Markscheme

November 2015

Chemistry

Higher level

Paper 2

16 pages

Subject Details: Chemistry HL Paper 2 Markscheme

Mark Allocation

Candidates are required to answer **ALL** questions in Section A **[40 marks]** and **TWO** question 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 <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.

Section A

1. (a) (i) IO_3^- *to* I_2 : V/+5 to 0;

I^- *to* I_2 : –I/–1 to 0; ***[2]***

Accept change in oxidation number –5 and +1.
Penalize incorrect notation such as 5+ or 5 once only.

(ii) *Oxidizing agent*: IO_3^-/iodate **and** *Reducing agent*: I^-/iodide; ***[1]***

(b) $0.250 \times 2.00 \times 10^{-3}$ / 5.00×10^{-4} (mol of KIO_3);

($5.00 \times 10^{-4} \times 214.00 =$) 0.107 (g); ***[2]***

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

(c) (i) 1.4 (%); ***[1]***

Accept 1 (%).

(ii) systematic;
dilute the orange juice; ***[2]***
Accept other valid suggestions, eg. compare with a standard (showing colour at equivalence) / look at mixture through a yellow filter / add more starch (for a sharper colour change) / filter orange juice (through charcoal).
Do not accept repeat titrations or alternative indicator.

(iii) 1.44×10^{-5} (mol); ***[1]***

(d) IO_3^- : $3C_6H_8O_6$ / 1:3 mole ratio;

(1.44×10^{-5} mol $\times 3 =$) 4.32×10^{-5} (mol); ***[2]***

Award ***[2]*** *for the correct final answer.*
Award ***[1 max]*** *for "4.80×10^{-6} (mol)" obtained from reversed ratio, 3:1.*

(e) ($4.32 \times 10^{-5} \times 176.14 =$) 7.61×10^{-3} (g); ***[1]***

Accept $M_r = 176$ and mass $= 7.60 \times 10^{-3}$(g).

(f) gradient $= -\frac{E_a}{R}$ / –1233 (K);

Accept value from –1200 to –1260 (K).

$E_a = (1233 \times 8.31 =)\ 1.02 \times 10^4\ \text{J mol}^{-1}$ / $10.2\ \text{kJ mol}^{-1}$

correct E_a value;

correct units; ***[3]***

Allow value in range 9.97 – 10.5 kJ mol^{-1}.
Answer must be given to three significant figures.
Award ***[3]*** *for correct final answer* ***and*** *units.*
Accept J or kJ instead of J mol^{-1} or kJ mol^{-1}.

2. (a) (Cu) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$ / $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$;
Do not accept [Ar] $4s^1 3d^{10}$.

(Cu^{2+}) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$; ***[2]***
Do not accept [Ar] $3d^9$.

(b) (NH_3) Lewis base **and** (Cu^{2+}) Lewis acid;
NH_3/ligand donates an electron pair (to Cu^{2+}) / Cu^{2+} accepts an electron pair (from NH_3);
forming coordinate/dative (covalent) bond; ***[3]***
Accept coordination bond.
Do not accept just covalent bond.

(c) d orbitals are split (into two sets of different energies);
(frequency/wavelength of visible) light absorbed by electrons moving between d levels/orbitals;
colour due to remaining frequencies/complementary colour transmitted;
Cu^{2+} has unpaired electrons/partially filled d sub-level / Zn^{2+} has filled d sub-level;

Accept d-d transitions possible between orbitals for M2. ***[4]***

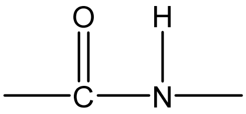
3. (a) $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$; ***[1]***
Ignore state symbols.

(b) *bonds broken:* 2(C–C)/694 + 8(C–H)/3304 + 5(O=O)/2490 / 6488 (kJ);
bonds made: 6(C=O)/4476 + 8(O–H)/3712 / 8188 (kJ);
(6488 – 8188 =) – 1700 (kJ mol^{-1}); ***[3]***
Ignore signs in M1 and M2.
*Award **[3]** for the correct final answer.*
*Award **[2]** for +1700 (kJ mol^{-1}).*
Accept values from 2016 data booklet to give 6494 (kJ) for M1, 8528 (kJ) for M2, and –2034 (kJ) for M3.

4. (a) $HOOC(CH_2)_4COOH$;
Accept $COOH(CH_2)_4COOH$ but not $COOH(CH_2)_4HOOC$ or $HOOC(CH_2)_4HOOC$.
$H_2N(CH_2)_6NH_2$; ***[2]***
Accept $NH_2(CH_2)_6NH_2$ but not $H_2N(CH_2)_6H_2N$ or $NH_2(CH_2)_6H_2N$.
Accept full or condensed structural formulas.

(b) *Type:* condensation (polymerization);
Structural feature: two functional groups on each monomer; ***[2]***

(c)



$$-\overset{\overset{\displaystyle O}{\|}}{C}-\overset{\overset{\displaystyle H}{|}}{N}-$$

Accept —CONH— ;
Accept this group if correctly identified as part of polymer chain.
water/H_2O; ***[2]***

5. (a) (i) ability of an atom to attract (a pair of) electrons in a covalent bond/molecule / ability of an atom to attract a shared pair of electrons; ***[1]***

Do not accept element/nucleus instead of atom.

(ii) do not form bonds/compounds / do not share electrons / have (full/stable) octet / have full/stable outer shell; ***[1]***

Accept (chemically) inert / do not react / stable electron arrangements/ configurations.

(b) *(Li → Cs)* atomic/ionic radius increases;
force of attraction between metal ions and <u>delocalized</u> electrons decreases;
Accept metallic bonding gets weaker.

(F → *I*) London/dispersion/instantaneous induced dipole-induced dipole forces increase;
Accept vdW/van der Waals' forces for London/dispersion forces.

with increasing number of electrons/molar mass/surface area/size of electron cloud; ***[3 max]***
Do not accept "with increasing size" or "with increasing mass" only.

(c) Na^+ has one less energy level/shell compared to Na atom / Na^+ has 2 energy levels/shells compared to 3 in Na atom;
(compared to Na atom) effective nuclear charge greater in Na^+ (so valence electrons attracted more strongly to nucleus) / (compared to Na atom) more protons than electrons in Na^+ (so valence electrons attracted more strongly to nucleus); ***[1 max]***

Section B

6. (a) possible to get iron **and** 3:1 ratio of the two equations;
The ratio may be shown in combining the equations/calculating overall ΔG/–29 (kJ).
possible to get iron **and** resultant ΔG is negative/–29 (kJ); ***[2]***
"Possible to get iron" needs only to be stated once.
Do not accept "possible to get iron" without any reason.
Do not accept "it is not possible to get iron because ΔG is positive".

(b) (i) $\Delta G^{\ominus} = [-1582 + 2 \times 10] - [-742]$;
$\Delta G^{\ominus} = -820 (\text{kJ mol}^{-1})$; ***[2]***
*Award **[2]** for the correct final answer.*

(ii) $\left(\Delta S^{\ominus} = [50.9 + 2(34.8)] - [87.5 + 2(28.3)]\right) = -23.6 (\text{J K}^{-1}\,\text{mol}^{-1})$; ***[1]***

(iii) $\Delta G^{\ominus} = [-825.2 - (298 \times (-0.0236))]$;
$\Delta G^{\ominus} = -818 (\text{kJ mol}^{-1}) / -8.18 \times 10^{5} (\text{J mol}^{-1})$; ***[2]***
*Award **[2]** for the correct final answer.*
*Award **[0]** if b(i) is repeated here.*

(c) (i)

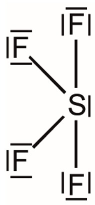
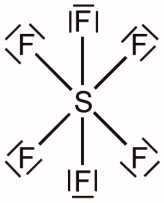
	NF_4^+	N_2H_2	N_2H_4
Hybridization	sp^3;	sp^2;	sp^3;

[3]

Do not penalize if it is not superscript.

(ii) *sigma bond:* overlapping of orbitals end to end/head on / overlapping of orbitals along internuclear axis;
Accept "axial overlapping of orbitals".

pi bond: side-ways/parallel overlapping of <u>p orbitals</u> (above and below internuclear axis); ***[2]***
Accept "overlapping of <u>p orbitals</u> above and below the internuclear axis".
Accept suitable labelled diagrams.

(iii)  ;
 ;

See saw; Octahedral; **[4]**

Accept any combination of lines, dots or crosses to represent electron pairs.
Penalize missing lone pairs on fluorine atoms once only.
For SF_4, lone pair on S required for the mark.
Do not allow ECF for a wrong Lewis structure.
Accept saw horse/distorted tetrahedron instead of see-saw.

(d) (i) $CH_3CH_2CH_3 < CH_3CHO < CH_3CH_2OH < CH_3COOH$;; **[2]**
*Award **[2]** for correct order.*
*Award **[1]** for $CH_3COOH > CH_3CH_2OH > CH_3CHO > CH_3CH_2CH_3$ as compounds are not listed in order of increasing boiling point.*
*Award **[1]** if one error in the order.*

(ii) $CH_3CH_2CH_3$ /London/dispersion/instantaneous induced dipole-induced dipole forces
CH_3CHO dipole-dipole forces (and London/dispersion forces)
CH_3CH_2OH H-bonding (and dipole-dipole and London/dispersion forces)
CH_3COOH H-bonding (and dipole-dipole and London/dispersion forces);;
*Award **[2]** for all four correct.*
*Award **[1]** for two or three correct.*

H-bonding strongest / London/dispersion forces weakest / dipole-dipole stronger than London/dispersion / dipole-dipole weaker than H-bonding;

Accept van der Waals' forces for London/dispersion forces.

CH_3COOH forms more/stronger H-bonds than CH_3CH_2OH / CH_3COOH is more polar than CH_3CH_2OH; **[4]**
Accept CH_3COOH has more electrons/higher molar mass than CH_3CH_2OH.

(e) ionization **and** (bombardment) by high energy/fast moving electrons/electron gun (to form positive ions);
acceleration **and** passing through electric field/potential difference/oppositely charged plates;
deflection **and** passing through magnetic field/electromagnet; **[3]**
*Award **[1]** for naming 3 processes (ionization, acceleration, deflection) in the correct order with incorrect details.*

7. (a) (i) *Increasing the pressure, at constant temperature:*
decreases;
more (gas) molecules/moles on the right / fewer (gas) molecules/moles on the left;

Increasing the temperature, at constant pressure:
increases;
(forward) reaction is endothermic; ***[4]***

(ii) equilibrium reached faster;
no change in the concentration of reactants/products/yield (at equilibrium) / position of equilibrium is not affected;
rates of forward and reverse reactions increase (equally);
reduces activation energy;
no change in *K*c; ***[3 max]***

(iii) $(K_c =)\dfrac{[H_2]^3[CO]}{[CH_4][H_2O]}$; ***[1]***

(iv) (increasing) temperature **and** (K_c) increases; ***[1]***
*Award **[0]** if both temperature and pressure stated.*

(b) $CO(g) + H_2O(g) \rightleftharpoons H_2(g) + CO_2(g)$
$(1.00 - x)\ (1.00 - x)\quad x\quad x$

$K_c = 10.0 = \dfrac{x^2}{(1.00 - x)^2} \,/\, \sqrt{10.0} = \dfrac{x}{(1.00 - x)}$;

$x = 0.760 \,/\, (1.00 - x) = 0.240$;

$[CO] = 0.240(\text{mol dm}^{-3})$ **and** $[H_2O] = 0.240(\text{mol dm}^{-3})$ **and** $[H_2] = 0.760(\text{mol dm}^{-3})$ **and** $[CO_2] = 0.760(\text{mol dm}^{-3})$; ***[3]***

(c) (i) *Order with respect to O_2*: first (order);
Order with respect to NO: second (order); ***[2]***

(ii) (rate $=$) $k\,[NO]^2[O_2]$; ***[1]***

(iii) 172.6 / 173;
$\text{mol}^{-2}\,\text{dm}^6\,\text{s}^{-1}$; ***[2]***
Accept $M^{-2}\,s^{-1}$/$mol^{-2}\,L^2\,s^{-1}$.

(iv) $NO + NO \rightleftharpoons N_2O_2$ (fast);
N_2O_2) $O_2 \rightarrow 2NO_2$ (slow);
second step is rate determining step;

OR

$NO + O_2 \rightleftharpoons O + NO_2$ (fast);
$O + NO \rightarrow NO_2$ (slow);
second step is rate determining step;

OR

$NO + O_2 \rightleftharpoons NO_3$ (fast);
$NO_3 + NO \rightarrow 2NO_2$ (slow);
second step is rate determining step;
Accept single arrow instead of reversible sign.
Accept fast/slow next to the equations.

*Do **not** accept the following mechanisms:*
$NO + NO \rightleftharpoons NO_2 + N$ (fast)
$N + O_2 \rightarrow NO_2$ (slow)

OR

$NO + NO + O_2 \rightleftharpoons N_2O_4$ (slow)
$N_2O_4 \rightarrow 2NO_2$ (fast) ***[3]***

(d) (i) $Pb < Ni < Fe < Zn$;; ***[2]***
*Award **[2]** for the correct order.*
*Award **[1]** for $Zn > Fe > Ni > Pb$ as metals not listed in order of increasing reactivity.*
*Award **[1]** if one error in the order.*

(ii) Pb^{2+}/ lead(II) (ions); ***[1]***
Do not accept Pb/lead.

(e) *Dilute sodium chloride:*

$$H_2O(l) \rightarrow \frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \, / \, 2OH^-(aq) \rightarrow \frac{1}{2}O_2(g) + H_2O(l) + 2e^-;$$

C*oncentrated sodium chloride:*

$$Cl^-(aq) \rightarrow \frac{1}{2}Cl_2(g) + e^-;$$ ***[2]***

*Award **[1 max]** if equations are given the wrong way round.*
Accept e instead of e^-.
Ignore state symbols and equilibrium sign.
Accept correct half-equations balanced with different coefficients.

8. (a) (i) *base I:* 7.0;
base II: 5.5; ***[2]***

(ii) *base I:* strong base **and** *base II:* weak base; ***[1]***

(iii) NaOH **and** KOH; ***[1]***
Accept LiOH.

(iv) (from the graph: initial $pH = 11, pOH = 3$) $[OH^-] = 10^{-3}(\text{mol dm}^{-3})$;

$K_b = \frac{10^{-3} \times 10^{-3}}{0.100 - x} / \frac{10^{-3} \times 10^{-3}}{0.100}$;

$K_b = 1.0 \times 10^{-5}$;

OR

at half-equivalence point, $pH = 9.0 = pK_a$ for base II;
$pK_b = 14.0 - 9.0 = 5.0$;
Award M1 and M2 for stating: "at half-equivalence point $pOH = 5 = pK_b$ for base II".

$K_b = 1.0 \times 10^{-5}$; ***[3]***
Accept other valid methods of working.
Accept a slightly different value of pK_b and so K_b if the student uses the pH at the end point, rather than the initial or half-neutralisation values.

(v) methyl red; ***[1]***
Do not accept bromocresol green (since from table 16 data booklet pH range, 3.8 is too low).

(b) (i) resists change in pH;
on addition of <u>small</u> amounts of acid and base; ***[2]***

(ii) (after mixing) $[NH_3] = [NH_4^+] / nNH_3 = nNH_4^+ / n = 4.00 \times 10^{-3}$ mol;

$[OH^-] = K_b \frac{[\text{base}]}{[\text{salt}]}$ / $pOH = pK_b = 4.75$;

pH = 9.25; ***[3]***
*Award **[1 max]** if no working shown.*
Accept other valid methods of working.

(c) (i) *Reaction A*: base **and** accepts a proton/H^+;
Accept donates a pair of electrons.

Reaction B: acid **and** donates a proton/H^+; ***[2]***

*Award **[1]** if acid and base identified correctly without a reason.*

(ii)

	Acid		Base
Conjugate acid-base pair 1/2	H_2CO_3	**and**	HCO_3^-;
Conjugate acid-base pair 2/1	HCO_3^-	**and**	CO_3^{2-};
Conjugate acid-base pair 1/2	H_3O^+	**and**	H_2O;

[2 max]

(d) (i) *strong acid:* (assumed to be) completely/100% dissociated/ionized **and**
weak acid: partially dissociated/ionized; ***[1]***

(ii) *Similarity*: bubbling/effervescence/gas / heat/increase in temperature / solid dissolves;
Difference: strong acid more vigorous / faster reaction / greater temperature increase; ***[2]***
Accept converse statements for weak acid.

(iii) $10^4(:1)$ / $10^{-1}:10^{-5}$ / $1:10^{-4}$; ***[1]***
Do not accept inverse ratio, 1:10^4*.*

(e) (i) Na **and** Mg: basic
Al: amphoteric
Do not accept amphiprotic.

Si **to** Cl: acidic
Ar: no oxide ;; ***[2]***
*Award **[2]** for three or four correct, award **[1]** for two correct.*
*Award **[1]** for stating oxides become more acidic towards the right/chlorine or more basic towards the left/sodium.*
Do not penalize incorrect formulas of oxides.

(ii) $Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$ / $Na_2O(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l)$;

Accept a correct equation with any acid or acidic oxide.

$SO_3(l) + H_2O(l) \rightarrow H_2SO_4(aq)$/ $SO_3(l) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$; ***[2]***
Accept a correct equation with any metal hydroxide, metal oxide, metal carbonate or metal hydrogen carbonate.
Do not accept equation with SO_2*.*

Ignore state symbols.
Accept ionic equations for M1 and/or M2.

9. (a) (i) $RBr(l) + NaOH(aq) \rightarrow ROH(aq) + NaBr(aq)$ /
$RBr(l) + OH^-(aq) \rightarrow ROH(aq) + Br^-(aq)$; ***[1]***
Ignore state symbols.

(ii) $(1.35 \times 10^{-2} - 7.36 \times 10^{-3} =)\ 6.14 \times 10^{-3}$ / 6.1×10^{-3} (mol); ***[1]***

(iii) $\left(\text{molar mass} = \frac{0.842}{6.14 \times 10^{-3}} =\right) 137\ (\text{g mol}^{-1})$; ***[1]***
Accept 138.

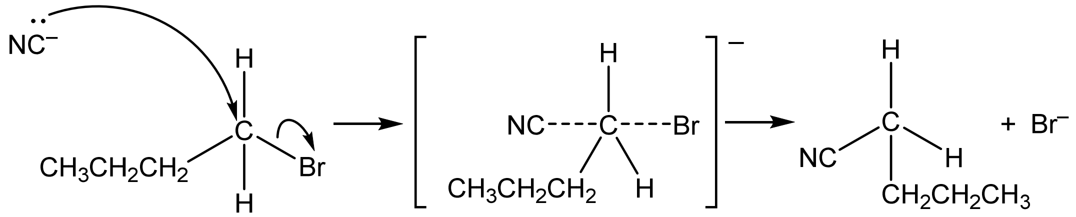
(iv) (137 − 80 = 57 which corresponds to C_4H_9, hence molecular formula)
C_4H_9Br; ***[1]***
Accept correct structural formula of one of the isomers as molecular formula.
Do not accept ECF from 9a(iii) for an impossible molecular formula, such as $C_4H_{10}Br$*.*

(v) $CH_3CH_2CH_2CH_2Br$ **and** primary;
$(CH_3)_2CHCH_2Br$ **and** primary;
$CH_3CHBrCH_2CH_3$ **and** secondary;
$(CH_3)_3CBr$ **and** tertiary;
If primary, secondary or tertiary not stated, award ***[3]*** *for four correct,* ***[2]*** *for three correct and* ***[1]*** *for two correct structural formulas.*
Penalize missing hydrogens once only.
Accept either full or condensed structural formulas.

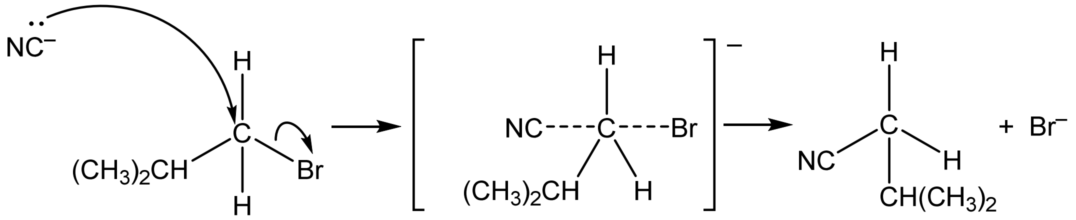
If $C_5H_{11}Br$ *was used, accept any correct structural formulas.*
$CH_3CH_2CH_2CH_2CH_2Br$ **and** primary;
$(CH_3)_2CHCH_2CH_2Br$ **and** primary;
$CH_3CH_2CH(CH_3)CH_2Br$ **and** primary;
$(CH_3)_3CCH_2Br$ **and** primary;
$CH_3CHBrCH_2CH_2CH_3$ **and** secondary;
$CH_3CH_2CHBrCH_2CH_3$ **and** secondary;
$CH_3CHBrCH(CH_3)_2$ **and** secondary;
$CH_3CH_2C(CH_3)_2Br$ **and** tertiary; ***[4]***
If primary, secondary or tertiary not stated, award ***[3]*** *for four correct,* ***[2]*** *for three correct and* ***[1]*** *for two correct structural formulas.*
Penalize missing hydrogens once only.
Accept either full or condensed structural formulas.

(b) (i) increase in carbon chain; ***[1]***

(ii)



OR



curly arrow going from lone pair/negative charge on NC^- to C;
curly arrow showing Br leaving;
Accept curly arrow either going from bond between C and Br to Br in 1-bromobutane/1-bromo-2-methylpropane or in the transition state.

representation of transition state showing negative charge, square brackets and partial bonds;
Do not penalize if NC and Br are not at 180° to each other.

Products: $CH_3CH_2CH_2CH_2CN$/$(CH_3)_2CHCH_2CN$ **and** Br^-/KBr; ***[4]***

Penalize missing hydrogens and/or incorrect bond linkages (eg CN–C instead of NC–C) only once in this question.
Remember to apply ECF from part (a)(v).

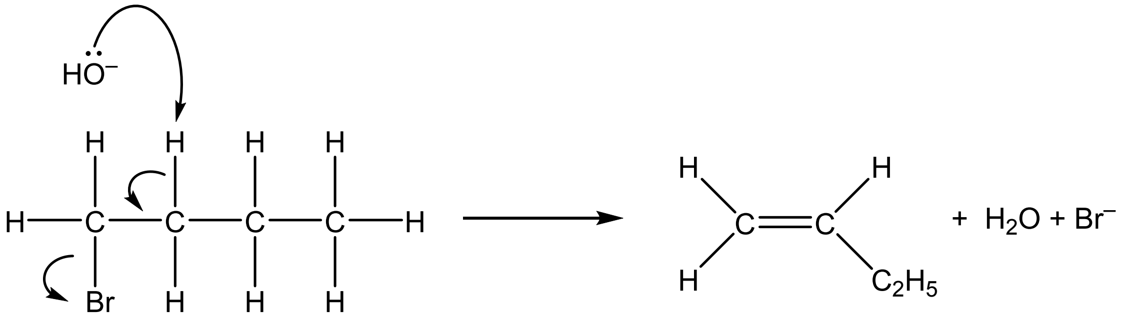
(iii) $CH_3CH_2CH_2CH_2CN + 2H_2 \rightarrow CH_3CH_2CH_2CH_2CH_2NH_2$

OR

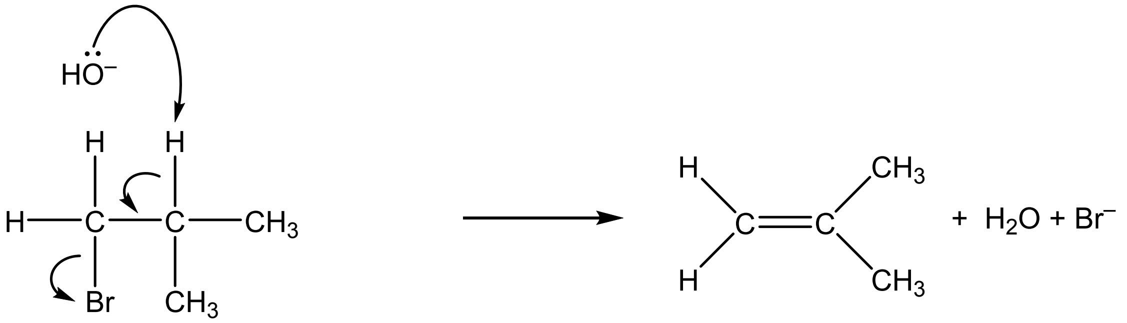
$(CH_3)_2CHCH_2CN + 2H_2 \rightarrow (CH_3)_2CHCH_2CH_2NH_2$;

Ni / Co / Ru; ***[2]***
Accept Pt/Pd/Cu/Rh.
Accept either chemical symbol or name.

(c) (i)



OR



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

curly arrow going from CH bond to form C=C bond;
curly arrow showing Br leaving;
$H_2C{=}CHCH_2CH_3 + H_2O + Br^-$ / $H_2C{=}C(CH_3)_2 + H_2O + Br^-$; ***[4]***

Accept NaBr for Br^-*.*
Remember to apply ECF from part (a)(v).
Do not penalize if mechanism shown with a secondary bromoalkane.
Do not penalize incorrect side-chain.
Penalize missing hydrogens only once in this question.

(ii) addition;
$-CH(C_2H_5)-CH_2-CH(C_2H_5)-CH_2-$ / $-C(CH_3)_2-CH_2-C(CH_3)_2-CH_2-$; ***[2]***
Continuation bonds required for the mark.

(d) Initiation:

$Cl_2 \xrightarrow{\text{UV}/hf/h\nu/heat} 2Cl\bullet$;

Reference to UV light or high temperatures must be included.

Propagation:

$Cl\bullet + C_2H_6 \rightarrow C_2H_5\bullet + HCl$;

$C_2H_5\bullet + Cl_2 \rightarrow C_2H_5Cl + Cl\bullet$;

Termination:

$Cl\bullet + Cl\bullet \rightarrow Cl_2$ / $C_2H_5\bullet + Cl\bullet \rightarrow C_2H_5Cl$ / $C_2H_5\bullet + C_2H_5\bullet \rightarrow C_4H_{10}$; ***[4]***

Accept representation of radical without • (eg, Cl, C_2H_5) if consistent throughout mechanism.
Accept further chlorination.
*Award **[3 max]** if initiation, propagation **and** termination are not stated or are incorrectly labelled for equations.*
Accept correct description of processes without equations.
*Award **[3 max]** if Br used correctly instead of Cl.*