Chem Factsheet

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# How to Answer Questions on Moles, Molarity etc

You need to know and understand all related ideas before you can gain maximum credit when answering exam questions on any particular topic. To help you, the following is a summary of the essential ideas under the topic heading, “moles etc”. However, applying these correctly to exam questions is really what this FactSheet is about. After studying this FactSheet you should be able to pick up a few more marks – or a lot!

Central idea is about measuring / calculating **amounts** of different chemical particles where amount is in terms of the **NUMBER** of chemical particles. Just like items in “pairs”, “dozens” etc – but much larger numbers!

Measurement of “amount” is in **MOLES** **EQUAL NUMBERS OF MOLES OF DIFFERENT CHEMICALS CONTAIN EQUAL NUMBERS OF CHEMICAL PARTICLES**

DEFINITION : **ONE MOLE OF A SUBSTANCE** = the mass that contains the same number of chemical particles (atoms, ions or molecules) as there are atoms in exactly 12g (ie one mole) of $^{12}C$.

**Relative Atomic Mass**, $A_r$

$$A_r = \frac{\text{average mass of one atom of an element}}{\text{mass of one atom of C-12}} \times 12$$

**Relative Molecular / Formula Mass**, $M_r$ / $F_r$

$$= \frac{\text{average mass of one molecule / formula}}{\text{mass of one atom of C-12}} \times 12$$

= **sum of $A_r$ in formula**

**ONE MOLE = $A_r$, $M_r$ or $F_r$ in grams**

$M_r$ or $F_r$ = sum of $A_r$ in formula

eg $H_2SO_4$

$M_r = 2(1) + 32 + 4(16)$

$= 98$

One mole $H_2SO_4$ = **98g**

Also called **mole mass**.

**AVOGADRO’S CONSTANT (L)**

The NUMBER of chemical particles in one mole of a substance.

$L \approx 6.02 \times 10^{23}$ mole$^{-1}$

No. of particles in a sample = L × no. moles (n).

**CONCENTRATION** measures how close together solute particles are in a given volume of solution. Measured in **mol dm$^{-3}$** (i.e. moles per dm$^3$)

**Molar concentration** (C) of a solution

$$= \frac{\text{Number of moles (n) of solute in solution}}{\text{Volume (V) of solution measured in dm}^3}$$

$1dm^3 = 1000cm^3$

$\rightarrow C = n \times 1000 / V_{cm3}$ → **$n = CV_{cm3} / 1000$**

**Calculating how many moles (n) are contained in a sample**

| Type of sample | (a) Weighed sample | (b) Sample in solution | (c) Gaseous sample | |
|---|---|---|---|---|
| Data needed | 1. Sample mass (w/g)<br>2. Mass of ONE mole calculated from formula (m / g) | 1. Volume of sample (V/cm$^3$)<br>2. Molar concentration (C/mol dm$^{-3}$) | 1. Volume(V/m$^3$)<br>2. Pressure (P/Pa)<br>3. Temp. (T/K)<br>4. Gas constant (R/JK$^{-1}$mol$^{-1}$) | or 1. Volume (V/dm$^3$) at known T and P.<br>2. Molar volume ($V_m$/ dm$^3$) at the SAME T and P. |
| Moles (n) in sample | **n = w/m** | **n = C × V / 1000** | **n = PV / RT** | **n = V/$V_m$** |

**NOTES**: K = °C + 273 ; Pa = kPa × 1000 ; m$^3$ = cm$^3$ × 10$^{-6}$ = dm$^3$ × 10$^{-3}$ ; $V_m$ = 24dm$^3$ at room T and P.

**EMPIRICAL FORMULA** = FORMULA SHOWING THE SIMPLEST RATIO OF THE NUMBER OF DIFFERENT ATOMS IN A COMPOUND

**MOLECULAR FORMULA** = FORMULA SHOWING THE ACTUAL NUMBERS OF DIFFERENT ATOMS IN A MOLECULE.

**Calculating an Empirical Formula:**
1. State atoms present
2. State grams (w) of each atom present in 100g i.e %
3. Calc no. moles of each atom by w/$A_r$
4. Calc simplest ratio by dividing by smallest no. moles
5. State empirical formula

**Molecular Formula** = Empirical formula × $M_r$ / $EF_r$

**% Atom Economy**

$$= \frac{\text{Mass of useful product(s) in equation} \times 100}{\text{Total mass of reactants in equation}}$$

**EMMA : Four Steps To Complete Any Mole Calculation Based On A Reaction:**

**E:** Write the balanced Equation for the reaction

**M:** Calculate the number of Moles for the “known” substance

**M:** Use the mole ratio from the balanced equation to calculate the number of Moles of the “target” substance from the number of moles of the “known” substance

**A:** If required, convert this to another Answer – concentration, volume, mass, purity etc

$$\textbf{\% Yield} = \frac{\text{Actual mass of product} \times 100}{\text{Theoretical mass of product}}$$

There follows a range of questions based on these ideas. Work your way through them carefully and then **seek out others – practising** this sort of question is perhaps more important than practising other types because it helps to instil the fundamental mathematical definitions, calculation techniques and calculation sequences.

> Remember to state **what** you are calculating and **how** you are calculating it. This may get you some credit even if your final answer is not correct. Also, make sure you use an appropriate number of significant figures in your final answer. As a guide, this should be the same as the **lowest** number of significant figures in the data used for the calculation(s).

**1. In an experiment, 0.0300 g $CaCO_3$ is added to 25.0 $cm^3$ of 0.050 mol $dm^{-3}$ HCl.**

**(i) Explain what is meant by "0.050 mol $dm^{-3}$ HCl".**

A This measures the concentration of the HCl solution. It means it contains 0.050 moles of HCl in each $dm^3$ ($1000cm^3$) of solution.

Note : read "mol $dm^{-3}$" as moles per $dm^3$. This then explains itself since "per" corresponds to "in each".

**(ii) How many moles of $CaCO_3$ were used in the experiment?**

A $F_r(CaCO_3) = 40.1 + 12.0 + 3(16.0) = 101.1$

∴ one mole of $CaCO_3$ = 100.1g

∴ moles of $CaCO_3$ in 0.0300g sample = w/m
= 0.0300/100.1 = **0.000300** (3sf)

Note: the use of $F_r$ rather than $M_r$ avoids the contradiction that $CaCO_3$ is a molecule!

**(iii) Calculate how many moles of HCl are needed to react with this amount of $CaCO_3$.**

A Balanced reaction equation is:

$CaCO_3 + \mathbf{2}HCl \rightarrow CaCl_2 + H_2O + CO_2$

∴ moles of HCl that react = **2** x moles $CaCO_3$ used
$= 0.000300 \times 2 = 0.000600$ (3sf)

**(iv) Hence show that the HCl is in excess.**

A Moles of HCl used $= CVcm^3 / 1000$
$= 0.050 \times 25.0/1000$
$= 0.00125$ (3sf)

∴ HCl is used in excess since only 0.000600 moles is required i.e. 0.000650 moles in excess.

Note: "complete" the question – **show** that the HCl **is** in excess using your calculated values – don't simply calculate those values.

**2. Magnesium hydroxide and hydrochloric acid react as shown below.**

**$Mg(OH)_2(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + 2H_2O(l)$**

**Calculate the volume, in $cm^3$, of 0.750 $moldm^{-3}$ hydrochloric acid required to react completely with 0.800g of magnesium hydroxide.**

Note: the balanced equation is often **given** at AS level. If not, always attempt to write an equation and make sure your calculations are consistent with it. Then, even if your equation is incorrect, it is likely that you can be awarded all other marks.

A $F_r(Mg(OH)_2) = 24.3 + 2(16.0) + 2(1.0) = 58.3$

∴ one mole of $Mg(OH)_2$ = 58.3g

∴ moles of $Mg(OH)_2$ in 0.800g sample = 0.800/58.3 = 0.013722

∴ moles of HCl needed = **2** × moles $Mg(OH)_2$ used
$= 2 \times 0.013722 = 0.027444$

∴ volume of HCl needed = $1000 \times n / C$
$= 1000 \times 0.027444 / 0.750$
= **36.0$cm^3$** (3sf)

Note: the answer is rounded to 3sf only at the end ; if you round at each stage of the calculation, significant errors can build up.

**3. Brass is composed of copper and zinc. Zinc reacts with 2.00 $moldm^{-3}$ hydrochloric acid but copper does not. The reaction is as shown in the equation below.**

**$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$**

**The percentages of copper and zinc in a sample of brass can be determined by (a) reacting a known mass with an excess of 2.00 $moldm^{-3}$ hydrochloric acid and (b) collecting the hydrogen gas produced, measuring its volume at a known temperature and pressure.**

**For OCR and EDEXCEL**
**A 1.20g sample of brass is used. 74.5 $cm^3$ of hydrogen at room temperature and pressure is formed. Given that 1 mole of gas molecules occupies 24.0 $dm^3$ at room temperature and pressure, calculate the percentage by mass of copper in the sample of brass.**

**For AQA A 1.20g sample of brass is used. 74.5 $cm^3$ of hydrogen at 20°C and 100kP is formed. Calculate the percentage by mass of copper in the sample of brass. (R = 8.31 J $mol^{-1}$ $K^{-1}$).**

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| | OCR and EDEXCEL | AQA |
|---|---|---|
| Moles $H_2$ formed | $= 74.5 / 24000$<br>$= 0.003014$ | $= \dfrac{100000 \times 74.5 \times 10^{-6}}{8.31 \times 293}$<br>$= 0.003060$ |
| ∴ Moles Zn reacted | $= 0.003014$ | $= 0.003060$ |
| ∴ Mass Zn reacted | $= 0.003014 \times 65.4$<br>$= 0.203$g | $= 0.003060 \times 65.4$<br>$= 0.200$g |
| ∴ Mass Cu in sample | $= 1.20 - 0.203$<br>$= 0.997$g | $= 1.20 - 0.200$<br>$= 1.00$g |
| ∴ % Cu in sample | $= 0.997 \times 100 / 1.20$<br>**= 83.1** | $= 1.00 \times 100 / 1.20$<br>**= 83.3** |

Note : 3sf is appropriate because the data values are all given to 3sf

**4. The mass of a single atom of $^{12}C$ is 1.99 × $10^{-23}$g. Use this information to calculate a value for the Avogadro constant (L). Show your working and state the appropriate units.**

A Mass of one mole of C-12 = 12.000g

∴ mass of L atoms of C-12 = 12.000g
but mass of one atom of C-12 = $1.99 \times 10^{-23}$g

∴ L = value of Avogadro's Constant
$= 12.000 / 1.99 \times 10^{-23}$ = **$6.03 \times 10^{23}$** $mole^{-1}$

Note: the units are $mole^{-1}$ since this means "per mole" and you have been asked how many particles per mole! Alternatively, think of it as g per mole / g = per mole = $mole^{-1}$.

**5. The chloride of an element X reacts with water according to the following equation.**

**$XCl_4 + 2H_2O \rightarrow XO_2 + 4HCl$**

**A 1.50 g sample of $XCl_4$ was added to water. The solid $XO_2$ was removed by filtration and the resulting solution made up to 250 $cm^3$ in a volumetric flask. A 25.0 $cm^3$ portion of this solution was titrated against a 0.140 mol $dm^{-3}$ solution of sodium hydroxide, of which 20.0 $cm^3$ were required to reach the end point.**
**Use this information to calculate the relative atomic mass, $A_r$, of element X and hence identify it.**

A Finding your way through this type of multi-step calculation is often a problem. Try to map out your route before beginning. Remember the EMMA approach often helps.

Hence:
titre → moles NaOH used → moles HCl titrated → moles HCl from sample → moles $XCl_4$ in sample → $M_r$ of $XCl_4$ → $A_r$ of X.

Moles of NaOH used in titration $= CV/1000 = 20.0 \times 0.140 / 1000 = 0.00280$
∴ since $NaOH + HCl \rightarrow NaCl + H_2O$, moles of HCl titrated = 0.00280
∴ moles HCl produced from $XCl_4$ sample = 0.002800 × 10 = 0.0280 (since 25 of 250 titrated)
∴ moles of $XCl_4$ in sample = 0.0280 / 4 = 0.0070 (since equation shows 1:4 ratio)
∴ $F_r$ of $XCl_4$ = mass of sample / no. moles in sample = 1.50 / 0.0070 = 214

but $F_r$ of $XCl_4 = A_r(X) + 4(35.5)$
∴ $A_r(X) = 214 - 4(35.5) =$ **72**
∴ Using the Periodic Table, X must be **germanium** (Ge).

**Notes:**
1. Should $F_r$ come out at 21.4, being impossible because 4Cl's are present, it should prompt you to remember the 10x factor resulting from the standard practice of using a sample for titration rather than the whole.
2. The answer "makes sense" because Ge is in group IV and a 1:4 formula is therefore to be expected.

**6. A compound contains 41.4% by mass of carbon, 3.4% hydrogen and 55.2% oxygen and its relative molecular mass is 174. Determine the molecular formula of this compound.**

Notes: You should recognise this as the type of data given for an empirical formula calculation. Hence, the sequence is (1) calculate the empirical formula, then (2) calculate the molecular formula.

This is a "mole-related" calculation because the first step is to covert the masses of atoms to moles of atoms so that the ratio of numbers of the different atoms can be compared.

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| | | | |
|---|---|---|---|
| Elements present | C | H | O |
| Combining masses/g | 41.4 | 3.4 | 55.2 |
| ∴ Moles combining | = 41.4 / 12<br>= 3.45 | = 3.4 / 1<br>= 3.40 | = 55.2 / 16<br>= 3.45 |
| ∴ Atoms combining | = 3.45 | = 3.40 | = 3.45 |
| ∴ Simplest ratio of atoms combining | = 3.45 / 3.40<br>= 1.01 | = 3.40 / 3.40<br>= 1.00 | = 3.45 / 3.40<br>= 1.01 |
| ∴ Empirical formula is | | **CHO** | |

Relative mass of empirical formula = 12 + 1 + 16 = 29
and relative mass of molecular formula = 174 (given)
∴ Ratio of molecular formula to empirical formula = 174 / 29 = 6
∴ Molecular formula = empirical formula × 6 = CHO × 6 = **$C_6H_6O_6$**

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