IB Chemistry HL - Acid-Base

Curated high-relevance past-paper questions (2010-2025)

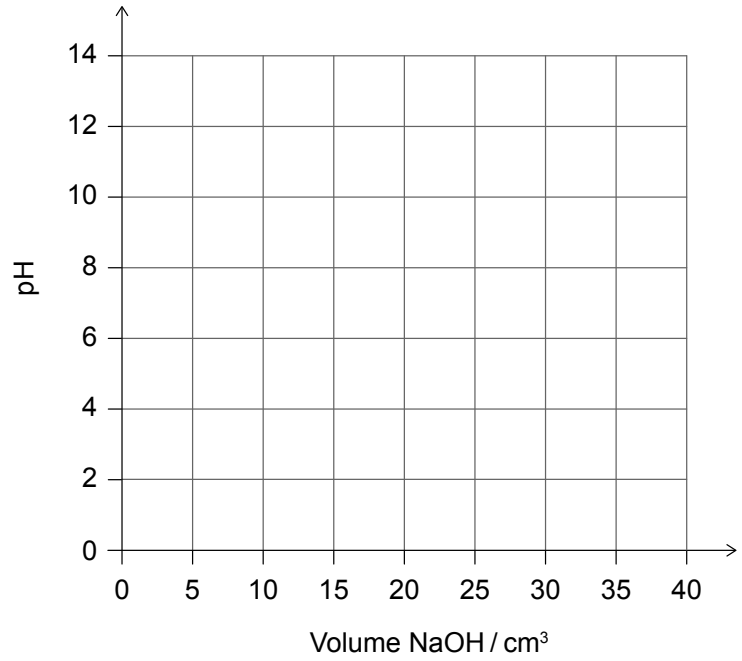
Focus: Bronsted-Lowry and Lewis acids/bases, strong vs weak acids/bases, Ka/Kb/Kw, pH/pOH, buffers, titration curves, indicators, and related equilibrium calculations.

Lower-relevance organic spectroscopy, kinetics, redox, structure-only, and unrelated context were removed where possible. Context needed to solve an acid-base part was retained.

Questions are taken from the user-provided IB Chemistry Paper 2 compilation.

5. 40.0 cm^3 of 1.0 mol dm^{-3} sodium hydroxide, NaOH(aq), was gradually added to 15.0 cm^3 of 1.0 mol dm^{-3} ethanoic acid, CH_3COOH(aq).

(a) Sketch a pH curve for this titration. [3]



(b) NaOH(aq) and CH_3COOH(aq) can be mixed to make a buffer solution.

(i) Describe how these solutions can produce the most effective buffer. [2]

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(ii) Write equations to show the action of the buffer solution when small amounts of a strong acid or a strong base are added. [2]

Addition of strong acid: . . . . . .

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Addition of strong base: . . . . . .

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3. Nitrous acid, HNO_2, is a weak acid which can be used to make acidic buffers.

(a) A 1.00 mol dm^{-3} solution of nitrous acid was prepared. This solution contains two conjugate acid–base pairs.

(i) State the formulas of the conjugate acid and conjugate base in each pair. [2]

Conjugate acid: . . . . . Conjugate base: . . . . . .

Conjugate acid: . . . . . Conjugate base: . . . . . .

(ii) This 1.00 mol dm^{-3} solution of nitrous acid was used to prepare a buffer with pH 3.00.

Calculate the concentration of the conjugate base of nitrous acid required to make this buffer. The pK_a of nitrous acid is 3.25. [3]

Concentration of conjugate base: . . . . . .

(Question 3 continued)

(c) Hydrocyanic acid, HCN(aq), has $K_a = 6.17 \times 10^{-10}$.

(i) Determine the pH of a 0.202 mol dm^{-3} aqueous solution of hydrocyanic acid. [3]

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(ii) State **one** assumption made for your calculation in (c)(i). [1]

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(iii) State the composition of a buffer solution containing hydrocyanic acid. [1]

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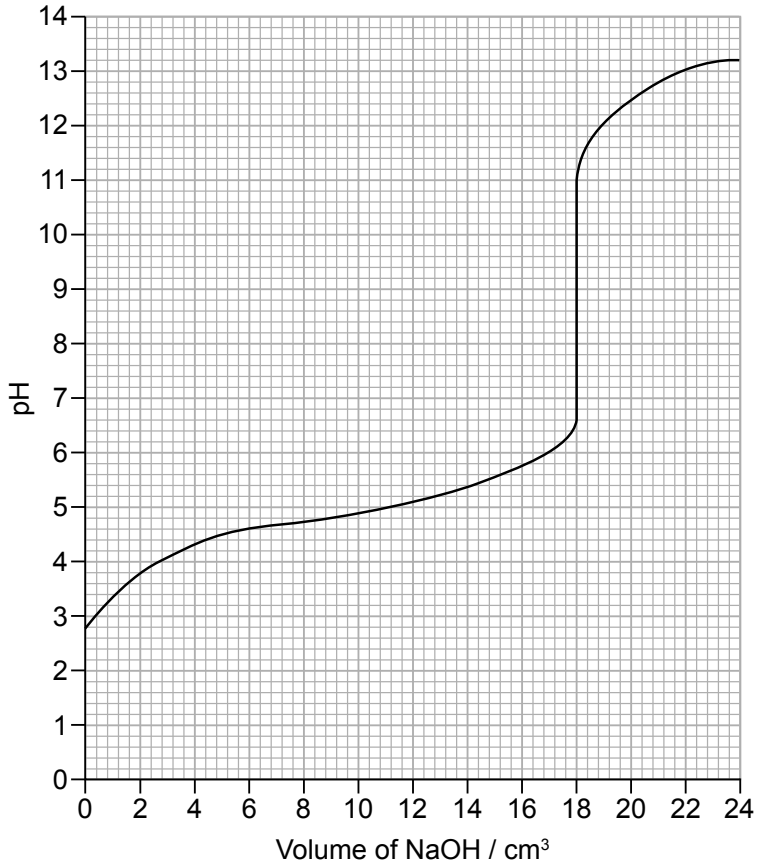
5. Organic acids are weak acids.

(a) A 20.00 cm^3 sample of a weak monoprotic acid with a concentration of 0.150 $mol\,dm^{-3}$ was titrated with a solution of sodium hydroxide, NaOH (aq), giving the pH curve shown.



(i) Determine the concentration, in $mol\,dm^{-3}$, of the NaOH (aq) used in the titration. [2]

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(Question 5 continued)

(ii) Determine the pK_a of the weak acid using the graph. [1]

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(iii) Outline why phenolphthalein can be used as an acid–base indicator. [1]

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(iv) Outline why phenolphthalein is suitable for this titration. Use section 22 of the data booklet. [1]

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(b) Outline how samples of the weak acid and a strong acid of the same concentration can be distinguished from each other. [2]

Method: . . . . . .

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Observation: . . . . . .

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(This question continues on the following page)

(Question 5 continued)

(c) The K_w of pure water is 1.00×10^{-14} at 25 °C.

(i) Suggest why the K_w value for pure water increases as temperature increases. [1]

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(ii) Calculate the pH and pOH of pure water at 60 °C. Use section 23 of the data booklet. [2]

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Answer **all** questions. Answers must be written within the answer boxes provided.

1. This question is about acid–base properties.

(a) (i) Deduce the ionic equation, including state symbols, for the reaction of hydrogen chloride gas with water. [2]

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(ii) Calculate the pH of 0.50 mol dm^{-3} hydrochloric acid. [1]

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(iii) Explain why a solution of ethanoic acid has a higher pH than hydrochloric acid of the same concentration. [1]

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(iv) A pH probe can be used to distinguish between the acids in part (a)(iii). Identify another simple instrumental method that could be used in a school laboratory to distinguish between the two acids. [1]

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(v) Outline how the instrumental method identified in part (a)(iv) distinguishes between the acids in part (a)(iii). [1]

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(Question 1 continued)

(b) Outline **one** chemical test, other than an indicator, that can distinguish between the two acids in part (a)(iii), and the expected result. [1]

Chemical test: . . . . . .

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Expected result: . . . . . .

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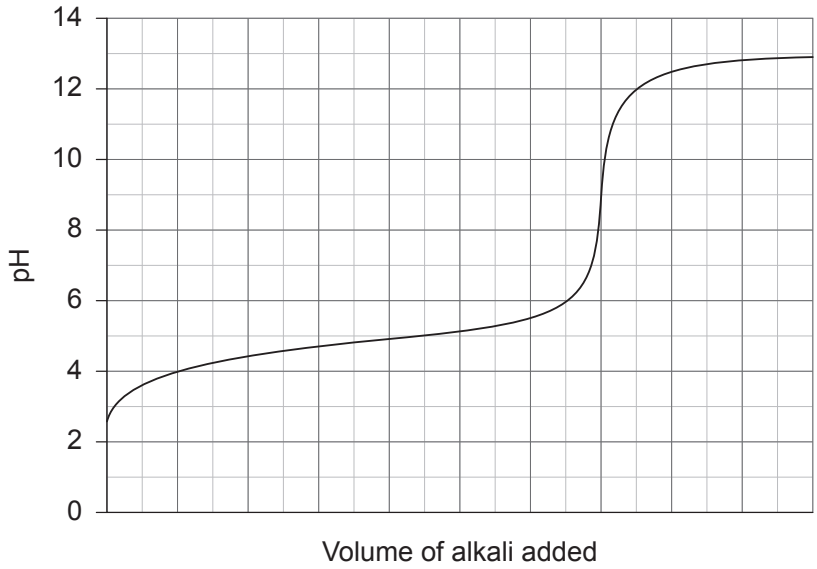
(Question 1 continued)

(c) A neutralization curve for a weak acid, HA, and a strong base is given.



(i) Estimate the pK_a of HA. [1]

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(ii) Explain, using an equation, why adding a strong base to the weak acid, HA, leads to very little change in pH in the buffer zone of the graph. [2]

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4. Ammonia is soluble in water and forms an alkaline solution:

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + HO^-(aq)$$

(a) State the relationship between NH_4^+ and NH_3 in terms of the Brønsted–Lowry theory. [1]

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(b) Determine the concentration, in mol dm^{-3}, of the solution formed when 900.0 dm^3 of $NH_3(g)$ at 300.0 K and 100.0 kPa, is dissolved in water to form 2.00 dm^3 of solution. Use sections 1 and 2 of the data booklet. [2]

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(c) (i) Calculate the concentration of hydroxide ions in an ammonia solution with pH = 9.3. Use sections 1 and 2 of the data booklet. [1]

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(ii) Calculate the concentration, in mol dm^{-3}, of ammonia molecules in the solution with pH = 9.3. Use section 21 of the data booklet. [2]

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(This question continues on the following page)

7. The overall equation for the production of hydrogen cyanide, HCN, is shown below.

$$CH_4(g) + NH_3(g) + \frac{3}{2}O_2(g) \rightarrow HCN(g) + 3H_2O(g)$$

(a) (i) State why NH_3 is a Lewis base. [1]

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(ii) Calculate the pH of a 1.00×10^{-2} mol dm^{-3} aqueous solution of ammonia.

$pK_b = 4.75$ at 298 K. [3]

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(iii) Justify whether a 1.0 dm^3 solution made from 0.10 mol NH_3 and 0.20 mol HCl will form a buffer solution. [1]

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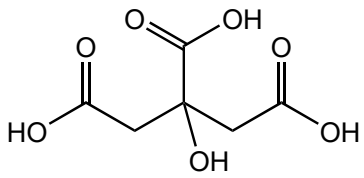
4. A molecule of citric acid, $C_6H_8O_7$, is shown.



The equation for the first dissociation of citric acid in water is

$$C_6H_8O_7(aq) + H_2O(l) \rightleftharpoons C_6H_7O_7^-(aq) + H_3O^+(aq)$$

(a) (i) Identify a conjugate acid–base pair in the equation. [1]

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(ii) The value of K_a at 298 K for the first dissociation is 5.01×10^{-4}.

State, giving a reason, the strength of citric acid. [1]

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(iii) The dissociation of citric acid is an endothermic process. State the effect on the hydrogen ion concentration, $[H^+]$, and on K_a, of increasing the temperature. [2]

Effect on $[H^+]$	**Effect on K_a**
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(iv) Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, in kJ mol^{-1}, for the first dissociation of citric acid at 298 K, using section 1 of the data booklet. [1]

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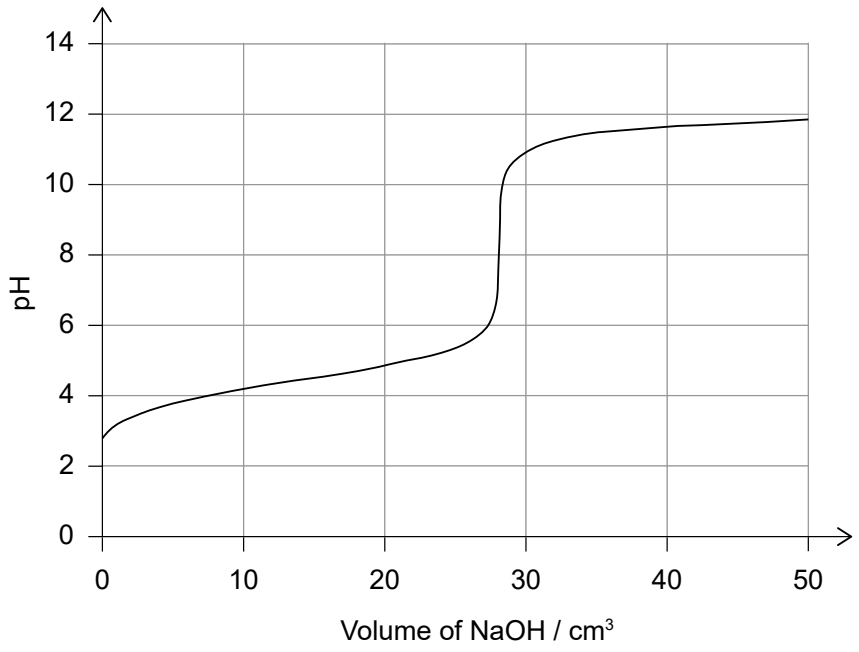
5. Another common acid found in food is ethanoic acid.

(a) A sample of ethanoic acid was titrated with sodium hydroxide solution, and the following pH curve obtained.



Annotate the graph to show the buffer region and the volume of sodium hydroxide at the equivalence point. [2]

(b) (i) Identify the most suitable indicator for the titration using section 22 of the data booklet. [1]

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(ii) Describe, using a suitable equation, how the buffer solution formed during the titration resists pH changes when a small amount of acid is added. [2]

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7. This question is about the weak acid methanoic acid, HCOOH.

(a) Calculate the pH of 0.0100 mol dm^{-3} methanoic acid stating any assumption you make. $K_a = 1.6 \times 10^{-4}$. [3]

Calculation:

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Assumption:

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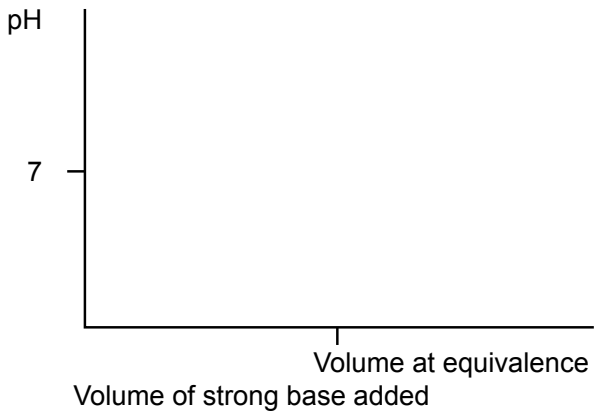
(b) (i) Sketch a graph of pH against volume of a strong base added to a weak acid showing how you would determine pK_a for the weak acid. [2]



(This question continues on the following page)

(Question 7 continued)

(ii) Explain, using an equation, why the pH increases very little in the buffer region when a small amount of alkali is added. [2]

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6. Acid–base chemistry can play a major role in chemical and biological processes.

(a) Ammonia, NH_3, can be used to clean ovens. The concentration of hydroxide ions, $OH^-(aq)$, in a solution of ammonia is $3.98 \times 10^{-3}\,mol\,dm^{-3}$. Calculate its pH, correct to **one** decimal place, at 298 K. *[2]*

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(b) White vinegar, which contains ethanoic acid, CH_3COOH, can be used as a cleaning agent to dissolve mineral deposits from coffee machines.

(i) Define an *acid* according to the Brønsted–Lowry theory and the Lewis theory. *[2]*

Brønsted–Lowry theory:

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Lewis theory:

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(ii) Ethanoic acid is an example of a weak acid. Distinguish between a *strong acid* and a *weak acid* in terms of the extent of dissociation. *[1]*

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(This question continues on the following page)

(Question 6 continued)

(c) Buffer solutions play a pivotal role in solution chemistry.

(i) State whether the following mixtures, in the appropriate molar ratios, can be classified as buffer solutions. Show your answer by stating **yes** or **no** in the table below. *[1]*

Mixture	Buffer
HCOOH and $HCOO^-K^+$	
HCl and excess NH_3	

(ii) A buffer solution contains lactic acid, $CH_3CH(OH)COOH\,(aq)$, with a concentration of $1.55 \times 10^{-1}\,mol\,dm^{-3}$ and sodium lactate, $NaCH_3CH(OH)COO\,(aq)$, with a concentration of $1.05 \times 10^{-1}\,mol\,dm^{-3}$. Determine the pH of this buffer solution, correct to **two** decimal places.
(K_a for lactic acid $= 1.40 \times 10^{-4}$ at 298 K.) *[4]*

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(Question 6 continued)

(d) Acid–base indicators are often organic dyes.

(i) Describe qualitatively the action of an acid–base indicator. *[3]*

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(ii) Using Table 16 of the Data Booklet, identify the most appropriate indicator for the titration of ethanoic acid with sodium hydroxide. Explain your choice. *[2]*

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(iii) $150\,cm^3$ of $5.00 \times 10^{-1}\,mol\,dm^{-3}$ HCl(aq) is mixed with $300\,cm^3$ of $2.03 \times 10^{-1}\,mol\,dm^{-3}$ NaOH(aq). Determine the pH of the solution, correct to **two** decimal places. *[4]*

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(This question continues on the following page)

(Question 6 continued)

(e) (i) State and explain whether the following solutions will be acidic, basic or neutral. *[4]*

$FeCl_3$:

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$CH_3CH_2NH_3NO_3$:

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(ii) The K_a value for HF is 6.80×10^{-4} at 298 K. Using this information and any additional information from Tables 2 and 15 of the Data Booklet, deduce whether a solution of NH_4F would be acidic, basic or neutral. *[2]*

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(Question 7 continued)

(c) Outline how the following factors account for the fact that HCl is a strong acid and HF is a weak acid.

(i) The strength of the hydrogen–halogen bond. *[1]*

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(ii) The interaction between an undissociated hydrogen halide molecule and a water molecule. *[1]*

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(d) Some students were provided with a $0.100\,mol\,dm^{-3}$ solution of a monobasic acid, HQ, and given the problem of determining whether HQ was a weak acid or a strong acid.

(i) Neelu and Charles decided to solve the problem by determining the volume of $0.100\,mol\,dm^{-3}$ sodium hydroxide solution needed to neutralize $25.0\,cm^3$ of the acid. Outline whether this was a good choice. *[2]*

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(This question continues on the following page)

(Question 7 continued)

(ii) Identify **one** indicator that could be used when titrating aqueous sodium hydroxide with both a strong acid and a weak acid, and outline the reason for your choice. *[2]*

Indicator:

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Reason:

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(iii) Neelu and Charles decided to compare the volume of sodium hydroxide solution needed with those required by known $0.100\,mol\,dm^{-3}$ strong and weak acids. Unfortunately they chose sulfuric acid as the strong acid. Outline why this was an unsuitable choice. *[1]*

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(iv) Francisco and Shamiso decided to measure the pH of the initial solution, HQ, and they found that its pH was 3.7. Deduce, giving a reason, the strength (weak or strong) of the acid HQ. *[2]*

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(This question continues on the following page)

(Question 7 continued)

(e) The second problem set for the students was to determine the acid dissociation constant, K_a, of the acid HQ and its pK_a.

(i) Explain how the pK_a could be determined from a graph of pH against the volume of 0.100 mol dm^{-3} sodium hydroxide added. *[2]*

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(ii) Francisco and Shamiso found that the pH of the initial 0.100 mol dm^{-3} solution was 3.7. However, this reading was inaccurate because they forgot to wash the pH probe. Calculate the pK_a of HQ using the reading they obtained. *[4]*

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(Question 7 continued)

(f) Manu and Lisa decided to convert the acid into a buffer solution by partly neutralizing it. They mixed $10.0\,cm^3$ of $0.100\,mol\,dm^{-3}$ sodium hydroxide solution with $40.0\,cm^3$ of the $0.100\,mol\,dm^{-3}$ solution of HQ. Determine the pH of the resulting solution, showing your working, given that the K_a of HQ is $1.80 \times 10^{-5}\,mol\,dm^{-3}$. *[5]*

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(Question 6 continued)

(d) (i) Hydrogen bromide forms a strong acid when dissolved in water whereas hydrogen fluoride forms a weak acid. Distinguish between the terms *strong acid* **and** *weak acid*. State equations to describe the dissociation of each acid in aqueous solution. *[3]*

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(Question 6 continued)

(ii) A student titrated 25.00 cm^3 of a 0.100 mol dm^{-3} solution of hydrofluoric acid, HF (aq), with 0.100 mol dm^{-3} NaOH (aq). Some of his data are presented below.

	A	B
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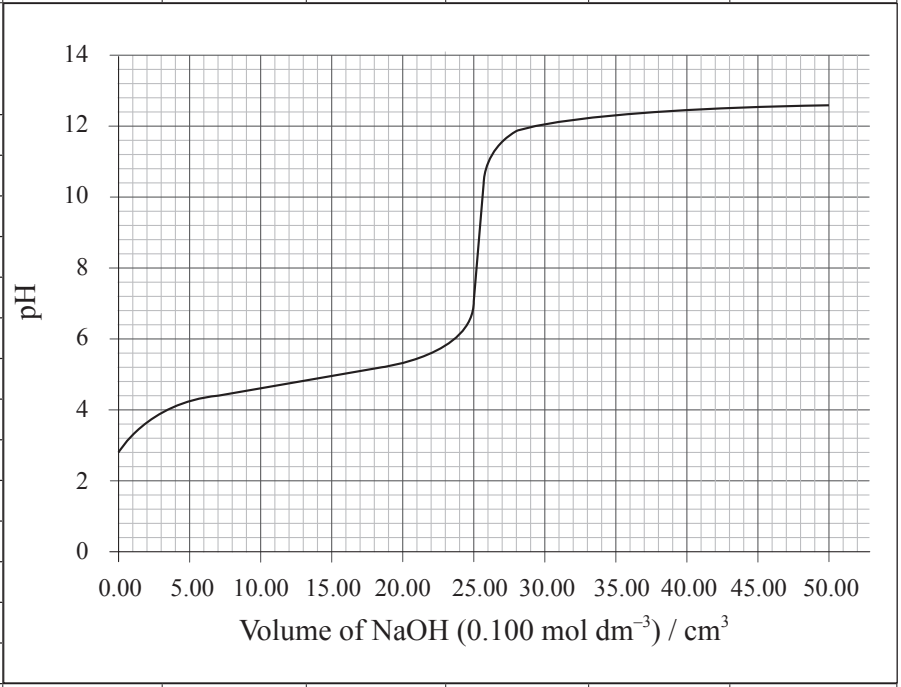
2	**Volume of NaOH (0.100 mol dm^{-3}) / cm^3**	**pH**
3	0.00	2.88
4	0.50	3.08
5	1.00	3.39
6	1.50	3.57
7	2.00	3.71
8	2.50	3.82
9	3.00	3.90
10	3.50	3.98
11	4.00	4.05
12	4.50	4.11
13	5.00	4.17
14	5.50	4.22
15	6.00	4.27
16	6.50	4.32
17	7.00	4.36
18	7.50	4.40
19	8.00	4.44
20	8.50	4.48
21	9.00	4.52
22	9.50	4.56
23	10.00	4.59
24	10.50	4.63
25	11.00	4.66
26	11.50	4.70
27	12.00	4.73
28	12.50	4.77
29	13.00	4.80
30	13.50	4.84
31	14.00	4.87



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(Question 6 continued)

Two different data points can be used to determine a value for the pK_a of HF (aq). Identify the data points and determine the pK_a using two different calculations. *[6]*

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(iii) Identify an indicator which could be used to find the equivalence point of the titration using Table 16 of the Data Booklet and explain your choice. *[2]*

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(Question 8 continued)

(d) A solution of ammonia has a concentration of 0.500 mol dm^{-3}.

Calculate the pH of the ammonia solution using information from Table 15 of the Data Booklet. State **one** assumption made. *[4]*

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(e) A buffer solution is made using 25.0 cm^3 of 0.500 mol dm^{-3} nitric acid, $HNO_3(aq)$, and 25.0 cm^3 of 1.00 mol dm^{-3} ammonia solution, $NH_3(aq)$.

(i) State the meaning of the term *buffer solution*. *[1]*

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(ii) Calculate the concentrations of ammonia and ammonium ion in the buffer solution. *[2]*

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(Question 8 continued)

(iii) Determine the pH of the buffer solution at 25 °C. *[2]*

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(iv) Explain why the pH of the buffer solution is different from the pH of the ammonia solution calculated in (d). *[1]*

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(v) Explain the action of the buffer solution when a few drops of nitric acid solution are added to it. *[2]*

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(Question 8 continued)

(f) Bromocresol green is an acid–base indicator. Information about bromocresol green is given in Table 16 of the Data Booklet.

(i) Identify the property of bromocresol green that makes it suitable to use as an acid–base indicator. *[1]*

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(ii) State and explain the relationship between the pH range of bromocresol green and its pK_a value. *[2]*

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3. Buffer solutions are widely used in both chemical and biochemical systems.

(a) Describe the composition of an acidic buffer solution. *[1]*

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(b) Determine the pH of a buffer solution, correct to **two** decimal places, showing your working, consisting of 10.0 g of CH_3COOH and 10.0 g of CH_3COONa in 0.250 dm^3 of solution. K_a for $CH_3COOH = 1.8 \times 10^{-5}$ at 298 K. *[5]*

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(Question 3 continued)

(d) (i) State an equation for the reaction of ethanoic acid with water. *[1]*

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(ii) Calculate the pH of 0.200 mol dm^{-3} ethanoic acid ($pK_a = 4.76$). *[3]*

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(e) Determine the pH of a solution formed from adding 50.0 cm^3 of 1.00 mol dm^{-3} ethanoic acid, $CH_3COOH(aq)$, to 50.0 cm^3 of 0.600 mol dm^{-3} sodium hydroxide, $NaOH(aq)$. *[4]*

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(f) Explain how the solution formed in part (e) can act as a buffer. Use equations to support your answer. *[2]*

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7. (a) Water is an important substance that is abundant on the Earth's surface.

(i) State the expression for the ionic product constant of water, K_w. *[1]*

(ii) Explain why even a very acidic aqueous solution still has some OH^- ions present in it. *[1]*

(iii) State and explain the effect of increasing temperature on the value of K_w given that the ionization of water is an endothermic process. *[3]*

(iv) State and explain the effect of increasing temperature on the pH of water. *[2]*

(b) Buffer solutions resist small changes in pH. A phosphate buffer can be made by dissolving NaH_2PO_4 and Na_2HPO_4 in water, in which NaH_2PO_4 produces the acidic ion and Na_2HPO_4 produces the conjugate base ion.

(i) Deduce the acid and conjugate base ions that make up the phosphate buffer and state the ionic equation that represents the phosphate buffer. *[3]*

(ii) Describe how the phosphate buffer minimizes the effect of the addition of a strong base, $OH^-(aq)$, to the buffer. Illustrate your answer with an ionic equation. *[2]*

(iii) Describe how the phosphate buffer minimizes the effect of the addition of a strong acid, $H^+(aq)$, to the buffer. Illustrate your answer with an ionic equation. *[2]*

(c) A 0.10 mol dm^{-3} ammonia solution is placed in a flask and titrated with a 0.10 mol dm^{-3} hydrochloric acid solution.

(i) Explain why the pH of the ammonia solution is less than 13. *[2]*

(ii) Estimate the pH at the equivalence point for the titration of hydrochloric acid with ammonia and explain your reasoning. *[2]*

(iii) State the equation for the reaction of ammonia with water and write the K_b expression for $NH_3(aq)$. *[2]*

(iv) When half the ammonia has been neutralized (the half-equivalence point), the pH of the solution is 9.25. Deduce the relationship between $[NH_3]$ and $[NH_4^+]$ at the half-equivalence point. *[1]*

(v) Determine pK_b and K_b for ammonia based on the pH at the half-equivalence point. *[3]*

(vi) Describe the significance of the half-equivalence point in terms of its effectiveness as a buffer. *[1]*

(Question 6 continued)

(c) A small piece of magnesium ribbon is added to solutions of nitric and hydrocyanic acid of the same concentration at the same temperature. Describe **two** observations that would allow you to distinguish between the two acids. *[2]*

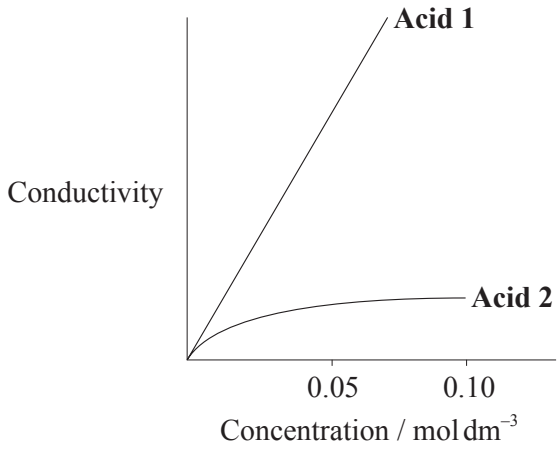
(d) A student decided to investigate the reactions of the two acids with separate samples of 0.20 mol dm^{-3} sodium hydroxide solution.

(i) Calculate the volume of the sodium hydroxide solution required to react exactly with a 15.0 cm^3 solution of 0.10 mol dm^{-3} nitric acid. *[1]*

(ii) The following hypothesis was suggested by the student: "Since hydrocyanic acid is a weak acid it will react with a smaller volume of the 0.20 mol dm^{-3} sodium hydroxide solution." Comment on whether or not this is a valid hypothesis. *[1]*

(iii) Use Table 16 of the Data Booklet to identify a suitable indicator for the titration of sodium hydroxide and hydrocyanic acid. *[1]*

(e) The graph below shows how the conductivity of the two acids changes with concentration.



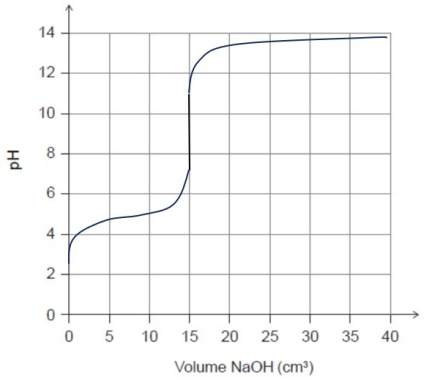
Identify **Acid 1** and explain your choice. *[2]*

IB Chemistry HL - Acid-Base

Official markscheme extracts for the curated question set

Answer sections are taken from the markschemes contained in the user-provided 2010-2025 master PDF.

Only the markscheme range for the selected question number is included; adjacent question content is clipped where the page layout allows.

5.	**(a)**		 Curve drawn by me non-symmetrical sigmoidal curve ***AND*** buffer region near pH 5 ✓ curve starting at pH 2-4 ***AND*** flattening out at pH>12 ✓ equivalence point pH 8-10 ***AND*** at volume of 15 cm^3 ✓	*Actual equivalence point is a 9.2 Near pH5 will be above 4 and below 6 and reasonably flat. The actual half neutralization point is pH 4.75.*	**3**

Question			Answers	Notes	Total
5.	**(b)**	**(i)**	high concentration of «both» acid ***AND*** «conjugate» base ✓ $n(CH_3COOH):n(NaOH) = 2:1$ ***OR*** *n*(acid):*n*(conjugate base) = 1:1 ***OR*** half-equivalence ✓	*Award 2 for "maximum possible/0.5 mol dm^{-3} concentration of acid **AND** conjugate base"*	**2**
5.	**(b)**	**(ii)**	*Addition of strong acid:* $CH_3COO^- + H^+ \rightarrow CH_3COOH$ ***OR*** $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$ ***AND*** reverse reaction favoured ✓ *Addition of strong base:* $CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$ ***OR*** $H^+ + OH^- \rightarrow H_2O$ ***AND*** more H^+ is released ***OR*** H^+ replaced <<by the acid>> ***OR*** $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$ ***AND*** forward reaction favoured ✓	*Accept equilibrium arrows only if statement of direction of shift is also given.*	**2**

3.	**(a)**	**(i)**	conjugate acid H_3O^+«(aq)» ***AND*** conjugate base H_2O«(l)» ✓ conjugate acid HNO_2«(aq)» ***AND*** conjugate base NO_2^-«(aq)» ✓		**2**
3.	**(a)**	**(ii)**	K_a «$10^{-3.25}$» = 5.62×10^{-4} ✓ « $[H^+] = 10^{-3.00}$ » = 0.001 «mol dm^{-3}» ✓ « $[A^-] = (5.62 \times 10^{-4} \times 1.00)/ 0.001$» = 0.562 «mol dm^{-3}» ✓ *Alternative solution:* pH = pK_a +$\log_{10}$[salt]/[acid] ✓ « $\log_{10}$[salt]/[acid]» = −0.25 ***OR*** «[salt]/[acid]» = 0.562✓ « $[A^-] = 0.562/1.00$» = 0.562 «mol dm^{-3}»✓	*Award **[3]** for correct final answer.*	**3**
3.	**(a)**	**(iii)**	+3 ✓	*Accept (III).* *Do **not** accept 3+ or 3.*	**1**

Question			Answers	Notes	Total
3.	(c)		$[H^+] = \sqrt{K_a \times [HCN]} \; / \; \sqrt{6.17 \times 10^{-10} \times 0.202}$ ✓ $[H^+] = 1.116 \times 10^{-5}$ «mol dm^{-3}» ✓ pH = 4.95 ✓	*Award **[3]** for correct final answer.*	**3**
3.	(c)	(ii)	$[H^+]$ << 0.202 / negligible dissociation ***OR*** $[H^+]$ from dissociation of H_2O negligible ✓	*Accept $[HCN]_{initial} = [HCN]_{eqm}$.*	**1**
3.	(c)	(iii)	combine «HCN» with «a similar concentration of» its conjugate base/CN^- ***OR*** partial neutralization «with strong base/OH^-» ✓	*Accept CN^- salts.*	**1**

Question			Answers	Notes	Total
5.	**(a)**	**(i)**	**«**n(NaOH) = n(H^+) = 0.150 x 20.0 x 10^{-3} =**»** 3.00×10^{-3} **«**mol**»** ***OR*** **«**volume at equivalence point =**»** 18.0 **«**cm^3**»** ✓ **«**[NaOH] =$\frac{3.00\times10^{-3}}{18.0\times10^{-3}}$ **»** = 0.167 **«**mol dm^{-3}**»** ✓	*Award **[2]** for correct final answer.*	**2**
5.	**(a)**	**(ii)**	**«**pK_a =**»** 4.8 ✓	*Accept answers in the range 4.7 – 4.9.*	
5.	**(a)**	**(iii)**	**«**conjugate**»** acid and base pair/forms **«**of phenolphthalein**»** have different colours ✓	*Do **not** accept just colorless in acid and pink in alkali.*	**1**

(continued…)

(Question 5 continued)

Question			Answers	Notes	Total
5.	**(a)**	**(iv)**	equivalence point falls within endpoint/pH range of indicator ***OR*** pH range of phenolphthalein is 8.3-10.0 ***AND*** pH at equivalence is within this range ***OR*** endpoint/pK_a «of phenolphthalein» is within vertical section of curve ✓		**1**
5.	**(b)**		***Alternative 1*:** *Method:* measure pH **«**of both acids**»** ✓ *Observation:* weak acid has higher pH ✓ ***Alternative 2:*** *Method:* react **«**both acids**»** with metal/metal oxide/hydroxide/hydrogen carbonate/carbonate ✓ *Observation:* weak acid reacts more slowly/less vigorously ✓ ***Alternative 3:*** *Method:* measure **«**electrical» conductivity ✓ *Observation:* weak acid has lower **«**electrical» conductivity ✓	*Accept specific examples for Alternative 2.* *Accept other suitable methods such as titration, indicator/pH paper, or enthalpy change and corresponding observations such as shape of curve/pH at equivalence point, colour, or enthalpy change/amount of heat released upon neutralization.*	**2**

(continued…)

(Question 5 continued)

Question			Answers	Notes	Total
5.	**(c)**	**(i)**	dissociation of water is endothermic ✓		**1**
5.	**(c)**	**(ii)**	**«**K_w = $[H^+][OH^-]$**»** **«**[H+] = $(9.55 \times 10^{-14})^{½}$ = 3.09×10^{-7}**»** pH = 6.51 ✓ pOH = 6.51 ✓	*Accept pOH = pH for M2.* *Award **[2]** for 6.51 without specifying whether it is pH or pOH.*	**2**

1.	**(a)**	**(i)**	$H_2O_{(l)} + HCl_{(g)} \rightarrow Cl^-_{(aq)} + H_3O^+_{(aq)}$ ✓✓	*One for the equation and one for the state symbols.* *Do not accept* $H_2O_{(l)} + H^+_{(g)} \rightarrow H_3O^+_{(aq)}$ *Do not accept equilibrium sign.*	**2**
1.	**(a)**	**(ii)**	«pH = $-\log_{10}[H^+] = -\log_{10}0.5$ =» 0.30 ✓		**1**
1.	**(a)**	**(iii)**	«Ethanoic acid» p*artially ionizes/dissociates/OWTTE* ***OR*** ***l**ower [H+]* ✓	*Do **not** accept weak acid only.* *Accept converse argument.*	**1**
1.	**(a)**	**(iv)**	conductivity/conductance meter/probe ***OR*** ammeter «with power supply» ✓	*Ignore any reference to indicators or any chemical methods.* *Accept Cl^- or ethanoate ion selective probe.*	**1**
1.	**(a)**	**(v)**	HCl higher conductivity «due to higher [ion]» ✓	*Accept explanation if alternative given in a(iv).* *Accept converse argument.* *Apply ECF for incorrect method.*	**1**

Question			Answers	Notes	Total
1.	(b)		Chemical test: use of carbonate/hydrogen carbonate/named metal ***AND*** Expected result: more bubbles per unit time/disappears faster/faster reaction in $HCl_{(aq)}$ ✓ ***OR*** Chemical test: add alkali/hydroxide/metal oxide ***AND*** Expected result: higher temperature rise with HCl ✓ ***OR*** Chemical test: add silver nitrate «solution»/$AgNO_3$«(aq)» ***AND*** Expected result: white precipitate/ppt. with HCl ✓	*Do **not** accept just metal.* *Accept active metal.* *Accept greater temperature change in place of more bubbles.*	**1**
1.	(c)	(i)	4.8 ✓	*Accept 4.7–4.9*	**1**

Question			Answers	Notes	Total
1.	(c)	(ii)	***ALTERNATIVE 1*** $HA + OH^- \rightleftharpoons A^- + H_2O$✓ added OH^- neutralized by HA ***OR*** strong base «OH^-» replaced by weak base «A^-»✓ ***ALTERNATIVE 2*** $HA \rightleftharpoons A^- + H^+$ ✓ added OH^- neutralized by H^+ ***OR*** strong base «OH^-» replaced by weak base «A^-»✓	*Must show* $\rightleftharpoons$ *for M1* *Accept molecular equation.* *Allow reference to Châtelier principle for M2*	**2**
1.	(c)	(iii)	$n(NH_3)_{init}$ = «0.08 dm^3 × 0.1 mol dm^{-3} =» 0.008 mol ***AND*** $n(HCl)_{init}$ = «0.04 dm^3 × 0.1 mol dm^{-3} =» 0.004 mol ✓ $n(NH_3)_{fin}$ = «0.008 mol – 0.004 mol =» 0.004 mol ***AND*** $n(NH_4^+)_{fin}$ = 0.004 mol ✓ «V_{fin} = 0.08 dm^3 + 0.04 dm^3 = 0.12 dm^3» «$c(NH_3)_{fin}$ = $c(NH_4^+)_{fin}$ = 0.004 mol/0.12 dm^3 = 0.033 mol dm^{-3}» $pK_a(NH_4^+)$ = «14 – $pK_b(NH_3)$ = 14 – 4.75 =» 9.25 ✓ pH = «9.25 + log(0.033/0.033) =» 9.25 ***OR*** pH = «9.25 + log(0.004/0.004) =» 9.25 ✓	*Award* ***[4]*** *for the correct final answer.* *Accept alternate working.*	**4**

Question			Answers	Notes	Total
4.	a		conjugate «acid and base» ✓		1
4.	b		amount of ammonia $\langle\langle = \frac{P.V}{R.T} = \frac{100.0\ kPa \times 900.0\ dm^3}{8.31\ J\ K^{-1}mol^{-1} \times 300.0\ K} \rangle\rangle$ = 36.1 «mol» ✓ concentration $\langle\langle = \frac{n}{V} = \frac{36.1}{2.00} \rangle\rangle$ = 18.1 «mol dm^{-3}» ✓	*Award **[2]** for correct final answer.*	2
4.	c	i	$[OH^-]\ \langle\langle = \frac{K_w}{[H^+]} = \frac{10^{-14}}{10^{-9.3}} = 10^{-4.7} \rangle\rangle = 2.0 \times 10^{-5}\ \langle\langle \text{mol dm}^{-3} \rangle\rangle$ ✓		1
4.	c	ii	$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$ / $\frac{10^{-4.7} \times 10^{-4.7}}{[NH_3]} \langle\langle = 10^{-4.75} \rangle\rangle$ ✓ $[NH_3] = \langle\langle = \frac{10^{-9.4}}{10^{-4.75}} = 10^{-4.65} \rangle\rangle$ = 2.24×10^{-5} «mol dm^{-3}» ✓	*Accept other methods of carrying out the calculation.* *Award **[2]** for correct answer.*	2

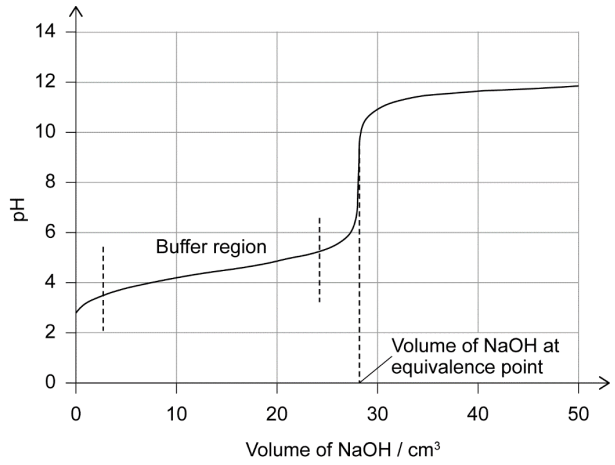
Question			Answers	Notes	Total
7.	a	i	donates «lone/non-bonding» pair of electrons ✓		1
7.	a	ii	$Kb = 10^{-4.75} / 1.78 \times 10^{-5}$ ***OR*** $Kb = \frac{[OH^-]^2}{[NH_3]}$ ✓ $[OH^-] =$ **«**$\sqrt{(1.00 \times 10^{-2} \times 10^{-4.75})}$ **=»** 4.22×10^{-4} **«**(mol dm^{-3})**»** ✓ pOH**«** $= -\log_{10}(4.22 \times 10^{-4})$**»** = 3.37 ***AND*** pH **= «**14 **–** 3.37**»** = 10.6 ***OR*** $[H^+]$**«** $= \frac{1.00 \times 10^{-14}}{4.22 \times 10^{-4}}$ **»** $= 2.37 \times 10^{-11}$ ***AND*** pH**«** $= -\log_{10} 2.37 \times 10^{-11}$**»** = 10.6 ✓	*Award **[3]** for correct final answer.*	3

(continued…)

(*Question 7 continued)*

Question			Answers	Notes	Total
7.	**a**	**iii**	no ***AND*** is not a weak acid conjugate base system ***OR*** no ***AND*** weak base **«**totally**»** neutralized/ weak base is not in excess ***OR*** no ***AND*** will not neutralize small amount of acid ✓	*Accept "no **AND** contains 0.10 mol NH_4Cl + 0.10 mol HCl"*.	**1**

Question			Answers	Notes	Total
4.	a	i	$C_6H_8O_7$ ***AND*** $C_6H_7O_7^-$ ***OR*** H_2O ***AND*** H_3O^+ ✓		1
4.	a	ii	weak acid ***AND*** partially dissociated ***OR*** weak acid ***AND*** equilibrium lies to left ***OR*** weak acid ***AND*** $K_a < 1$ ✓		1
4.	a	iii	**Effect on $[H^+]$** | **Effect on K_a^+** increases ✓ | increases ✓		2
4.	a	iv	«$\Delta G^\ominus = -RT\ln K = -8.31\,J\,K^{-1}\,mol^{-1} \times 298\,K \times \ln(5.01 \times 10^{-4}) \div 1000 =$» 18.8 «$kJ\,mol^{-1}$» ✓		1

Question			Answers	Notes	Total
5.	**a**		 buffer region on graph ✓ equivalence point/V_{eq} on graph ✓	*Construction lines not required.*	**2**
5.	**b**	**i**	phenolphthalein ✓	*Accept phenol red.*	**1**

(continued…)

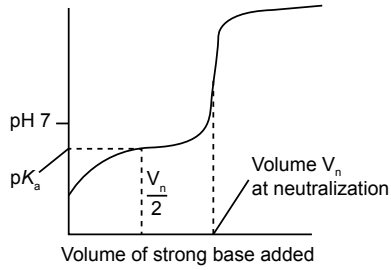
(Question 5b continued)

Question			Answers	Notes	Total
5.	b	ii	***ALTERNATIVE 1:*** $H^+(aq) + CH_3COO^-(aq) \rightarrow CH_3COOH(aq)$ ✓ added acid neutralised by ethanoate ions ***OR*** «weak» $CH_3COOH(aq)$/ethanoic acid replaces $H^+(aq)$ ***OR*** CH_3COOH/CH_3COO^- ratio virtually/mostly unchanged ✓ ***ALTERNATIVE 2:*** $CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$ ✓ equilibrium shifts to the ethanoic acid side ***OR*** CH_3COOH/CH_3COO^- ratio virtually/mostly unchanged ✓		**2**

Question			Answers	Notes	Total
7.	**a**		*Calculation*: ***ALTERNATIVE 1:*** $[H^+] = (K_a \times [HA])^{1/2} / (1.6 \times 10^{-4} \times 0.0100)^{1/2} / 1.3 \times 10^{-3}$ **«**mol dm^{-3}**»** ✓ pH = **«**$-\log_{10}[H^+]$ ≈**»** 2.9 ✓ ***ALTERNATIVE 2:*** pH = 0.5(pK_a − $\log_{10}$[HA]) ✓ pH = 2.9 ✓ *Assumption*: ionisation is << 0.0100 so 0.0100 − [A^-] ≈ 0.0100 ***OR*** $[HA]_{eqm} = [HA]_{initial}$ ***OR*** all H^+ ions in the solution come from the acid **«**and not from the self-ionisation of water**»** ***OR*** $[H^+] = [HCOO^-]$ ✓	*Award **[2]** for correct final answer.* *Do not accept partial dissociation.*	**3**

(continued)

(Question 7 continued)

Question			Answers	Notes	Total
	b	i	 correct shape of graph ✓ pH at half neutralization/equivalence ✓	*M1: must show buffer region at pH < 7 and equivalence at pH > 7.* *Accept graph starting from where two axes meet as pH scale is not specified.*	**2**
	b	ii	***ALTERNATIVE 1:*** $HCOOH \rightleftharpoons HCOO^- + H^+$ ✓ H^+ ions consumed in reaction with OH^- are produced again as equilibrium moves to the right «so $[H^+]$ remains almost unchanged» ✓ ***ALTERNATIVE 2:*** $HCOOH + OH^- \rightleftharpoons HCOO^- + H_2O$ ✓ added OH^- are neutralized by HCOOH ***OR*** strong base replaced by weak base ✓	*Accept HA or any other weak acid in equations.* *Equilibrium sign must be included in equation for M1.*	**2**

6. (a) $[H_3O^+] = \frac{K_w}{[OH^-]} = \frac{(1.00\times10^{-14})}{(3.98\times10^{-3})} = 2.51\times10^{-12}\,(\text{mol dm}^{-3})$;

$\text{pH}\left(= -\log[H_3O^+] = -\log(2.51\times10^{-12})\right) = 11.6$; ***[2]***

OR

$\text{pOH} = \left(-\log(5.98\times10^{-3}) =\right) 2.4$;

$\text{pH} = (14.00 - 2.40) = 11.6$;

*Award **[2]** for correct final answer.*
Allow correct use of H^+ instead of H_3O^+ throughout.

(b) (i) *Brønsted-Lowry theory:*
proton/H^+ donor;

Lewis theory:
electron pair acceptor; ***[2]***

(ii) *Strong acid:* acid/electrolyte (assumed to be almost) completely/100% dissociated/ionized (in solution/water) / *OWTTE* **and** *Weak acid:* acid/electrolyte partially dissociated/ionized (in solution/water) / *OWTTE*; ***[1]***

(c) (i)

Mixture	Buffer
HCOOH and KHCOO	Yes
HCl and excess NH_3	Yes;

[1]

*Award **[1]** for both "yes".*
*Award **[0]** for any "no".*

(ii) $K_a = \frac{[H_3O^+][X^-]}{[HX]}$ / $[H_3O^+] = \frac{K_a[HX]}{[X^-]}$;

$[H_3O^+] = \frac{1.40\times10^{-4}\times1.55\times10^{-1}}{1.05\times10^{-1}}$;

$[H_3O^+] = 2.07\times10^{-4}\,(\text{mol dm}^{-3})$;

$\text{pH}\left(= -\log(2.07\times10^{-4})\right) = 3.68$;

OR

$pK_a = 3.854$;

$\text{pH} = pK_a + \log\frac{[X^-]}{[HX]}$ / $\text{pH} = pK_a - \log\frac{[HX]}{[X^-]}$;

$\text{pH} = 3.854 - 0.169$;

$\text{pH} = 3.68$; ***[4]***

*Award **[4]** for correct final answer.*
Allow correct use of H^+ instead of H_3O^+ throughout.
Allow acid for HX, conjugate base/salt for X^- throughout.

(d) (i) $\underset{\text{Colour A}}{HIn(aq)} \rightleftharpoons \underset{\text{Colour B}}{H^+(aq) + In^-(aq)}$ / $\underset{\text{Colour A}}{HIn(aq)} + H_2O(l) \rightleftharpoons \underset{\text{Colour B}}{In^-(aq)} + H_3O^+(aq)$;

Allow statement such as solution of weak acid with different colours for conjugate base/$In^-(aq)$ ***and*** *undissociated acid/HIn(aq) / OWTTE.*
Equilibrium sign required.
Ignore state symbols.
Allow corresponding argument for an indicator as a weak base.
for example, $BOH(aq) \rightleftharpoons B^+(aq) + OH^-(aq)$ etc.

in acid/presence of H^+ equilibrium lies to left (so colour A);
in alkali/base/presence of OH^- equilibrium lies to right (so colour B);
colour changes/end point when $[HIn(aq)] \approx [In^-(aq)]$; ***[3 max]***

(ii) phenolphthalein/phenol red;
indicator changes colour in range of pH at equivalence point which is above 7 / *OWTTE*; ***[2]***
M2 can be scored independently even if indicator is incorrect.
Accept it is a titration of weak acid with a strong base for M2.

(iii) $n(HCl)\left(=\frac{(150\times5.00\times10^{-1})}{(1000)}\right) = 7.50\times10^{-2}(\text{mol})$ **and**

$n(NaOH)\left(=\frac{(300\times2.03\times10^{-1})}{(1000)}\right) = 6.09\times10^{-2}(\text{mol})$;

$n(HCl)_{\text{remaining}}(=(7.50-6.09)\times10^{-2}) = 1.41\times10^{-2}(\text{mol})$;

$[HCl] = (1.41\times10^{-2})(1000)/(450) = 3.13\times10^{-2}(\text{mol dm}^{-3})$;

$pH = 1.50$; ***[4]***

Award ***[4]*** *for correct final answer.*
Award ***[3max]*** *for $pH = -\log(1.41\times10^{-2}) = 1.85$.*

(e) (i) *$FeCl_3$:*
acidic;
Fe^{3+} ion attracts electrons in OH bonds of water ligands releasing H^+ ions (due to high charge density) / *OWTTE*;
Accept suitable equations such as $[Fe(H_2O)_6]^{3+} \rightleftharpoons [Fe(H_2O)_5(OH)]^{2+} + H^+$ / $[Fe(H_2O)_6]^{3+} + H_2O \rightleftharpoons [Fe(H_2O)_5(OH)]^{2+} + H_3O^+$ for M2.
Accept equations indicating the formation of $[Fe(H_2O)_4(OH)_2]^+$, $[Fe(H_2O)_3(OH)_3]$, $[Fe(H_2O)_2(OH)_4]^-$.
Do not penalize $\rightarrow$.
M2 can only be awarded if M1 correct.

$CH_3CH_2NH_3NO_3$:
acidic;
$CH_3CH_2NH_3^+$ is conjugate acid of weak base, $CH_3CH_2NH_2$ so acidic and NO_3^- is conjugate base of strong acid, HNO_3, so pH-neutral / salt of a weak base and a strong acid / *OWTTE*; ***[4]***
M4 can only be awarded if M3 correct.
Do not allow the salt produces a strong acid and weak base in solution.

(ii) acidic;
$K_a(NH_4^+) > K_b(F^-)$ / $pK_a(NH_4^+) < pK_b(F^-)$; ***[2]***
*M2 can only be awarded if M1 correct but award **[1max]** for neutral as salt of weak acid and weak base.*

(c) (i) H–F bond stronger than H–Cl bond / H–Cl bond weaker than H–F bond; ***[1]***

(ii) H–F can hydrogen bond to water **and** H–Cl cannot; ***[1]***

(d) (i) not a good choice / poor choice;
requires same volume of base / the amount/volume to react/for neutralization does not depend on the acid strength; ***[2]***

(ii) phenolphthalein / phenol red;
pH at equivalence point 7 or above; ***[2]***
Accept pH range for colour change/end-point corresponds to rapid change in pH.

(iii) sulfuric acid is diprotic/dibasic/liberates two protons/H^+; ***[1]***
Accept "reacts with 2 moles of alkali/base".

(iv) weak;
strong $0.100\,\text{mol dm}^{-3}$ acid has a pH of 1/lower than that observed; ***[2]***
Accept "pH value of 3.7 means that it produces only $10^{-3.7}/2.0\times10^{-4}$ $[H^+]$ in water".

(e) (i) when volume of alkali is half equivalence volume/volume required for neutralization;
pK_a is equal to the pH; ***[2]***

(ii) $[H^+] = 10^{-3.7} = 2.00\times10^{-4}\,(\text{mol dm}^{-3})$;

$$K_a = \frac{[H^+][Q^-]}{[HQ]} = \frac{(2.00\times10^{-4})^2}{0.100};$$

$= 3.98\times10^{-7}$;

$pK_a = 6.4$; ***[4]***

*Award **[4]** for correct final answer.*

(f) amount NaQ = amount NaOH $= 0.001\,(\text{mol})$;

excess HQ $= 0.004 - 0.001 = 0.003\,(\text{mol})$;

$[\text{Q}^-] = 0.001 \times \dfrac{1000}{50} = 0.02\,(\text{mol dm}^{-3})$ **and** $[\text{HQ}] = 0.003 \times \dfrac{1000}{50} = 0.06\,(\text{mol dm}^{-3})$;

$[\text{H}^+] = K_\text{a} \dfrac{[\text{HQ}]}{[\text{Q}^-]} = 1.8 \times 10^{-5} \dfrac{0.06}{0.02} = 5.4 \times 10^{-5}\,(\text{mol dm}^{-3})$;

$\text{pH} = -\log(5.4 \times 10^{-5}) = 4.268$; ***[5]***

Accept other methods of reaching the answer.

*Award **[3 max]** if final answer given without working.*

(d) (i) *Strong acid:* acid/electrolyte (assumed to be almost) 100%/completely dissociated/ionized (in solution/water) / *OWTTE* **and** *Weak acid:* acid/electrolyte only partially/slightly dissociated/ionized (in solution/water) / *OWTTE*;

$HBr(aq) \rightarrow H^+(aq) + Br^-(aq)$;

$HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$; ***[3]***

(ii) *Data points:*
(0.00, 2.88) **and** (12.50, 4.77);

For first point also accept volume = 0.00 with pH in range 2.8–2.9.
For second point also accept either:
volume in range between 12.5–12.6 and pH 4.8–4.9
OR
volume in range between 25.0–25.2 and pH 8.0–10.0

For (0.00, 2.88):
$[H^+] = [F^-]$;

$pK_a = 2pH - 1$ / $K_a = \frac{[H^+]^2}{0.100}$;

For (12.50, 4.77):
$[HF] = [F^-]$;
$pK_a = pH$;

$pK_a = 4.77$; ***[6]***
Accept any value in range 4.7–4.9 if consistent with data points.
Accept alternative calculation method if other data points from the table or graph are used and the pK_a in correct range.

(iii) bromothymol blue / phenol red / phenolphthalein;
pK_a/end point of indicator in range 7–10 as pH at equivalence in range 7–10; ***[2]***

(e) (i) *Br_2:* 0
HBr: –1
HOBr: +1 ***[2]***
*Award **[2]** for three correct.*
*Award **[1]** for any two correct.*

(ii) bromine is oxidized **and** reduced / disproportionation; ***[1]***

(iii) $K_c < 1$; ***[1]***

(f) (i) F_2/fluorine; ***[1]***
Do not allow F.

(ii) 50 (cm^3) / 0.050 dm^3; ***[1]***

(d) $[OH^-] = \left(\sqrt{0.500 \times 1.78 \times 10^{-5}}\right) = 2.98 \times 10^{-3}\ \text{mol dm}^{-3}$;

$\text{pOH} = -\log_{10}[OH^-] = 2.526$ / $[H^+] = \left(\frac{1.00 \times 10^{-14}}{2.98 \times 10^{-3}}\right) = 3.35 \times 10^{-12}\ \text{mol dm}^{-3}$;

$\text{pH} = 11.47$;

Accept correct answer obtained using another method.

Assumption:
$[NH_3] = 0.500\ \text{mol dm}^{-3}$ / $[NH_4^+] = [OH^-]$ / all OH^- ions come from the reaction of ammonia with water and not from the dissociation of water / temperature is 25 °C/298 K / *OWTTE*; ***[4]***

(e) (i) resists change in pH when <u>small</u> amounts of a strong base/strong acid/water are added to it; ***[1]***

(ii) $[NH_3] = 0.250\ \text{mol dm}^{-3}$;
$[NH_4^+] = 0.250\ \text{mol dm}^{-3}$; ***[2]***

(iii) $\text{pOH} = \text{p}K_\text{b} = 4.75$;
$\text{pH} = 9.25$; ***[2]***

(iv) equilibrium shifted left in buffer / *OWTTE*; ***[1]***

(v) acid neutralized by hydroxide / most of the added H^+ ions react with NH_3;
more ammonia reacts with water to replace hydroxide ions / more NH_4^+ ions form so there is little change in the pH / *OWTTE*; ***[2]***
Accept equations.

(f) (i) colours of HIn and In^- are different / *OWTTE*; ***[1]***

(ii) colour change occurs when $[HIn] = [In^-]$;
$\text{pH} = \text{p}K_\text{a}$;

OR

pH range is a range of pH values either side of pK_a value;
lower pH when acid colour is seen **and** upper pH when alkaline colour seen; ***[2]***

3. (a) (solution containing significant/equal amounts of a) weak acid **and** its salt / (solution containing) strong base to which excess of weak acid has been added / *OWTTE*; ***[1]***

*Accept (solution containing) weak acid **and** conjugate base.*
Do not accept descriptions with specific compounds alone (e.g. CH_3COOH and CH_3COONa) unless compounds are stated as weak acid and its salt.
Accept answer such as (solution containing) x mol of weak acid and $\frac{1}{2}x$ mol of strong base.

(b) $M_r(CH_3COOH) = 60.06$ **and** $M_r\ CH_3COONa = 82.04$;
$[CH_3COOH] = 6.66\times10^{-1}/0.666\ \text{mol dm}^{-3}$;

$[CH_3COO^-] = 4.88\times10^{-1}/0.488\ \text{mol dm}^{-3}$;
$[H_3O^+]/[H^+] = (1.8\times10^{-5}\times6.66\times10^{-1})/4.88\times10^{-1} = 2.46\times10^{-5}/0.0000246\ \text{mol dm}^{-3}$;

$\text{pH} = \left(-\log[H_3O^+] = -\log(2.46\times10^{-5}) =\right) 4.61\ (2\text{dp})$;
*Award **[5]** for correct final answer of pH = 4.61 with some working shown.*
*Award **[2 max]** for pH = 4.61 without any working at all shown.*
Two decimal places are required for M5.

OR

$M_r(CH_3COOH) = 60.06$ **and** $M_r\ CH_3COONa = 82.04$;
$[CH_3COOH] = 6.66\times10^{-1}/0.666\ \text{mol dm}^{-3}$;

$[CH_3COO^-] = 4.88\times10^{-1}/0.488\ \text{mol dm}^{-3}$;

$\text{pH} = -\log(1.8\times10^{-5}) + \log\frac{[\text{salt}]}{[\text{acid}]}$;
$= \left(4.74 + \log\frac{0.488}{0.666} = 4.74 - 0.135 =\right) 4.61\ (2\text{dp})$; ***[5]***

M4 can be scored even if not explicitly stated if M5 is correct based on previous values.
*Award **[5]** for correct final answer of pH = 4.61 with some working shown.*
*Award **[2 max]** for pH = 4.61 without any working at all shown.*
Two decimal places are required for M5.

(d) (i) $CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$;

OR

$CH_3COOH(l) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$;

OR

$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$; ***[1]***

Must include $\rightleftharpoons$.
Ignore state symbols.

(ii) $K_a = 10^{-4.76} / 1.74 \times 10^{-5}$

$1.74 \times 10^{-5} = \frac{[H^+]^2}{0.200}$ / $[H^+] = 0.00187$;

pH = 2.73; ***[3]***

*Award **[3]** for correct final answer, allow mark for correct conversion of $[H^+]$ to pH even if $[H^+]$ incorrect.*

(e) (initial) $[CH_3COOH] = 0.500$ mol dm^{-3} and) eqm $[CH_3COOH] = 0.200$ mol dm^{-3};
(initial) $[CH_3COO^-] = 0.300$ mol dm^{-3} and) eqm $[CH_3COO^-] = 0.300$ mol dm^{-3};
Allow 0.02 moles and 0.03 moles instead of 0.200 and 0.300 mol dm^{-3}.

$$[H^+] = K_a \frac{[CH_3COOH]}{[CH_3COO^-]} = 1.16 \times 10^{-5} \text{ mol dm}^{-3} / \text{ pH} = pK_a + \log \frac{[SALT]}{[ACID]};$$

pH = 4.94; ***[4]***

*Award **[3 max]** for correct final answer if no working shown.*

(f) (if acid added) $CH_3COO^- + H^+ \rightarrow CH_3COOH$;
(if alkali added) $CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$; ***[2]***

Explanation marks cannot be awarded without equations.
Accept $H^+ + OH^- \rightarrow H_2O$ as OH^- reacts with H^+ in the buffer to form water.

7. (a) (i) $(K_w) = [H^+][OH^-] / (K_w) = [H_3O^+][OH^-]$; ***[1]***

Do not award mark if [ ] omitted or other brackets are used.

(ii) $[H^+]$ increases, $[OH^-]$ decreases but still some present (K_w constant) / $[OH^-]$ cannot go to zero as equilibrium present / $[OH^-] = \frac{K_w}{[H^+]}$, thus $[OH^-]$ cannot be zero / *OWTTE*; ***[1]***

(iii) (changing T disturbs equilibrium) endothermic reaction / forward reaction favoured / equilibrium shifts to the right;
to use up (some of the) heat supplied;
K_w increases (as both $[H^+]$ and $[OH^-]$ increase); ***[3]***

(iv) (as $[H^+]$ increases) pH decreases / pH < 7;
No mark for more acidic.
inverse relationship between pH and $[H^+] / \text{pH} = -\log[H^+] / \text{pH} = \log_{10} \frac{1}{[H^+]}$; ***[2]***
Accept $[H_3O^+]$ in place of $[H^+]$.

(b) (i) *Acid*: $H_2PO_4^-$;
(Conjugate) base: HPO_4^{2-};
No mark for NaH_2PO_4 or Na_2HPO_4.

$H_2PO_4^-(aq) \rightleftharpoons H^+(aq) + HPO_4^{2-}(aq)$; ***[3]***
Accept reverse equation or reaction with water.
Ignore state symbols, but equilibrium sign is required.
Accept OH^- (ions) react with H^+ (ions) to form H_2O.

(ii) strong base/OH^- replaced by weak base (HPO_4^{2-}, and effect minimized) / strong base reacts with acid of buffer / equilibrium in (i) shifts in forward direction;

$OH^-(aq) + H_2PO_4^-(aq) \rightarrow H_2O(l) + HPO_4^{2-}(aq)$; ***[2]***
Ignore state symbols, accept equilibrium sign.
Accept OH^- added reacts with H^+ to form H_2O.

(iii) strong acid/H^+ replaced by weak acid ($H_2PO_4^-$, and effect minimized) / strong acid reacts with base of buffer / equilibrium in (i) shifts in reverse direction;
$H^+(aq) + HPO_4^{2-}(aq) \rightarrow H_2PO_4^-(aq)$; ***[2]***
Accept reaction with H_3O^+.
Ignore state symbols.

(c) (i) NH_3 weak(er) base/partial dissociation;
$[OH^-] < 0.1(0)$ /pOH > 1 (thus pH < 13 / pH + pOH = 14); ***[2]***

(ii) around $pH = 5$;
Accept a value between 4 and 6.

strong acid–weak base titration, (thus acidic) / at equivalence point, NH_4^+ present is acidic / $NH_4^+ \rightleftharpoons NH_3 + H^+$; ***[2]***

(iii) $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$;
Ignore state symbols, but equilibrium sign required.

$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$; ***[2]***

(iv) $[NH_3] = [NH_4^+]$; ***[1]***

(v) $pOH = 14.00 - 9.25 = 4.75$;
$pK_b\ (= pOH) = 4.75$;
$K_b = 1.78 \times 10^{-5}$; ***[3]***
Ignore units.
*Award **[3]** for correct final answer.*

(vi) optimum/most effective/highest buffer capacity/50%–50% buffer/equally effective as an acidic buffer and a basic buffer / *OWTTE*; ***[1]***

(c) *With HNO_3 :*
faster rate of bubble/hydrogen/gas production;
faster rate of magnesium dissolving;
higher temperature change; ***[2 max]***
Accept opposite argument for HCN.
Reference to specific observations needed.
*Award **[1]** if 2 observations given but acid is not identified.*

(d) (i) (nitric acid) $7.5\,cm^3$; ***[1]***

(ii) not valid as hydrocyanic acid reacts with same volume/ $7.5\,cm^3$; ***[1]***

(iii) bromothymol blue / phenol red / phenolphthalein; ***[1]***

(e) HNO_3;
(higher conductivity for solutions with same concentration as) there are more ions in solution; ***[2]***