Victorian Certificate of Education

CHEMISTRY 2026 Unit 3

SAC 2 AOS 2 Outcome 2

Reading time: 5 minutes

Writing time: 50 minutes

Directions to students

Student's Name: _____

Teacher: _____

Structure of booklet

Section	Question to be answered	Total marks
Short answer	5	50
	Total	50

Materials

- Students are permitted to bring into the examination room: pencils, highlighters, erasers, sharpeners, rulers, and an approved scientific calculator.

- Students are NOT permitted to bring into the examination room:
white out liquid/tape, phones or electronic devices, including smart watches.

- Students are provided with the following: Question and answer book of 17 pages and VCAA Data booklet.

The task

- Please ensure that you write your name and teacher's name on this booklet. This paper consists of short answer questions.

- There are a total of 50 marks available.

- Be sure to include states with all chemical equations.

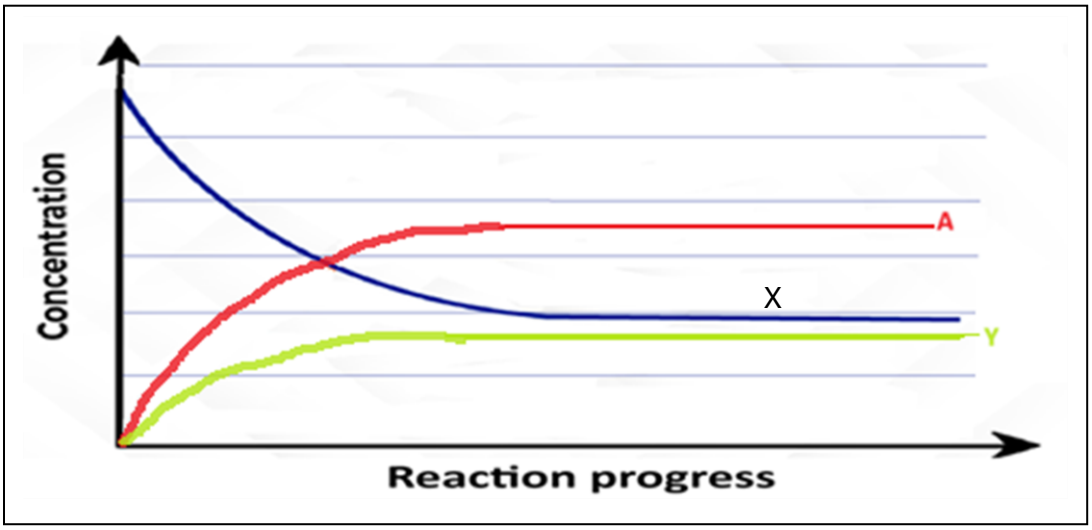
- All numerical answers need to be quoted to the correct number of significant figures.

- All working out must be shown in the space provided.

1. A given amount of compound X was placed in a sealed vessel and allowed to reach equilibrium, at constant temperature, according to the reaction below.

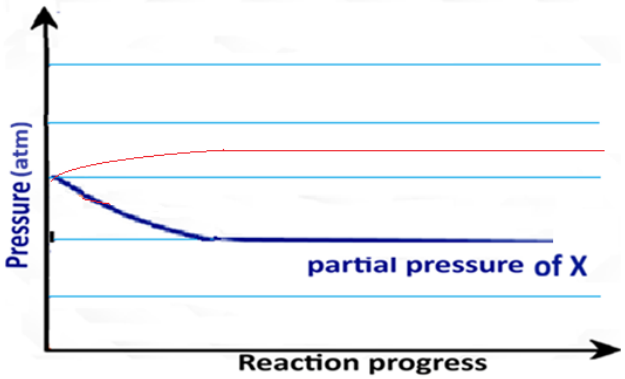
$$2X\,(g) \rightleftharpoons 2A\,(g) + Y(g)\ \Delta H>0$$

a. Draw the changes to [A] and [Y] on the graph below. *1 mark*



1-----mark for correct ratio and shape of both graphs.

b. The partial pressure of X is shown on the graph below. Draw the graph for the total pressure of the system over time. *2 marks*



Amount of X reacted

$X \text{ consumed} = 3 - 2 = 1\ atm$

Use stoichiometry

From reaction: $2X \rightarrow 2A + Y$

- *2 moles X → 3 moles total products (2A + Y)*
  (Ratio = 3/2 = 1.5)

=> products formed = 1 X 1.5 atm

Total pressure at equilibrium

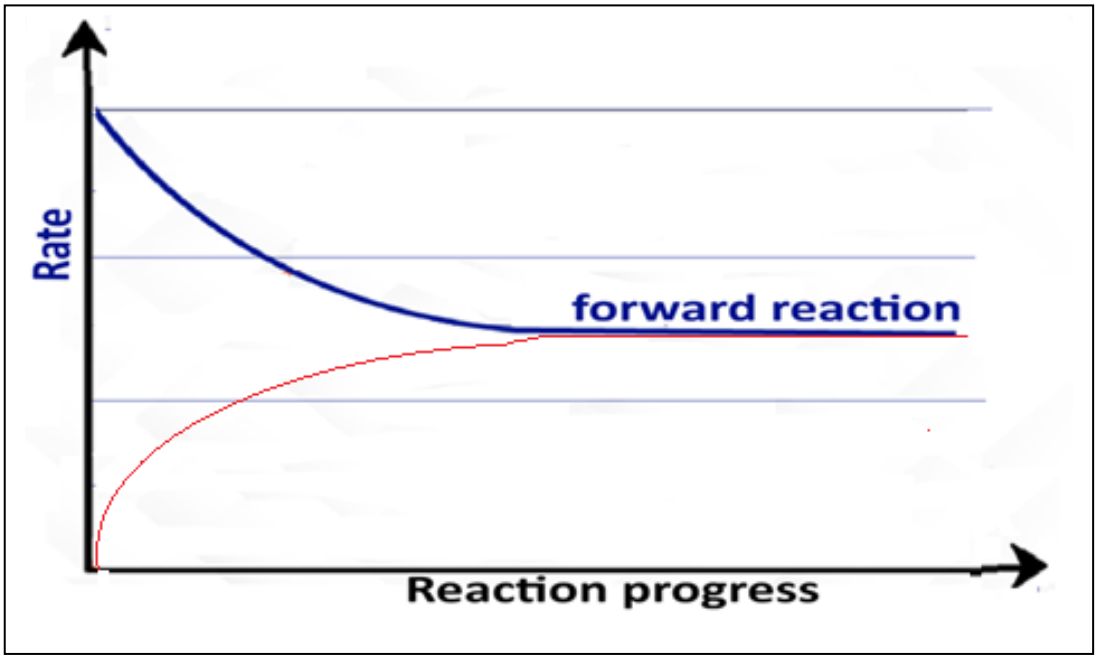
$P_{total} = \text{unreacted } X + \text{products}$

$P_{total} = 2 + 1.5 = 3.5\ atm$

1-----mark for correct shape and total pressure increases by 1.5 times the decrease in the partial pressure of X"

1----mark for correct calculations as shown in the text box above.

c. The rate of the forward reaction is shown below. Draw how the rate of the reverse reaction changes with time on the graph below. *1 mark*

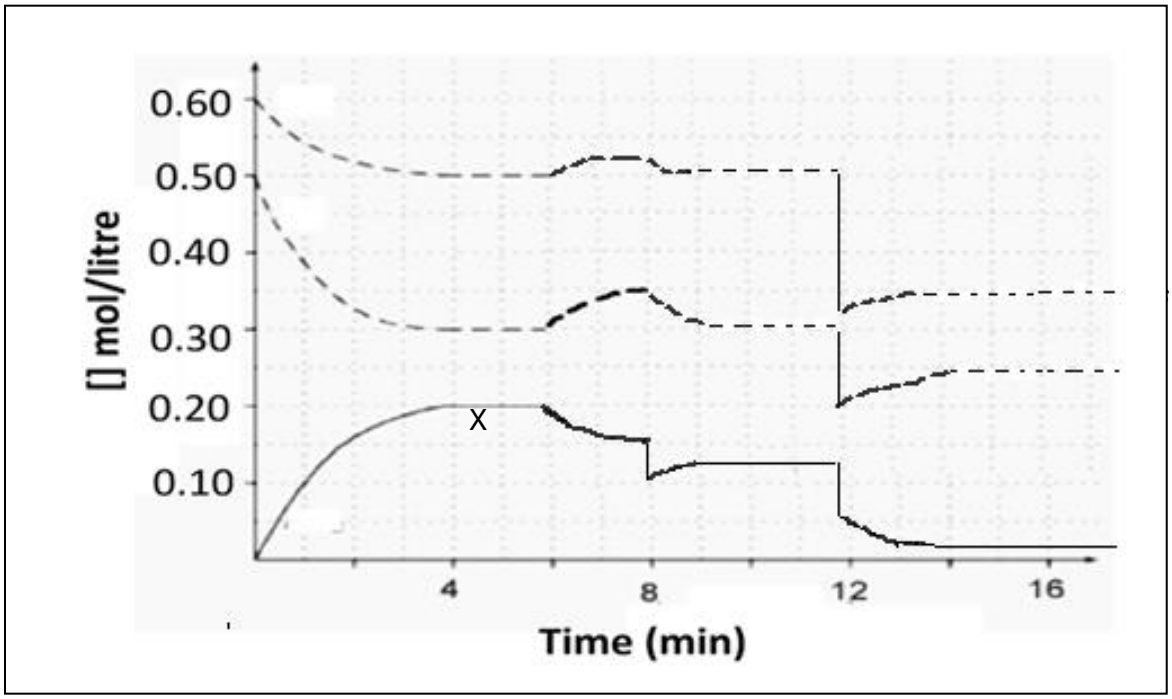


1-----mark for correct shape and positioning on the graph so that both forward and reverse rates are equal at equilibrium

d. Justify your answer to c above with reference to collision theory.

1-----mark Correctly stating the collision theory as it impacts rate, such as "rate is proportional to the concentration of reacting species as this increases the chance of fruitful or successful collisions.
1-----mark as the product increases in concentration so does the rate do the reverse reaction.

e. In another sealed vessel A and Y were mixed and allowed to reach equilibrium. The reaction progress is shown in fig 4, below.



The following stresses were applied to the system. Draw on the graph above how the system responds. Clearly label all graphs.

Students were not penalized if the ratio was not exact but an attempt must have being made to show some proportionality of the responses of each species.

i. At the 6 minute mark the temperature of the reaction vessel was changed, equilibrium was reestablished by the 8 minute mark. The graph indicates how the concentration of one of the species changed. Graph the concentrations of the other two species. *1 mark*

1----mark awarded for correctly showing the change of X and Y.

ii. At the 8 minute mark, an amount of X was removed which decreased [X] to 0.1 M. Equilibrium was reestablished by the 12 minute mark. *1 mark*

1----mark awarded for correctly showing the change of X and the responses of A and Y. No mark was given if the stress applied was totally undone.

iii. At the 12 minute mark the volume of the reaction vessel increased by 50% and equilibrium was reestablished by the 14 minute mark. *1 mark*

1----mark awarded for correctly showing the change of all concentrations and how the system responded with correct adjustments to A, X and Y. No mark was given if the stress applied was totally undone.

iv. A catalyst was added to the mixture at the 16 minute mark. *1 mark*

1----mark awarded for correctly showing that no change to the system occurred.

v. With reference to the graph in fig 4, describe how the temperature may have changed at the 6 minute mark. Justify you answer.

1-----mark for correctly noticing that the reaction 2A (g) + Y(g) ⇌ 2X(g) ΔH<0 is exothermic.

1-----mark for correctly recognizing that the reaction will now move in the reverse direction if temperature is increased. A reference to the graph was necessary indicating that the reaction moved in the reverse direction due to temperature increase.

f. At 88 °C a given amount of gas X is placed in a sealed vessel and allowed to come to equilibrium according to the reaction below.

$$2X\,(g) \rightleftharpoons 2A\,(g) + Y(g)\ \Delta H>0$$

The K_c at this temperature has a magnitude of 10.0.

The concentrations of each gas present at equilibrium, at 88°C, are given below.

- [X] = 2.000 M
- [Y]= 1.000 M
- [A] = 0.500 M

i. Give the Q_c expression for this equilibrium system. Clearly indicate the appropriate units.

$$\frac{[A]^2[Y]}{[X]^2} = \text{M or mol/L}$$

ii. Calculate Q_c at this temperature.

1-----mark for correct magnitude and units.

1-----mark for correct sig figs

$$\frac{[0.500]^2\,[1.00]}{[2.00]^2} = 0.0625\ \text{M}$$

iii. Using the value of K_c given in the stem of the question and your calculation of Q_c, determine whether the system is favouring the forward or reverse reaction at the time of sampling. Justify your answer.

1-----mark $Q_c < K_c$ so therefore the system is not at equilibrium.
1-----mark for suggesting the system is moving in a net forward direction to increase Q_c by producing more product.

g. A student suggested that the reaction quotient (Q_c) is constant at a given temperature and its value is called the equilibrium constant (K_c). Define Q_c and K_c and discuss whether this statement is true or false.
*1-----mark for definition "The reaction quotient (Q_c) calculated using the **concentrations** of each species at any given time (not necessarily at equilibrium)"*

1-----mark for explaining that Qc is not constant, it changes as the reaction proceeds and when the system is placed under different stresses. Kc on the other hand, is constant at a given temperature when equilibrium is established, Qc = Kc.

2. In industry, high yields and fast rates of reaction are essential for a viable economy. Conditions for optimal yield and optimal rate can be conflicting.

a. Using the two reactions below, suggest how optimal yield and optimal rate are achieved in the industrial production of products using endothermic and exothermic reactions. In your explanations suggest how optimal yield and optimal rate are achieved.

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

ii. --------- $CO_2(g)+3H_2(g) \rightleftharpoons CH_3OH(g)+H_2O(g) \Delta H=+49$ kJ mol^{-1}

For the endothermic reaction

1-----mark A high temperature favours the forward reaction thus increasing both yield and rate. There is less conflict between rate and yield in endothermic reactions. I say "less conflict" as there is a limit to how high a temperature can be applied from an economic point of view. But students were not penalised for this.

For the exothermic reaction:
1-----mark Low temperatures favour higher yields, however this results in a slow reaction rate.

1-----mark A moderate temperature of around 450 °C is used to achieve a compromise between yield and rate. A high pressure is applied to favour the forward reaction (fewer gas moles), increasing yield. A catalyst (iron) is used to increase the rate without affecting equilibrium.

Unreacted gases are recycled to improve overall yield. To get this mark a student needs to mention a compromise temperature and give one other way that yield and rate are increased.

b. Using Item 24, Part II, page 24 of the 2026 data booklet:

i. give two Green Chemistry Principles that are addressed by the industrial production of ammonia

- Green Chemistry Principle (1) _*Catalysis* _*1 mark*

- Green Chemistry Principle (2)___*Design for energy efficiency* _____*1 mark*

ii. Give a brief explanation of how these principles are relevant.

1-----mark Using a catalyst lowers the activation energy (E_a) thus increasing the rate at lower temperatures. This also makes the process energy efficient.

_____*1 mark*

3. Consider the energy profile shown in fig. 5

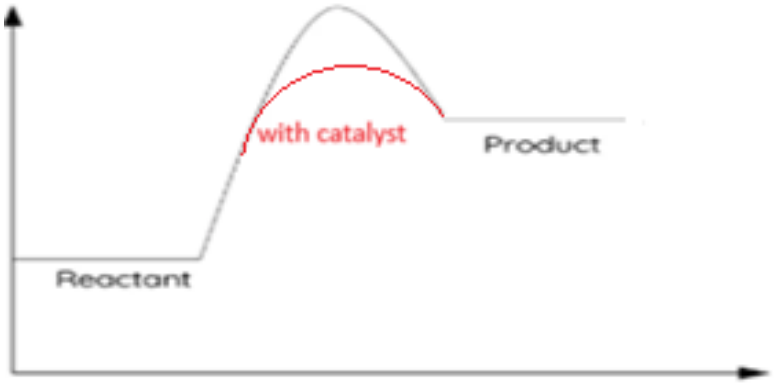


Figure 5 – An energy profile of an endothermic reaction

a. Indicate how the energy profile will change by the addition of a catalyst. *1 mark*

b. Give a clear explanation as to how the catalyst impacts the reaction.

A catalyst provides an alternative reaction pathway with a lower activation energy, increasing the rate of both the forward and reverse reactions without being consumed.

1----mark was awarded if the student had the underlined text in some way mentioned in their response.

c. Suggest a reason why, at constant temperature and without a catalyst, the reverse of an endothermic reaction generally occurs at a faster rate.

1-----mark Student need to state that the reverse reaction is exothermic, has lower activation energy . A diagram was not needed but could have been used to enhance the explanation.

1-----mark For this mark the student needed explain using collision theory that the proportion of fruitful collisions would be higher with a lower activation energy.

d. Consider the equilibrium system represented by the reactions below.

$$3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H<0$$

i. Indicate on the diagram in fig. 6 how the forward and reverse rates will change as a result of a temperature increase at t_2. *1 mark*

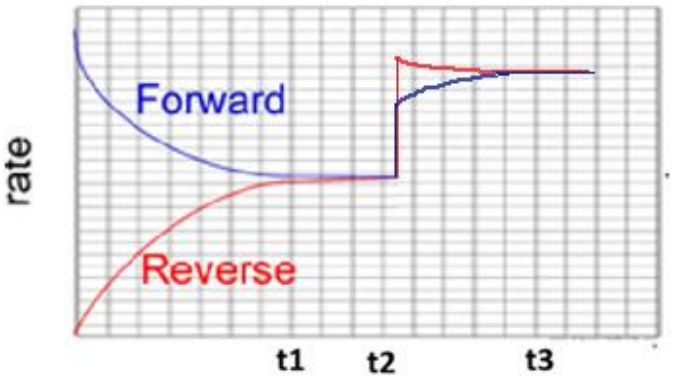


Figure 6 – rate time diagram of the reaction

$$3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)$$

Since there is temperature increase both rates will increase but since there is a net reverse reaction the rate of the reverse reaction needs to be higher. Bothe the forward and reverwe rates will eventually become equal as equilibrium is reestablished but at a higher rate than before the temperature increase.

ii. Indicate on the diagram in fig 7 how the forward and reverse rates will change as a result of the addition of a catalyst at t_2. *1 mark*

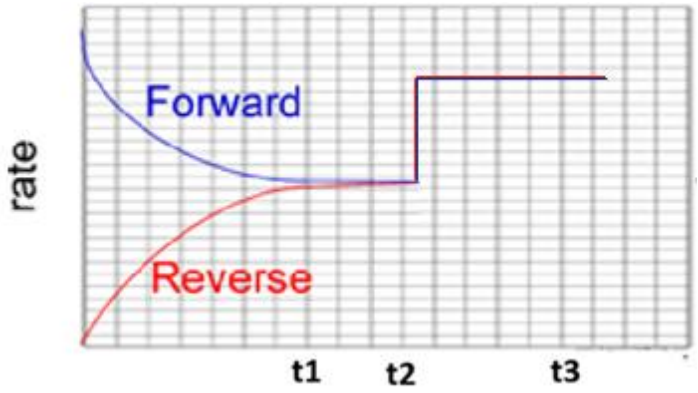


Figure 7– rate time diagram of the reaction

$3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)$

Catalyst increases both the forward and reverse reactions equally at equilibrium.

4. Complete the table shown below by circling the correct response in the right hand column that best identifies the response of the system to the stress. *7 marks*

System already at equilibrium	Stress	Response (circle correct response)	
$NH_3(aq) + HCl(aq) \rightleftharpoons NH_4^+(aq) + Cl^-(aq)$ This system exists in 100 mL volume of water	0.1 gram of $AgNO_3$ is added. *Assume no change to volume of the system.*	Q_c	increases, no change, decreases
		K_c	increases, no change, decreases
		$[NH_4^+]$	increases, no change, decreases
		Mol of Cl^-	increases, no change, decreases
$NH_3(aq) + HCl(aq) \rightleftharpoons NH_4^+(aq) + Cl^-(aq)$ This system exists in 100 mL volume of water	20 mL of distilled water is added	Q_c	increases, no change, decreases
		K_c	increases, no change, decreases

		$[NH_4^+]$	increases, no change, decreases
		Mol of Cl^-	increases, no change, decreases
$2\ H_2\ (g) + CO\ (g) \rightleftharpoons CH_3OH\ (g)$ This system exists in a sealed 100 mL vessel	Volume of the vessel is doubled.	Q_c	increases, no change, decreases
		K_c	increases, no change, decreases
		[CO]	increases, no change, decreases
		Mol of CO	increases, no change, decreases
$2\ H_2\ (g) + CO\ (g) \rightleftharpoons CH_3OH\ (g)$	N_2 gas was added	Reaction proceeds to the Left right no response	
$2\ H_2\ (g) + CO\ (g) \rightleftharpoons CH_3OH\ (g)$	Catalyst added	Reaction proceeds to the Left right no response	

5. Consider the electrolytic cell shown below in fig. 8. A piece of copper metal is to be plated with a layer of nickel metal.

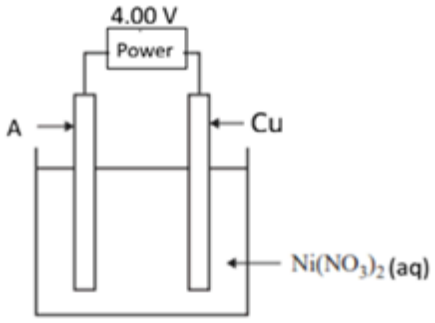


Figure 8 – Electrolysis with $Ni(NO_3)_2(aq)$

a. What is the polarity of electrode A?

1-----mark Positive (+) => it is the anode where oxidation (Ni(s) →Ni^{2+}+2e) takes place.

b. Which electrode represents the cathode, justify your answer using a balanced half-equation?

1-----mark The Cu electrode

1-----mark Reduction takes place ($Ni^{2+} + 2e \rightarrow Ni(s)$)

c. What material is the anode composed of?

1-----mark Ni(s)

d. Write the balanced equation, states included, for the reaction taking place at the anode.

___*(Ni(s)* $\rightarrow Ni^{2+} + 2e$ _____ *1 marks*

e. A current of 4.00 amps is applied for a fixed time period to deposit a total mass of 1.174 grams of nickel on the copper metal.

i. Using the answer to question d, above and given that the cell operates at 80% efficiency, calculate the total charge, in coulombs (C), needed to deposit the amount of nickel metal stated in the stem of the question. *3 marks*

1-----mark $n = \frac{1.174}{58.69} = 0.02001\ mol$

$$n(e^-) = 0.02001 \times 2 = 0.04002\ mol\ e^-$$

1-----mark

$$Q = nF = 0.04002 \times 96485 = 3862\ C$$

$$Q_{actual} = \frac{3862}{0.80} = 4828\ C$$

1-----mark => 4.83 X 10^3 C 3.(sig figs)

f. Calculate the time, in seconds, the cell was allowed to operate for. *1 mark*

$$t = \frac{Q}{I} = \frac{4828}{4.00}$$
$$t = 1207 \text{ s}$$

g. An electrolyser operating at 80 °C uses an proton exchange membrane (PEM) to produce hydrogen gas, as shown in Fig. 9.

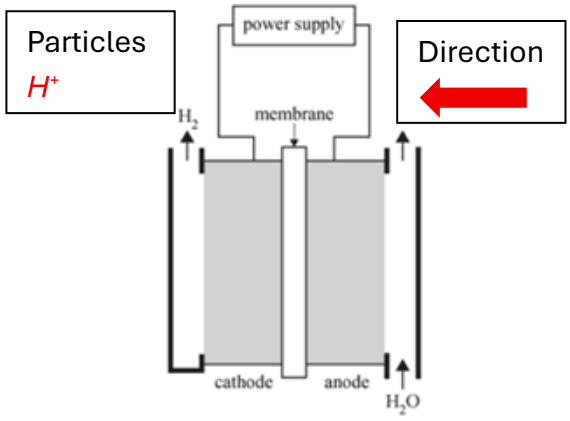


Figure 9 -An PEM electrolyser producing hydrogen gas

i. In the boxes provided in the diagram, identify the particles that travel through the membrane. Indicate the direction of movement with arrows. *1 mark*

1-----mark for both H^+ and the directions from right to left.

ii. Write the half-equation for the reaction occurring at the anode.

$2H_2O(l) \rightarrow 4e^- + 4H^+(aq) + O_2(g)$

1-----mark for balanced charge with states.

1-----mark for correct species.