A-Level Chemistry

pH Curves and Titrations

Question Paper

Time available: 61 minutes
Marks available: 53 marks

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1. This question is about pH.

Pure water dissociates slightly.

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq) \qquad \Delta H = +57 \text{ kJ mol}^{-1}$$

The equilibrium constant, $K_c = \frac{[H^+][OH^-]}{[H_2O]}$

The ionic product of water, $K_w = [H^+][OH^-]$

(a) Explain why $[H_2O]$ is not shown in the K_w expression.

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(1)

Table 1 shows how K_w varies with temperature.

Table 1

Temperature / °C	**K_w / mol^2 dm^{-6}**
10	2.93×10^{-15}
20	6.81×10^{-15}
25	1.00×10^{-14}
30	1.47×10^{-14}
50	5.48×10^{-14}

(b) Explain why the value of K_w increases as the temperature increases.

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(2)

(c) Give the expression for pH.

Calculate the pH of pure water at 50 °C
Give your answer to 2 decimal places.

Explain why water is neutral at 50 °C

Expression ____

Calculation

pH ________________

Explanation ____

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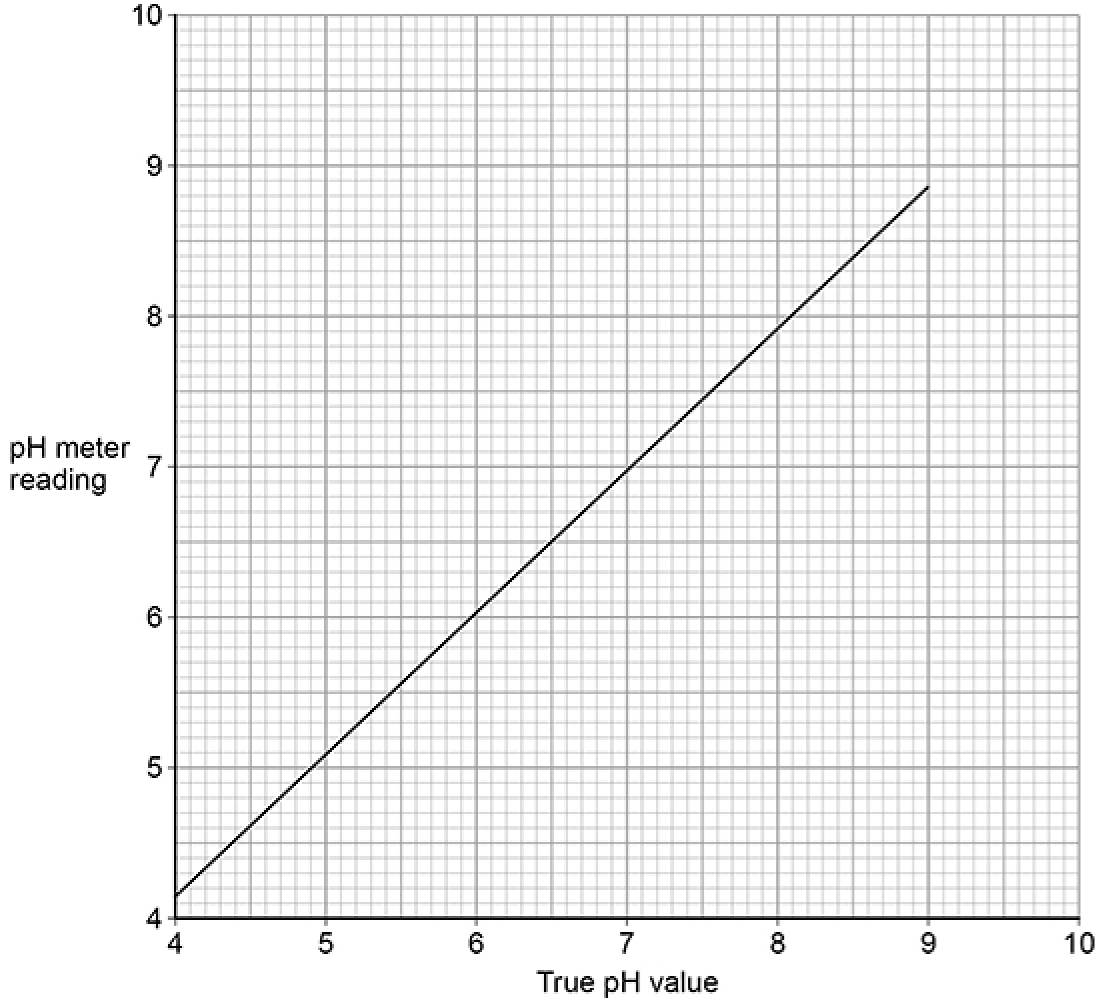
(4)

A pH meter is calibrated using a calibration graph.
To create the calibration, the pH meter is used to measure the pH of separate solutions, each with a known, accurate pH.

Figure 1 shows the calibration graph.

Figure 1



(d) Use **Figure 1** to give the true pH value when the pH meter reading is 5.6

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(1)

(e) Suggest why the pH probe is washed with distilled water between each of the calibration measurements.

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(1)

(f) The calibrated pH meter is used to monitor the pH during a titration of hydrochloric acid with sodium hydroxide.

Explain why the volume of sodium hydroxide solution added between each pH measurement is smaller as the end point of the titration is approached.

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(1)

Figure 2 shows the pH curve for a titration of hydrochloric acid with sodium hydroxide solution.

Figure 2

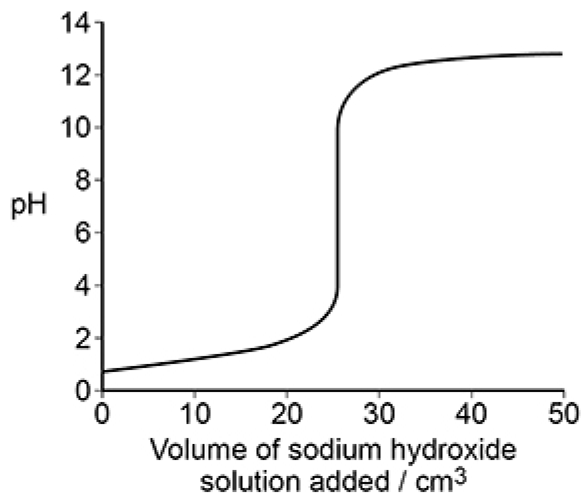

Table 2 shows data about some indicators.

Table 2

Indicator	**pH range**	**Colour at low pH**	**Colour at high pH**
Bromocresol green	3.8 – 5.4	yellow	blue
Phenol red	6.8 – 8.4	yellow	red
Thymolphthalein	9.3 – 10.5	colourless	blue

The student plans to do the titration again using one of the indicators in **Table 2** to determine the end point.

(g) State why all three of the indicators in **Table 2** are suitable for this titration.

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(1)

(h) 36.25 cm^3 of 0.200 mol dm^{-3} sodium hydroxide solution are added to 25.00 cm^3 of 0.150 mol dm^{-3} hydrochloric acid.

Calculate the pH of the final solution at 25 ºC

$K_w = 1.00 \times 10^{-14}$ mol^2 dm^{-6} at 25 ºC

pH _______________

(5)

(Total 16 marks)

2. This question is about different pH values.

(a) For pure water at 40 °C, pH = 6.67
A student thought that the water was acidic.

Explain why the student was incorrect.

Determine the value of K_w at this temperature.

Explanation ____

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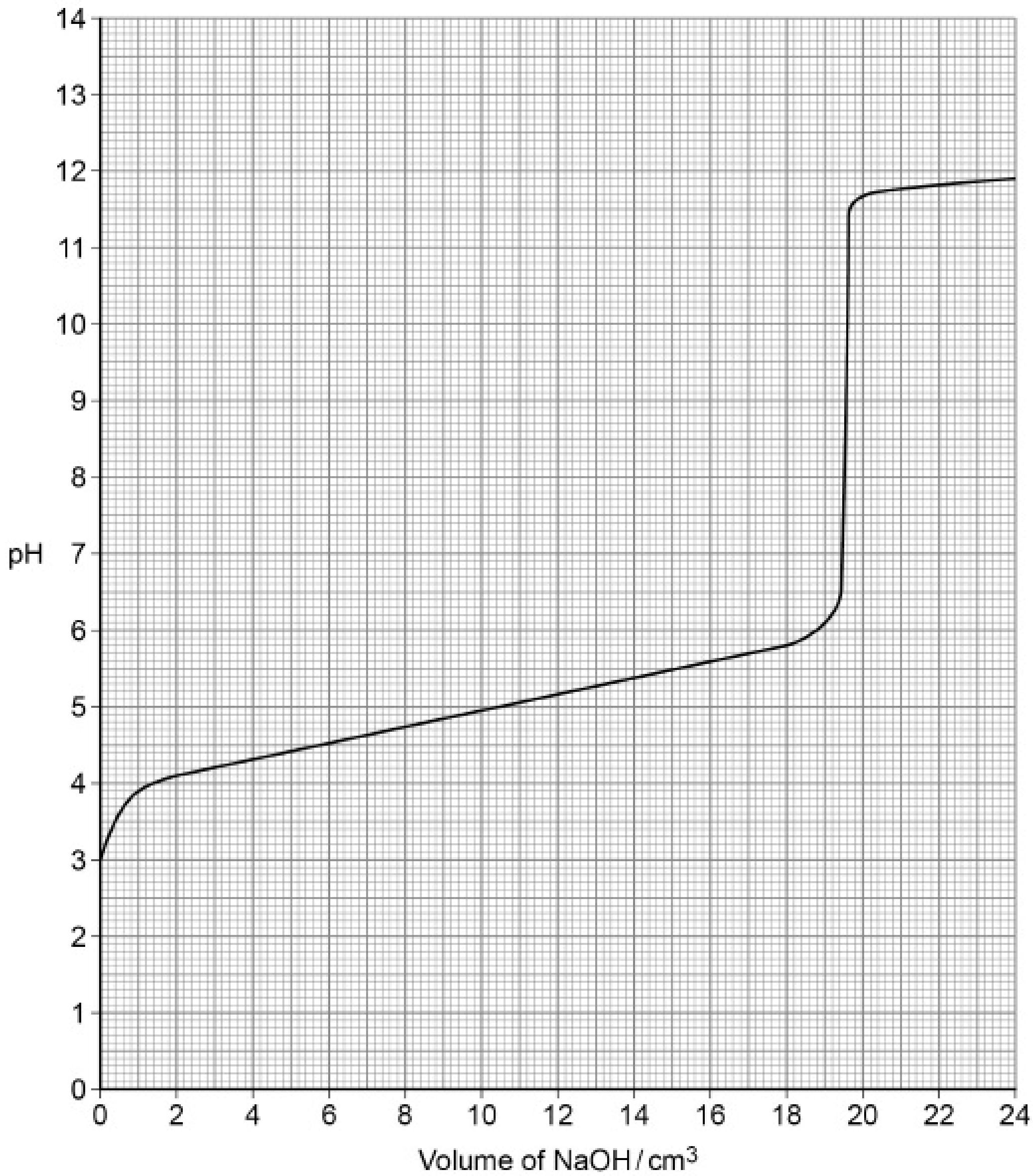
K_w ______________________ $mol^2\ dm^{-6}$

(4)

(b) Sodium hydroxide solution was added gradually from a burette to 25 cm^3 of 0.080 mol dm^{-3} propanoic acid at 25 °C
The pH was measured and recorded at regular intervals.

The results are shown in the diagram.



Use the diagram above to determine the value of K_a for propanoic acid at 25 °C

Show your working.

K_a ______________________________ mol dm^{-3}

(3)

(c) Suggest which indicator is the most appropriate for the reaction in part **(b)**?
Tick (✓) **one** box.

Indicator	**pH range**	**Tick (✓) one box**
methyl orange	3.1 - 4.4	
bromothymol blue	6.0 - 7.6	
cresolphthalein	8.2 - 9.8	
indigo carmine	11.6 - 13.0	

(1)

(d) A student prepared a buffer solution by adding 0.0136 mol of a salt KX to 100 cm^3 of a 0.500 mol dm^{-3} solution of a weak acid HX and mixing thoroughly.

The student then added 3.00×10^{-4} mol of potassium hydroxide to the buffer solution.

Calculate the pH of the buffer solution after adding the potassium hydroxide.

For the weak acid HX at 25 °C the value of the acid dissociation constant, $K_a = 1.41 \times 10^{-5}$ mol dm^{-3}.

Give your answer to two decimal places.

pH ______________________________

(6)

(e) A buffer solution has a constant pH even when diluted.

Use a mathematical expression to explain this.

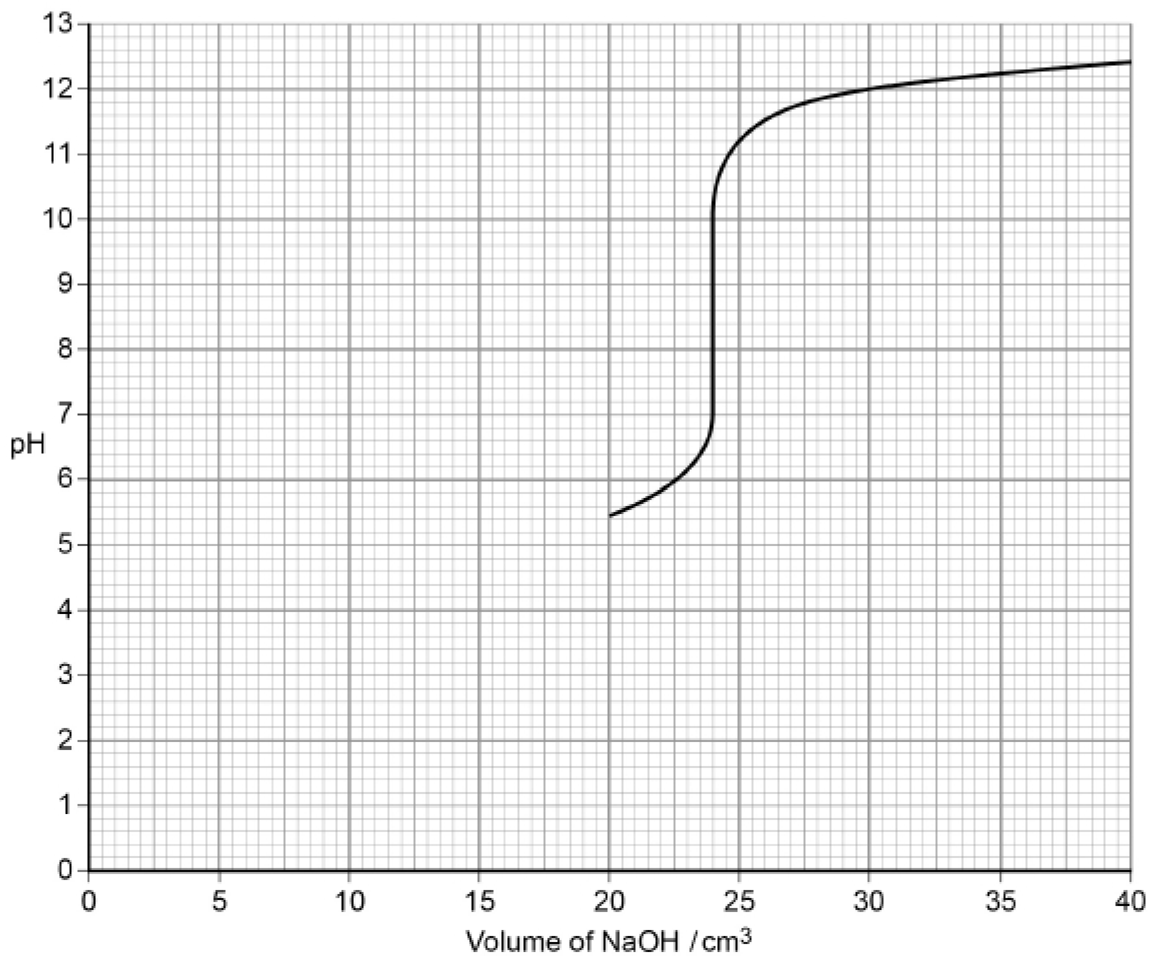
(1)
(Total 15 marks)

3. A 0.100 mol dm^{-3} solution of sodium hydroxide was gradually added to 25.0 cm^3 of a solution of a weak acid, HX, in the presence of a suitable indicator.

A graph was plotted of pH against the volume of sodium hydroxide solution, as shown in the figure below.

The first pH reading was taken after 20.0 cm^3 of sodium hydroxide solution had been added.

The acid dissociation constant of HX, K_a, = 2.62 × 10^{-5} mol dm^{-3}



(a) The pH range of an indicator is the range over which it changes colour.

Suggest the pH range of a suitable indicator for this titration.

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(1)

(b) Give the expression for the acid dissociation constant of HX.

K_a =

(1)

(c) Calculate the concentration of HX in the original solution.

Concentration ____________________ $mol\,dm^{-3}$

(2)

(d) Calculate the pH of the solution of HX before the addition of any sodium hydroxide.

(If you were unable to calculate a value for the concentration of HX in part (c) you should use a value of 0.600 $mol\,dm^{-3}$ in this calculation. This is not the correct value.)

pH of HX ____________________

(2)

(e) Calculate the pH of the solution when half of the acid has reacted.

pH of solution ____________________

(1)

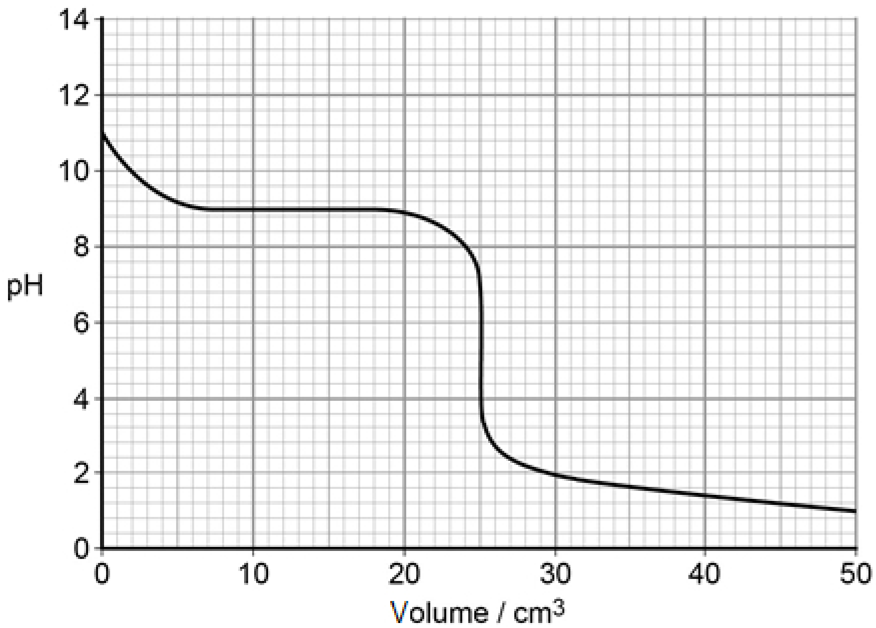
(f) Plot your answers to part (d) and part (e) on the grid in the figure above.

Use these points to sketch the missing part of the curve between 0 and 20 cm^3 of NaOH solution added.

(2)

(Total 9 marks)

4. The graph was obtained from an experiment in which an acid was reacted with an alkali.



(a) Suggest possible formulae for an acid and an alkali that could be used to produce the curve shown in the graph.

Acid ____

Alkali ____

(2)

(b) Suggest briefly a practical procedure that a student could use to obtain data from which the curve in the graph could be plotted.

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(3)

(c) The student was provided with samples of three different indicators.

Suggest how the practical procedure in part **(b)** could be refined by the student to identify the most suitable indicator.

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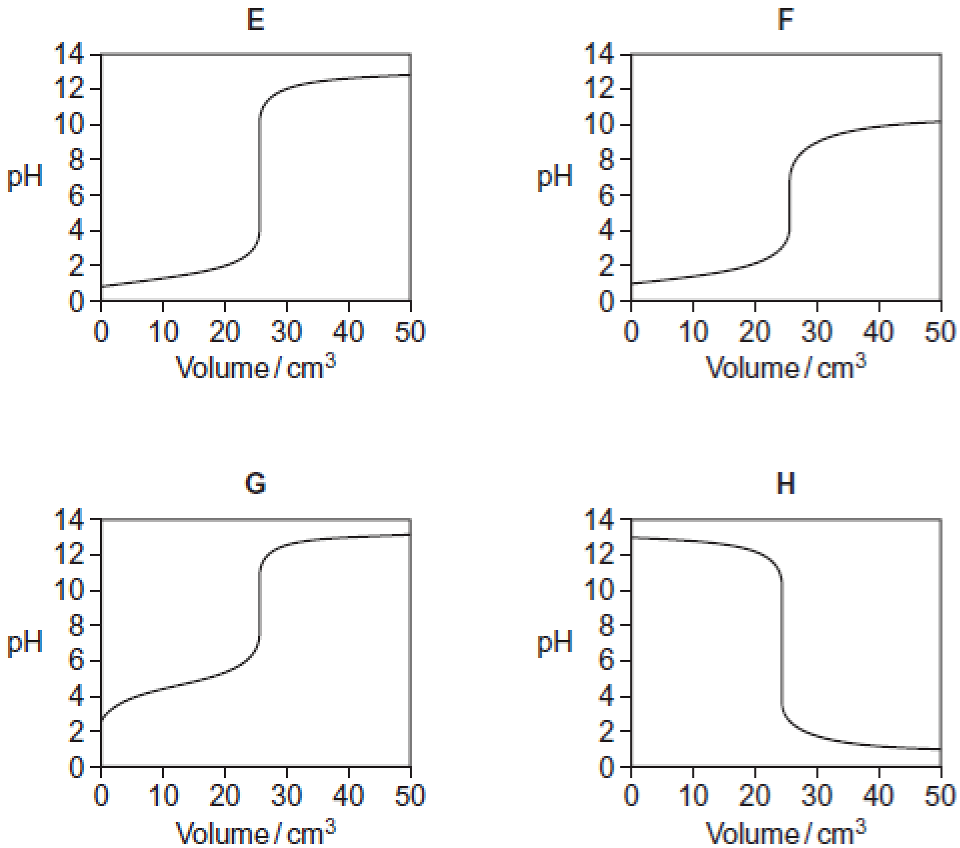
(2)

(Total 7 marks)

5. Titration curves, labelled **E**, **F**, **G** and **H**, for combinations of different aqueous solutions of acids and bases are shown below.

All solutions have concentrations of 0.1 mol dm^{-3}.



(a) In this part of the question, write the appropriate letter in each box.

From the curves **E**, **F**, **G** and **H**, choose the curve produced by the addition of

(i) sodium hydroxide to 25 cm^3 of ethanoic acid ☐

(1)

(ii) ammonia to 25 cm^3 hydrobromic acid ☐

(1)

(iii) hydrochloric acid to 25 cm^3 of potassium hydroxide ☐

(1)

(b) The table shows information about some acid-base indicators.

Indicator	**pH range**	**Lower pH colour**	**Higher pH colour**
pentamethoxy red	1.2−3.2	violet	colourless
naphthyl red	3.7−5.0	red	yellow
4−nitrophenol	5.6−7.0	colourless	yellow
cresol purple	7.6−9.2	yellow	purple

(i) Which indicator in the table could be used for the titration that produces curve **E** but **not** for the titration that produces curve **F**?

Tick (✓) **one** box.

pentamethoxy red ☐

naphthyl red ☐

4−nitrophenol ☐

cresol purple ☐

(1)

(ii) Give the colour change at the end point of the titration that produces curve **H** when naphthyl red is used as the indicator.

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(1)

(iii) A beaker contains 25 cm^3 of a buffer solution at pH = 6.0
Two drops of each of the four indicators in the table are added to this solution.

State the colour of the mixture of indicators in this buffer solution.
You should assume that the indicators do **not** react with each other.

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(1)
(Total 6 marks)