1 Ethyne gas, C_2H_2, is manufactured in large quantities for a variety of uses.

Much of this ethyne is manufactured from methane as shown in the equation below.

$$2CH_4(g) \rightleftharpoons C_2H_2(g) + 3H_2(g) \qquad \Delta H = +377\,kJ\,mol^{-1}$$

(a) Write an expression for K_c for this equilibrium. **[1]**

(b) A research chemist investigates how to improve the synthesis of ethyne from methane at a high temperature.

- The chemist adds CH_4 to a $4.00\,dm^3$ container.
- The chemist heats the container and allows equilibrium to be reached at constant temperature. The total gas volume does not change.
- The equilibrium mixture contains 9.36×10^{-2} mol CH_4 and 0.168 mol C_2H_2.

(i) Calculate the amount, in mol, of H_2 in the equilibrium mixture.

amount of H_2 = ... mol **[1]**

(ii) Calculate the equilibrium constant, K_c, at this temperature, including units.

Give your answer to **three** significant figures.

K_c = ... units ....**[3]**

(iii) Calculate the amount, in mol, of CH_4 that the chemist originally added to the container.

amount of CH_4 = ... mol **[1]**

(c) The chemist repeats the experiment three times.
In each experiment the chemist makes **one** change but uses the **same** initial amount of CH_4.

Complete the table to show the predicted effect of each change compared with the original experiment.

Only use the words **greater**, **smaller** or **same**.

Change	K_c	**Equilibrium amount of C_2H_2(g) / mol**	**Initial rate**
The container is heated at constant pressure			
A smaller container is used			
A catalyst is added to CH_4 at the start			

[3]

(d) In this manufacture of ethyne, hydrogen is also produced. To improve the atom economy of the process, it is important to make use of the hydrogen. For example, hydrogen can be used in the extraction of some metals from their ores.

State **two** other large-scale uses of the hydrogen.

1 ....

2 ....
[1]

[Total: 10]

2 Hydrogen and iodine react together in a reversible reaction:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9\,kJ\,mol^{-1}$$

A chemist mixes together 2.00×10^{-3} mol $H_2(g)$ and 4.00×10^{-3} mol $I_2(g)$ in a $1.00\,dm^3$ container.
The chemist seals the container.
The mixture is heated and left to reach equilibrium.

At equilibrium, the mixture contains 3.00×10^{-4} mol of H_2.

(a) Calculate the equilibrium constant, K_c, including units, if any, for this equilibrium.

Give your answer to **three** significant figures.

K_c = ... units .... **[5]**

(b) The chemist repeats the experiment several times. In each experiment, the chemist makes one change.

(i) The chemist uses 3.00×10^{-3} mol $H_2(g)$ instead of 2.00×10^{-3} mol $H_2(g)$.

Predict whether the amounts of $H_2(g)$, $I_2(g)$ and HI(g) in the equilibrium mixture would be greater, smaller or the same as in the original experiment.

Answer by placing ticks in the appropriate boxes of the table below.

	$H_2(g)$	$I_2(g)$	HI(g)
Greater			
Smaller			
The same			

[2]

(ii) The chemist heats the mixture to a higher temperature at constant pressure.

Explain whether the value of K_c would be greater, smaller or the same.

....

....

.... **[1]**

(iii) The chemist increases the pressure of the mixture at constant temperature.

Explain whether the value of K_c would be greater, smaller or the same.

....

....

.... **[1]**

[Total: 9]

3 A chemist carries out an investigation on the equilibrium system shown below.

$$2CO(g) + 2NO(g) \rightleftharpoons 2CO_2(g) + N_2(g) \qquad \Delta H = -788\,kJ\,mol^{-1}$$

The chemist mixes 0.46 mol of CO with 0.45 mol of NO. The mixture is left to reach equilibrium at constant temperature.

The student analyses the equilibrium mixture and finds that 0.25 mol NO remains. The total volume of the equilibrium mixture is 1.0 dm^3.

(a) **(i)** Write the K_c expression for this equilibrium.

[1]

(ii) What are the units of this equilibrium constant?

.... **[1]**

(iii) Determine the value of K_c for this equilibrium mixture.

Show all your working.

K_c = ... **[4]**

(iv) What does your value of K_c suggest about the position of equilibrium in this experiment?

....

....

.... **[1]**

(b) The chemist increases **both** the temperature and the pressure of the equilibrium mixture. The mixture is left to reach equilibrium again.

(i) What is the effect, if any, on the value of K_c? Explain your answer.

....

....

.... **[1]**

(ii) Explain why it is difficult to predict what would happen to the position of equilibrium after these changes in temperature and pressure.

....

....

....

....

.... **[2]**

[Total: 10]

4 Potassium manganate(VII) can be prepared in the laboratory by a two-step synthesis starting from manganese(IV) oxide.

Step 1

In this step, manganese(IV) oxide is heated strongly with potassium hydroxide and potassium chlorate(V), a powerful oxidising agent.

Manganese(IV) oxide, MnO_2, is oxidised to manganate(VI) ions.

Step 2

Potassium manganate(VI) is separated from the alkaline mixture from **step 1** as a green solid.

In this step, potassium manganate(VI) is heated in water. Manganate(VI) ions disproportionate forming manganate(VII) ions and a precipitate of manganese(IV) oxide.

(a) In **step 1**, a redox reaction takes place.

Add the correct number of electrons to the correct sides of the incomplete oxidation and reduction half-equations shown below.

$$MnO_2 + 4OH^- \rightarrow MnO_4^{2-} + 2H_2O$$

$$3H_2O + ClO_3^- \rightarrow 6OH^- + Cl^-$$

[2]

(b) In **step 2**, an equilibrium is set up.

$$3MnO_4^{2-}(aq) + 2H_2O(l) \rightleftharpoons 2MnO_4^-(aq) + MnO_2(s) + 4OH^-(aq)$$

The equilibrium position can be shifted by bubbling carbon dioxide gas through the mixture.

Suggest, with the aid of an equation, how the equilibrium position shifts.

....

....

....

....

....

.... **[3]**

(c) Aqueous potassium manganate(VII), $KMnO_4$, in acidic conditions can be used in analysis.

A student analyses a sample of sodium sulfite, Na_2SO_3, using the following method.

- The student dissolves 0.720 g of impure sodium sulfite in water.
- The solution is made up to 100.0 cm^3.
- The student titrates 25.0 cm^3 of this solution with 0.0200 mol dm^{-3} $KMnO_4$ under acidic conditions. The volume of $KMnO_4$(aq) required to reach the end-point is 26.2 cm^3.

The equation for the reaction is shown below.

$$2MnO_4^{-} + 6H^{+} + 5SO_3^{2-} \rightarrow 2Mn^{2+} + 5SO_4^{2-} + 3H_2O$$

Determine the percentage purity of the sample of sodium sulfite.

percentage purity = ... % **[5]**

[Total: 10]

5 Nitric acid, HNO_3, is manufactured in large quantities. The main use of nitric acid is in the manufacture of fertilisers.

In its industrial preparation, nitric acid is produced in three main stages.

Stage 1
Ammonia is heated with oxygen in the air to form nitrogen monoxide, NO.

Stage 2
The hot nitrogen monoxide gas is then mixed with air and cooled under pressure. Nitrogen dioxide, NO_2, forms in a reversible reaction.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = -115 \text{ kJ mol}^{-1}$$

Stage 3
The nitrogen dioxide is reacted with water in a series of reactions to form nitric acid, HNO_3. The first of these reactions forms a mixture of nitric acid, HNO_3, and nitrous acid, HNO_2.

(a) In **Stage 2**, explain why the equilibrium mixture is both cooled **and** put under pressure.

....

....

....

....

....

....

....

.... **[3]**

(b) Construct an equation for

- the reaction that takes place in **Stage 1**
- the first reaction that takes place in **Stage 3**.

Stage 1: ....

Stage 3: .... **[2]**

(c) An industrial chemist carries out some research into the $NO/O_2/NO_2$ equilibrium used in **Stage 2** of the manufacture of nitric acid.

- The chemist mixes together 0.80 mol NO(g) and 0.70 mol of O_2(g) in a container with a volume of 2.0 dm^3.
- The chemist heats the mixture and allows it to stand at constant temperature to reach equilibrium.
  The container is kept under pressure so that the total volume is maintained at 2.0 dm^3.
- At equilibrium, 75% of the NO has reacted.

(i) Write an expression for K_c for this equilibrium.

[1]

(ii) Calculate the equilibrium constant, K_c, including units, for this equilibrium.

K_c = ... units .... **[5]**

[Total: 11]

6 Dinitrogen tetroxide, N_2O_4(g), and nitrogen dioxide, NO_2(g), coexist in the following equilibrium.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H = -57\,kJ\,mol^{-1}$$

A chemist adds 4.00 mol NO_2 to a container with a volume of 2.00 dm^3. The container is sealed, heated to a constant temperature and allowed to reach equilibrium.

The equilibrium mixture contains 3.20 mol NO_2.

(a) Calculate the value for K_c under these conditions.

[5]

(b) The experiment is repeated but the pressure in the container is doubled.

Explain in terms of K_c the effect on the concentrations of NO_2 and N_2O_4 when the mixture has reached equilibrium.

....

....

....

....

....

....

.... **[3]**

[Total: 8]