Q8.

Calculate the enthalpy change, in kJ, for this dissociation of mole of propan-1-ol.

$$C_3H_7OH(g) \longrightarrow 3C(g) + 8H(g) + O(g)$$

	C—H	C—C	C—O	O—H
Mean bond dissociation enthalpy / kJ mol^{-1}	412	348	360	463

A −4751 ○

B −4403 ○

C +4403 ○

D +4751 ○

(Total 1 mark)

Q9.

(a) Write an equation, including state symbols, for the reaction with enthalpy change equal to the standard enthalpy of formation for $CF_4(g)$.

____

(1)

(b) Explain why CF_4 has a bond angle of 109.5°.

____

____

____

____

____

(2)

(c) **Table 1** gives some values of standard enthalpies of formation ($\Delta_f H^\ominus$).

Table 1

Substance	F_2(g)	CF_4(g)	HF(g)
$\Delta_f H^\ominus$ / kJ mol^{-1}	0	−680	−269

The enthalpy change for the following reaction is −2889 kJ mol^{-1}.

$$C_2H_6(g) + 7F_2(g) \longrightarrow 2CF_4(g) + 6HF(g)$$

Use this value and the standard enthalpies of formation in **Table 1** to calculate the standard enthalpy of formation of C_2H_6(g).

Standard enthalpy of formation of C_2H_6(g) = ____________________ kJ mol^{-1}

(3)

(d) Methane reacts violently with fluorine according to the following equation.

$$CH_4(g) + 4F_2(g) \longrightarrow CF_4(g) + 4HF(g) \quad \Delta H = -1904 \text{ kJ mol}^{-1}$$

Some mean bond enthalpies are given in **Table 2**.

Table 2

Bond	C−H	C−F	H−F
Mean bond enthalpy / kJ mol^{-1}	412	484	562

A student suggested that one reason for the high reactivity of fluorine is a weak F−F bond.

Is the student correct? Justify your answer with a calculation using these data.

____

____

(4)
(Total 10 marks)

Q10.

Many chemical processes release waste products into the atmosphere. Scientists are developing new solid catalysts to convert more efficiently these emissions into useful products, such as fuels. One example is a catalyst to convert these emissions into methanol. The catalyst is thought to work by breaking a H–H bond.

An equation for this formation of methanol is given below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \quad \Delta H = -49 \text{ kJ mol}^{-1}$$

Some mean bond enthalpies are shown in the following table.

Bond	C=O	C–H	C–O	O–H
Mean bond enthalpy / kJ mol⁻¹	743	412	360	463

(a) Use the enthalpy change for the reaction and data from the table to calculate a value for the H–H bond enthalpy.

H–H bond enthalpy = _______________ kJ mol^{-1}

(3)

(b) A data book value for the H–H bond enthalpy is 436 kJ mol^{-1}.

Suggest **one** reason why this value is different from your answer to part (a).

___

___

___

(1)

(c) Suggest **one** environmental advantage of manufacturing methanol fuel by this reaction.

___

___

___

(1)

(d) Use Le Chatelier's principle to justify why the reaction is carried out at a high pressure rather than at atmospheric pressure.

____

____

____

____

____

____

(3)

(e) Suggest why the catalyst used in this process may become less efficient if the carbon dioxide and hydrogen contain impurities.

____

____

____

(1)

(f) In a laboratory experiment to investigate the reaction shown in the equation below, 1.0 mol of carbon dioxide and 3.0 mol of hydrogen were sealed into a container. After the mixture had reached equilibrium, at a pressure of 500 kPa, the yield of methanol was 0.86 mol.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Calculate a value for K_p
Give your answer to the appropriate number of significant figures.
Give units with your answer.

K_p = ________________ Units = ________________

(7)

(Total 16 marks)

Q11.

Hydrogen is produced by the reaction of methane with steam. The reaction mixture reaches a state of dynamic equilibrium.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

Some enthalpy data is given in the table.

Bond	C–H	O–H	H–H	C≡H
Bond enthalpy / kJ mol^{-1}	413	463	436	To be calculated

Use the information in the table and the stated enthalpy change to calculate the missing bond enthalpy.

A 234 ○

B 1064 ○

C 1476 ○

D 1936 ○

(Total 1 mark)

Q12.

Standard enthalpy of combustion data can be used to calculate enthalpies of formation.

(a) State the meaning of the term standard enthalpy of combustion.

(3)

(b) The equation corresponding to the enthalpy of formation of propan-1-ol is shown.

$$3C(s) + 4H_2(g) + \frac{1}{2}O_2(g) \longrightarrow CH_3CH_2CH_2OH(l)$$

Table 1 contains some standard enthalpy of combustion data.

Table 1

	C(s)	**$H_2(g)$**	**$CH_3CH_2CH_2OH(l)$**
$\Delta H_c^\ominus$ / kJ mol^{-1}	–394	–286	–2010

Use data from **Table 1** to calculate a value for the standard enthalpy of formation of propan-1-ol. Show your working.

(3)

(c) An equation for the complete combustion of gaseous propan-1-ol is shown.

$$CH_3CH_2CH_2OH(g) + 4\tfrac{1}{2}O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g) \quad \Delta H = -1893\ \text{kJ mol}^{-1}$$

Table 2 shows some bond enthalpy data.

Table 2

	C–H	C–O	O–H	C=O	O=O
Bond enthalpy / kJ mol^{-1}	412	360	463	805	496

Use data from **Table 2** and the enthalpy change for this reaction to calculate a value for the bond enthalpy of a C–C bond in propan-1-ol.

(3)

(Total 9 marks)

Q13.

(a) Propanone can be formed when glucose comes into contact with bacteria in the absence of air.

(i) Balance the following equation for this reaction of glucose to form propanone, carbon dioxide and water.

$$\text{.......}C_6H_{12}O_6 \longrightarrow \text{.......}CH_3COCH_3 + \text{.......}CO_2 + \text{.......}H_2O$$

(1)

(ii) Deduce the role of the bacteria in this reaction.

(1)

(b) Propanone is also formed by the oxidation of propan−2−ol.

(i) Write an equation for this reaction using [O] to represent the oxidising agent.

(1)

(ii) State the class of alcohols to which propan−2−ol belongs.

(1)

(c) A student determined a value for the enthalpy change when a sample of propanone was burned. The heat produced was used to warm some water in a copper calorimeter. The student found that the temperature of 150 g of water increased by 8.0 °C when 4.50×10^{-3} mol of pure propanone was burned in air.

Use the student's results to calculate a value, in kJ mol^{-1}, for the enthalpy change when one mole of propanone is burned.
(The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

(3)

(d) Define the term **standard enthalpy of combustion**.

(3)

(e) Use the mean bond enthalpy data in the table and the equation given below the table to calculate a value for the standard enthalpy change when gaseous propanone is burned.

	C−H	**C−C**	**C−O**	**O−H**	**C=O**	**O=O**
Mean bond enthalpy / kJ mol^{-1}	412	348	360	463	805	496

$$CH_3COCH_3(g) + 4O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(g)$$

(3)

(f) Suggest **two** reasons why the value obtained by the student in part (c) is different from the value calculated in part (e).

Reason 1 ____

Reason 2 ____

(2)

(Total 15 marks)

Q14.

The table contains some bond enthalpy data.

Bond	H−H	O=O	H−O
Bond enthalpy / kJ mol^{-1}	436	496	464

(a) The value for the H−O bond enthalpy in the table is a mean bond enthalpy.

State the meaning of the term **mean bond enthalpy** for the H−O bond.

(2)

(b) Use the bond enthalpies in the table to calculate a value for the enthalpy of formation of water in the gas phase.

(3)

(c) The standard enthalpy of combustion of hydrogen, forming water in the gas phase, is almost the same as the correct answer to part (b).

(i) Suggest **one** reason why you would expect the standard enthalpy of combustion of hydrogen to be the same as the answer to part (b).

(1)

(ii) Suggest **one** reason why you would expect the standard enthalpy of combustion of hydrogen to differ slightly from the answer to part (b).

(1)

(Total 7 marks)

Mark Scheme

Q8.

C

[1]

Q9.

(a) $C(s) + 2F_2(g) \longrightarrow CF_4(g)$

State symbols essential

1

(b) Around carbon there are 4 bonding pairs of electrons (and no lone pairs)

1

Therefore, these repel equally and spread as far apart as possible

1

(c) $\Delta H = \Sigma\ \Delta_f H$ products – $\Sigma\ \Delta_f H$ reactants or a correct cycle

1

Hence = (2 × –680) + (6 × –269) – (x) = –2889

1

x = 2889 – 1360 – 1614 = –85 (kJ mol^{-1})

1

Score 1 mark only for +85 (kJ mol^{-1})

(d) Bonds broken = 4(C–H) + 4(F–F) = 4 × 412 + 4 × F–F

Bonds formed = 4(C–F) + 4(H–F) = 4 × 484 + 4 × 562

Both required

1

–1904 = [4 × 412 + 4(F–F)] – [4 × 484 + 4 × 562]

4(F–F) = –1904 – 4 × 412 + [4 × 484 + 4 × 562] = 632

1

F–F = 632 / 4 = 158 (kJ mol^{-1})

1

The student is correct because the F–F bond energy is much less than the C–H or other covalent bonds, therefore the F–F bond is weak / easily broken

Relevant comment comparing to other bonds

(Low activation energy needed to break the F–F bond)

1

[10]

Q10.

(a) Bonds broken = 2(C=O) + 3(H–H) = 2 × 743 + 3 × H–H

Bonds formed = 3(C–H) +(C–O) + 3(O–H) = 3 × 412 + 360 + 3 × 463

Both required

1

$-49 = [2 \times 743 + 3 \times (\text{H–H})] - [3 \times 412 + 360 + 3 \times 463]$

$3(\text{H–H}) = -49 - 2 \times 743 + [3 \times 412 + 360 + 3 \times 463] = 1450$

Both required

1

H–H = 483 (kJ mol^{-1})

Allow 483.3(3)

1

(b) Mean bond enthalpies are not the same as the actual bond enthalpies in CO_2 (and / or methanol and / or water)

1

(c) The carbon dioxide (produced on burning methanol) is used up in this reaction

1

(d) 4 mol of gas form 2 mol

1

At high pressure the position of equilibrium moves to the right to lower the pressure / oppose the high pressure

1

This increases the yield of methanol

1

(e) Impurities (or sulfur compounds) block the active sites

Allow catalyst poisoned

1

(f) Stage 1: moles of components in the equilibrium mixture

Extended response question

$$CO_2(g) \ + \ 3H_2(g) \rightleftharpoons CH_3OH(g) + \ H_2O(g)$$

Initial moles	1.0	3.0	0	0
Eqm moles	(1–0.86) = 0.14	(3–3×0.86) = 0.42	0.86	0.86

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction × p_{total}

1

p_{CO_2} = mol fraction × p_{total} = 0.14 × 500 / 2.28 = 30.7 kPa

p_{H_2} = mol fraction × p_{total} = 0.42 × 500 / 2.28 = 92.1 kPa

M3 is for partial pressures of both reactants

Alternative M3 =

pp_{CO2} = 0.0614 × 500

pp_{H2} = 0.1842 × 500

1

p_{CH3OH} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

p_{H2O} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

M4 is for partial pressures of both products

Alternative M4 =

pp_{CH3OH} = 0.3772 × 500
pp_{H2O} = 0.3772 × 500

1

Stage 3: Equilibrium constant calculation
$K_p = p_{CH3OH} \times p_{H2O} / p_{CO2} \times (p_{H2})^3$

1

Hence $K_p = 188.6 \times 188.6 / 30.7 \times (92.1)^3 = 1.483 \times 10^{-3} = 1.5 \times 10^{-3}$

Answer must be to 2 significant figures

1

Units = <u>kPa</u>$^{-2}$

1

[16]

Q11.

B

[1]

Q12.

(a) The <u>enthalpy / heat energy change</u> when <u>1 mol</u> (of a substance)

If enthalpy of formation definition given CE=O

***NOT** just 'energy'*

***ALLOW** alternatives for substance e.g. molecule/compound/element*

1

Is <u>burned/reacts completely in oxygen</u>

***ALLOW** reacts in excess oxygen*

1

With all reactants and products in their <u>standard states</u>
OR
With all reactants and products in their normal states at 298K/given temp & 100kPa

***ALLOW** 'everything' for 'reactants and products'*

Penalise incorrect conditions if given

***ALLOW** 'normal states under standard conditions'*

1

(b) $\Delta H = \Sigma\Delta H_c$(reactants) - $\Sigma\Delta H_c$ (products)

OR

Correctly and fully balanced cycle

Correct answer scores 3

1

$\Delta H = [3(-394) + 4(-286)] - (-2010)$

OR

$\Delta H = -2326 + 2010$

M2 also scores M1

1

$\Delta H = -316$ (kJ mol^{-1})

+316 scores 1 mark only

***IGNORE** units*

Check for AE in working – can award M3 as ecf (error carried forward) from M2 if M2 not given due to AE

1

(c) ΔH/-1893 = ΣB(reactants) - ΣB(products)

OR

ΔH/-1893 = ΣBonds broken - ΣBonds formed

OR

ΔH/-1893 = 2B(C-C) + 7B(C-H) + B(C-O) + B(O-H) + 4½ B(O=O) – 6B(C=O) – 8B(O-H)

Correct answer scores 3

1

-1893= 2B(C-C) + 7(412) + 360 + 463 + 4½(496) – 6(805) – 8(463)

OR

-1893= 2B(C-C) +5939 – 8534

OR

-1893= 2B(C-C) -2595

OR

2B(C-C) = 702

M2 also scores M1

May see no 463 in bonds broken and 7x463 in made (gives 5476 – 8071)

1

B(C-C) = (+)351(kJ mol^{-1})

*If **NOT** 351 check for AE. This would lose M2, but could gain M1 and M3*

(+)234 scores 1 (due to 3(C-C))

***NOT** M3 from incorrect M2 unless incorrect M2 is due to AE*

***IGNORE** units*

If no other mark awarded then

***ALLOW** 1 if 5939 or 5476 or 8534 or 8071 seen*

1

[9]

Q13.

(a) (i) $2C_6H_{12}O_6 \longrightarrow 3CH_3COCH_3 + 3CO_2 + 3H_2O$

Or multiples

1

(ii) to speed up the reaction

OR

(provide a) catalyst or catalyses the reaction or biological catalyst
OR
release / contain / provides an enzyme

Ignore "fermentation"

Ignore "to break down the glucose"

Not simply "enzyme" on its own

1

(b) (i) $CH_3CH(OH)CH_3 + [O] \longrightarrow CH_3COCH_3 + H_2O$

Any correct representation for the two organic structures. Brackets not essential.

Not "sticks" for the structures in this case

1

(ii) Secondary (alcohol) OR 2° (alcohol)

1

(c) **M1** $q = m\,c\,\Delta T$

OR $q = 150 \times 4.18 \times 8.0$

Award full marks for correct answer

*In **M1**, do not penalise incorrect cases in the formula*

M2 = (±) 5016 (J) ***OR*** 5.016 (kJ) ***OR*** 5.02 (kJ)
(also scores M1)

M3 This mark is for dividing correctly the number of kJ by the number of moles and arriving at a final answer in the range shown.
Using 0.00450 mol

therefore ΔH = **− 1115** ($kJ\ mol^{-1}$)

***OR* − 1114.6 to − 1120** ($kJ\ mol^{-1}$)

Range (+)1114.6 to (+)1120 gains 2 marks

BUT − 1110 gains 3 marks and +1110 gains 2 marks

AND − 1100 gains 3 marks and +1100 gains 2 marks

Award full marks for correct answer

*In **M1**, do not penalise incorrect cases in the formula*

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; **(+)1114.6 to (+)1120 gains 2 marks***

*Penalise **M2** for arithmetic error and mark on*

If $\Delta T = 281$; score $q = m\,c\,\Delta T$ only

*If c = 4.81 (leads to 5772) penalise **M2** ONLY and mark on for **M3** = − 1283*

*Ignore incorrect units in **M2***

*If units are given in **M3** they must be either kJ or $kJ\ mol^{-1}$ in this case*

3

(d) **M1** The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / element

M2 is burned / combusts / reacts completely in oxygen
OR
burned / combusted / reacted in excess oxygen

M3 with (all) reactants and products / (all) substances in standard / specified states

OR
(all) reactants and products / (all) *substances in normal states under standard conditions* / 100 kPa / 1 bar and specified T / 298 K

*For **M3***

Ignore reference to 1 atmosphere

3

(e) **M1**
Σ B **(reactants)** − Σ B **(products)** = Δ*H*
OR
Sum of bonds broken − Sum of bonds formed = Δ*H*
OR
2B(C−C) + B(C=O) + 6B(C−H) + 4B(O=O) (LHS)

− 6B(C=O) − 6B(O−H) (RHS) = Δ*H*

M2 (also scores **M1**)
2(348)+805+6(412)+4(496) [LHS = **5957**]

(696) (2472) (1984)

− 6(805) − 6(463) [RHS = (−) **7608**] = Δ*H*

(4830) (2778)

OR using only bonds broken and formed (**5152 − 6803**)

M3
Δ*H*= **− 1651** (kJ mol^{-1})

Candidates may use a cycle and gain full marks.

Correct answer gains full marks

Credit 1 mark for (+) 1651 (kJ mol^{-1})

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication / addition error; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with 4O_2, 3CO_2 and 3H_2O OR a clear statement of **M1** which could be in words and scores **only M1***

Allow a maximum of one mark if the only scoring point is LHS = 5957 (or 5152) OR RHS = 7608 (or 6803)

Award 1 mark for + 1651

3

(f) **For the two marks M1 and M2, any two from**

- heat loss or not all heat transferred to the apparatus or heat absorbed by the apparatus or (specific) heat capacity of the apparatus not considered

- incomplete combustion / not completely burned / reaction is not complete
- The idea that the water may end up in the gaseous state (rather than liquid)
- reactants and / or products may not be in standard states.
- MBE data refers to gaseous species but the enthalpy of combustion refers to liquids in their standard states / liquid propanone and liquid water in standard states
- MBE <u>do not refer to specific compounds</u> OR MBE <u>values vary with different compounds / molecules</u> OR are average / mean values taken <u>from a range of compounds / molecules</u>

Apply the list principle but ignore incomplete reasons that contain correct chemistry

Ignore "evaporation"

Ignore "faulty equipment"

Ignore "human error"

Not enough simply to state that "MBE are mean / average values"

2

[15]

Q14.

(a) The enthalpy (change) to break <u>1 mol</u> of H—O / bonds

Allow heat energy

1

Averaged over a range of compounds / molecules

Penalise energy but mark on

ignore states

CE = 0 for ionic bonds

1

(b) $H_2 + \frac{1}{2} O_2 \longrightarrow H_2O$

$\Delta H = (\text{H−H}) + \frac{1}{2}(\text{O = O}) - 2(\text{H−O})$ / sum of (bonds broken) − sum of (bonds formed)

1

$= 436 + 496 / 2 - 2 \times 464$

1

$= -244$ (kJ mol^{-1})

Allow 1 mark only for +244 and −488

Units not essential but penalise incorrect units

1

(c) (i) same reaction / same equation / same number / same reactants and same products / same number and type of bonds broken and formed

Do not allow similar

1

(ii) There must be a slight difference between the actual bond enthalpy (in water) and mean bond enthalpies for the O−H bond (in other molecules)

Allow bond enthalpy value for enthalpy of formation may not be under standard conditions.

Allow reference to bond energy rather than bond enthalpy

Do not allow heat loss or experimental error

Do not allow mean bond enthalpies are not accurate

1

[7]