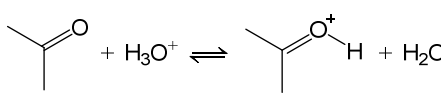


Suggested Answers to Self-Check Questions

- 1 (a) (i) A Brønsted–Lowry acid is a proton donor while a Brønsted–Lowry base is a proton acceptor.
In this case, an acid–base reaction involves the transfer of a proton from the acid to the base.
- (ii) Acid 1 and base 1 constitute one conjugate acid–base pair.
Acid 2 and base 2 constitute another conjugate acid–base pair.
- I. $\text{CH}_3\text{COOH} + \text{H}_2\text{SO}_4 \rightleftharpoons \text{CH}_3\text{COOH}_2^+ + \text{HSO}_4^-$
base 1 acid 2 acid 1 base 2
- II. $\text{CH}_3\text{NH}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CH}_3\text{NH}_3^+(\text{aq}) + \text{OH}^-(\text{aq})$
base 1 acid 2 acid 1 base 2
- III. $\text{HNO}_2(\text{aq}) + \text{CN}^-(\text{aq}) \rightleftharpoons \text{HCN}(\text{aq}) + \text{NO}_2^-(\text{aq})$
acid 1 base 2 acid 2 base 1
- (b) (i) A Lewis acid is an electron–pair acceptor while a Lewis base is an electron–pair donor.
In this case, an acid–base reaction involves the formation of a dative covalent bond between the acid and the base.
- (ii) I. $(\text{CH}_3)_3\text{N}(\text{g}) + \text{BF}_3(\text{g}) \rightleftharpoons (\text{CH}_3)_3\text{NBF}_3(\text{s})$
base acid
- II. $\text{Al}(\text{OH})_3(\text{s}) + \text{OH}^-(\text{aq}) \rightleftharpoons [\text{Al}(\text{OH})_4]^-(\text{aq})$
acid base
- (c) (i) $\text{HBr}(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{Br}^-(\text{aq})$
Brønsted–Lowry acid base
Lewis acid base
- (ii) $\text{HIO} + \text{NH}_2^- \rightleftharpoons \text{NH}_3 + \text{IO}^-$
Brønsted–Lowry acid base
Lewis acid base
- (iii) 
Brønsted–Lowry base acid
Lewis base acid

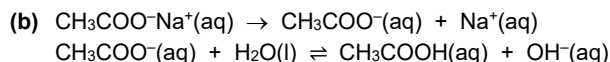
2	(a) 0.010 mol dm⁻³ H₂SO₄ (<i>strong dibasic acid</i>) $\text{H}_2\text{SO}_4(\text{aq}) \longrightarrow 2\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$ $[\text{H}^+] = 2 \times 0.010 = 0.0200 \text{ mol dm}^{-3}$ pH = $-\lg(0.0200) = \underline{1.70}$	(b) 0.40 g dm⁻³ NaOH (<i>strong base</i>) $\text{NaOH}(\text{aq}) \longrightarrow \text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq})$ $[\text{OH}^-] = \frac{0.40}{23.0 + 16.0 + 1.0} = 0.0100 \text{ mol dm}^{-3}$ pOH = $-\lg(0.0100) = 2.00$ pH = $14 - 2.00 = \underline{12.0}$
	(c) 14.00 cm³ of 0.10 mol dm⁻³ H₂SO₄ is added to 20.00 cm³ of 0.10 mol dm⁻³ NaOH (<i>strong acid partially neutralised by strong base</i>) $n_{\text{H}^+} = 2 \times \frac{14.00}{1000} \times 0.10 = 0.0028 \text{ mol}$ $n_{\text{OH}^-} = \frac{20.00}{1000} \times 0.10 = 0.002 \text{ mol}$ n_{H^+} in resultant solution = $0.0028 - 0.002 = 0.0008 \text{ mol}$ $[\text{H}^+] \text{ in resultant solution} = \frac{0.0008}{(14.00 + 20.00)} \times 1000$ $= 0.02353 \text{ mol dm}^{-3}$ pH of resultant solution = $-\lg(0.02353) = \underline{1.63}$	(d) 0.30 mol dm⁻³ CH₃CH₂COOH (<i>weak acid</i>) $\text{CH}_3\text{CH}_2\text{COOH}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{CH}_3\text{CH}_2\text{COO}^-(\text{aq})$ $K_a = \frac{[\text{H}^+][\text{CH}_3\text{CH}_2\text{COO}^-]}{[\text{CH}_3\text{CH}_2\text{COOH}]}$ $K_a = 10^{-\text{p}K_a} = 10^{-4.89} = 1.288 \times 10^{-5} \text{ mol dm}^{-3}$ Since CH₃CH₂COOH is a weak acid with a small K_a, $[\text{CH}_3\text{CH}_2\text{COOH}]_{\text{eqm}} \approx [\text{CH}_3\text{CH}_2\text{COOH}]_{\text{initial}} = 0.30 \text{ mol dm}^{-3}$ $[\text{H}^+] = \sqrt{K_a [\text{CH}_3\text{CH}_2\text{COOH}]} = \sqrt{1.288 \times 10^{-5} \times 0.30}$ $= 1.966 \times 10^{-3} \text{ mol dm}^{-3}$ pH = $-\lg(1.966 \times 10^{-3}) = \underline{2.71}$

(e) 2.00 mol dm⁻³ CH₃CH₂NH₂ (<i>weak base</i>) CH₃CH₂NH₂(aq) + H₂O(l) ⇌ CH₃CH₂NH₃⁺(aq) + OH⁻(aq) $K_b = \frac{[OH^-][CH_3CH_2NH_3^+]}{[CH_3CH_2NH_2]}$ Since CH₃CH₂NH₂ is a weak base with a small K_b, [CH₃CH₂NH₂]_{eqm} ≈ [CH₃CH₂NH₂]_{initial} = 2.00 mol dm⁻³ $[OH^-] = \sqrt{K_b [CH_3CH_2NH_2]} = \sqrt{5.1 \times 10^{-4} \times 2.00}$ $= 0.03194 \text{ mol dm}^{-3}$ pOH = -lg (0.03194) = 1.496 pH = 14 - 1.496 = <u>12.5</u>	(f) 0.015 mol dm⁻³ C₆H₅COO⁻K⁺ (<i>basic salt containing C₆H₅COO⁻ which is the conjugate base of the weak acid C₆H₅COOH</i>) C₆H₅COO⁻(aq) + H₂O(l) ⇌ C₆H₅COOH(aq) + OH⁻(aq) $K_b = \frac{[OH^-][C_6H_5COOH]}{[C_6H_5COO^-]}$ Since C₆H₅COO⁻ is a weak base with a small K_b, [C₆H₅COO⁻]_{eqm} ≈ [C₆H₅COO⁻]_{initial} = 0.015 mol dm⁻³ $[OH^-] = \sqrt{K_b [C_6H_5COO^-]}$ $[OH^-] = \sqrt{\frac{K_w}{K_a} [C_6H_5COO^-]} = \sqrt{\frac{1.0 \times 10^{-14}}{6.5 \times 10^{-5}} \times 0.015}$ $= 1.519 \times 10^{-6} \text{ mol dm}^{-3}$ pOH = -lg (1.519 × 10⁻⁶) = 5.818 pH = 14 - 5.818 = <u>8.18</u>
(g) 0.25 mol dm⁻³ methylammonium nitrate CH₃NH₃NO₃ (<i>acidic salt containing CH₃NH₃⁺ which is the conjugate acid of the weak base CH₃NH₂</i>) CH₃NH₃⁺(aq) + H₂O(l) ⇌ CH₃NH₂(aq) + H₃O⁺(aq) $K_a = \frac{[H_3O^+][CH_3NH_2]}{[CH_3NH_3^+]}$ Since CH₃NH₃⁺ is a weak acid with a small K_a, [CH₃NH₃⁺]_{eqm} ≈ [CH₃NH₃⁺]_{initial} = 0.25 mol dm⁻³ $[H_3O^+] = \sqrt{K_a [CH_3NH_3^+]}$ $= \sqrt{\frac{K_w}{K_b} [CH_3NH_3^+]}$ $= \sqrt{\frac{1.0 \times 10^{-14}}{4.4 \times 10^{-4}} \times 0.25}$ $= 2.384 \times 10^{-6} \text{ mol dm}^{-3}$ pH = -lg (2.384 × 10⁻⁶) = <u>5.62</u>	(h) A solution containing 0.50 mol dm⁻³ CH₃CH₂COOH and 0.35 mol dm⁻³ CH₃CH₂COO⁻K⁺ (<i>buffer</i>) CH₃CH₂COOH(aq) ⇌ CH₃CH₂COO⁻(aq) + H⁺(aq) $pH = pK_a + \lg \frac{[CH_3CH_2COO^-]}{[CH_3CH_2COOH]}$ $= -\lg(1.3 \times 10^{-5}) + \lg \left(\frac{0.35}{0.50} \right) = 4.73$
(i) A solution containing 0.060 mol dm⁻³ of NH₃ and 0.080 mol dm⁻³ of NH₄Cl (<i>buffer</i>) NH₃(aq) + H₂O(l) ⇌ NH₄⁺(aq) + OH⁻(aq) $pOH = pK_b + \lg \frac{[NH_4^+]}{[NH_3]}$ $= -\lg(1.74 \times 10^{-5}) + \lg \left(\frac{0.080}{0.060} \right) = 4.884$ pH = 14 - 4.884 = <u>9.12</u>	

3 (a) HX(aq) + H₂O(l) ⇌ H₃O⁺(aq) + X⁻(aq)

At equilibrium, [H₃O⁺] = [X⁻] = 10^{-3.25} = 5.623 × 10⁻⁴ mol dm⁻³
[HX] = 1.00 × 10⁻³ - 5.623 × 10⁻⁴ = 4.377 × 10⁻⁴ mol dm⁻³

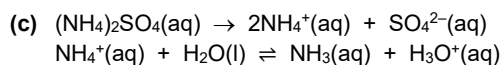
$$K_a = \frac{[H_3O^+][X^-]}{[HX]} = \frac{(5.623 \times 10^{-4})^2}{4.377 \times 10^{-4}} = 7.23 \times 10^{-4} \text{ mol dm}^{-3}$$



At equilibrium, $[\text{CH}_3\text{COOH}] = [\text{OH}^-] = 10^{-(14 - 8.37)} = 2.344 \times 10^{-6} \text{ mol dm}^{-3}$
 $[\text{CH}_3\text{COO}^-] = 1.00 \times 10^{-2} - 2.344 \times 10^{-6} = 9.998 \times 10^{-3} \text{ mol dm}^{-3}$

$$K_b = \frac{[\text{CH}_3\text{COOH}][\text{OH}^-]}{[\text{CH}_3\text{COO}^-]} = \frac{(2.344 \times 10^{-6})^2}{9.998 \times 10^{-3}} = 5.497 \times 10^{-10} \text{ mol dm}^{-3}$$

$\text{p}K_b$ of $\text{CH}_3\text{COO}^- = -\lg(5.497 \times 10^{-10}) = 9.260$
 $\text{p}K_a$ of $\text{CH}_3\text{COOH} = 14 - 9.260 = \underline{4.74}$



Initial $[\text{NH}_4^+] = (2)(0.050) = 0.100 \text{ mol dm}^{-3}$

At equilibrium, $[\text{NH}_3] = [\text{H}_3\text{O}^+] = 10^{-5.12} = 7.586 \times 10^{-6} \text{ mol dm}^{-3}$
 $[\text{NH}_4^+] = 0.100 - 7.586 \times 10^{-6} = 0.100 \text{ mol dm}^{-3}$

$$K_a = \frac{[\text{NH}_3][\text{H}_3\text{O}^+]}{[\text{NH}_4^+]} = \frac{(7.586 \times 10^{-6})^2}{0.100} = 5.755 \times 10^{-10} \text{ mol dm}^{-3}$$

$\text{p}K_a$ of $\text{NH}_4^+ = -\lg(5.755 \times 10^{-10}) = 9.240$
 $\text{p}K_b$ of $\text{NH}_3 = 14 - 9.240 = \underline{4.76}$

4 (Ans: B)

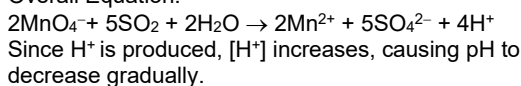
In the absence of water, $\text{HCl}(\text{g})$ remains as an undissociated simple molecule, and is not dissociated into H^+ and Cl^- ions, thus it does not have acidic properties (options A, C and D are incorrect) and does not act as mobile charge carriers (option B is correct).

5 (Ans: D)

K_a only changes with temperature. Since the temperature is constant, K_a remains constant as volume changes.

6 (Ans: D)

Overall Equation:



7 (Ans: B)

At 25°C ,

$\text{pH} = -\lg[\text{H}^+] = -\lg(10^{-7}) = \underline{7}$ and
 $\text{p}K_w = \underline{14}$

At equilibrium,

$[\text{H}^+] = [\text{OH}^-] = 10^{-7} \text{ mol dm}^{-3}$

$[\text{H}_2\text{O}] = 1000/18 = 55.56 \text{ mol dm}^{-3}$ (See note below)

$$K_a = \frac{[\text{H}^+][\text{OH}^-]}{[\text{H}_2\text{O}]} = \frac{(10^{-7})^2}{55.56} = 1.800 \times 10^{-16} \text{ mol dm}^{-3}$$

$\text{p}K_a$ of $\text{H}_2\text{O} = -\lg(1.800 \times 10^{-16}) = \underline{15.7}$

Hence, $\text{pH} < \text{p}K_w < \text{p}K_a$

Note: How to find $[\text{H}_2\text{O}]$?

Consider 1 dm^3 of water,

Assume density of water = 1 g cm^{-3}

$\Rightarrow$ mass of 1 dm^3 of $\text{H}_2\text{O} = 1000 \text{ g}$

$$n_{\text{H}_2\text{O}} = \frac{1000}{2 \times 1.0 + 16.0} = 55.56 \text{ mol}$$

$\therefore [\text{H}_2\text{O}] = 55.56 \text{ mol dm}^{-3}$

8 (Ans: A)

Pyruvic acid is a weak acid, hence upon titration with NaOH (strong base), at equivalence point, $\text{pH} > 7$ due to anion hydrolysis.

