Rates of reaction, calculations, acids and bases

2018

Question one

(a) In the iodine clock reaction, a solution of hydrogen peroxide is mixed with a solution containing potassium iodide, starch and sodium thiosulfate.

After some time the colourless mixture suddenly turns dark blue.

The table shows the time taken for the reaction performed at different temperatures. The concentration of all reactants was kept constant.

Temperature / °C	Time for blue colour to appear / s
20	15
30	9
40	4

Explain the effect of changing temperature on the rate of reaction.

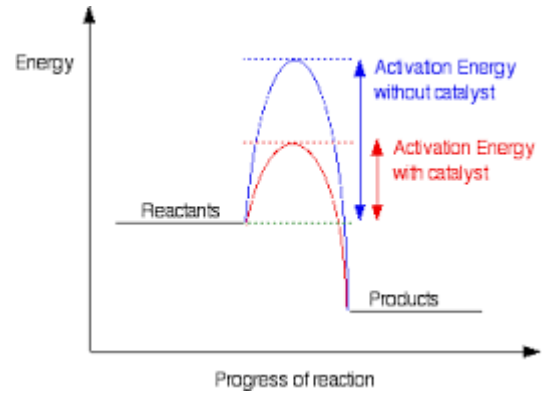
Refer to collision theory and activation energy in your answer.

(b) Consider the following observations in another experiment using hydrogen peroxide.

- When hydrogen peroxide is mixed with solution **X,** which contains universal indicator, the colour changes from the blue to green to yellow to orange-red **over a time of one hour.**
- If a crystal of **ammonium molybdate** is added to solution **X** before the hydrogen peroxide is added, the colour changes will be seen in **three to four minutes.**

(i) Identify and explain the role of ammonium molybdate.

Use a diagram and refer to activation energy in your answer,



(ii) The pH of the original solution **X** is 10.8

Calculate the hydronium ion concentration [H_3O^+] and the hydroxide ion concentration, [OH^-] in the solution.

[H_3O^+]	**=**
**[OH^-= **	**=**

(iii) The sodium hydroxide solution, NaOH(*aq*), used to prepare solution **X** has a concentration of 0.0125 mol L^{-1}.

Calculate the pH of the sodium hydroxide solution.

(iv) Another chemical in solution **X** is a slat, sodium ethanoate, CH_3COONa. When solid sodium ethanoate is dissolved in water it separates into ions.

Use TWO relevant equations to explain whether the **solution** is acidic or basic.

2017

Question two

The addition of a small amount of iron to a mixture of nitrogen and hydrogen gases helps to speed up the production of ammonia gas.

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

(a) Identify and explain the role of iron in this reaction.

In your answer, you should refer to activation energy and collision theory.

You may include a diagram or diagrams in your answer.

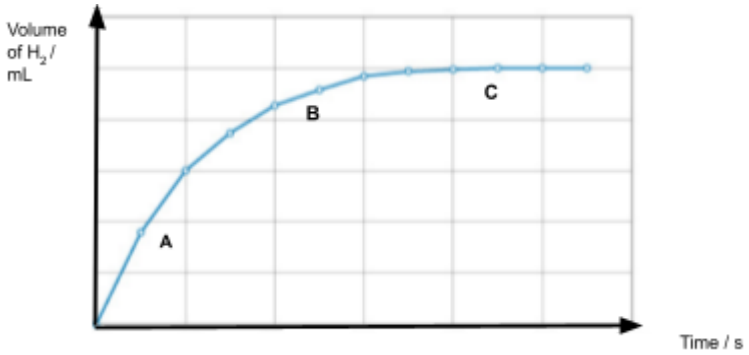
2016

Question 1

(a) Cleaned magnesium ribbon, Mg(s), reacts with a solution of hydrochloric acid, HCl(aq). The reaction is shown by the equation below:

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

The reaction is monitored by measuring the volume of hydrogen gas produced over a given period of time. This is shown in the graph below.



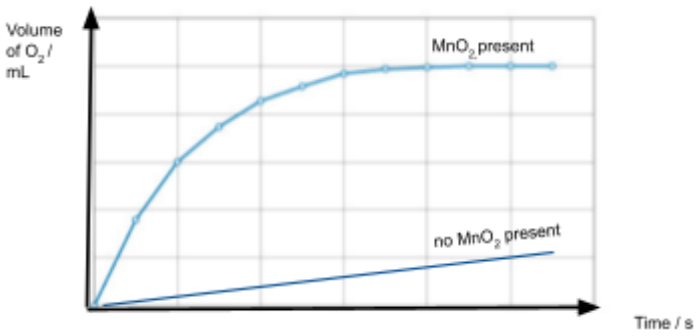
Explain the changes in the rate of reaction between magnesium, Mg(s), and hydrochloric acid,HCl(aq), in terms of collision theory.
Refer to parts A,B and C of the graph in your answer.

(b) Compare and contrast the reaction of 0.5g of magnesium ribbon, Mg(s), with 50.0 mL of 0.100 mol L^{-1} hydrochloric acid, HCl(aq), and 0.5 g of magnesium powder, Mg(s) with 50.0 mL of 0.100 mol L^{-1} hydrochloric acid, HCl(aq).
Refer to collision theory and rates of reaction in your answer.

(c) The decomposition reaction of hydrogen peroxide solution, $H_2O_2(aq)$, is a slow reaction. This reaction is represented by the equation:

$2H_2O_2(aq) \rightarrow 2H_2O(l) \quad O_2(g)$

The rate of the reaction can be changed by adding a small amount of magnesium oxide, $MgO_2(s)$. The graph below shows the volume of oxygen gas formed in the reaction with and without magnesium dioxide, $MnO_2(s)$.



(i) State the role of manganese dioxide in this reaction.

(ii) Elaborate in how manganese dioxide, $MnO_2(s)$, changes the rate of the decomposition reaction of the hydrogen peroxide, $H_2O_2(aq)$.
In your answer you should refer to the activation energy and collision theory. You may also include diagrams in your answer.

2015

Question one

(a) The 'elephant toothpaste' demonstration shows the decomposition of hydrogen peroxide, H_2O_2, into water and oxygen gas.

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

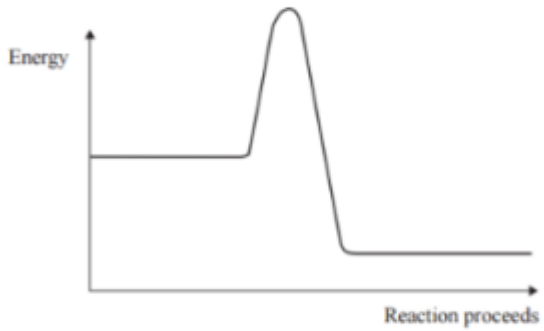
This reaction can be observed by adding detergent to the hydrogen peroxide solution. As oxygen gas is produced, the detergent foams up, as seen in the photograph on the right. The time taken for the foam to reach the top of the measuring cylinder can be used to measure the rate of the reaction. Three experiments were carried out to investigate factors that change the rate of the reaction.

Experiment	Concentration of H_2O_2	Temperature / ^0C	Presence of small amount of MnO_2
1	20%	20	Yes
2	20%	30	Yes
3	30%	20	Yes

(a) The decomposition reaction of hydrogen peroxide, H_2O_2, is very slow. By adding a small amount of powdered manganese dioxide, MnO_2, the rate of the reaction can be increased.

(i) Explain why only a small amount of manganese dioxide is needed to increase the rate of the reaction.

(ii) The diagram below shows the energy diagram for the decomposition reaction without manganese dioxide. Label this diagram and use it to help you explain how the addition of manganese dioxide speeds up the rate of the reaction.



(b) Compare Experiment 2 with Experiment 1. In your answer, you should:
• identify the factor being changed, and the effect this will have on the rate of reaction
• explain the effect on the rate of reaction by referring to the collision of particles and activation energy, where appropriate.

(c) Compare Experiment 3 with Experiment 1. In your answer, you should:
• identify the factor being changed, and the effect this will have on the rate of reaction
• explain the effect on the rate of reaction by referring to the collision of particles and activation energy, where appropriate.

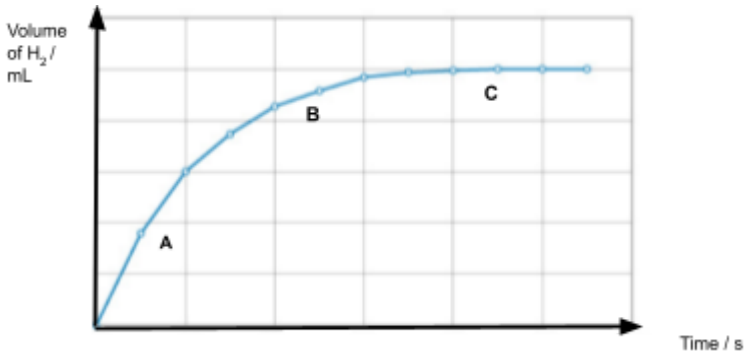
2014

Question 1

(a) The equation for the reaction between zinc granules (lumps), Zn(s), and sulfuric acid, $H_2SO_4(aq)$, is represented by:

$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$

The graph below shows how the volume of hydrogen gas produced changes with time, when zinc is reacted with excess sulfuric acid at 20°C.



Explain the changes in the reaction rate during the periods **A**, **B** and **C**. In your answer you should refer to collision theory.

A	
B	
C	

(b) The rate of the reaction between zinc and sulfuric acid can be changed by the addition of small pieces of copper, Cu(s), as a catalyst. Explain the role of the copper catalyst in the reaction between zinc and sulfuric acid. In your answer you should refer to collision theory.

(c) The pH values of 0.100 mol L^{-1} solutions of two acids, HA and HB, are given in the table below.

Solution	**pH**
0.100 mol L^{-1} HA(aq)	1.0
0.100 mol L^{-1} HB(aq)	2.2

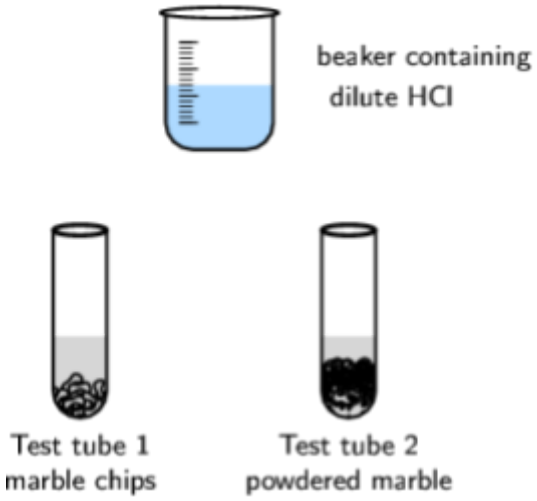
(i) Compare the relative strengths of the two acids, HA(aq) and HB(aq), using the information given above. Your answer should include equations and calculations.

(ii) Predict and compare, with reasons, what would be observed when two 5 g samples of calcium carbonate chips, $CaCO_3$(s), are reacted, separately, with excess HA and HB.

2013

Question 1

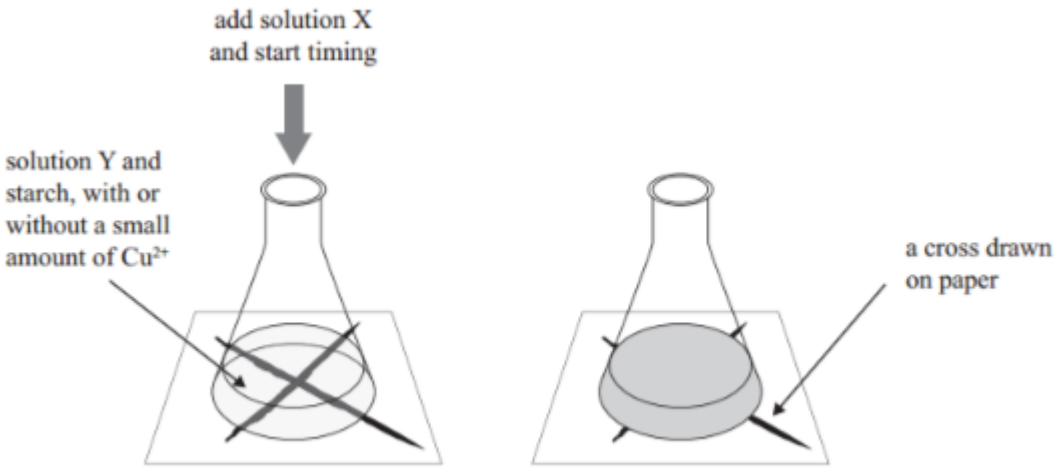
(a) Hydrochloric acid was reacted with calcium carbonate in the form of marble chips (lumps) and powder (crushed marble chips) in an experiment to investigate factors affecting the rate of a chemical reaction.



(i) Identify the factor being investigated.

(ii) Explain why the hydrochloric acid would react faster with the powder.

(b) A clock reaction involves mixing solution X and solution Y with starch present. When the reaction is complete the solution turns blue-black in colour. A student carried out this reaction between solution X and solution Y in a conical flask. Over time, the cross on the piece of paper under the flask disappeared when viewed from above.



The following experiments were carried out, and the times taken for the cross to disappear recorded.

Experiment		Temperature / °C	Time for cross to disappear / s
1	No Cu^{2+} present	25	42
2	No Cu^{2+} present	50	23
3	Cu^{2+} present	25	5

Elaborate on why the reactions in **Experiment 2** and **Experiment 3** occur faster than the reaction in **Experiment 1**. In your answer, include the following words or terms:

Collisions **activation energy** **temperature** **effective catalyst**

Acids and bases, calculations

2018

Question Three

(a) The hydrogensulfate ion, HSO_4^-, is an amphiprotic species because it can both accept or donate a proton, this acting as an acid or base.

Complete the equations for the reaction of the hydrogensulfate ion, HSO_4^-, with water in the box below.

HSO_4^- acting as	**Equation**

an acid	$HSO_4^-(aq) + H_2O(l) \leftrightharpoons SO_4^{2-}(aq) + H_3O^+(aq)$
a base	$HSO_4^-(aq) + H_2O(l) \leftrightharpoons H_2SO_4aq) + OH^-(aq)$

(b) The pH and relative electrical conductivity of aqueous solutions of potassium hydroxide, KOH(*aq*), and ammonia, $NH_3(aq)$, are shown in the table below. Both have concentrations of 0.100 mol L^{-1}.

Chemical	pH	Electrical conductivity
KOH (*aq*)	13	good
NH_3 (*aq*)	11.1	poor

Explain the difference in pH and conductivity of these two solutions.

Use relevant equations in your answer.

KOH is a strong base which completely dissociates into its ions, ie K^+ and OH^-. Therefore there are 0.100 mol L^{-1} of OH^- ions in solution giving a pH of 13.
$KOH(aq) \rightarrow K^+(aq) + OH^-(aq)$
As dissociation is complete there are also 0.100 mol L^{-1} of K^+ ions in solution, giving 0.200 mol L^{-1} of charged particles free to move around and conduct electricity, hence 0.100 mol L^{-1} KOH is a good conductor.

As the same concentration NH_3 (0.100 mol L^{-1}) has a lower pH (11.1) than KOH it does not release as many OH^- ions when dissociating, therefore it is a weak base and is at equilibrium.
$NH_3(aq) + H_2O(l) \leftrightharpoons NH_4^+(aq) + OH^-(aq)$.
Therefore in solution there are considerably less than 0.100 mol L^{-1} of ions released - there is more NH_3 in solution which has no charged particles - and conductivity is poor.

(c) The table below gives the pH of solutions of ethanoic acid, CH_3COOH (*aq*), and nitric acid, HNO_3 (*aq*), of concentrations of 0.200 mol L^{-1}.

Solution	CH_3COOH (*aq*)	HNO_3 (*aq*)
pH	2.73	0.70

(i) Use the pH values to analyse the strength of the acids by calculating the concentration of their H_3O^+ ions.

CH_3COOH has a $[H_3O^+] = 10^{-2.73}$ which is 1.86×10^{-3} mol L^{-1}
meaning the 0.200 mol L^{-1} CH_3COOH does not fully dissociate into its ions, meaning it is a weak acid.

HNO_3 has a $[H_3O^+]$ of $10^{-0.70}$ which is 0.1995 or 0.200 mol L^{-1} meaning it completely dissociates into its ions making it a strong acid.

(ii) Using your calculations in (i) above, predict the rate of reaction of each acid with a 2 cm strip of cleaned magnesium ribbon, Mg.

Refer to the collision theory in your answer.

As HNO_3 is a strong acid that completely dissociates in comparison to CH_3COOH which is a weak acid and only partially dissociates there are more reactant particles present in the HNO_3 when the Mg ribbon is added. This means there will be more collisions and therefore more successful collisions, with a greater proportion having more energy than the activation energy, meaning the rate of reaction in the HNO_3 will be quicker.

2017

Question one

(a) Propanoic acid, CH_3CH_2COOH, is dissolved in water and the resulting solution has a pH of 4.2.

(i) Complete the equation by writing the formulae of the two products:

$$C_2H_5COOH\ (aq) + H_2O\ (l) \rightleftharpoons \mathbf{C_2H_5COO^-(aq)\ + H_3O^+\ (aq)}$$

(ii) Explain the proton, H^+, transfer in this reaction, and identify the two conjugate acid-base pairs.

Propanoic acid is Bronsted-Lowry acid as it donates a proton (H^+), forming its conjugate base, propanoate, $C_2H_5COO^-$. The water in the reaction acts as the Bronsted-Lowry base by accepting the donated proton, forming its conjugate acid hydronium, H_3O^+.

(b) Sodium ethanoate, CH_3COONa (*s*), is a salt. When dissolved in water, it dissociates into ions.

Explain, including TWO relevant equations, whether a solution of sodium ethanoate is acidic or basic.

Sodium ethanoate is an ionic solid which dissolves in water to give the ethanoate and sodium ions:
$CH_3COONa\ (s) \rightarrow CH_3COO^-\ *(aq) + Na^+\ (aq)$.

The ethanoate ion reacts (hydrolyses) with water producing OH^- ions:
$CH_3COO^-\ *(aq) + H_2O\ (l) \leftharpoondown CH_3COOH\ (aq) + OH^-\ (aq)$

These extra hydroxide ions mean the solution has an excess of OH^- compared to H_3O^+ and is therefore basic

(c)

(i) A solution of sodium hydroxide, NaOH (*aq*), has a pH of 11.6.

Calculate the hydronium ion concentration, $[H_3O^+]$, and the hydroxide ion concentration, $[OH^-]$, in the solution.

$Kw = 1 \times 10^{-14}$

$[H_3O^+]$	$10^{-11.6} = 2.52 \times 10^{-12}$ mol L^{-1}
$[OH^-]$	$10^{-(14-11.6)}$ $10^{-(2,4)} = 3.98 \times 10^{-3}$ mol L^{-1}

(ii) Calculate the pH of a 2.96×10^{-4} mol L^{-1} solution of potassium hydroxide, KOH (*aq*).

pH	$pH = -\log_{10}[H_3O^+]$ work out hydronium,or $pH = 14-pOH$ where $pOH = -\log_{10}[OH^-] = -\log_{10}[2.96 \times 10^{-4}] = 3.5287$ $pH = 14-pOH$ $pH = 14-3.5287$ $pH = 10.47$ $pH = 10.5$

(d) Solutions of ammonia, NH_3 (*aq*), and sodium carbonate, Na_2CO_3 (*aq*), are both basic. Compare and contrast the electrical conductivity of these two solutions.

2016

Question 1

(a) Water is an amphiprotic substance because it can accept or donate a proton, therefore acting as an acid or a base.

Complete the equations for the reactions of water, H_2O, with ammonia, NH_3, and the ammonium ion, NH_4^+, below.

H_2O acting as	**Equation**
an acid	$H_2O(l) + NH_3(aq) \leftrightharpoons$
a base	$H_2O(l) + NH_4^+(aq) \leftrightharpoons$

(b) Sodium carbonate, $Na_2CO_3(s)$, is a salt. When dissolved in water,it dissociates into ions. Explain whether a solution of sodium carbonate, $Na_2CO_3(aq)$, would be acidic or basic. In your answer you should include TWO relevant equations.

(c) (i) Calculate the pH of a 0.0341 mol L^{-1} hydrochloric acid, HCl(aq), solution.

pH =

(ii) A solution of sodium hydroxide, NaOH(aq), has a pH of 12.4
Calculate the concentrations of both hydronium ions, H_3O^+, and hydroxide ions, OH^-, in this solution.

$[H_3O^+]$ =	
$[OH^-]$ =	

(d) The table shows the pH of three acidic solutions, ammonium chloride, NH_4Cl, propanoic acid, C_2H_5COOH, and hydrogen chloride, HCl.

	NH_4Cl(aq)	**C_2H_5COOH(aq)**	**HCl(aq)**
Concentration / mol L^{-1}	0.1	0.1	0.1
pH	5.62	3.44	1.0

(i) Explain why each of the three solutions in the table above has the same concentration, but a different pH. Use equations to support your answer.

(ii) Explain why the solution of ammonium chloride, NH_4Cl(aq), is a good conductor of electricity, while the solution of propanoic acid, C_2H_5COOH(aq), is a poor conductor of electricity.

2015

Question 1

(a) Ammonia solution, NH_3(aq), is a common chemical in the school laboratory.

(i) Explain, using an equation, whether ammonia solution is acidic or basic.

(ii) Bottles of ammonia solution are often labelled ammonium hydroxide, NH_4OH(aq). Explain why both names, ammonia and ammonium hydroxide, are appropriate.

(b) The hydrogen carbonate ion, HCO_3^-, is an amphiprotic species because it can donate or accept a proton, therefore acting as an acid or base. Write equations for the reactions of HCO_3^- with water: one where it acts as an acid, and one where it acts as a base

HCO_3^- acting as	**Equation**
an acid	$HCO_3^- + H_2O \leftrightharpoons$
a base	$HCO_3^- + H_2O \leftrightharpoons$

(c) (i) A solution of nitric acid, $HNO_3(aq)$, has a hydronium ion, H_3O^+, concentration of 0.0243 mol L^{-1}. Determine, by calculation, the pH and the concentration of hydroxide ions, OH^-, in this solution.

$K_w = 1 \times 10–14$

pH =	
$[OH^-]$ =	

(ii) Determine the hydroxide ion concentration, $[OH^-]$, of a solution of potassium hydroxide, KOH(aq), with a pH of 11.8.

(d) Ethanoic acid solution, $CH_3COOH(aq)$, and ammonium chloride solution, $NH_4Cl(aq)$, are both weakly acidic. Identify and justify, using equations, which acid solution has greater electrical conductivity.

(e) The table shows the pH of two acidic solutions, methanoic acid, HCOOH, and hydrochloric acid, HCl, which both have a concentration of 0.1 mol L^{-1}

Solution	HCOOH(aq)	HCl(aq)
pH	2.4	1

Compare and contrast the pH of each solution, and their expected rate of reaction with a 2 cm strip of cleaned magnesium ribbon, Mg.

2014

Question one

(a) Ammonia, NH_3, is dissolved in water and the resulting solution has a pH of 11.3.

(i) Complete the equation by writing the formulae of the two products.

$NH_3(aq) + H_2O(l) \leftrightharpoons$ +

(ii) Explain what is occurring during this reaction. In your answer you should:
• identify the acid and its conjugate base
• identify the base and its conjugate acid
• describe the proton transfer that occurs.

(b) (i) In a solution of potassium hydroxide, KOH, the pH is found to be 12.8. Calculate the hydronium ion concentration, $[H_3O^+]$, and the hydroxide ion concentration, $[OH^-]$, in the solution.

$[H_3O^+]$ =	
$[OH^-]$ =	

(ii) Calculate the pH of a 2.25 × 10–4 mol L–1 sodium hydroxide, NaOH, solution.

pH =

(c) The table below shows the relative electrical conductivity of five solutions of the same concentration, and the colour of pieces of litmus paper which have been dipped into each solution.

Solution	**A**	**B**	**C**	**D**	**E**
Electrical conductivity	poor	good	good	poor	good
Red litmus	turns blue	stays red	stays red	stays red	turns blue
Blue litmus	stays blue	turns red	stays blue	turns red	stays blue

Identify a strong base and a neutral salt, using the information in the table above. In your answer you should justify your choices by referring to the properties of the identified solution.

2013

Question one

(a) The table below shows two acids with their conjugate base.

Acid	**Conjugate base**
HCl	Cl^-
HSO_4^-	SO_4^{2-}

Explain the relationship between an acid and its conjugate base using one example from the table above.

(b) In a solution of nitric acid, HNO_3, the concentration of H_3O^+ ions is 0.0125 mol L^{-1}. Determine the concentration of hydroxide ions, OH^-, and the pH of this solution.

$[OH^-]$ =	
pH =	

(c) A solution of ethanoic acid, CH_3COOH, is found to be acidic.

(i) Complete the equation for the reaction of ethanoic acid with water.

$CH_3COOH + H_2O \rightleftharpoons$

(ii) Explain why the solution is acidic.

(d) The following table shows the concentration and pH of three acids, and the relative rate of reaction with magnesium (Mg) metal.

Acid	**Concentration / mol L^{-1}**	**pH**	**Relative rate of reaction with Mg**
HA	0.100	3.4	slow
HB	0.0100	2	fast
HC	1.00×10^{-5}	5	very slow

(i) Write an equation for the reaction of HA with magnesium in the box below.

(ii) Explain the difference between a strong acid and a weak acid.

(iii) Compare and contrast the reactivity of the three acids with magnesium. In your answer:
•determine the concentration of hydronium ions, H_3O^+, in each acid
• compare the concentration of hydronium ions to the concentration of the acid
•explain the relative rate of reaction for each acid with magnesium by referring to the information in the table above.

Equilibrium

2018

Question Two

The Contact Process is used industrially in the manufacture of sulfuric acid, H_2SO_4, One step in this process is the oxidation of sulfur dioxide, $SO_2(g)$ to sulfur trioxide, SO_3 (g).

$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

(a) Write the equilibrium constant expression for this reaction.

$Kc = [SO_3]^2 / [SO_2]^2 [O_2]$

(b) (i) Calculate the equilibrium constant (K_c) for this reaction at 600°C using the following concentrations:

$[SO_2]$ = 0.100 mol L^{-1}

$[O_2]$ = 0.200 mol L^{-1}

$[SO_3]$ = 0.0930 mol L^{-1}

$Kc = [0.0930]^2 / [0.100]^2 \times [0.200]$ $Kc = 0.008649 / 0.02$ $Kc = 0.43245$ $Kc = 0.432$

(ii) Explain what the size of the K_c value indicates about the extent of the reaction at equilibrium.

The larger the value of Kc the more the forward reaction is favoured, When Kc is large, greater than 1, the reaction is strongly in favour of the products. With a Kc value of 0.432 equilibrium is starting to move in the direction of the forward reaction and favouring the production of SO_3.

(c) Explain, using equilibrium principles, why it is important for an industrial pant to continue to remove the sulfur trioxide gas, SO_3 (g), as it is produced.

According to equilibrium principles the system will respond to minimise changes made by external factors, in this case the removal of SO_3 . This means the reaction will proceed forward, producing more SO_3 to replace that removed in the industrial process which is beneficial in the industrial formation of SO_3 cost wise and production wise.

(d) Predict, using equilibrium principles, the effect on the concentration of sulfur trioxide gas, $SO_3(g)$, of carrying out the reaction in a **larger** reaction vessel.

By using a larger reaction vessel the pressure that the system at equilibrium is under will decrease, meaning the system will respond by favouring the reaction that will increase the pressure. This means the reverse reaction will be favoured as this increases the pressure - there are 3 moles of gas as reactants as opposed to 2 moles of gas as products.

(e) When the reaction is carried out at 450^{0}C, the K_c value is higher that the value at 600^{o}C.

Justify whether the oxidation of sulfur dioxide gas, $SO_2(g)$, to sulfur trioxide gas, $SO_3(g)$. Is exothermic or endothermic.

With a decrease in temperature the system will respond to minimise this by releasing energy, ie by favouring the exothermic reaction. As Kc is higher with a lowered temperature the forward reaction is being favoured, producing more SO_3, therefore the production of SO_3 by oxidising SO_2 is exothermic.

2017

Question two

The reaction described above (that between hydrogen and nitrogen)(2017, question two (a), under rates of reaction) is an equilibrium reaction, as represented by the following equation:

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

(b)

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

$K_c =$

(ii) The value of the equilibrium constant, K_c is 640 at 25^{o}C.

Show by calculation, using the concentrations of the gases given in the table below, whether or not the reaction is at equilibrium.

Explain your answer.

Gas	N_2	H_2	NH_3
Concentration (mol L^{-1})	0.0821	0.0583	0.105

Is the mixture at equilibrium?

(circle) **Yes** **No**

Calculation and explanation:

(c) As the temperature increases, the value of the equilibrium constant, K_c, decreases from 640 at 25°C to 0.440 at 200°C.
Justify whether the formation of ammonia, NH_3 (*g*), is an endothermic or exothermic reaction.

Question three

(b) Two different cobalt (II) complex ions, $[Co(H_2O)_6]^{2+}$, exist together in a solution in equilibrium with chloride ions, Cl^- (*aq*).
The forward reaction is endothermic, ΔH is positive. The equation for this equilibrium is shown below.

$[Co(H_2O)_6]^{2+}$ (*aq*) + $4Cl^-$ (*aq*) ⇋ $[CoCL_4]^{2-}$ (*aq*) + $6H_2O$ (*l*)

pink *blue*

Explain using equilibrium principles, the effect on the colour of the solution if:

(i) more water is added to the reaction mixture

(ii) a test tube containing the reaction mixture is placed in a beaker of ice-cold water.

(c) Brown nitrogen dioxide gas, NO_2(*g*), exists in equilibrium with the colourless gas, dinitrogen tetroxide, N_2O_4 (*g*).

$2NO_2$ (*g*) ⇋ N_2O_4 (*g*)

brown colourless

Explain using equilibrium principles, the effect of decreasing the volume of the container (therefore increasing the pressure) on the observations of this equilibrium mixture.

2016

Question 1

(a) The equilibrium constant expression for a reaction is:

$$K_c = \frac{[CH_3OH]}{[CO]\,[H_2]^2}$$

Write the equation for this reaction.

(b) The ionisation of water is represented by the equation:

$2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

Give an account of the extent of ionisation of water, given $K_w = 1 \times 10^{-14}$

(c) When acid is added to a yellow solution of chromate ions, $CrO_4^{2-}(aq)$, the following equilibrium is established:

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

Analyse this equilibrium using equilibrium principles to explain the effect on the colour of the solution when:

(i) more dilute acid is added:

(ii) dilute base is added:

(d) When hydrogen gas, $H_2(g)$, and Iodine gas, $I_2(g)$, are mixed they react to form HI(g), and an equilibrium is established.

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $\quad K_c = 64$ at 445^0C.

(i) Calculate the concentration of HI in an equilibrium mixture at 445^0C when the concentrations of $H_2(g)$ and $I_2(g)$ are both 0.312 mol L^{-1}.

(ii) Explain the effect on the system on the position of equilibrium if the overall pressure of the equilibrium system is increased.

(iii) When the temperature of the equilibrium system is increased to 510^0C, the K_c value decreases to 46. Justify, using equilibrium principles, whether the forward reaction is exothermic or endothermic.

2015

Question 1

(a) The equilibrium constant for a reaction involving compounds A, B, C, and D is shown as:

$$K_c = \frac{[C]^3\,[D]}{[A]\,[B]^2}$$

Write the chemical equation for this reaction.

(b) The reaction between ethanoic acid and ethanol is reversible. Ethyl ethanoate and water are the products formed. In a closed system, a dynamic equilibrium is set up.

ethanoic acid + ethanol ⇋ ethyl ethanoate + water

$CH_3COOH(aq) + C_2H_5OH(aq) \leftrightharpoons CH_3COOC_2H_5(aq) + H_2O()$

(i) Explain, using equilibrium principles, the effect of adding more ethanol to the reaction mixture.

(ii) The reaction is quite slow, so a small amount of concentrated sulfuric acid is added as a catalyst. Explain, using equilibrium principles, the effect of adding this catalyst to the equilibrium mixture.

(c) The following chemical equation represents a reaction that is part of the Contact Process which produces sulfuric acid.

$2SO_2(g) + O_2(g) \leftrightharpoons 2SO_3(g)$ $\Delta_rH^o = -200$ kJ mol^{-1}, $K_c = 4.32$ at 600°C

(i) Write an equilibrium constant expression for this reaction.

$k_c =$

(ii) A reaction mixture has the following concentration of gases at 600°C:
$[SO_2(g)] = 0.300$ mol L^{-1}
$[O_2(g)] = 0.100$ mol L^{-1}
$[SO_3(g)] = 0.250$ mol L^{-1}

Justify why this reaction mixture is not at equilibrium. In your answer you should use the equilibrium expression from part (c)(i) and the data provided above to show that the reaction mixture is not at equilibrium.

(iii) The reaction on the previous page was repeated at 450°C. Explain, using equilibrium principles, how the change in temperature will affect:
• the value of K^c
• the position of equilibrium.

2014

Question 1

(a) Hydrogen can be produced industrially by reacting methane with water. An equation for this reaction can be represented by:

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $K_c = 4.7$ at 1127°C

(a) (i) Complete the equilibrium constant expression for this reaction:

$k_c =$

(ii) The concentrations of the four gases in a reaction mixture at 1127°C are found to be:

Gas	CH_4	H_2O	CO	H_2
Concentration / mol L^{-1}	0.0300	0.0500	0.200	0.300

Use these values to carry out a calculation to determine if the reaction is at equilibrium.

mixture at equilibrium **Yes** **No** circle correct answer

Calculation:

(b) The reaction shown in the equation below is at equilibrium.
$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$

Describe the effect of each of the following changes on the equilibrium concentration of methanol (increase, decrease, stay the same). Justify your answers using equilibrium principles.

A copper oxide, CuO, catalyst is added.

Amount of $CH_3OH(g)$ would: **increase** OR **decrease** OR **stay the same**
(circle correct answer

Reason:

$H_2(g)$ is removed.

Amount of $CH_3OH(g)$ would: **increase** OR **decrease** OR **stay the same**
(circle correct answer

Reason:

(c) In a reaction, the brown gas nitrogen dioxide, $NO_2(g)$, exists in equilibrium with the colourless gas dinitrogen tetroxide, $N_2O_4(g)$. The equation for this reaction is represented by:
$2NO_2(g) \rightleftharpoons N_2O_4(g)$
brown gas colourless gas

The table below shows the observations when changes were made to the system.

Change		**Observations**
pressure	increased (by decreasing the volume of the container)	Colour faded
	decreased (by increasing the volume of the container)	Colour darkened
temperature	container with reaction mixture put into hot water	Colour darkened
	container with reaction mixture put into ice water	Colour faded

Analyse these experimental observations. In your answer you should:
• link all of the observations to equilibrium principles
• justify whether the formation of dinitrogen tetroxide from nitrogen dioxide is endothermic or exothermic.

2013

Question 1

(a) Ammonia gas, $NH_3(g)$, is formed from hydrogen gas and nitrogen gas, as shown in the following equation.

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

Complete the equilibrium constant expression for this reaction.

$k_c =$

(b) The K_c for a different reaction is:

$$k_c = \frac{[SO_3(g)]^2}{[SO_2(g)]^2\,[O_2(g)]}$$

Write the chemical equation that corresponds to this expression in the box below.

$\rightleftharpoons$

(c) The two reactions shown in the following table are both at equilibrium.

Reaction	**Equation**	**Affected by increased pressure**
One	$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$	No
Two	$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$	Yes

Compare and contrast the effect of increasing the pressure on both reactions, with reference to the equilibrium positions.

(d) For Reaction Two in part (c), the values of K^c at different temperatures are shown below.

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

Temperature / ^{0}C	227°C	327°C	427°C	527°C
K_c	90	3	0.3	0.04

Use this information to determine whether the formation of NH3(g) is endothermic or exothermic. Justify your reasoning using equilibrium principles.

(e) For Reaction One in part (c), the K_c value is 46.8 at 491°C.

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

Calculate the concentration of HI(g), at equilibrium, at 491°C, if the concentration of $H_2(g)$ is 0.0190 mol L^{-1} and the concentration of $I_2(g)$ is 0.210 mol L^{-1}.