Self-Check Answers

1 Calculate the pH of the following solutions at 25 °C.

0.1 mol dm^{-3} NaOH	NaOH is a **strong** base that undergoes **complete** ionisation in water. $NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)$ $[OH^-] = [NaOH(aq)] = 0.1$ mol dm^{-3} $pOH = -\lg [OH^-] = -\lg (0.1) = 1.00$ $pH = 14 - pOH = 14 - 1.00 =$ **13.0**
0.1 mol dm^{-3} NH_4^+ K_b of $NH_3 = 1.8 \times 10^{-5}$	NH_4^+ is the **conjugate** acid of NH_3. NH_4^+ undergoes **hydrolysis** in water. K_a of $NH_4^+ = \frac{10^{-14}}{1.8\times10^{-5}} = 5.555 \times 10^{-10}$ mol dm^{-3} $[H^+] = \sqrt{5.555 \times 10^{-10} \times 0.1} = 7.453 \times 10^{-6}$ mol dm^{-3} $pH = -\lg(7.453 \times 10^{-6}) =$ **5.13**
0.1 mol dm^{-3} CH_3NH_2 0.2 mol dm^{-3} $CH_3NH_3^+$ K_b of $CH_3NH_2 = 4.4 \times 10^{-4}$	CH_3NH_2 and $CH_3NH_3^+$ are a conjugate acid-base pair. This solution is a **buffer**. $pOH = pK_b + \lg (\frac{[CH_3NH_3^+]}{[CH_3NH_2]})$ $= -\lg(4.4 \times 10^{-4}) + \lg(\frac{0.2}{0.1})$ $= 3.66$ $pH = 14 - pOH = 14 - 3.66 =$ **10.3**

2 Answer: **B**

A buffer is formed if the resulting solution has a weak acid and its conjugate base, or a weak base and its conjugate acid.

	After mixing
A	NH_3 (weak base), NH_4^+ (conjugate acid) → buffer
B	All $K_2CO_3(aq)$ and $H_2SO_4(aq)$ reacted to form $K_2SO_4(aq)$, CO_2 and H_2O. Thus, no conjugate acid-base pair present to form a buffer.
C	(Note: $CH_3CO_2^-$, being a conjugate base of a weak acid, can react with H^+ from HC*l* to form CH_3CO_2H) Since equal volumes of $CH_3CO_2^-$ and HC*l* are used, $CH_3CO_2^-$ is in excess. After the reaction, there will be an equal amount of $CH_3CO_2^-$ and CH_3CO_2H present. CH_3CO_2H (weak acid), $CH_3CO_2^-$ (conjugate base) → buffer
D	HOOC–COOH is in excess while NaOH is limiting. HOOC–COOH will undergo neutralisation reaction with NaOH to form its conjugate base $HOOC–COO^-$. HOOC–COOH (weak acid), $HOOC–COO^-$ (conjugate base) → buffer

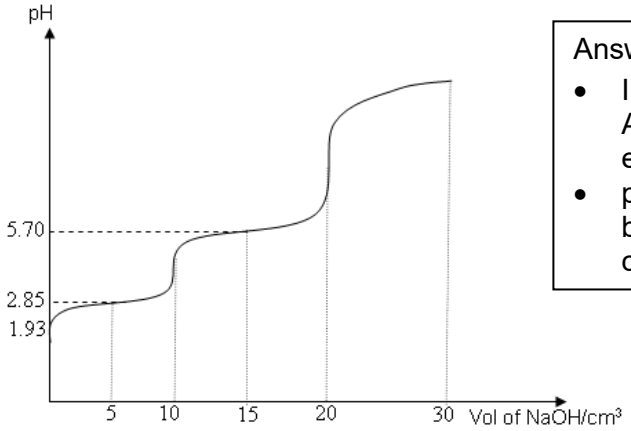
3 **(i)** $FCH_2CO_2H + H_2O \rightleftharpoons FCH_2COO^- + H_3O^+$ **[1]**

Acid: FCH_2CO_2H Conjugate base: FCH_2COO^- **[1]**
Base: H_2O Conjugate acid: H_3O^+ **[1]**

(ii) $[H^+] = \sqrt{K_{a_1} \times c_0} = \sqrt{1.4125 \times 10^{-3} \times 0.1} = 1.1885 \times 10^{-2}$ mol dm^{-3} **[1]**

$pH = -\lg[H^+] = 1.93$ **[1]**

(iii)



Answer should include:
- Initial pH (ans from **(a)(iii)**) AND volume of NaOH at both equivalence points **[1]**
- pH and volume of NaOH at both maximum buffer capacities (acidic buffer) **[1]**

(iv) At point **A**, it is the second equivalence point and the species present is $^-O_2CCH_2CO_2^-$Being the conjugate base of a weak acid, $^-O_2CCH_2CO_2^-$ undergoes hydrolysis to give OH^- ions causing $[OH^-] > [H^+]$.

$^-O_2CCH_2CO_2^- + H_2O \rightleftharpoons {}^-O_2CCH_2CO_2H + OH^-$

(v) Note: The solution containing $HO_2CCH_2CO_2^-$ (weak acid with pK_{a2}) and $^-O_2CCH_2CO_2^-$ (conjugate base of $HO_2CCH_2CO_2^-$) is a buffer.

$$pH = pK_{a2} + \lg\frac{[\text{conjugate base}]}{[\text{weak acid}]}$$

$$= 5.70 + \lg\frac{0.20}{0.50}$$

$= 5.30$ **[1]**

Name: …… ( ) Class: …….
Date: …….

Raffles Institution
Year 6 H2 Chemistry 2025

Set A T1W10 – Acid-Base Equilibria

☐— Pre-ChemFocus Activity —☐

- Familiarise yourself with the equations and the use of the equations.
- To view infopack at IVY > C2025 – H2 CHEMISTRY > Pages > [ChemFocus] T1W10 Acid-Base Equilibria > **FIRST VIDEO ONLY**

Notes:

Thought process

Examples

Calculate the pH of the following solutions at 25 °C.

0.1 mol dm^{-3} HC*l*	HC*l* is a _____ acid that undergoes _____ ionisation in water.
0.1 mol dm^{-3} CH_3COOH K_a of CH_3COOH = 1.8 x 10^{-5}	CH_3COOH is a _____ acid that undergoes _____ ionisation in water.
0.1 mol dm^{-3} CH_3COO^- K_a of CH_3COOH = 1.8 x 10^{-5}	CH_3COO^- is the conjugate _____ of CH_3COOH. CH_3COO^- undergoes _____ in water.

Self-Check Questions

Check your answers at IVY > C2025 – H2 CHEMISTRY > Pages > [ChemFocus] T1W10 Acid-Base Equilibria > Remaining videos

1 Calculate the pH of the following solutions at 25 °C.

0.1 mol dm^{-3} NaOH	NaOH is a _____ base that undergoes _____ ionisation in water.
0.1 mol dm^{-3} NH_4^+ K_b of NH_3 = 1.8 x 10^{-5}	NH_4^+ is the _____ acid of NH_3. NH_4^+ undergoes _____ in water.
0.1 mol dm^{-3} CH_3NH_2 0.2 mol dm^{-3} $CH_3NH_3^+$ K_b of CH_3NH_2 = 4.4 x 10^{-4}	CH_3NH_2 and $CH_3NH_3^+$ are a conjugate acid-base pair. This solution is a _____.

2 Which pair of substances, when mixed in equal volumes, does **not** produce a buffer?

A 0.1 mol dm^{-3} NH_3(aq) and 0.1 mol dm^{-3} NH_4Cl(aq)

B 0.1 mol dm^{-3} K_2CO_3(aq) and 0.1 mol dm^{-3} H_2SO_4(aq)

C 0.1 mol dm^{-3} CH_3CO_2Na(aq) and 0.05 mol dm^{-3} HCl(aq)

D 0.1 mol dm^{-3} $HO_2C–CO_2H$(aq) and 0.05 mol dm^{-3} NaOH(aq)

3 The South African plant *Dichapetalum cymosum* contains fluoroethanoic acid, FCH_2CO_2H, and malonic acid, $HO_2CCH_2CO_2H$. Data about these acids is given in Table 1.1.

Table 1.1

acid	formula	pK_{a1}	pK_{a2}
malonic	$HO_2CCH_2CO_2H$	2.85	5.70
fluoroethanoic	FCH_2CO_2H	2.57	–

(i) Write the equation for the dissociation of FCH_2CO_2H in water and identify the *conjugate acid-base pairs* that are present.

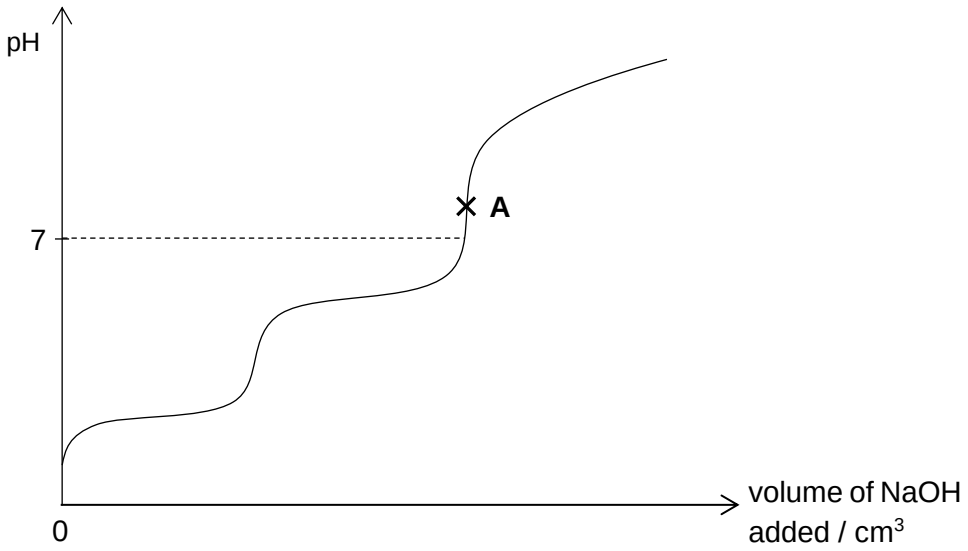
……..

..……[2]

(ii) Calculate the pH of a 0.10 mol dm^{-3} solution of malonic acid (ignore the effect of pK_{a2} on the pH).

[2]

The pH–volume curve when 30 cm^3 of 0.10 mol dm^{-3} NaOH is added to 10 cm^3 of 0.10 mol dm^{-3} malonic acid is shown below.



(iii) Using your answer from **(a)(ii)** and the information provided in Table 1.1, label various key points on the axes above.

(iv) With the aid of an equation, explain why the pH at point **A** on the graph has a value greater than 7.

.....[1]

(v) Calculate the pH of a solution that contains 0.50 mol of $HOOCCH_2COO^-$ and 0.20 mol of $^-OOCCH_2COO^-$ dissolved in 1.0 dm^3 of water.

[1]

Tutorial Discussion Questions (to complete before Chemfocus session)

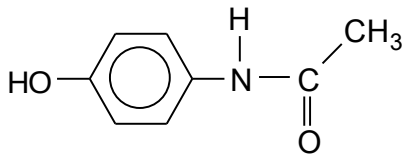
1a The pK_b value of $CH_3CH_2NH_2$ and pK_w at 60 °C are given below.

temperature / °C	pK_w	pK_b of $CH_3CH_2NH_2$
60	13.0	3.0

A buffer mixture at 60 °C was prepared using 10 cm^3 of 0.10 mol dm^{-3} HNO_3(aq) and 20 cm^3 of 0.10 mol dm^{-3} $CH_3CH_2NH_2$(aq). Deduce the resultant pH.

[1]

2a Paracetamol is a common painkiller used to relief minor aches and pains. Its structure is shown below.



Paracetamol

Paracetamol is a weak monobasic acid with its –OH group having a pK_a value of 9.50 at 25 °C.

In an experiment, 25.0 cm^3 of a solution of paracetamol was titrated against 0.100 mol dm^{-3} of aqueous NaOH. It was found that 13.20 cm^3 of NaOH was required for complete neutralisation.

(i) Calculate the concentration of the paracetamol solution and hence, its initial pH.

[3]

(ii) Identify the species present at equivalence and calculate its concentration.

[2]

(iii) Hence, calculate the pH at equivalence.

[2]

Tutorial Practice Questions (to be attempted **IN CLASS**)

1b The pK_b value of NH_3 and pK_w at 30 °C are given below.

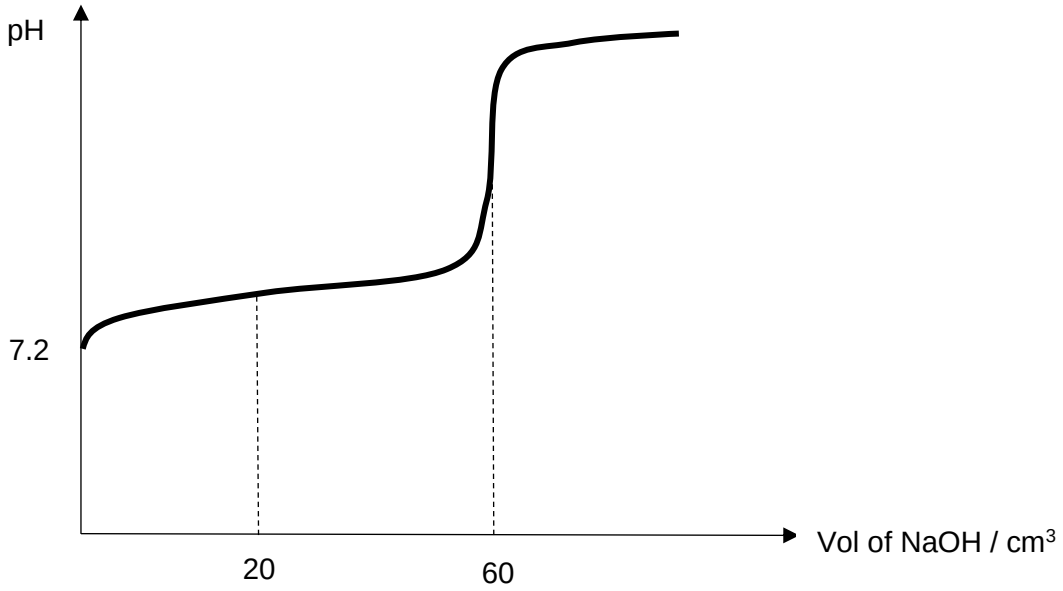
temperature / °C	pK_w	pK_b of NH_3
30	13.8	4.7

A buffer mixture at 30 °C was prepared using equal volumes of 0.10 mol dm^{-3} NH_4Cl (aq) and 0.020 mol dm^{-3} NaOH(aq). Calculate the resultant pH.

[2]

2b A student titrated 20 cm^3 of the buffer sample containing an acid and its salt, with 0.1 mol dm^{-3} NaOH(aq) and obtained the titration curve below. The maximum buffer capacity is obtained when 20 cm^3 of NaOH is added. The equivalence point of the titration is obtained when 60 cm^3 of aqueous sodium hydroxide is added.

[You may use HA and A^- to represent the species in the buffer sample.]



(i) Determine the total amount of acid in the buffer. Hence, show that the ratio of concentrations of the [HA] and [A^-] at the start of the titration is 3:1.

[2]

(ii) Calculate the K_a value of the acid.

[2]

(iii) Hence, calculate the pH at equivalence.

[2]

Set A Tutorial Discussion Questions (to complete before Chemfocus session)

1a

	$CH_3CH_2NH_2$	+ H^+ →	$CH_3CH_2NH_3^+$
Initial amt/mol	0.002	0.001	0
Amt after reaction/mol	0.001	0	0.001

The weak base is in excess and after reaction, the resultant solution is a 1:1 mixture of a weak base ($CH_3CH_2NH_2$) and its conjugate acid ($CH_3CH_2NH_3^+$); i.e. a buffer solution at maximum buffer capacity.

Therefore,

$$pOH = pK_b + \lg\frac{[CH_3CH_2NH_3^+]}{[CH_3CH_2NH_2]}$$

$$pOH = pK_b + \lg 1$$

$$pOH = pK_b$$

Since the buffer was prepared at 60 °C,
where pK_w = 13.0 and pK_b of $CH_3CH_2NH_2$ = 3.0,
and pH = pK_w – pOH

$$pOH = 3.0$$

$$pH = 13.0 - 3.0 = 10.0$$

2a **(i)** Let HA be paracetamol, since it is monobasic.

HA + NaOH → NaA + H_2O

Amount of OH^- reacted = $\frac{13.20}{1000} \times 0.10 = 1.32 \times 10^{-3}$ mol

Since paracetamol is monobasic,
Amount of paracetamol reacted = 1.32 x 10^{-3} mol

Initial [paracetamol] = (1.32 x 10^{-3}) $\div \frac{25.0}{1000} = 0.0528$ mol dm^{-3} **[1]**

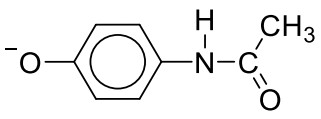
K_a of paracetamol = $10^{-9.50}$ = 3.162 x 10^{-10} mol dm^{-3}
Since paracetamol is a weak acid with a small K_a, assume that
$[paracetamol]_{eqm} \approx [paracetamol]_{initial}$

$[H^+] = \sqrt{K_a \times [paracetamol]} = \sqrt{(3.162 \times 10^{-10}) \times 0.0528}$

= 4.086 x 10^{-6} mol dm^{-3} **[1]**

pH = – lg (4.086 x 10^{-6}) = <u>5.39</u> **[1]**

(ii)



$[A^-]$ produced at equivalence point = $\frac{1.32 \times 10^{-3}}{\frac{25.0+13.20}{1000}}$ = 0.03455 mol dm^{-3}

(iii) A^- can undergo hydrolysis:

$$A^-(aq) + H_2O(l) \rightleftharpoons HA(aq) + OH^-(aq)$$

Since A^- is a weak base, with a small K_b, assume that $[A^-]_{eqm} \approx [A^-]_{initial}$

$[OH^-] = \sqrt{K_b \times [A^-]} = \sqrt{(10^{-14}/10^{-9.5}) \times 0.03455}$

$= 1.045 \times 10^{-3}$ mol dm^{-3} **[1]**

pOH = –log 1.0459×10^{-3} = 2.98

pH = 14 – 2.98 = <u>11.0</u> **[1]**

<u>Set A Tutorial Practice Questions</u> (to be attempted **<u>IN CLASS</u>**)

1b Let volume of each solution be V dm^3

	NH_4^+	+ OH^-	→ NH_3 + H_2O
Initial amt/mol	$0.10V$	$0.020V$	0
Amt after reaction/mol	$0.080V$	0	$0.020V$

$pOH = pK_b + \lg\frac{[NH_4^+]}{[NH_3]}$

$pOH = pK_b + \lg\frac{0.080V}{0.020V}$

pOH = 4.7 + lg4 = 5.302

pH = 13.8 – 5.302 = <u>8.50</u>

2b **(i)** Since the equivalence point is obtained at 60 cm^3 of NaOH,

Initial amount of HA present = $0.060 \times 0.1 = 0.006$ mol

Amount of HA left when 20 cm^{-3} of NaOH was added = 0.006 – 0.002

= 0.004 mol

= amount of A^- at mbc

Amount of A^- formed from HA when reacted with 20 cm^3 of NaOH

= 0.002 mol

Initial amount of A^- = amount of A^- at mbc – amount of A^- produced from HA

= 0.004 – 0.002 = 0.002 mol

Hence, $\frac{[HA]}{[A^-]} = \frac{0.006}{0.002} = \frac{3}{1}$

(ii) $pH = pK_a + \lg\frac{[A^-]}{[HA]}$

$7.2 = pK_a + \lg(\frac{1}{3})$

$pK_a = 7.2 - \lg(\frac{1}{3}) = 7.677$

value of $K_a = 10^{-7.677} = 2.10 \times 10^{-8}$

(iii) $[A^-]$ at equivalence = $(0.006 + 0.002) \div \frac{60+20}{1000} = 0.100$ mol dm^{-3}

A^- undergoes hydrolysis: $A^- + H_2O \rightleftharpoons HA + OH^-$

K_b of $A^- = 10^{-14} \div (2.103 \times 10^{-8}) = 4.755 \times 10^{-7}$ mol dm^{-3}

$[OH^-] = \sqrt{4.755 \times 10^{-7} \times 0.100} = 2.180 \times 10^{-4}$ mol dm^{-3}
$pOH = -\lg(2.180 \times 10^{-4}) = 3.661$
$pH = 14 - 3.661 = \underline{10.3}$