Revision – rates and equilibrium

Graph analysis Part (A)

1. Consider the reaction shown below.

   $A(aq) \rightleftharpoons C(aq) + 2D(aq)$ ΔH=-49 kJ

   a. Using fig 1, identify the species represented by the graphs coloured:

   - Green _____*A*_____ *1 mark*

   - Blue ______ *C*____________*1 mark*

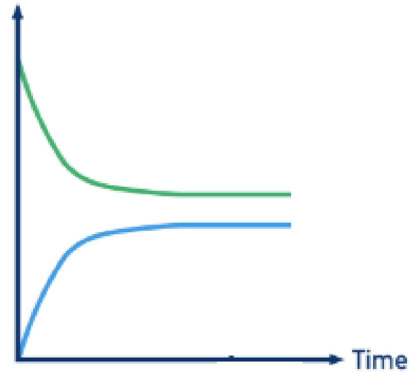


Figure 1 - $A(aq) \rightleftharpoons C(aq) + 2D(aq)$ ΔH=-49 kJ

   b. Which of the following could be the likely units of the Y-axis? Circle the correct response/s.

1-----mark was given for [ ] or mol or both.

   i. kJ
   ii. atm
   iii. [✓ [ ]]
   iv. Rate
   v. [✓ mol]

   c. Explain your reasoning as to why you selected the options you did to question b. above and why the others were not considered.

i. This represents energy, not the amount of a substance. Energy changes would not show separate curves for A and C in this way.
ii. This is pressure, which only applies to gases. Since the reaction involves aqueous species (aq), pressure is not relevant.
iii. The Y-axis most likely represents concentration because the graph is tracking how the amounts of reactants and products change over time as the system moves towards equilibrium. In equilibrium graphs, we typically observe concentrations of species becoming constant when equilibrium is reached. Since A is decreasing and C is increasing until they level off, this behaviour matches concentration changes.
iv. Reaction rate usually decreases over time but does not produce separate curves for individual species like this, instead, it refers to how fast concentrations change.
v. While moles measure quantity, graphs like this are typically expressed in concentration (mol L^{-1}), not total moles, because volume is assumed constant and concentration is more meaningful for equilibrium systems.Consider the reaction shown in fig. 2, showing the decomposition of ammonia .
1-----mark for each explanation

2. $2NH_3(g) \rightleftharpoons 3H_2(g) + N_2(g)$ ΔH=+92 kJ

a. Which of the following could be the likely units of the Y-axis where T_1 represents the time at which the amount, in mol, of NH_3 and H_2 are constant? Circle the correct response/s

1 mark

i. kJ
ii. atm
ii. [ ]
iv. [✓ Rate]
v. mol

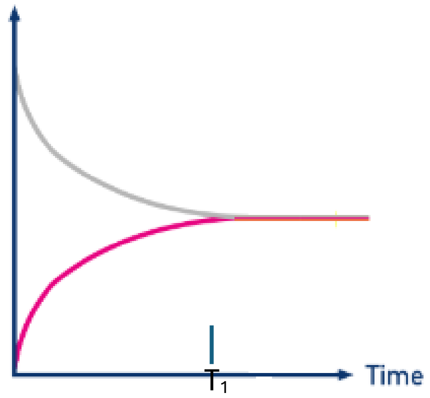


Figure 2 – graphing of a feature of the reaction

$2NH_3(aq) \rightleftharpoons 3H_2(aq) + N_2(aq)$ ΔH=+92 kJ

b. Explain your reasoning as to why you selected the options you did to question b. above and why the others were not considered.

- *i. kJ – This represents energy. Although the reaction has an enthalpy change (ΔH = +92 kJ), energy is not what is being plotted since separate curves for NH_3 and H_2 are shown.*
- *ii. Pressure is only relevant for gases if the partial pressure for each species is in the right ratio as per equation. The grey graph starts high so it would most likely be NH_3 and the purple is most likely H_2 or N_2. Clearly the graphs are not in the right ratio for partial pressures to be represented by the graphs.*
- *iii. Concentration could be used in equilibrium graphs, but the question specifically states a gaseous homogeneous equilibrium, so concentration is not appropriate here.*
- *iv. It is most likely rate of the reverse and forward reactions. At equilibrium they are both equal as clearly shown on the graph. The forward reactions starts high and decreases as reactant particles decrease in number. The reverse reaction strats at zero and increases as the number of product particles increase*
- *v. Mol cannot be the y-axis units. For every 2 mol of NH_3 that decomposed 3 mol of H_2 is formed and 1 mol of N_2 . The lines are not in the right ratio.*
  1-----mark for each correct response

3. Consider the reaction shown in fig. 3, shown below of the decomposition of ammonia. The reaction takes place in a sealed vessel after the addition of an unknown amount of NH_3 gas.

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g) \ \underline{\Delta H} = -206 \text{ kJ}$$

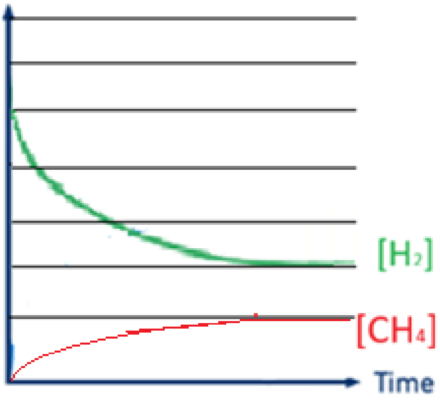


Fig 3 - $CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$ $\underline{\Delta H}$=-206 kJ

a. In the graph in fig. 3, draw a labelled line of the [CH_4] over time. *2 marks*

1-----mark correct shape starting from zero.

` *1----- mark correct ratio of 3:1*

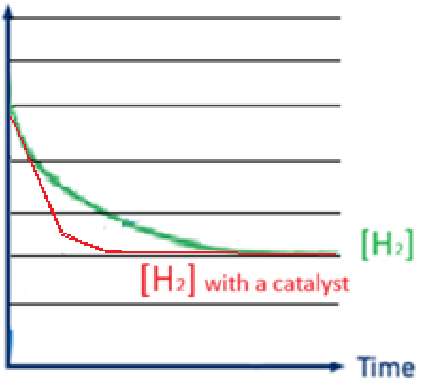


Fig 4 - $CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$ $\underline{\Delta H}$=-206 kJ

c. In the graph shown in fig. 4 on the right:
   - draw a labelled graph of [H_2] in the presence of a catalyst.

   1-----mark correct shape, starts at the same point as the uncatalyzed and ends at the same point.
   1-----mark showing steeper gradient and reaching the plateau earlier at the same level as the uncatalyzed..

   - explain the factors you considered when drawing this graph and why it looks similar or different to that drawn in question a. above?

   1-----mark for suggesting that a catalyst does not change the amount of yield, so the catalysed graph starts and finished in exactly the same point as the uncatalysed reaction
   1-----mark A catalyst causes the reaction to reach equilibrium quicker than the uncatalyzed reaction
   1-----mark for stating how a catalyst increases the rate by providing an alternative pathway with lower activation energy.

d. The graph shown in fig. 5 below, is of the [H_2] produced by the reaction shown below at 100°C.

- draw a labelled graph of [H_2] if the reaction below takes place at 300°C.

  1-----mark for steeper gradient

  1-----mark for plateauing earlier.

$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$ <u>ΔH</u> = -206 kJ

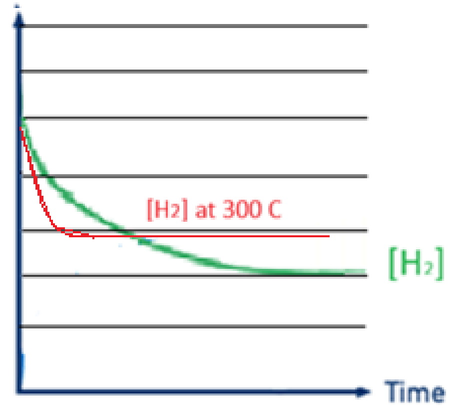


Fig 5 - $CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$ <u>ΔH</u>=-206 kJ

- explain the factors you considered when drawing this graph and why it looks similar or different to that drawn in question a. above?

  1-----mark for steeper gradient since an increase in temperature will increase the <u>proportion</u> of particles that have kinetic energy greater or equal to the activation energy.

  1-----mark Since it is an exothermic reaction rate and yield are conflicted.

  1-----mark Lower yield must be shown as less reactant being used up hence the graph plateaus earlier.

4. A mixture of H_2 and Cl_2 gases was placed in a reaction vessel, at a temperature of 100 °C and allowed to reach equilibrium according to the reaction shown below.
   $2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$ <u>ΔH</u> = +184.6 kJ

   a. The graph of the forward and reverse rates of reaction are shown on the right, in fig. 6.

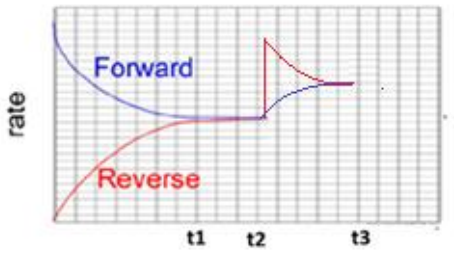


Figure 6 – rate time diagram of the reaction

$2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$ <u>ΔH</u> = +184.6 kJ

1----mark reverse shoots up as there are now more product particles to undergo fruitful collisions
1-----mark forward reaction now starts to increase as the number of reactant particles also increase.
1-----mark equilibrium is reestablished when both rates are equal.
Student just had to show the right shapes without justifying their answer.

i. Explain, in terms of particle theory, what is taking place in the reaction vessel between t_1 and t_2.

1-----mark Between t_1 and t_2, the system is at dynamic equilibrium. The concentrations (or amounts) of H_2, Cl_2 and HCl remain constant because there is no net change in the number of particles of reactants and products. The underlined phrase must be used for the point.
1-----mark At the particle level, reactant particles (H_2 and Cl_2) and product particles (HCl) continue to collide. These collisions are successful (fruitful collisions) in both the forward and reverse directions. The rate of the forward reaction is equal to the rate of the reverse reaction, so for every HCl molecule formed, one is also decomposed.

ii. At t_2 additional H_2 gas was added to the reaction equilibrium mixture. On the graph shown in fig. 6, continue the graphs of the forward and reverse reactions, clearly label each graph as reverse or forward.

iii. Immediately after the addition of H_2, at t_2, explain how Q_P and K_P may have changed. In your response give the Q_P expression

1-----mark expression correctly written $Q_p = [P_{H_2}][P_{Cl_2}] / [P_{HCl}]^2$

1-----mark Q_p increases.

1-----mark K_p no change (no change in temperature so K_p is constant at a given temperature.

iv. At t_2 the temperature of the reaction vessel was decreased to 50°C. On the graph shown in fig. 7, continue the graphs of the forward and reverse reactions. Clearly label the two graphs as reverse or forward. *3 marks*

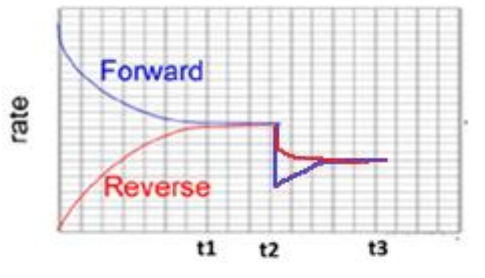


Figure 7– rate time diagram of the reaction

$2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$ ΔH = +184.6 kJ

1-----mark => both rates fall as temp is lower.

1-----mark => reverse reaction falls less as there is a net backward reaction because the forward reaction is endothermic.

1-----mark => both rates then meet in the middle signifying a new equilibrium position where both rates are equal but lower than before the stress.

v. Explain the shape of each graph drawn in question iii. Above, with reference to Le Chatelier's priniciple how the system responds to the stress applied (ie. temperature change)

1-----mark => When the temperature is decreased, the system experiences a stress because the forward reaction is endothermic and all rates fall due to a lower proportion of particles with the right activation energy.
1-----mark => According to Le Châtelier's principle, the system responds by favouring the exothermic (reverse) reaction to counteract the temperature decrease. As a result, the forward reaction rate falls more, the reverse reaction rate falls less and so the system goes in a net backward direction.
1-----mark => A new equilibrium is established at lower rates as both rates converge to be equal.

vi. Explain how K_P and Q_P change as a result of the temperature drop in the system as discussed in question iii. Above.

1-----mark => A drop in temperature favours a net backward reaction in an endothermic reaction

1-----mark =>. Since there are less product particles and more reactant particles the reaction quotient Q_p decrease.
1-----mark => Since there is a temperature change the K_p will also change to a new constant at this new temperature. It will be lower.

vi. At t_2 the volume of the reaction vessel was doubled. On the graph shown in fig. 8, continue the graphs of the forward and reverse reactions. Clearly label the two graphs as reverse or forward
1-----mark => both drop because of concentration decrease.
1-----mark => both drop the same distance as the concentration change impacted both the same.
1-----mark => the system does not move since the same number of particles are present on both sides of equation. Both rates continue being equal.

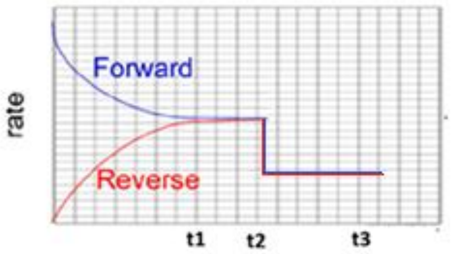


Figure 8– rate time diagram of the reaction

$2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$ $\underline{\Delta H}$ = +184.6 kJ

Students did not need to justify the shape of their graph. 3 marks were awarded if the graphs looked like the sample answer above.

vii. Explain how the values of Q_P and K_P change when the volume is doubled. Justify your response with a simple calculation given the equilibrium partial pressure of each species as $[H_2]$ = 1 atm, $[Cl_2]$ = 1 atm, [HCl] = 1 atm.

For the reaction:

$$2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$$

$$Q_p = \frac{P_{H_2} \cdot P_{Cl_2}}{(P_{HCl})^2}$$

1-----mark => for the correct reaction quotient expression

Step 1 - Initial equilibrium (before volume change)

$$Q_p = K_p = \frac{(1)(1)}{(1)^2} = 1$$

1-----mark => for calculating correct Q_p before

Doubling the volume halves all partial pressures

- $P_{H_2} = 0.5atm$
- $P_{Cl_2} = 0.5atm$
- $P_{HCl} = 0.5atm$

$$Q_p = \frac{(0.5)(0.5)}{(0.5)^2} = \frac{0.25}{0.25} = 1$$

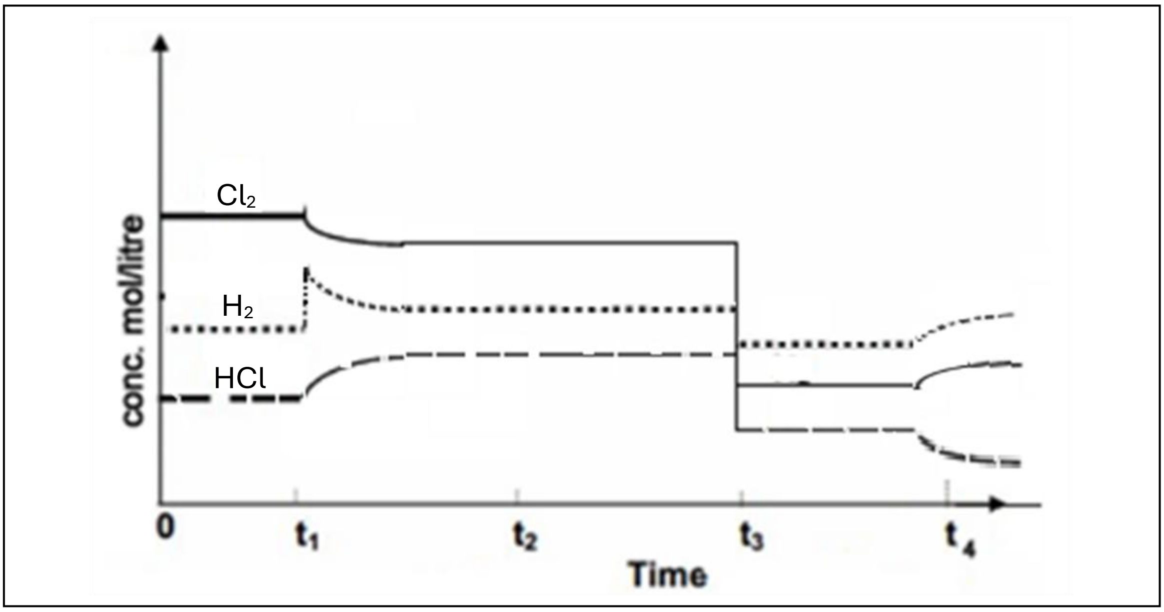
1-----mark => for correctly calculating the Q_p after the stress is applied

1-----mark => for explanation. No temperature change so K_p does not change. It is the same before and after volume change. System does not respond.

The underlined must appear somewhere in the student's response for the mark to be awarded.

5. Consider the graph of concentration vs time for the equilibrium system below.

$$H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)\ \Delta H = -184.6\ kJ$$



Give the possible stress applied at each time interval and justify your answer with reference to the graph.

Time t_1

1-----mark => H_2 is added system responds by moving in a net forward reaction

1-----mark => Indicated by a spike in the concentration of H_2

Time t_2

1-----mark => The graph shows no response whilst concentrations do not change.
1-----mark => most likely a catalyst is added

Time t_3

1-----mark => All concentrations have being halved.
1-----mark => most likely volume has being doubled

Time t_4

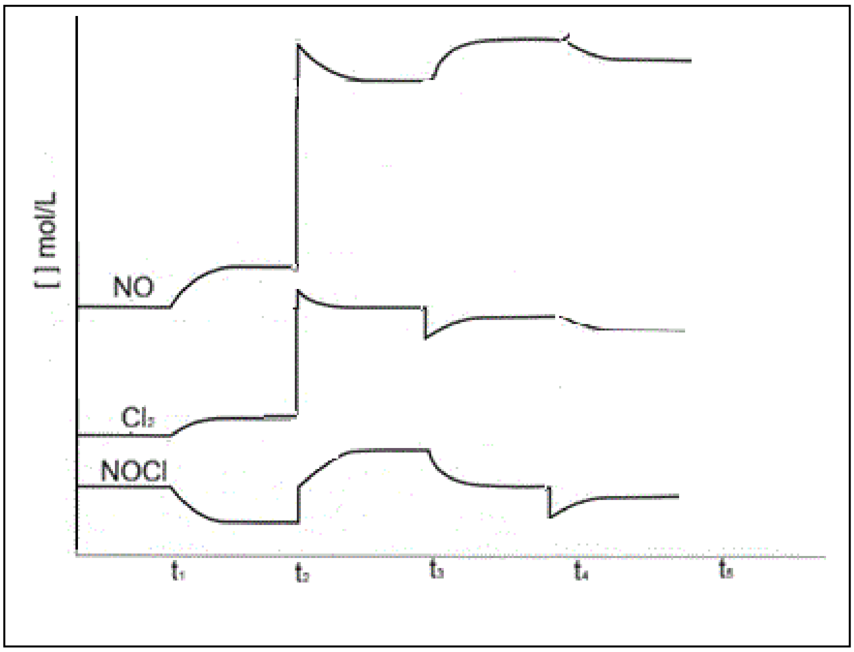
1-----mark => The graph shows a gradual change in concentrations indicative of a net backward reaction.
1-----mark => most likely a temperature increase

6. A mixture of two gases nitrogen monoxide (NO) and chlorine gas (Cl_2) was introduced into a sealed vessel and allowed to reach equilibrium. The temperature of the vessel cooled as the reaction proceeded to form $NOCl_2$.
   a. Write a balanced thermochemical equation for the equilibrium system given above. The sign and units of the ΔH need only be given.

   $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl\ \Delta H > 0$

   1-----mark for balanced equation
   1----mark for correct sign of the ΔH

   b. Consider the concentration vs time graph shown below.



      i. What is the likely stress applied to the system at t_1? Explain how this impacted the Q_c and K_c.

      1-----mark for stating temperature is decreased.
      1-----mark for stating Q_c and K_c both decrease as the system reaches a new equilibrium position.

      ii. What was the change made to the system at t_2? Complete the diagram for the [NO].
      1-----mark Volume is halved.
      1---- mark for correct shape of [NO] and clearly showing the curve as doubled in concentration.

iii. What was the stress applied to the system at t_3? Indicate how the system responded by completing the graphs of [NO] and [Cl_2].

1-----mark - Cl_2 was removed.
1-----mark for clearly showing the right shape of both [NO] and [Cl_2]
1----mark for showing that [Cl_2] does not return to its original value but is shown lower than the original value when equilibrium is established once again.

At t_4 NOCl was removed from the system. Indicate how the system responded by completing the graphs of [NO], [Cl_2] and [NOCl].
1-----mark – NOCl was removed showing a spike downwards of [NOCl]
1-----mark for clearly showing the right shape of both [NO] and [Cl_2] and changes are in the right ratio.
1----mark for showing that [NOCl] does not return to its original value but is shown lower than the original value when equilibrium is established once again.

7. Consider the graphs shown below when answering the following questions. A graph can be used more than once.

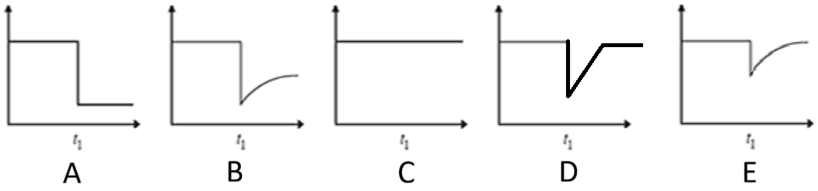


Figure 11 – Graphs representing [ ] or rate of a system after a stress at t_1.

a. A catalyst is used to conduct the reaction. When equilibrium is reached the catalyst is removed from the system at t_1. Which graph best represents the rate of the forward reaction? Justify your answer.
1-----mark graph A
1----- mark A catalyst increases the rate of both the forward and reverse reactions equally by lowering the activation energy. When the catalyst is ***removed at t_1,*** *both the forward and reverse reaction rates decrease instantly. Since the system is already at equilibrium both reactions proceed at equal rates just lower.*
There is ***no shift in equilibrium****, so no gradual change occurs.*

b. A system at equilibrium has one of its reactants reduced in concentration at t_1 whilst maintaining a constant temperature. Which graph best represents the concentration of this reactant? Justify your answer

1-----mark Graph B

At time t_1, the concentration of the reactant is directly reduced, so there is an instant decrease in its concentration (a vertical drop).

The system is no longer at equilibrium, so according to Le Châtelier's principle, it will shift to produce more of the reactant. This causes the concentration to gradually increase after t_1 until a new equilibrium is established.

1-----mark Therefore, the graph must show an immediate drop followed by a gradual increase, which corresponds to Graph B. Most important reactant never returns to its original concentration

c. The following reaction is allowed to reach equilibrium in a closed vessel.

$$A(g) + B(g) \rightleftharpoons D(g) + C(g)$$

At t_1 the volume of the reaction vessel was changed. Which graph best represents the [A]? Justify your answer

1-----mark- graph A

1-----mark - A change in volume causes an instant change in concentration of all gases. If the volume is increased, the concentration of A decreases immediately (vertical drop).

For the reaction $A(g) + B(g) \rightleftharpoons D(g) + C(g)$, there are equal numbers of gas moles on both sides ($2 \rightleftharpoons 2$), so there is no shift in equilibrium after the change.

Therefore, after the initial sudden change at t_1, the concentration of A reduces suddenly and remains constant (no gradual increase or decrease). This corresponds to Graph A, which shows an instant change followed by a flat line.

d. The system $A(g) + B(g) \rightleftharpoons D(g)$ is at equilibrium. At time t_1, the total pressure is greatly increased by injecting an inert gas. Which graph best represents the change in the partial pressure of D? Justify your answer.

1-----mark – Graph C

1-----mark - Injecting an inert gas at constant volume increases the total pressure, but it does not change the partial pressures of the reacting gases (A, B, or D), because their number of moles and the volume remain unchanged.

Since the partial pressures remian unchanged, the system remains at equilibrium with no shift and no gradual change.

Therefore, the correct graph must show no change at t_1 (a flat line throughout), which corresponds to Graph C.

Equilibrium – application of Le Chatelier's principle Part (B)

8. Complete the table below by circling the correct response.

Equilibrium system All systems below are at equilibrium	Stress	Response of the system right (→), left (←), unchanged (-)	What changes? Reaction quotient, Equilibrium constant
$A(aq)+X(aq)\rightleftharpoons 3D(aq)$ $\underline{\Delta H <0}$	Product D is removed	[✓ (→)] (←) (-)	K_c ↓ ↑ [✓ ▬] Q_c [✓ ↓] ↑ ▬
$2A(aq)+D(aq)\rightleftharpoons 2G(aq)+Z(aq)$ $\underline{\Delta H <0}$	Volume of reaction vessel is halved	(→) (←) [✓ (-)]	K_c ↓ ↑ [✓ ▬] Q_c ↓ ↑ [✓ ▬]
$J(g)+3Z(g)\rightleftharpoons A(g)+D(g)$ $\underline{\Delta H >0}$	Pressure increases considerably by adding He	(→) (←) [✓ (-)]	K_g ↓ ↑ [✓ ▬] Q_g ↓ ↑ [✓ ▬]
$J(aq)+3Z(aq)\rightleftharpoons A(aq)+D(aq)$ $\underline{\Delta H >0}$	Catalyst added at constant temperature	(→) (←) [✓ (-)]	K_c ↓ ↑ [✓ ▬] Q_c ↓ ↑ [✓ ▬]
$J(aq)+3Z(aq)\rightleftharpoons A(aq)+D(aq)$ $\underline{\Delta H >0}$	Temperature increased.	[✓ (→)] (←) (-)	K_c ↓ [✓ ↑] ▬ Q_c ↓ [✓ ↑] ▬

9. Consider the equilibrium system given by the equation below.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad \underline{\Delta H} = +53 \text{ kJ}$$

A mixture of gas at equilibrium was sampled at SLC and found to contain 0.0150 mol of H_2, 0.0200 mol of I_2 and 10.05 mol of HI.

a. Calculate the equilibrium constant at SLC. *4 marks*

$$\frac{[HI]^2}{[H_2][I_2]} = \frac{[10.05]^2}{[0.0150\,][0.0200\,]} = 3.37 \text{ X } 10^5$$

1-----mark => correct equation

1-----mark => for correct answer

1-----mark => for no units

1-----mark => 3 sig figs

It was imperative that students understood that they did not need the volume to work out the concentration of the gases. Having equal particles on both sides of the equations means that the units of volume cancel out.

b. What does the magnitude of the K_C tell you about the reaction, in particular its rate and its yield at SLC.

1-----mark => Very high K_c , the reaction proceeds in forward direction to produce a vey high yield.

1----mark => K_c indicates yield not rate.

c. The temperature of the reaction vessel was increased to 75 °C.

i. How do you expect the K_c to change. Justify your response with a clear explanation.

1-----mark => Increase

1-----mark => An increase in temperature will drive an endothermic reaction in the forward direction increasing products and hence $K_{c.}$

ii. How do you expect the rate of reaction to change. Justify your response with a clear explanation

1-----mark => rate will increase.

1-----mark => Higher temperatures causes a <u>greater proportion</u> of particles to have the necessary activation energy to undergo <u>fruitful collisions</u>.

The underlined phrases were expected to be in the student's answer .

10. Consider the equilibrium shown below. $FeSCN^{2+}$ is shown in red to highlight the fact that it is red in solution whilst Fe^{3+} is yellow.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons \mathbf{FeSCN}^{2+}(aq) \quad \underline{\Delta H} = -45 \text{ kJ}$$

a. A mixture composed of 50 mL 0.1M $Fe(NO_3)_3$ and 50.0 mL of NaSCN is allowed to come to equilibrium at 25°C. The following stresses were applied to the system whilst at equilibrium. For each stress discuss how the system will visibly change in colour and offer an explanation using le Chatelier's principle.

i. The system is heated

1-----mark => The system will fade in red and appear more yellow as the equilibrium position shifts to the left.

1-----mark => Heating an exothermic reaction favours the reverse reaction.

ii. 1 drop of 1.0 M $AgNO_3$ is placed in a slightly red coloured equilibrium mixture. AgSCN is an insoluble solid

1-----mark => SCN^{-} is removed.

1-----mark => according to Le Chatelier's principle the system will move to the left to partially undo the change and appear less red and more yellow.

iii. 1 drop NaSCN is added to a somewhat reddish coloured equilibrium mixture.

1-----mark => $[SCN^{-1}]$ is increased.

1-----mark => according to Le Chatelier's principle the system will move to the right to partially undo the change and will appear more red.

b. In 200 mL of pure water at 25.0 °C, 2.00 mol of Fe^{3+} ions were added and mixed with 2.00 mol of SCN^{-}. The mixture was allowed to reach equilibrium at which point the temperature of the water was recorded at 38.5°C.

i. Calculate the energy, in kJ, absorbed by the water.

$$q = 200 \times 4.18 \times 13.5$$
$$q = 11286\, J$$
$$q = 11.3\, kJ$$

1-----mark => for correct formula
1-----mark => for correct answer. Units not required as they were mentioned in the stem of the question.

ii. Calculate the mol of Fe^{3+} and SCN^- ions that reacted.

1-----mark => mol $FeSCN^{2+}$formed = heat released / ΔH

Fe^{3+}(aq) + SCN^-(aq) → $FeSCN^{2+}$(aq) ΔH = −45 kJ/mol

$$n = \frac{11.3}{45} = 0.25\ mol$$

1-----mark for correct application of ratio

Stoichiometry is 1:1:

- *Fe^{3+}reacted = 0.25 mol*
- *SCN^-reacted = 0.25 mol*

iii. Calculate the following concentrations at equilibrium.

1-----mark => Fe^{3+}= 2.00 mol - 0.25mol = 1.749mol

1-----mark => SCN^-= 2.00 mol - 0.25mol = 1.749 mol

iv. Write the expression for the reaction quotient and calculate the value of K_c at this temperature. Include units.

1-----mark => correct concentrations at equilibrium

Fe^{3+}:

$$[Fe^{3+}] = \frac{1.749}{0.200} = 8.75 = 8.744\ M$$

SCN^-:

$$[SCN^-] = 8.744\ M$$

$FeSCN^{2+}$:

$$[FeSCN^{2+}] = \frac{0.2511}{0.200} = 1.256\ M$$

1-----mark => correct expression

$$K_c = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^-]}$$

1-----mark => correct answer with correct units (M^-) and sig figs.

$$K_c = \frac{1.256}{(8.744)(8.744)} = \frac{1.25}{76.56} = 0.0164\ M^-$$

Students are advised to retain full calculator precision for all intermediate values and only round the final answer. If a previous result is used in a later calculation, the unrounded value should be carried forward. This prevents the accumulation of rounding errors and ensures the final answer is as accurate as possible.

11. Consider the following reaction at equilibrium.

$$SO_4^{2-}(aq) + H^+(aq) \rightleftharpoons HSO_4^-(aq) \quad \Delta H = -\mathbf{37.0}\ \text{kJ}$$

2.00 mol of SO_4^{2-} ions was placed in 100 mL of water along with 1.00 mol of H^+ ions. The mixture was allowed to come to equilibrium. The setup is shown below.

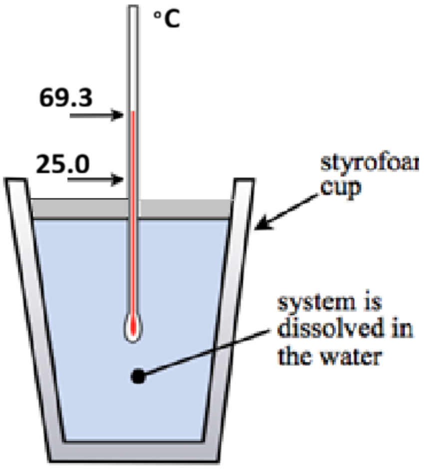


Figure 8 – insulated coffee cup used as a calorimeter.

a. Assuming no energy loss to the surroundings, calculate the amount, in kJ, of energy that was released from this reaction.

1-----mark for correct formula E(J) = 4.18 X mass X ΔT

1-----mark for correct answer in kJ = 4.18 X 100 X 44.3 = 18.5
Units not required since it was stated in the stem of the question it had to be in kJ.

b. Using your answer to question a. above, calculate the amount, in mol, of SO_4^{2-} and H^+ that reacted.

$$SO_4^{2-}(aq) + H^+(aq) \rightleftharpoons HSO_4^-(aq) \quad \Delta H = -37.0\ kJ$$

According to the balanced thermochemical equation given above 1 mol of SO_4^{2-} is needed to produce 37 kJ of heat energy. Using stoichiometric ratio we can work the mol of SO_4^{2-} that reacted.
1-----mark *mol of SO_4^{2-} reacted = 18.5 / 37.0 = 0.500*
1-----mark *mol of H^+ reacted = 0.500*

c. Calculate the amount, in mol, of each species, shown below, remaining at equilibrium.

3

marks

- $n_{SO_4^{2-}}$

1-----mark 2.00 – 0.500 = 1.50 mol reamining

- n_{H^+}
- *1-----mark 1.00 – 0.500 = 0.50 mol remaining*
- $n_{HSO_4^-}$
- *1-----mark 0.50 mol produced*

d. Calculate the concentration of each species. *1 mark*

- $[SO_4^{2-}]$ = *15.0 M*

- $[H^+]$ = *5.0 M*

- $[HSO_4^-]$ = *5.0 M*

1-----mark was awarded if mol of species calculated in c. was expressed as [ ] by dividing by 0.100L

e. Calculate the reaction quotient (Q_c) at this temperature and give the appropriate units. *3 marks*

1-----mark for correct expression of $Q_c = [HSO_4^-] / ([H^+] [SO_4^{2-}])$

1-----mark for correct value of Q_c
=> 5.0/(5.0 X 15.0) = 6.7 X 10^{-2}*M*$^{-}$

1-----mark for correct unit.

f. What is the equilibrium constant(K_c) for the equilibrium system shown below at the same temperature. *1 mark*

$$HSO_4^- (aq) \rightleftharpoons SO_4^{2-}(aq) + H^+(aq) \quad \Delta H = +\mathbf{37}\ \text{kJ}$$

1-----mark for correct value and units
$K_c = 1 / (6.7 X 10^{-2}) = 15\ M$
No mark was awarded if units were not correctly shown.