IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

MARKSCHEME

November 2007

CHEMISTRY

Higher Level

Paper 2

17 pages

Subject Details: Chemistry HL Paper 2 Markscheme

General

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

- Alternative answers are separated by a slash (/) – this means that either answer is acceptable.

- Words underlined are essential for the mark.

- Material in brackets (…) is not needed for the mark.

- The order in which candidates score marks does not matter (unless stated otherwise).

- The use of **_OWTTE_** in a markscheme (the abbreviation for "or words to that effect") means that if a candidate's answer contains words different to those in the markscheme, but which can be interpreted as having the same meaning, then the mark should be awarded.

- Please remember that many candidates are writing in a second language, and that effective communication is more important than grammatical accuracy.

- In some cases there may be more acceptable ways of scoring marks than the total mark for the question part. In these cases, tick each correct point, and if the total number of ticks is greater than the maximum possible total then write the maximum total followed by **MAX**.

- In some questions an answer to a question part has to be used in later parts. If an error is made in the first part then it should be penalized. However, if the incorrect answer is used correctly in later parts then "follow through" marks can be scored. Show this by writing **ECF** (error carried forward). This situation often occurs in calculations but may do so in other questions.

- Units for quantities should always be given where appropriate. In some cases a mark is available in the markscheme for writing the correct unit. In other cases the markscheme may state that units are to be ignored. Where this is not the case, penalize the omission of units, or the use of incorrect units, once only in the paper, and show this by writing **−1(U)** at the first point at which it occurs.

- Do not penalize candidates for using too many significant figures in answers to calculations, unless the question specifically states the number of significant figures required. If a candidate gives an answer to fewer significant figures than the answer shown in the markscheme, penalize this once only in the paper, and show this by writing **−1(SF)** at the first point at which this occurs.

- 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.

- 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 the question specifically asks for this. In some cases, where more complicated equations are to be written, more than one mark may be available for an equation – in these cases follow the instructions in the mark scheme.

- Ignore missing or incorrect state symbols in an equation unless these are specifically asked for in the question.

- Mark positively. Give candidates credit for what they have got correct, rather than penalizing them for what they have got wrong.

- If candidates answer a question correctly, but by using a method different from that shown in the markscheme, then award marks; if in doubt consult your Team Leader.

SECTION A

1. (a) $M(\text{BaSO}_4)\left(=137.34+32.06+4(16.00)\right)=233.40\,(\text{g mol}^{-1})$;

   Accept 233.4 but not 233

   $\text{n}(\text{BaSO}_4)\left(=\dfrac{0.672\ \text{g}}{233.40\ \text{g mol}^{-1}}\right)=0.00288\,/\,2.88\times10^{-3}\,(\text{mol})$;   **[2]**

   ECF from M value

   (b) n (alkali metal sulfate) $=0.00288\,/\,2.88\times10^{-3}\,(\text{mol})$;   **[1]**

   ECF

   (c) $M=\left(\dfrac{m}{n}=\dfrac{0.502\ \text{g}}{0.00288\ \text{mol}}=\right)174.31\,/\,174.3\,/\,174$;

   ECF

   units: g mol^{-1} ;   **[2]**

   (d) $\left(2(A_\text{r})+32+4(16)=174,\ \text{thus}\right)A_\text{r}=39\,/\,A_\text{r}=\left(\dfrac{(174-(32+(4\times16))}{2}\right)=39$;

   Accept answer between 38.9 and 39.2
   ECF
   potassium / K;   **[2]**
   ECF from A_r value

   (e) $\text{K}_2\text{SO}_4(\text{aq})+\text{BaCl}_2(\text{aq})\rightarrow\text{BaSO}_4(\text{s})+2\text{KCl}(\text{aq})$ **[2]**

   *Award **[1]** for balanced equation and **[1]** for state symbols*
   ECF if another alkali metal arrived at in (d)
   Accept net ionic equation
   If no answer arrived at in (d), but correct equation given involving any alkali metal,
   *then award **[1 max]***

2. (a) (i)   ratio of <u>average</u> mass of an atom to $\dfrac{1}{12}$ the mass of C-12 isotope / <u>average</u> mass

of an atom on a scale where one atom of C-12 has a mass of 12 / sum of the weighted <u>average</u> mass of isotopes of an element compared to C-12 / *OWTTE*;   *[1]*
Award no mark if 'element' is used in place of 'atom'

     (ii) ^{63}Cu (more abundant) since A_r (Cu) is closer in mass to 63;   *[1]*
Explanation needed for mark

  (b) (i)   same nuclear charge, fewer electrons (thus more energy required to remove successive electrons) / harder to remove an electron from an ion with increasing positive charge / nucleus has greater effect on smaller number of electrons / *OWTTE*;   *[1]*

     (ii)   <u>large</u> increases in IE when 2nd **and** 10th electron removed;
thus, 1st electron further from nucleus than 2nd electron;
and 9th electron further from nucleus than 10th electron;
large increases indicate changes in main energy levels / *OWTTE*;

       OR

outermost/3p electron has low IE because it is far/furthest from the nucleus;
electron(s) in second shell/2p electrons are much closer (to nucleus) **and** need much more energy to remove / IE much higher/very high / there is a big jump in IE;
electron(s) in first/innermost shell/1s electrons are even closer (to nucleus) and need much more energy to remove (than those in second shell/2s or 2p electrons);   *[3 max]*

  (c) V^{2+} / V^{3+};
loss of $4s^2$ electrons / loss of $4s^2$ and a d electron;   *[2]*
Do not accept $V^{5+}/VO_2^+/VO_3^-$ but ECF from V^{5+} if correct number of electrons from the right orbitals stated.

3. (a)   same (average kinetic energy);
at same temperature/KE $\propto$ (absolute/Kelvin) temperature;   *[2]*

  (b)   methane / CH_4;
$M_r(O_2) = 32$, $M_r(CH_4) = 16$ / $M_r(O_2) > M_r(CH_4)$ / $M_r(CH_4) < M_r(O_2)$ / because oxygen molecules are heavier than methane molecules / methane molecules are lighter than oxygen molecules / lighter methane gas has greater average velocity;   *[2]*
No second mark for any reference to bigger/smaller molecules

  (c)   greater;   *[1]*
equal masses more moles/molecules (of gas);
greater velocity;
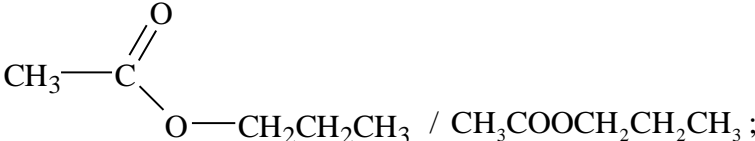more <u>frequent</u> collisions (with walls of flask);   *[2 max]*

4. (a) (i) $I- = -1/1-$ **and** $IO_3^- = +5/5+$; **[1]**

Both answers needed for [1] mark,
Signs must be included
Do not accept Roman numerals

(ii) *oxidation*
I^- (to I_2), increase in oxidation number / loss of electron(s);
reduction
IO_3^- (to I_2), decrease in oxidation number / gain of electron(s); **[2]**

(iii) $5I^-(aq) + IO_3^-(aq) + 6H^+(aq) \rightarrow 3I_2(aq) + 3H_2O(l)$; **[2]**
Award [2] if correctly balanced
Award [1] for correct reactants and products.
States not required for mark.
[1 max] if HCl on left and Cl^- on right side.

(b) $Cu^{2+}(aq) + e^- \rightleftharpoons Cu^+(aq) : E^\ominus = (+)0.15(V), Cu(s) \rightleftharpoons Cu^+(aq) + e^- : E^\ominus = -0.52(V)$ /
$(+)0.15$ and $-0.52(V)$;
*No mark if 0.34 or 0.52 quoted, but then ECF*

$\left(Cu^{2+}(aq) + Cu(aq) \rightleftharpoons 2Cu^+(aq) \right) E^\ominus$ value for reaction $= -0.37(V)$;

Award [2] for correct $E^\ominus_{rxn}$ even if equations are not given, states not required.
(negative value means) not spontaneous; **[3]**
Allow ECF: if positive value, can score third mark for 'spontaneous'.

5. (a) (i)

$CH_3 - C \overset{\displaystyle O}{\underset{\displaystyle O - CH_2CH_2CH_3}{}}$ / $CH_3COOCH_2CH_2CH_3$; **[1]**

(ii) propan-1-ol / 1-propanol;
$CH_3CH_2CH_2OH$;
Accept full structural formula showing all bonds and atoms but no mark if H atoms missing

ethanoic acid / acetic acid;
CH_3COOH ;
Accept full structural formula penalize missing Hs only once **[4]**

ECF from incorrect ester in (a) (i) above

(b) (i)
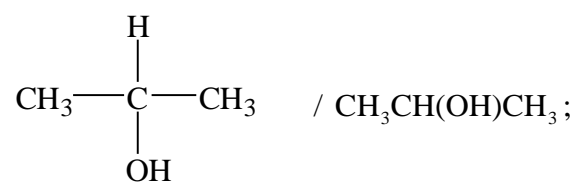
$$CH_3 - \underset{\underset{OH}{|}}{\overset{\overset{H}{|}}{C}} - CH_3 \quad / \ CH_3CH(OH)CH_3 \ ; \qquad \textbf{\textit{[1]}}$$

Allow bond to HO rather than OH or halfway between the two

(ii) secondary;   *[1]*

(iii) CH_3COCH_3 / propanone / acetone;   *[1]*
       Allow ECF from a different alcohol drawn in (b) (i)

SECTION B

6. (a) $IE_S < IE_O$:

   valence electron in S in n$=3$, in O in n$=2$ / e^- further away / S has another electron shell / atomic radius of S greater than that of O;
   less attracted to nucleus / experiences greater screening from inner electrons;

   $IE_S < IE_P$:

   electron removed from S is paired;
   greater repulsion due to two electrons in the <u>same</u> (p) orbital / <u>paired</u> electrons in S;   *[4]*

   (b) (i) Mg has greater nuclear charge / greater charge on cation / more valence e^- / greater number of delocalized electrons / Na has lesser nuclear charge / lesser charge on cation / less valence e^- / lesser number of delocalized electrons;
      stronger attraction between cation and <u>delocalized</u> / <u>free</u> / valence electrons;   *[2]*
      If neither mark scored, accept stronger metallic bonding in Mg for [1 max].

   (ii) giant / network / lattice / macromolecular structure;
      many / strong <u>covalent</u> bonds (need to be broken);   *[2]*

   (iii) (simple) molecular substances;
      weak van der Waals'/dispersion/London forces <u>between</u> molecules;   *[2]*
      Weak intermolecular forces' not sufficient for second mark

   (c) (i) Zn^{2+} has full d sub-shell / Zn^{2+} does not have partially filled d sub-shell / Cu^{2+} has partially filled d sub-shell/orbitals;
      d orbitals are split (into two sets of different energy levels);
      colour due to electron transition between (split) d orbitals;   *[3]*
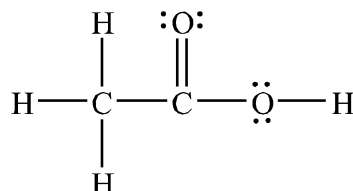
   (ii) $[Fe(CN)_6]^{3-}$;
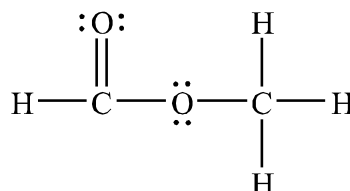   octahedral / suitable diagram;   *[2]*
      Accept square bipyramidal

   (d) (i) I   II

      Award [1] for each structure, penalize missing lone electron pairs only once.
      Accept straight lines and pairs of dots / crosses or a combination of all three.
      Accept other possibilities such as alkene with two –OH groups.   *[2]*

   (ii) II;
      dipole-dipole interaction in II is weaker than hydrogen bonding in I / weaker inter-particle forces in ester;   *[2]*

(e) XeF_2 : linear;
      Accept diagram/Lewis structure only if shape shown is linear

      $180°$;
      2 bonded, 3 non-bonded electron pairs (arranged as far apart as possible);
      Award mark only if word explanation given and not just from structure drawn
      If XeF_2 : given as bent, and angle stated as $120°$ based on 5 pairs of electrons,
      then award [1] otherwise no ECF.

      BrF_2^+ : bent / V-shaped / angular / non-linear;
      Accept diagram / Lewis structure only if shape shown is bent

      $\angle$ less than 109° / accept $\angle$ between 90 and 109° ;
      Note: the experimental bond angle is 93.5° due to impact of other factors such as
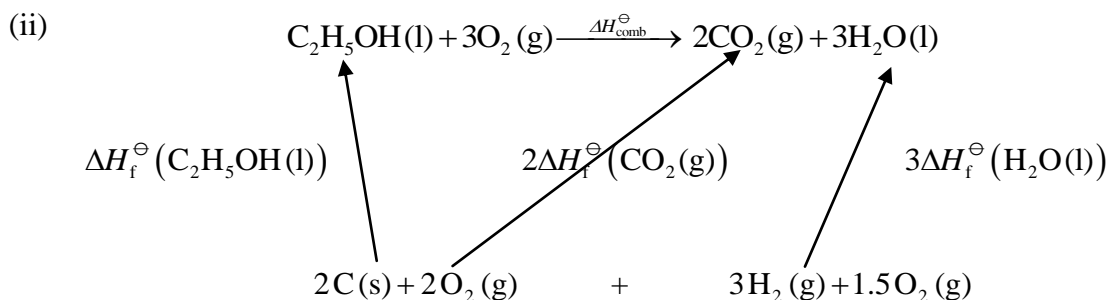   *electronegativity on angles*

      2 bonded, 2 non-bonded electron pairs;   [6]
      Award mark only if word explanation given and not just from structure drawn
      No ECF

7.   (a)   (i)   change in energy for the formation of (1 mol) of a substance from its elements;
under standard conditions / 1 atm pressure or 101 kPa and 298 K / 25°C ;   *[2]*

(ii)

$$C_2H_5OH(l) + 3O_2(g) \xrightarrow{\Delta H^{\ominus}_{comb}} 2CO_2(g) + 3H_2O(l)$$

$\Delta H^{\ominus}_f\left(C_2H_5OH(l)\right)$ $2\Delta H^{\ominus}_f\left(CO_2(g)\right)$ $3\Delta H^{\ominus}_f\left(H_2O(l)\right)$

$$2C(s) + 2O_2(g) \qquad + \qquad 3H_2(g) + 1.5O_2(g)$$

States not required.
Correct cycle showing:
$\Delta H^{\ominus}_{comb}$;
$\Delta H^{\ominus}_f\left(C_2H_5OH(l)\right)$;
$2\Delta H^{\ominus}_f\left(CO_2(g)\right)$ and $3\Delta H^{\ominus}_f\left(H_2O(l)\right)$;
$\left(\Delta H^{\ominus}_f\left(C_2H_5OH(l)\right) = \left(2\Delta H^{\ominus}_f\left(CO_2(g)\right) + 3\Delta H^{\ominus}_f\left(H_2O(l)\right) - \Delta H^{\ominus}_{comb}\right)\right.$
$= 2(-394) + 3(-286) + 1371$;
$= -275\,\text{kJ mol}^{-1}$;   *[5 max]*
If values are substituted for symbols in the enthalpy cycle diagram to give correct
answer, award last [2] marks.

If no enthalpy cycle drawn but equation written and Hess's Law applied or calculated
as follows, then [3 max]

$\left(\Delta H_r = \Sigma \Delta H_f(\text{products}) - \Sigma \Delta H_f(\text{reactants})\right)$
$-1371 = (-394 \times 2) + (-286 \times 3) - \Delta H_f(\text{ethanol})$;
$\Delta H_f(\text{ethanol}) = -788 - 858 + 1371$;
$= -275(\text{kJ mol}^{-1})$;

Award [2] for correct answer without enthalpy cycle and without working and
[1] for 275 or +275 .

(b)   (i)   energy required to break (a mole of) bonds in the <u>gaseous</u> state / energy given
out when (a mole of) bonds are made in the <u>gaseous</u> state;
average value from a number of <u>similar</u> compounds;   *[2]*

(ii) $\left(\Delta H^{\ominus}_{reaction} = (\Sigma BE_{break} - \Sigma BE_{make})\right)$
$= \left[(837) + 2(436)\right] - \left[(348 + 4(412)\right]$;
$= -287 \ (\text{kJ / kJ mol}^{-1})$;   *[2]*

Award [1 max] for 287 or +287.

(iii)   (BE): C–Cl > C–Br > C–I / C–X bond becomes weaker;
halogen size / radius increases / bonding electrons further away from the nucleus
/ bonds become longer;   *[2]*

(c) (i) molecularity is the number of molecules / particles in the slowest / slow / rate determining step / a step of the reaction;
S_N1 : unimolecular / molecularity of 1 **and** S_N2 : bimolcular / molecularity of 2;   *[2]*
Question asks for molecularity, not order: do not accept 1st order or 2nd order.
Need both unimolecular or 1 and bimolecular or 2 to receive the second mark.

(ii)
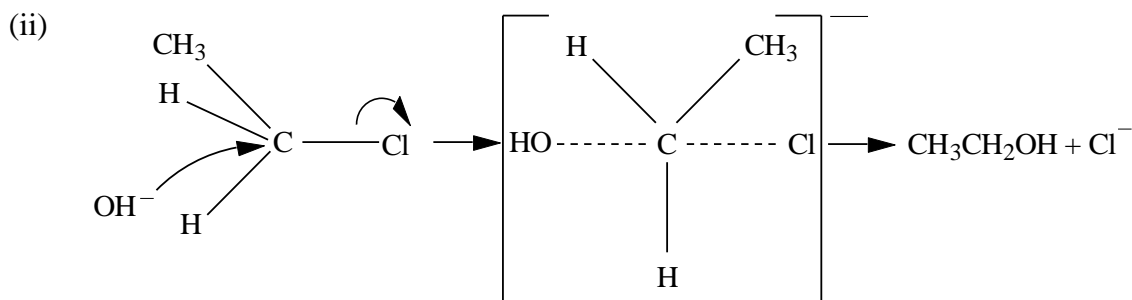
curly arrows showing attack of nucleophile;
Origin of arrow from a lone pair of electrons on O, or from O or from negative charge, but not from H for the mark.

curly arrow showing the C–Cl bond simultaneously breaking;
transition state with negative charge;
*Between C and O, and C and Cl, diagrams need dotted lines to score mark for transition state.*

for products;   *[4]*

Award [1] for correct S_N1 mechanism

(iii) (rate): $RCl < RBr < RI$ / $RI > RBr > RCl$ / increases;   *[1]*

(iv) primary < secondary < tertiary / tertiary > secondary > primary;   *[1]*

(d) (i) 4;
Accept 5 peaks if TMS is taken into account
1 : 1 : 4 : 6;   *[2]*

(ii) $3230-3550 \, cm^{-1}$ (due to O-H);
$2840-3095 \, cm^{-1}$ (due to C-H);
$1000-1300 \, cm^{-1}$ (due to C-O);   *[2 max]*
Award [2 max] for all three answers, and [1 max] for any two answers

8. (a) (i) rate $= k[CH_3COCH_3][H^+]$;

rate $= k[CH_3COCH_3]^2$;

rate $= k[H^+]^2$;   *[3]*

(ii) $[CH_3COCH_3]$ doubles, rate doubles **and** $[H^+]$ doubles, rate doubles;

$[Br_2]$ double, no effect on rate;

OR

$[CH_3COCH_3]$ doubles, rate quadruples;

$[Br_2]$ doubles / $[H^+]$ doubles, no effect on rate;

OR

$[H^+]$ doubles, rate quadruples;

$[Br_2]$ doubles / $[CH_3COCH_3]$ doubles, no effect on rate;   *[2]*

The answer given must correspond to the selected expression in 8(a)(i).

(iii) constant half-life;

at least two sets of data to justify statement;   *[2]*

e.g. [ ] from 1.6 to 0.8 mol dm⁻³, 10 s; 0.8 to 0.4, 10 s; 0.4 to 0.2, 10 s.

(iv) decrease in the colour of the bromine / *OWTTE*;

catalyst;

increases rate / speeds up reaction;

by lowering E_a / activation energy (by providing an alternate pathway);   *[4]*

(b) (i) $CH_4(g) + 2H_2O(g) \rightleftharpoons 4H_2(g) + CO_2(g)$;

States not required. Award [1] for balanced equation and [1] for equilibrium sign.

$$K_c = \frac{[H_2]^4[CO_2]}{[CH_4][H_2O]^2}$$;

ECF

units: $mol^2 \, dm^{-6}$ / $mol^2 \, L^{-2}$ / $mol^2 \, l^{-2}$; *do not accept: M²*   *[4]*

ECF

(ii) (endothermic reaction) increase in temperature (favours the forward reaction);

absorbs (some of) the heat supplied / *OWTTE*;

Award no marks for saying: "because of Le Chatelier's principle".

low pressure (will allow system to occupy more volume);

$V_{product} > V_{reactant}$ / reaction proceeds to greater number of <u>gaseous</u> moles / molecules / more moles of <u>gases</u> on right / *OWTTE*;

ECF from (b) (i)   *[4]*

(iii) at high pressure concentration increases / reaction rate faster;

more frequent collisions;   *[2]*

(iv) $\left(CH_4(g) + 2H_2O(g) \rightleftharpoons 4H_2(g) + CO_2(g) \right)$
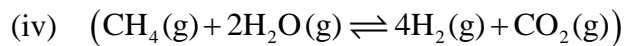
(2.0 mol H_2 produced at equilibrium) 0.50 mol CO_2 formed;

$(0.50 \, mol \, CH_4$ reacted) $[CH_4]_{eq} = 1.00 - 0.50 = 0.50 \, mol$;

ECF

$(1.0 \, mol \, H_2O$ reacted) $[H_2O]eq = 3.0 - 1.0 = 2.0 \, mol$;

ECF

$$K_c = \frac{[H_2]^4 \, [CO_2]}{[CH_4] \, [H_2O]^2} = \frac{[2.0]^4 \, [0.50]}{[0.50] \, [2.0]^2} = 4.0 \, ;$$ *[4 max]*

ECF

9. (a) (i) $NH_3(aq) + HCl(aq) \rightarrow NH_4Cl(aq)$; **[1]**
States not required for mark

(ii) $n(HCl) = cV = 0.100\,mol\,dm^{-3} \times 0.0250\,dm^3 = 0.00250\,mol$;
$n(NH_3) = n(HCl) = 0.00250\,mol$; **[2]**
ECF

(iii) $(M(NH_3) = 14.01 + 3(1.01) =)\ 17.04 / 17.0\ (g\,mol^{-1})$;
$m(NH_3) = 0.00250\,mol \times 17.04\,g\,mol^{-1} = 0.0426\,g / 0.0425\,g$; **[2]**
ECF

(b) (i)
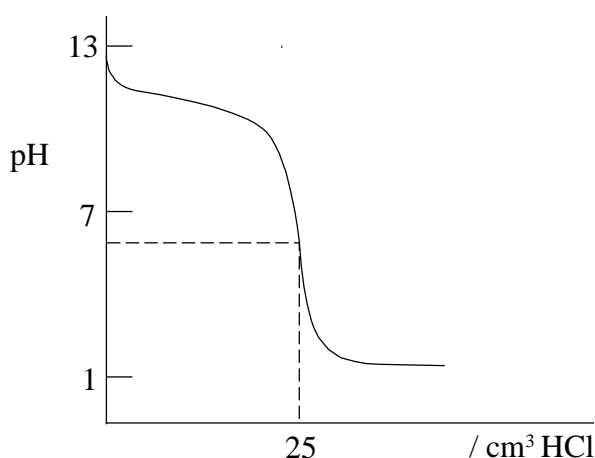
graph starting at $pH < 13$;
Award [0] for pH = 13.

equivalence point $pH < 7$;
Accept anything between 4 – 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]**

(c) (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

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

(v) at half neutralization: $\left[NH_3\right] = \left[NH_4^+\right]$;
therefore, $K_b = \left[OH^-\right]$ / $pK_b = pOH$;
$pH = 14.00 - 4.75 = 9.25$;
Award only [2] for pH = 9.25 if working is not shown *[3]*