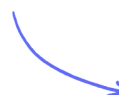


Reversibility & Equilibrium

Reversible Reactions / Energy Changes & Reversible Reactions / Equilibrium / The Effect of Changing Conditions on Equilibrium / The Effect of Changing Concentration / The Effect of Temperature Changes on Equilibrium / The Effect of Pressure Changes on Equilibrium

Easy (5 questions)	/35
Medium (10 questions)	/43
Hard (5 questions)	/42
Total Marks	/120

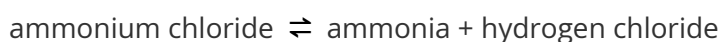
Scan here to return to the course
or visit [savemyexams.com](https://www.savemyexams.com)



Easy Questions

- 1 (a) When solid ammonium chloride is heated, ammonia gas and hydrogen chloride gas are produced.

The equation for this reaction is:



What does the symbol $\rightleftharpoons$ mean?

Answer

The symbol means:

- It is a reversible reaction

OR

Ammonium chloride can form ammonia and hydrogen chloride **AND** ammonia and hydrogen chloride can react to form ammonium chloride

OR

The reaction can go both ways; [1 mark]

[Total: 1 mark]

(1 mark)

- (b) What type of reaction is the reaction in part (a)?

Tick (✓) **one** box.

Neutralisation	
Combustion	
Thermal decomposition	
Reduction	

Answer

The type of reaction is:

Neutralisation	
Combustion	
Thermal decomposition	✓; [1 mark]
Reduction	

[Total: 1 mark]

- The reaction required **heat** to **break down** ammonium chloride

(1 mark)

(c) Circle **one** phrase from the box to complete the sentence.

The reaction can be reversed by

heating it. cooling it. adding water.

Answer

The correct words are:

- The reaction can be reversed by cooling it; [1 mark]

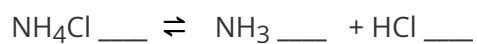
[Total: 1 mark]

- The direction of a reversible reaction can be changed by changing the conditions
- This reaction required heat for the forward reaction (ammonium chloride → ammonia + hydrogen chloride) so would need the opposite, i.e. cooling it, for the reverse reaction (ammonia + hydrogen chloride → ammonium chloride)

(1 mark)

(d) The balanced symbol equation is shown below.

Complete the equation by adding the correct state symbols.



Answer

The completed equation is:

- $\text{NH}_4\text{Cl} (\text{s}) \rightleftharpoons \text{NH}_3 (\text{g}) + \text{HCl} (\text{g})$; [2 marks]
 - allow 1 mark for 1 or 2 correct state symbols

[Total: 2 marks]

- The states of the substances were given to you in the information in part (a), make sure you read questions carefully to extract the required information
- (s) represents solids, (g) represents gases

(2 marks)

- 2 (a)** Hydrated copper sulfate is a blue salt that contains water molecules within its lattice structure.

When heated, the water is removed from the structure, forming white anhydrous copper sulfate.

Complete the word equation for the reaction.

hydrated copper sulfate $\rightleftharpoons$ _____ + _____

Answer

The missing products are:

- Anhydrous copper sulfate; [1 mark]
- Water; [1 mark]

Words can be in either order

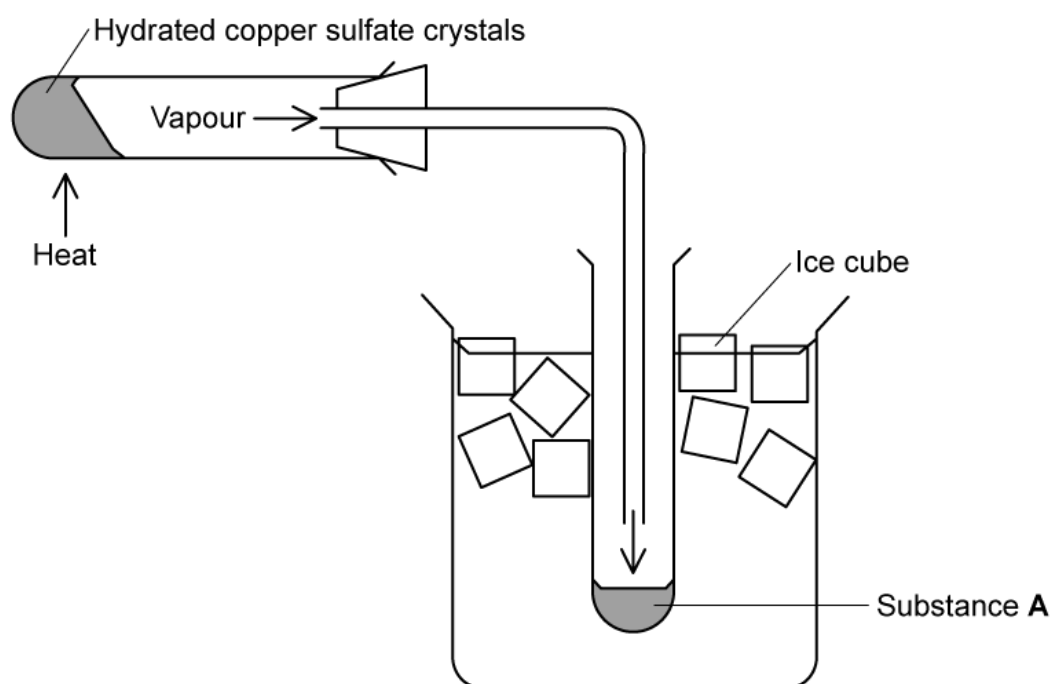
[Total: 2 marks]

- The correct equation is:
 - hydrated copper sulfate $\rightleftharpoons$ anhydrous copper sulfate + water
- The information required is given in the question

(2 marks)

- (b)** A student heated hydrated copper sulfate using the equipment in **Figure 1**.

Figure 1



What **two** observations would be made when hydrated copper sulfate was heated? Tick (✓) **two** boxes.

Hydrated copper sulfate turns white	
Hydrated copper sulfate turns blue	
Substance A is a colourless liquid	
Substance A is a white solid	
Substance A is a blue solution	

Answer

The two observations would be:

Hydrated copper sulfate turns white	✓; [1 mark]
Hydrated copper sulfate turns blue	
Substance A is a colourless liquid	✓; [1 mark]
Substance A is a white solid	
Substance A is a blue solution	

[Total: 2 marks]

- When blue hydrated copper sulfate is heated, anhydrous copper sulfate and water are produced
- Anhydrous copper sulfate is white
- The water that is produced will be a gas (steam) which will travel down the delivery tube into the empty test tube
- The ice around the empty test tube cools the steam which condenses to form water (a colourless liquid)

(2 marks)

(c) When hydrated copper sulfate is heated, an endothermic reaction occurs.

What type of reaction occurs when water is added to anhydrous copper sulfate?

Answer

When water is added to anhydrous copper sulfate, the reaction is :

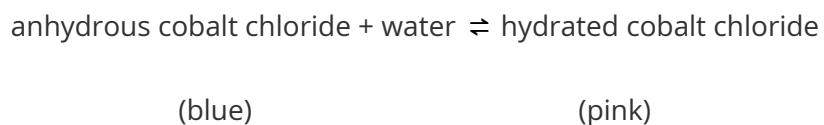
- Exothermic; [1 mark]

[Total: 1 mark]

- Water added to anhydrous copper sulfate is the reverse reaction of hydrated copper sulfate being heated
- If a reversible reaction is endothermic in one direction, it will be exothermic in the opposite direction

(1 mark)

(d) The word equation between anhydrous cobalt chloride and water is shown below.



What colour change would be seen when hydrated cobalt chloride is heated?

Answer

The colour change would be:

- From pink; [1 mark]
- To blue; [1 mark]

[Total: 2 marks]

- Hydrated cobalt chloride is pink
- When it is heated, it loses the water contained in its lattice (water of crystallisation) to form anhydrous cobalt chloride which is blue

(2 marks)

(e) 5.2 g of hydrated cobalt chloride was heated in a test tube.

3.0 g of anhydrous cobalt chloride remained after heating.

Calculate the mass of water that was given off in grams.

Answer

The mass of water given off is:

- $5.2 - 3.0$; [1 mark]
- $= 2.2 \text{ (g)}$; [1 mark]
Allow 2 marks for 2.2 (g) with no working

[Total: 2 marks]

- The mass of the reactant (hydrated cobalt chloride) will be equal to the mass of the products (anhydrous cobalt chloride and water)
- The mass of the water will therefore be the mass of hydrated cobalt chloride – the mass of anhydrous cobalt chloride

(2 marks)

(f) Calculate the percentage of water contained in 5.2 g of hydrated cobalt chloride.

Give your answer to 2 significant figures.

Answer

The percentage is:

- $\frac{2.2}{5.2} \times 100$; [1 mark]
- $= 42.3 \text{ (%)}$; [1 mark]
- $= 42 \text{ (%)}$; [1 mark]
An answer of 42 (%) scores 3 marks
Allow ecf from part (e)

[Total: 3 marks]

- Ensure you give your answer to the required number of significant figures, this is an easy mark to gain!

(3 marks)

3 (a) When a reversible reaction occurs in a closed system, it will reach equilibrium.

What is meant by a closed system?

Tick (✓) **one** box.

Only gases are allowed to escape	
Energy is unable to escape	
The reactants and products are unable to escape	

Answer

In a closed system:

Only gases are allowed to escape	
Energy is unable to escape	
The reactants and products are unable to escape	✓; [1 mark]

[Total: 1 mark]

- In a closed system, whilst the reactants and products are unable to escape, energy can be transferred with its surroundings

(1 mark)

(b) Which of the following statements is true about equilibrium?

Tick (✓) **one** box.

When equilibrium is reached, the reaction stops	
At equilibrium, the amount of reactants is the same as the amount of products	
At equilibrium, the rate of the forward reaction is equal to the rate of the reverse reaction	
When equilibrium is reached, all of the reactants have been used up	

Answer

The true statement is:

When equilibrium is reached, the reaction stops	
At equilibrium, the amount of reactants is the same as the amount of products	
At equilibrium, the rate of the forward reaction is equal to the rate of the reverse reaction	✓; [1 mark]
When equilibrium is reached, all of the reactants have been used up	

[Total: 1 mark]

- The reaction does not stop when equilibrium is reached, even though there are no observable changes
- Equilibrium is said to be **dynamic** as chemical reactions are constantly occurring as the molecules on the left and right of the equations are changing into each other at the same rate

(1 mark)

- (c) Aqueous copper(II) ions can react with chloride ions to form copper chloride. The reaction is a reversible reaction. Aqueous copper(II) ions are blue and copper chloride solution is yellow.



blue

yellow

When left for a few minutes, the reaction reaches equilibrium. Complete the sentences using words from the box.

green	blue	yellow
copper(II) ions	chloride ions	copper chloride

At equilibrium, the reaction mixture is _____ because the reaction mixture contains _____ and _____.

Answer

The correct sentence is:

- At equilibrium, the reaction mixture is green; [1 mark]
- because the reaction mixture contains copper(II) ions; [1 mark]
- and copper chloride; [1 mark]

[Total: 3 marks]

- At equilibrium, all reactants and products will be present
- The colour of the reaction mixture will be a mixture of the blue copper(II) ions and yellow copper chloride solution

(3 marks)

- (d) The concentration of copper(II) ions was increased in the reaction in part (c).

Circle **one** word/phrase in each box to complete the sentences.

- The system will respond to

counteract
maximise
increase

 the change.
- The amount of products will

increase
decrease
remain the same

 until equilibrium is reached again.
- The reaction mixture will turn

green.
yellow.
blue.

Answer

The correct sentences are:

- The system will respond to counteract the changes; [1 mark]
- The amount of products will increase until equilibrium is reached again; [1 mark]
- The reaction mixture will turn yellow; [1 mark]

[Total: 3 marks]

- Le Chatalier's Principle predicts the effects of changing conditions on a system at equilibrium
- The concentration of copper(II) ions had been increased
- The forward reaction is favoured to decrease the concentration of copper(II) ions
- More product is formed which is yellow copper chloride
- The reaction mixture will turn yellow

(3 marks)

- 4 (a)** The reaction between nitrogen and hydrogen to form ammonia is a reversible reaction. The forward reaction is exothermic.

Complete the word equation for the reaction, including the correct symbol that shows the reaction is reversible.

nitrogen + _____ ammonia

Answer

The missing parts of the equation are:

- Hydrogen; [1 mark]
- $\rightleftharpoons$; [1 mark]

[Total: 2 marks]

- The full word equation is nitrogen + hydrogen $\rightleftharpoons$ ammonia
- The symbol $\rightleftharpoons$ shows that the reaction is reversible
- The missing reactant is given in the information in the question

(2 marks)

- (b)** Predict what would happen to the amount of ammonia produced when the following change of conditions occur.

Choose a word from the box below to complete the table.

increase	decrease	remain the same
----------	----------	-----------------

Change of condition	Amount of ammonia produced would:
Increasing concentration of nitrogen	
Increasing the temperature	
Using a catalyst	

Answer

The amount of ammonia would:

Change of condition	Amount of ammonia produced would:
Increasing concentration of nitrogen	Increase; [1 mark]
Increasing the temperature	Decrease; [1 mark]
Using a catalyst	Remain the same; [1 mark]

[Total: 3 marks]

- The system will respond to counteract any changes – this is Le Chatelier's Principle
- When the concentration of a reactant (nitrogen) is increased, more product (ammonia) will be produced, thus reducing the concentration of nitrogen, until equilibrium is reached again
- Increasing the temperature of an exothermic reaction will decrease the amount of product (ammonia) by favouring the endothermic reaction (the reverse reaction)
- Using a catalyst does not alter the position of equilibrium so the amount of product is unaltered

(3 marks)

(c) In the reaction in part (a), nitrogen, hydrogen and ammonia are all gases.

In addition to the condition in part (b), what other condition could be changed that may alter the position of equilibrium?

Answer

Another condition that could be changed is:

- Pressure; [1 mark]

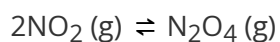
[Total: 1 mark]

- If there are a different number of gas molecules on either side of the equation, then changing the pressure will alter the position of equilibrium
- If the pressure is increased, the equilibrium will move to reduce the pressure
- The reaction with the least number of gas molecules will be favoured which lowers the pressure

(1 mark)

- 5 (a)** Nitrogen dioxide, NO_2 , which is a dark brown gas, exists in equilibrium with colourless, gaseous dinitrogen tetroxide, N_2O_4 .

The balanced symbol equation for this reaction is shown below.



dark brown colourless

How many atoms of oxygen are there in a molecule of dinitrogen tetroxide?

Answer

The number of oxygen atoms in a molecule of dinitrogen tetroxide is:

- 4; [1 mark]

[Total: 1 mark]

- The subscripted numbers tell you how many of each atom of that element is present in one molecule
- The formula N_2O_4 tells you there are 2 atoms of nitrogen and 4 atoms of oxygen in each molecule of dinitrogen tetroxide

(1 mark)

- (b)** When the pressure increases, what happens to the amount of dinitrogen, N_2O_4 , in the reaction mixture?

Choose words from the box to complete the sentence.

increases	fewer
larger	decreases
remains the same	

The amount of dinitrogen tetroxide _____ because the equilibrium position will shift towards the side with _____ number of molecules.

Answer

The amount of dinitrogen tetroxide:

- Increases; [1 mark]
- Fewer/smaller; [1 mark]

[Total: 2 marks]

- Shifting to the side with fewer number of molecules will reduce the pressure and therefore counteracts the change

(2 marks)

- (c) What would you expect to happen to the colour of the reaction mixture if the pressure was increased?

Circle the correct answer.

Become paler	Become darker	Remain the same colour
--------------	---------------	------------------------

Answer

The reaction mixture would:

- Become paler; [1 mark]

Allow ecf from part (b)

- If answer to part (b) was amount of dinitrogen tetroxide decreases, accept becomes darker for 1 mark
- If answer to part (b) was amount of dinitrogen tetroxide remains the same, accept remain the same colour for 1 mark

[Total: 1 mark]

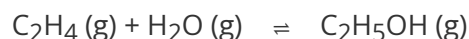
- As the pressure increases, equilibrium favours the forward reaction to counteract this change as there are fewer molecules of gas on this side of the reaction
- More N_2O_4 is produced which is a colourless gas
- Less NO_2 , which is dark brown, is present in the reaction mixture
- The reaction mixture becomes paler

(1 mark)

Medium Questions

- 1 (a) A company manufactures ethanol ($\text{C}_2\text{H}_5\text{OH}$) for sale to other chemical companies as a raw ingredient for many products.

The reaction for the process is as follows:



The forward reaction is **exothermic**.

The temperature and pressure of the reaction can be adjusted to increase the yield of ethanol when the reaction is at equilibrium.

Explain what is meant by the term **equilibrium**.

Answer

Equilibrium means:

- The forward and backward reactions occur; [1 mark]
 - *allow reversible*
- At (exactly) the same rate; [1 mark]
- In a closed system; [1 mark]
- So the concentrations of the reactants and products remain constant; [1 mark]

[Total: 4 marks]

- **Remember** that even though the concentrations of the reactants and products remain constant, it doesn't mean that the concentration of the reactants are the same as the concentration of the products

(4 marks)

- (b) Explain what effect increasing the temperature would have on the **yield** of ethanol at equilibrium.

Answer

The effect of changing temperature on yield is:

- Increasing the temperature would lower the yield of ethanol

OR

The position of equilibrium moves to the left; [1 mark]

- Since the backwards reaction is endothermic / the forward reaction is exothermic; [1 mark]
- The system opposes the change (according to Le Chatelier's principle); [1 mark]
- By favouring the reverse / backwards reaction; [1 mark]

[Total: 4 marks]

(4 marks)

- (c) Explain what effect increasing the pressure would have on the **yield** of ethanol at equilibrium.

Answer

The effect pressure has on yield is:

- (Increasing the pressure would) increase the yield of ethanol

OR

The position of equilibrium moves to the right / product side; [1 mark]

- (Because the position of equilibrium) moves in the direction of the lower number of moles of gas / fewer molecules [1 mark]

[Total: 2 marks]

(2 marks)

(d) How can the direction of a reversible reaction be changed?

Answer

The direction of a reversible reaction can be changed by:

- Adjusting the conditions of the reaction; [1 mark]
- To favour either the reverse or the forward reaction; [1 mark]

[Total: 2 marks]

(2 marks)

(e) **Figure 1** shows the effect of changing pressure on the percentage yield of ethanol at three different temperatures.

Figure 1

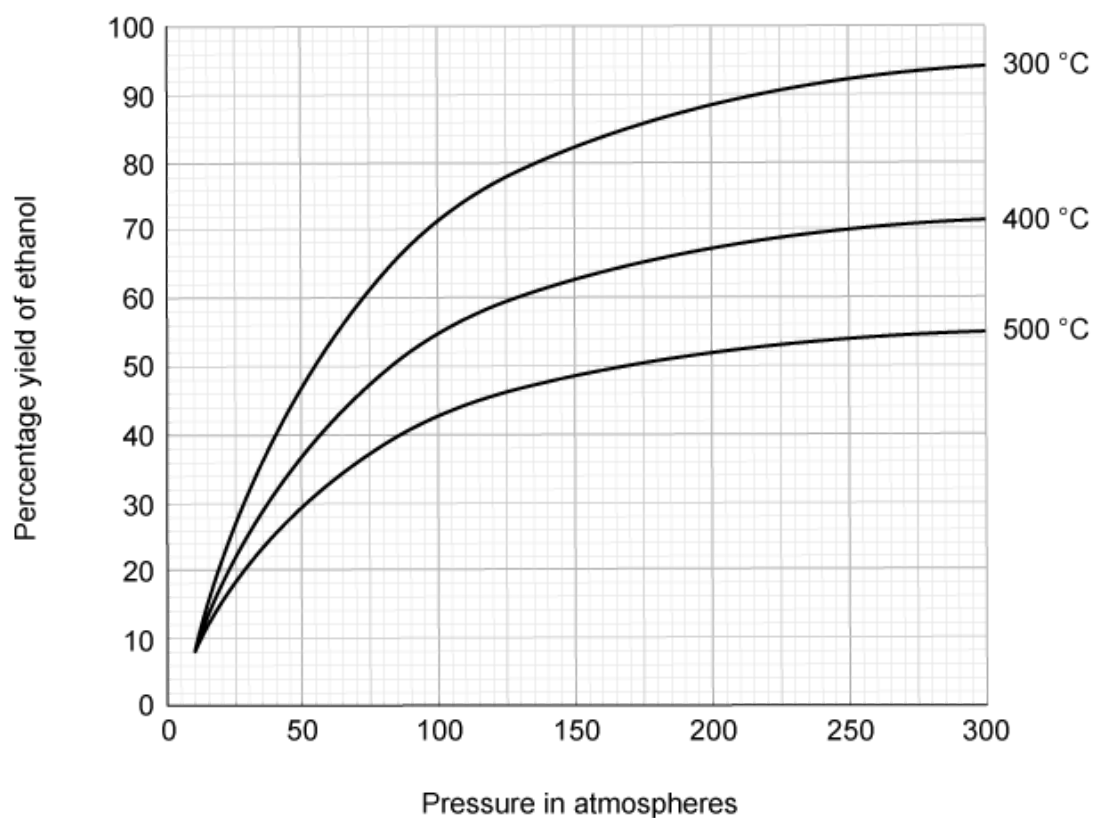
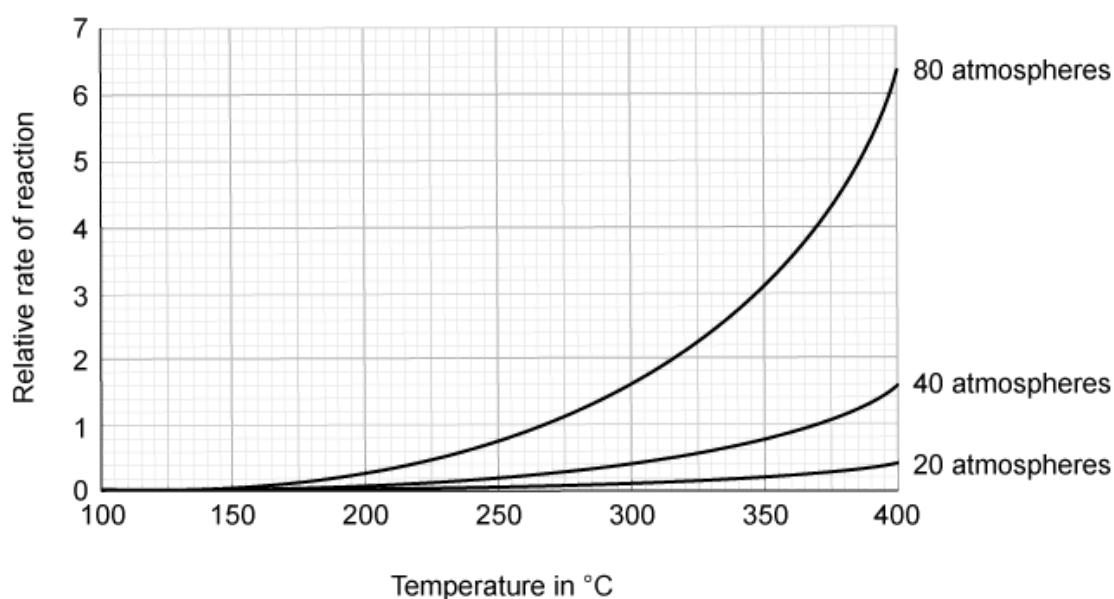


Figure 2 shows the effect of changing temperature on the rate of reaction at three different pressures.

Figure 2



The conditions for the reaction of ethene with steam in one of the processes are:

- 65 atm
- 300 °C
- a catalyst.

Use your knowledge and the information in **Figure 1** and **Figure 2** to justify this choice of conditions.

Answer

Level 3 [5 – 6 marks]:

- The effect of all three factors on the reaction are fully described
- A summary / conclusion explains the compromise in conditions for the reaction

Level 2 [3 – 4 marks]:

- The effect of two factors on the reaction are correctly described
- Summary / conclusion of compromise is attempted.

Level 1 [1–2 marks]:

- The effect of at least one factor on the reaction is given
- There is no / limited conclusion

Examples of the points made in the response

Temperature

- A higher temperature gives a lower yield / higher temperature gives a faster rate

Pressure

- A higher pressure gives a higher yield / increase in yield gets less as pressure increases
- A higher pressure gives a faster rate / increase in rate increases as pressure increases

Catalyst

- Using a catalyst speeds up reaction / catalysts allow a lower temperature to be used and so save energy / reduce energy costs

Compromise

- A higher pressure gives a greater yield & a faster rate but increases costs / risks
- A high temperature makes reaction faster but reduces yield while a catalyst makes reaction faster so a lower temperature can be used which will increase the yield

[Total: 6 marks]

(6 marks)

- 2** The Haber process is an example of a reversible reaction where the forward reaction is exothermic:



What is **not** true about this system when it is at equilibrium?

- A.** The energy change of the reverse reaction is endothermic
- B.** The equilibrium occurs within a closed system

- C.** The reaction has reached completion and stopped
- D.** The rate of the forward reaction is equal to the rate of the reverse reaction

Answer

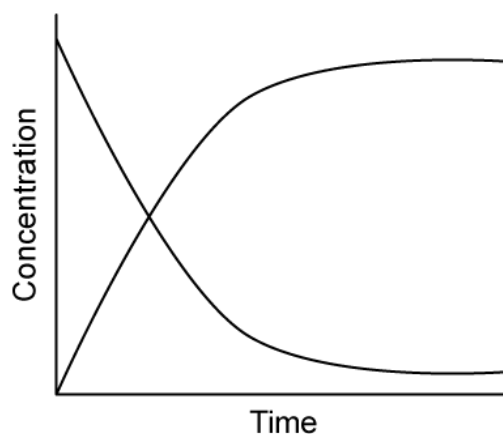
The correct answer is C because:

- When a system is at equilibrium
 - The energy change of the reverse reaction is the opposite to the energy change of the forward reaction
 - The equilibrium exists in a closed system
 - The forward and reverse reactions continue to occur but at equal rates, with no overall change in the concentrations of reactants or products

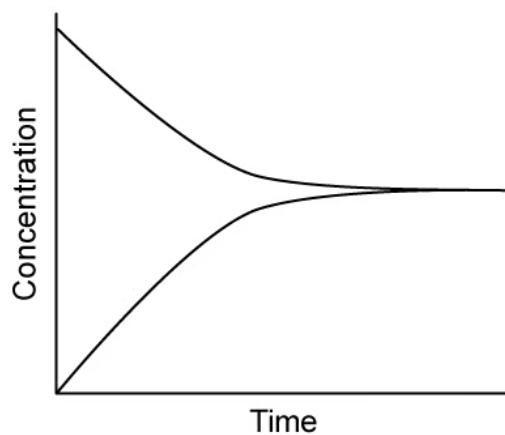
(1 mark)

3 Which graph shows the highest yield of products?

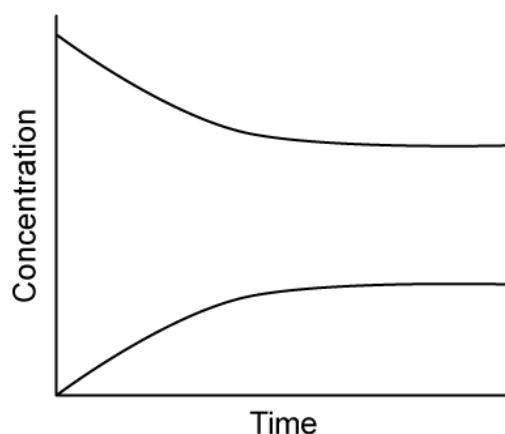
A.



B.



C.



D. All of the above have the same yield of products

Answer

The correct answer is A because:

- The concentration of the product starts at 0 and increases during the reaction until equilibrium is reached
- The concentration of the reactant decreases during the reaction until equilibrium is reached
- Equilibrium is reached when the concentrations of reactant and product remain constant (when the lines go flat)
- The greatest yield occurs when the relative amount of product is the highest compared to the relative amount of reactant left when equilibrium is reached

(1 mark)

4 (a) A pink coloured compound of cobalt reacts with hydrochloric acid.

The word equation for the reaction is:

pink cobalt compound + hydrochloric acid $\rightleftharpoons$ blue cobalt compound + water

The forward reaction is endothermic.

If carried out under correct conditions the reaction reaches equilibrium.

The mixture at equilibrium contains both cobalt compounds and the mixture is purple.

The equilibrium mixture is cooled.

Explain what happens to the concentration of the pink cobalt compound on cooling.

Answer

As the pink cobalt compound cools:

- The concentration increases; [1 mark]
- As the equilibrium position moves to the left / reactant side; [1 mark]
- Since the reverse reaction is exothermic / forward reaction is endothermic; [1 mark]

[Total: 3 marks]

(3 marks)

(b) A chemist adds more hydrochloric acid to the reaction.

Explain what happens to the colour of the mixture.

Answer

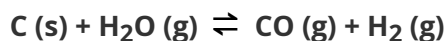
As more hydrochloric acid is added:

- The mixture becomes blue; [1 mark]
- As the equilibrium position moves to the right / product side; [1 mark]

[Total: 2 marks]

(2 marks)

5 The gasification of carbon is a reversible endothermic reaction:



Which of the following conditions could be changed to **increase** the relative amount of H_2 gas produced?

- A. Increase the surface area to volume ratio of the carbon
- B. Increase the pressure
- C. Increase the temperature
- D. Add a catalyst

Answer

The correct answer is C because:

- Increasing the temperature will increase the relative amount of products at equilibrium for an endothermic reaction

A is incorrect as the surface area to volume ratio does not affect the equilibrium position, only the rate

B is incorrect as increasing the pressure will cause the equilibrium position to shift towards the side with the smaller number of molecules of gas, which is the reactant side, decreasing the product

D is incorrect as catalysts do not affect the equilibrium position, only the rate

(1 mark)

6 Which statement is **not** true about Le Chatelier's Principle?

- A. If changes to the conditions of a system are made, the system responds to counteract the change
- B. If the concentration of the product is decreased, more reactants will react until an equilibrium position is reached again
- C. Increasing the pressure will shift the position of the equilibrium to the side with the smaller number of molecules of gas
- D. If temperature is decreased for an exothermic reaction, the relative amount of products made at the equilibrium point decreases

Answer

The correct answer is D because:

- When temperature is decreased in an exothermic reaction, the equilibrium will shift so that the relative amount of products **increases** rather than decreases
- This is how the system counteracts the change
 - This change is a temperature drop that cools down the system
 - The system counteracts the change by 'trying' the heat back up
 - This means that the exothermic reaction occurs more

(1 mark)

7 Hydrogen gas and iodine vapour can react to form hydrogen iodide:



Which statement is **not** true?

- A. This reaction is reversible
- B. Equal amounts of reactants and product are eventually made at equilibrium
- C. This reaction can reach an equilibrium point in a closed system
- D. There are equal total numbers of moles of reactant and product

Answer

The correct answer is B because:

- When equilibrium is reached there may be a greater amount of product, or a greater amount of reactant
- This depends on the conditions
- It is possible for the amounts of reactant and product to be equal, but this is just as likely as other ratios

(1 mark)

8 Which option shows **two** correct statements about reversible reactions and equilibrium?

	Statement 1	Statement 2
A	The sign for a reversible reaction is $\rightleftharpoons$	Reversible reactions are slower than non-reversible ones
B	At equilibrium the rate of the forward reaction and the rate of the reverse reaction are equal	An endothermic reaction is exothermic if reversed
C	Reversible reactions are not useful in industry as they do not go to completion	To reach an equilibrium the reaction must occur in a closed system
D	The rate of the reaction is zero at equilibrium	The concentration of the product is constant at equilibrium

Answer

The correct answer is B because:

- At equilibrium the rate of the forward reaction and the rate of the reverse reaction are equal
- An endothermic reaction is exothermic if reversed

A is incorrect as a reaction being reversible does not affect the initial rate and makes it faster or slower

C is incorrect as reversible reactions are often used in industry and workarounds put in place to minimise loss

D is incorrect as the rate of the reaction is not zero at equilibrium as the forward and reverse reactions still both occur, just at equal rates

(1 mark)

9 (a) This question is about chemical equilibrium and reversible reactions.

If carried out in a closed system, reversible reactions can reach a state of equilibrium.

Explain what a closed system is.

Answer

A closed system means:

- Nothing can enter; [1 mark]
- (and) nothing can leave the reaction vessel; [1 mark]
 - *allow sealed reaction vessel*

[Total: 2 marks]

(1 mark)

(b) When a reversible reaction reaches equilibrium, it appears to have stopped.

Explain why.

Answer

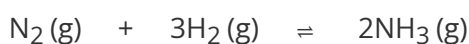
The reaction appears to have stopped because:

- The forward and backward reactions occur at the same rate; [1 mark]
- So there is no overall change in quantities of reactants and products; [1 mark]
 - *allow concentrations of reactants and products do not change*

[2 marks]

(2 marks)

- (c) In the Haber process, the reaction of nitrogen with hydrogen to produce ammonia is reversible.



Explain, with reasons, what happens to the amount of ammonia produced at equilibrium if the pressure is increased.

Answer

When the pressure increases:

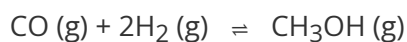
- The amount / yield of ammonia increases; [1 mark]
- Equilibrium shifts to the right / product side; [1 mark]
- Because the right side has fewer moles / molecules of gas; [1 mark]
Allow because there are 2 moles on the RHS and 4 moles on the LHS
Reject 'atoms'

[Total: 3 marks]

- When you see a question regarding the position of equilibrium and pressure, count the number of moles / molecules of each substance
- Some students make the mistake of counting the number of atoms, not molecules—the molecules is the big number in front of the formula, if there is no number, there is one molecule of that substance

(3 marks)

- 10 (a)** Methanol is produced by reacting carbon monoxide with hydrogen as shown in the equation:



The reaction is normally performed at a temperature of 250 °C and a pressure of 100 atm.

The forward reaction is exothermic.

Explain what would happen to the yield of methanol if a temperature higher were used.

Answer

If a higher temperature was used:

- A smaller yield would be achieved; [1 mark]
- Since the forward reaction is exothermic; [1 mark]
- The system opposes the change (according to Le Chatelier's principle); [1 mark]
- By favouring the reverse / backwards reaction; [1 mark]

[Total: 4 marks]

(4 marks)

- (b)** Explain why the high pressure gives a greater yield of methanol and an increased rate of reaction.

Answer

High pressure gives a greater yield and quicker rate of reaction because:

- The equilibrium position moves to the product side / right; [1 mark]
- Because there are fewer moles / molecules on the product side / right; [1 mark]
- The rate of reaction increases; [1 mark]
- As there is less space in between the reactant particles and therefore more frequent collisions / collisions per second / unit time; [1 mark]

[Total: 4 marks]

(4 marks)

Hard Questions

1 (a) This question is about equilibrium.

An ionic equation for the reaction between iron (III), Fe^{3+} and thiocyanate ions, SCN^{-} is shown below:

At room temperature, the mixture of the equilibrium solution is orange.

	$\text{Fe}^{3+}(\text{aq})$ +	$\text{SCN}^{-}(\text{aq}) \rightleftharpoons$	$\text{FeSCN}^{2+}(\text{aq})$
Colour of solution	yellow	colourless	red

Which solvent would be used to dissolve the ions in this reaction?

Answer

The solvent used to dissolve the ions is:

- Water; [1 mark]

[Total: 1 mark]

- The equation shows the (aq) state symbol which indicates the ions are dissolved in water

(1 mark)

(b) Explain the effect, if any, of changing pressure on the colour of the equilibrium mixture.

Answer

The effect of pressure will be:

- No effect on the change of colour; [1 mark]
- The position of equilibrium does not change; [1 mark]
- (Because) there are no gases present; [1 mark] *allow only ions in aqueous solutions present*

[Total: 3 marks]

- **Remember:** pressure will only affect reactions that involve gases so look carefully at the equation
- Look at the number of marks to help you
 - What is the effect on the colour? There is no effect on the colour
 - Why is there no effect? Because the position of the equilibrium doesn't change
 - Why does the position of equilibrium not change? Because the reaction does not involve gases
- This question is usually asked for a reaction involving gases when the number of molecules of product and reactant is the same so make sure you double check the state symbols

(3 marks)

- (c) A few drops of a colourless solution containing a high concentration of Fe^{3+} ions are added to the orange equilibrium mixture.

Explain the colour change observed.

Answer

The colour change observed is:

- The mixture becomes (more) red; [1 mark]
- (Because the position of) equilibrium moves to the right; [1 mark]
allow the concentration of Fe^{3+} ions increases
allow the forward reaction is favoured
- (So that) the concentration of Fe^{3+} is reduced; [1 mark]
allow so that the increase in concentration of Fe^{3+} is counteracted

[Total: 3 marks]

- **Remember:** When a condition is changed (temperature, pressure, concentration), the system will oppose the change made
- So if the concentration of Fe^{3+} is increased then the system will try and reduce the concentration
- In order to do this, the rate of the forward reaction will increase and more FeSCN^{2+} will be produced which is red

(3 marks)

- (d) A water bath is set up at a temperature below room temperature.

When a test tube containing the orange equilibrium mixture is placed in the water bath, the mixture becomes more red.

Explain what this shows about the energy change for the forward reaction.

Answer

The forward reaction is:

- Exothermic; [1 mark]
allow the forward reaction releases energy
- (Because) the equilibrium moves to the right; [1 mark]
allow the favours the forward reaction
- This shift acts to oppose the reduction in temperature; [1 mark]
allow so that the reduction in temperature is counteracted
allow the shift produces energy / heat (to counteract the cooling) allow applies Le Chatelier's Principle (to increase the temperature)

[Total: 3 marks]

- If the solution is placed in a water bath below room temperature, the temperature of the reaction has been decreased
- The reaction will oppose this change and attempt to increase the temperature
- A red solution is observed
 - The forward reaction produces a red solution so the rate of the forward reaction must have increased
- The forward reaction must therefore be exothermic

(3 marks)

- (e) Other metal ions form coloured equilibrium mixtures with thiocyanate ions.

Which metal ion could form a coloured equilibrium mixture with thiocyanate ions?

Tick (✓) **one** box.

Mg^{2+}	
Al^{3+}	
Li^{+}	
Cu^{2+}	

Answer

The other metal ion which could form coloured compounds with thiocyanate ions is:

- Cu^{2+} ; [1 mark]

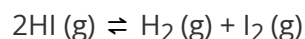
[Total: 1 mark]

- Transition metal ions form coloured compounds
- Copper is the only transition metal on the list

(1 mark)

2 (a) This question is about reversible reactions.

The decomposition of hydrogen iodide into hydrogen and iodine is reversible.



The forward reaction is endothermic.

Explain the effect of increasing temperature on the amount of hydrogen iodide, HI.

Answer

The effect of increasing temperature on the amount of HI would be:

- Reduced / lower amount (of HI); [1 mark]
- Because the equilibrium shifts to the right
OR
Because the forward reaction is favoured; [1 mark]

[Total: 2 marks]

- If the temperature is increased, the system will oppose the change and reduce the temperature
- To do this the endothermic reaction will be favoured as endothermic reactions take in energy and reduce temperatures
- If the rate of the forward reaction increases, the amount of reactant, HI will decrease

(2 marks)

- (b) Explain what effect, if any, increasing the pressure will have on the amount of hydrogen iodide at equilibrium.

Answer

The effect of increasing the pressure on the amount of hydrogen iodide at equilibrium is:

- No effect; [1 mark]
- There are the same number of molecules/moles on each side; [1 mark]

[Total: 2 marks]

- When increasing pressure, equilibrium will shift to oppose the change by favouring the side with fewer molecules.
- As the reaction has an equal number of molecules on either side of the equation, the equilibrium cannot shift in a way to reduce the pressure again

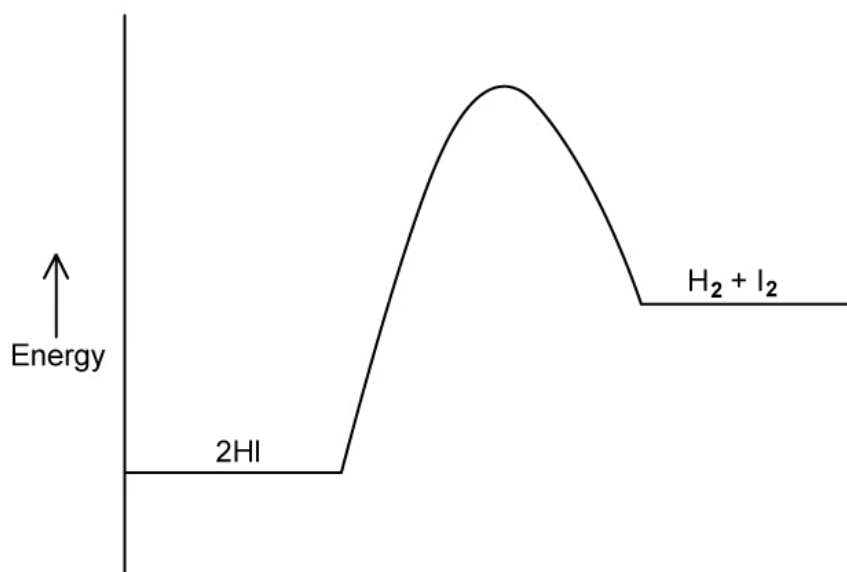
(2 marks)

- (c) An endothermic reaction can be represented using the following reaction profile in **Figure 1**.

Label

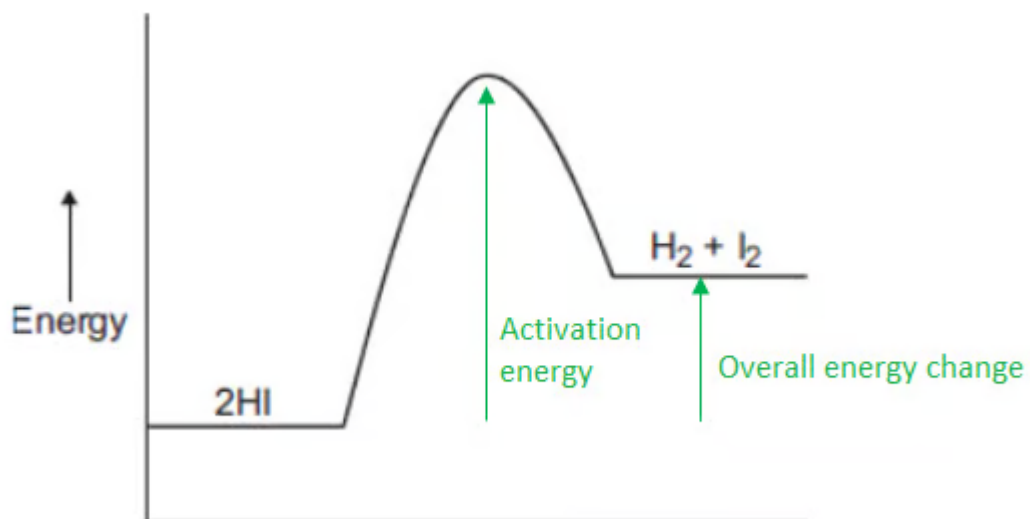
- Activation energy
- Overall energy change

Figure 1



Answer

The labelled reaction profile is:



- Correctly labelled activation energy; [1 mark]
- Correctly labelled overall energy change; [1 mark]

[2 marks]

(2 marks)

(d) How does the diagram show that the reaction is endothermic?

Answer

The reaction profile is endothermic because:

- (Energy of the) products is higher than the (energy of) the reactants; [1 mark]

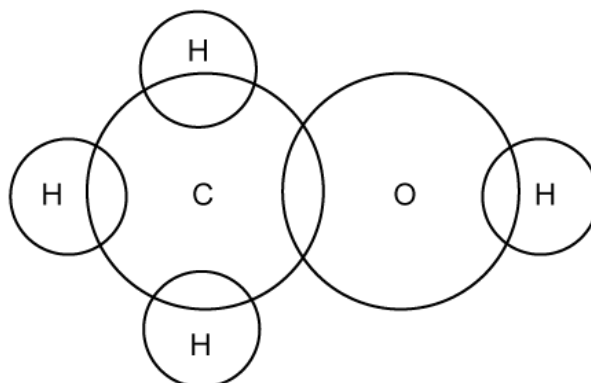
[Total: 1 mark]

- Endothermic reactions take in energy from the surroundings so the product has more energy than the reactants

(1 mark)

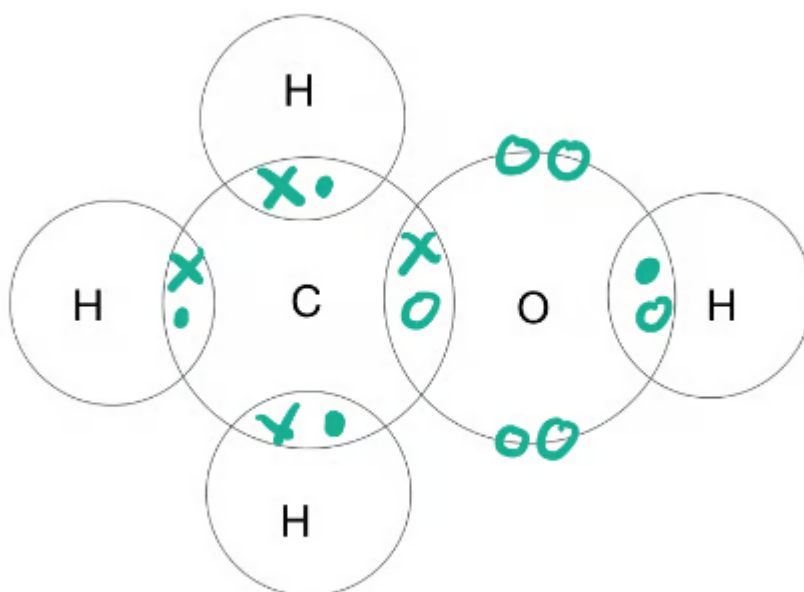
3 (a) Methanol, CH_3OH , is a fuel that can be produced from carbon monoxide and hydrogen.

Complete the dot and cross diagram to show the bonding in methanol.



Answer

The dot and cross diagram is:



- 5 bonding pairs; [1 mark]
- 4 non-shared electrons on oxygen atom; [1 mark]
allow any combination of symbols

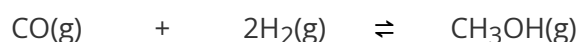
[Total: 2 marks]

- If a dot and cross diagram is more than one mark, this means there are electrons not being shared between atoms
- **Remember:** Look at the periodic table to check which group the element is in and determine the number of electrons in the outer shell of each element
- When you have finished, count around each atom to check the outer shell is full (2 electrons for hydrogen, 8 for everything else)

(2 marks)

- (b)** The reaction between carbon monoxide and hydrogen to produce methanol is shown below.

The forward reaction is exothermic.



Explain why the highest equilibrium yield of methanol is obtained at high pressure.

Answer

The highest equilibrium yield of methanol is obtained at high pressure because:

- There are fewer product molecules/moles than reactant molecules
Accept the forward reaction produces fewer molecules /moles
Accept left hand side for reactants and right hand side for products
OR
There are 3 reactant molecules/moles and 1 product molecule/mole
OR
3 volumes of gas become 1 volume of gas; **[1 mark]**

[Total: 1 mark]

- If an equilibrium question on pressure is only one mark then your answer **must** comment on the number of molecules on each side of the equation
- If it is more than one mark, then add in which direction the equilibrium shifts to

(1 mark)

(c) The temperature used is 250 °C.

Explain why this temperature is a compromise between the rate of reaction and the equilibrium yield of product.

Answer

This is a compromise because:

Any **three** from:

- Low temperatures give the best yield
OR
High temperatures give a low yield; [1 mark]
- Because the reaction is exothermic
OR
Because the reverse reaction is endothermic; [1 mark]
- Low temperatures give a slow rate of reaction
OR
High temperatures give a fast rate of reaction; [1 mark]
- Temperature used gives a reasonable yield; [1 mark]

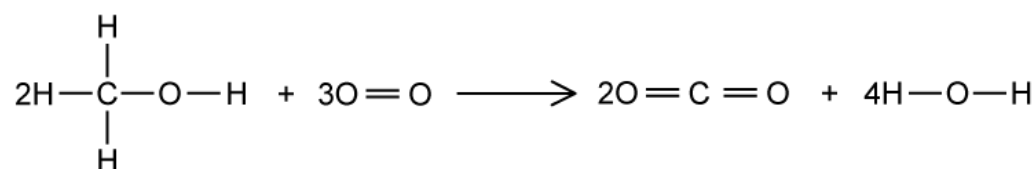
allow get less product but it takes less time for 2 marks

[Total: 3 marks]

(3 marks)

(d) Methanol can undergo combustion to release energy.

The equation for this reaction is shown below:



Bond energies are shown in **Table 1**.

Table 1.

	C-H	C-O	O=O	C=O	O-H
Bond energy in kJ / mol	410	360	496	800	466

Calculate the overall energy change for the reaction using the diagram and table above.

Answer

The overall energy change for the combustion of methanol is calculated as follows:

- (Bonds broken) = 5600 (kJ per mole); [1 mark]
- (Bonds made) = 6928 (kJ per mole); [1 mark]
- Overall energy change (= 5600 - 6928) = (-)1328 (kJ per mole); [1 mark]
ecf from bonds broken/made
ignore sign
correct answer without working scores 3 marks

[Total: 3 marks]

- This type of calculation requires care as it is very easy to forget to take into account a bond
- A useful technique is to cross each bond out when you have included it in your calculation
- Don't forget to take into account the balancing numbers – it is a common mistake to forget this
- Bonds broken:
 - $(6 \times \text{C-H}) + (2 \times \text{C-O}) + (2 \times \text{O-H}) + (3 \times \text{O=O})$
 - $(6 \times 410) + (2 \times 360) + (2 \times 466) + (3 \times 496)$
 - = 5600 kJ per mole
- Bonds made:

- $(4 \times \text{C}=\text{O}) + (8 \times \text{H}-\text{O})$
- $= (4 \times 800) + (8 \times 466)$
- $= 6928 \text{ kJ per mole}$
- Overall energy change = Energy taken in to break bonds – energy released to make bonds
 - $= 5600 - 6928$
 - $= -1328 \text{ kJ per mole}$

(3 marks)

(e) A catalyst is used in the reaction to produce methanol to increase the rate of the reaction.

Explain how it increases the rate of reaction.

Answer

A catalyst increases the rate of reaction by:

- Providing an alternative pathway for the reaction; [1 mark] *allow provides a different mechanism/ route*
- (With a) lower activation energy; [1 mark]

[Total: 2 marks]

(2 marks)

(f) State the effect, if any, of using a catalyst on the equilibrium yield of methanol.

Answer

The effect of a catalyst on the equilibrium yield is:

- No effect; [1 mark]

[Total: 1 mark]

- A catalyst is only able to increase the rate at which equilibrium is achieved by speeding up the rate of reaction
- it has no effect on the yield of the produce

(1 mark)

- (g) How many moles of carbon monoxide completely react with 6.0×10^3 mol of hydrogen?

Use the equation in part (b) to help you.

Answer

The number of moles of carbon monoxide that will completely react with 6.0×10^3 mol of hydrogen is:

- 3.0×10^3 moles; [1 mark]

[Total: 1 mark]

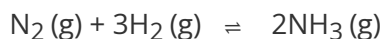
- The equation in part (b) shows:



- The ratio of carbon monoxide to hydrogen is 1:2
- You therefore have half the number of moles of carbon monoxide compared to hydrogen

(1 mark)

4 (a) Ammonia is produced from the reaction of nitrogen with hydrogen in the Haber process:



The forward reaction is exothermic.

The conditions normally used in the Haber process are:

- 450 °C
- Pressure of 200 atm
- Iron catalyst

Use your knowledge of reversible reactions and the equation to explain why these conditions are used.

To gain full marks you must consider **both** rate of reaction **and** yield in your answer.

Answer

Level 3 [5 – 6 marks]:

- The effect of all three factors on the reaction are fully described

Level 2 [3 – 4 marks]:

- The effect of two factors on the reaction are correctly described

Level 1 [1–2 marks]:

- The effect of at least one factor on the reaction is given

200 atmospheres pressure

- High pressure gives a high yield of ammonia
- Too high a pressure causes risk of explosion
- High pressure costly to maintain
- A high pressure will cause the rate to be higher
- 4 moles of gas become 2 (or fewer moles of gas in products)

450 °C

- High temperature increases the rate of reaction
- Optimum temperature
- Forward reaction is exothermic so a high yield of ammonia requires a low temperature
- But too low a temperature causes the rate of reaction to be too slow

Iron catalyst

- A catalyst speeds up the reaction
- An iron catalyst allows a lower temperature to be used (saving energy and causing a higher yield)
- Iron catalyst increases the rate of reaction equally in both reactions

Others

- Compromise conditions
- Unreacted nitrogen and hydrogen is recycled

[Total: 6 marks]

- **Note:** the Haber process and its conditions are revisited in a later topic for those students taking the separate Chemistry course with an emphasis on the compromise of the conditions

(6 marks)

(b) 425 dm³ of ammonia is produced when nitrogen reacts with 825 dm³ of hydrogen.

Calculate the volume of unreacted hydrogen.

Give your answer in cm³

Answer

To calculate the volume of unreacted hydrogen:

- Ratio of hydrogen: ammonia = 3: 2; [1 mark]
- (Hydrogen needed): $425 \times \frac{3}{2}$ OR $425 \div 2 \times 3 = 637.5 \text{ (dm}^3\text{)}$; [1 mark]
- Unreacted hydrogen: $825 - 637.5 = 187.5 \text{ (dm}^3\text{)}$; [1 mark]
- $187500 \text{ (cm}^3\text{)}$; [1 mark]

[Total: 4 marks]

- Don't forget to convert your answer to cm^3 at the end by multiplying the volume in dm^3 by 1000

(4 marks)

5 The decomposition of ammonium chloride is endothermic:



Which changes to the conditions would **both decrease** the amount of product in this reaction?

	Change 1	Change 2
A	Increase pressure	Decrease temperature
B	Decrease pressure	Decrease temperature
C	Increase pressure	Increase temperature
D	Decrease pressure	Increase temperature

Answer

The correct answer is A because:

- An increase in pressure causes the equilibrium position to shift towards the side with the smaller number of molecules of gas
 - There are 2 moles of product and 1 mole of reactant
 - Therefore, an increase in pressure will shift the equilibrium to the left-hand side
- A decrease in temperature for an endothermic reaction causes the equilibrium position to shift to decrease the relative amount of products

(1 mark)