

F325: Equilibria, Energetics and Elements

5.1.3 Acids, Bases & Buffers

1. (i) H^+ /proton donor (1) 1
 (ii) partially dissociates/ionises (1) 1
[2]

2. $\text{C}_6\text{H}_5\text{OH}(\text{aq}) + \text{OH}^-(\text{aq}) \rightleftharpoons \text{C}_6\text{H}_5\text{O}^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$

acid 1
base 2
base 1
acid 2 (1)

[1]

3. (i) $K_a = [\text{C}_6\text{H}_5\text{O}^-(\text{aq})][\text{H}^+(\text{aq})] / [\text{C}_6\text{H}_5\text{OH}(\text{aq})]$ (1) 1
 (ii) $M_r \text{C}_6\text{H}_5\text{OH} = 94$ (1)
 $[\text{C}_6\text{H}_5\text{OH}(\text{aq})] = 4.7/94 = 0.050 \text{ mol dm}^{-3}$ (1)
 $1.3 \times 10^{-10} \approx [\text{H}^+(\text{aq})]^2 / 0.050 \text{ mol dm}^{-3}$ (1) ('=' sign is acceptable)
 $[\text{H}^+] = \sqrt{\{(1.3 \times 10^{-10}) \times (0.050)\}} = 2.55 \times 10^{-6} \text{ mol dm}^{-3}$ (1)
 $\text{pH} = -\log[\text{H}^+] = -\log 2.55 \times 10^{-6} = 5.59$ (1)
 3 marks: $[\text{H}^+]$; pH expression ; calc of pH from $[\text{H}^+]$ 5
[6]

4. $[\text{H}^+(\text{aq})] = 1.99 \times 10^{-9} \text{ mol dm}^{-3}$ (1)
 $[\text{C}_6\text{H}_5\text{O}^-(\text{aq})] = K_a [\text{C}_6\text{H}_5\text{OH}(\text{aq})] / [\text{H}^+(\text{aq})]$ (1)
 $[\text{C}_6\text{H}_5\text{O}^-(\text{aq})] = 0.13 \text{ mol dm}^{-3}$ (1)

Calculation should use half the original concentration of phenol to find the concentration of sodium phenoxide in the buffer. This should then be doubled back up again.

*Do **not** penalise an approach that uses the original concentration of phenol in the expression above.*

[3]

5. (a) (i) Ionic product (1) 1
 (ii) $K_w = [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})]$ (1) state symbols not needed 1

(b) moles of HCl = $\frac{5 \times 10^{-3} \times 21.35}{1000} = 1.067 \times 10^{-4} \text{ mol (1)}$

moles of $\text{Ca(OH)}_2 = \frac{1.067 \times 10^{-4}}{2} = 5.34 \times 10^{-5} \text{ mol (1)}$

concentration of $\text{Ca(OH)}_2 = 40 \times 5.34 \times 10^{-5}$
 $= 2.136 \times 10^{-3} \text{ mol dm}^{-3} \text{ (1)}$

2 marks for $4.27 \times 10^{-3} / 8.54 \times 10^{-3} \text{ mol dm}^{-3}$
 (no factor of 4)

3

(c) $[\text{OH}^-] = 2 \times 2.7 \times 10^{-3} = 5.4 \times 10^{-3} \text{ mol dm}^{-3} \text{ (1)}$

$[\text{H}^+(\text{aq})] = \frac{K_w}{[\text{OH}^-(\text{aq})]} = \frac{1.0 \times 10^{-14}}{5.4 \times 10^{-3}} = 1.85 \times 10^{-12} \text{ mol dm}^{-3} \text{ (1)}$

$\text{pH} = -\log(1.85 \times 10^{-12}) = 11.73/11.7 \text{ (1)}$

3

ecf is possible for pH mark providing that the $[\text{H}^+]$ value has been derived from $K_w/[\text{OH}^-]$

If pOH method is used, $\text{pOH} = 2.27$. would get 1st mark,
 $\text{pH} = 14 - 2.27 = 11.73$ gets 2nd mark.

Commonest mistake will be to not double OH^- and to use 2.7×10^{-3}
 This gives ecf answer of 11.43/11.4, worth 2 marks.
 $\text{pH} = 11.13$ from dividing by 2: worth 2 marks

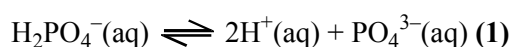
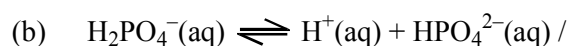
(d) 8 (1)

1

[9]



1



(or equivalent with H_2O forming H_3O^+)

1

- (c) (i) HPO_4^{2-} (1) 1
- (ii) H_3PO_4 (1) 1
- (iii) H_2PO_4^- produced $\text{Ca}(\text{H}_2\text{PO}_4)_2$ or on LHS of an attempted equilibrium equation (1)
 2 equations/equilibria to shown action of buffer (1)(1)
 from:
 $\text{H}_2\text{PO}_4^- + \text{H}^+ \rightleftharpoons \text{H}_3\text{PO}_4$ /
 $\text{H}_2\text{PO}_4^- \rightleftharpoons \text{H}^+ + \text{HPO}_4^{2-}$ /
 $\text{H}_2\text{PO}_4^- + \text{OH}^- \rightleftharpoons \text{H}_2\text{O} + \text{HPO}_4^{2-}$ /
 $\text{H}^+ + \text{OH}^- \rightleftharpoons \text{H}_2\text{O}$ 3

[7]

7. proton donor ✓
 partially dissociates ✓

[2]

8. $K_a = \frac{[\text{HCOO}^-][\text{H}^+]}{[\text{HCOOH}]} / \frac{[\text{H}^+]^2}{[\text{HCOOH}]} / [\text{H}^+] = \sqrt{K_a \times [\text{HA}]}$ /
 $1.58 \times 10^{-4} = \frac{[\text{H}^+]^2}{0.025}$ / ✓
 $[\text{H}^+] = \sqrt{\{(1.58 \times 10^{-4}) \times (0.025)\}} = 1.99 \times 10^{-3} \text{ mol dm}^{-3}$ ✓
 $\text{pH} = -\log[\text{H}^+] = -\log 1.99 \times 10^{-3} = 2.70$ ✓
 5.4034 (no square root) **with working** would score 1 mark.

[3]

9. (i) A solution that minimises pH changes/resists pH changes/opposes pH changes ✓
 (not pH is kept constant/pH maintained/pH cancelled out. 1
- (ii) $\text{HCOONa}/\text{HCOO}^-/\text{NaOH}$ ✓
 HCOO^- is the conjugate base/
 HCOONa is the salt of the weak acid or HCOOH /
 HCOONa supplies HCOO^- ✓ 2

- (iii) *Two points from:*
 Ka /pKa /acid strength/amount of dissociation ✓
 temperature ✓ (but **not** "temperature & pressure")
 ratio/amounts/concentrations of weak acid and
conjugate base/salt ✓ (or reverse ratio)
 (**not** concentration of base as it could imply
 NaOH)

2 max

[5]

10. Mass of $\text{HNO}_3 = \frac{1400 \times 65}{100} / 910\text{g} \checkmark$
 Moles of $\text{HNO}_3 = \frac{910}{63} = 14.4 \checkmark$
 $\text{pH} = -\log[\text{H}^+] = -\log 14.4 = -1.16/1.2 \checkmark$ calc -1.15836
 pH from ignoring 65% $\text{pH} = -1.35$: **with working**, 2 marks.

[3]

11. $\rightarrow \dots\dots\dots \text{CO}_2 + \text{H}_2\text{O} \checkmark$
 Complete correct balanced equation for 2nd mark:
 $2\text{HNO}_3 + \text{CaCO}_3 \rightarrow \text{Ca}(\text{NO}_3)_2 + \text{CO}_2 + \text{H}_2\text{O} /$
 $2\text{H}^+ + \text{CaCO}_3 \rightarrow \text{Ca}^{2+} + \text{CO}_2 + \text{H}_2\text{O} /$
 $2\text{H}^+ + \text{CO}_3^{2-} \rightarrow \text{CO}_2 + \text{H}_2\text{O} \checkmark$

[2]

12. Two species differing by H^+ AW✓
 one pair: HNO_3 and $\text{NO}_3^- \checkmark$
 other pair: HCOOH and $\text{HCOOH}_2^+ \checkmark$

[3]

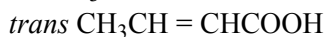
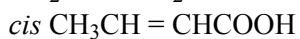
13. moles of $\text{NaOH} = \frac{0.1263 \times 23.75}{1000} / 3.00 \times 10^{-3} \text{ mol} \checkmark$
 moles of acid $= 3.00 \times 10^{-3} \text{ mol} \checkmark$
 moles of acid in flask $= 10 \times 3.00 \times 10^{-3} = 3.00 \times 10^{-2} \text{ mol} \checkmark$
 molar mass of compound $= \frac{\text{mass}}{n} = \frac{2.58}{3.00 \times 10^{-2}} = 86 \checkmark$ 4

Molecular formula = C₄H₆O₂ ✓

A 4 carbon carboxylic acid

(e.g. butanoic acid) shown (bod) ✓

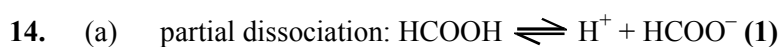
Any 2 possible isomers ✓✓ from:



4

Accept structural formulae that are unambiguous.

[8]



1

- (b) (i) $\text{pH} = -\log(1.55 \times 10^{-3}) = 2.81/2.8$ (1)
[H⁺] deals with negative indices over a very wide range/
pH makes numbers manageable
/removes very small numbers (1)

2

(ii) $K_a = \frac{[\text{H}^+(\text{aq})][\text{HCOO}^-(\text{aq})]}{[\text{HCOOH}(\text{aq})]}$ (1) (state symbols not needed)

1

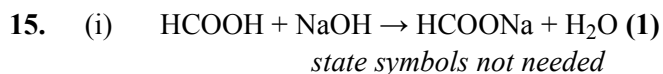
(iii) $K_a = \frac{[\text{H}^+(\text{aq})]^2}{[\text{HCOOH}(\text{aq})]} = \frac{(1.55 \times 10^{-3})^2}{0.015}$ (1)
 $= 1.60 \times 10^{-4} (\text{mol dm}^{-3})$ (1)
 $\text{p}K_a = -\log K_a = -\log(1.60 \times 10^{-4}) = 3.80$ (1)

3

(iv) Percentage dissociating = $\frac{(1.55 \times 10^{-3}) \times 100}{0.015} = 10.3\%$ /
10% (1)
(working not required)

1

[8]



1

- (ii) $n(\text{HCOOH}) = 0.0150 \times 25.00/1000 = 3.75 \times 10^{-4}$ (1)
 volume of NaOH(aq) that reacts is 30 cm³ (1)
 so $[\text{NaOH}] = 3.75 \times 10^{-4} \times 1000/30 = 0.0125 \text{ mol dm}^{-3}$ (1) 2
- (iii) $K_w = [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})]$ (1)
 $\text{pH} = -\log(1 \times 10^{-14}/0.0125) = 12.10/12.1$ (1)
 (calc 12.09691001) 3
- (iv) metacresol purple (1)
 pH range coincides with pH change **during sharp rise** OR
 pH 6-10 /coincides with equivalence point/end point (1) 2

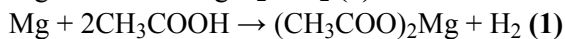
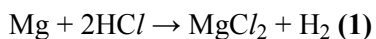
[8]

16. (a) strength of acid/extent of dissociation/ionisation (1) 1
- (b) (i) $\text{H}_2\text{SO}_3(\text{aq}) + \text{CH}_3\text{COOH}(\text{aq}) \rightleftharpoons \text{HSO}_3^-(\text{aq}) + \text{CH}_3\text{COOH}_2^+(\text{aq})$
 acid 1 base 2 (1) base 1 acid 2 (1) 2
 1 mark for labels on each side of equation
- (ii) CH_3COOH is the stronger acid/
 K_a CH_3COOH is greater/
 CH_3COOH is more acidic ORA (1)
- $\text{C}_6\text{H}_5\text{OH}(\text{aq}) + \text{CH}_3\text{COOH}(\text{aq}) \rightleftharpoons \text{C}_6\text{H}_5\text{OH}_2^+(\text{aq}) + \text{CH}_3\text{COO}^-(\text{aq})$ (1) 2
- (c) For HCl, $\text{pH} = -\log[\text{H}^+]$ (1) (or with values).
 Could be awarded below
 $= -\log 0.045 = 1.35$ (1) (accept 1.3)
- For CH_3COOH , $[\text{H}^+] = \sqrt{(K_a \times [\text{CH}_3\text{COOH}]}$ /
 $\sqrt{(1.70 \times 10^{-5} \times 0.045)}$ (1)
 $[\text{H}^+] = 8.75 \times 10^{-4} \text{ mol dm}^{-3}$ (1)
 $\text{pH} = -\log 8.75 \times 10^{-4} = 3.058/3.06$ (1) (accept 3.1) 5

[10]

17. HCl and CH₃COOH have same number of moles/
release same number of moles H⁺ /
1 mole of each acid produce ½ mol of H₂ (1)

[H⁺] in CH₃COOH < [H⁺] in HCl/
CH₃COOH is a weaker acid than HCl (ora) (1)



or



4

[4]

18. amount of NaOH in titration = 0.175 x 22.05/1000
or 3.86×10^{-3} (1) (calc: 3.85875×10^{-3})

amount of A in 25.0 cm³ = 0.5 × mol NaOH

or 1.93×10^{-3} (1) (calc: 1.929375×10^{-3})

amount of A in 250 cm³ = $10 \times 1.93 \times 10^{-3}$ or 1.93×10^{-2} (1)

1.93×10^{-2} mol A has a mass of 2.82 g

molar mass of A = $2.82 / 1.93 \times 10^{-2} = 146 \text{ g mol}^{-1}$ (1)

(or *M_r* of A is 146)

Therefore A is adipic acid / HOOC(CH₂)₄COOH (1)

5

[5]

19. (i) proton donor (1)

1

(ii) partially dissociates (1)

1

[2]

20. C₆H₅OH(aq) + OH⁻(aq) ⇌ C₆H₅O⁻(aq) + H₂O(l)
acid 1 base 2 (1) base 1 acid 2 (1)
1 mark for each acid-base pair

[2]

21. (i) $K_a = \frac{[\text{C}_6\text{H}_5\text{O}^-][\text{H}^+]}{[\text{C}_6\text{H}_5\text{OH}]} \quad (1)$ 1

- (ii) concentration = $38/94 \quad (1) = 0.40 \text{ mol dm}^{-3} \quad (1)$
(first mark for M_r of phenol – incorrect answer here will give ecf for remainder of question)

$$1.3 \times 10^{-10} \approx \frac{[\text{H}^+(\text{aq})]^2}{0.40} \quad (1)$$

(‘=’ sign is acceptable)

$$[\text{H}^+] = \sqrt{\{(1.3 \times 10^{-10}) \times (0.40)\}} = 7.2 \times 10^{-6} \text{ mol dm}^{-3} \quad (1)$$

$$\text{pH} = -\log[\text{H}^+] = -\log 7.2 \times 10^{-6} = 5.14 \quad (1)$$
 5

3 marks: $[\text{H}^+]$ (1); pH expression (1); calc of pH from $[\text{H}^+]$ (1)

Common errors:

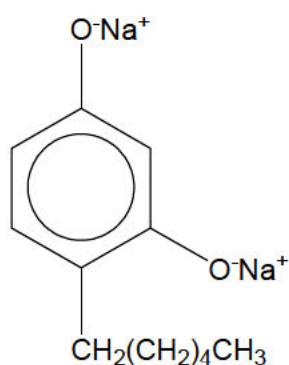
Without square root, answer = 10.28 (1)(1)(0)

Use of 38 as molar concentration does not score 1st 2 marks.

This gives an answer of 4.15 for 3 marks (1)(1)(1)

[6]

22.



/ NaOH / Na (1)

weak acid/base pair mixture formed (1)

On structure, 1 mark for O Na on either or both phenol groups.

2

[2]

23. (i) completely dissociates/ionised (1)
 proton donor (1) 2

- (ii) $\text{NO}_3^- \quad (1)$ 1

[3]

24. (i) $\text{pH} = -\log[\text{H}^+] / -\log(0.015) \quad (1) = 1.82 / 1.8 \quad (1)$ (Not 2) 2

(ii) $[H^+] = 0.0075 \text{ mol dm}^{-3}$
 $\text{pH} = -\log(0.0075) = 2.12 / 2.1$ (1) 1 [3]

25. (i) $K_w = [H^+(\text{aq})][OH^-(\text{aq})]$ (1) 1
state symbols not needed

(ii) $[H^+(\text{aq})] = 10^{-\text{pH}} = 10^{-13.54} = 2.88/2.9 \times 10^{-14} \text{ mol dm}^{-3}$ (1)
 $[NaOH] / [OH^-(\text{aq})] = \frac{K_w}{[H^+(\text{aq})]} = \frac{1.0 \times 10^{-14}}{2.88 \times 10^{-14}}$
 $= 0.347 / 0.35 \text{ mol dm}^{-3}$ (1) 2 [3]

26. (i) a solution that minimises/resists/opposes pH changes (1) 1

(ii) The buffer must contain both CH_3COOH and CH_3COONa / CH_3COO^- / weak acid and conjugate base(*) (1)
 Solution A is a mixture of CH_3COOH (*) and CH_3COONa (*) / has an excess of acid / is acidic (1)
 Solution B, contains only CH_3COONa / only CH_3COO^- / only the salt / is neutral (1)
 $\text{CH}_3\text{COOH}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{CH}_3\text{COONa}(\text{aq}) + \text{H}_2\text{O}(\text{l})$ / acid/alkali has been neutralised / $\text{CH}_3\text{COOH}(\text{aq})$ and NaOH react together (1) 4 [5]

27. $[H^+]$ increases (1)
 H_2O ionises more /
 for $\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-$, equilibrium moves to the right (1) 2
exo/endo is 'noise' [2]