Equilibria, Energetics and Elements
Acids, Bases & Buffers

117 marks

1. Phenol, C_6H_5OH, is a powerful disinfectant and antiseptic.

Phenol is a weak Brønsted–Lowry acid.

$$C_6H_5OH(aq) \rightleftharpoons H^+(aq) + C_6H_5O^-(aq) \qquad K_a = 1.3 \times 10^{-10} \text{ mol dm}^{-3}$$

Define the following terms:

(i) A Brønsted–Lowry acid,

.....

[1]

(ii) A *weak* acid.

.....

[1]

[Total 2 marks]

2. When phenol is mixed with aqueous sodium hydroxide, an acid–base reaction takes place.

$C_6H_5OH(aq)$ + $OH^-(aq)$ $\rightleftharpoons$ $C_6H_5O^-(aq)$ + $H_2O(l)$

....

In the available spaces,

- label one conjugate acid–base pair as **acid 1** and **base 1**,
- label the other conjugate acid–base pair as **acid 2** and **base 2**.

[Total 1 mark]

3. A solution of phenol in water has a concentration of 4.7 g dm^{-3}.

(i) Write an expression for the acid dissociation constant, K_a, of phenol.

[1]

(ii) Calculate the pH of this solution of phenol.

[5]

[Total 6 marks]

4. As part of an investigation, a student needed to prepare a buffer solution with a pH value of 8.71. From the K_a value of phenol, the student thought that a mixture of phenol and sodium phenoxide could be used to prepare this buffer solution.

The student decided to use a 0.200 mol dm^{-3} solution of phenol, mixed with an equal volume of sodium phenoxide.

Use your knowledge of buffer solutions to determine the concentration of sodium phenoxide solution that the student would need to mix with the 0.200 mol dm^{-3} phenol solution.

[Total 3 marks]

5. In sewage plants, biological activity can be reduced by increasing the pH of the water. This is achieved by adding small amounts of solid calcium hydroxide, $Ca(OH)_2$, to the sewage water.

In all parts of this question, assume that measurements have been made at 25 °C.

(a) The pH of aqueous solutions is determined by K_w.

K_w has a value of 1.0×10^{-14} mol^2 dm^{-6} at 25 °C.

(i) What name is given to K_w?

.....

[1]

(ii) Write the expression for K_w.

.....

[1]

(b) A chemist checked the concentration of aqueous calcium hydroxide, $Ca(OH)_2$, in the sewage water by titration with 5.00×10^{-3} mol dm^{-3} hydrochloric acid.

$$Ca(OH)_2(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + 2H_2O(l)$$

The chemist titrated 25.0 cm^3 of the sewage water with 21.35 cm^3 of HCl to reach the endpoint of the titration.

Calculate the concentration, in mol dm^{-3}, of the calcium hydroxide in the sewage water.

concentration = ... mol dm^{-3}

[3]

(c) The chemist analysed a sample of water from another part of the sewage works and he found that the calcium hydroxide concentration was 2.7×10^{-3} mol dm^{-3}.

When solid calcium hydroxide dissolves in water, its ions completely dissociate.

$$Ca(OH)_2(s) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$$

Calculate the pH of this sample.

[3]

(d) After further treatment, the water could be used for drinking. In the drinking water produced, the OH^- concentration was 100 times greater than the H^+ concentration.

What was the pH of this drinking water?

[1]

[Total 9 marks]

6. 'Superphosphate' fertilisers contain calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$. This compound is one of the world's most important fertilisers. When dissolved in water, $Ca(H_2PO_4)_2$ dissociates forming $H_2PO_4^-$ ions which are easily taken up by plants.

(a) Calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$, is produced by treating rock phosphate, containing $Ca_3(PO_4)_2$, with sulphuric acid, H_2SO_4.

Write a balanced equation for this reaction.

.....

[1]

(b) Aqueous $H_2PO_4^-$ ions can act as a weak acid.

Write an equation to represent the dissociation of the $H_2PO_4^-$ ion.

.....

[1]

(c) The $H_2PO_4^-$ ion can act as either an acid or a base.

(i) State the formula of the conjugate **base** of $H_2PO_4^-$.

.....

[1]

(ii) State the formula of the conjugate **acid** of $H_2PO_4^-$.

.....

[1]

(iii) A solution of calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$, in water acts as a buffer solution.

Suggest, with the aid of equations, how this buffering action takes place.

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[3]

[Total 7 marks]

7. This question looks at two acids:

- methanoic acid, HCOOH, a weak organic acid;
- nitric acid, HNO_3, a strong acid which can also act as a powerful oxidising agent.

Methanoic acid is a weak Brønsted-Lowry acid.

Explain what is meant by a *weak Brønsted-Lowry acid.*

.....

.....

.....

[Total 2 marks]

8. Calculate the pH of a 0.025 mol dm^{-3} solution of methanoic acid. Show your working.

For HCOOH, K_a = 1.58 x $l0^{-4}$mol dm^{-3}.

pH = ...

[Total 3 marks]

9. Methanoic acid is a component of a buffer solution used in shampoos. The buffer solution can be made by mixing methanoic acid with another chemical.

(i) State what is meant by a *buffer solution.*

.....

.....

[1]

(ii) Suggest a chemical that could be added to methanoic acid to prepare a buffer solution. Explain your answer.

.....

.....

[2]

(iii) What factors determine the pH of a buffer solution?

.....

.....

.....

[2]

[Total 5 marks]

10. Nitric acid, $HN0_3$, is sold by a chemical supplier as a 65% solution, by mass. As supplied, each cubic decimetre of this nitric acid has a mass of 1400g.

Calculate the pH of this solution.

pH = ...

[Total 3 marks]

11. When dilute, nitric acid behaves as a typical acid.

Write an equation for the reaction of nitric acid with limestone.

.....

[Total 2 marks]

12. When nitric acid is added to methanoic acid, the acid-base equilibrium below is set up.

$$HNO_3 + HCOOH \rightleftharpoons NO_3^- + HCOOH_2^+$$

Use this equilibrium to explain what is meant by the term *conjugate acid-base pairs.*

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[Total 3 marks]

13. A student analysed an unsaturated carboxylic acid, **A**, using a titration procedure.

The student dissolved 2.580 g of the compound in water and made the solution up to 250.0cm^3. The student titrated 25.0 cm^3 of this solution with 0.1263mol dm^{-3} NaOH. The volume of NaOH(aq) required to reach the end point was 23.75cm^3.

Each molecule of **A** has one acidic hydrogen atom and **A** behaves as a monoprotic (or monobasic) acid.

- Calculate the molar mass of the unsaturated carboxylic acid.
- Determine the molecular formula and possible displayed or skeletal formulae of the carboxylic acid.

[Total 8 marks]

14. Methanoic acid, HCOOH, is a weak organic acid which occurs naturally in ants and stinging nettles.

(a) Use an equation for the dissociation of methanoic acid to show what is meant by a *weak acid*.

.....

.....

[1]

(b) A 1.50×10^{-2} mol dm^{-3} solution of HCOOH has $[H^+] = 1.55 \times 10^{-3}$ mol dm^{-3}.

(i) Calculate the pH of this solution and give one reason why the pH scale is a more convenient measurement for measuring acid concentrations than $[H^+]$.

.....

.....

.....

[2]

(ii) Write the expression for K_a for methanoic acid.

[1]

(iii) Calculate the values of K_a and pK_a for methanoic acid.

[3]

(iv) Estimate the percentage of HCOOH molecules that have dissociated in this aqueous solution of methanoic acid.

[1]

[Total 8 marks]

15. A student titrated the 1.50×10^{-2} mol dm^{-3} methanoic acid with aqueous sodium hydroxide.
A 25.00 cm^3 sample of the HCOOH(aq) was placed in a conical flask and the NaOH(aq) was added from a burette until the pH no longer changed.

(i) Write a balanced equation for the reaction between HCOOH(aq) and NaOH(aq).

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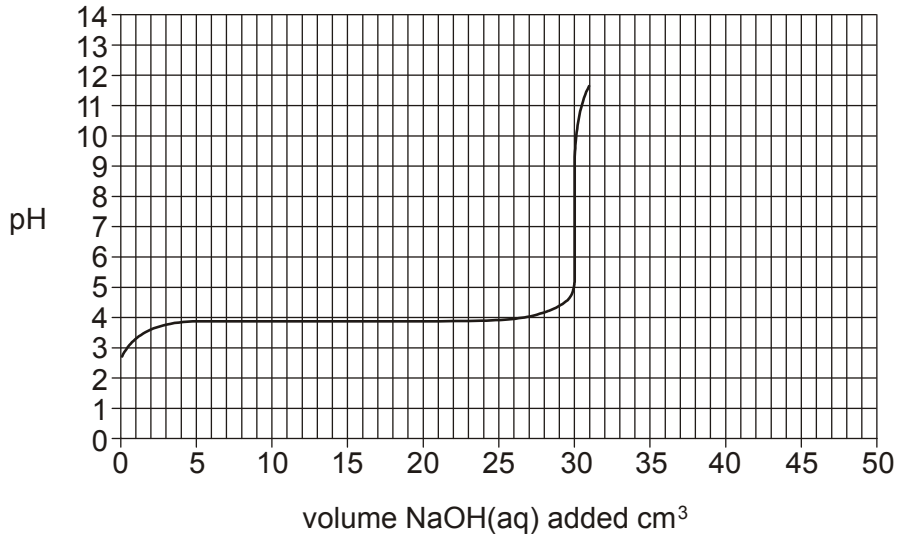
[1]

(ii) Part of the pH curve for this titration is shown below.



Calculate the concentration, in mol dm^{-3}, of the aqueous sodium hydroxide.

concentration = ...mol dm^{-3}

[3]

(iii) Calculate the pH of the aqueous sodium hydroxide.
$K_w = 1.00 \times 10^{-14}$ mol dm^{-3}

pH = ...

[2]

(iv) The pH ranges in which colour changes for three acid-base indicators are shown below.

indicator	pH range
metacresol purple	7.4 – 9.0
2,4,6-trinitrotoluene	11.5 – 13.0
ethyl orange	3.4 – 4.8

Explain which of the three indicators is suitable for this titration.

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[2]

[Total 8 marks]

16. The K_a values for three acids are shown in the table below.

acid		K_a / mol dm^{-3}
ethanoic acid	CH_3COOH	1.70×10^{-5}
phenol	C_6H_5OH	1.28×10^{-10}
sulphurous acid	H_2SO_3	1.50×10^{-2}

(a) What information is provided by K_a values?

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.....

[1]

(b) When sulphurous acid and ethanoic acid are mixed together, an acid-base reaction takes place.

$H_2SO_3(aq)$ + $CH_3COOH(aq)$ $\rightleftharpoons$ $HSO_3^-(aq)$ + $CH_3COOH_2^+(aq)$

....

(i) In the spaces above

- label one **conjugate acid-base pair** as acid 1 and base 1,
- label the other **conjugate acid-base pair** as acid 2 and base 2.

[2]

(ii) Predict and explain the acid-base reaction that would take place if ethanoic acid were mixed with phenol. Include an equation in your answer.

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[2]

(c) The pH value of 0.0450 mol dm^{-3} hydrochloric acid is different from that of 0.0450 mol dm^{-3} ethanoic acid.

Calculate the pH values of these two acids. Show all your working.

[5]

[Total 10 marks]

17. An excess of magnesium was added to 100 cm^3 of 0.0450 mol dm^{-3} hydrochloric acid. The same mass of magnesium was added to 100 cm^3 of 0.0450 mol dm^{-3} ethanoic acid.

Both reactions produced 54 cm^3 of hydrogen gas, measured at room temperature and pressure, but the reaction with ethanoic acid took much longer to produce this gas volume.

Explain why the reactions produced the same volume of a gas but at different rates.

Use equations in your answer.

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[Total 4 marks]

18. Chocolate mousse contains gelatine and a compound to promote fast setting of the mousse.

Compound **A** is such a setting agent. It has two acidic hydrogen atoms per molecule and is one of the six acids listed below.

oxalic acid	HOOCCOOH
malonic acid	$HOOCCH_2COOH$
succinic acid	$HOOC(CH_2)_2COOH$
glutaric acid	$HOOC(CH_2)_3COOH$
adipic acid	$HOOC(CH_2)_4COOH$
pimelic acid	$HOOC(CH_2)_5COOH$

The student analysed a sample of compound **A** by titration.

The student dissolved 2.82 g of compound **A** in water and made the solution up to 250 cm3 in a volumetric flask. He titrated 25.0 cm^3 of this solution with 0.175 mol dm^{-3} NaOH.

22.05 cm^3 of NaOH were required for complete neutralisation.

Use the results of the student's analysis to identify compound **A** from the list above.

Show all of your working.

[Total 5 marks]

19. Phenol, C_6H_5OH, is a powerful disinfectant and antiseptic. Phenol is a weak Brønsted-Lowry acid.

What is meant by the following terms;

(i) a *Brønsted-Lowry* acid;

.....

[1]

(ii) a *weak* acid?

.....

.....

[1]

[Total 2 marks]

20. When phenol is mixed with aqueous sodium hydroxide, an acid-base reaction takes place.

$C_6H_5OH(aq)$ + $OH^-(aq)$ $\rightleftharpoons$ $C_6H_5O^-(aq)$ + $H_2O(l)$

....

In the spaces above,

- label one **conjugate acid-base pair** as acid 1 and base 1,
- label the other **conjugate acid-base pair** as acid 2 and base 2.

[Total 2 marks]

21. A solution of phenol in water has a concentration of 38 g dm^{-3}.
The acid dissociation constant, K_a, of phenol is 1.3×10^{-10} mol dm^{-3}.

(i) Write an expression for the acid dissociation constant, K_a, of phenol.

[1]

(ii) Calculate the pH of this solution.

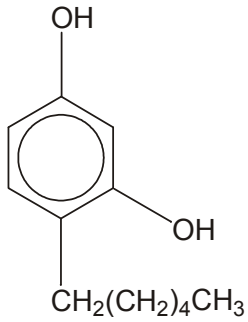
answer.....

[5]

[Total 6 marks]

22. Hexylresorcinol is an antiseptic used in solutions for cleansing wounds and in mouthwashes and throat lozenges.

The structure of hexylresorcinol is shown below.



Identify a compound that could be added to hexylresorcinol to make a buffer solution. Explain your answer.

[Total 2 marks]

23. A student carried out an investigation with aqueous solutions of nitric acid, sodium hydroxide, ethanoic acid and water.

Nitric acid, HNO_3, is a strong Brønsted-Lowry acid.

(i) Explain what is meant by a *strong acid* and a *Brønsted-Lowry acid*.

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[2]

(ii) What is the conjugate base formed from HNO_3?

.....

[1]

[Total 3 marks]

24. A student carried out an investigation with aqueous solutions of nitric acid, sodium hydroxide, ethanoic acid and water.

The student diluted 0.015 mol dm^{-3} nitric acid with an equal volume of water and measured the pH of the diluted acid at 25 °C.

(i) Calculate the pH of 0.015 mol dm^{-3} nitric acid.

[2]

(ii) Calculate the pH of the diluted acid.

[1]

[Total 3 marks]

25. A student measured the pH of a solution of sodium hydroxide as 13.54 at 25 °C.

Kw = 1.0×10^{-14} mol^2 dm^{-6} at 25 °C.

(i) Write down an expression for the ionic product, K_w, for water.

.....

[1]

(ii) Calculate the concentration, in mol dm^{-3}, of this solution of sodium hydroxide.

[2]

[Total 3 marks]

26. A student prepared two solutions.

- Solution **A** was made by mixing together 25 cm^3 0.010 mol dm^{-3} aqueous sodium hydroxide with 50 cm^3 0.010 mol dm^{-3} ethanoic acid, CH_3COOH. Solution **A** is a buffer solution.
- Solution **B** was made by mixing together 25 cm^3 0.020 mol dm^{-3} aqueous sodium hydroxide with 50 cm^3 0.010 mol dm^{-3} ethanoic acid, CH_3COOH. Solution **B** is **not** a buffer solution.

(i) What is meant by a *buffer solution*?

.....

.....

[1]

(ii) Explain why Solution **A** is a buffer solution whereas Solution **B** is **not**.

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[4]

[Total 5 marks]

27. A student measured the pH of water as 7.0 at 25 °C. The student then warmed the water to 40 °C and measured the pH as 6.7.

What do these results tell you about the tendency of water to ionise as it gets warmer? Explain your reasoning in terms of equilibrium.

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[Total 2 marks]