.

SOLUTION

(a)

$$C : H : O = 40.0\% : 6.71\% : 53.3\%$$

If we consider the total mass of lactic acid to be 100g,

then

$$C : H : O = 40.0g : 6.71g : 53.3g$$

$$= 40.0\cancel{g}\,C \times \frac{1\,mol\,C}{12\cancel{g}\,C} : 6.71\cancel{g} \times \frac{1\,mol\,H}{1\cancel{g}\,H} : 53.3\cancel{g} \times \frac{1\,mol\,O}{16\,\cancel{g}\,O}$$

$$= \frac{3.33\,mol}{3.33} : \frac{6.71\,mol}{3.33} : \frac{3.33\,mol}{3.33}$$

$$= 1 : 2 : 1$$

$$\boxed{CH_2O}$$

(b)

$$n(CH_2O) = \text{molecular formula}$$

$$n(CH_2O) = 90.08\,g/mol$$

$$n(12 + 2 \times 1 + 16)\,g/mol = 90.08\,g/mol \Rightarrow n = 3$$

$$\boxed{C_3H_6O_3}$$

Balancing Chemical Equations

Balancing a Chemical Equation

Translate the statement

Magnesium and oxygen gas react to give magnesium oxide:

$$\mathbf{Mg + O_2 \rightarrow MgO}$$

Balance the atoms using *coefficients*; *formulas cannot be changed*

$$\mathbf{2Mg + O_2 \rightarrow 2MgO}$$

Adjust coefficients if necessary

Check that all atoms balance

Specify states of matter

$$\mathbf{2Mg\ (\textit{s}) + O_2\ (\textit{g}) \rightarrow 2MgO\ (\textit{s})}$$

Sample Problem 3.12

Octane (C_8H_{18}) mixes with oxygen from the air and burns to form carbon dioxide and water vapor. Write a balanced equation for this reaction.

SOLUTION

$$2 \times \left(C_8H_{18}(l) + 12.5\,O_2(g) \rightarrow 8\,CO_2(g) + 9\,H_2O(g) \right)$$

$$\boxed{2\,C_8H_{18}(l) + 25\,O_2(g) \rightarrow 16\,CO_2(g) + 18\,H_2O(g)}$$

Related Problems

Problem 3.11 (d)

Calculate the molar mass of $Ca(C_2H_3O_2)_2$.

Problem 3.15 (c)

Calculate the number of H^- ions in 5.82g of SrH_2.

Sr^{2+} H^-

Problem 3.21 (a)

Calculate the mass % of I in strontium periodate.

Sr^{2+} IO_4^-

Related Problems

Problem 3.41 (d)

What is the Molecular Formula when the given Empirical Formula is $C_7H_4O_2$ (Molar Mass = 240.20 g/mol).

Problem 3.44

An oxide of nitrogen contains 30.45 mass % N.

(a) What is the empirical formula of the oxide?

(b) If the molar mass is 90 $\pm$5 g/mol, what is the molecular formula?

Problem 3.46

A sample of 0.600 mol of a metal M reacts completely with excess fluorine to form 46.8 g of MF_2.

(a) How many moles of F are in the sample of MF_2 that forms?

(b) How many grams of M are in this sample of MF_2?

(c) What element is represented by the symbol M?

Related Problems

Problem 3.56 (b)

Balance: $\_\_P_4O_{10}$ (s) + $\_\_H_2O$ (l) → $\_\_H_3PO_4$ (l)

Problem 3.58 (c)

Balance: $\_\_H_3PO_4$ (aq) + $\_\_NaOH$ (aq) → $\_\_Na_2HPO_4$ (aq) + $\_\_H_2O$ (l)

Problem 3.60 (b)

Balance: Liquid hexane burns in oxygen gas to form carbon dioxide gas and water vapor.

Problem 3.61 (a)

Balance: When lead(II) nitrate solution is added to potassium iodide solution, solid lead(II) iodide forms and potassium nitrate solution remains.

Reaction Stoichiometry

Stoichiometric Calculations

$$C_3H_8\ (g)\ +\ 5O_2\ (g) \rightarrow 3CO_2\ (g)\ +\ 4H_2O\ (g)$$

- The coefficients in a balanced chemical equation
  - represent the relative number of reactant and product particles
  - and the relative number of moles of each.

- Since moles are related to mass
  - the equation can be used to calculate masses of reactants and/or products for a given reaction.

- The **mole ratios** from the balanced equation are used as **conversion factors**.

Sample Problem 3.14

Copper is obtained from copper(I) sulfide by roasting it in the presence of oxygen gas to form powdered copper(I) oxide and gaseous sulfur dioxide. How many moles of oxygen are required to roast 10.0 mol of copper(I) sulfide?

SOLUTION

$\overset{+1}{Cu}\ \overset{-2}{S}$ $\quad$ $\overset{+1}{Cu}\ \overset{-2}{O}$

Cu_2S $\quad$ Cu_2O

$$2\,Cu_2S_{(s)} + 3\,O_{2(g)} \rightarrow 2\,Cu_2O_{(s)} + 2\,SO_{2(g)}$$

$$10.0\ \text{mol}\ \cancel{Cu_2S} \times \frac{3\ \text{mol}\ O_2}{2\ \text{mol}\ \cancel{Cu_2S}} = \boxed{15.0\ \text{mol}\ O_2}$$

Sample Problem 3.15

During the process of roasting copper(I) sulfide, how many grams of sulfur dioxide form when 10.0 mol of copper(I) sulfide reacts?

$$2Cu_2S\ (s) + 3O_2\ (g) \rightarrow 2Cu_2O\ (s) + 2SO_2\ (g)$$

SOLUTION

$$10.0\ \cancel{\text{mol } Cu_2S} \times \frac{2\ \cancel{\text{mol } SO_2}}{2\ \cancel{\text{mol } Cu_2S}} \times \frac{64\ \text{g } SO_2}{1\ \cancel{\text{mol } SO_2}}$$

$$= \boxed{640\ \text{g } SO_2}$$

M.M. SO_2

$= (32 + 2 \times 16)\text{g}$

$= 64\text{g}$

Sample Problem 3.16

During the roasting of copper(I) sulfide, how many kilograms of oxygen are required to form 2.86 kg of copper(I) oxide?

$$2Cu_2S\ (\textit{s}) + 3O_2\ (\textit{g}) \rightarrow 2Cu_2O\ (\textit{s}) + 2SO_2\ (\textit{g})$$

SOLUTION

$$2.86\ \cancel{kg\ Cu_2O} \times \frac{1000\ \cancel{g\ Cu_2O}}{1\ \cancel{kg\ Cu_2O}} \times \frac{1\ \cancel{mol\ Cu_2O}}{142\ \cancel{g\ Cu_2O}} \times \frac{3\ \cancel{mol\ O_2}}{2\ \cancel{mol\ Cu_2O}}$$

$$\times \frac{32\ \cancel{g\ O_2}}{1\ \cancel{mol\ O_2}} \times \frac{1\ kg\ O_2}{1000\ \cancel{g\ O_2}}$$

$$= \boxed{0.96\ kg\ O_2}$$

M.M. Cu_2O = 142 g

M.M. O_2 = 16 g

Limiting Reactant

- So far we have assumed that reactants are present in the correct amounts to react completely.
- In reality, one reactant may ***limit*** the amount of product that can form.
- The ***limiting*** reactant gets completely used up in the reaction.
- The reactant that is **not limiting** is in ***excess*** – some of this reactant will be left over.

$$2Cu_2S\ (s) + 3O_2\ (g) \rightarrow 2Cu_2O\ (s) + 2SO_2\ (g)$$

Sample Problem 3.19

In the balanced equation:

$$Cl_2\ (g) + 3F_2\ (g) \rightarrow 2ClF_3\ (g)$$

0.750 mol of Cl_2 reacts with 3.00 mol of F_2. Find the limiting reactant.

SOLUTION

Cl_2 is limiting reactant

$$0.750\ \cancel{mol\ Cl_2} \times \frac{2\ mol\ ClF_3}{1\ \cancel{mol\ Cl_2}} = 1.50\ mol\ ClF_3$$

$$3.00\ \cancel{mol\ F_2} \times \frac{2\ mol\ ClF_3}{3\ \cancel{mol\ F_2}} = 2.00\ mol\ ClF_3$$

Sample Problem 3.20

Hydrazine (N_2H_4) and dinitrogen tetraoxide (N_2O_4) ignite on contact to form nitrogen gas and water vapor.

(a) How many grams of nitrogen gas form when 1.00×10^2 g of N_2H_4 and 2.00×10^2 g of N_2O_4 are mixed?

SOLUTION

$$\boxed{2\,N_2H_4\,(l) + N_2O_4\,(l) \longrightarrow 3\,N_2(g) + 4\,H_2O(g)}$$

i) $$1.00 \times 10^2\ \cancel{g\ N_2H_4} \times \frac{1\ \cancel{mol\ N_2H_4}}{32\ \cancel{g\ N_2H_4}} \times \frac{3\ \cancel{mol\ N_2}}{2\ \cancel{mol\ N_2H_4}} \times \frac{28\ g\ N_2}{1\ \cancel{mol\ N_2}}$$

$$= \boxed{1.31 \times 10^2\ g\ N_2}$$

ii) $$2.00 \times 10^2\ \cancel{g\ N_2O_4} \times \frac{1\ \cancel{mol\ N_2O_4}}{92\ \cancel{g\ N_2O_4}} \times \frac{3\ \cancel{mol\ N_2}}{1\ \cancel{mol\ N_2O_4}} \times \frac{28\ g\ N_2}{1\ \cancel{mol\ N_2}}$$

$$= \boxed{1.82 \times 10^2\ g\ N_2}$$

$N_2H_4 \rightarrow$ lim. reactant

1.31×10^2 g of N_2

Sample Problem 3.20 (continued)

(b) How many grams of the excess reactant remain unreacted when the reaction is over?

$$2N_2H_4\ (l) + N_2O_4\ (l) \rightarrow 3N_2\ (g) + 4H_2O\ (g)$$

SOLUTION

$$1.00 \times 10^2\ \cancel{g\ N_2H_4} \times \frac{1\ \cancel{mol\ N_2H_4}}{32\ \cancel{g\ N_2H_4}} \times \frac{1\ \cancel{mol\ N_2O_4}}{2\ \cancel{mol\ N_2H_4}} \times \frac{92\ g\ N_2O_4}{1\ \cancel{mol\ N_2O_4}}$$

$$= 1.43 \times 10^2\ g\ N_2O_4$$

Excess N_2O_4 left behind after the reaction is complete $= (2.00 \times 10^2 - 1.43 \times 10^2)\ g$

$= 57\ g.$

Percentage Yield

- The **theoretical yield** is the amount of product ***calculated*** using the mole ratios from the balanced equation.

- The **actual yield** is the amount of product actually obtained in an experiment or any reaction process.

- The actual yield is usually less than the theoretical yield.

$$\textbf{\% yield} = \frac{\textbf{actual yield}}{\textbf{theoretical yield}} \times \textbf{100\%}$$

Sample Problem 3.21

Silicon carbide (SiC) is made by reacting sand (silicon dioxide, SiO_2) with powdered carbon at high temperature. Carbon monoxide is also formed. What is the percent yield if 51.4 kg of SiC is recovered from processing 100.0 kg of sand?

SOLUTION

$$SiO_{2(s)} + 3C_{(s)} \rightarrow SiC_{(s)} + 2CO_{(g)}$$

$$100.0\ \cancel{kg\ SiO_2} \times \frac{1000\ \cancel{g\ SiO_2}}{1\ \cancel{kg\ SiO_2}} \times \frac{1\ \cancel{mol\ SiO_2}}{60\ \cancel{g\ SiO_2}} \times \frac{1\ \cancel{mol\ SiC}}{1\ \cancel{mol\ SiO_2}} \times \frac{40\ \cancel{g\ SiC}}{1\ \cancel{mol\ SiC}} \times \frac{1\ kg\ SiC}{1000\ \cancel{g\ SiC}}$$

$$= \boxed{66.6\ kg\ SiC} \leftarrow \text{Theoretical yield}$$

$$\%\ \text{yield} = \frac{51.4\ \cancel{kg\ SiC}}{66.6\ \cancel{kg\ SiC}} \times 100\ \% = \boxed{77.1\ \%}$$

Related Problems

Problem 3.70

Potassium nitrate decomposes on heating to produce potassium oxide and gaseous nitrogen and oxygen. Write a balanced equation for the process.

To produce 56.6 kg of oxygen, how many **(a)** moles and **(b)** grams of potassium nitrate must be heated?

Problem 3.71

Chromium (III) oxide reacts with hydrogen sulfide (H_2S) gas to form chromium (III) sulfide and water. Write a balanced equation for the process.

To produce 421 g of chromium (III) sulfide, how many **(a)** moles and **(b)** grams of chromium (III) oxide are required?

Problem 3.75

Elemental sulfur occurs as octatomic molecules, S_8. What mass (in grams) of fluorine gas is needed to react completely with 17.8 g of sulfur to form sulfur hexafluoride?

Related Problems

Problem 3.76

Solid iodine trichloride is prepared in two steps: first, a reaction between solid iodine and gaseous chlorine to form solid iodine monochloride; then treatment with more chlorine.

(a) Write a balanced equation for each step.

(b) Write a balanced equation for the overall reaction.

(c) How many grams of iodine are needed to prepare 2.45 kg of final product?

Problem 3.79

Metal hydrides react with water to form hydrogen gas and the metal hydroxide:

$$SrH_2\ (s) + 2H_2O\ (l) \rightarrow Sr(OH)_2\ (s) + 2H_2\ (g)$$

You wish to calculate the mass in grams of H_2 gas that can be prepared from 5.70 g of SrH_2 and 4.75 g of H_2O.

(a) How many moles of H_2 can be produced from the given mass of SrH_2?

(b) How many moles of H_2 can be produced from the given mass of H_2O?

(c) Which is the limiting reactant?

(d) How many grams of H_2 can be produced?

Related Problems

Problem 3.85

Calcium nitrate and ammonium fluoride react to form calcium fluoride, dinitrogen monoxide, and water vapor. How many grams of each substance are present after 16.8g of calcium nitrate and 17.50g of ammonium fluoride react completely?

Problem 3.86

Two successive reactions, A $\rightarrow$ B and B $\rightarrow$ C, have yields of 73% and 68%, respectively. What is the overall percent yield for conversion of A $\rightarrow$ C?

Problem 3.96

Sodium borohydride ($NaBH_4$) is used industrially in many organic syntheses. One way to prepare it is by reacting sodium hydride with gaseous diborane (B_2H_6). Assuming an 88.5% yield, how many grams of $NaBH_4$ can be prepared by reacting 7.98g of sodium hydride and 8.16g of diborane?


Thank you!