**1.** moles methane = $\frac{0.10}{16}$ = $6.25 \times 10^{-3}$ **(1)**

kJ evolved = $6.25 \times 10^{-3} \times 890 = 5.56$ **(1)**

$5.56 \times 10^3$ joules = (mc)$\Delta$T **(1)**

$\Delta T = \frac{5.56 \times 10^3}{120}$ = 46.4 K **(1)** 4

**[4]**

**2.** $C_6H_{11}OH + 8½O_2 \rightarrow 6CO_2 + 6H_2O$/double or multiple equation **(1)**

**[1]**

**3.** (a) by definition **(1)** 1

(b) $Li(s) + \frac{1}{2}O_2(g) + \frac{1}{2}H_2(g) \rightarrow LiOH(s)$ equation **(1)**
ss **(1)** 2

(c) $Li(s) + H_2O(l) \rightarrow Li^+(aq) + OH^-(aq) + \frac{1}{2}H_2(g)$ equation **(1)**
ss **(1)** 2

(d) $\Delta H = \Delta H_f^{\ominus}$ (LiOH(aq)) – $\Delta H_f^{\ominus}$ ($H_2O$(l)) or cycle **(1)**
= – 487 – 21 – (–286) **(1)**
= – 222 (kJ $mol^{-1}$) **(1)**
(allow **(1)** for – 201)

reactivity increases **(1)**

*Relationship between $\Delta H^{\ominus}$* and reactivity none **(1)**
*Reason* reactivity governed by rate ( or Ea) **(1)** 3

**[8]**

**4.** (a) enthalpy (or energy) to break (or dissociate) a bond; 1
averaged over different molecules (environments); 1

enthalpy (or heat energy) change when one mole of a compound; 1
is formed from its elements; 1
in their standard states; 1

(b) enthalpy change = Σ(bonds broken) –Σ(bonds formed) or cycle; 1
= 4 × 388 +163 + 2 × 146 +4 × 463 -(944 + 8 × 463); 1
*(or similar)*
= –789 ; 1
*(+ 789 scores 1 only)*

(c) (i) zero; 1

(ii) *AH* = Σ (enthalpies of formation of products)
–Σ(enthalpies of formation of reactants) 1
= 4 × –242-(75 + 2 × –133); 1
= -777; 1
*( + 777 scores one only)*

(d) mean bond enthalpies are not exact 1
*(or indication that actual values are different from real values)*

**[13]**

**5.** (a) (i) <u>enthalpy change</u> when 1 mol of a substance (or compound) (QL mark) 1
is (completely) burned in oxygen (or reacted in <u>excess</u> oxygen) 1
at 298 K and 100 kPa (or under standard conditions) 1

(ii) heat produced = mass of water × Sp heat capacity *x$\Delta T$* (or *$mc\Delta T$*) 1
= 150×4.18×64 (note if mass = 2.12 lose first 2 marks then conseq)
= 40100 J or = 40.1 kJ (allow 39.9-40.2 must have correct units) 1
moles methanol = mass/$M_r$ = 2.12/32 (1) 1
= 0.0663

$\Delta H$ = – 40.1/0.0663 = – 605 kJ ($mol^{-1}$) 1
(allow –602 to –608 or answer in J)

*(note allow conseq marking after all mistakes but note use of 2.12 g loses 2 marks*

(b) $\Delta H = \Sigma\Delta H_c^\ominus$(reactants) – $\Sigma\Delta H_c^\ominus$(products) (or correct cycle) 1

$\Delta H_c^\ominus(CH_3OH) = \Delta H_c^\ominus(CO) + 2 \times \Delta H_c^\ominus(H_2) - \Delta H$ 1
= (–283) + (2 × –286) – (–91) (mark for previous equation or this)
= –764 (kJ $mol^{-1}$) ( *units not essential but lose mark if units wrong)* 1
*(note + 764 scores 1/3)*

**[10]**

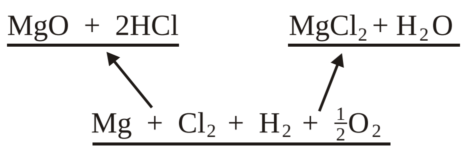
**6.** (a) (i) enthalpy (or heat or heat energy) <u>change</u> when 3
<u>1 mol</u> of a substance **(1)** (QL mark) is formed from its elements **(1)**
<u>all</u> substances in their standard states **(1)** **(**or normal states at 298K, 100 kPa or std condits)

***not** STP, NTP*

(b) <u>enthalpy change</u> (or <u>enthalpy of reaction</u>) is independent of route **(1)**

$\Delta H = \Sigma\Delta H_f^\ominus$ prods - $\Sigma\Delta H_f^\ominus$ reactants (or cycle) **(1)**

minimum correct cycle is:




$\Delta H$ = -642 – 286 – (–602 + 2 × –92) **(1)**
= –142 (kJ $mol^{-1}$) **(1)** 4

*penalise this mark for wrong units*

*+142 scores 1 mark out of the last three*

(c) $\Delta H = mcT$ **(1)** (or $mc\Delta T$)

$= 50 \times 4.2 \times 32 = 6720$ J = 6.72J **(1)**

*mark is for 6720 J or 6.72 kJ*

moles HCl = $\frac{\text{vol}}{1000} \times \text{conc} = \frac{50}{1000} \times 3$ **(1)**

= 0.15 **(1)**

*if error here mark on conseq.*

Therefore moles of MgO reacted = moles HCl/2 **(1)** (mark is for/2, CE if not/2)

= 0.15/2 = 0.075

Therefore $\Delta H$ = 6.72/0.075 **(1)** 8

= –90 kJ ($mol^{-1}$)

*kJ must be given, allow 89 to 91*

*value **(1)***

*sign **(1)**; this mark can be given despite CE for /2*

Note various combinations of answers to part (c) score as follows:

–89 to –91 kJ **(8)** (or –89000 to 91000J)

*no units **(7)***

+89 to +91 kJ **(7)** (or + 89000 to +91000J)

*no units **(6)***

–44 to –46 kJ **(5)** (or -44000 to -46000J)

*no units **(4)** if units after 6.72 or 6720 (5)*

+44 to +46 kJ **(4)** (or +44000 to + 46000)

*if no units and*

*if no units after 6.72 or 6720 **(3)***

*otherwise check, could be **(4)***

**[15]**

**7.** (a) Enthalpy (Energy) to break a (covalent) bond **(1) OR dissociation energy**

Varies between compounds so average value used **(1) QL mark**

**OR average of dissociation energies in a single molecule / e.g. $CH_4$**

**Do not allow mention of energy to form bonds**

**but with this case can allow second mark otherwise 2nd mark consequential on first**

2

(b) (i) $1/2\ N_2 + 3/2\ H_2 \rightarrow NH_3$ **(1)**

**Ignore s s**

(ii) $\Delta H = (\Sigma)$bonds broken – $(\Sigma)$bonds formed **(1)**

$= 1/2 \times 944 + 3/2 \times 436 - 3 \times 388$ **(1)**

= –38 kJ $mol^{-1}$ **(1)**

**Ignore no units, penalise wrong units**

**Score 2/3 for -76**

**1/3 for +38**

**Allow 1/3 for +76**

4

(c) 4 (C–H) + (C=C) + (H–H) – (6 (C–H) + (C–C)) = –136 **(1)**
(C=C) + (H–H) – ((C–C) + 2 (C–H)) = –136
2 (C–H) = 836 **(1)**
(C–H) = 418 (kJ $mol^{-1}$) **(1)**
**Note: allow (1) for –836**
**another (1) for –418**

3

**[9]**

**8.** (a) $C_3H_6 + 4O_2 \rightarrow 3CO_2 + 3H_2O$ **(1)** (or multiple) 1

(b) (i) $\frac{1.45}{58}$ **(1)** = 0.0250 **(1)**

*allow 0.025*
*allow conseq on wrong $M_r$*
*1.45/100, CE;* $\frac{1.45}{58.1}$ *C.E.*

(ii) heat released = mcΔT
= 100 × 4.18 × 58.1 **(1)**
*if 1.45 used in place of 100 CE = 0*

= 24300 J **(1)** (or 24.3kJ)
*allow 24200 to 24300*
*ignore decimal places*
*units tied to answer*
*If use 0.1 × 4.18 × 51.8 allow ½ for 24.3 with no units*

(iii) $\frac{24.3}{0.0250}$ = –972 (kJ $mol^{-1}$) **(1)** 5

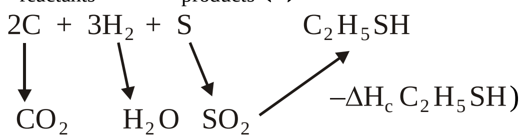
*allow –968 to –973*
*allow +972*
*allow conseq*
*allow no units*
*penalise wrong units*

(c) (i) Heat loss **(1)** or energy loss
*do not allow incomplete combustion*

(ii) *Difference*: more negative **(1)** (or more exothermic)
*QoL mark*

*Explanation*: heat (*or energy*) released when water vapour condenses **(1)** 3
or heat/energy required to vaporise water
or water molecules have more energy in the gaseous state

(d) ΔH = Σ$\Delta H_{reactants}$ – Σ$\Delta H_{products}$ **(1)**
(or cycle




= (2 × –394) + (3 × –286) + (–297) – (–1170) **(1)** = –773 **(1)** 3
*ignore units even if wrong*
*Allow* 1/3 *for +773*

**[12]**

**9.** (a) {heat / {enthalpy change for formation of <u>1 mol</u> of a {molecule / {substance / {compound **(1)**

from its <u>elements</u> **(1)**

in their <u>standard states</u> * (at 298 K, 100 kPa) **(1)**

(*) or natural/normal states at 298 K, 100 kPa

*must have 2nd mark to score third* 3

(b) $C(s) + \frac{3}{2} H_2(g) + \frac{1}{2} N_2(g) + O_2(g) \rightarrow CH_3NO_2(\mathbf{l})$

equation **(1)**

*not × 2*

state symbols **(1)**

*can score for unbalanced equation or × 2* 2

(c) Hess's law **(1)**

*or 1st Law or conservation of energy* 1

(d) $\Delta H_f^{\ominus}$ refers to $\frac{1}{2} H_2(g) + C(s) + \frac{1}{2} N_2(g) \rightarrow HCN(g)$ **(1)**

$\Delta H^{\ominus} = \frac{1}{2}\Delta H_c^{\ominus}(H_2) + \Delta H_c^{\ominus}(c) + \frac{1}{2}\Delta H_c^{\ominus}(N_2) - \Delta H_c^{\ominus}(HCN)$ **(1)**

= –121 –394 + 34 – (–611) **(1)**

= + 130 ($kJmol^{-1}$) **(1)**

| (for wrong answers | | allow ) |
|---|---|---|
| ( | –130 | **(2)** ) |
| ( | +260 | **(3)** ) |
| ( | –260 | **(1)** ) |

4

**[10]**

**10.** (a) (Energy required) to break a given <u>covalent</u> bond **(1)**
averaged over a range of compounds **(1)**
**Penalise first mark if 'energy' / 'enthalpy' evolved**

2

(b) (i) $4 \times$ C-H = $4 \times 413$ = +1652
$1 \times$ C-C = $1 \times 347$ = 347
$1 \times$ C=O = $1 \times 736$ = 736
2½ × O=O = $2.5 \times 498$ = 1245 **(1)**
= 2735 + 1245 = +3980 **(1)**
**first mark for 4 : 1: 1 or 2735 ignore sign**

(ii) $4 \times$ H-O = $-4 \times 464$ = –1856
$4 \times$ C-O = $-4 \times 736$ = –2944 **(1)**
= –4800 **(1)**
**First mark for 4 : 4**

(iii) $\Delta H_R$ = ∑Bonds broken - ∑Bonds made
= +3980 - 4800 = -820 **(1)**
**Conseq Mark for incorrect answers in (i) and (ii) as**
**(i) Answer + (ii) Answer =**

5

**[7]**

**11.** (a) (Enthalpy change) when 1 mol **(1)** of a compound is formed from its constituent elements **(1)** in their standard states **(1)**
**Allow energy or heat, Ignore evolved or absorbed**
**Mark each point independently**

3

(b) (The enthalpy change for a reaction is) independent of the route **(1)** 1

(c) $\Delta H_R = \Sigma\Delta H_f$ products - $\Sigma\Delta H_f$ reactants **(1)**
= [(3 × -286) + (3 × -394)] - (-248) **(1)**
= -1792 **(1)** (kJ $mol^{-1}$)
**Deduct one mark for each error to zero**

3

**[7]**

**12.** (a) standard enthalpy of formation **(1)**

*<u>allow</u> enthalpy of formation under standard conditions*

<u>1 mol</u> of a compound produced **(1)**
from <u>elements</u> under standard conditions **(1)**
reactants and products in <u>standard states</u> **(1)**

*<u>allow</u> normal <u>or</u> most stable states under standard conditions*

*correct explanation <u>not</u> linked to correct name* 4

(b) (i) $NO + \frac{5}{2}H_2 \rightarrow NH_3 + H_2O$ <u>or</u> doubled **(1)**

*<u>allow</u> two equations, single and doubled*
*<u>mark on</u> from wrong moles of $H_2$ (for which $\Delta H_f$ is zero)*

(ii) $NO \rightleftharpoons \frac{1}{2}N_2 + \frac{1}{2}O_2$ $\Delta H = -91$ kJ $mol^{-1}$

$\frac{1}{2}N_2 + \frac{3}{2}H_2 \rightleftharpoons NH_3$ $\Delta H = -46$ kJ $mol^{-1}$

$\frac{1}{2}O_2 + H_2 \rightleftharpoons H_2O$ $\Delta H = -242$ kJ $mol^{-1}$

correct equations or cycle **(1)**

$\therefore \Delta H = -91 \ -46 \ -242$ **(1)** = $-379$ kJ $mol^{-1}$ **(1)**

*minus 1 for each wrong sign*

*if eqn in (i) and value in (ii) do not match, then MAX 2 ex 3*

*$\Delta H = \sum \Delta H_{prod} - \sum \Delta H_{react}$ (shown) gets 1 if zero otherwise* 4

**[8]**

**13.** (a) $H^+ + OH^- \rightarrow H_2O$ or $H_3O^+ + OH^- \rightarrow 2H_2O$ **(1)**
**Ignore state symbols; ignore 'spectator' ions** **1**

(b) Mol H+ = 50·0×1·00/1000 = $5\times10^{-2}$ **(1)** 1

(c) Heat energy evolved = MCΔT/MS θ or in words **(1)**

= 100 × 4·18 × 6·5 = 2717 Allow 2700 –2717 **(1)**

or = 0.1 × 4·18 × 6·5 = 2·717 Allow 2·7–2·717 **(1)**

or = 0.1 × 4·2 × 6·5 = 2·730 (or 2730) if 4·2 used for 'c'
**Ignore units in part (c)**

2

(d) Molar enthalpy change = $-2{\cdot}717/5{\cdot}00 \times 10^{-2}$ **(1)**

= –54·3 kJ $mol^{-1}$ **(1)**

*Allow conseq to answers in (b) and (c)*
**Mark CE if this inverted**

2

**[6]**

**14.** (a) (The enthalpy/heat change) when one mole **(1)** is completely burned/combusted in oxygen/air **(1)**

under standard conditions or 100K Pa/lbar/latm/760mm Hg **(1)** and 298K or STP
**Penalise first mark if heat adsorped. Penalise first mask if "energy change" stated**

3

(b) $\Delta H_R^\ominus = \Sigma\Delta H_f^\ominus$ products – $\Delta H_f^\ominus$ reactants or cycle or
$\Delta H_R^\ominus = \Delta H_f^\ominus CO_2 + 2\Delta H_f^\ominus H_2O - \Delta H_f^\ominus CH_4$ **(1)**

= (–394) +2 (–286) – (–75) **(1)**

= –891 (kJ mol$^{-1}$)

***Allow +891 [max 1]***

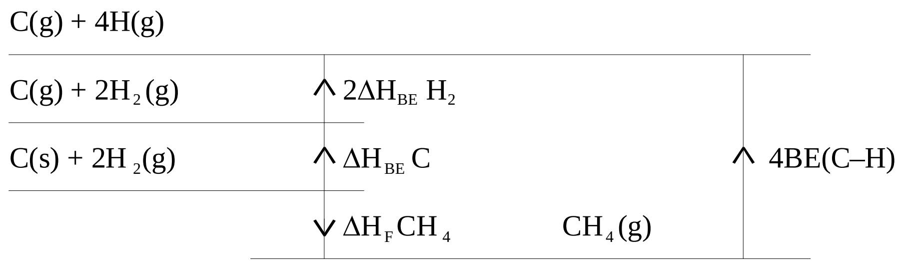
3

(c) (i) Enthalpy (Do not allow energy) required to break a covalent bond **(1)**

*Allow second mark separately*

averaged over (many) compounds **(1)**

(ii) $\Delta Ha = \Sigma$ Bonds broken – $\Sigma$ Bonds made or cycle **(1)**




Allow –415 to –416 Max **(2)**

Allow 1662 Max **(1)**

$$\text{BE (C–H)} = \frac{715 + 2(436) - (-75)}{4}$$ **(1)** = 415·5 (kJ mol$^{-1}$) **(1)**

*Allow 415–416*

(iii) 4020 = 2BE (C–C) + 8 BE (C–H) **(1)**

**CE if 3BE(C–C) used**

$$\text{BE (C–C)} + \frac{4020 - 8(415\cdot5)}{2}$$ = 348 (kJmol$^{-1}$) **(1)** *Allow 346–350* 7

**Mark conseq**

**Note: Using 390, the given answer, BE (C–C) = 450 [2]**

**The common wrong answer in C(ii) is 378 this gives BE(C–C) as 498 conseq [2]**

**[13]**

**15.** (a) enthalpy change when 1 mol of a compound **(1)**

is completely burned in oxygen **(1)**

under standard conditions **(1)** 3

(b) $CH_3SH + 3O_2 \rightarrow CO_2 + 2H_2O + SO_2$ 1

(c) enthalpies of combustion of C, $H_2$, S

*one correct (1)*

*three correct (2)*

*(or enthalpies of formation of $CO_2$, $H_2O$, $SO_2$)*

*one correct (1)*

*three correct (2)* 2

(d) $\Delta H^{\ominus} = -\Delta H_f^{\ominus}(CS_2) + \Delta H_f^{\ominus}(CO_2) + 2\Delta H_f^{\ominus}(SO_2)$ **(1)**

*or cycle with the same information*

$= -88 - 394 - 594$ **(1)**

$= -1076\ kJ\ mol^{-1}$ **(1)**

*+1076 scores one, –900 scores 1 cycle mark* 3

**[9]**

**16.** (a) enthalpy change **(1)**
independent of reaction route **(1)** 2

(b) enthalpy change for 1 mol **(1)**
completely burned in oxygen **(1)**
under standard condition **(1)** 3

(c) (i) *Equation for formation of $CS_2$* $C(s) + 2S(s) \rightarrow CS_2(l)$ **(1)**

*Equation for combustion of $CS_2$* $CS_2(l) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)$ **(1)**

(ii) $\Delta H_f^{\ominus} = \Delta H_c^{\ominus}(C) + 2\Delta H_c^{\ominus}(S) - \Delta H_f^{\ominus}(CS_2)$ **(1)**
(or correct cycle)
$= -394 + 2(-297) - 88$ **(1)**
$= -1076\ kJ\ mol^{-1}$ **(1)** 5

(d) $\Delta H^{\ominus} = \Delta H_f^{\ominus}(CO) + 2\Delta H_f^{\ominus}(SO_2) - (\Delta H_f^{\ominus}(CS_2) + 5\Delta H_f^{\ominus}(NO))$ **(1)**
(or correct cycle)

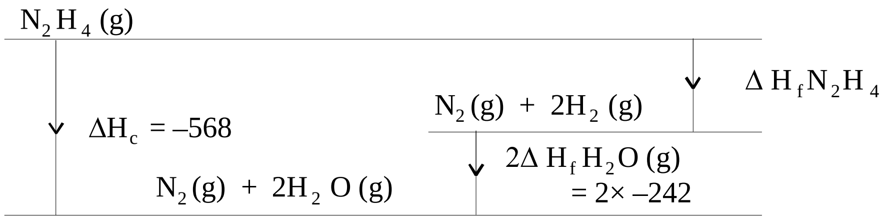
$= -111 + 2(-297) - (88 + 5 \times 90)$ **(1)**
$= -1243\ kJ\ mol^{-1}$ **(1)** 3

**[13]**

**17.** (a) (i) $N_2 + 2H_2 \rightarrow N_2H_4$ **(1)**

(ii) $N_2H_4 + O_2 \rightarrow N_2 + 2H_2O$ **(1)**

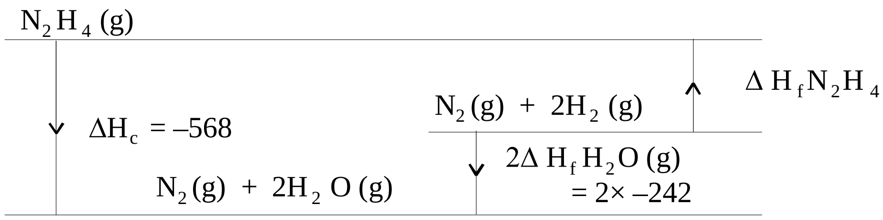
(iii)




$\Delta Hf = -484 + 568 = +84$ kJ mol–1 **(1)**
[OR $\Delta H_f = 2\Delta H_f\ H_2O(g) - \Delta H_c\ N_2H_4$ **(1)** = 84 kJ mol–1 **(1)**] 4

(b) Enthalpy or heat required to break a covalent bond **(1)**
Average over a range of compounds 2

(c)




Hence (N–N) = 872 + 945 – 84 – 1556 **(1)** = 177 kJ $mol^{-1}$ **(1)**

Note:– Mark consequentially to $\Delta H_f N_2H_4$ from a(iii) 3

(d) The N–H bond enthalpies used in the calculation were mean values or depend on environment **(1)** 1

**[10]**

**18.** (a) enthalpy change for one mole of compound **(1)**
formed from its elements **(1)**
in their standard states **(1)** 3

(b) by definition **(1)** 1

(c) $\Delta H = 2 \times \Delta H_f^{\ominus}(CF_4) + 6 \times \Delta H_f^{\ominus}(HF) - \Delta H_f^{\ominus}(C_2H_6)$ **(1)**
= 2 × –680 + 6 × – 269 – (–85) **(1)**
= –2889 **(1)** (kJ $mol^{-1}$) 3

(d) (i) bond energies (enthalpies) vary between compounds **(1)**
∴ an average value is used **(1)**

(ii) *First step in the reaction* F–F bond breaks **(1)**

*Reason* weakest bond **(1)** 4

**[11]**

**19.** (a) *Standard enthalpy of formation* The enthalpy change when one mole of a compound **(1)** is formed from its consistuent element **(1)** in their normal or standard state **(1)** under standard conditions

*Standard enthalpy of combustion* The enthalpy change when one mole of a compound **(1)** is completely burnt in oxygen **(1)** under standard condition or at 298K and 100kPa **(1)**

6

(b) $\Delta H$ = $\sum \Delta H_f$ products – $\sum \Delta H_f$ reactants or cycle **(1)**

= $3\Delta H_f CO_2 + 4\Delta H_f H_2O - \Delta H_f C_3H_7OH$ **(1)**

= –2022 kJ $mol^{-1}$ **(1)** 3

(c) (i) Enthalpy = 200 × 4.2 × 15 **(1)**

= 12.6 kJ **(1)**

(ii) Moles $C_3H_7OH$ = 0.90/60 **(1)**

12.6 kJ **(1)**

(iii) Enthalpy of combustion = –12.6/0.015 **(1)**

= –840 kJ $mol^{-1}$ **(1)**

(iv) *Reason 1* Incomplete combustion

Heat lost to surroundings

*Reason 2* Heat capacity of the apparatus

Any two **(2)** 8

**[17]**

**20.** (a) ΔH = Σ $\Delta H_f$ products – Σ $\Delta H_f$ reactants or cycle **(1)**
= [(3 × –393) + (3 × – 242)] – [+53] **(1)**
= –1905 – 53
= –1958 kJ $mol^{-1}$ **(1)** 3

(b) The enthalpy required to break a covalent bond **(1)**
average over a wide range of compounds **(1)** 2

(c) In; 3 × C–C; 3 × 347 = +1041
6 × C–H; 6 × 413 = +2478
4.5 × 0 = 0; 4.5 × 498 = + 2241
Total in + 5760 **(1)**

Out; 6 × C=O; 6 × –805 = –4830
6 × O–H; 6 × –464 = –2784
Total out –7614 **(1)**

Enthalpy change = 5760 – 7614 = –1854 kJ $mol^{-1}$ **(1)** 3

(d) Cyclopropane has a strained ring structure **(1)**
Bonds in cyclopropane are weaker OR
Bond enthalpies depend on environment OR
Mean bond enthalpies used in the calculation **(1)** 2

**[10]**