IB Chemistry – HL
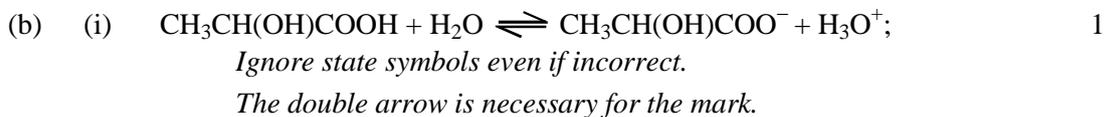**Topic 8 Answers**

1. D

2. B

3. A

4. D
5. C

6. A

7. C

8. B
9. B
10. B
11. B
12. C
13. D
14. B

15. C

16. C

17. A

18. B

19. A

20. A

21. A

22. C

23. A

24. B

25. C

26. D

27. C

28. A

29. B

30. C

31. B

32. A

33. D

34. D

35. (a) (i) $pK_a = 3.75$, therefore $K_a = 1.78 \times 10^{-4}$ (accept 1.8×10^{-4})   1
              No units required.

     (ii) weak acid;
          less $[H^+]$/partial dissociation/more reactants/less products/
          $K_a \ll 1$/small K_a;   2

     (iii) $(HCOOH(aq) \rightleftharpoons H^+(aq) + HCOO^-(aq))$

$$K_a = \frac{[H^+][HCOO^-]}{[HCOOH]} = \frac{x^2}{0.010};$$
          $(x^2 = 1.78 \times 10^{-6})$
          $x = 1.33 \times 10^{-3}$ mol dm^{-3} = $[H^+]$ (*no mark without units*);
              ECF from (a)(i).
              No penalty for incorrect significant figures.

          pH = 2.88/2.9 *(ECF)*;
          assume $x \ll 0.010$/25°C/negligible dissociation;   4

    (b) add strong base/sodium hydroxide or other named alkali/salt of methanoic
       acid/HCOONa to methanoic acid;
       in equimolar amounts/quantities/so that $[HCOOH] = [HCOO^-]$;
       (from K_a expression) pH = pK_a (= 3.75);   3

                                                            [10]

36. (a) $HIn(aq) \rightleftharpoons H^+(aq) + In^-(aq)$;   1
         $\rightleftharpoons$ *needed for mark. State symbols not essential.*

    (b) (i) yellow as equilibrium shifts to left to remove (added) $H^+(aq)$;   1
          Colour and explanation needed for the mark.

     (ii) green/blue-yellow;
          both $HIn(aq)$ and $In^-(aq)$ are present;   2

                                                            [4]

37. (a) (i) $K_w = [H^+][OH^-]$;   1

     (ii) $[H^+] = 1.5 \times 10^{-7}$(mol dm^{-3});   1
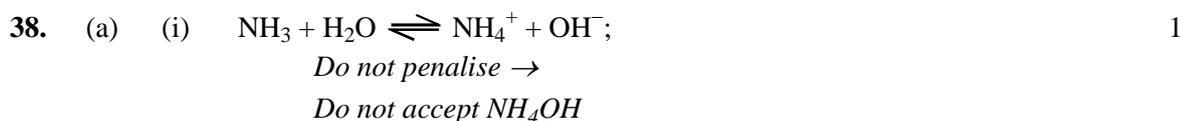
Accept answer in range 1.5 to 1.55.

(b) (i) $CH_3CH(OH)COOH + H_2O \rightleftharpoons CH_3CH(OH)COO^- + H_3O^+$;   1
Ignore state symbols even if incorrect.
The double arrow is necessary for the mark.

(ii) $k_a = \dfrac{[CH_3CH(OH)COO^-][H^+]}{[CH_3CH(OH)COOH]}$;   1
Allow $[H_3O^+]$ for $[H^+]$ in the expression.

(iii) $5.3 \times 10^{-3} = [H^+]$;

pH = 2.3;   2
Allow ECF pH based on wrong $[H^+]$ in the value, award [1].
Award [2] for correct pH.

(iv) pH = 3.85;   1
Accept answer in range 3.8 to 3.9.

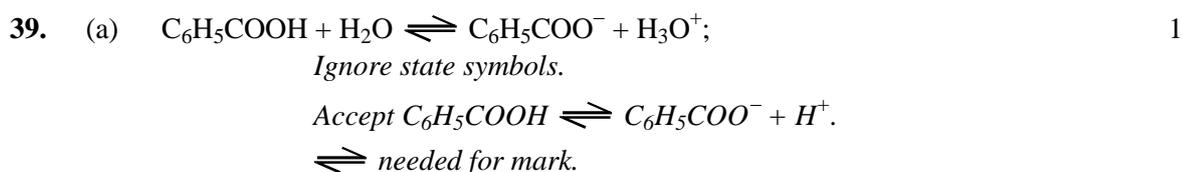   **[7]**

38. (a) (i) $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$;   1
Do not penalise $\rightarrow$
Do not accept NH_4OH

(ii) $K_b = \dfrac{[NH_4^+][OH^-]}{[NH_3]}$;   1

(b) $K_b = 10^{-4.75} = 1.78 \times 10^{-5}$;

$[OH^-] = \sqrt{1.78 \times 10^{-5} \times 0.2} = (1.89 \times 10^{-3})$;

$pOH = -\log[OH^-] = 2.72$;   3
Accept answer in range 2.68 to 2.76.
Correct answer scores [3].
Apply ECF throughout this part.

     [5]

39. (a) $C_6H_5COOH + H_2O \rightleftharpoons C_6H_5COO^- + H_3O^+$;   1
Ignore state symbols.
Accept $C_6H_5COOH \rightleftharpoons C_6H_5COO^- + H^+$.
$\rightleftharpoons$ needed for mark.

(b) $K_a (= 10^{-4.20}) = 6.31 \times 10^{-5}$ (mol dm^{-3});   1
Units not needed for mark, but penalize incorrect units.

(c) $K_a = \dfrac{[C_6H_5COO^-][H^+]}{[C_6H_5COOH]}$ / $\dfrac{[C_6H_5CO_2^-][H_3O^+]}{[C_6H_5CO_2H]}$;

$[H^+] = \sqrt{K_a[C_6H_5COOH]}/3.55 \times 10^{-3}$ (mol dm^{-3});
pH = 2.45; 3
  Apply ECF from (b) and from [H$^+$] to pH.
  Correct final answer scores [3].

  [5]

40. (a) $(K_w =)\ [H^+][OH^-]/[H_3O^+]\ [OH^-]$;

$= 2.89 \times 10^{-14} / 2.9 \times 10^{-14}$; 2
  Units not needed.

(b) pH = 6.8; 1
  Accept answer in range 6.7 to 6.8.

(c) neutral;

$[H^+] = [OH^-]/[H_3O^+] = [OH^-]$/*OWTTE*; 2

  [5]

41. (i) acidic;
Fe(H$_2$O)$_6$$^{3+}$ is a weak acid/Fe^{3+} reacts with OH$^-$/equation to show
formation of HCl or H$^+$;
"FeCl$_3$ is acidic" is not acceptable. 2

(ii) neutral;
NaNO$_3$ / sodium nitrate is formed from strong base and strong
acid/ions do not hydrolyse; 2

(iii) alkaline;
As CO$_3$$^{2-}$ is weak base/combines with H$^+$/equation showing
formation of OH$^-$; 2
  Acidic, neutral, alkali mark in each case is independent of
  reason.

  [6]

42. (i) 8.7 ± 0.7;
low [H$^+$] thus small addition of OH$^-$ has great effect/OH$^-$ increases
rapidly as NaOH is a strong base/logarithmic nature of pH; 2

(ii) volume of NaOH = 8.2 cm^3 (*exact*);
amount of NaOH $= \dfrac{8.2}{1000} \times 0.1 = 0.00082$ mol;

$[HA] = \dfrac{0.00082}{0.010} \times 0.1 = 0.082$ mol dm^{-3}/0.082 M; 3
  Correct answer [3], units needed for last mark.

(iii) correct pH reading from graph (2.9) *(allow 2.8 or 3.0)*;
thus $[H^+] = 1.26 \times 10^{-3}$ (mol dm^{-3})

$$K_a = \frac{10^{-2.9} \times 10^{-2.9}}{0.082}$$
$$= 1.9 \times 10^{-5} \text{ (mol dm}^{-3}\text{)};$$
$pK_a = 4.71$ 5

              Accept 4.7 and allow ECF from (ii).

              If pH given as 2.8, $K_a = 3.06 \times 10^{-5}$ and $pK_a = 4.51$

              If pH given as 2.8, $K_a = 1.22 \times 10^{-5}$ and $pK_a = 4.91$

              If half equivalence method used:
              Volume = 4.1 cm^3
              $pK_a = 4.75$
              Award [2] out of last [4].

                                                          [10]

43. (i) a solution that resists pH change/maintains a (nearly) constant pH;
when **small** amounts of acid or alkali are added;   2

(ii) M_r of sodium ethanoate;
moles of sodium ethanoate $= \dfrac{0.25}{82} = (0.0030)$;

$[CH_3COO^-] = \dfrac{0.0030}{0.2} = 0.015$ (mol dm^{-3}) *2 sig figs only*;   3

(iii) $K_a = \dfrac{[H^+][CH_3COO^-]}{[CH_3COOH]}$ *(or with substituted values)*;

May be assumed from later work.

$[H^+] = \dfrac{10^{-4.76} \times 0.10}{0.015} = (1.159 \times 10^{-4})$;

pH = 3.9(4);   3
              Allow ECF throughout (ii) and (iii).

                                                             [8]

44. (a) $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$
              Accept correct equation with NH_4OH instead of NH_3.

    .   mol $H_2SO_4 = 0.0201 \times 0.150$;
      $2NH_3 = H_2SO_4$/mol $NH_3 = 6.03 \times 10^{-3}$;
      $[NH_3] = 0.241$ (mol dm^{-3});   4
              Apply –1(SF) if appropriate.
              Award [3] for the correct final answer for the
              concentration calculation.

(b) bromocresol green;
reaction of weak base and strong acid/*OWTTE*;

pH range of bromocresol green is 3.8 to 5.4 / occurs at pH < 7;   3

(c) $K_b = 10^{-4.75} = 1.78 \times 10^{-5}$;

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

$$[OH^-] = \sqrt{1.78 \times 10^{-5} \times 0.121} \ ;$$

pOH = 2.83;   4

         Award [4] for the correct final answer.

         Allow ECF, for example any correct conversion of [OH$^-$]

                 [11]

45.   (i)   a solution which resists change in pH/changes pH very slightly/
       keeps pH constant/*OWTTE*;
       when <u>small</u> amounts of acid or base are added;
       weak acid and its salt/weak acid and its conjugate base;   3

     (ii)   mol NH_3 = 0.0050 and mol HCl = 0.0025;
        $[NH_4^+] = [NH_3]$;
        $[OH^-] = K_b = 1.78 \times 10^{-5}$
        (pOH = 4.75 so) pH = 9.25 *(allow 9.2 to 9.3)*;   4

           Award [4] for correct final answer.

           Accept other valid methods such as Henderson-Hasselbach
           equation.

                 [7]

46.   bromophenol blue is blue **and** phenol red is yellow;

      pH of 4.8 is above range of bromophenol blue/bromphenol blue shows
      its alkaline colour/*OWTTE*;
      pH of 4.8 is below range of phenol red/phenol red shows its acidic
      colour/*OWTTE*;   3

                 [3]

47. $K_a = \dfrac{[CH_3COO^-][H^+]}{[CH_3COOH]}$ /rearrangement for [H$^+$];

$$[H^+] = \frac{1.74 \times 10^{-5} \times 0.0500}{0.100} = 8.70 \times 10^{-6} \, (mol \, dm^{-3});$$

pH (= $-\log[H^+]$) = 5.06;   3

    OR

$$pH = pk_a + \log \frac{[CH_3COO^-]}{[CH_3COOH]};$$

$$pH = 4.76 + \log\left(\frac{0.10}{0.05}\right);$$

$$pH = 5.06;$$

Accept answer in range 5.0 to 5.1.

ECF from [H⁺].

Award [3] for correct final answer.

[3]

48.   weak acid + salt of weak acid/weak acid + conjugate base.

Accept equivalent descriptions of a basic buffer.

the solution resists pH change;

Do not accept pH does not change.

when small amounts of acid or base are added;

Only award if previous answer correct.

[3]

49.   (i) $pH = -\log[H^+]$;   1

(ii)   curve should include the following:
starting $pH = 1$;
equivalence point: 25.0 cm^3 of NaOH;
pH at equivalence point $= 7$;
pH to finish $= 12-13$;
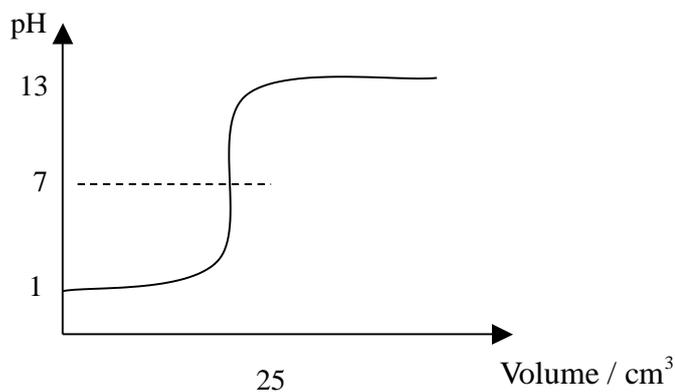
Penalise [1] if profile incorrect.

4

(iii) $K_a = 10^{-4.76}/1.74\times10^{-5}$;

$$K_a = [H^+]^2 \div [CH_3COOH]/1.74\times10^{-5} = \frac{[H^+]^2}{0.100};$$

$[H^+] = 1.32\times10^{-3}$ (mol dm^{-3});
starting $pH = 2.88$;

Accept 3 sig. fig.

Award [4] for correct pH.

Allow ECF.

pH at equivalence point: 8–9;   5

[10]

50. (i) HIn is a weak acid;
$HIn \rightleftharpoons H^+ + In^-$ and two colours indicated;

In acid <u>equilibrium</u> moves left or vice versa;   3

(ii) phenolphthalein/phenol red/bromothymol blue;
colour change of indicator occurs within the range of pH at equivalence
point/on vertical part of graph;   2

[5]

51. (i) specific examples of weak base and its salt/specific strong acid and
weak base;   1
e.g. NH_3 and NH_4Cl.

(ii) pH changes very little/most acid neutralized by base;
equation from (i);   2
e.g. $NH_3 + H^+ \rightarrow NH_4^+$ /$NH_4OH + H^+ \rightarrow NH_4^+ + H_2O$.

[3]

52. acidic;

$[Al(H_2O_6)]^{3+}$ is (weak) acid due to the formation of H^+/
$[Al(H_2O)_6]^{3+} \rightleftharpoons [Al(H_2O)_5(OH)]^{2+} + H^+$;   2

[2]

53. (i) 0.1 (mol dm^{-3});   1

(ii) 3;   1

(iii) 28(.0) (cm^3);   1

(iv) nNaOH/HNO$_3$ (= 0.100×0.0280) = 2.80×10^{-3} (mol);
ECF from value in (iii).
[HNO$_3$] (= 2.80×10^{-3}÷0.025) = 0.112 (mol dm^{-3});   2
ECF from n above.
Correct final answer scores [2].

[5]

54. (a) $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+ (aq) + OH^-(aq)$;   1
Ignore state symbols and accept $\rightarrow$.

(b) $K_b = \dfrac{[NH_4^+][OH^-]}{[NH_3]}$ 1

(c) $[OH^-] = 2.1 \times 10^{-3}$

pOH = 2.7/$[H^+]$ = 4.8×10^{-12}
pH = 11.3;   3

Allow ECF for the value of pOH and pH.

[5]

55. (i) a solution which resists change in pH;
when a <u>small</u> amount of strong acid or base is added to it;   2

(ii) react excess ammonia with nitric acid;
stated volumes with about 50% more ammonia solution;
gives a solution containing the weak base and its salt with the acid/
NH_4^+ and NH_3;   3

*Accept suitable volumes from about 20 cm^3 to about 500 cm^3
for 2nd mark.*

[5]

56. (pK_a (propanoic) = 4.87)

$$k_a = \frac{[CH_3CH_2COO^-][H_3O^+]}{[CH_3CH_2COOH]};$$

$[H_3O^+]$ = 1.16×10^{-3} (mol dm^{-3});

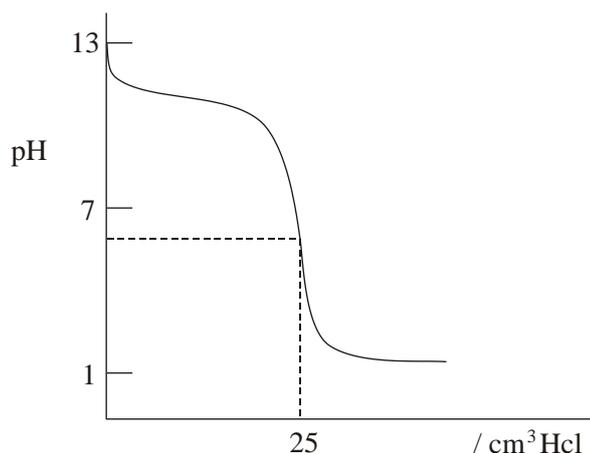pH = 2.94;   3

Award [3] for correct answer.

[3]

57. (i)

graph starting at pH < 13;
Award [0] for pH=13.

equivalence point pH < 7;
Accept anything between 4 and 6

bottom end of graph: pH between 3 and 1;

NH_3 is a weak base/partially dissociated/$[OH^-]</<<0.10\,mol\,dm^{-3}$

(therefore, pH < 13);

NH_4^+ formed is a weak acid/$NH_4^+ \rightleftharpoons NH_3 + H^+$/$NH_4^+$ dissociates into
a weak base and a strong acid (thus acidic at equivalence point);
HCl is a strong acid, thus graph finishes close to pH = 1;　　　　　6

 (ii) methyl orange/bromocresol green/bromophenol blue/methyl red;
   pK_a of indicator centred around pH at equivalence/end point/indicator
   pH range falls where there is a sharp pH change/*OWTTE*;　　　2

                        [8]

58. (i) weak acid **and** salt of the weak acid/its conjugate base;　　　1

 (ii) $HCl/HNO_3/H_2SO_4$;

   Amount < 0.10 mol for HCl/HNO_3/< 0.05 mol for H_2SO_4;　　　2

 (iii) (added) OH^- reacts with NH_4^+ present/acid of buffer;

   (added) H^+ reacts with NH_3 present/base of buffer;

   $OH^- + NH_4^+ \rightarrow NH_3 + H_2O$ (strong base replaced by weak base);

   $H^+ + NH_3 \rightarrow NH_4^+$ (strong acid replaced by weak acid);　　　4

 (iv) $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$;
      States not required for mark

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

                        [9]

59. (a) (i) acidic **and** $[Fe(H_2O)_6]^{3+}$ is a weak acid
     $[Fe(H_2O)_6]^{3+}(aq) \rightarrow [Fe(OH)(H_2O)_5]^{2+}(aq) + H^+(aq)$;　　1
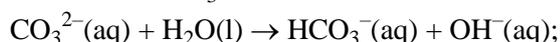   *"FeCl₃ is acidic" is not acceptable.*

   (ii) neutral **and** $NaNO_3$/sodium nitrate is formed from strong base
     and strong acid/ions do not hydrolyze;　　　1

   (iii) alkaline **and** CO_3^{2-} is a weak base/
     $CO_3^{2-}(aq) + H_2O(l) \rightarrow HCO_3^-(aq) + OH^-(aq)$;　　　1
      Award [1] only for correct identification of solutions as acidic,
      neutral and alkaline only, without explanation.

  (b) nitrogen **and** sulfur;
    kills/harms fish/aquatic life in lakes/rivers;
    leaching of soils damages plant life/trees;　　　3

60. (a) $2NH_3(aq) + H_2SO_4(aq) \rightarrow (NH_4)_2SO_4(aq)$;   4

Accept correct equation with NH₄OH instead of NH₃.

$n(H_2SO_4) = 0.0201 \times 0.150$ (mol);

$n(NH_3) = 6.03 \times 10^{-3}$ (mol);

$[NH_3] = 0.241$ (mol dm^{-3});

Award [3] for the correct final answer for the concentration calculation.

(b) bromocresol green;
reaction of weak base and strong acid;
pH range of bromocresol green is 3.8 to 5.4/occurs at pH < 7;   3

(c) (i) $K_b = 10^{-4.75} = 1.78 \times 10^{-5}$;

$K_b = \dfrac{[NH_4^+][OH^-]}{[NH_3]} / [OH^-] = \sqrt{K_b[NH_3]}$;

$[OH^-] = \sqrt{1.78 \times 10^{-5} \times 0.121}$;

pOH = 2.83;   4

Award [4] for the correct final answer.

Allow ECF, for example any correct conversion of [OH⁻] to pOH.

(ii) a solution which resists change in pH/changes pH very slightly;
when <u>small</u> amounts of acid or base are added;
weak acid and its salt/weak acid and its conjugate base;   3

(iii) $n(NH_3) = 0.00500$ (mol) **and** $n(HCl) = 0.00250$ (mol);

$[NH_4^+] = [NH_3]$;

$[OH^-] = K_b = 1.78 \times 10^{-5}$;

(pOH = 4.75 so) pH = 9.25 *(allow 9.2 to 9.3)*;   4

Award [4] for correct final answer.

[18]