Topic 9: Acids and Bases (HL)

Markscheme Notes:

1. A markscheme often has more marking points than the total allows. This is intentional. Do not award more than the maximum marks allowed for part of a question.

2. Each marking point has a separate line and the end is signified by means of a semicolon (;).

3. An alternative answer or wording is indicated in the markscheme by a slash (/) – either wording can be accepted.

4. Words in brackets ( ) in the markscheme are not necessary to gain the mark.

5. Words that are <u>underlined</u> are essential for the mark.

6. The order of marking points does not have to be as in the markscheme, unless stated otherwise.

7. If the candidate's answer has the same "meaning" or can be clearly interpreted as being of equivalent significance, detail and validity as that in the markscheme then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by writing **OWTTE** (or words to that effect).

8. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

9. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. Indicate this with **ECF** (error carried forward).

10. Only consider units at the end of a calculation. Unless directed otherwise in the markscheme, unit errors should only be penalized once in the paper. Indicate this by writing –**1(U)** at the first point it occurs and **U** on the cover page.

11. Significant digits should only be considered in the final answer. Deduct **1 mark in the paper** for an **error of 2 or more digits** unless directed otherwise in the markscheme.

    e.g. if the answer is 1.63:
    2   *reject*
    1.6   accept
    1.63   accept
    1.631   accept
    1.6314   *reject*

    Indicate the mark deduction by writing –**1(SD)** at the first point it occurs and **SD** on the cover sheet.

12. If a question specifically asks for the name of a substance, do not award a mark for a correct formula, similarly, if the formula is specifically asked for, do not award a mark for a correct name.

13. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the markscheme.

14. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the markscheme.

Answers:

1. C
                                                                                        [1]

2. D
                                                                                        [1]

3. D
                                                                                        [1]

4. (i)   *[CH_3CH_2COOH]:*
          (1.6 – 0.80 =) 0.8 (mol dm^{-3});
          [CH_3OH]:
          (2.0 – 0.80 =) 1.2 (mol dm^{-3});
          [H_2O]:
          0.80 (mol dm^{-3});   3

    (ii) (K_c =) ;
          (K_c = =) 0.7;   2
          Allow 0.67.
          Award [1 max] for 0.83.
                                                                                        [5]

5. *Volume of KOH*: 20 (cm^3);
    Allow any value between 20 and 21 (cm^3).

    pH at the equivalence point: 8.0–10.0;   2
                                                                                        [2]

6. (i)   HIn is a weak acid / weak base;
             HIn H^+ + In^-;
          colour 1   colour 2
           required.
          Award [2] for M2 alone.

          in base equilibrium moves to right / in acid equilibrium moves to left;   3

(ii)   phenolphthalein;
        indicator colour change occurs in range of pH at the equivalence
        point / *OWTTE*;   2
        M2 can be scored independently even if indicator is incorrect.

                                                                                    [5]

7.   acidic;
      $[Fe(H_2O)_6]^{3+}$ $[Fe(H_2O)_5(OH)]^{2+} + H^+$ /
      $[Fe(H_2O)_6]^{3+} + H_2O$ $[Fe(H_2O)_5(OH)]^{2+} + H_3O^+$;   2
      Accept equations indicating the formation of
      $[Fe(H_2O)_4(OH)_2]^+$
      $[Fe(H_2O)_3(OH)_3]$
      $[Fe(H_2O)_2(OH)_4]^-$
      Do not penalize →.

                                                                                    [2]

8. $n(HCl) = (0.100 \times 0.50) = 0.050$ (mol);
      $n(NaOH) = (0.200 \times 0.10) = 0.020$ (mol);
      $n(HCl)_{remaining} = (0.050 - 0.020) = 0.030$ (mol);
      $[HCl] = = 0.10$ (mol dm^{-3});
      pH = 1.0;   5
      *Award **[2 max]** for just pH = 1.0 without working.*

                                                                                    [5]

9.   A
                                                                                    [1]

10.   B
                                                                                    [1]

11.   C
                                                                                    [1]

12. $K_b = = 10^{-4.75} / 1.78 \times 10^{-5}$;
      $[OH^-] = = 4.22 \times 10^{-4}$ (mol dm^{-3});
      pOH = $-\log_{10}(4.22 \times 10^{-4}) = 3.37$ / $[H^+] = = 2.37 \times 10^{-11}$;

pH = 14 – 3.37 = 10.6;   4
Award [2 max] for correct final answer if no working shown.

        [4]

13. (a)   initial amount of HCl = × 1.00×10^{-2} = 2.50×10^{-4} mol
       and initial amount of NH_3 = × 1.00×10^{-2} = 5.00×10^{-4} mol;
       final amount of NH_4^+ and NH_3 both = 2.50×10^{-4} mol;
       final $[NH_4^+]$ and $[NH_3]$ both = = 3.33×10^{-3} mol dm^{-3};
       $[OH^-] = K_b \times = K_b = 10^{-4.75}/1.78 \times 10^{-5}$;
       pOH = 4.75 hence pH = 9.25;   5
       Award final two marking points if half-equivalence method used.

    (b)   a buffer solution resists a change in pH when <u>small amounts</u> of
       acid or base are added to it;
       Do not accept description in terms of composition of buffer.

       when H+ is added it reacts with NH_3 to form NH_4^+;
       when OH^- is added it reacts with NH_4^+ to form NH_3 and H_2O;   3
       Accept equations for last two marking points.

           [8]

14. (i)   NaCl is the salt of a strong acid and a strong base / no hydrolysis
       with (Na^+ and Cl^- ion);
       the CO_3^{2-} ions combine with H^+ from water to form a weak acid
       leaving OH^- ions / $CO_3^{2-} + H_2O$ $HCO_3^- + OH^-$ / *OWTTE*;   2

    (ii) Fe^{3+} has a small radius and a high charge / Fe^{3+} has a high
       charge density;
       it forms bonds with the OH^- ions from water leaving H^+ ions /
       it increases the polarity of the O–H bond (in the water ligands) /
       $[Fe(H_2O)_6]^{3+}$ $[Fe(H_2O)_5(OH)]^{2+} + H^+$ *etc*;   2

           [4]

15. B

           [1]

16. A

           [1]

17.   A

[1]

18. (a) (i) $CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$;

OR

$CH_3COOH(l) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$;

OR

$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$;
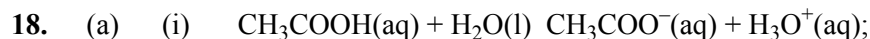
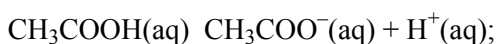*Must include .*
Ignore state symbols.   1

(ii) $K_a = 10^{-4.76} / 1.74 \times 10^{-5}$
       $1.74 \times 10^{-5} = / [H^+] = 0.00187$;
       $pH = 2.73$;
       Award [3] for correct final answer, allow mark for correct
       conversion of $[H^+]$ to pH even if $[H^+]$ incorrect.   3

(b)   (initial)$[CH_3COOH] = 0.500$ mol dm^{-3} and) eqm $[CH_3COOH] = 0.200$ mol dm^{-3};
      (initial)$[CH_3COO^-] = 0.300$ mol dm^{-3} and) eqm $[CH_3COO^-] = 0.300$ mol dm^{-3};
      Allow 0.02 moles and 0.03 moles instead of 0.200 and 0.300 mol dm^{-3}.

      $[H^+] = K_a = 1.16 \times 10^{-5}$ mol dm^{-3} / $pH = pK_a + log$;
      $pH = 4.94$;
      *Award **[3 max]** for correct final answer if no working shown.*   4
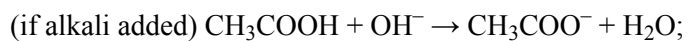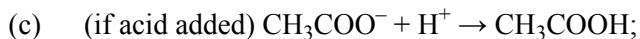
(c)   (if acid added) $CH_3COO^- + H^+ \rightarrow CH_3COOH$;
      (if alkali added) $CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$;
      Explanation marks cannot be awarded without equations.
      Accept $H^+ + OH^- \rightarrow H_2O$ as OH^- reacts with H^+ in the buffer to form water.   2

[10]

19.   C

[1]

20. C

[1]

21. A

[1]

22. C

[1]

23. (i) $(K_w) = [H^+][OH^-]$ / $(K_w) = [H_3O^+][OH^-]$;
Do not award mark if [ ] omitted or other brackets are used. 1

(ii) $[H^+]$ increases, $[OH^-]$ decreases but still some present (K_w constant) /
$[OH^-]$ cannot go to zero as equilibrium present / $[OH^-] =$,
thus $[OH^-]$ cannot be zero / *OWTTE*; 1

(iii) (changing T disturbs equilibrium) endothermic reaction / forward reaction
favoured / equilibrium shifts to the right;
to use up (some of the) heat supplied;
K_w increases (as both $[H^+]$ ☒and $[OH^-]$ increase); 3

(iv) (as $[H^+]$ increases) pH decreases / pH < 7;
No mark for more acidic.

inverse relationship between pH and $[H^+]$/pH $= -\log[H^+]$/pH $= \log_{10}$;

Accept $[H_3O^+]$ in place of $[H^+]$. 2

[7]

24. (i) Acid: $H_2PO_4^-$;
(Conjugate) base: HPO_4^{2-};
No mark for NaH_2PO_4 or Na_2HPO_4.

$H_2PO_4^-(aq)$ $H^+(aq) + HPO_4^{2-}(aq)$;
Accept reverse equation or reaction with water.
Ignore state symbols, but equilibrium sign is required.
Accept OH^- (ions) react with H^+ (ions) to form H_2O. 3

(ii) strong base/OH⁻ replaced by weak base ($H_2PO_4^{2-}$, and effect minimized) / strong base reacts with acid of buffer / equilibrium in (i) shifts in forward direction;

$$OH^-(aq) + H_2PO_4^-(aq) \rightarrow H_2O(l) + HPO_4^{2-}(aq);$$
Ignore state symbols, accept equilibrium sign.
Accept OH⁻ added reacts with H⁺ to form H₂O. 2

(iii) strong acid/H⁺ replaced by weak acid ($H_2PO_4^-$, and effect minimized) / strong acid reacts with base of buffer / equilibrium in (i) shifts in reverse direction;
$$H^+(aq) + HPO_4^{2-}(aq) \rightarrow H_2PO_4^-(aq);$$
Accept reaction with H_3O^+.
Ignore state symbols. 2

[7]

25. (i) NH_3 weak(er) base/partial dissociation;
$[OH^-] < 0.1(0)$ /pOH > 1 (thus pH < 13 / pH + pOH = 14); 2

(ii) around pH = 5;
Accept a value between 4 and 6.

strong acid–weak base titration, (thus acidic) / at equivalence point, NH_4^+ present is acidic / NH_4^+ $NH_3 + H^+$; 2

(iii) $NH_3(aq) + H_2O(l)$ $NH_4^+(aq) + OH^-(aq)$;
Ignore state symbols, but equilibrium sign required.
$K_b = $; 2

(iv) $[NH_3] = [NH_4^+]$; 1

(v) pOH = 14.00 – 9.25 = 4.75;
$pK_b (= pOH) = 4.75$;
$K_b = 1.78 \times 10^{-5}$;
Ignore units.
Award [3] for correct final answer. 3

(vi) optimum/most effective/highest buffer capacity/50 %–50 % buffer/equally effective as an acidic buffer and a basic buffer / *OWTTE*; 1

[11]

26. A

[1]

27. C

[1]

28. C

[1]

29. C

[1]

30. (a) (i) strong acid completely dissociated/ionized **and** weak acid partially
dissociated/ionized;
$HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$;
$HCN(aq)\ H^+(aq) + CN^-(aq)$;
Insist on both arrows as shown.
State symbols not needed.
Accept H_2O and H_3O^+. 3

(ii) $K_a =$
Allow H_3O^+ instead of H^+.
$K_a = 10^{-9.21} = 6.17 \times 10^{-10}$; 2

(iii) $[H^+] = $;
$= 8.16 \times 10^{-6}$;
Allow in the range 8.13×10^{-6} to 8.16×10^{-6}.
$pH = 5.09$;

OR

$pH = (pK_a - \log[HCN]) / (9.21 - \log 0.108)$;
$= 5.09$;
$[H^+] = 10^{-5.09} = 8.16 \times 10^{-6}$;
Allow in the range 8.13×10^{-6} to 8.16×10^{-6}.
*If expression for $[H^+]$ missing but both answers correct, award **[3]**,
if one answer correct, award **[2]**.*

assume $[H^+] \ll 0.108$ / negligible dissociation; 4

(b) *With HNO₃:*
     faster rate of bubble/hydrogen/gas production;
     faster rate of magnesium dissolving;
     higher temperature change;
     Accept opposite argument for HCN.
     Reference to specific observations needed.
     Award [1] if 2 observations given but acid is not identified.   2 max

(c) (i)   (nitric acid) 7.5 cm³;   1

     (ii)   not valid as hydrocyanic acid reacts with same volume/ 7.5 cm³;   1

     (iii) bromothymol blue / phenol red / phenolphthalein;   1

(d) HNO₃;
     (higher conductivity for solutions with same concentration as) there are
     more ions in solution;   2

                                                                                          [16]

31. D
                                                                                           [1]

32. C
                                                                                           [1]

33. (a) (i) $CH_3CH_2COOH + H_2O \rightleftharpoons CH_3CH_2COO^- + H_3O^+$
                     / $CH_3CH_2COOH \rightleftharpoons CH_3CH_2COO^- + H^+$;
                     ⇌ required for mark.   1

         (ii)   (pK_a for propanoic acid = 4.87)
                $[H^+]^2 = 0.100 \times K_a$;
                $[H^+] = 1.16 \times 10^{-3}$ (mol dm⁻³);   2

     (b) sketch to show:

          indicator range between pH 3.0 and pH 4.6 (with "yellow" at
          pH 3.0 and "blue" at pH 4.6);

initial pH of acid at 2.9 ± 1.0 (when no KOH has been added);
half-equivalence point (does not need to be named) at pH 4.9
when 12.5 cm^3 of KOH have been added;

equivalence point at approx pH 8.5–9.0 when 25.0 cm^3 of KOH(aq) added;

upper part of curve from 25.0–50.0 cm^3 added identical to original curve;
Award [1] each for any three points.   3 max

[6]

34.   C

[1]

35.   D

[1]

36.   A

[1]

37.   B

[1]

38.   (i) $K_a = 6.310 \times 10^{-5} / 6.31 \times 10^{-5}$;
Accept 6.3 × 10^{-5}   1

(ii)   weak (acid);
$K_a \ll 1$/ small K_a;   2

(iii) $[H_3O^+]/[H^+] =$;
$[H_3O^+]/[H^+] = 7.9 \times 10^{-4}$ (mol dm^{-3});
pH = 3.10/3.1/3.12;
Award [3] for correct final answer of pH.

assume x $\ll$ 0.010 (mol dm^{-3})/ ionization of water is insignificant /
$[C_6H_5COOH]_{initial} = [C_6H_5COOH]_{aq}$ / temperature 25 °C/298 K;   4

[7]

39. B

[1]

40. C

[1]

41. C

[1]

42. A

[1]

43. (i) 9.5;
Accept any value in the range 9.4–9.6. 1

(ii) titration involves a weak acid **and** a strong base;
salt formed at equivalence point is basic due to hydrolysis;
$A^-(aq) + H_2O(l)$ $HA(aq) + OH^-(aq)$;
Ignore state symbols. 3

(iii) ;
$= 0.136$ (mol dm^{-3}); 2

(iv) at half neutralization point, $pH = pK_a$;
$pK_a = 5.3$;
Accept any value in the range 5.2–5.4.

$K_a = 5.0 \times 10^{-6}$ (mol dm^{-3});
Accept calculations based on initial pH or on pH of salt. 3

(v) phenolphthalein;
Accept thymolphthalein.
Allow ECF from (a)(i). 1

[10]

44. $HIn(aq) \rightleftharpoons H^+(aq) + In^-(aq)$;
colour A   colour B
in presence of acid/H^+, equilibrium shifts to left, colour A;
in presence of base/OH^-, equilibrium shifts to right, colour B;   3

[3]

45. (i) buffer solution resists change in pH;
on addition of <u>small</u> amount of acid or base;   2

(ii) after mixing $[CH_3COO^-] = [CH_3COOH] = 0.050$ mol dm^{-3};
$K_a = [H^+]$/ $pK_a = $ pH;
pH $= 4.76$;
Working must be shown to score [3].
Award [1] if 4.76 stated with no working.   3

[5]

46. acidic;
$[Al(H_2O)_6]^{3+}(aq) \rightleftharpoons [Al(H_2O)_5(OH)]^{2+}(aq) + H^+(aq)$;
Accept AlCl₃ + 3H₂O → Al(OH)₃ + 3HCl.   2

[2]

47. (i) $[H^+] = = 7.81 \times 10^{-12}$ mol dm^{-3} / pOH $= -\log 1.28 \times 10^{-3} = 2.90$;
pH $= (14.0 - 2.90) = 11.1$;
Award [2] for the correct final answer   2

(ii) $K_b = $;
$= $;
$= 1.66 \times 10^{-5}$ /1.64×10^{-5};   3

[5]

48. A

[1]

49. D

[1]

50. D

[1]

51. (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 hydrolyse;   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

[6]

52. (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) $K_b = 10^{-4.75} = 1.78 \times 10^{-5}$;
$K_b =$
$[OH^-] =$
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);

       [OH$^-$] = K_b = 1.78×10^{-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.
                                                                                   [18]