Titanium(IV) oxide (TiO₂, \( M_r = 79.9 \)) is used as a white pigment in some paints. The pigment can be made as shown in the following equation.

\[
\text{TiCl}_4(l) + 2\text{H}_2\text{O}(l) \rightarrow \text{TiO}_2(s) + 4\text{HCl}(aq)
\]

a  i  Calculate the percentage atom economy for the formation of TiO₂.

.................................................................................................................................................. (2 marks)

..................................................................................................................................................

.................................................................................................................................................. (2 marks)

ii  In view of the low atom economy of this reaction, suggest how a company can maximise its profits without changing the reaction conditions or the production costs.

..................................................................................................................................................

..................................................................................................................................................

.................................................................................................................................................. (1 mark)

b  In an experiment 165 g of TiCl₄ were added to an excess of water.

i  Calculate the amount, in moles, of TiCl₄ in 165 g.

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

.................................................................................................................................................. (2 marks)

ii  Calculate the maximum amount, in moles, of TiO₂ which can be formed in this experiment.

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

.................................................................................................................................................. (1 mark)

iii  Calculate the maximum mass of TiO₂ formed in this experiment.

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

.................................................................................................................................................. (1 mark)
In this experiment only 63.0 g of TiO$_2$ were produced. Calculate the percentage yield of TiO$_2$.

\[
\text{Percentage yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100
\]

(1 mark)

---

From AQA Chemistry Unit 1 Foundation Chemistry CHEM1 June 2011 (Question 2).

Norgessaltpeter was the first nitrogen fertiliser to be manufactured in Norway. It has the formula Ca(NO$_3$)$_2$.

\[\text{a} \quad \text{Norgessaltpeter can be made by the reaction of calcium carbonate with dilute nitric acid as shown by the following equation.}\]

\[\text{CaCO}_3(s) + 2\text{HNO}_3(aq) \rightarrow \text{Ca(NO}_3)_2(aq) + \text{CO}_2(g) + \text{H}_2\text{O(l)}\]

In an experiment, an excess of powdered calcium carbonate was added to 36.2 cm$^3$ of 0.586 mol dm$^{-3}$ nitric acid.

\[\text{i} \quad \text{Calculate the amount, in moles, of HNO}_3 \text{ in 36.2 cm}^3 \text{ of 0.586 mol dm}^{-3} \text{ nitric acid.}\]

Give your answer to three significant figures.

(1 mark)

\[\text{ii} \quad \text{Calculate the amount, in moles, of CaCO}_3 \text{ that reacted with the nitric acid.}\]

Give your answer to three significant figures.

(1 mark)

\[\text{iii} \quad \text{Calculate the minimum mass of powdered CaCO}_3 \text{ that should be added to react with all of the nitric acid.}\]

Give your answer to three significant figures.

(2 marks)
State the type of chemical reaction that occurs when calcium carbonate reacts in a test tube with nitric acid.

(1 mark)

b Norgessaltipeter decomposes on heating as shown by the following equation.

\[ 2\text{Ca(NO}_3\text{)}_2(s) \rightarrow 2\text{CaO}(s) + 4\text{NO}_2(g) + \text{O}_2(g) \]

A sample of Norgessaltipeter was decomposed completely.

The gases produced occupied a volume of \(3.50 \times 10^{-3}\) m\(^3\) at a pressure of 100 kPa and a temperature of 31°C. (The gas constant \(R = 8.31\) J K\(^{-1}\) mol\(^{-1}\))

i Calculate the total amount, in moles, of gases produced.

(3 marks)

ii Hence calculate the amount, in moles, of oxygen produced.

(1 mark)

c Hydrated calcium nitrate can be represented by the formula \(\text{Ca(NO}_3\text{)}_2.x\text{H}_2\text{O}\) where \(x\) is an integer.

A 6.04 g sample of \(\text{Ca(NO}_3\text{)}_2.x\text{H}_2\text{O}\) contains 1.84 g of water of crystallisation.

Use this information to calculate a value for \(x\). Show your working.

(3 marks)
3 From AQA Chemistry Unit 1 Foundation Chemistry CHEM1 January 2009 (Question 5).

A metal carbonate MCO₃ reacts with hydrochloric acid as shown in the following equation.

\[
\text{MCO}_3 + 2\text{HCl} \rightarrow \text{MCl}_2 + \text{H}_2\text{O} + \text{CO}_2
\]

A 0.548 g sample of MCO₃ reacted completely with 30.7 cm³ of 0.424 mol dm⁻³ hydrochloric acid.

a i Calculate the amount, in moles, of HCl which reacted with 0.548 g MCO₃.

................................................................................................................................................. (1 mark)

ii Calculate the amount, in moles, of MCO₃ in 0.548 g.

................................................................................................................................................. (1 mark)

iii Calculate the relative formula mass of MCO₃.

................................................................................................................................................. (1 mark)

b Use your answer from part a iii to deduce the relative atomic mass of metal M and suggest its identity.

(If you have been unable to calculate a value for the relative formula mass of MCO₃ you should assume it to be 147.6 but this is not the correct answer.)

Relative atomic mass ...................................................................................................................

.................................................................................................................................................

.................................................................................................................................................

Identity of M ............................................................................................................................... (2 marks)

c Suggest a piece of apparatus that could be used to measure 30.7 cm³ of hydrochloric acid accurately.

................................................................................................................................................. (1 mark)
The metal lead reacts with warm dilute nitric acid to produce lead(II) nitrate, nitrogen monoxide and water according to the following equation:

$$3\text{Pb(s)} + 8\text{HNO}_3(\text{aq}) \rightarrow 3\text{Pb(NO}_3)_2(\text{aq}) + 2\text{NO(g)} + 4\text{H}_2\text{O(l)}$$

a In an experiment, an 8.14 g sample of lead reacted completely with a 2.00 mol dm$^{-3}$ solution of nitric acid.
Calculate the volume, in dm$^3$, of nitric acid required for complete reaction. Give your answer to three significant figures.

b In a second experiment, the nitrogen monoxide gas produced in the reaction occupied 638 cm$^3$ at 101 kPa and 298 K. Calculate the amount, in moles, of NO gas produced. (The gas constant $R = 8.31$ J K$^{-1}$ mol$^{-1}$)

c When lead(II) nitrate is heated it decomposes to form lead(II) oxide, nitrogen dioxide and oxygen.

i Balance the following equation that shows this thermal decomposition.

$$\text{Pb(NO}_3)_2(\text{s}) \rightarrow \ldots\text{PbO(s)} + \ldots\text{NO}_2(\text{g}) + \ldots\text{O}_2(\text{g})$$

ii When this experiment is carried out the amount of nitrogen dioxide collected is often less than expected. Suggest one reason for this.
iii Suggest one reason why it is difficult to obtain a pure sample of nitrogen dioxide when this reaction is carried out in a laboratory.

................................................................................................................................................................................................. (1 mark)

5 From AQA Chemistry Unit 1 Foundation Chemistry CHEM1 January 2010 (Question 2).

Ammonium sulfate reacts with sodium hydroxide to form ammonia, sodium sulfate and water as shown in the equation below.

\[(\text{NH}_4)_2\text{SO}_4(s) + 2\text{NaOH}(aq) \rightarrow 2\text{NH}_3(g) + \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l)\]

a A 3.14 g sample of ammonium sulfate reacted completely with 39.30 cm\(^3\) of a sodium hydroxide solution.

i Calculate the amount, in moles, of \((\text{NH}_4)_2\text{SO}_4\) in 3.14 g of ammonium sulfate.

.................................................................................................................................................................................................................................................. (2 marks)

ii Hence calculate the amount, in moles, of sodium hydroxide which reacted.

........................................................................................................................................................................................................................................................................ (1 mark)

iii Calculate the concentration, in mol dm\(^{-3}\), of the sodium hydroxide solution used.

........................................................................................................................................................................................................................................................................ (1 mark)

b Calculate the percentage atom economy for the production of ammonia in the reaction between ammonium sulfate and sodium hydroxide.

........................................................................................................................................................................................................................................................................ (2 marks)
2 Amount of substance
Exam-style questions

**c** Ammonia is manufactured by the Haber process:

\[ N_2 + 3H_2 \rightleftharpoons 2NH_3 \]

Calculate the percentage atom economy for the production of ammonia in this process.

..................................................................................................................................................  (1 mark)

**d** A sample of ammonia gas occupied a volume of \(1.53 \times 10^{-2} \text{ m}^3\) at 37°C and a pressure of 100 kPa. (The gas constant \(R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}\))

Calculate the amount, in moles, of ammonia in this sample.

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................  (3 marks)

**e** Glauber’s salt is a form of hydrated sodium sulfate that contains 44.1% by mass of sodium sulfate. Hydrated sodium sulfate can be represented by the formula \(\text{Na}_2\text{SO}_4.x\text{H}_2\text{O}\) where \(x\) is an integer. Calculate the value of \(x\).

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................  (3 marks)