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VCE Chemistry ¾
AOS 2 Revision (Rates & Equilibrium) [2.0]
SAC 3 Solutions

50 Marks. 12 Minutes Reading. 75 Minutes Writing.

Section A: Multiple Choice Questions (5 Marks)

Question 1 (1 mark)

[2.6.1] Explain how factors increase frequency of collisions.

Which of the following changes will definitely lead to a faster reaction rate?

A. Lower temperature, addition of a catalyst and higher concentrations.

B. Higher temperature, lower concentrations and the addition of a catalyst.

C. Greater surface area, higher temperatures and higher concentrations.

D. Greater surface area, lower temperatures and lower concentrations.

Every change in option C will increase the reaction rate.

Question 2 (1 mark)

[2.6.2] Explain how temperature & catalyst affect the proportion of successful collisions.

When a catalyst is added to a reaction:

A. An alternative reaction pathway is provided that requires a lower activation energy.

B. The activation energy is increased enabling more particle

C. The kinetic energy of particles is increased, allowing mor

D. The activation energy is unchanged but a higher percentage of particles are above that level.

Catalysts lead to faster reactions. They do this by providing alternative reaction pathways. These pathways have to be easier, meaning the activation energy is lower.

Question 3 (1 mark)

[2.7.2] Identify the extent of reaction.

In the decomposition of NOCl, the reaction is:

$$2NOCl(g) \rightleftarrows 2NO(g) + Cl_2(g) \quad K = 1.2 \times 10^{-5}\ M \quad \text{at } 30°C.$$

In an equilibrium mixture at 30°C, the amount of:

A. Cl_2 is half the amount of NOCl.

B. NO will equal the amount of NOCl.

C. NO is far less than the amount of NOCl.

D. NO added to the amount of Cl_2 will give the amount of NOCl.

The key to this question is the very low value of K. For K to be very low, the amounts of products has to be much lower than the amounts of reactants.

Question 4 (1 mark)

[2.9.4] Find equilibrium constant changes due to temperature.

Given:

$$2A(g) \rightleftharpoons B(g) + C(g)\ \Delta H = +27kJ\ mol^{-1} \quad K_c = 3.2 \times 10^{-4}$$

Which of the following would be true if the temperature were increased from 25°C to 800°C?

1. The value of K_c would be smaller.
2. The value of K_c would be greater.
3. The concentration of A(g) would be increased.
4. The concentration of B(g) would be increased.

A. 1 & 3 only.

B. 3 only.

C. 2 & 4 only.

D. 4 only.

Question 5 (1 mark)

[2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance.

For the following system:

$$2CrO_4{}^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7{}^{2-}(aq) + H_2O(l)$$

Dichromate ions are orange.

State the change in colour overall if dichromate ions are removed.

A. More intensely orange.

B. Less intensely orange.

C. Same intensity of orange.

D. Unable to determine from information.

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Section B: Short Answer Questions (45 Marks)

Question 6 (5 marks)

The reaction between nitrogen monoxide and chlorine is a reversible one:

$$2NO(g) + Cl_2(g) \rightleftarrows 2NOCl(aq)$$

In a 20.0 L reactor, the equilibrium amounts of the three chemicals are:

$$NO = 3.6\ mol \qquad Cl_2 = 2.8\ mol \qquad NOCl = 3.2\ mol$$

a. Calculate the value of K_c for this mixture. (2 marks)

[2.7.1] Write equilibrium constant expression & find its value (including units).

$$[NO] = \frac{3.6}{20} = 0.18\ M \qquad [Cl_2] = \frac{2.8}{20} = 0.14\ M \qquad [NOCl] = \frac{3.2}{20} = 0.16\ M$$

$$K = \frac{0.16^2}{0.18^2 \times 0.14} = 5.64\ M^{-1}$$

b. In another 20.0 L equilibrium mixture at the same temperature, the concentration of NOCl is found to be 0.56 M and the concentration of Cl_2 is 0.40 M. Determine the amount of the NO present. (2 marks)

[2.7.1] Write equilibrium constant expression & find its value (including units).

$$\frac{0.56^2}{x^2 \times 0.4} = 5.64^*$$

$$x^2 = \frac{0.317}{2.26} = 0.14^* \quad \Rightarrow x = 0.37\ M^*$$

$$n = c \times V = 0.37 \times 20 = 7.49\ mol$$

c. State the equilibrium constant value for the reverse reaction. (1 mark)

[2.7.3] Find equilibrium constant when equation is changed.

$$\frac{1}{5.64} = 0.177\ M$$

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Question 7 (8 marks)

A mixture of hydrogen gas and iodine gas is injected into a vessel that is then sealed. The mixture will establish an equilibrium system as described by the following equation:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad \Delta H = -300\ kJ\ mol^{-1}$$

a. State the optimum temperature conditions to maximise both rate of production of hydrogen iodide, and the equilibrium yield of hydrogen iodide. (1 mark)

[2.9.5] Find optimum operating conditions in all circumstances such as the rate-yield conflict.

moderate temperature (rate-yield conflict).

b. In an experiment, 3.00 mol of iodine and 2.00 mol of hydrogen were added to a 2.00 L reaction vessel. The amount of iodine present at equilibrium was 1.07 mol. A constant temperature was maintained in the reaction vessel throughout the experiment.

i. Write the expression for the equilibrium constant for this reaction. (1 mark)

[2.7.1] Write equilibrium constant expression & find its value (including units).

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

ii. Calculate the value of the equilibrium constant. (3 marks)

[2.7.5] Apply RICE tables to find K_c.

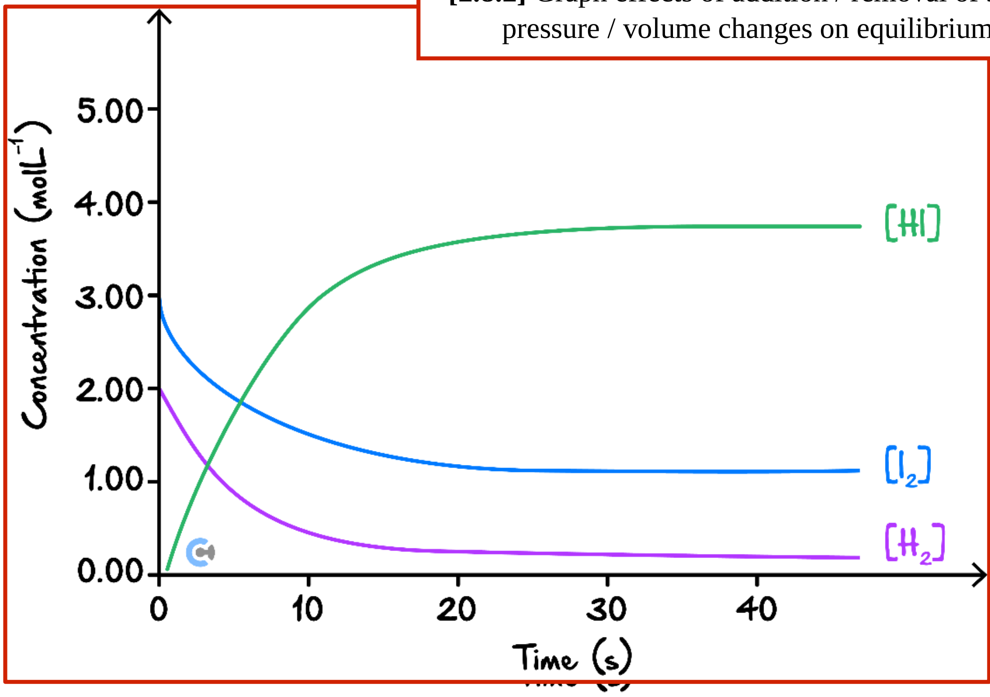
R	H_2 +	I_2 ⇌	$2HI$
n_i	3.00 mol	2.00 mol	0 mol
n_c	−0.93 mol	−0.93 mol	+1.86 mol
n_e	2.07 mol	1.07 mol	1.86 mol

$$K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{\left(\frac{1.86}{2}\right)^2}{\frac{2.07}{2} \times \frac{1.07}{2}} = 1.56 \text{ (no units)}$$

c.

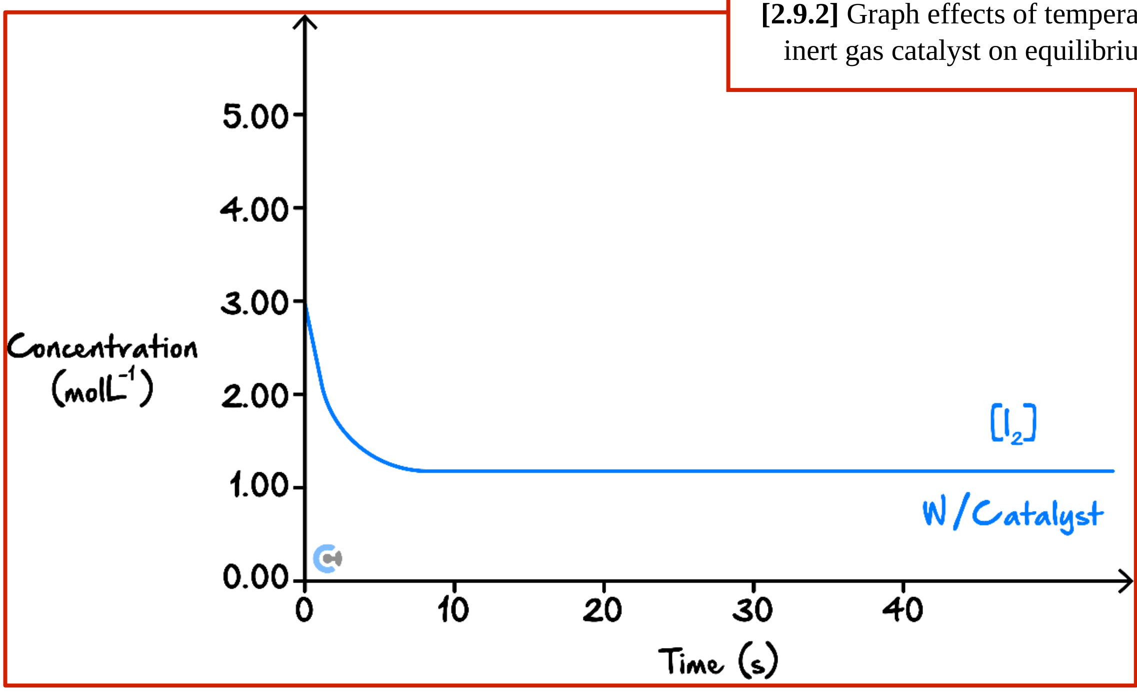
i. A graph of the decrease in the concentration of I_2 until equilibrium is effectively reached is given in the figure below. In the figure, draw clearly labelled graphs to show how the concentrations of H_2 and HI changed over the same period. (2 marks)

[2.8.2] Graph effects of addition / removal of substances or pressure / volume changes on equilibrium system.



ii. Indicate in the figure below how the iodine concentration would have been changed if a catalyst had been added to the vessel as well. Assume all other conditions remained the same. (1 mark)

[2.9.2] Graph effects of temperature, inert gas catalyst on equilibrium.



Question 8 (10 marks)

Phosgene gas is a known toxin used in chemical warfare. It is produced according to the equation below:

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

This gas ($COCl_2$) quickly decomposes when strongly heated to CO and Cl_2 gases.

a. According to the information given suggests whether the synthesis of phosgene is an exothermic or endothermic reaction. Justify your answer. (2 marks)

[2.9.1] Explain effects of temperature, inert gas or catalyst on equilibrium system.

Exothermic. When temperature increases, system opposes change by decreasing temperature, favouring the endothermic reaction. As reaction shifts reverse, the reverse reaction is endothermic, and the forwards reaction is exothermic.

b. At a given temperature of 100°C the reaction below takes place:

$$COCl_2\ (g) \rightleftharpoons CO(g) + Cl_2\ (g)$$

If 0.100 mol of phosgene, $COCl_2$, is placed in a 2.00 L sealed vessel, calculate the concentration of carbon monoxide at equilibrium if at equilibrium 0.0250 mol of phosgene was detected. Fill out the information below. (4 marks)

[2.7.5] Apply RICE tables to find K_c.

Use an ICE table:

1mol 1mol 1 mol c=n/v $c(COCl_2) = 0.100/2 = 0.0500M$

$c(COCl_2)_{eq} = 0.0250/2 = 0.0125M$

	$COCl_2(g) \rightleftharpoons$	$CO(g)$ +	$Cl_2(g)$
I (initial)	0.0500M	------	------
C (change)	-0.0375	+0.0375	+0.0375
E (equilibrium)	0.0125M	0.0375	0.0375

$[CO]_{equilibrium}$ = $[CO]_{eq} = 0.0375$ M

K_C = And the $K_c = (0.0375)^2 / 0.0125 = 0.113$ M

c. Calculate the K_C value of this reaction based on your value obtained in **part b.** above. (2 marks)

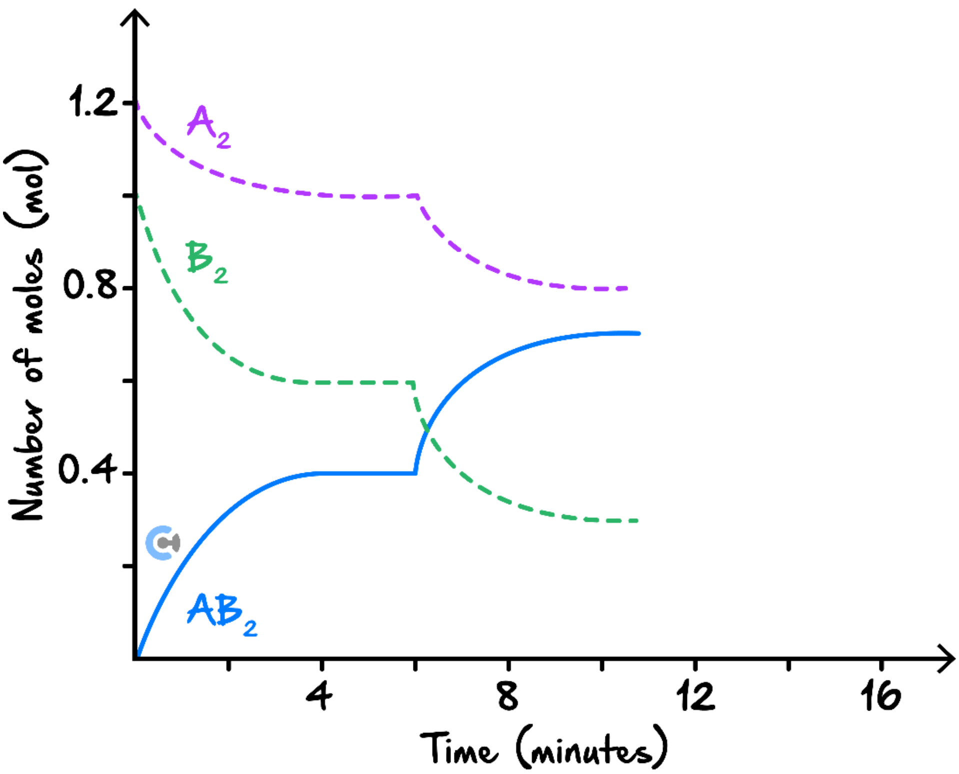
$$3CO(g) + 3Cl_2(g) \rightleftharpoons 3COCl_2$$

[2.7.3] Find equilibrium constant when equation is changed.

Reverse the Kc from (ii) (reciprocal)and cube
New K_c = $(1/(0.113))^3$ = 693 M^{-3}

d. Reactants *A* and *B* are placed in a 2.00 *L* sealed reaction vessel and allowed to reach equilibrium. The reaction is given below.

$$A_2(g) + 2B_2(g) \rightleftharpoons 2AB_2\ (g) \quad \Delta H = \text{positive}\ kJ/mol$$



What happened at the 6-minute mark? Justify your answer. (2 marks)

[2.9.3] Find the change made to system from equilibrium graph.

The system is moving forward which is the endothermic side. There has been a temperature increase to cause this.

Question 9 (16 marks)

Hydrogen gas (H_2) reacts with gaseous iodine (I_2) reversibly at high temperature in the following reaction:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g); \quad \Delta H > 0$$

[2.7.1] Write equilibrium constant expression & find its value (including units).

a. Write an expression for the equilibrium constant, K, of the above reaction. (1 mark)

The mark is awarded for **either** of the following expressions:

- $\frac{[HI]^2}{[H_2][I_2]}$
- $\frac{[HI]_{eq}^2}{[H_2]_{eq}[I_2]_{eq}}$

To a 1.00 L container at 698 K, Eddie adds 0.200 mol of H_2 and 0.200 mol of I_2. At equilibrium, which is established after 2 minutes, 0.316 mol of HI is present in the container.

[2.7.1] Write equilibrium constant expression & find its value (including units).

b. Determine the percentage yield of HI in this reaction. (2 marks)

One mark should be awarded for each of the following:

- simply indicating (not necessarily explicitly stating) that the theoretical yield/maximum amount of HI that can be produced is 0.400 mol of HI
- the correct answer, which is 79.0%

$$n(HI)_{max} = 0.400 \text{ mol}$$
$$\%(\text{yield}) = \frac{0.316}{0.400} \times 100\% = 79.0\%$$

c. Determine the value of K. (2 marks)

[2.7.1] Write equilibrium constant expression & find its value (including units).

One mark is awarded for each of the following:

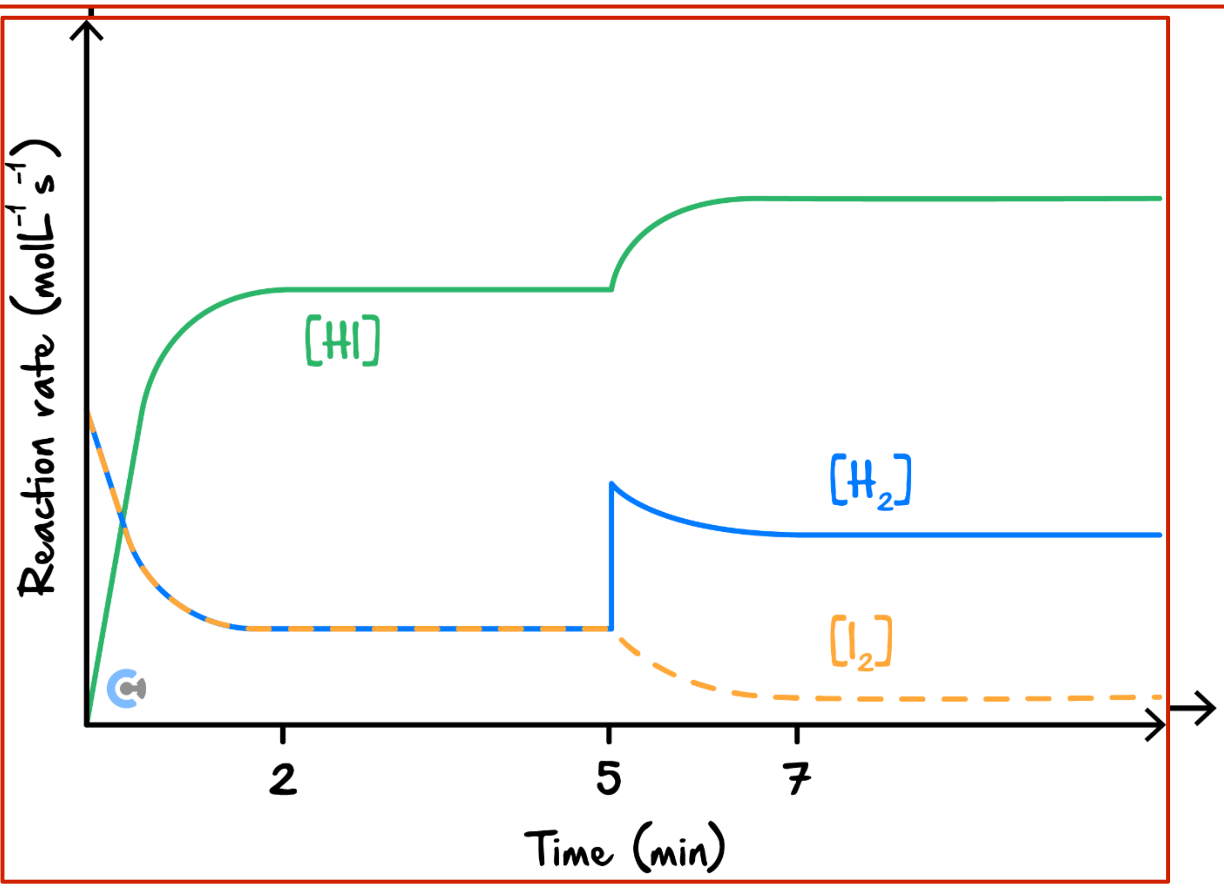
- simply indicating (not necessarily explicitly stating) that the equilibrium concentrations of H_2 and I_2 are both 0.042 M
- the correct answer, which is **57** (no units)

$$[HI]_{eq} = 0.316 \text{ M}$$
$$n(H_2)_{eq} = 0.200 - \frac{0.316}{2} = 0.042 \text{ mol}$$
$$[H_2]_{eq} = 0.042 \text{ M}$$
$$n(I_2)_{eq} = 0.200 - \frac{0.316}{2}$$
$$[I_2]_{eq} = 0.42 \text{ M}$$
$$K = \frac{0.316^2}{0.042 \times 0.042} = 57$$

Another 0.200 mol of H_2 was added to the container after 5 minutes, after the system had already reached equilibrium. At 7 minutes, the system re-established equilibrium.

d. On the axes below, draw a **concentration-time** graph for each gas over the 7 minutes. (3 marks)

[2.8.2] Graph effects of addition / removal of substances or pressure / volume changes on equilibrium system.



Marks must be awarded as follows:

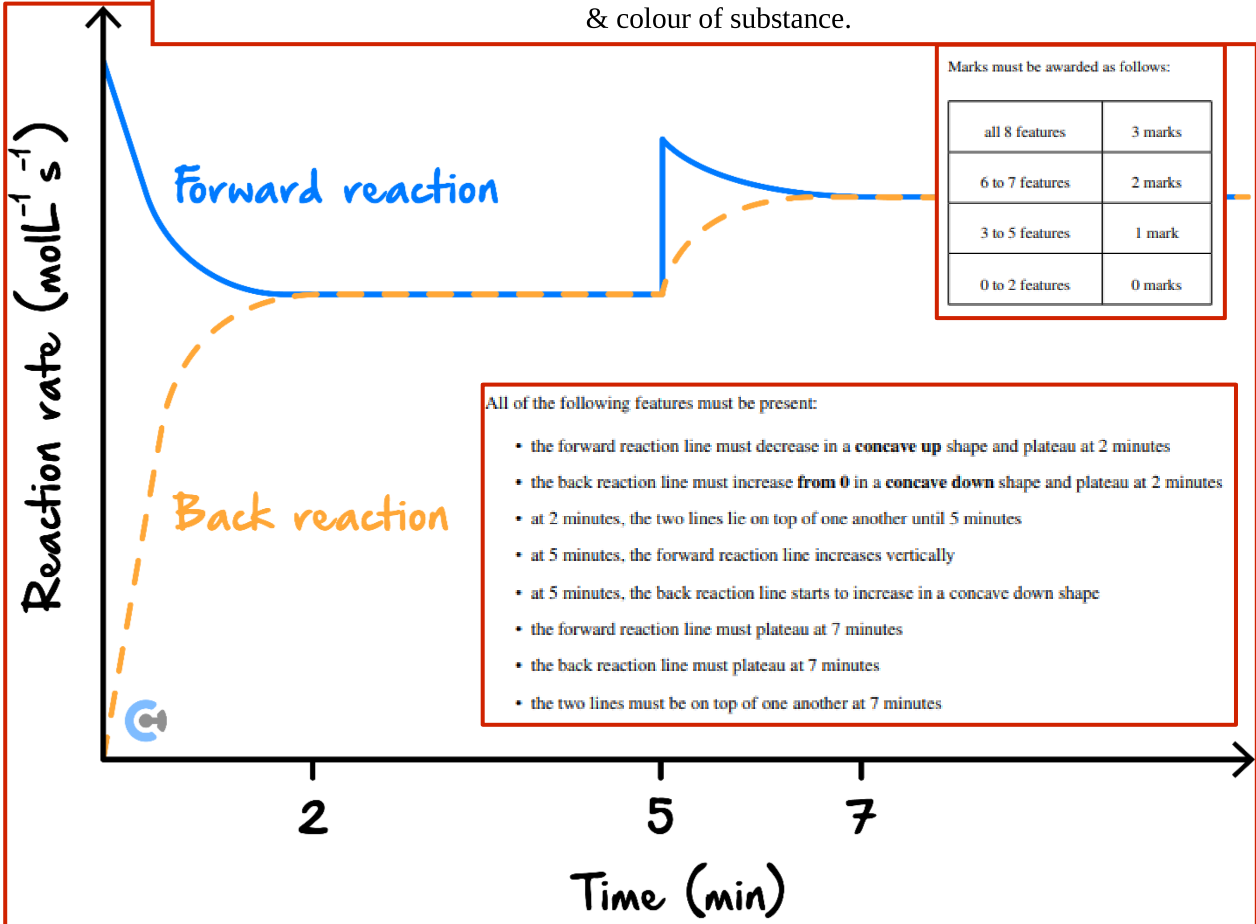
all 9 features	3 marks
6 to 8 features	2 marks
3 to 5 features	1 mark
0 to 2 features	0 marks

All of the following features must be present:

- the HI line (labelled!) must initially increase from 0 and plateau at 2 minutes and remaining straight until 5 minutes
- the H_2 and I_2 lines must be drawn below the HI line for the first two minutes, decreasing from some reasonable non-zero number and plateauing at 2 minutes and remaining straight for 5 minutes
- the H_2 and I_2 lines must be drawn one on top of the other for the first 5 minutes
- the HI line must start increasing in a **concave down** shape at 5 minutes
- the H_2 line must increase vertically at 5 minutes
- the I_2 line must start increasing in a **concave down** shape at 5 minutes
- the HI line must plateau at 7 minutes
- the H_2 line must decrease in a **concave up** shape at 5-7 minutes and plateau at 7 minutes
- the I_2 line must plateau at 7 minutes

e. On the axes below, draw a **reaction rate–time** graph of the forward and back reactions over the 7 minutes. (3 marks)

[2.8.3] Apply partial opposition during equilibrium to the effects on amount, concentration & colour of substance.



Marks must be awarded as follows:

all 8 features	3 marks
6 to 7 features	2 marks
3 to 5 features	1 mark
0 to 2 features	0 marks

All of the following features must be present:

- the forward reaction line must decrease in a **concave up** shape and plateau at 2 minutes
- the back reaction line must increase **from 0** in a **concave down** shape and plateau at 2 minutes
- at 2 minutes, the two lines lie on top of one another until 5 minutes
- at 5 minutes, the forward reaction line increases vertically
- at 5 minutes, the back reaction line starts to increase in a concave down shape
- the forward reaction line must plateau at 7 minutes
- the back reaction line must plateau at 7 minutes
- the two lines must be on top of one another at 7 minutes

f. The volume of the container was quickly expanded to 2 *L* at 7 minutes.

[2.8.1] Explain effects of addition / removal of substances or pressure / volume changes on equilibrium system.

i. In which direction will the equilibrium shift? Circle your answer. (1 mark)

Forwards Backwards No change

The mark should be awarded if '**no change**' is circled.

ii. Explain your answer to **part (f) (i)** using Le Chatelier's principle. (2 marks)

One mark should be awarded for each of the following points:

- initially, the total pressure of the system/the total concentration of gaseous species decreases and the system attempts (subsequently) to oppose that change and increase the pressure of the system/the concentration of gaseous species
- the system cannot do this, as the number of molecules of gas on either side of the equation are the same

[2.8.1] Explain effects of addition / removal of substances or pressure / volume changes on equilibrium system.

Bronson, keen to replicate this experiment, added 0.200 mol of H_2 and 0.200 mol of I_2 to a rigid 1.00 L container at a different temperature. However, he only got a yield of 0.240 mol of HI at equilibrium.

g. Determine the difference between the conditions used by Eddie and Bronson in their reaction of hydrogen with iodine. Explain your answer. (2 marks)

[2.9.1] Explain effects of temperature, inert gas or catalyst on equilibrium system.

One mark should be awarded for the following points:

- stating that Bronson must have used **lower temperatures**
- explaining that this is so because temperature is the only possible way for the yield to be lower (as no change of amount of reactant has occurred and no change in volume can change equilibrium position) and the reaction is endothermic

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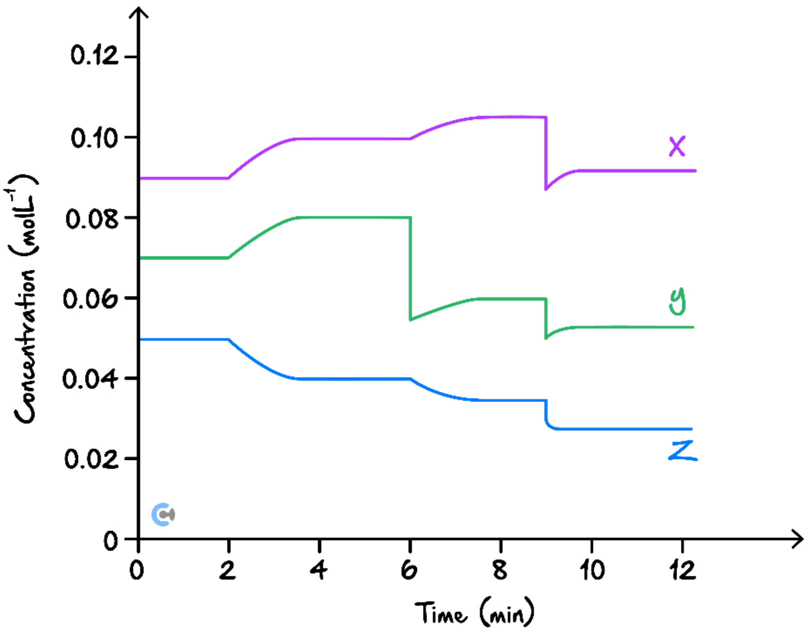
Question 10 (6 marks)

The gases X, Y and Z are components of an equilibrium reaction shown by the following equation:

$$X(g) + Y(g) \rightleftharpoons Z(g) \qquad \Delta H = -108\ kJ\ mol^{-1}$$

The graph below shows the variation in concentration of the components of an equilibrium mixture in a closed vessel of fixed, unchangeable volume with time.



a. Complete the table below to identify the changes made to the equilibrium system at the specified times, and explain why the system responded as shown. (4 marks)

[2.9.3] Find the change made to system from equilibrium graph
[2.8.1] Explain effects of addition / removal of substances or pressure / volume changes on equilibrium system.

Time of Change	**Description of change**	**Why**
2 minutes	Increase in temperature	For an exothermic reaction, increasing the temperature will favour the reactants, as this opposes the change by using up some of the heat introduced.
9 minutes	Removal of some of the mixture	When mixture is removed, the concentration of all species decreases. The concentration fraction value increases. Reaction moves in reverse to restore the concentration fraction to the equilibrium constant value.

b. State the amount of different values of K_c are evident in the graph above? Explain your choice. (2 marks)

[2.9.4] Find equilibrium constant changes due to temperature.

two — 1 mark

Only a change in temperature will change the value of the K_c. There are two different values of the K_c: one before 2 minutes and one after 2 minutes. — 1 mark

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