CHEMISTRY
LEVEL 4C
(CHM415115)

MOLE CONCEPT
&
STOICHIOMETRY

THEORY SUMMARY
&
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CHEMISTRY LEVEL 4C (CHM 415115)

MOLE CONCEPT & STOICHIOMETRY

(CRITERION 8)

INTRODUCTION:

Quantitative problems in chemistry ask us to answer questions involving "how much......?" and in this unit we shall carry out chemical calculations to investigate the quantities of substances that react together or the chemical composition of various substances.
Calculations relating to the chemical quantities involved in chemical compounds and the reactions between chemical compounds are called **STOICHIOMETRIC** calculations.
All such calculations rely upon having correct chemical formulae and balanced chemical equations.
We will commence with a review of some of the terms we used in a previous unit where we considered Atomic Structure and a model for the atom.

ATOMIC NUMBER (Z):

Atomic number is defined as the **number of protons** in the nucleus of an atom.
Each element is uniquely identified by its atomic number which is usually written at the lower left-hand side of the element's symbol.
e.g.
Carbon (Z= 6) : all carbon atoms possess 6 protons in each nucleus. ${}_{6}C$

Aluminium (Z= 13) : all aluminium atoms possess 13 protons in each nucleus. ${}_{13}Al$

Copper (Z= 29) : all copper atoms possess 29 protons in each nucleus. ${}_{29}Cu$

Gold (Z= 79) : all gold atoms possess 79 protons in each nucleus. ${}_{79}Au$

Hydrogen (Z= 1) : all hydrogen atoms possess 1 proton in each nucleus. ${}_{1}H$

NOTE: An electrically neutral atom will have the same number of electrons as protons

Q1. What is the atomic number of the element selenium and how many electrons are there in a neutral selenium atom.

(34, 34)

Q2. A neutral atom possesses 49 protons per nucleus. Identify the element.

(In, indium)

Q3. Identify the element where:

(i) a 2+ ion of this element has 78 electrons. (Hg, mercury)

(ii) a 3− ion of this element has 36 electrons. (As, arsenic)

MASS NUMBER:

This is defined as the (**<u>number of protons + the number of neutrons)</u>** in the nucleus of an atom and is usually written at the upper left-hand side of the element's symbol.
Because atoms of the ***same*** element can have differing numbers of neutrons, there are consequently atoms of the same element possessing different mass numbers. These are called ***isotopes*** of that element.
e.g.
magnesium atoms (atomic number 12) must possess 12 protons but the number of neutrons in magnesium atoms can vary.
i.e.

Some Mg atoms have 12 neutrons and thus have mass no. = (12 + 12) = 24 i.e. $^{24}_{12}Mg$

Some Mg atoms have 13 neutrons and thus have mass no. = (12 + 13) = 25 i.e. $^{25}_{12}Mg$

Some Mg atoms have 14 neutrons and thus have mass no. = (12 + 14) = 26 i.e. $^{26}_{12}Mg$

Thus, magnesium exists in three different isotopic forms and magnesium extracted from compounds anywhere in the Earth's crust shows the same % abundance. When it comes to calculations requiring an atomic mass, we use an average mass number which takes into account the individual isotopic abundances and their respective mass numbers.
e.g.
In the case of magnesium the % abundances for the three naturally occurring isotopes are:

$^{24}_{12}Mg$= 78.7%, $^{25}_{12}Mg$= 10.1% $^{26}_{12}Mg$= 11.2%

Thus the "average mass number" of magnesium is calculated as follows:

$$\begin{aligned}\text{Ave. mass no.} &= \{(78.7/100) \times 24\} + \{(10.1/100) \times 25\} + \{(11.2/100) \times 26\} \\ &= 18.89 + 2.53 + 2.91 \\ &= 24.33 \quad \text{(or 24.3 to 3 sig. figs)}\end{aligned}$$

So instead of having to worry about the fact that some magnesium atoms have mass numbers of 24, some 25 and some 26, we work on the principle that magnesium atoms behave as if they ALL have a mass number of 24.3

Q4. Chlorine exists on Earth as only two naturally occurring isotopes, chlorine-35 and chlorine-37. The approximate natural abundances are:

$^{35}_{17}Cl$ = 77.4% and $^{37}_{17}Cl$ = 22.6%

Use these data to determine the "average mass number" of chlorine to 3 significant figures.
(35.5)

Q5. The element boron exists on Earth as only two naturally occurring isotopes, boron-10 and boron-11. If the "average mass number" of boron to 4 significant figures is 10.81 what are the % abundances of the two isotopes? ($^{10}_{5}B$ = 19.0% & $^{11}_{5}B$ = 81.0%)

Consider the element tin (Sn) which has an 'average mass number' of 118.7 and so it follows that tin has two or more stable isotopes with mass numbers of around 118.
Although no such isotope exists we could possibly imagine that ***all*** tin atoms are represented by $^{118.7}_{50}Sn$. This hypothetical representation tells us that on average, each tin atom possesses (118.7 − 50) = 68.7 neutrons.

Q6. If the 'average mass number' of copper is 63.54 what is the number of
(i) protons in one million copper atoms? (i) 29 million)
(ii) neutrons in one million copper atoms? (ii) 34.54 million)

Q7. The noble gas neon (Ne) exists on Earth as only two naturally occurring isotopes, neon-20 and neon-22. The isotopic % abundances are: $^{20}_{10}Ne$= 91.1% & $^{22}_{10}Ne$= 8.9%
Use these data to find the:
(i) 'average mass number' for neon. (20.2)
(ii) number of protons in one billion neon atoms. (10 billion)
(iii) number of neutrons in one billion neon atoms. (10.2 billion)

RELATIVE ATOMIC MASS (A_r):

Atoms of different elements have different masses but because their masses are so small, it proved practically impossible for early chemists to determine the masses of individual atoms.
They overcame this problem by ***comparing*** masses and originally hydrogen atoms being the lightest were assigned a mass of 1. As carbon atoms were twelve times heavier than hydrogen atoms, carbon was assigned a relative mass of 12.
As magnesium atoms were about twice the mass of carbon atoms they were assigned a relative mass of just over 24.
In this way chemists have been able to compile a table of comparative atomic masses for the 100 or so elements.

The comparison of atomic masses these days is done super accurately with the $^{12}_{6}C$ atom used as the standard and it being assigned a relative mass of exactly 12.

We call this the **RELATIVE ATOMIC MASS** of an element and abbreviate the term by $\mathbf{A_r}$

$\mathbf{A_r}$ values you should know;

ELEMENT	SYMBOL	ATOMIC NO.	A_r
carbon	C	6	12.0
hydrogen	H	1	1.0
oxygen	O	8	16.0
nitrogen	N	7	14.0
sodium	Na	11	23.0
chlorine	Cl	17	35.5

* It is very important to realise that the relative atomic mass (which used to be called the atomic weight) is **NOT** the mass of an atom of that element! It is purely a number expressing the ratio of an atom's mass compared to a carbon-12 atom's mass which is assigned the value 12.

Refer to the list of elements and their relative atomic masses on page 23

You may now see the close relationship that exists between the relative atomic mass and the average mass number we considered on page 4.

Q8. A potassium atom has a mass that is 3.26 times greater than carbon atom. What is the relative atomic mass of potassium? ($A_r(K) = 39.1$)

Q9. Compare the mass of a cadmium atom with the mass of a carbon atom. (9.37 times heavier)

Q10. Atoms of element X are found to be 3.32 times heavier than nickel atoms. Given that the $A_r(Ni)$ is 58.7, what is the likely identity of element X? (platinum)

RELATIVE MOLECULAR MASS (M_r):

Knowing the relative atomic masses of the atoms individually means that by simple summation we can determine the relative molecular mass for a molecule. Normally we only use A_r values to the first decimal place even though the A_r table often gives more figures.

e.g. 1. Calculate the relative molecular mass of nitric acid which has the formula HNO_3

$$\begin{aligned} \text{Thus } M_r(HNO_3) &= \{1 \times A_r(H)\} + \{1 \times A_r(N)\} + \{3 \times A_r(O)\} \\ &= 1.0 + 14.0 + (3 \times 16.0) \\ &= 63.0 \end{aligned}$$

This means that a nitric acid molecule is just over 5 times heavier than a carbon atom.

e.g. 2. Calculate the relative molecular mass of glucose which has the formula $C_6H_{12}O_6$

$$\begin{aligned} \text{Thus, } M_r(C_6H_{12}O_6) &= \{6 \times A_r(C)\} + \{12 \times A_r(H)\} + \{6 \times A_r(O)\} \\ &= (6 \times 12.0) + (12 \times 1.0) + (6 \times 16.0) \\ &= 72.0 + 12.0 + 96.0 \\ &= 180.0 \end{aligned}$$

Q11. Using your table of relative atomic masses find the M_r of :

(i) H_2	(2.0)	(ii) NH_3	(17.0)
(iii) CO_2	(44.0)	(iv) H_2SO_4	(98.1)
(v) P_4O_{10}	(284.0)	(vi) CH_3COOH	(60.0)

MOLAR MASS (M) or RELATIVE FORMULA MASS

Many compounds are not covalent molecular but are ionic. For example, the ionic compound common salt, NaCl does not exist as individual "molecules" or particles of NaCl. The crystals of salt exist as a vast array of (+) and (−) ions where the ratio of $(Na^+) : (Cl^-)$ is 1**:**1.
Thus, for ionic compounds the term "relative molecular mass" is not appropriate as there are no molecules as such. The term we use in place of relative molecular mass is **MOLAR MASS** or **RELATIVE FORMULA MASS**.
In general, **molar mass** or **relative formula mass** are calculated in exactly the same way as we did for relative molecular mass although ***molar mass*** is followed by the unit "g mol^{-1}" and is abbreviated by the letter "M". Using M_r without units is acceptable as well and stands for the ***relative formula mass.***

Example 1: Calculate the relative formula mass for sodium carbonate, Na_2CO_3.

$$\begin{aligned} M_r(Na_2CO_3) &= \{2 \times A_r(Na)\} + \{1 \times A_r(C)\} + \{3 \times A_r(O)\} \\ &= (2 \times 23.0) + (1 \times 12.0) + (3 \times 16.0) \\ &= 46.0 + 12.0 + 48.0 \\ &= 106.0 \end{aligned}$$

Example 2: Calculate the relative formula mass for aluminium sulfate, $Al_2(SO_4)_3$.

$$\begin{aligned} M_r(Al_2(SO_4)_3) &= M_r(Al_2S_3O_{12}) \\ &= \{2 \times A_r(Al)\} + \{3 \times A_r(S)\} + \{12 \times A_r(O)\} \\ &= (2 \times 27.0) + (3 \times 32.1) + (12 \times 16.0) \\ &= 54.0 + 96.3 + 192.0 \\ &= 342.3 \end{aligned}$$

Example 3: When compounds involve '***water of crystallisation***' they are said to be **HYDRATED CRYSTALS** and the contribution of the water molecules must be added in too. Each water molecule adds an extra 18.0 to the M_r because the $M_r(H_2O) = 18.0$
e.g.
Calculate the relative formula mass for ***hydrated*** magnesium sulfate $MgSO_4.7H_2O$.

$$\begin{aligned} M_r(MgSO_4.7H_2O) &= \{1 \times A_r(Mg)\} + \{1 \times A_r(S)\} + \{4 \times A_r(O)\} + \{7 \times M_r(H_2O)\} \\ &= (1 \times 24.3) + (1 \times 32.1) + (4 \times 16.0) + (7 \times 18.0) \\ &= 24.3 + 32.1 + 64.0 + 126.0 \\ &= 246.4 \end{aligned}$$

Q12. (i) Calculate the relative formula mass for barium nitrate, $Ba(NO_3)_2$. (ANS. 261.3)
(ii) Calculate the molar mass for barium nitrate, $Ba(NO_3)_2$. (ANS. 261.3 g mol^{-1})

Q13. Calculate the molar mass for calcium phosphate, $Ca_3(PO_4)_2$. (ANS. 310.3 g mol^{-1})

Q14. Calculate the molar mass for hydrated copper(II) sulfate, $(CuSO_4.5H_2O)$
(ANS. 249.6 g mol^{-1})

Q15. What is the relative formula mass for neon, (Ne)? (ANS. 20.2)

Q16. What is the relative formula mass for oxygen, (O_2)? (ANS. 32.0)

PERCENTAGE COMPOSITION BY MASS

The relative formula mass or molar mass enables us to easily determine the % mass composition of a compound. This is a particularly important analytical technique used by chemists when information is required about the mass of a given element in a certain mass of compound. For example, a nutritionist may wish to know information about the mass of iodide ions in a food supplement of sodium iodide.

EXAMPLE 1:
A gardener wishes to add nitrogen to his lawn by application of ammonium sulfate ("sulfate of ammonia" lawn fertilizer.). What is the percentage by mass of nitrogen in ammonium sulfate?
ANS. The chemical formula for ammonium sulfate is = $(NH_4)_2SO_4$

$$\begin{aligned} M_r\{(NH_4)_2SO_4\} &= M_r(N_2H_8S_1O_4) \\ &= \boldsymbol{\{2 \times A_r(N)\}} + \{8 \times A_r(H)\} + \{1 \times A_r(S)\} + \{4 \times A_r(O)\} \\ &= \mathbf{(2 \times 14.0)} + (8 \times 1.0) + (1 \times 32.1) + (4 \times 16.0) \\ &= \mathbf{28.0} + 8.0 + 32.1 + 64.0 \\ &= 132.1 \end{aligned}$$

Of the total formula mass of 132.1, the nitrogen's contribution was 28.0 (*see in bold above*)

$$\begin{aligned} \text{Percentage by mass of nitrogen} &= \{(28.0/132.1) \times 100\}\% \\ &= 21.2\% \end{aligned}$$

Thus, percentage by mass of nitrogen in ammonium sulfate is 21.2%.

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In some instances you may be required to calculate the % by mass of ***each*** element in a compound rather than find the % mass of just one element; (see problem below).

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EXAMPLE 2:
What is the percentage by mass of each element in the amino acid 'alanine', which has the chemical formula $C_3H_7NO_2$?

ANS. $$\begin{aligned} M_r\{C_3H_7NO_2\} &= \{3 \times A_r(C)\} + \{7 \times A_r(H)\} + \{1 \times A_r(N)\} + \{2 \times A_r(O)\} \\ &= (3 \times 12.0) + (7 \times 1.0) + (1 \times 14.0) + (2 \times 16.0) \\ &= 36.0 + 7.0 + 14.0 + 32.0 \\ &= 89.0 \end{aligned}$$

Thus:

ELEMENT	% CALCULATION	% BY MASS
Carbon	$\{(36.0/89.0) \times 100\}$	= 40.4%
Hydrogen	$\{(7.0/89.0) \times 100\}$	= 7.9 %
Nitrogen	$\{(14.0/89.0) \times 100\}$	= 15.7%
Oxygen	$\{(32.0/89.0) \times 100\}$	= 40.0%
TOTAL (as a check)	-	100.0%
In some instances you may be given the % by mass of an element in a unknown compound and then asked to identify the element; (see problem below).		

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EXAMPLE 3:
The compound X_2O_3 is analysed and found to contain 69.0% oxygen by mass. Find the $A_r(X)$ and hence identify element X.
ANS.

$$M_r(X_2O_3) = (2a + 48.0) \qquad \text{where } a = A_r(X)$$

Thus percentage oxygen $= \{48.0/(2a + 48.0)\} \times 100 = 69.0$ (given)
Solving for 'a' gives: $4800 = 69.0\{2a + 48.0\}$

$$138a = 4800 - (69.0 \times 48.0)$$
$$138a = 4800 - 3312$$
$$a = 10.8$$

Thus, $A_r(X) = 10.8$ which suggests that X is probably boron (B)

QUESTIONS ON PERCENTAGE COMPOSITION:

Q17. What is the percentage by mass of oxygen in aluminium sulfate, $Al_2(SO_4)_3$?
(56.1%)

Q18. What is the percentage by mass of hydrogen in acetic acid, CH_3COOH?
(6.67%)

Q19. What is the percentage by mass of oxygen in ***hydrated*** magnesium sulfate $MgSO_4.7H_2O$? (note: there are 11 oxygen atoms in the formula!)
(71.4%)

Q20. What is the percentage composition by mass of each of the individual elements in the compound sucrose ($C_{12}H_{22}O_{11}$)? (42.1% C)
(check that they total 100%) (6.4% H)
(51.5% O)

Q21. (i) What is the percentage water of crystallisation in hydrated sodium carbonate which has the chemical formula $Na_2CO_3.10H_2O$? (62.9%)
(ii) If 100.0 g of $Na_2CO_3.10H_2O$ crystals were heated strongly and the water driven off as steam to leave just Na_2CO_3,
(a) what mass of steam would be driven off? (62.9 g)
(b) what mass of Na_2CO_3 would remain? (37.1 g)

Q22. Which compound, sodium sulfate or potassium sulfite has the higher percentage by mass of sulphur? (Na_2SO_4)
(%S in Na_2SO_4 = 22.6%)
(%S in K_2SO_3 = 20.3%)

Q23. The compound X_2O_7 is analysed and found to contain 61.2% oxygen by mass. Find the $A_r(X)$ and hence identify element X. (35.5 Cl)

THE MOLE

For any element, the mass of that element in grams contains the same number of atoms and this number is 6.022 x 10^{23}. (normally 6.02 x 10^{23} to 3 sig. figs will be used)
e.g.

A_r(C) = 12.0 thus 12.0 g of carbon contains 6.02 x 10^{23} carbon atoms.
A_r(Na) = 23.0 thus 23.0 g of sodium contains 6.02 x 10^{23} sodium atoms.
A_r(O) = 16.0 thus 16.0 g of oxygen contains 6.02 x 10^{23} oxygen atoms.
A_r(Au) = 197 thus 197 g of gold contains 6.02 x 10^{23} gold atoms.
A_r(H) = 1.0 thus 1.0 g of hydrogen contains 6.02 x 10^{23} hydrogen atoms.

etc……..

The number 6.02 x 10^{23} is of such special significance to us as chemists that we give it a special name and we call it 1 mole.
Just as humans have invented the word "billion" to mean a counting number of one thousand, thousand, thousand, similarly we use the word ***mole*** as a counting number too although it is far too large to be used for counting everyday items like cars, people,…….etc

EXAMPLES:

1 mole of tennis balls (6.02 x 10^{23} tennis balls) would cover the whole of the Australian continent to a depth of over a thousand kilometres!!!

A super-computer carrying out 1 billion computations per second would take about 20 million years to perform 1 mole of calculations!!

1 mole of tiny sand grains laid side by side would create a line of such length that it would reach to the sun and back 20 million times!

ONE MOLE OF PARTICLES CONTAINS 6.022 x 10^{23} PARTICLES
THIS NUMBER IS SOMETIMES REFERRED TO AS AVOGADRO'S NUMBER OR AVOGADRO'S CONSTANT AND INDICATED BY N_A.
THE WORD 'MOLE' IS OFTEN ABBREVIATED TO 'MOL'

Q24. What is the mass in grams of:
(a) 1.00 mole of chromium atoms? (52.0 g)
(b) 6.02 x 10^{23} gold atoms? (197 g)
(c) 1 silicon atom? (4.67 x 10^{-23} g)
(d) one million phosphorus atoms? (5.15 x 10^{-17} g)

Q25. Identify element X given that one single atom of element X has a mass of:
(a) 2.28 x 10^{-22} g (Ba = barium)
(b) 1.80 x 10^{-23} g (B = boron)
(c) 1.67 x 10^{-24} g (H = hydrogen)

Q26. How many atoms of sulfur are there in 100.0 g of sulfur? (1.88 x 10^{24})

Q27. How many mol of atoms are there in:

(i) 50.0 g of tungsten atoms? (0.272 mol)

(ii) 50.0 g of neon atoms? (2.48 mol)

(iii) 2.50×10^{24} atoms of element 'Z'? (4.15 mol)

From our discussions above, it follows that if we have the relative molecular mass of any substance expressed as grams, it will contain 1 mole of molecules of that substance.

e.g.

(i) $M_r(CO_2)$ = 44.0 thus 44.0 g of carbon dioxide contains 6.02×10^{23} carbon dioxide molecules or one mole of carbon dioxide molecules.

(ii) $M_r(NH_3)$ = 17.0 thus 17.0 g of ammonia contains 6.02×10^{23} ammonia molecules or one mole of ammonia molecules.

(iii) $M_r(H_2SO_4)$ = 98.1 thus 98.1 g of sulfuric acid contains 6.02×10^{23} sulfuric acid molecules or one mole of sulfuric acid molecules.

(iv) $M_r(O_2)$ = 32.0 thus 32.0 g of oxygen contains 6.02×10^{23} oxygen molecules or one mole of oxygen molecules. etc……..

Q28. What is the mass of 1.00 mole of SO_2 molecules? (64.1 g)

Q29. What is the mass of 6.02×10^{23} molecules of HNO_3? (63.0 g)

Q30. How many mole of molecules are there in 500.0 g of glucose which has the formula $C_6H_{12}O_6$? (M_r = 180.0) (2.78 mol)

Q31. What is the mass in grams of:

(i) 1.00 mole of propane (C_3H_8) molecules? (44.0 g)

(ii) 1 single molecule of propane? (7.31×10^{-23} g)

Q32. What is the mass in grams of:

(i) 5.55 mole of chlorine (Cl_2) molecules? (394 g)

(ii) 1 single molecule of chlorine? (1.18×10^{-22} g)

Q33. Given that 1.20×10^{23} molecules of the hydrocarbon compound C_xH_8 have a mass of 11.2 g, find the $M_r(C_xH_8)$ and hence the value of x. (56.0 x = 4)

Q34. How many molecules of hydrogen sulfide (H_2S) are there in 100.0 g of hydrogen sulfide which is also known as 'rotten egg gas'? (1.77×10^{24})

Q35. How many mole of hydrogen atoms are there in 10.0 mole of NH_3? (30.0 mol)

EMPIRICAL FORMULA

The empirical formula for a compound is a formula giving the ratio of atoms present in the compound. Sometimes it is the same as the chemical formula.
For example, the compound butane has the (true) molecular formula of C_4H_{10} but considering the ratio 4 **:** 10 = 2 **:** 5, butane has the empirical formula of C_2H_5.
A compound like propane (C_3H_8) has the same empirical formula as molecular formula because there is no simpler ratio than 3 **:** 8.
Similarly, a compound like $Na_2S_2O_3$ has the same empirical formula as chemical formula because there is no simpler ratio than 2 **:** 2 **:** 3.
Note that a formula like HNO_3 really means $H_1N_1O_3$.

EXAMPLES: You complete the final 4 rows

COMPOUND	CHEMICAL FORMULA	EMPIRICAL FORMULA
hydrogen peroxide	H_2O_2	HO
glucose	$C_6H_{12}O_6$	$C_1H_2O_1$
sulfuric acid	H_2SO_4	H_2SO_4
sucrose	$C_{12}H_{22}O_{11}$	$C_{12}H_{22}O_{11}$
phosphorus(V) oxide	P_4O_{10}	P_2O_5
oct-1-ene	C_8H_{16}	CH_2
sulfur dioxide	SO_2	
hydrazine	N_2H_4	
acetic acid	$C_2H_4O_2$	
borax	$Na_2B_4O_7$	

Questions requiring us to calculate the empirical formula of a compound from analytical data are best tackled by determining the ratio of ***moles of atoms*** of each element present. We use the letter 'n' to designate "***the number of mole of***………."

The number of mole of ***atoms*** is found by dividing the mass of the element by its A_r.

Q: How many moles of carbon atoms are there in 40.0 g of carbon?
ANS.

$$n(C) = (\text{mass of carbon})/A_r(C)$$
$$n(C) = (40.0/12.0)\ \text{mol}$$
$$n(C) = 3.33\ \text{mol}$$

Q36. Find the number of mole of ***atoms*** in the following:
(i) 100.0 g of aluminium. (3.70 mol)
(ii) 66.0 g of chlorine. (1.86 mol)
(iii) 13.0 g of hydrogen. (13.0 mol)
(iv) 6.00 g of lead. (0.0290 mol)

EMPIRICAL FORMULA CALCULATIONS

The key to these calculations is to follow the steps as shown in the sample calculations below:

e.g.1. A pure compound is analysed and found to have the following percentage composition by mass.

carbon = 52.2% hydrogen = 13.0% oxygen = 34.8%

We now work on the basis of 100.0 g of compound and find the ratio of moles of atoms of each element; i.e.

	n(C)	:	n(H)	:	n(O)	
=	(52.2/12.0)	:	(13.0/1.00)	:	(34.8/16.0)	divide masses by A_r
=	(4.35)	:	(13.0)	:	(2.18)	work to 3 S.F.
=	(4.35/2.18)	:	(13.0/2.18)	:	(2.18/2.18)	divide each term by the smallest i.e. 2.18
=	(2.00)	:	(5.96)	:	(1.00)	
=	2	:	6	:	1	rounding off

Thus the compound must have empirical formula $C_2H_6O_1$.

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e.g.2. A pure compound is analysed and found to have the following percentage composition by mass.

potassium = 33.5% boron = 18.5% oxygen = 48.0%

Once again we work on the basis of 100.0 g of compound and find the ratio of moles of atoms of each element; i.e.

	n(K)	:	n(B)	:	n(O)	
=	(33.5/39.1)	:	(18.5/10.8)	:	(48.0/16.0)	divide masses by A_r
=	(0.857)	:	(1.71)	:	(3.00)	work to 3 S.F.
=	(0.857/0.857)	:	(1.71/0.857)	:	(3.00/0.857)	divide each term by the smallest i.e. 0.857
=	(1.00)	:	(2.00)	:	(3.50)	
=	2	:	4	:	7	multiply all x2

Thus the compound must have empirical formula $K_2B_4O_7$.
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TYPICAL EMPIRICAL FORMULA QUESTIONS

Q37. A pure compound is analysed and found to have the following percentage composition by mass; 42.9% carbon and 57.1% oxygen. Calculate the compound's empirical formula from these data. (CO)

Q38. A pure compound is analysed and found to have the following percentage composition by mass; 55.2% strontium and 44.8% chlorine. Calculate the compound's empirical formula from these data. ($SrCl_2$)

Q39. A pure compound is analysed and found to have the following percentage composition by mass; 81.1% calcium and 18.9% nitrogen. Calculate the compound's empirical formula from these data. (Ca_3N_2)

Q40. Given that 2.00 g of sulfur reacts with 3.55 g of fluorine to form the compound X, find the empirical formula for X. (SF_3)

Q41. Given that 10.0 g of iron reacts with oxygen to form 14.3 g of an oxide of iron, use these data to find the empirical formula for this oxide. (Fe_2O_3)

Q42. The compound sodium cobaltinitrite is analysed gravimetrically (by weighing procedures) and found to have the following composition:

sodium = 17.1% by mass
cobalt = 14.6% by mass
nitrogen = 20.8% by mass
oxygen = 47.5% by mass

Use these data to find the empirical formula for sodium cobaltinitrite.

($Na_3CoN_6O_{12}$)

Q43. The hydrocarbon compound 'Z' is analysed and found to contain 85.7% carbon and 14.3% hydrogen by mass.

(i) Find the empirical formula for compound Z. (CH_2)

(ii) Given that further analysis reveals that compound Z has a relative molecular mass (M_r) of 84.0 find the molecular formula for Z. (C_6H_{12})

Q44. A pure compound is analysed and found to have the following percentage composition by mass;

19.5% chromium 40.0% chlorine 40.5% water of crystallisation.

Calculate the compound's empirical formula from these data.

Hint. In this problem, find the ratio of:

$n(Cr)$ **:** $n(Cl)$ **:** $n(H_2O)$

($CrCl_3.6H_2O$)

Q45. A pure compound is analysed and found to have the following percentage composition by mass;

28.8% iron 29.4% fluorine 41.8% water of crystallisation.

Calculate the compound's empirical formula from these data. ($Fe_2F_6.9H_2O$)

MOLARITY (SOLUTION CONCENTRATION)

The concentrations of solutions used in the chemistry laboratory are usually given in units of ***mol*** $\boldsymbol{L^{-1}}$ which is often referred to as the '***molarity***' of the solution.
The substance being dissolved is called the ***solute*** whereas the dissolving liquid which is usually water is called the ***solvent***.

DEFINITION:

$$\text{Molarity of a solution} = \frac{\text{(moles of solute dissolved)}}{\text{(litres of solution)}} = \frac{n(\text{solute})}{V}$$

The word "strength" of a solution should NOT be used in the context of describing concentration because it has a different chemical meaning. Strength refers to the degree of ionisation.
Be careful to have the solution's volume in ***litres*** because in many cases the volumes of solutions are expressed in mL.

Q. If 15.0 g of $CuSO_4.5H_2O$ crystals are dissolved in 355 mL of solution, what is the concentration of this solution as a molarity?
ANS.

$$\begin{aligned} M_r(CuSO_4.5H_2O) &= 249.6 \\ \text{Thus,} \quad n(CuSO_4.5H_2O) &= (15.0/249.6)\text{ mol} \\ &= 6.01 \times 10^{-2}\text{ mol} \\ \text{So,} \quad \text{molarity of solution} &= \text{moles divided by litres} = \text{moles/L} \\ &= (6.01 \times 10^{-2}\text{ mol})/(0.355\text{ L}) \\ &= 0.169\text{ mol L}^{-1} \quad \text{(sometimes written as 0.169 M)} \end{aligned}$$

Q46. What is the molarity of a solution prepared by dissolving 75.0 g of NaCl crystals in 875 mL of solution? (1.47 mol L^{-1})

Q47. What mass of Na_2CO_3 crystals are needed to prepare 250.0 mL of a solution that has a concentration of 0.0500 mol L^{-1}? (1.33 g)

Q48. What volume of 0.200 mol L^{-1} oxalic acid solution can be prepared from 10.0 g of oxalic acid crystals having the formula $H_2C_2O_4.2H_2O$? (397 mL)

Q49. If 50.0 mL of 1.20 mol L^{-1} hydrochloric acid solution is diluted with water to a total volume of 200.0 mL, what is the final concentration of $HCl_{(aq)}$? (0.300 mol L^{-1})

Q50. If 65.0 g of $Fe_2(SO_4)_3$ crystals are dissolved in 700.0 mL of solution, what is the concentration of the:
(i) $Fe_2(SO_4)_3$ solution as a molarity? (0.232 mol L^{-1})
(ii) iron(III) ions in this solution? (0.464 mol L^{-1})
(iii) sulfate ions in this solution? (0.697 mol L^{-1})

REACTING QUANTITY CALCULATIONS

Once we have a balanced chemical equation, the mole concept for counting particles enables us to link together the amounts of reactants and products that undergo reaction.
For example, suppose we have the hypothetical equation: $2A + 3B \rightarrow 2C$
There are several very similar ways of seeing the combining amounts:
(i) 2 particles of A react with 3 particles of B to form 2 particles of C
(ii) 200 particles of A react with 300 particles of B to form 200 particles of C
(iii) 2 million particles of A react with 3 million particles of B to form 2 million particles of C
*(iv) 2 mol of A particles react with 3 mol of B particles to form 2 mol of C particles.

*In statement (iv) we see why the mole concept is so important for chemists because we know the mole amounts correspond to certain masses as determined by their M_r values.

IN ALL REACTING QUANTITY CALCULATIONS WE PERFORM, IT IS CRITICALLY IMPORTANT TO HAVE A **BALANCED** CHEMICAL EQUATION AND TO RELATE THE REACTING AMOUNTS IN **MOLE** QUANTITIES.

SAMPLE MOLE QUANTITY CALCULATION: (NOTE THE STEPS WE USE)

Q. What mass of oxygen is required for the complete reaction of 100.0 g of calcium according to the balanced chemical equation:

$$2Ca_{(s)} + 1O_{2(g)} \rightarrow 2CaO_{(s)} \quad ?$$

STEP 1. Ensure that the equation is balanced.
STEP 2. Identify the ***known*** species. In this case it is 100.0 g of calcium.
STEP 3. Express the known as an amount in ***moles***.
i.e. n(Ca) = (100.0/40.1) mol   divide mass in grams by M_r
= 2.49 mol
STEP 4. Now use the equation coefficients to link the known to the ***unknown*** which is oxygen in this case.
i.e. $n(O_2)$ = 2.49 x (**1/2**) mol $n(O_2) = ½ \times n(Ca)$
= 1.25 mol
STEP 5. Convert the mole answer from step 4 into a mass answer as required by the question.
i.e. mass of O_2 = (moles x M_r) g
= 1.25 x 32.0 g $M_r(O_2) = 32.0$
= 39.9 g
STEP 6. Express your answer properly in accordance with the way in which the question was asked.
i.e. mass of oxygen required = 39.9 g

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"ROUNDING OFF ERRORS"

Throughout any calculations involving multiple steps, leave your calculator switched on and don't clear the display otherwise you will very likely incur a 'rounding off' error. Although your calculator display may well show 9 significant figures, it is usually desirable to present your final answer to just 3 S.F. or at least the minimum number that appears amongst the question data.

Q51. Consider the reaction for the combustion of ethanol (C_2H_6O):

$$C_2H_6O_{(l)} \quad + \quad O_{2(g)} \quad \rightarrow \quad CO_{2(g)} \quad + \quad H_2O_{(l)}$$

(i) Balance the equation.
(ii) What mass of oxygen is needed to react with 10.0 g of ethanol? (20.9 g)
(iii) What mass of CO_2 is produced when 10.0 g of ethanol is burnt? (19.1 g)

Q52. Consider the reaction for the reaction between white phosphorus (P_4) and chlorine:

$$P_{4(s)} \quad + \quad Cl_{2(g)} \quad \rightarrow \quad PCl_{5(g)}$$

(i) Balance the equation.
(ii) What mass of chlorine is needed to react with 45.0 g of phosphorus? (258g)
(iii) What mass of PCl_5 would be produced in this case? (303 g)
(iv) Use 'The Law of Conservation of Mass' to check your answer to part (iii).

Q53. The combustion of petrol may be considered to involve the reaction below:

$$2C_8H_{18(g)} \quad + \quad 25O_{2(g)} \quad \rightarrow \quad 16CO_{2(g)} \quad + \quad 18H_2O_{(g)}$$

(i) How many moles of petrol are there in 1.00 kg of petrol? (8.77 mol)
(ii) What mass of oxygen is needed to burn 1.00 kg of petrol? (3.51 kg)
(iii) What mass of CO_2 is produced when 1.00 kg of petrol is burnt? (3.09 kg)
(iv) What mass of H_2O is produced when 1.00 kg of petrol is burnt? (1.42 kg)
(v) Use 'The Law of Conservation of Mass' to check your answer to part (iv).

Q54. When hydrated magnesium sulfate is heated strongly, the water of crystallisation is driven off as steam in accordance with the chemical equation:

$$MgSO_4.7H_2O_{(s)} \quad \rightarrow \quad MgSO_{4(s)} \quad + \quad 7H_2O_{(g)}$$

If 10.00 g of the hydrated compound ($MgSO_4.7H_2O_{(s)}$) is heated strongly;
(i) what mass of the anhydrous form ($MgSO_{4(s)}$) would be formed? (4.89 g)
(ii) what mass of steam must have been driven off? (5.11 g)

Q55. The oxidation of ammonia (NH_3) occurs according to the chemical equation:

$$4NH_{3(g)} \quad + \quad 7O_{2(g)} \quad \rightarrow \quad 4NO_{2(g)} \quad + \quad 6H_2O_{(g)}$$

If 76.5 g of ammonia is oxidised, find:
(i) the $n(NH_3)$ oxidised. (4.50 mol)
(ii) the $n(O_2)$ required for this reaction. (7.88 mol)
(iii) actual number of oxygen ***molecules*** required. (4.74×10^{24})
(iv) actual number of oxygen ***atoms*** required. (9.48×10^{24})
(v) the mass of oxygen required. (252 g)

PERCENTAGE PURITY QUESTIONS

Q. A sample of the mineral bauxite is analysed and found to contain 46.2% by mass alumina (Al_2O_3) with the remaining percentage being iron compounds and silica (SiO_2)
What mass of aluminium metal could be obtained theoretically from 1.00 tonne of this bauxite? (1 tonne = 10^6 g)

ANS. mass of bauxite = 1.00×10^6 g

Thus, mass of alumina (Al_2O_3) = $(1.00 \times 10^6) \times (46.2/100)$ g = 4.62×10^5 g   as only 46.2% of the ore is alumina

Now; $M_r(Al_2O_3)$ = $(2 \times 27.0) + (3 \times 16.0)$ = 102   so the aluminium makes up a fraction of 54/102

Thus, mass of Al obtainable = mass of $Al_2O_3 \times (54.0/102)$ g
= $4.62 \times 10^5 \times (54.0/102)$ g
= 2.45×10^5 g

So theoretical mass of Al metal obtainable = 2.45×10^5 g or 245 kg

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Q56. The plant fungicide 'bordeaux' is a mixture including 'basic' copper(II) sulfate $CuSO_4.Cu(OH)_2$ as the only copper containing compound.
A sample of 'bordeaux' is analysed and found to contain 35.0% by mass $CuSO_4.Cu(OH)_2$. What mass of copper is present in a 10.0 g sample of 'bordeaux'?
(1.73 g)

Q57. A brand of soup is labelled as containing 1.54% salt (NaCl) by mass. What is the mass of ***sodium*** ions (Na^+) ingested by a person who consumes 455 g of this soup?
(2.75 g)

Q58. The metal mercury is obtained from the mineral cinnabar that occurs in Hungary and Russia. A sample of ore containing cinnabar is found to have 11.7% by mass mercury(II) sulfide HgS. What mass of mercury metal could be obtained theoretically from 5.00 kg of ore containing cinnabar? (504 g)

Q59. The average adult human requires 650 mg of calcium in their diet per day. A person who is allergic to all dairy products has their calcium intake through tablets containing $CaCO_3$ powder, glucose and flavouring. If they are to take ***four*** tablets per day:

(i) what mass of calcium must ***each*** tablet contain? (163 mg)
(ii) what mass of $CaCO_3$ must ***each*** tablet contain? (406 mg)
(iii) If the mass of each tablet is 1.50 g, what should be the % by mass of $CaCO_3$ in each tablet? (27.1%)
(iv) If the mass of each tablet is 1.50 g, what should be the % by mass of Ca in each tablet? (10.8%)

Q60. A sample of the uranium containing ore 'yellowcake' contains 23.60% by mass U_3O_8.

(i)What mass of uranium is obtainable from 800.0 kg of yellowcake? (160.1 kg)
(ii) If only 0.71% by mass of uranium atoms are the fissionable isotope ${}^{235}_{92}U$, what mass of ${}^{235}_{92}U$ is obtainable from the 800.0 kg of yellowcake? (1.1 kg)
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QUESTIONS WITH REACTING SOLUTIONS

Q. What volume of 0.400 mol L^{-1} phosphoric acid solution ($H_3PO_{4(aq)}$) is required to neutralise 5.00 g of calcium hydroxide ($Ca(OH)_{2(s)}$)?

ANS. As with all such reacting quantity problems, a balanced equation is an essential starting point; i.e.

$$2H_3PO_{4(aq)} \quad + \quad 3Ca(OH)_{2(s)} \quad \rightarrow \quad Ca_3(PO_4)_{2(aq)} \quad + \quad 6H_2O_{(l)}$$

STEP 1. Ensure that the equation is balanced.

STEP 2. Identify the ***known*** species. In this case it is 5.00 g of calcium hydroxide.

STEP 3. Express the known as an amount in ***moles***.

i.e. $n(Ca(OH)_2)$ = (5.00/74.1) mol   divide mass in grams by M_r
= 0.0675 mol $M_r(Ca(OH)_2) = 74.1$

STEP 4. Now use the equation coefficients to link the known to the ***unknown*** which is phosphoric acid in this case.

i.e. $n(H_3PO_4)$ = 0.0675 x (**2/3**) mol $n(H_3PO_4) = 2/3 \times n(Ca(OH)_2)$
= 0.0450 mol

STEP 5. Convert the mole answer from step 4 into a volume answer as required by the question.

i.e. volume of H_3PO_4 = (moles/molarity) L $c = n/V$ or $V = n/c$
= 0.0450/0.400 L
= 0.122 L

STEP 6. Express your answer properly in accordance with the way in which the question was asked.

i.e. volume of H_3PO_4 required = 0.112 L (or 112 mL)

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Q61. For the reaction:

$$2HCl_{(aq)} \quad + \quad Mg_{(s)} \quad \rightarrow \quad MgCl_{2(aq)} \quad + \quad H_{2(g)}$$

What mass of Mg metal just reacts with 35.0 mL of 0.500 mol L^{-1} hydrochloric acid?

(0.213 g)

Q62. For the reaction between copper metal and hot concentrated nitric acid, the chemical equation is:

$$Cu_{(s)} \quad + \quad 4HNO_{3(aq)} \quad \rightarrow \quad Cu(NO_3)_{2(aq)} \quad + \quad 2NO_{2(g)} \quad + \quad 2H_2O_{(l)}$$

What volume of 15.0 mol L^{-1} nitric acid is required to just react with 100.0 g of copper?

(420 mL)

Q63. For the reaction:

$$H_2SO_{4(aq)} \quad + \quad 2NaOH_{(aq)} \quad \rightarrow \quad Na_2SO_{4(aq)} \quad + \quad 2H_2O_{(aq)}$$

What volume of 0.700 mol L^{-1} sodium hydroxide solution just reacts with 55.0 mL of 0.250 mol L^{-1} sulfuric acid? (39.3 mL)

Q64. If 25.0 mL of 0.250 mol L^{-1} potassium hydroxide solution is neutralised by 35.2 mL of phosphoric acid solution, find $[H_3PO_{4(aq)}]$.   Note: "[x]" means molarity of x

$$H_3PO_{4(aq)} \quad + \quad 3KOH_{(aq)} \quad \rightarrow \quad K_3PO_{4(aq)} \quad + \quad 3H_2O_{(aq)}$$

(0.0592 mol L^{-1})
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LIMITING REACTANT CALCULATION

In some more difficult reacting quantity questions, the amounts of two substances reacting are given but one of the two is present as an excess reagent and the initial step is to work out which reactant is in ***excess*** and which reactant is the ***limiting*** reactant.

EXAMPLE:

Q. If 50.0 g of aluminium metal is mixed with 170.4 g of chlorine gas and they react together until one of the reactants is consumed (used up), find the mass of aluminium chloride formed and the mass of the excess reactant that is left over and unreacted.

ANS:
The balanced equation is: $2Al_{(s)} + 3Cl_{2(g)} \rightarrow 2AlCl_{3(s)}$

Now: n(Al) added = (mass/M_r)
= (50.0/27.0)
= 1.85 mol

M_r(Al) is the same as its A_r and this would need (3/2) x 1.85 = 2.78 mole of Cl_2 to react completely.

But: n(Cl_2) added = (mass/M_r)
= (170.4/71.0) mole
= 2.40 mole

$M_r(Cl_2)$ = 2 x 35.5 = 71.0 and so this is not enough to react with ***all*** the $Al_{(s)}$

Thus, there is too much aluminium (Al is "excess") and the "limiting reactant" is Cl_2.

We now work all further calculations with the 2.40 mole of chlorine which is the "limiting" reactant and will all be reacted and we recognise that there will be some Al left over as the excess reactant!

ONLY USE THE ***LIMITING*** REACTANT TO DETERMINE THE AMOUNTS OF PRODUCTS FORMED

Now:
The balanced equation is: $2Al_{(s)} + 3Cl_{2(g)} \rightarrow 2AlCl_{3(s)}$
i.e.
2 moles of Al react with 3 moles of Cl_2 to form 2 moles of aluminium chloride ($AlCl_3$)
i.e.
(2/3) x 2.40 mole of Al react with 2.40 mole of Cl_2 to form (2/3) x 2.40 mole of $AlCl_3$
i.e.
1.60 mole of Al reacts with 2.40 mole of Cl_2 to form 1.60 mole of $AlCl_3$

At the completion of the reaction: (i) all of the chlorine is used up.
(ii) 1.60 mole of $AlCl_3$ will have been formed
(iii) (1.85 – 1.60) = 0.25 mole of Al is left over (excess)

ANSWER CONTINUED

Mass of aluminium chloride formed = (moles x M_r) g
= 1.60 x 133.5 g $M_r(AlCl_3)$ = 133.5
= 213.6 g

Mass of ***excess*** aluminium metal Al = (moles x M_r) g
= 0.250 x 27.0 g
= 6.75 g

NOTE: As a check, the total mass of reactants was (50.0 + 170.4) = 220.4 g and the total mass of the end products is (213.6 + 6.75) = 220.4 g which is the same! (Law of Conservation of Mass!)

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Q65. Consider the reaction: $2H_2S_{(g)} + 3O_{2(g)} \rightarrow 2SO_{2(g)} + 2H_2O_{(g)}$

Determine which is the excess reactant in each of the following cases and give the number of mole of ***excess*** reactant left over after the reaction is complete.

(i) 2.0 mol of H_2S is mixed with 4.0 mol of O_2 (1.0 mol of O_2 xs)
(ii) 3.0 mol of H_2S is mixed with 4.0 mol of O_2 (0.33 mol of H_2S xs)
(iii) 5.0 mol of H_2S is mixed with 7.0 mol of O_2 (0.33 mol of H_2S xs)
(iv) 0.20 mol of H_2S is mixed with 0.35 mol of O_2 (0.050 mol of O_2 xs)
(v) 0.16 mol of H_2S is mixed with 0.21 mol of O_2 (0.020 mol of H_2S xs)

Q66. When 4.10 g of potassium iodide crystals ($KI_{(s)}$) are dissolved in water and then mixed with a solution containing 4.80 g of lead(II) nitrate ($Pb(NO_3)_2$) a precipitate of yellow lead(II)iodide ($PbI_{2(s)}$) forms.

The equation is: $2KI_{(aq)} + Pb(NO_3)_{2(aq)} \rightarrow PbI_{2(s)} + 2KNO_{3(aq)}$

Given $M_r(KI)$ = 166.0 and $M_r(Pb(NO_3)_2)$ = 331.2 , find:

(i) the amount in mol of the two reactants added.
(ii) which reactant is in excess and which is the limiting reactant. (KI)
(iii) the mass of the PbI_2 precipitate formed. (5.67 g)

Q67. When 15.0 g of aluminium chloride crystals ($AlCl_{3(s)}$) are dissolved in water and then mixed with an aqueous solution containing 10.8 g of sodium hydroxide (NaOH), a precipitate of aluminium hydroxide ($Al(OH)_{3(s)}$) is formed.

The equation is: $3NaOH_{(aq)} + AlCl_{3(aq)} \rightarrow Al(OH)_{3(s)} + 3NaCl_{(aq)}$

Find the mass of aluminium hydroxide precipitate formed. (7.02 g)

Q68. A chemist prepares a solution by dissolving 2.98 grams of lead(II) nitrate ($Pb(NO_3)_2$) in 200.0 mL of aqueous solution. This solution was then added to 200.0 mL of 0.0800 mol L^{-1} sodium sulfate solution ($Na_2SO_{4(aq)}$). A white precipitate of lead(II)sulfate formed.

(i) Find the mass of $PbSO_{4(s)}$ precipitate formed. (2.73 g)
(ii) Find the concentration of aqueous sulfate ions in the final solution.
(final $[SO_4{}^{2-}{}_{(aq)}]$ = 0.0175 mol L^{-1})

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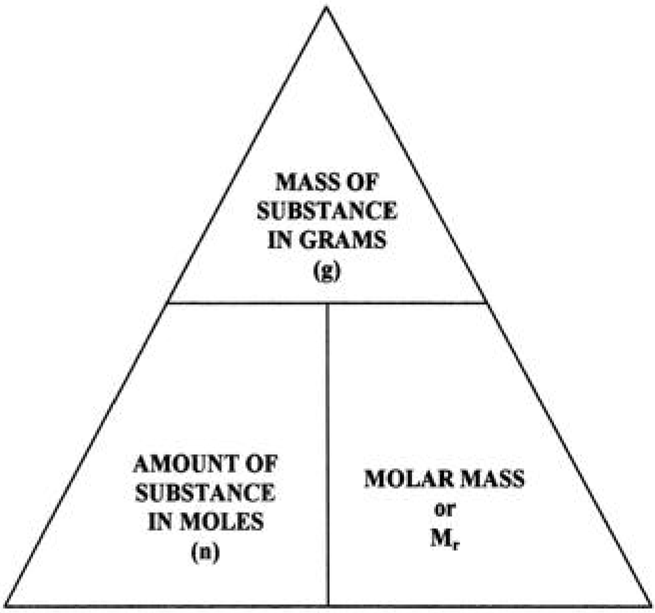
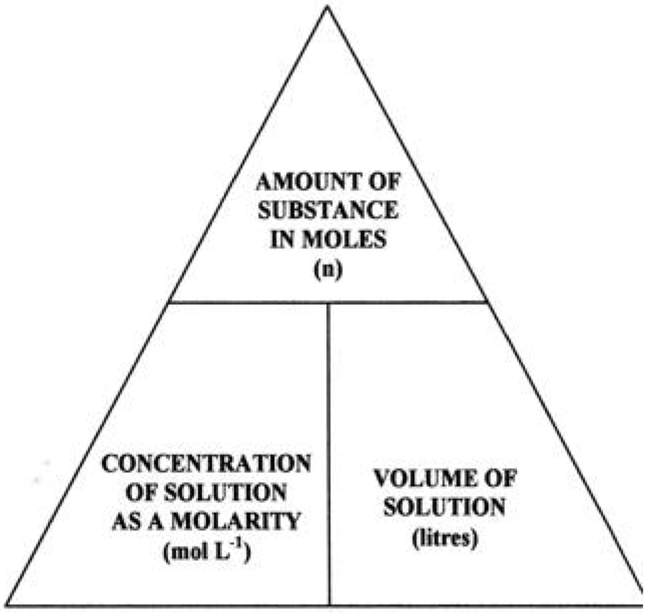
USEFUL MOLE CONCEPT RELATIONSHIPS

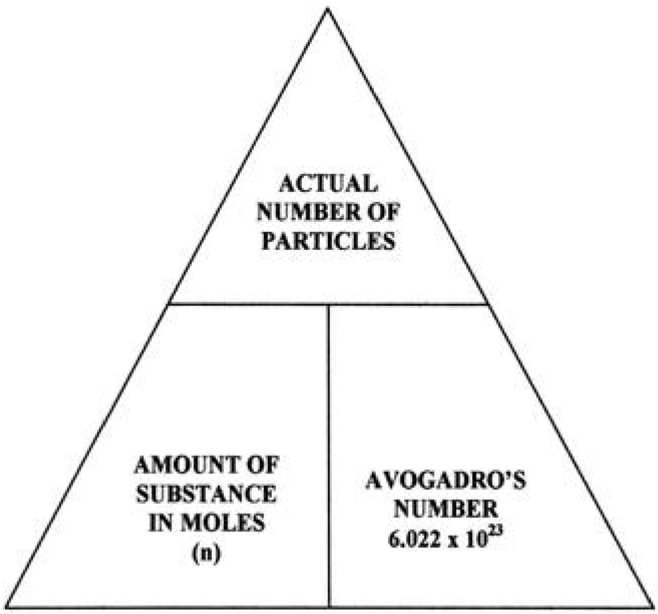
SOLIDS



SOLUTIONS



PARTICLES



EMPIRICAL FORMULA CALCULATIONS

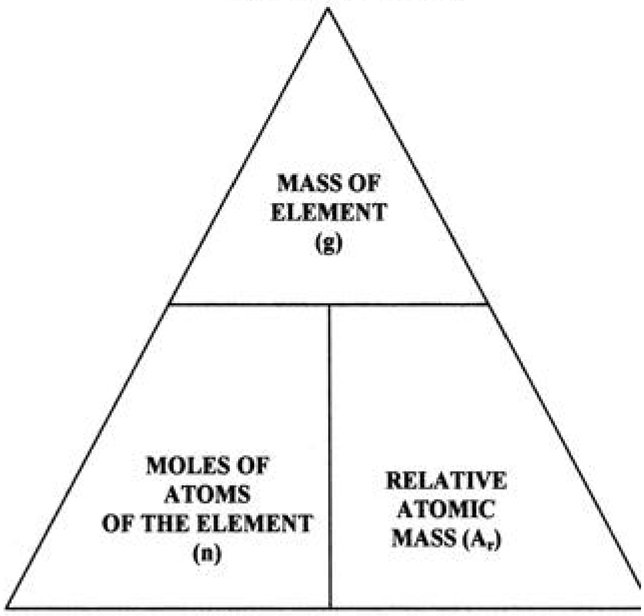


TABLE OF RELATIVE ATOMIC MASSES (BASED ON $^{12}C = 12.00$)							
Name	**Symbol**	**Atomic Number**	**Relative Atomic Mass**	**Name**	**Symbol**	**Atomic Number**	**Relative Atomic Mass**
actinium	Ac	89	227.03	mercury	Hg	80	200.6
aluminium	Al	13	26.98	molybdenum	Mo	42	95.94
americium	Am	95	-	neodymium	Nd	60	144.2
antimony	Sb	51	121.8	neon	Ne	10	20.18
argon	Ar	18	39.95	neptunium	Np	93	-
arsenic	As	33	74.92	nickel	Ni	28	58.71
astatine	At	85	-	niobium	Nb	41	92.91
barium	Ba	56	137.3	nitrogen	N	7	14.01
berkelium	Bk	97	-	nobelium	No	102	-
beryllium	Be	4	9.012	osmium	Os	76	190.2
bismuth	Bi	83	209.0	oxygen	O	8	16.00
boron	B	5	10.81	palladium	Pd	46	106.4
bromine	Br	35	79.90	phosphorus	P	15	30.97
cadmium	Cd	48	112.4	platinum	Pt	78	195.1
caesium	Cs	55	132.9	plutonium	Pu	94	-
calcium	Ca	20	40.08	polonium	Po	84	-
californium	Cf	98	-	potassium	K	19	39.10
carbon	C	6	12.01	praseodymium	Pr	59	140.9
cerium	Ce	58	140.1	promethium	Pm	61	-
chlorine	Cl	17	35.45	protactinium	Pa	91	-
chromium	Cr	24	52.00	radium	Ra	88	226.03
cobalt	Co	27	58.93	radon	Rn	86	-
copper	Cu	29	63.54	rhenium	Re	75	186.2
curium	Cm	96	-	rhodium	Rh	45	102.9
dysprosium	Dy	66	162.5	rubidium	Rb	37	85.47
einsteinium	Es	99	-	ruthenium	Ru	44	101.1
erbium	Er	68	167.3	samarium	Sm	62	150.4
europium	Eu	63	152.0	scandium	Sc	21	44.96
fermium	Fm	100	-	selenium	Se	34	78.96
fluorine	F	9	19.00	silicon	Si	14	28.09
francium	Fr	87	-	silver	Ag	47	107.9
gadolinium	Gd	64	157.3	sodium	Na	11	22.99
gallium	Ga	31	69.72	strontium	Sr	38	87.62
germanium	Ge	32	72.59	sulfur	S	16	32.06
gold	Au	79	197.0	tantalum	Ta	73	180.9
hafnium	Hf	72	178.5	technetium	Tc	43	-
helium	He	2	4.002	tellurium	Te	52	127.6
holmium	Ho	67	164.9	terbium	Tb	65	158.9
hydrogen	H	1	1.008	thallium	Tl	81	204.4
indium	In	49	114.8	thorium	Th	90	232.0
iodine	I	53	126.9	thulium	Tm	69	168.9
iridium	Ir	77	192.2	tin	Sn	50	118.7
iron	Fe	26	55.85	titanium	Ti	22	47.90
krypton	Kr	36	83.80	tungsten	W	74	183.9
lanthanum	La	57	138.9	uranium	U	92	238.0
lawrencium	Lr	103	-	vanadium	V	23	50.94
lead	Pb	82	207.2	xenon	Xe	54	131.3
lithium	Li	3	6.941	ytterbium	Yb	70	173.0
lutetium	Lu	71	175.0	yttrium	Y	39	88.91
magnesium	Mg	12	24.31	zinc	Zn	30	65.37
manganese	Mn	25	54.94	zirconium	Zr	40	91.22
mendelevium	Md	101	-				

GENERAL REVISION PROBLEMS

Q1. A compound has the following percentage composition by mass; 26.0% sodium, 42.4% arsenic and the remainder is oxygen. Calculate the empirical formula for this compound.
($Na_4As_2O_7$)

Q2. Glucose has the formula $C_6H_{12}O_6$. What maximum mass of carbon could be obtained from 200.0 g of glucose? (80.0 g)

Q3. The chief source of chromium is from the ore 'chromite' which has the formula $Fe(CrO_2)_2$. What mass of chromium metal can be obtained theoretically from 1.00 kg of rock that contains 87.3% chromite by mass? (406 g)

Q4. Assuming that crop of wheat removes 20.0 kg of nitrogen per hectare of ground, what mass of urea $CO(NH_2)_2$ is required theoretically for fertilizing 100 hectares?
(Note: 1000 kg = 1 tonne) (4.29 tonnes)

Q5. One atom of element Z has a mass of 3.27×10^{-22} g. Use these data to find the $A_r(Z)$ and thus, the likely identity of element Z. (197, Au)

Q6. When 50.0 g of the ionic compound XCl_2 is dissolved in 750 mL of solution, the resulting ***chloride ion*** concentration is 1.40 mol L^{-1}. Use these data to find the $A_r(X)$ and thus, the likely identity of element X. (24.2, Mg)

Q7. For the reaction: $H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$, what is the concentration of a sulfuric acid solution given that 20.0 mL of the acid is neutralized by 34.6 mL of 0.350 mol L^{-1} KOH solution? (0.303 mol L^{-1})

Q8. When 10.0 g of magnesium metal is reacted with 10.0 g of O_2 gas, what is the mass of MgO formed and what is the mass of excess reactant? (16.6 g MgO)
(3.40 g O_2 is xs)

Q9. Consider the reaction $2Fe + 3Cl_2 \rightarrow 2FeCl_3$. If 100.0 g of iron is mixed with 150.0 g of chlorine gas, find the mass of iron(III) chloride formed and the mass of reactant that is in excess. (229 g of $FeCl_3$)
(21.2 g Fe is xs)

Q10. A particular brand of orange juice contains 18.4 mg of vitamin "C" ($C_6H_8O_6$) in 100 mL of the juice. Express this concentration in mol L^{-1}. (1.05×10^{-3} mol L^{-1})

Q11. If 125 g of hydrated sodium carbonate ($Na_2CO_3.10H_2O$) is heated strongly it is converted into the anhydrous form of sodium carbonate (Na_2CO_3). What mass of water is driven off? (78.7 g H_2O)

Q12. When 260 mL of 0.200 mol L^{-1} $AgNO_{3(aq)}$ is mixed with 180 mL of 0.100 mol L^{-1} $BaCl_{2(aq)}$

(i) what mass of AgCl precipitate forms? (5.17 g)

(ii) what is the final concentration of silver ions ***in solution?***

([Ag+] = 0.0364 mol L^{-1})

Q13. An aqueous solution of potassium dichromate was prepared by dissolving 2.312 g of $K_2Cr_2O_7$ crystals in 500.0 mL of acidic solution.
A piece of 'impure' iron wire of mass 0.597 g was completely dissolved in sulfuric acid so that the iron was now ALL in the form of $Fe^{2+}_{(aq)}$ ions. The resulting solution was diluted to 100.0 mL and then 25.0 mL samples of this solution were then titrated against the acidified potassium dichromate solution.
The average volume of $K_2Cr_2O_{7(aq)}$ required was 27.8 mL.

(i) By using the half-equation method, balance the net redox equation:

$$Cr_2O_7{}^{2-}{}_{(aq)} \quad + \quad H^+{}_{(aq)} \quad + \quad Fe^{2+}{}_{(aq)} \quad \rightarrow \quad Cr^{3+}{}_{(aq)} \quad + \quad Fe^{3+}{}_{(aq)} \quad + \quad H_2O_{(l)}$$

(ii) Hence, find the % iron (by mass) in the impure iron wire. (98.0%)

Q14. A pure compound is analysed and found to contain 38.8 % calcium, 20.0 % phosphorus and 41.2 % oxygen (% by mass).
Find the empirical formula for this compound. ($Ca_3P_2O_8$)

Q15. If a single atom of element X has a mass of 8.63 x 10^{-23} g, find the A_r(X) and hence identify the element if possible. (52.0 Cr)

Q16. Consider the chemical equation for the acid-base neutralization reaction:

$$3NaOH_{(s)} \quad + \quad H_3PO_{4(aq)} \rightarrow Na_3PO_{4(aq)} \quad + \quad 3H_2O_{(l)}$$

What volume of 0.250 mol L^{-1} $H_3PO_{4(aq)}$ will be required to react with 4.00 g of solid NaOH? (133 mL)

Q17. When a solution of barium nitrate $Ba(NO_3)_{2(aq)}$, is mixed with a solution of potassium sulfate $K_2SO_{4(aq)}$, a white precipitate of barium sulfate $BaSO_{4(s)}$ forms. The other product is potassium nitrate ($KNO_{3(aq)}$).

(a) Write the balanced total equation for the reaction described.

(b) Write the net ionic equation for the reaction described.

(c) What are the spectator ions in this reaction?

In a particular experiment, 365 mL of 0.600 mol L^{-1} $Ba(NO_3)_{2(aq)}$ was mixed with 135 mL of 0.685 mol L^{-1} $K_2SO_{4(aq)}$.

(d) By determining the "limiting" reactant, find the mass of $BaSO_{4(s)}$ precipitate formed.

(21.6 g)

Q18. What is the % by mass of hydrogen in hydrated oxalic acid crystals which have the chemical formula $H_2C_2O_4.2H_2O$? (4.76%)

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NAME...

CHEMISTRY (LEVEL 4C)
STOICHIOMETRY TEST

CRITERION 8 **(TOTAL = 26 marks)**

1. What mass of hydrated barium hydroxide crystals $Ba(OH)_2.8H_2O$ is needed to prepare 250.0 mL of a solution that has a **hydroxyl ion** concentration of 0.300 mole L^{-1}?

(4 marks)

2. What volume of concentrated (11.0 mole L^{-1}) $HCl_{(aq)}$ is needed to prepare 500.0 mL of dilute $HCl_{(aq)}$ given that the diluted solution is to have molarity of 0.500 mole L^{-1}?

(4 marks)

3. Consider the acid-base neutralization reaction:

$$2KOH_{(aq)} + H_2SO_{4(aq)} \rightarrow K_2SO_{4(aq)} + 2H_2O_{(l)}$$

In a particular reaction, a 20.00 mL sample of 0.250 mole L^{-1} $H_2SO_{4(aq)}$ was titrated against an unknown solution of $KOH_{(aq)}$. The end-point occurred when 22.35 mL of the potassium hydroxide solution had been added. Use these data to determine the concentration of the $KOH_{(aq).}$

(4 marks)

4. Hydrated chromium(III) chloride has the formula $CrCl_3.xH_2O$ where x is a whole number. When 10.00 g of $CrCl_3.xH_2O$ crystals were heated strongly, the product was found to be 5.95 g of anhydrous $CrCl_3$. Use this information to find the value of x. Show your workings.

(4 marks)

5. Consider the chemical reaction: $4Cr + 3O_2 \rightarrow 2Cr_2O_3$

If 0.175 mole of chromium is mixed with 0.120 mole of oxygen,

(i) which is the limiting reactant?

(ii) how many mole of excess reactant remains?

(4 marks)

6. One atom of element Z has a mass of 2.70×10^{-22} g. Use these data to find the $A_r(Z)$ and thus, the likely identity of element Z.

(2 marks)

7. How many mole of oxygen atoms are there in 10.0 mole of $Ba(OH)_2.8H_2O$ crystals?

(2 marks)

8. A pure compound contains 31.1% boron and 68.9% oxygen by mass. Find the empirical formula.

(2 marks)

NAME ANSWERS

CHEMISTRY (LEVEL 5C)

STOICHIOMETRY TEST

CRITERION 10 **(TOTAL = ~~30~~ 26 marks)**

1. What mass of hydrated barium hydroxide crystals $Ba(OH)_2.8H_2O$ is needed to prepare 250.0 mL of a solution that has a **hydroxyl ion** concentration of 0.300 mole L^{-1}?

$Ba(OH)_{2(aq)} \longrightarrow Ba^{2+}_{(aq)} + 2OH^-_{(aq)}$

$\therefore$ If $[OH^-_{(aq)}] = 0.300 \text{ mol } L^{-1}$

$\Rightarrow Ba(OH)_{2(aq)} = 0.150 \text{ mol } L^{-1}$

Now $M_r(Ba(OH)_2.8H_2O) = 315.0$

$n(Ba(OH)_2.8H_2O) = \text{molarity} \times L$

$= (0.150 \times 0.250) \text{ mol}$

$= 0.0375 \text{ mol}$

$\therefore$ Mass needed $= (\text{mol} \times M_r) = (0.0375 \times 315$

Mass needed $= 11.8g$

2. What volume of concentrated (11.0 mole L^{-1}) $HCl_{(aq)}$ is needed to prepare 500.0 mL of dilute $HCl_{(aq)}$ given that the diluted solution is to have molarity of 0.500 mole L^{-1}?

Let the volume of conc. HCl needed $= x$ mL

Now $n(HCl)$ in conc. soln $= n(HCl)$ in diluted soln

$\Rightarrow 11.0 \times x \times 10^{-3} = 0.500 \times 500 \times 10^{-3}$

$\therefore x = \frac{250}{11.0} = 22.7 \text{ mL}$

$\therefore$ Volume needed $= 22.7$ mL

(4 marks)

3. Consider the acid-base neutralization reaction:

$2KOH_{(aq)} + H_2SO_{4(aq)} \rightarrow K_2SO_{4(aq)} + 2H_2O_{(l)}$

In a particular reaction, a 20.00 mL sample of 0.250 mole L^{-1} $H_2SO_{4(aq)}$ was titrated against an unknown solution of $KOH_{(aq)}$. The end-point occurred when 22.35 mL of the potassium hydroxide solution had been added.
Use these data to determine the concentration of the $KOH_{(aq)}$.

$n(H_2SO_4)$ reacted $= \text{molarity} \times L$

$= 0.250 \times 20.0 \times 10^{-3}$

$= 5.00 \times 10^{-3}$ mole

$\therefore n(KOH) = (5.00 \times 10^{-3} \times \frac{2}{1}) = 0.0100 \text{ mol}$

$\therefore [KOH_{(aq)}] = \frac{mol}{L} = \frac{0.0100}{22.35 \times 10^{-3}}$

(4 marks)

$\therefore [KOH_{(aq)}] = 0.447 \text{ mol } L^{-1}$

JAK

4. Hydrated chromium(III)chloride has the formula $CrCl_3.xH_2O$ where x is a whole number. When 10.00 g of $CrCl_3.xH_2O$ crystals were heated strongly, the product was found to be 5.95 g of anhydrous $CrCl_3$. Use this information to find the value of x. Show your workings.

$$CrCl_3 \cdot xH_2O_{(s)} \longrightarrow CrCl_{3(s)} + xH_2O$$

10.00g 5.95g 4.05g

Thus $n(CrCl_3) : n(H_2O)$

$= \left(\frac{5.95}{158.5}\right) : \left(\frac{4.05}{18.0}\right)$ divide masses by M_r

$= 0.0375 : 0.225$

$= 1 : 6 \Rightarrow x = 6$

(4 marks)

5. Consider the chemical reaction: $4Cr + 3O_2 \rightarrow 2Cr_2O_3$

If 0.175 mole of chromium is mixed with 0.120 mole of oxygen,

(i) which is the limiting reactant?

(ii) how many mole of excess reactant remains?

$$4Cr + 3O_2 \longrightarrow 2Cr_2O_3$$

0.160mol + 0.120mol

∴ all 0.120mole of O_2 is used up ∴ O_2 is LIMITING

(0.175 − 0.160) = 0.015mol of Cr is EXCESS

(4 marks)

6. One atom of element Z has a mass of 2.70×10^{-22} g. Use these data to find the $A_r(Z)$ and thus, the likely identity of element Z.

$A_r(Z)$ = mass of 1 atom × 6.02×10^{23}

$= 2.70 \times 10^{-22} \times 6.02 \times 10^{23}$ ∴ Z = dysprosium (Dy)

$= 162.5$

(2 marks)

7. How many mole of oxygen atoms are there in 10.0 mole of $Ba(OH)_2.8H_2O$ crystals?

1 mole of $Ba(OH)_2 \cdot 8H_2O$ contains 10.0 mole of O atoms

∴ 10.0 - - - - - - - - - - - - - - - - 100.0 mole of O atoms

(2 marks)

8. A pure compound contains 31.1% boron and 68.9% oxygen by mass. Find the empirical formula.

$n(B) : n(O)$

$= \left(\frac{31.1}{10.8}\right) : \left(\frac{68.9}{16.0}\right)$

$= 2.88 : 4.31$

$= 1 : 1.50$

$= 2 : 3$

∴ Empirical formula is B_2O_3

(2 marks)

JAK