WJEC Chemistry A-level

1.7: Equilibria and Acid-base Reactions

Practice Questions

Wales Specification

1. (a) Planners have to ensure a secure supply of energy in the future. It has been suggested that the use of fossil fuels should be reduced, the use of renewable energy increased and that energy efficiency should be greatly improved.

By considering both the benefits and the difficulties involved, discuss whether you think that these suggestions are realistic.

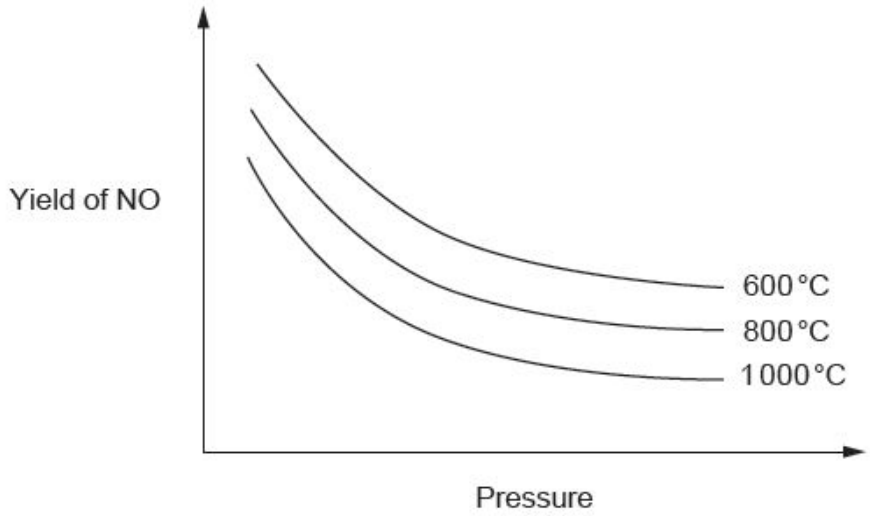
[4] QWC [1]

(b) Nitric acid is produced by the Ostwald process.

The first stage involves the oxidation of ammonia over a platinum/rhodium catalyst.

$$\text{ammonia} + \text{oxygen} \rightleftharpoons \text{nitric oxide} + \text{water}$$

The graph below shows how the yield of nitric oxide, NO, depends on the temperature and pressure used in its production.



(i)

I. State the general variations in this yield with temperature and pressure

[1]

II. Use the graphs to explain whether the reaction is endothermic or exothermic and whether there are more moles of gaseous products than reactants.

[4] QWC [1]

(ii) Normally the process is carried out at a temperature of around 900 °C.

Suggest why this temperature is used.

[2]

(iii) State the **type** of catalyst used.

[1]

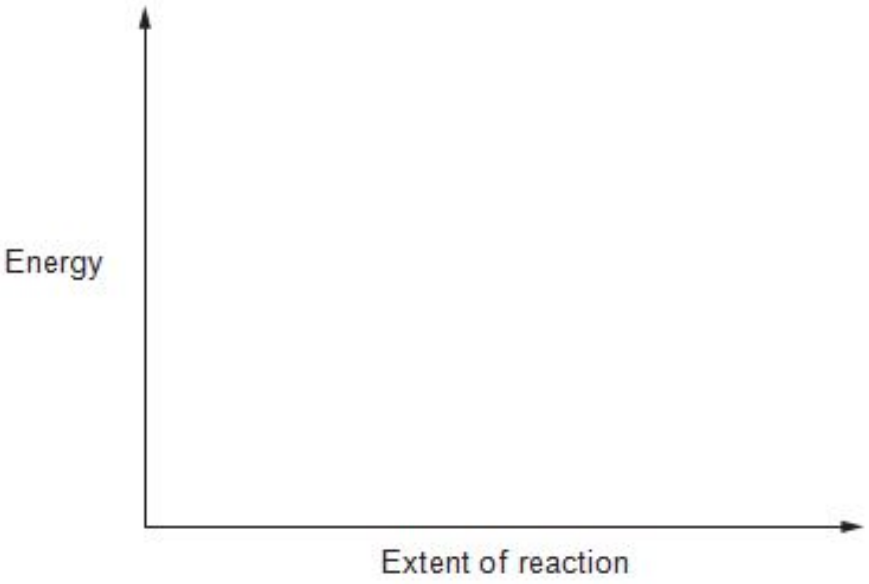
(iv) Explain why there has been much research to find a better catalyst.

[2]

(v) The next stage in the Ostwald process is to convert the nitric oxide to nitrogen dioxide.

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g) \qquad \Delta H = -114 \text{ kJ mol}^{-1}$$

Sketch on the axes below the energy profile for this reaction, clearly labelling the enthalpy change of reaction, ΔH. [2]



(vi) Write an expression that connects the enthalpy change of a reaction, ΔH, with the activation energies of the forward (E_f) and reverse (E_b) reactions. [1]

Total [19]

2. The decomposition of dinitrogen(IV) oxide into nitrogen(IV) oxide is a reversible reaction that establishes a dynamic equilibrium.

$$\underset{\text{pale yellow}}{N_2O_4(g)} \rightleftharpoons \underset{\text{dark brown}}{2NO_2(g)} \qquad \Delta H = +57 \text{ kJ mol}^{-1}$$

(a) State the meaning of the term ***dynamic equilibrium***.

[1]

(b) The conditions applied to an equilibrium mixture of dinitrogen(IV) oxide and nitrogen(IV) oxide were changed. For each of the following, state what was **seen** and explain any change that occurred.

[5]

Temperature increased

Pressure increased

A catalyst was added

(c) Hydrazine, N2H4, is an unstable liquid that decomposes according to the following equation.

$$N_2H_4(l) \longrightarrow N_2(g) + 2H_2(g)$$

(i) Calculate the volume of gas that could be obtained from 14 kg of hydrazine.

Assume that the volume of 1 mol of gas is 24.0 dm^3

[3]

Volume of gas = ... dm^3

(ii) Use of hydrazine is as a fuel in rockets. Apart from any energy changes, state **one** feature of this reaction that suggests it would be useful in rocket propulsion.

[1]

(d) Nitrogen (IV) oxide reacts with water.

$$H_2O + 2NO_2 \longrightarrow HNO_2 + HNO_3$$

Both nitric(III) acid, HNO_2, and nitric(V) acid, HNO_3, are described as being acids.

(i) Define an *acid*. [1]

(ii) Complete the equation to show nitric(III) acid behaving as an acid. [1]

$$HNO_2 + H_2O \longrightarrow$$

(iii) When concentrated nitric(V) acid is mixed with concentrated sulfuric acid the reaction shown below occurs.

$$HNO_3 + H_2SO_4 \longrightarrow H_2NO_3^+ + HSO_4^-$$

Explain this reaction in terms of acid-base behaviour. [2]

Total [14]

3. (a) An aqueous solution of methanoic acid can be used to dissolve 'limescale' in kettles. The concentration of a methanoic acid solution used for this purpose can be found by a titration using sodium hydroxide solution. For this purpose a 25.0 cm^3 sample of aqueous methanoic acid was diluted to 250 cm^3.

(i) State the name of the piece of apparatus used to

I. measure out 25.0 cm^3 of aqueous methanoic acid,

[1]

II. contain exactly 250 cm^3 of the diluted solution.

[1]

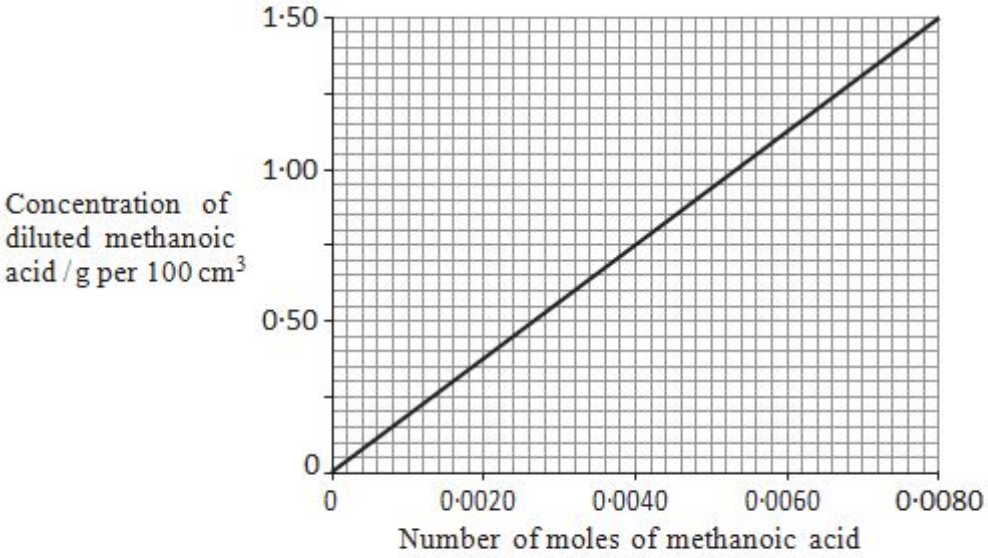
(ii) A 25.0 cm^3 sample of the diluted methanoic acid was titrated with sodium hydroxide solution of concentration 0.200 mol dm^{-3}. A volume of 32.00 cm^3 was needed to react with all the methanoic acid present.

Calculate the number of moles of sodium hydroxide used.

[1]

Moles of sodium hydroxide = **.....**mol

(iii) Methanoic acid and sodium hydroxide react together in a 1:1 molar ratio. Use the graph below and your result from (ii) to find the concentration of methanoic acid present in the diluted solution in g per 100 cm^3 of solution. [1]



Concentration = ... g per 100 cm^3

(iv) State the concentration of the original methanoic acid in g per 100 cm^3 solution. [1]

(b)

Methanoic acid reacts with propan-1-ol to give 1-propyl methanoate.

$$HCOOH + CH_3CH_2CH_2OH \rightleftharpoons HCOOCH_2CH_2CH_3 + H_2O$$

1-propyl methanoate

(i) This reaction eventually reaches dynamic equilibrium. State what is meant by *dynamic equilibrium*. [1]

(ii) Give the empirical formula of 1-propyl methanoate. [1]

(Total 7)

4. Weak *acids* establish a ***dynamic equilibrium*** when dissolved in water.

Give brief explanations of what is meant by the following terms.

[2]

Acid

Dynamic equilibrium

(Total 2)

5. Halogens and their compounds take part in a wide variety of reactions.

(a) Give the chemical name of a chlorine-containing compound of commercial or industrial importance. State the use made of this compound. [1]

(b) Hydrogen reacts with iodine in a reversible reaction.

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

An equilibrium was established at 300 K, in a vessel of volume 1 dm^3, and it was found that 0.311 mol of hydrogen, 0.311 mol of iodine and 0.011 mol of hydrogen iodide were present.

(i) Write the expression for the equilibrium constant in terms of concentration, K_c. [1]

(ii) Calculate the value of K_c at 300 K. [1]

K_c = ...

(iii) What are the units of K_c, if any? [1]

(iv) Equilibria of H_2, I_2 and HI were set up at 500 K and 1000 K and it was found that the numerical values of K_c were 6.25×10^{-3} and 18.5×10^{-3} respectively.

Use these data to deduce the sign of ΔH for the forward reaction. Explain your reasoning. [3]

(Total 7)

6. (a) Chlorine reacts with aqueous sodium hydroxide in one of two ways, depending on the temperature used.

(i)Write the equation for the reaction of chlorine with

I. cold aqueous sodium hydroxide,

[1]

II. hot aqueous sodium hydroxide.

[1]

(ii) Classify this type of redox reaction.

[1]

(b) A flask containing an initial mixture of 0.100 mol of ethanoic acid and 0.083 mol of methanol was kept at 25 °C until the following equilibrium had been established.

$$CH_3COOH + CH_3OH \rightleftharpoons CH_3COOCH_3 + H_2O \qquad \Delta H = -3\,kJ\,mol^{-1}$$

The ethanoic acid present at equilibrium required 32.0 cm^3 of a 1.25 mol dm^{-3} solution of sodium hydroxide for complete reaction.

(i) Write an expression for the equilibrium constant, K_c, giving the units, if any. [2]

(ii) Calculate the number of moles of ethanoic acid present at equilibrium. [1]

(iii) Calculate the value of the equilibrium constant, K_c, for this reaction. [2]

(iv) State, giving a reason, what happens to the value of the equilibrium constant, K_c, if the temperature is increased. [1]

(Total 9)

7. In an experiment, Aled titrated 25.00 cm^3 of potassium hydroxide solution with hydrochloric acid, and obtained the following results.

	1	2	3	4
Initial burette reading / cm^3	0.10	0.25	1.20	21.30
Final burette reading / cm^3	20.85	20.45	21.30	41.60
Volume used / cm^3				

(a) Complete the table to show the volume used in each titration.

[1]

(b) Calculate the mean volume that Aled should use for his further calculations.

[1]

.....cm³

(Total 2)

8. *(a)* A student obtained some measurements of the partial pressures of reactants and products for the reaction between sulfur(IV) oxide and nitrogen(IV) oxide.

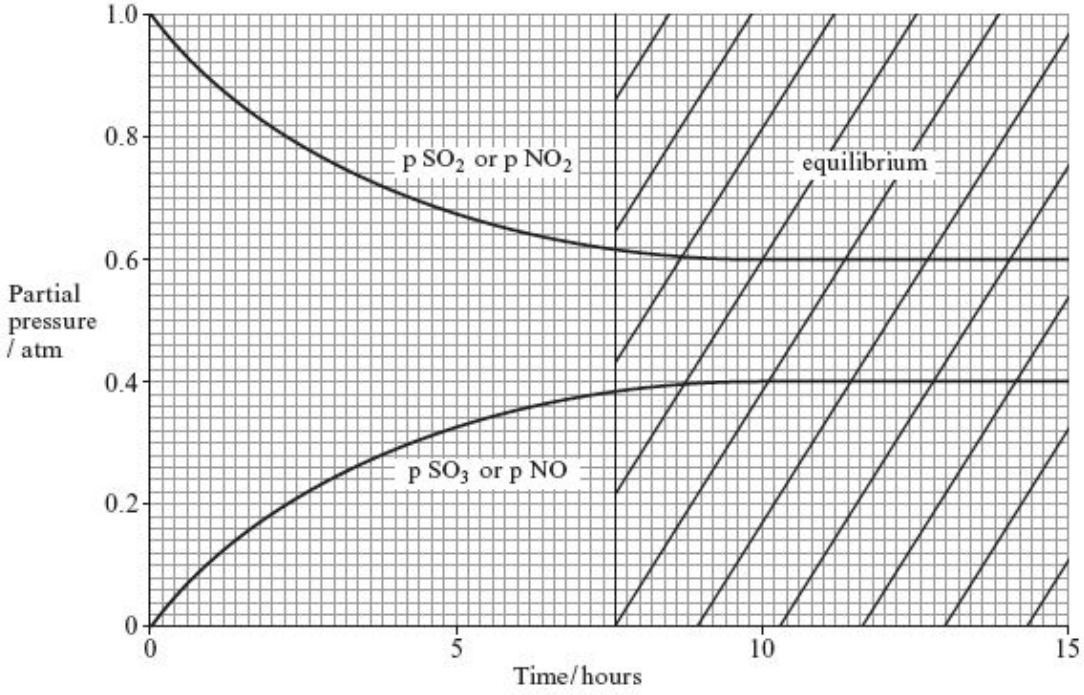
$$SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$$

The numerical value of K_p for this reaction is 2.5.

(i) Give the expression for the equilibrium constant in terms of partial pressures, K_p, stating its units (if any). [2]

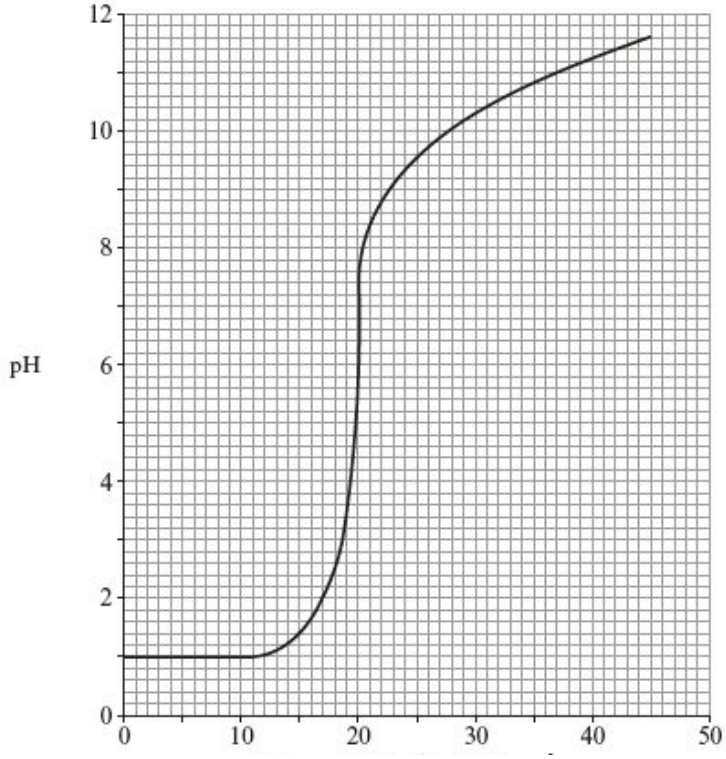
(ii) He decided to present his results in the form of the diagram below.

State the **two** things that are wrong with this diagram, explaining your answer. [4]



(iii) The enthalpy change for this reaction is -41 kJ mol^{-1}. State and explain how the value of the equilibrium constant would change (if at all) when the reaction is run at a higher temperature. [2]

(b) The acid-base titration curve for the reaction between aqueous solutions of nitric acid, HNO_3, and ammonia, both of concentration 0.100 mol dm^{-3}, is shown in the diagram. In this strong acid-weak base system, aqueous ammonia was added to 20.0 cm^3 of aqueous nitric acid.



(i) Describe and explain the shape of the curve obtained when aqueous ammonia is added to the aqueous nitric acid. [3]

QWC [1]

(ii) Deduce, using information obtained from the graph, the mole ratio of the two reactants in this titration. Explain your reasoning. [2]

(iii) I Explain why the pH of a solution of ammonium nitrate is not 7. [1]

II Use the graph to state the pH of the ammonium nitrate solution obtained at the equivalence point. [1]

(iv) Use your answer to (iii) to state the colour obtained if a few drops of the acid-base indicator bromophenol blue are added to the ammonium nitrate solution, giving the reason for your answer. [1]

pH	Colour
$\leqslant$ 2.8	yellow
$\geqslant$ 4.7	blue

(c) Ammonium nitrate (M_r = 80) is used in 'cold packs' to give a cooling effect for sports injuries. The solid crystals are added to water producing an endothermic reaction.

A typical 'cold pack' contains 40 g of ammonium nitrate that is dissolved in water to make 200 g of the solution. Calculate the molar concentration of the ammonium nitrate solution and hence the drop in temperature that occurs when this pack is used.

[1 mole of ammonium nitrate dissolved in water to make 1 kg of solution produces a drop in temperature of 6.2 °C] [3]

Total [20]

9. Hydrated sodium carbonate, $Na_2CO_3.xH_2O$, is a crystalline solid that can be used to prepare a standard solution for titration.

(a) The relative molecular mass of this hydrated sodium carbonate is 286.2. Calculate the value of x in this formula. [1]

x = ...

(b) Emily wants to prepare 250 cm^3 of a solution of sodium carbonate of concentration 1.200 $moldm^{-3}$ using this hydrated sodium carbonate.

(i) Calculate the mass of hydrated sodium carbonate needed to prepare this solution.

[2]

Mass of hydrated sodium carbonate = ... g

(ii) Emily proposes to make the solution by the following method.

- Weigh the required mass of hydrated sodium carbonate.
- Place the hydrated sodium carbonate in a beaker and add 250 cm^3 of distilled water.
- Stir the mixture until all the sodium carbonate dissolves.
- Transfer the solution to the volumetric flask and shake.

Her teacher said that the method was not correct. Suggest **two** changes that Emily should make to her method.

[2]

(c) Emily then prepared 250 cm^3 of sodium carbonate solution of concentration 0.200 mol dm^{-3} using a correct method. She took 25.0 cm^3 samples of the sodium carbonate solution and titrated these using a solution of sulfuric acid, H_2SO_4, of unknown concentration. The acid was placed in the burette.

(i) Describe how Emily should perform one titration to find the volume of sulfuric acid needed for complete reaction.

[4] QWC [1]

(Total 10)

10. *(a)* Write an expression for the ionic product of water, K_w, giving its units, if any. [2]

$K_w =$

Units .....

(b) (i) The value for K_w at 298 K is 1.0×10^{-14}. Explain why the pH of pure water at this temperature has a value of 7. [2]

(ii) Calculate the pH of the final solution if 10 cm^3 of 0.10 mol dm^{-3} hydrochloric acid is added to 990 cm^3 of pure water. [2]

(c) Calculate the pH of a solution which is 0.010 mol dm^{-3} with respect to ethanoic acid and 0.020 mol dm^{-3} with respect to sodium ethanoate at 298 K. [3]

[K_a for ethanoic acid = 1.78×10^{-5} mol dm^{-3} at 298 K]

pH = ...

(d) If 10 cm^3 of 0.10 mol dm^{-3} hydrochloric acid is added to 990 cm^3 of the solution described in *(c)* the change in pH is only 0.06. Explain why this change in pH is much smaller than that in *(b)*(ii). [3]

Total [12]

11.

Read the passage below and then answer the questions in the spaces provided.

Acids Through The Ages

The ancient Greeks started to classify materials as salt-tasting, sweet-tasting, sour-tasting and bitter-tasting. In this classification acids were those considered to be sour-tasting – the name comes from the Latin *acere*.

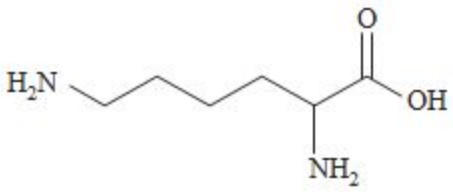
Taste continued to be an important consideration – even today many people would think of the sour taste of a lemon as being typical of an acid. However it was found that, as well as taste, these compounds had other properties in common. The dye litmus had been extracted from lichens and it was found that acids changed the colour of this to red. They also corroded metals.

Many acids were identified – citric acid could be extracted from citrus fruit and methanoic acid could be extracted, by distillation, from red ants. Methanoic acid used to be called formic acid since the biological term for an ant is *formica*.

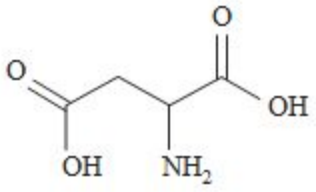
The modern classification of acids is based on the theory suggested by Lowry and Brønsted although more recent classifications, based on electron pair donation, have been suggested by Lewis.

Using the Lowry-Brønsted classification both citric acid and methanoic acid are described as being weak. For methanoic acid, HCOOH, the value of the acid dissociation constant, K_a, is 1.75×10^{-4} mol dm^{-3}.

Acids have a wide variety of uses in modern chemistry. They can, for example, be used as catalysts in hydrolysis reactions and work is currently being done to investigate the possibility of obtaining biofuels by the hydrolysis of farm waste such as straw. In some situations however acids can destroy catalytic effects. The tertiary structure and therefore the shape of the active sites of some enzyme catalysts can be maintained by ionic attractions. This could arise, for example, when the enzyme involves the amino acids lysine and aspartic acid. The NH_2 on the lysine can be protonated to give a positive ion, whilst the COOH can be deprotonated to give a negative ion. Attraction between oppositely charged ions holds the shape but if the pH is altered and one of the charges is lost the shape can change and the enzyme becomes denatured.



lysine



aspartic acid

The possible alteration of the shapes of molecules in biological systems means that it is important that the pH of, for example shampoos, is maintained within a small range. For best results shampoo should stay at a pH just below 7.

- End of passage -

(a) State what is meant by a Lowry-Brønsted acid. *(line 12)*

[1]

(b) Define pH

[1]

(c) David and Peter were discussing acids and bases. David said that you could decide whether an acid was strong or weak by measuring the pH of the acid solution. He said that the strong acid would have a lower pH. Peter said that he felt that the strength of the acid was not the only factor that affected pH.

Discuss the factors that affect pH.

[4] QWC [1]

(d) Methanoic acid is a weak acid.

(i) Write the expression for the acid dissociation constant, K_a, of methanoic acid. [1]

(ii) Using the information in *lines 16* and *17* of the article, calculate the pH of 0.10 mol dm^{-3} methanoic acid. [3]

pH = ...

(e) The article *(line 29)* states that it is important to maintain the pH of shampoo within a small range.

(i) What name is given to a system designed to maintain pH within a small range?

[1]

(ii) The pH of a shampoo is maintained within a small range by using a weak acid, RCOOH, and its sodium salt, RCOONa

Explain how this mixture maintains pH within a small range.

[3]

(Total 15)

12. Vinegar is a dilute solution of a weak acid.

(a) State what is meant by an *acid.*

[1]

(b) Suggest a pH value for vinegar.

[1]

(Total 2)