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)**

5.56×10^3 joules = (mc)ΔT **(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) enthalpy change when 1 mol of a substance (or compound) (QL mark) 1
is (completely) burned in oxygen (or reacted in excess 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

ΔH = – 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

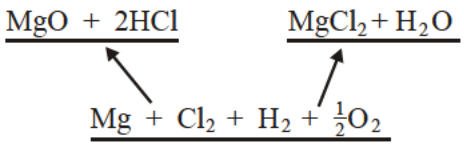
$\Delta H_c^{\ominus}(CH_3OH) = \Delta H_c^{\ominus}(CO) + 2 \times \Delta H_c^{\ominus}(H_2) - \Delta H$ 1
= (–283) + (2 × –286) – (–91) (mark for previous equation or this)
= –764 (kJ mol^{-1}) (*units not essential but lose mark if units wrong)* 1
(note + 764 scores 1/3)

[10]

6. (a) (i) enthalpy (or heat or heat energy) change when 3
1 mol of a substance **(1)** (QL mark) is formed from its elements **(1)**
all substances in their standard states **(1)** (or normal states at 298K, 100 kPa or std condits)
***not** STP, NTP*

(b) enthalpy change (or enthalpy of reaction) 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:



ΔH = -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 $= 6.72$J **(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 = $mc\Delta T$
$= 100 \times 4.18 \times 58.1$ **(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) $\Delta H = \Sigma \Delta H_{reactants} – \Sigma \Delta H_{products}$ **(1)**
(or cycle $2C + 3H_2 + S$ → C_2H_5SH
CO_2 H_2O SO_2 → $-\Delta H_c\ C_2H_5SH$)
$= (2 \times –394) + (3 \times –286) + (–297) – (–1170)$ **(1)** $= –773$ **(1)** 3
ignore units even if wrong
Allow 1/3 for +773

[12]

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

from its elements **(1)**

in their standard states * (at 298 K, 100 kPa) **(1)**

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

must have 2nd mark to score third 3

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

$= -121 \quad -394 \quad +34 \quad -(-611)$ **(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 covalent 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 = $1 \times 736 = 736$
$2½ \times$ 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) $\Delta H_R = \sum$Bonds broken - $\sum$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)**
$= [(3 \times -286) + (3 \times -394)] - (-248)$ **(1)**
$= -1792$ **(1)** (kJ mol^{-1})
Deduct one mark for each error to zero

3

[7]

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

allow enthalpy of formation under standard conditions

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

allow normal or most stable states under standard conditions

correct explanation not 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 ΔH_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+ = $50{\cdot}0 \times 1{\cdot}00/1000 = 5 \times 10^{-2}$ **(1)** 1

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

$= 100 \times 4{\cdot}18 \times 6{\cdot}5 = 2717$ Allow 2700 –2717 **(1)**

or $= 0.1 \times 4{\cdot}18 \times 6{\cdot}5 = 2{\cdot}717$ Allow 2·7–2·717 **(1)**

or $= 0.1 \times 4{\cdot}2 \times 6{\cdot}5 = 2{\cdot}730$ (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)**

$= -54{\cdot}3$ 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]

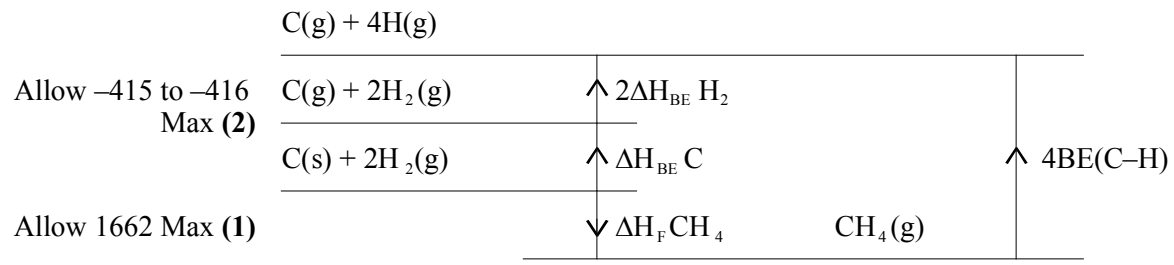
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(c) (i) Enthalpy (Do not allow energy) required to <u>break a covalent bond</u> **(1)**

Allow second mark separately

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

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



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

Allow 415–416

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

CE if 3BE(C–C) used

BE (C–C) $+ \dfrac{4020 - 8(415 \cdot 5)}{2} = 348$ (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

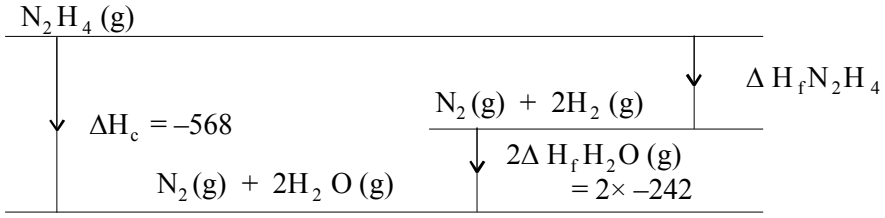
(d) $\Delta H^{\ominus} = \Delta H_f^{\ominus}(CO) + 2\Delta H_f^{\ominus}(SO_2) - (\Delta H_f^{\ominus}(CS_2) + 5\Delta H_f^{\ominus}(NO))$ **(1)**
(or correct cycle)
$= -111 + 2(-297) - (88 + 5 \times 90)$ **(1)**
$= -1243$ kJ mol^{-1} **(1)** 3

[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)**

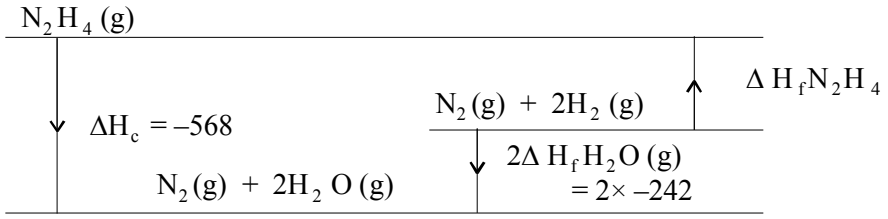
(iii)



$\Delta Hf = -484 + 568 = +84$ 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)**
$= 2 \times -680 + 6 \times -269 - (-85)$ **(1)**
$= -2889$ **(1)** (kJ mol^{-1}) 3

(d) (i) bond energies (enthalpies) vary between compounds **(1)**
$\therefore$ 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) $\Delta H = \Sigma \Delta H_f$ products – $\Sigma \Delta H_f$ 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]