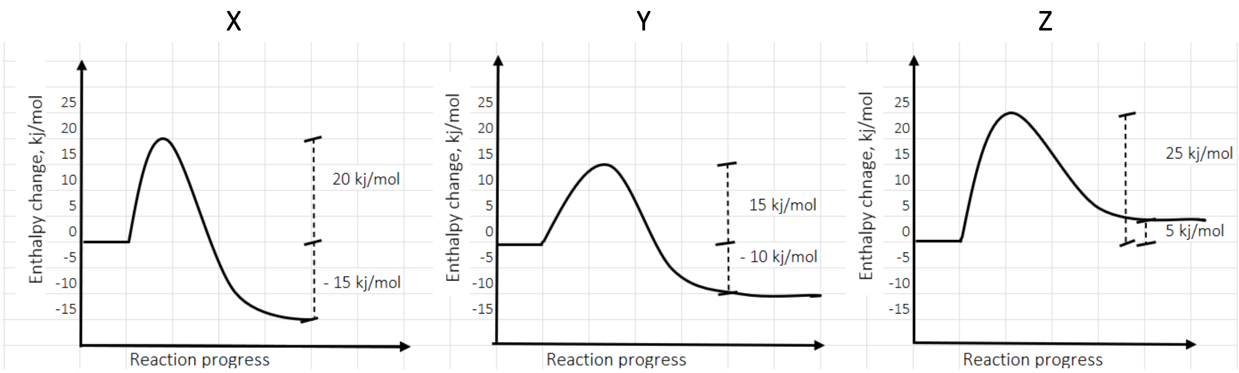
Unit 3 Chemistry SAC 2 – Assessment Guide

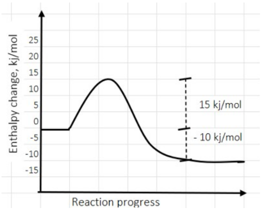
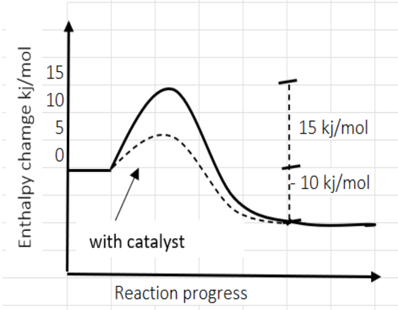
Problem-solving, including calculations, using chemistry concepts and skills applied to real-world contexts.

Below are the energy profiles for three reactions, X, Y and Z.



factors affecting the frequency and success of reactant particle collisions and the rate of a chemical reaction in open and closed systems, including temperature, surface area, concentration, gas pressures, presence of a catalyst, activation energy and orientation	**Question 1a** (1 mark) Rank the rate of the forward reactions from slowest to fastest.	**Answer:** • *Z < X < Y* **Marking Protocol:** One mark for the above point. Explanation: The lower the activation energy, the faster the reaction.

factors affecting the frequency and success of reactant particle collisions and the rate of a chemical reaction in open and closed systems, including temperature, surface area, concentration, gas pressures, presence of a catalyst, activation energy and orientation	**Question 1b** (1 mark) Rank the rate of the reverse reactions from fastest to slowest.	**Answer:** • *Z > Y > X* **Marking Protocol:** One mark for the above point. Explanation: The activation energy values will be 35 kJ/mol for reverse reaction X, 25 kJ/mol for reverse reaction Y, and 20 kJ/mol for reverse reaction Z.

the role of catalysts in increasing the rate of specific reactions, with reference to alternative reaction pathways of lower activation energies and represented using energy profile diagrams *plot graphs involving two variables that show linear and non-linear relationships*	**Question 1c** (1 mark) Draw on the graph for reaction Y below to show how the reaction will progress when a catalyst is used.  	**Answer:**  **Marking Protocol:** One mark for the above graph. N.B. The start and the end of the dotted graph must be at the same level of energies as the original and the graph's peak must be drawn lower than the original. Units are arbitrary.

A mixture of 0.800 mol of $NO_{(g)}$, 0.400 mol of $H_{2(g)}$ and 0.800 mol of $H_2O_{(g)}$ was placed in a 4.00 L closed vessel to reach equilibrium. The reaction is:

$$2NO_{(g)} + 2H_{2(g)} \rightleftarrows N_{2(g)} + 2H_2O_{(g)}$$

When the system reached equilibrium, at a temperature T, ˚C, the concentration of $NO_{(g)}$ was 0.124 M.

calculations involving equilibrium expressions (including units) for a closed homogeneous equilibrium system and the dependence of the equilibrium constant (K) value on the system temperature and the equation used to represent the reaction	**Question 2a** (1 mark) Write the expression for the equilibrium constant, K.	**Answer:** • $K = \frac{[N_2][H_2O]^2}{[NO]^2[H_2]^2}$ **Marking Protocol:** One mark for the above point.

calculations involving equilibrium expressions (including units) for a closed homogeneous equilibrium system and the dependence of the equilibrium constant (K) value on the system temperature and the equation used to represent the reaction

process quantitative data using appropriate mathematical relationships and units, including calculations of ratios, percentages, percentage change and mean

use appropriate numbers of significant figures in calculations

Question 2b (4 marks)
Calculate the equilibrium constant at temperature T°C.

Answer:

V= 4.00L	***NO***	***H_2***	***N_2***	***H_2O***
Initial (mol)	*0.800*	*0.400*	*0*	*0.800*
Change (mol)	-2x *-0.304*	-2x *-0.304*	+x *+0.152*	+2x *+0.304*
Equilibrium (mol) n = cV	n= 0.124x4 *= 0.496* 0.800-2x =0.496 x = 0.152	0.400-0.304 *= 0.0960*	*0.152*	0.800+0.304 *= 1.104*
Equilibrium (M (mol/L)) c = n/V	*0.124*	0.096/4 = *0.024*	0.152/4= *0.0380*	1.104/4= *0.276*

- $$K = \frac{[N_2][H_2O]^2}{[NO]^2[H_2]^2} = = \frac{[0.0380][0.276]^2}{[0.124]^2[0.024]^2} = 326.84 = 327\,M^{-1}$$

Marking Protocol:
One mark for correct calculation of n(NO). One mark for correct mol of H_2, N_2 and H_2O at equilibrium. One mark for correct concentrations of H_2, N_2 and H_20. One mark for correct value of K with correct units.

N.B. Text in blue shows detailed calculations; they are not required for full marks, but are part of the calculations to derive the final results (in black). Alternative answers can be considered if the value of K is different due to calculation errors or due to incorrect expression of K.

the distinction between reversible and irreversible reactions, and between rate and extent of a reaction

Question 2c (2 marks)
Discuss the extent of the reaction with reference to the K value calculated in Question 2b.

Answer:

- *The K value shows that there is a significant amount of both reactants and products available at equilibrium.*
- *However, given that the calculated K value is larger than 1, there are more products than reactants at equilibrium.*

Marking Protocol:
One mark for each of the above points.
N.B. Alternative answers can be considered if the value of K is different to 2b due to calculation errors.

the reaction quotient (Q) as a quantitative measure of the extent of a chemical reaction: that is, the relative amounts of products and reactants present during a reaction at a given point in time *the distinction between reversible and irreversible reactions, and between rate and extent of a reaction* *discuss relevant chemical information, ideas, concepts, theories and models and the connections between them*	**Question 2d** (2 marks) A change was made to the system so that it was no longer at equilibrium. Shortly after the change, at time t, the equilibrium quotient (Q) was found to be 200 M^{-1}. With reference to the K value calculated in Question 2b, explain what is required for the system to reach equilibrium.	**Answer:** • *At time t, Q < K, meaning that the concentration of products is smaller than at equilibrium and the concentration of reactants is higher than at equilibrium.* • *To reach equilibrium, the reaction needs to produce more products (i.e. the reaction needs to shift forward).* **Marking Protocol:** One mark for each of the above points. N.B. Alternative answers can be considered if the value of K is different to 2b due to calculation errors.

the application of Le Chatelier's principle to identify factors that favour the yield of a chemical reaction	**Question 2e** (1 mark) What measure can be applied to the system to increase the yield of nitrogen production?	**Answer:** • *Increasing the pressure.* • *Removing product(s).* • *Adding reactant(s).* **Marking Protocol:** One mark for any one of the above points. Explanation: Each of the above measures will result in the forward reaction to be favoured; therefore, the concentrations of N_2 and H_2O will increase and concentrations of NO and H_2 will decrease. The yield of N_2 will increase. N.B. The stem does not give thermochemical information; hence, any discussion about temperature would be speculative.

the change in position of equilibrium that can occur when changes in temperature or species or volume (concentration or pressure) are applied to a system at equilibrium, and the representation of these changes using concentration-time graphs

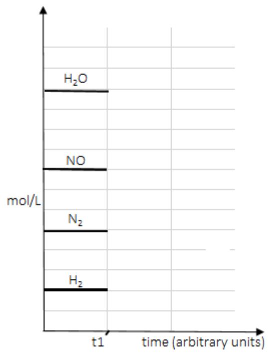
the dynamic nature of homogenous equilibria involving aqueous solutions or gases, and their representation by balanced chemical or thermochemical equations (including states) and by concentration-time graphs

plot graphs involving two variables that show linear and non-linear relationships

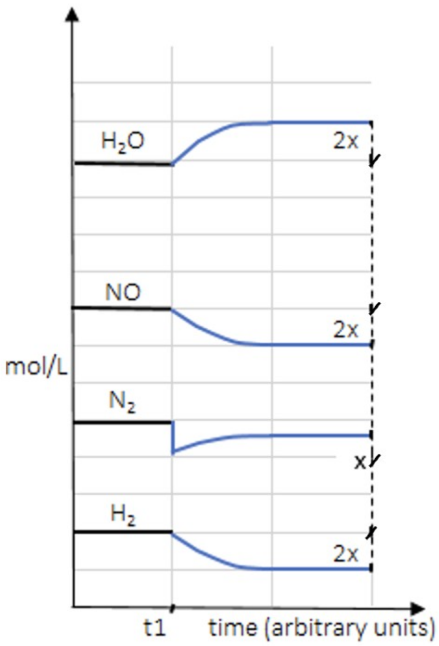
Question 2f (3 marks)

The following figure shows the concentrations of all species at the first equilibrium. At time t_1, some N_2 is removed from the system.

Continue the graphs to show the changes that occur for each species until a new equilibrium is re-established.



Answer:



Marking Protocol:

One mark for an initial change showing a decrease in the concentration of N_2 (any vertical drop) and no immediate changes for the concentrations of H_2O, NO and H_2.

One mark for the correct shapes of increasing concentrations of N_2 and H_2O and decreasing concentrations of NO and H_2 (noting that the curve for N_2 cannot be above the line for the first equilibrium).

One mark for showing correct changes in the concentrations for all of the reactants and products as the system returns to and reaches a new equilibrium simultaneously. The curves of H_2O and N_2 increase by 2x and x respectively, whilst the curves of NO and H_2 decrease by 2x.

A nickel-plating experiment is designed to investigate the electrolytic conditions required for optimal product outcomes. A beaker containing 200 mL of green 1.00 M $NiSO_{4(aq)}$ solution is electrolysed using a carbon electrode. The second electrode is an object that is made of a material that needs to be nickel-plated. The object is not reactive.

the use and limitations of the electrochemical series to explain or predict the products of the electrolysis of particular chemicals, given their state (molten liquid or in aqueous solution) and the electrode materials used, including the writing of balanced equations (with states) for the reactions occurring at the anode and cathode and the overall redox reaction for the cell

Question 3a (2 marks)

Write the half equations for the oxidation and reduction reactions for this experiment.

Answer:

- *Oxidation:* $2H_2O_{(l)}$ --> $O_{2(g)} + 4H^+_{(aq)} + 4e-$
- *Reduction:* $Ni^{2+}_{(aq)} + 2e^-$ --> $Ni_{(s)}$

Marking Protocol:

One mark for each of the above points.

N.B. Correct states must be included.

the application of Faraday's Laws and stoichiometry to determine the quantity of electrolytic reactant and product, and the current or time required to either use a particular quantity of reactant or produce a particular quantity of product *use appropriate chemical terminology, representations and conventions, including standard abbreviations, graphing conventions, algebraic equations, units of measurement and significant figures* *use appropriate numbers of significant figures in calculations*	**Question 3b** (5 marks) For optimal plating, the $Ni^{2+}_{(aq)}$ concentration in solution needs to be maintained above 0.350 M. Assuming the cell operates consistently with a current of 3.00 A, and a voltage of 5 V, calculate the time, in seconds, before the initial 1.00 M $NiSO_4$(aq) solution would need replacing.	**Answer:** • *n(Ni^{2+} initial) = cV = 1.00 x 0.200 = 0.200 mol* *n(Ni^{2+} final) = cV = 0.350 x 0.200 = 0.0700 mol* • *n(Ni^{2+} available to react) = 0.200 - 0.0700 = 0.130 mol* • *n(e-) = 2n($Ni_{(s)}$) = 2 x 0.130= 0.260 mol* • *Q = n(e-) x F = 0.260 x 96500 = 25090 C* • *t = Q/I = 25090/3.00 = 8363.33 s = 8.36 x 10^3 s* **Marking Protocol:** One mark for each of the above points. N.B. The final result must include the correct units and be rounded to three significant figures. Consequential marks are allowed (to a maximum of four marks).

the common design features and general operating principles of commercial electrolytic cells (including, where practicable, the removal of products as they form), and the selection of suitable electrode materials, the electrolyte (including its state) and any chemical additives that result in a desired electrolysis product (no specific cell is required) *identify and analyse experimental data qualitatively, handling, where appropriate, concepts of: accuracy, precision, repeatability, reproducibility, resolution, and validity of measurements; and errors (random and systematic)*	**Question 3c** (2 marks) State two observations that could be noticed in the nickel-plating cell while it is operating.	**Answer:** • *The green colour of the solution would fade (becoming a lighter green).* • *Bubbles would be observed at the anode (due to O_2 gas being formed).* • *Nickel would be plated on the object at the cathode.* **Marking Protocol:** One mark for any of the above points, to a maximum of two.

the application of Faraday's Laws and stoichiometry to determine the quantity of electrolytic reactant and product, and the current or time required to either use a particular quantity of reactant or produce a particular quantity of product *use appropriate chemical terminology, representations and conventions, including standard abbreviations, graphing conventions, algebraic equations, units of measurement and significant figures* *use appropriate numbers of significant figures in calculations*	**Question 3d** (4 marks) If the cell operates with a consistent current of 3.00 A, calculate the time, in seconds, for 2.00 g nickel to be plated on the object.	**Answer:** • *n(Ni) = m/M = 2.00/58.7 = 0.03407 mol* • *n(e-) = 2n(Ni) = 0.06814 mol* • *Q = n(e^-) x F = 0.06814 x 96500= 6576* • *t = Q/I = 6576/3.00 = 2191.9. s = 2.19 x 10^3 s* **Marking Protocol:** One mark for each of the above points. N.B. The final result must include the correct units and be rounded to three significant figures. Consequential marks are allowed (to a maximum of three marks).

the application of Faraday's Laws and stoichiometry to determine the quantity of electrolytic reactant and product, and the current or time required to either use a particular quantity of reactant or produce a particular quantity of product *evaluate data to determine the degree to which the evidence supports the aim of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation*	**Question 3e** (1 mark) Assuming that each object needs to have a plating of 2.00 g, identify one change that could be made to this experiment so that more objects can be fully plated without having to top up the electrolyte with Ni^{2+} (aq).	**Answer:** • *Use a higher concentration of $NiSO_{4(aq)}$ in the electrolyte.* • *Replace the carbon electrode with a $Ni_{(s)}$ electrode, which then becomes a source of Ni^{2+}(aq) in the electrolyte, depositing as $Ni_{(s)}$ on the object.* **Marking Protocol:** One mark for either of the above points.

A trial investigates the effect of changes in the reaction conditions for the following reaction, which is carried out in a closed vessel.

$2SO_{2(g)} + O_{2(g)} \rightleftarrows 2SO_{3(g)}$ $\Delta H < 0$

factors affecting the frequency and success of reactant particle collisions and the rate of a chemical reaction in open and closed systems, including temperature, surface area, concentration, gas pressures, presence of a catalyst, activation energy and orientation

responses to the conflict between optimal rate and temperature considerations in producing equilibrium reaction products, with reference to the green chemistry principles of catalysis and designing for energy efficiency

the distinction between reversible and irreversible reactions, and between rate and extent of a reaction

Question 4a (1 mark)
What are the observed effects on the rate of reaction, the equilibrium constant and the position of equilibrium when the volume of the vessel is halved at constant temperature?

Answer:

Change in reaction conditions	Rate of Reaction	Equilibrium Constant Value (K)	Position of Equilibrium Shifts
Halving the volume of the vessel	*Increases*	*No effect*	*Shifts right (forward)*

Marking Protocol:
One mark for all the above points.
Explanation: Halving the volume implies a doubling of the pressure and the concentration per unit of volume; an increased concentration increases the reaction rate. Temperature change is the only factor that will cause a change in the value of K. Since the temperature is constant, there will be no effect on K.
The system will favour the side with the lower amount of moles (particles) to release the pressure; this is the product side or forward reaction.

factors affecting the frequency and success of reactant particle collisions and the rate of a chemical reaction in open and closed systems, including temperature, surface area, concentration, gas pressures, presence of a catalyst, activation energy and orientation

responses to the conflict between optimal rate and temperature considerations in producing equilibrium reaction products, with reference to the green chemistry principles of catalysis and designing for energy efficiency

the distinction between reversible and irreversible reactions, and between rate and extent of a reaction

Question 4b (1 mark)
What are the observed effects on the rate of reaction, the equilibrium constant and the position of the equilibrium when the temperature is increased?

Answer:

Change in reaction conditions	Rate of Reaction	Equilibrium Constant Value (K)	Position of Equilibrium Shifts
Increasing the temperature	*Increases*	*Decreases*	*Shifts left (reverse)*

Marking Protocol:
One mark for all of the above points.
Explanation: An increased temperature increases reaction rate as the average kinetic energy of particles increases.
Temperature change influences the K value; an increase in temperature will decrease the K value for an exothermic reaction.
The reaction is exothermic; an increased temperature inhibits the exothermic reaction and the system will favour the side that will cool down the reaction, which is the reactant side (the reverse reaction).

factors affecting the frequency and success of reactant particle collisions and the rate of a chemical reaction in open and closed systems, including temperature, surface area, concentration, gas pressures, presence of a catalyst, activation energy and orientation *responses to the conflict between optimal rate and temperature considerations in producing equilibrium reaction products, with reference to the green chemistry principles of catalysis and designing for energy efficiency* *the distinction between reversible and irreversible reactions, and between rate and extent of a reaction*	**Question 4c** (1 mark) What are the observed effects on the rate of reaction, the equilibrium constant and the effect on the position of equilibrium when a catalyst is used?	**Answer:** <table><tr><th>Change in reaction conditions</th><th>Rate of Reaction</th><th>Equilibrium Constant Value (K)</th><th>Position of Equilibrium Shifts</th></tr><tr><td>**Using a catalyst**</td><td>*Increases*</td><td>*No effect*</td><td>*No effect*</td></tr></table> **Marking Protocol:** One mark for all of the above points. Explanation: The catalyst will increase the rate of the reaction as it provides an alternative pathway with a lower activation energy. Catalysts do not influence the equilibrium constant or the position of equilibrium.

Cobalt dissolves in hydrochloric acid and forms coloured solutions, as shown in the reaction below.

$Co(H_2O)_6{}^{2+}{}_{(aq)} + 4Cl^-{}_{(aq)} \rightleftarrows CoCl_4{}^{2-}{}_{(aq)} + 6H_2O_{(l)}$ $\Delta H > 0$

<u>pink</u> <u>blue</u>

the dynamic nature of homogenous equilibria involving aqueous solutions or gases, and their representation by balanced chemical or thermochemical equations (including states) and by concentration-time graphs	**Question 5a** (2 marks) At equilibrium, and a particular temperature, the solution has a violet colour. What colour will be observed if the concentration of $Cl^-(aq)$ is increased? Justify your response with reference to Le Chatelier's Principle.	**Answer:** • *Blue or violet-blue.* • *An increase in the concentration of the reactants will favour the forward reaction, leading to an increased concentration of $CoCl_4{}^{2-}$ and a decreased concentration of $Co(H_2O)_6{}^{2+}$.* **Marking Protocol:** One mark for each of the above points.

the dynamic nature of homogenous equilibria involving aqueous solutions or gases, and their representation by balanced chemical or thermochemical equations (including states) and by concentration-time graphs	**Question 5b** (2 marks) What colour will be observed when the system is cooled? Explain your answer.	**Answer:** • *Pink.* • *The reaction is endothermic; a decrease in temperature will favour the reverse reaction, leading to an increased concentration of $Co(H_2O)_6{}^{2+}$ and a decreased concentration of $CoCl_4{}^{2-}$.* **Marking Protocol:** One mark for each of the above points.

The Edison battery was developed by Thomas Edison in the 1900s. It uses iron and nickel electrodes and potassium hydroxide as the electrolyte. The overall reaction in the battery during discharge is:

$Fe_{(s)} + 2NiO(OH)_{(s)} + 2H_2O_{(l)} \text{-->} Fe(OH)_{2(s)} + 2Ni(OH)_{2(s)}$

the common design features and general operating principles of rechargeable (secondary) cells, with reference to discharging as a galvanic cell and recharging as an electrolytic cell, including the conditions required for the cell reactions to be reversed and the electrode polarities in each mode	**Question 6a** (1 mark) Write the half equation for the reaction occurring at the cathode during discharge.	**Answer:** • *$NiO(OH)_{(s)} + H_2O_{(l)} + e^- \text{-->} Ni(OH)_{2(s)} + OH^-_{(aq)}$* **Marking Protocol:** One mark for the above point. N.B: It is recommended that students use KOHES steps in alkaline conditions.

the common design features and general operating principles of rechargeable (secondary) cells, with reference to discharging as a galvanic cell and recharging as an electrolytic cell, including the conditions required for the cell reactions to be reversed and the electrode polarities in each mode	**Question 6b** (1 mark) Write the half equation for the reaction occurring at the cathode during recharge.	**Answer:** • $Fe(OH)_{2(s)} + 2e^- \text{-->} Fe_{(s)} + 2OH^-_{(aq)}$ **Marking Protocol:** One mark for the above point. N.B: It is recommended that students use KOHES steps in alkaline conditions.

the common design features and general operating principles of rechargeable (secondary) cells, with reference to discharging as a galvanic cell and recharging as an electrolytic cell, including the conditions required for the cell reactions to be reversed and the electrode polarities in each mode	**Question 6c** (1 mark) During the recharge process, will the nickel electrode be the anode or the cathode? What polarity will it have?	**Answer:** • *The nickel electrode will be the anode; it will be positive.* **Marking Protocol:** One mark for the above point.