M15/4/CHEMI/HP2/ENG/TZ1/XX/M

Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2015

Chemistry

Higher level

Paper 2

15 pages

Subject details: chemistry HL paper 2 markscheme

Mark allocation

Candidates are required to answer **ALL** questions in Section A **[40 marks]** and **TWO** questions in Section B **[2 x 25 marks]**. Maximum total = **[90 marks]**.

1. A markscheme often has more marking points than the total allows. This is intentional.

2. Each marking point has a separate line and the end is shown 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 underlined 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 ***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. When marking, indicate this by adding **ECF** (error carried forward) on the script.

10. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the markscheme.

11. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the markscheme. Similarly, if the formula is specifically asked for, unless directed otherwise in the markscheme do not award a mark for a correct name.

12. 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.

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

Section A

1. (a) $\left(\frac{(12.70+12.50)}{2}=\right)12.60\,(\text{cm}^3)$;

$(0.01260\times0.100=)1.26\times10^{-3}\,(\text{mol})$; **[2]**

*Award **[2]** for correct final answer.*

(b) (i) $\left(\frac{1.26\times10^{-3}}{2}=\right)6.30\times10^{-4}\,(\text{mol})$; **[1]**

(ii) $(6.30\times10^{-4}\times10=)6.30\times10^{-3}\,(\text{mol})$; **[1]**

(iii) $\left(\frac{0.795}{6.30\times10^{-3}}=\right)126\,(\text{g mol}^{-1})$; **[1]**

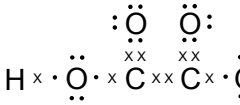
(iv) $M_r(C_2H_2O_4)=90.04$ **and** $M_r(H_2O)=18.02$;

$x=2$; **[2]**

Accept integer values for M_r's of 90 and 18 and any reasonable calculation.
*Award **[1 max]** if no working shown.*

(c) hydrogen bonding; **[1]**

(d)



; **[1]**

Mark cannot be scored if lone pairs are missing on oxygens.
Accept any combination of lines, dots or crosses to represent electron pairs.

(e) *Acid*:
one double and one single bond / one shorter and one longer bond;
Accept "two double and two single".

Conjugate base:
two 1.5 bonds / both bonds same length;
Accept "four / all".

electrons delocalized / resonance forms; **[3]**
Award marks for suitable diagrams.

2. (a) $Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$;

Accept $Na_2O(s) + H_2O(l) \rightarrow 2Na^+(aq) + 2OH^-(aq)$.

$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$; **[2]**

Accept $P_2O_5(s) + 3H_2O(l) \rightarrow 2H_3PO_4(aq)$.

Accept $P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H^+(aq) + 4H_2PO_4^-(aq)$.

Ignore state symbols.

(b) (i) Na_2O ionic **and** P_4O_{10} covalent (within molecule);
Na_2O in giant/3D/network/lattice structure with strong (ionic) bonds **and** P_4O_{10} has a (simple) molecular structure/weak intermolecular forces (between molecules); **[2]**

*Award **[1]** for stating that bonds require more energy to break in Na_2O than in P_4O_{10}.*

(ii)

	Phosphorus(V) oxide	Sodium oxide
Solid state	no	no
Molten state	no	yes

;; **[2]**

*Award **[2]** for four correct.*
*Award **[1]** for two or three correct.*

(c) *Ammonium chloride:*
Accept any value in the range: $3 < pH < 7$;

$NH_4^+(aq) \rightleftharpoons NH_3(aq) + H^+(aq)$;

Sodium methanoate:
$7 < pH < 11$;

$HCOO^-(aq) + H_2O(l) \rightleftharpoons HCOOH(aq) + OH^-(aq)$; **[4]**

*Award **[1 max]** for both M1 and M3 combined if stated "pH < 7/acidic for ammonium chloride and pH > 7/alkaline/basic for sodium methanoate".*

Accept alternative suitable equations.
*Award **[1 max]** for two correct explanations, such as "salt of weak acid and strong base" or "salt of weak base and strong acid", without equations.*
Penalize missing equilibrium sign once only.
Ignore state symbols.

3. (a) change in concentration of reactant/product with time / rate of change of concentration; **[1]**
Accept "increase" instead of "change" for product and "decrease" instead of "change" for reactant.
Accept "mass/amount/volume" instead of "concentration".
Do not accept substance.

(b) collision frequency;
two particles must collide;
particles must have sufficient energy to overcome the activation energy/ $E \geq E_a$;
Concept of activation energy must be mentioned.

appropriate collision geometry/orientation; **[3 max]**

(c) (i) increases yield;
(equilibrium shifts to the right/products as) more gaseous moles in reactants/on left / fewer gaseous moles in products/on right; **[2]**

(ii) $\text{Eqm}[O_2] = 2.6\,(\text{mol dm}^{-3})$;
$\text{Eqm}[SO_2] = 1.2\,(\text{mol dm}^{-3})$;
$K_c = \dfrac{[SO_3]^2}{[SO_2]^2[O_2]}$;
$K_c = 0.17$; **[4]**
*Award **[4]** for correct final answer.*
Ignore units.

(iii) (K_c) decreases; **[1]**

(d) catalyst increases rate of reaction / equilibrium reached faster / increases yield of product per unit time;
reduces costs / reduces energy needed; **[2]**
Do not accept just "increases the yield".

4. (a) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ / $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$; **[1]**

(b) *Physical:*
^{63}Cu lower boiling point/melting point/density/greater rate of diffusion than ^{65}Cu;
Accept converse argument.
Do not accept "different mass".

Chemical:
(properties identical because) same electron configuration/arrangement of electrons; **[2]**
*Accept "same number of protons **and** electrons".*
Do not accept "same number of electrons" OR "same valence (electrons)" OR "same atomic number" only.

(c) electrostatic attraction;
between (a lattice of) cations/positive ions **and** delocalized/sea of electrons; **[2]**
Do not award any mark for only stating "metallic bonding".

Section B

5. (a) *Equation:*
$CH_2CH_2 + H_2O \rightarrow CH_3CH_2OH$ / $C_2H_4 + H_2O \rightarrow C_2H_5OH$;

Conditions:
(concentrated) sulfuric acid/H_2SO_4;
Do not accept dilute sulfuric acid.
Accept phosphoric acid/H_3PO_4 (on pellets of silicon dioxide) (for industrial preparation).

heat / high temperature; **[3]**
Do not accept warm.
Accept high pressure (for industrial preparation) for M3 only if H_3PO_4 is given for M2.

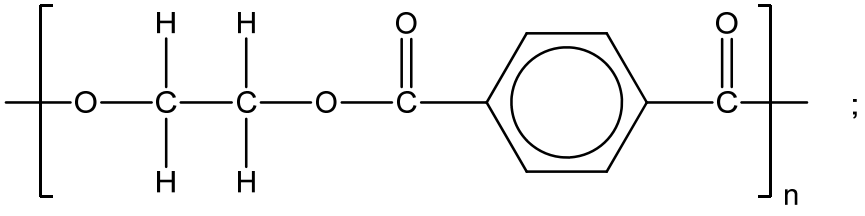
(b) (i) energy needed to break (1 mol of) a bond in the gaseous state/phase;
(averaged over) similar compounds; **[2]**
Do not accept "similar bonds" instead of "similar compounds".
Concept of "similar" is important for M2.

(ii) $CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$;
Bonds broken:
$347 + (5 \times 413) + 358 + 464 + (3 \times 498) / 4728\,(kJ)$ /
C–C + 5C–H + C–O + O–H + 3O=O;
Bonds made:
$(4 \times 746) + (6 \times 464) = 5768\,(kJ)$ / 4C=O + 6O–H;
$\Delta H = (4728 - 5768 =) -1040\,(kJ\,mol^{-1})$ / bonds broken – bonds formed; **[4]**
*Award **[4]** for correct final answer.*
*Award **[3]** for (+)1040 (kJ mol^{-1}).*

(c) heat loss (to the surroundings); **[1]**

(d) $CH_3CH_2OH + CH_3CH_2COOH \rightleftharpoons CH_3CH_2OOCCH_2CH_3 + H_2O$;
ethyl propanoate; **[2]**
Do not penalize if equilibrium arrow missing.

(e) (i) *Repeating unit*:



;

Continuation lines must be shown.
Ignore brackets and n.
Accept condensed formulas such as CH_2 and C_6H_4.

Other product:
H_2O/water; **[2]**

(ii) condensation; **[1]**

(f) (i) $3C(s) + 3H_2(g) + O_2(g) \rightarrow CH_3CH_2COOH(l)$;

$\Delta H_f^\ominus = \sum \Delta H_c^\ominus (reactants) - \sum \Delta H_c^\ominus (products)$;

Accept any suitable energy cycle.

$\sum \Delta H_c^\ominus (reactants) = 3 \times (-394) + 3 \times (-286) / -2040\ (kJ\,mol^{-1})$;

$(\Delta H_f^\ominus = [3 \times (-394) + 3 \times (-286)] - (-1527) =) - 513\ (kJ\,mol^{-1})$;

OR

$CH_3CH_2COOH(l) + 3.5O_2(g) \rightarrow 3CO_2(g) + 3H_2O(g)$;

$\Delta H_c^\ominus = \sum \Delta H_f^\ominus (products) - \sum \Delta H_f^\ominus (reactants)$;

$\sum \Delta H_f^\ominus (products) = 3 \times (-394) + 3 \times (-286) / -2040\ (kJ\,mol^{-1})$;

$(\Delta H_f^\ominus = [3 \times (-394) + 3 \times (-286)] - (-1527) =) - 513\ (kJ\,mol^{-1})$; **[4]**

Ignore state symbols.
*Award **[4]** for correct final answer.*

(ii) negative;
reduction in the number of gaseous molecules; **[2]**

(g) *Allotropes:*
*Any **three** allotropes for **[1]** from:*
diamond
graphite
fullerene
graphene;
Allow (carbon) nanotubes for graphene.
Accept C_{60} /C_{70} /buckminsterfullerene/bucky balls for fullerene.

Structures:
*Any three for **[3]** from:*
Diamond:
tetrahedral arrangement of (carbon) atoms/each carbon bonded to four others / sp^3 **and** 3D/covalent network structure;
Graphite:
each carbon bonded to three others (in a trigonal planar arrangement) / sp^2 **and** 2D / layers of (carbon) atoms;
Fullerene:
each (carbon) atom bonded to three others (in a trigonal arrangement) / sp^2 **and** joined in a ball/cage/sphere/connected hexagons and pentagons;
Accept "trigonal planar" for "each carbon atom bonded to three others" part in M4.
Graphene:
each carbon bonded to three others (in a trigonal arrangement) / sp^2 **and** 2D structure; **[4]**

6. (a) $CH_4 + Br_2 \rightarrow CH_3Br + HBr$; **[1]**

(b) (i) *Initiation:*

$Br_2 \xrightarrow{UV/hf/h\upsilon} 2Br\bullet$;

Reference to UV/light or high temperatures must be included.

Propagation:

$Br\bullet + CH_4 \rightarrow CH_3\bullet + HBr$;

$CH_3\bullet + Br_2 \rightarrow CH_3Br + Br\bullet$;

Termination:

*Award **[1 max]** for any one of:*

$Br\bullet + Br\bullet \rightarrow Br_2$;

$CH_3\bullet + Br\bullet \rightarrow CH_3Br$;

$CH_3\bullet + CH_3\bullet \rightarrow C_2H_6$; **[4 max]**

Allow representation of radical without • (eg Br, CH_3) if consistent throughout mechanism.

*Award **[3 max]** if initiation, propagation and termination are not stated or are incorrectly labelled for equations.*

(ii) methanol/CH_3OH; **[1]**

(c) C–I bond is weaker than the C–Br bond so more easily broken;

C–I bond is longer than the C–Br bond / I larger than Br so bonding electrons not as tightly held / I^- is better leaving group than Br^-; **[2]**

(d) (i) *Positive electrode (anode):*

$2Br^- \rightarrow Br_2(g) + 2e^- \; / \; Br^- \rightarrow \frac{1}{2}Br_2(g) + e^-$;

Negative electrode (cathode):

$Na^+ + e^- \rightarrow Na(l)$; **[2]**

*Award **[1 max]** for correct equations at incorrect electrodes.*

Ignore state symbols.

Accept e *instead of* e^-.

Penalize use of equilibrium signs once only.

(ii) *Positive electrode (anode):*

bromine/Br_2;

Negative electrode (cathode):

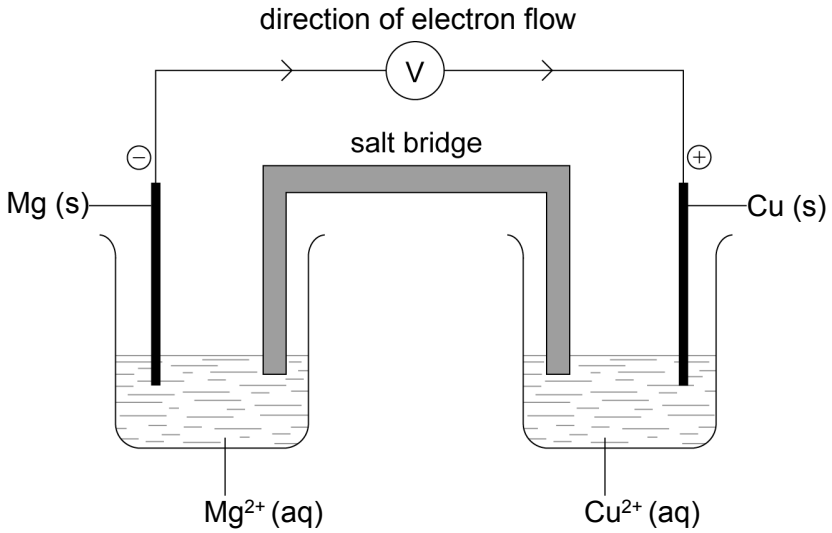
hydrogen/H_2; **[2]**

Allow sodium hydroxide/NaOH/hydroxide/OH^- formation.

(e) bromine/Br_2; **[1]**
Do not accept bromide/Br^-.

(f) (i) potential of reduction half-reaction under standard conditions measured relative to standard hydrogen electrode/SHE / potential under standard conditions relative to standard hydrogen electrode/SHE; **[1]**
Instead of standard state allow either solute concentration of 1 mol dm^{-3} or 100 kPa/1.00 $\times 10^5$ Pa for gases.
Allow 1 bar for 100 kPa/1.00 $\times 10^5$ Pa.
Allow 1 atm.
Allow voltage instead of potential.

(ii)



correct diagram including (voltmeter), 4 correct species (state symbols not required) and connecting wires;
No credit if wires to electrodes immersed in the solutions.
Accept ammeter/meter/lamp instead of voltmeter.

labelled salt bridge;
Accept an appropriate salt (name or formula) instead of salt bridge (eg, potassium nitrate).

correctly labelled electrodes as +/cathode **and** –/anode;
flow of electrons from Mg to Cu in external circuit; **[4]**

(iii) *Random uncertainty:* (±) 0.01 (V);
Significant figures: 3; **[2]**

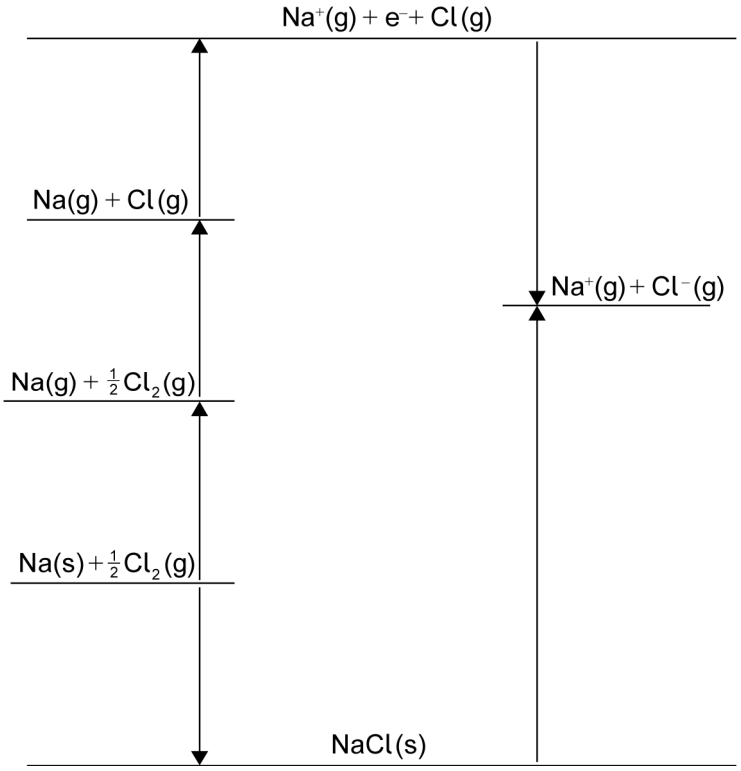
(iv) repeat readings **and** take an average / use more precise equipment; **[1]**

(g) atomization of chlorine $= \frac{1}{2}$ bond enthalpy / $\frac{1}{2}$ 243 / 121.5 (kJ mol^{-1});

correct values for *ionization* Na (+496 kJ mol^{-1}) **and** *electron affinity* Cl (–349 kJ mol^{-1}) **and** lattice enthalpy of NaCl (+790 kJ mol^{-1} / +769 kJ mol^{-1});

Born-Haber energy cycle;

Accept lines or arrows in energy cycle.



$\Delta H_f^{\ominus}(NaCl(s)) = -413.5 / -413 / -414\,(kJ\ mol^{-1})$; **[4]**

Accept –392.5 / –392 / –393 if +769 used for lattice enthalpy.

*Award **[4]** for correct final answer.*

7. (a) (i) *Ethanal*: distill off product as it forms;

Accept distillation.

Ethanoic acid: (heat under) reflux / use excess oxidizing agent; **[2]**

(ii) *Ethanol:* –2/–II;

Ethanal: –1/–I; **[2]**

Do not accept 2–, 1– but penalize once only.

(iii) $CH_3CH_2OH \rightarrow CH_3CHO + 2H^+ + 2e^-$; **[1]**

Half-equation required. Do not accept $C_2H_5OH + 2[O] \rightarrow CH_3CHO + H_2O$.

Accept e for e$^-$.

(iv) $3CH_3CH_2OH(aq) + Cr_2O_7^{2-}(aq) + 8H^+(aq) \rightarrow 2Cr^{3+}(aq) + 3CH_3CHO(l) + 7H_2O(l)$

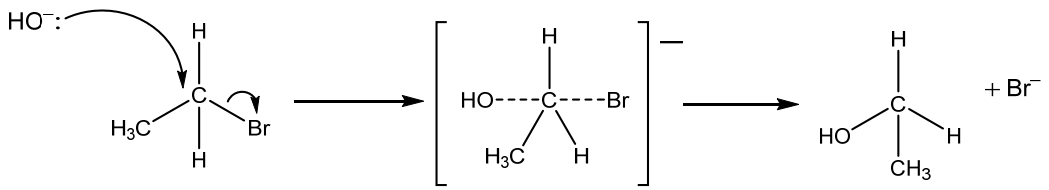
correct reactants and products;

correct balancing; **[2]**

M2 can only be scored if M1 correct.

Ignore state symbols.

(b)



curly arrow going from lone pair/negative charge on O in HO^- to C;
Do not allow curly arrow originating on H in HO^-.

curly arrow showing Br leaving;
Accept curly arrow either going from bond between C and Br to Br in bromoethane or in the transition state.

representation of transition state showing negative charge, square brackets and partial bonds;
Do not penalize if HO and Br are not at 180° to each other.
Do not award M3 if OH----C bond is represented.

formation of organic product CH_3CH_2OH **and** Br^-; **[4]**
*Award **[3 max]** for correct S_N1 mechanism.*

(c) (i) $[NaOH] / [OH^-]$ is 1/first order **and** $[C_4H_9Br]$ is 1/first order;
$rate = k[OH^-][C_4H_9Br]$ / $rate = k[NaOH][C_4H_9Br]$; **[2]**
Square brackets must be used for M2.

(ii) $\left(\frac{1.02\times10^{-4}}{0.25\times0.25} = \right) 0.0016 / 1.6\times10^{-3}$;
$mol^{-1}\,dm^3\,s^{-1}$; **[2]**
Accept $M^{-1}\,s^{-1}$.
Ignore order of units.
Must use experiment 3 data.

(iii) bimolecular/2; **[1]**
Accept dimolecular.

(d) (i) chiral/asymmetric carbon / carbon attached to 4 different groups / non-super imposable mirror images; **[1]**

(ii) enantiomers rotate plane of (plane-) polarized light;
in opposite directions (by equal amounts); **[2]**

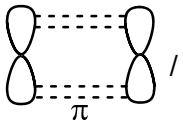
(e) $CH_3CHBrCH_2CH_3 + OH^- \rightarrow CH_3CHCHCH_3 + H_2O + Br^-$ /
$CH_3CHBrCH_2CH_3 + OH^- \rightarrow CH_2CHCH_2CH_3 + H_2O + Br^-$ /
$CH_3CHBrCH_2CH_3 + CH_3CH_2O^- \rightarrow CH_3CHCHCH_3 + CH_3CH_2OH + Br^-$;
Accept equations with NaOH.

<u>alcoholic</u> sodium hydroxide / <u>ethanolic</u> OH^-; **[2]**

(f) *Sigma bonds*:

result from head-on/end-on overlap of orbitals / *OWTTE*;
Accept axial overlap of orbitals.
Accept "symmetric orbital" with respect to same plane / OWTTE.

Pi bonds:



result from sideways overlap of orbitals / *OWTTE*; **[2]**
Accept "antisymmetric orbitals" with respect to (defining) plane (containing at least one atom) / OWTTE.

(g) $79.91 = 79x + 81(1-x)$;
Award M1 for any suitable calculation.
(abundance ^{79}Br =) 54.5 %; **[2]**
*Award **[2]** for correct final answer.*

8. (a) (i) weak acids dissociate only partially **and** strong acids (are assumed to) dissociate fully; **[1]**

(ii) measuring electrical conductivity **and** strong acids have greater electrical conductivity/weak acids have lower electrical conductivity;
Do not accept conductivity for electrical conductivity.
Accept explanation in terms of lightbulb in circuit.

measure pH/use universal indicator **and** pH higher for weak acid/pH lower for strong acid;

conduct titration with a strong base **and** equivalence point higher for weak acid / buffer region for weak acid;

adding a reactive metal/carbonate/hydrogen carbonate **and** stronger effervescence/faster reaction with strong acids;
Accept converse argument.
Accept correct example.

adding a strong base **and** strong acid would increase more in temperature/ weak acids increase less in temperature; **[3 max]**
Accept correct example.

*Award **[1 max]** for three suitable tests without correct results.*
Accept specific examples with given strong acid and weak acid.
*Accept "addition of $AgNO_3$ (aq) **and** white precipitate with HCl (aq)".*
Do not accept "smell".

(b) $\frac{1.40}{60.06} = 0.0233\,(\text{mol})$ **and** $\frac{0.0233}{0.500} = 0.0466\,(\text{mol dm}^{-3})$;
$(\text{p}K_a = 4.76)\ K_a = 1.7 \times 10^{-5}$;
$[\text{H}^+] = \sqrt{K_a[\text{HA}]} = 8.9 \times 10^{-4}$;
Accept 9.0×10^{-4}.
$\text{pH} = 3.05$; **[4]**
*Award **[4]** for correct final answer.*
Accept alternative methods.

(c) (i) *Equivalence point*: pH of 9.5;
Accept values between 9 and 10.

$\text{p}K_a = \text{pH}$ at half equivalence point;
$\text{p}K_a = 5.4$; **[3]**
Accept any value between 5.2 and 5.6.
*Award **[2]** for M2 and M3 if correct $\text{p}K_a$ given without explanation.*

(ii) phenolphthalein; **[1]**

(iii) $\text{HIn (aq)} \rightleftharpoons \text{H}^+\text{ (aq)} + \text{In}^-\text{ (aq)}$ **and** HIn and In^- have different colours;
Ignore state symbols.
equilibrium shifts depending on addition of H^+ and OH^- / more HIn in acid/low pH / more In^- in alkali/high pH; **[2]**

(d) (i) $\text{CH}_2\text{ClCOO}^-$; **[1]**

(ii) stronger because $\text{p}K_a$ of chloroethanoic acid is < $\text{p}K_a$ of ethanoic acid; **[1]**

(iii) *Concentration of acid*: $\frac{0.030}{0.300} = 0.10\,(\text{mol dm}^{-3})$;
Concentration of base/salt: $\frac{0.020}{0.300} = 0.067\,(\text{mol dm}^{-3})$;
$[\text{H}^+] = \frac{K_a \times [\text{HA}]}{[\text{A}^-]} / \frac{1.3 \times 10^{-3} \times 0.10}{0.067} / 1.9 \times 10^{-3}\ (\text{mol dm}^{-3})$;
$\text{pH} = 2.72$; **[4]**
*Award **[4]** for correct final answer.*
Accept 2.69, 2.70 or 2.7.
Alternative for M3 and M4 if Henderson-Hasselbalch equation used:
M3: $pH = pKa + \log\frac{[base]}{[acid]}$ / $2.87 + \log\left(\frac{0.067}{0.10}\right)$
M4: $pH = 2.70$.
*Award **[1 max]** for* $n_{acid} (= 100 \times 0.50 \div 1000) = 0.050\,mol$ ***and***
$n_{base} (= 200 \times 0.10 \div 1000) = 0.020\,mol$.

(e) Cl has 7 valence electrons **and** is in group 7;
Accept "group 17" as suggested by IUPAC.

Cl has 3 occupied (electron) shells/energy levels **and** so is in period 3; **[2]**

(f)

Molecule	Shape	Bond angle	Polarity
SCl_2	bent/angular/ v-shaped	< 109.5° *Accept 100° − 108°. Literature value is 103°.*	polar
$SClF_5$	Octahedral *Accept square bipyramidal.*	90° (180°)	polar

;;; **[3]**

Do not accept ECF for bond angles and polarities from incorrect shapes.
*Award **[3]** for all six correct.*
*Award **[2]** for four or five correct.*
*Award **[1]** for two or three correct.*