How far [55 marks]

1. [Maximum mark: 16]

Sulfur trioxide is an important compound in industry.

(a) Sulfur trioxide has more than one possible Lewis (electron dot) structure.

(a.i) Sketch a Lewis (electron dot) structure for SO_3 which obeys the octet rule. [1]

(a.ii) Predict the length of each S to O bond in pm. Use section 10 of the data booklet. [1]

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(a.iii) State the molecular geometry and the O-S-O bond angle in SO_3.

Molecular geometry: .....

Bond angle: .....

[2]

(b) Suggest why atmospheric SO_3 (g) is an environmental concern. [1]

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(c) State the name of a post-combustion method used to lower the quantity of SO_3 (g) released to the atmosphere. [1]

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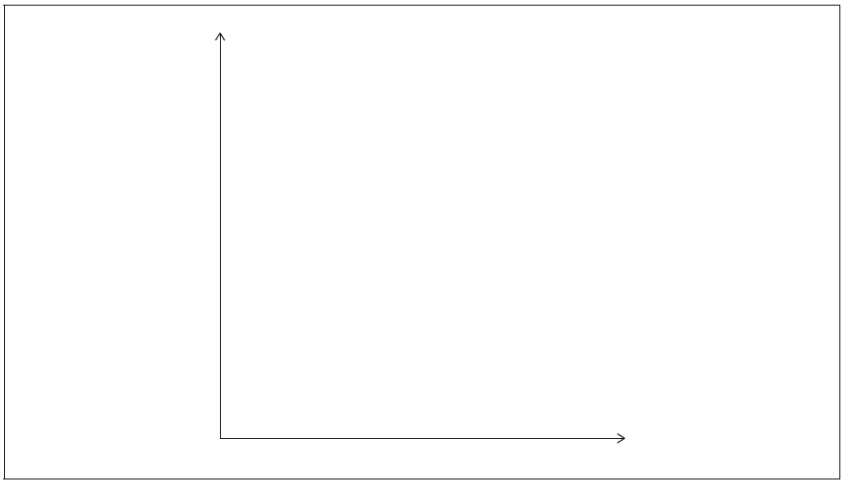
(d) SO_3 (g) is made using the contact process.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H^{\ominus} < 0$

(d.i) Sketch a potential energy profile for this reaction on the axes provided. Label E_a and include labels on the axes.



[3]

(d.ii) Explain why increasing the temperature increases the rate of reaction. [2]

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(d.iii) Vanadium pentoxide, V_2O_5, is used as a catalyst. Explain how a catalyst increases the rate of a reaction.

[2]

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(d.iv) During the reaction, V_2O_5 changes to V_2O_4. Identify the oxidation states of vanadium in each compound.

V_2O_5: . . . . . .
V_2O_4: . . . . . .

[1]

(d.v) State the equilibrium constant expression, K_c, for the production of SO_3.

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

[1]

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(d.vi) Outline, with a reason, the effect of increasing the pressure on the position of equilibrium. [1]

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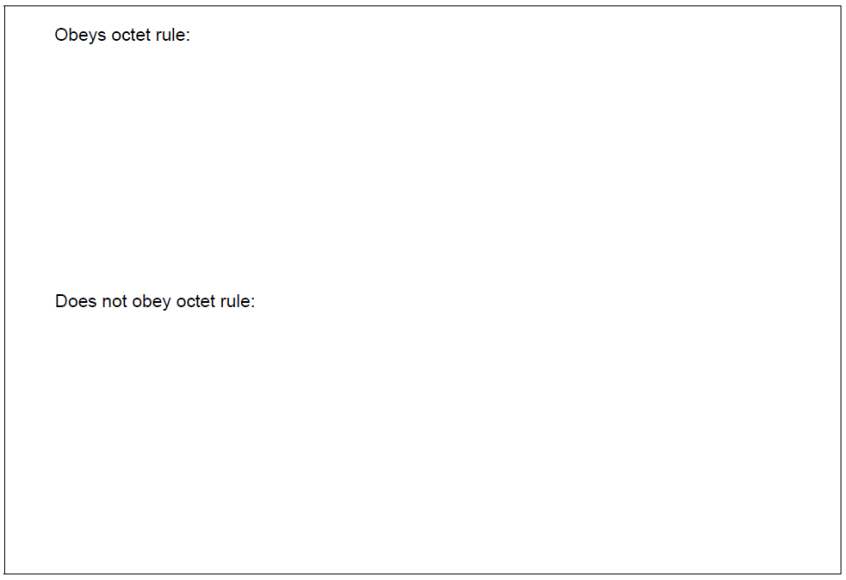
2. [Maximum mark: 22]

Sulfur trioxide is an important compound in industry.

(a) Sulfur trioxide has more than one possible Lewis (electron dot) structure.

(a.i) Sketch **two** Lewis (electron dot) structures for SO_3, one of which obeys the octet rule and one of which does not.



[2]

(a.ii) State how chemists decide which Lewis (electron dot) structure is more stable. [1]

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(a.iii) Predict the length of each S to O bond in pm. Use section 10 of the data booklet. [1]

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(b) Suggest why atmospheric SO_3 (g) is an environmental concern. [1]

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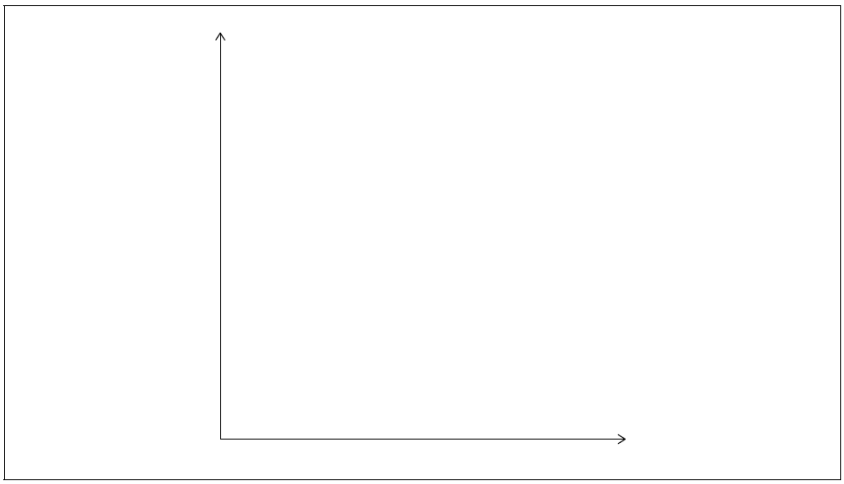
(c) State the name of a post-combustion method used to lower the quantity of SO_3 (g) released to the atmosphere. [1]

(d) $SO_3(g)$ is made using the contact process.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H^{\ominus} < 0$

(d.i) Sketch a potential energy profile for this reaction on the axes provided. Label E_a and include labels on the axes.



[3]

(d.ii) Explain why increasing the temperature increases the rate of reaction. [2]

(d.iii) Vanadium pentoxide, V_2O_5, is used as a catalyst. Explain how a catalyst increases the rate of a reaction. [2]

(d.iv) During the reaction, V_2O_5 changes to V_2O_4. Identify the oxidation states of vanadium in each compound.

V_2O_5: .....

V_2O_4: ..... [1]

(d.v) State the equilibrium constant expression, K_c, for the production of 1 mol of SO_3.

$SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$ [1]

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(d.vi) Calculate the entropy change, $\Delta S^{\ominus}$, in $J\,K^{-1}\,mol^{-1}$, for the production of 1 mol of $SO_3(g)$. Use the absolute entropy values given in the table.

	$S^{\ominus}$ /J K^{-1} mol^{-1}
$SO_2(g)$	248.2
$O_2(g)$	205.2
$SO_3(g)$	256.8

[1]

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(d.vii) Outline, with reference to the equation, why the sign for the entropy change obtained in part (vi) is expected. [1]

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(d.viii) Calculate the value of Gibbs free energy, $\Delta G^{\ominus}$, of the reaction, in kJ mol^{-1}, at 773 K. Use section 1 of the data booklet and $\Delta H^{\ominus} = -98.5$ kJ mol^{-1}. If you did not obtain an answer for (d)(vi), use -100 J K^{-1} mol^{-1}, although this is not the correct answer. [1]

(d.ix) Calculate the value of the equilibrium constant for the formation of SO_3 (g) at 773 K. Use sections 1 and 2 of the data booklet. If you did not obtain an answer to (d)(viii), use -25.0 kJ mol^{-1}, although this is not the correct answer. [2]

(d.x) A flask contains 0.120 mol dm^{-3} SO_2 (g), 0.050 mol dm^{-3} O_2 (g) and 0.150 mol dm^{-3} SO_3 (g) at 773 K. Deduce whether the system is at equilibrium and in which direction the reaction will proceed spontaneously if not at equilibrium. [2]

3. [Maximum mark: 1]

The equilibrium constant for $N_2O_4(g) \Leftrightarrow 2NO_2(g)$ is $K_c = 0.0059$ at 298 K.

What is the value of the equilibrium constant at 298 K for $4NO_2(g) \rightleftharpoons 2N_2O_4(g)$?

A. $\frac{1}{0.0059}$

B. $\frac{1}{0.0059^2}$

C. 0.0059

D. 0.0059^2 [1]

4. [Maximum mark: 1]

Which pair of changes will both shift the position of equilibrium to the left?

$2H_2(g) + CO(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -92\,kJ$

	Temperature	Pressure
A.	increase	increase
B.	decrease	decrease
C.	increase	decrease
D.	decrease	increase

[1]

5. [Maximum mark: 1]

Consider the equilibrium between dinitrogen tetraoxide, $N_2O_4(g)$, and nitrogen dioxide, $NO_2(g)$.

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$

At a certain temperature, the K_c value for this reaction is 5. What is the K_c value for the reaction below at the same temperature?

$2NO_2(g) \rightleftharpoons N_2O_4(g)$

A. 5

B. $\frac{1}{5}$

C. $\sqrt{5}$

D. 5^2

[1]

6. [Maximum mark: 1]

The value of K_c for the equilibrium between $H_2(g)$ and $I_2(g)$ is 51 at 720 K. Which combination is correct?

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

	Position of equilibrium	Free energy change at 720 K
A.	products are favoured	ΔG is positive
B.	products are favoured	ΔG is negative
C.	reactants are favoured	ΔG is positive
D.	reactants are favoured	ΔG is negative

[1]

7. [Maximum mark: 8]

The complex ion $[CuCl_4]^{2-}$ is formed when concentrated hydrochloric acid is added to an aqueous solution of hydrated copper(II) ions.

$Cu^{2+}(aq) + 4Cl^{-}(aq) \rightleftharpoons [CuCl_4]^{2-}(aq)$

Blue Yellow

(a) State an expression for the equilibrium constant, K_c, corresponding to this equation. [1]

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(b) The numerical value of K_c under standard conditions is 4.2×10^5. Calculate the ratio when the chloride ion concentration is 0.210 mol dm^{-3}. [2]

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(c) Explain why $Cu^{2+}(aq)$ is coloured, with reference to its electronic structure and section 15 of the data booklet. [3]

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(d) State, with a reason, the effect of an increase in temperature on the value of K_c. $\Delta H^{\boxtimes} > 0$ [1]

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(e) State, with a reason, the effect of adding aqueous silver nitrate, $AgNO_3(aq)$, on the position of this equilibrium.

$Ag^+(aq) + Cl^-(aq) \rightleftharpoons AgCl(s)$ [1]

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8. [Maximum mark: 1]
Which of the following equilibria would shift left with an increase in pressure?

A. $H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$

B. $C(s) + H_2O(g) \rightleftharpoons CO(g) + H_2(g)$

C. $NO(g) + \frac{1}{2}O_2(g) \rightleftharpoons NO_2(g)$

D. $4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(l)$

[1]

9. [Maximum mark: 1]
What can increase the amount of $CS_2(g)$ present in the following system already at equilibrium?

$$S_2Cl_2(l) + CCl_4(l) \rightleftharpoons CS_2(g) + 3Cl_2(g) \qquad \Delta H^{\ominus} = 84.3 \text{ kJ}$$

A. Adding a catalyst to the system

B. Increasing the volume of the reaction vessel

C. Adding some Cl_2 (g) to the system

D. Cooling the system

[1]

10. [Maximum mark: 1]
The system 2A (g) $\rightleftharpoons$ B (g) + 3C (g) is at equilibrium where the concentrations of A, B and C are all 2 mol dm^{-3}.

What is the value of the equilibrium constant, K_c?

A. 2

B. 3

C. 4

D. 8

[1]

11. [Maximum mark: 1]
The exothermic reaction I_2 (g) + 3Cl_2 (g) $\rightleftharpoons$ 2ICl_3 (g) is at equilibrium in a fixed volume. What is correct about the reaction quotient, Q, and shift in position of equilibrium the instant temperature is raised?

A. $Q > K$, equilibrium shifts right towards products.

B. $Q > K$, equilibrium shifts left towards reactants.

C. $Q < K$, equilibrium shifts right towards products.

D. $Q < K$, equilibrium shifts left towards reactants. [1]

12. [Maximum mark: 1]

What is the intercept on the *y*-axis when a graph of ln*k* is plotted against $\frac{1}{T}$ on the *x*-axis?

$$\ln k = -\frac{E_a}{RT} + \ln A$$

A. ln*A*

B. $-\frac{E_\mathrm{a}}{R}$

C. $-\frac{R}{E_\mathrm{a}}$

D. E_a [1]

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