1. This question is about two oxides of sulfur: sulfur dioxide, SO_2, and sulfur trioxide, SO_3.

SO_3 decomposes to form SO_2 and O_2, as shown in **Equilibrium 18.1**.

$$SO_3(g) \rightleftharpoons SO_2(g) + \tfrac{1}{2}O_2(g) \qquad \Delta H = +99 \text{ kJ mol}^{-1} \qquad \textbf{Equilibrium 18.1}$$

i. 2.25 moles of SO_3 is heated to 550 °C in the presence of a catalyst and the resulting mixture allowed to reach equilibrium.

The equilibrium mixture contains 0.900 mol of SO_2 and the total pressure is 2.80 atm.

Calculate the numerical value for K_p for **Equilibrium 18.1** under these conditions and state the units of K_p.

Give your answer to **3** significant figures.

K_p = ...

units ..... **[5]**

ii. The numerical values of K_p for **Equilibrium 18.1** at temperatures T_1 and T_2 are shown below.

Temperature	K_p
T_1	3.3×10^{-5}
T_2	7.7×10^{-2}

Explain why T_2 is a higher temperature than T_1.

[2]

iii. Suggest how the value of K_p would change if the reaction was repeated with no catalyst added and the pressure of the system increased.

Tick (✓) one box in each row.

Change	Decrease	No change	Increase
No catalyst			
Increased pressure			

[2]

2. Chloroethanoic acid, C*l*CH_2COOH, is a weak monobasic acid.

i. Write the expression for the acid dissociation constant, K_a, of C*l*CH_2COOH.

[1]

ii. The expression for the acid dissociation constant, K_a, of C*l*CH_2COOH can be simplified to:

$$K_a = \frac{[H^+]^2}{[ClCH_2COOH]}$$ **Expression 19.1**

State one approximation that allows the expression from **(a)(i)** to be simplified to **Expression 19.1**.

[1]

iii. A student carries out an experiment to determine the pK_a value of a solution of C*l*CH_2COOH.

- The concentration of C*l*CH_2COOH is 0.090 mol dm^{-3}.
- The pH of C*l*CH_2COOH is 1.95.

Use **Expression 19.1** to calculate the pK_a value of C*l*CH_2COOH.

Give your answer to **2** decimal places.

pK_a = ... **[3]**

3. In the UK, most sulfuric acid, H_2SO_4, is manufactured by the Contact process.

One stage in the Contact process involves the equilibrium between sulfur dioxide, oxygen and sulfur trioxide.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

This equilibrium is investigated:

Step 1 5.82×10^{-2} mol of SO_2 is mixed with 7.40×10^{-2} mol of O_2 in a 2.00 dm^3 container.

Step 2 The container is sealed and allowed to reach equilibrium at constant temperature.

Step 3 At equilibrium, 5.20×10^{-2} mol of SO_3 is formed.

Determine the equilibrium concentrations and calculate K_c, including units.

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

4. This question is about acids and bases.

A student reacts an excess of magnesium with 25.0 cm^3 of 0.500 mol dm^{-3} hydrochloric acid, HC*l*.

The student also reacts an excess of magnesium with 25.0 cm^3 of 0.500 mol dm^{-3} ethanoic acid, CH_3COOH.

i. Construct an ionic equation for the reaction of magnesium with an acid.

[1]

ii. Explain why these two reactions of magnesium produce the same volume of gas but at different rates.

[3]

5(a). This question is about equilibria involving hydrogen.

***** Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H = -92 kJ\ mol^{-1}$ **Equilibrium 20.1**

1.20 mol $N_2(g)$ is mixed with 3.60 mol $H_2(g)$ in a 8.00 dm^3 container.

The mixture is heated to 550 °C with an iron catalyst and allowed to reach equilibrium.

The equilibrium mixture contains 0.160 mol of NH_3.

Determine the equilibrium constant K_c for **Equilibrium 20.1**, and explain why the operational conditions used by industry may be different from those required for a maximum equilibrium yield of ammonia.

[6]

(b). In industry, hydrogen is used to reduce the iron oxide Fe_3O_4 as shown in **Equilibrium 20.2**.

The reaction is carried out at 500 °C.

$Fe_3O_4(s) + 4H_2(g) \rightleftharpoons 3Fe(s) + 4H_2O(g)$ **Equilibrium 20.2**

i. When the temperature is decreased, the value of K_p decreases.
Determine whether the forward reaction is exothermic or endothermic.
Explain your answer.

[1]

ii. Two students are discussing the effect of pressure on the equilibrium position of **Equilibrium 20.2**.

Student 1 says:

"There are more moles of products than reactants, so increasing the pressure will shift the equilibrium to the left hand side."

Student 2 disagrees.

Determine which student is correct. Justify your answer.

[1]

6. Two students plan to investigate **Equilibrium 4.1**, shown below.

$CoCl_4^{2-}(aq) + 6H_2O(l) \rightleftharpoons [Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq)$ **Equilibrium 4.1**

blue pink

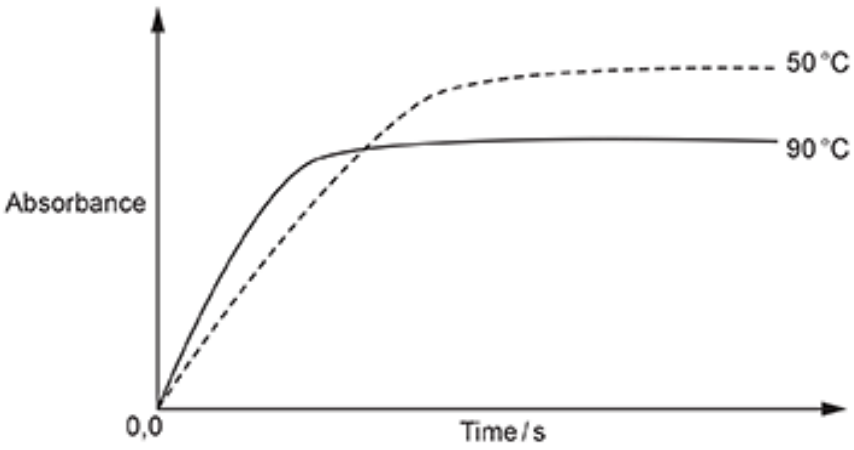
The students are supplied with the equilibrium mixture in **Equilibrium 4.1** at room temperature.

- One student heats 20 cm^3 of the mixture to 50°C.
- The other student heats 20 cm^3 of the mixture to 90°C.

The students use colorimetry to observe how the colour of the equilibrium mixture changes over time.

- The colorimeter is set up so that the greater the absorbance, the greater the concentration of $[Co(H_2O)_6]^{2+}$.
- The initial absorbance is set to zero.
- The absorbance is recorded every 30 seconds.

The students plot the graph below from the results of the experiment.



Use the graph and relevant chemical theory to answer the following. Include all reasoning:

- Explain the different initial rates at 50°C and 90°C.
- Predict the sign of ΔH for the forward reaction in **Equilibrium 4.1**.

[4]