71 Sodium sulfate, Na_2SO_4, reacts in aqueous solution with lead nitrate, $Pb(NO_3)_2$, as follows:

$$Na_2SO_4(aq) + Pb(NO_3)_2(aq) \rightarrow PbSO_4(s) + 2NaNO_3(aq)$$
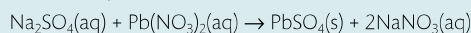
In an experiment, 35.30 cm^3 of a solution of sodium sulfate reacted exactly with 32.50 cm^3 of a solution of lead nitrate. The precipitated lead sulfate was dried and found to have a mass of 1.13 g. Determine the concentrations of the original solutions of lead nitrate and sodium sulfate. State what assumptions are made.

Challenge problems

72 The fertilizer tri-ammonium phosphate is made from 'phosphate rock' by:

1 reacting the phosphate rock with sulfuric acid, H_2SO_4, to produce phosphoric acid, H_3PO_4;
2 reacting the phosphoric acid with ammonia, NH_3, to give tri-ammonium phosphate, $(NH_4)_3PO_4$.

If the phosphate rock contains 90% by mass $Ca_3(PO_4)_2$ from which the overall yield of tri-ammonium phosphate is 95%, calculate the mass of phosphate rock required to make 1000 tonnes of tri-ammonium phosphate.

73 The combustion of both ammonia, NH_3, and hydrazine, N_2H_4, in oxygen gives nitrogen and water only. When a mixture of ammonia and hydrazine is burned in pure oxygen, the volumetric $N_2 : H_2O$ ratio in the product gas is 0.40. Calculate the % by mass of ammonia in the original mixture. What assumptions are being made here?

74 Sulfuric acid, H_2SO_4, is produced from sulfur in a three-step process:

1 $S(s) + O_2(g) \rightarrow SO_2(g)$
2 $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$
3 $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(l)$

Assuming 100% conversion and yield for each step, what is the minimum mass of sulfur in kg needed to produce 980 tonnes of H_2SO_4?

75 The concentration of hydrogen peroxide, H_2O_2, in excess aqueous sulfuric acid, H_2SO_4, can be determined by redox titration using potassium permanganate, $KMnO_4$ as follows:

$$2KMnO_4(aq) + 5H_2O_2(l) + 3H_2SO_4(aq) \rightarrow 2MnSO_4(aq) + K_2SO_4(aq) + 8H_2O(l) + 5O_2(g)$$

A 10.00 cm^3 sample of H_2O_2 solution requires 18.00 cm^3 of a 0.05 mol dm^{-3} solution of $KMnO_4$ to reach the equivalence point in a titration. Calculate the concentration of H_2O_2 in the solution.

76 Mixtures of sodium carbonate, Na_2CO_3, and sodium hydrogencarbonate, $NaHCO_3$, in aqueous solution are determined by titration with hydrochloric acid, HCl, in a two-step procedure.

1 Titrate to the phenolphthalein end-point:

$$Na_2CO_3(s) + HCl(aq) \rightarrow NaHCO_3(aq) + NaCl(aq)$$
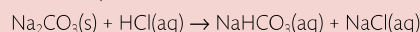
2 Continue titration to the methyl orange end-point:

$$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$$
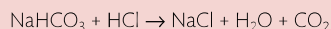
For an X cm^3 sample of a sodium carbonate / sodium hydrogencarbonate mixture titrated with Y mol dm^{-3} HCl, the respective end-points are Step 1 = P cm^3 HCl, Step 2 = Q cm^3 HCl. Derive relationships between X, Y, P, and Q to obtain the concentrations of sodium carbonate and sodium hydrogencarbonate in the original mixture.

77 A sealed vessel with fixed total internal volume 2.00 m^3 contains 0.720 kg pentane, C_5H_{12}, and oxygen only. The pentane is ignited and undergoes 100% conversion to carbon dioxide and water. Subsequently the temperature and pressure in the vessel are respectively 740 K, 400 kPa. Calculate the initial amount and mass in kg of oxygen in the vessel.

Practice questions

1 How many oxygen atoms are in 0.100 mol of $CuSO_4.5H_2O$?

A 5.42×10^{22} **B** 6.02×10^{22} **C** 2.41×10^{23} **D** 5.42×10^{23}

2 What is the sum of the coefficients when the following equation is balanced using whole numbers?

$$\underline{\quad} Fe_2O_3(s) + \underline{\quad} CO(g) \rightarrow \underline{\quad} Fe(s) + \underline{\quad} CO_2(g)$$
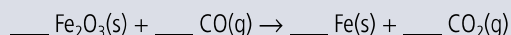
A 5   **B** 6   **C** 8   **D** 9

3 Four identical containers under the same conditions are filled with gases as shown below. Which container and contents will have the highest mass?

nitrogen	oxygen	ethane	neon
A	**B**	**C**	**D**
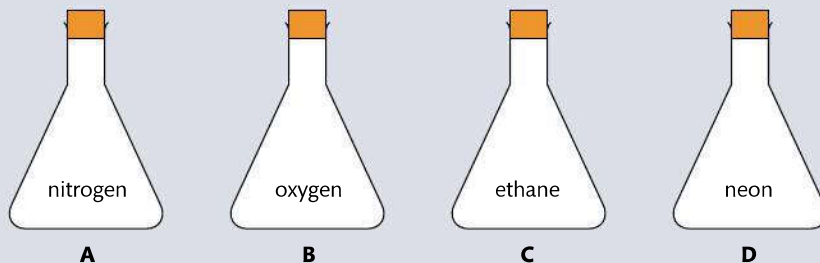
4 $1.0 \ dm^3$ of an ideal gas at 100 kPa and 25 °C is heated to 50 °C at constant pressure. What is the new volume in dm^3?

    A 0.50   **B** 0.90   **C** 1.1   **D** 2.0

5 What is the amount, in moles, of sulfate ions in 100 cm^3 of 0.020 mol dm^{-3} $FeSO_4(aq)$?

    A 2.0×10^{-3} **B** 2.0×10^{-2} **C** 2.0×10^{-1} **D** 2.0

6 1.7 g of $NaNO_3$ ($M_r = 85$) is dissolved in water to prepare 0.20 dm^3 of solution. What is the concentration of the resulting solution in mol dm^{-3}?

    A 0.01   **B** 0.1   **C** 0.2   **D** 1.0

7 What mass, in g, of hydrogen is formed when 3 mol of aluminium react with excess hydrochloric acid according to the following equation?

$$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$$

    A 3.0   **B** 4.5   **C** 6.0   **D** 9.0

8 The relative molecular mass of a gas is 56 and its empirical formula is CH_2. What is the molecular formula of the gas?

    A CH_2 **B** C_2H_4 **C** C_3H_6 **D** C_4H_8

9 What is the sum of all coefficients when the following equation is balanced using the smallest possible whole numbers?

$$\underline{\quad} \ C_2H_2 + \underline{\quad} \ O_2 \rightarrow \underline{\quad} \ CO_2 + \underline{\quad} \ H_2O$$

    A 5   **B** 7   **C** 11   **D** 13

10 What is the total number of hydrogen atoms in 1.0 mol of benzamide, $C_6H_5CONH_2$?

    A 7   **B** 6.0×10^{23} **C** 3.0×10^{24} **D** 4.2×10^{24}

11 Chloroethene, C_2H_3Cl, reacts with oxygen according to the equation below:

$$2C_2H_3Cl(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(g) + 2HCl(g)$$

What is the amount, in mol, of H_2O produced when 10.0 mol of C_2H_3Cl and 10.0 mol of O_2 are mixed together, and the above reaction goes to completion?

    A 4.00   **B** 8.00   **C** 10.0   **D** 20.0

12 What is the concentration of NaCl, in mol dm^{-3}, when 10.0 cm^3 of 0.200 mol dm^{-3} NaCl solution is added to 30.0 cm^3 of 0.600 mol dm^{-3} NaCl solution?

    A 0.450   **B** 0.300   **C** 0.500   **D** 0.800

13 On analysis, a compound with molar mass 60 g mol^{-1} was found to contain 12 g of carbon, 2 g of hydrogen, and 16 g of oxygen. What is the molecular formula of the compound?

    A CH_2O **B** CH_4O **C** C_2H_4O **D** $C_2H_4O_2$

14 300 cm^3 of water is added to a solution of 200 cm^3 of 0.5 mol dm^{-3} sodium chloride. What is the concentration of sodium chloride in the new solution?

A 0.05 mol dm^{-3} **B** 0.1 mol dm^{-3} **C** 0.2 mol dm^{-3} **D** 0.3 mol dm^{-3}

15 What is the approximate molar mass, in g mol^{-1}, of $MgSO_4.7H_2O$?

A 120   **B** 130   **C** 138   **D** 246

16 Which is both an empirical and a molecular formula?

A C_5H_{12} **B** C_5H_{10} **C** C_4H_8 **D** C_4H_{10}

17 Airbags are an important safety feature in vehicles. Sodium azide, potassium nitrate, and silicon dioxide have been used in one design of airbag.

Two students looked at data in a simulated computer-based experiment to determine the volume of nitrogen generated in an airbag.

Sodium azide, a toxic compound, undergoes the following decomposition reaction under certain conditions.

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$
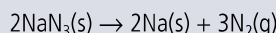
Using the simulation program, the students entered the following data into the computer.

Temperature (T) / °C	Mass of NaN$_3$(s) (m) / kg	Pressure (p) / atm
25.00	0.0650	1.08

(a) Stage the number of significant figures for the temperature, mass, and pressure data. (1)

(b) Calculate the amount, in mol, of sodium azide present. (1)

(c) Determine the volume of nitrogen gas, in dm^3, produced under these conditions based on this reaction. (4)

(Total 6 marks)

18 An important environmental consideration is the appropriate disposal of cleaning solvents. An environmental waste treatment company analysed a cleaning solvent, **J**, and found it to contain the elements carbon, hydrogen, and chlorine only. The chemical composition of **J** was determined using different analytical chemistry techniques.

Combustion reaction:

Combustion of 1.30 g of J gave 0.872 g CO_2 and 0.089 g H_2O.

Precipitation reaction with $AgNO_3$(aq):

0.535 g of J gave 1.75 g AgCl precipitate.

(a) Determine the percentage by mass of carbon and hydrogen in **J**, using the combustion data. (3)

(b) Determine the percentage by mass of chlorine in **J**, using the precipitation data. (1)

(c) The molar mass was determined to be 131.38 g mol^{-1}. Deduce the molecular formula of **J**. (3)

(Total 7 marks)

19 Nitrogen monoxide may be removed from industrial emissions via a reaction with ammonia as shown by the equation below:

$$4NH_3(g) + 6NO(g) \rightarrow 5N_2(g) + 6H_2O(l)$$
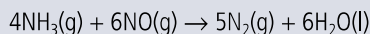
30.0 dm^3 of ammonia reacts with 30.0 dm^3 of nitrogen monoxide at 100 °C. Identify which gas is in excess and by how much and calculate the volume of nitrogen produced. (2)

20 The percentage by mass of calcium carbonate in eggshell was determined by adding excess hydrochloric acid to ensure that all the calcium carbonate had reacted. The excess acid left was then titrated with aqueous sodium hydroxide.

(a) A student added 27.20 cm^3 of 0.200 mol dm^{-3} HCl to 0.188 g of eggshell. Calculate the amount, in mol, of HCl added. (1)

(b) The excess acid requires 23.80 cm^3 of 0.100 mol dm^{-3} NaOH for neutralization. Calculate the amount, in mol, of acid that is in excess. (1)

(c) Determine the amount, in mol, of HCl that reacted with the calcium carbonate in the eggshell. (1)

(d) State the equation for the reaction of HCl with the calcium carbonate in the eggshell. (2)

(e) Determine the amount, in mol, of calcium carbonate in the sample of the eggshell. (2)

(f) Calculate the mass and the percentage by mass of calcium carbonate in the eggshell sample. (3)

(g) Deduce one assumption made in arriving at the percentage of calcium carbonate in the eggshell sample. (1)

(Total 11 marks)

21 A 2.450 g sample of a mixture of sodium chloride and calcium chloride was dissolved in distilled water. The chloride solution was treated with excess silver nitrate solution, $AgNO_3$(aq). The precipitated silver chloride, AgCl(s), was collected, washed and dried. The mass of the dried silver chloride was 6.127 g. Calculate the percent by mass of the sodium chloride and calcium chloride in the original mixture. (2)

22 A hydrate of potassium carbonate has the formula $K_2CO_3.xH_2O$. A 10.00 g sample of the hydrated solid is heated, and forms 7.93 g of anhydrous salt.

(a) Calculate the number of moles of water in the hydrated sample. (1)

(b) Calculate the number of moles of anhydrous salt that form. (1)

(c) Determine the formula of the hydrate. (1)

(d) How could you determine when all the hydrated salt has been converted into anhydrous form? (1)

(Total 4 marks)

23 625 cm^3 of ammonia, NH_3, at 42°C and 160 kPa is combined with 740 cm^3 of hydrogen chloride at 57°C and 113.3 kPa. The reaction produces ammonium chloride as follows:

NH_3(g) + HCl (g) → NH_4Cl(s)

(a) Which reactant is in excess? (1)

(b) Which reactant is limiting? (1)

(c) What mass of ammonium chloride forms? (1)

(Total 3 marks)