**Energetics**

**Q1.**          (a)     State what is meant by the term *mean bond enthalpy*.

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**(2)**

(b)     Ethanal has the structure 

Gaseous ethanal burns as shown by the equation

CH3CHO(g)   +   2½O2(g)   →   2H2O(g)   +   2CO2(g)

Use the mean bond enthalpy data given below to answer the following questions.

|  |  |
| --- | --- |
| Bond | Mean bond enthalpy/kJ mol–1 |
| C—H | +413 |
| C—C | +347 |
| C==O | +736 |
| O==O | +498 |
| O—H | +464 |

(i)      Calculate the enthalpy change which occurs when all the bonds in the reactants shown in the above equation are broken.

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(ii)     Calculate the enthalpy change which occurs when all the bonds in the products shown in the above equation are formed.

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(iii)     Hence, calculate the enthalpy change for the complete combustion of ethanal as shown in the equation above.

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**(5)**

**(Total 7 marks)**

**Q2.**          (a)     Define the term *standard molar enthalpy of formation*, Δ*H*f.

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**(3)**

(b)     State Hess’s law.

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**(1)**

(c)     Propanone, CH3COCH3, burns in oxygen as shown by the equation

CH3COCH3(l)   +   4 O2(g)  →  3H2O(l)   +   3CO2(g)

Use the data given below to calculate the standard enthalpy of combustion of propanone.

|  |  |  |  |
| --- | --- | --- | --- |
|   | CO2(g) | H2O(l) | CH3COCH3(l) |
| Δ*H*f/kJ mol–1 | –394 | –286 | –248 |

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**(3)**

**(Total 7 marks)**

**Q3.**A 50.0 cm3 sample of a 0.200 mol dm–3 solution of silver nitrate was placed in a polystyrene beaker. An excess of powdered zinc was added to this solution and the mixture stirred. Zinc nitrate, Zn(NO3)2, and silver were formed and a rise in temperature of 3.20 °C was recorded.

(a)     Write an equation for the reaction between silver nitrate and zinc.

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**(1)**

(b)     Calculate the number of moles of silver nitrate used in the experiment.

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**(2)**

(c)     Calculate the heat energy evolved by the reaction in this experiment assuming that all the energy evolved is used to heat only the 50.0 g of water in the mixture.
(Specific heat capacity of water is 4.18 J g–1 K–1)

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**(2)**

(d)     Calculate the heat energy change for the reaction per mole of zinc reacted.

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**(2)**

(e)     Explain why the experimental value for the heat energy evolved in this experiment is less than the correct value.

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**(1)**

**(Total 8 marks)**

**Q4.**          (a)     What is the meaning of the term *enthalpy change*?

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**(2)**

(b)     (i)      Define the term *standard enthalpy of formation* of a compound.

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(ii)     Write an equation, including state symbols, for the formation from its elements of solid sodium sulphate, Na2SO4

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**(5)**

(c)     State Hess’s Law.

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**(1)**

(d)     Some standard enthalpy changes are difficult to measure directly but can be determined from standard enthalpies of combustion.
Maleic acid, C4H4O4, reacts with oxygen to form carbon dioxide and water as shown by the following equation.

C4H4O4(s)   +   3O2(g)   →   4CO2(g)   +   2H2O(l)

Use the standard enthalpy of combustion data given below to calculate a value for the standard enthalpy change for the following reaction.

4C(s)   +   2H2(g)   +   2O2(g)   →   C4H4O4(s)

|  |  |  |  |
| --- | --- | --- | --- |
|   | C4H4O4(s) | C(s) | H2(g) |
| Δ*H*c / kJ mol–1 | –1356 | –393.5 | –285.8 |

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**(3)**

**(Total 11 marks)**

**Q5.**The table below contains some mean bond enthalpy data.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bond | H––H | C––C | C=C | N≡N | N––H |
| Mean bond enthalpy / kJ mol–1 | 436 | 348 | 612 | 944 | 388 |

(a)     Explain the term *mean bond enthalpy.*

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**(2)**

(b)     (i)      Write an equation for the formation of one mole of ammonia, NH3, from its elements.

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(ii)     Use data from the table above to calculate a value for the enthalpy of formation of ammonia.

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**(4)**

(c)     Use the following equation and data from the table above to calculate a value for the C–H bond enthalpy in ethane.



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**(3)**

**(Total 9 marks)**

**Q6.**          (a)     Write an equation for the complete combustion of propanone, C3H6O, to form carbon dioxide and water.

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**(1)**

(b)     In a laboratory experiment, 1.45 g of propanone were burned completely in oxygen. The heat from this combustion was used to raise the temperature of 100 g of water from 293.1 K to 351.2 K.

(i)      Calculate the number of moles of propanone in the 1.45 g.

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(ii)     Calculate the heat energy required to raise the temperature of 100 g of water from 293.1 K to 351.2 K.
(The specific heat capacity of water is 4.18 J K–1 g–1)

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(iii)     Hence, calculate a value, in kJ mol–1, for the enthalpy of combustion of propanone.

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**(5)**

(c)     In a similar experiment, the enthalpy of combustion of butanone, C4H8O, was found to be –1290 kJ mol–1. A data book value for the same reaction is Δ*H*c = –2430 kJ mol–1.

(i)      Suggest one reason why the experimental value is very different from the data book value.

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(ii)     This data book value of Δ*H*c for butanone (–2430 kJ mol–1) refers to the formation of carbon dioxide gas and water in the gaseous state. How would this value differ if it referred to the formation of water in the liquid state? Explain your answer.

*Difference* ...........................................................................................

*Explanation* .........................................................................................

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**(3)**

(d)     Calculate a value for the standard enthalpy of formation for liquid ethanethiol,C2H5SH. Use the equation given below and enthalpy of combustion data from the following table.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Substance | C2H5SH(l) | C(s) | H2(g) | S(s) |
| Δ*H*c / kJ mol–1 | –1170 | –394 | –286 | –297 |

2C(s) + 3H2(g) + S(s) → C2H5SH(l)

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**(3)**

**(Total 12 marks)**

**Q7.**          (a)     Define the term *standard* *enthalpy of formation*.

**(3)**

(b)     State Hess’s Law and use it, together with the data given in the table below, to calculate the standard enthalpy change for the following reaction.

MgO(s)  +  2HCl(g)  →  MgCl2(s)  +  H2O(l)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   | MgO | HCl(g) | MgCl2 | H2O |
| Δ*H*f/kJ mol–1 | –602 | –92 | –642 | –286 |

**(4)**

(c)     In an experiment, an excess of solid magnesium oxide was added to 50 cm3 of 3.0 mol dm–3 hydrochloric acid. The initial temperature of the solution was 21 °C. After reaction, the temperature had risen to 53 °C. (The specific heat capacity of water is 4.2 J K–1 g–1)

Use this information to calculate the enthalpy change for the reaction of one mole of magnesium oxide with hydrochloric acid. For your calculation you should assume that all the heat from the reaction is used to raise the temperature of 50 g of water.

**(8)**

**(Total 15 marks)**

**Q8.**          (a)     The table below contains some mean bond enthalpy data.

|  |  |  |  |
| --- | --- | --- | --- |
| Bond | H–O | O–O | O=O |
| Mean bond enthalpy/kJ mol–1 | 463 | 146 | 496 |

The bonding in hydrogen peroxide, H2O2, can be represented by H–O–O–H. Use these data to calculate the enthalpy change for the following reaction.

H2O2(g) → H2O2(g) + O2(g)

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**(3)**

(b)     The standard enthalpy of formation, Δ*H*f for methane, is –74.9 kJ mol–1. Write an equation, including state symbols, for the reaction to which this enthalpy change applies.

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**(2)**

(c)     The enthalpy changes for the formation of atomic hydrogen and atomic carbon from their respective elements in their standard states are as follows.

H2(g) → H(g)      Δ*H* = +218 kJ mol–1

C(s) → C(g)           Δ*H* = +715 kJ mol–1

(i)      By reference to its structure, suggest why a large amount of heat energy is required to produce free carbon atoms from solid carbon.

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(ii)     Parts (b) and (c) give enthalpy data for the formation of CH4(g), H(g) and C(g).
Use these data and Hess’s Law to calculate the value of the enthalpy change for the following reaction.

CH4(g) → C(g) + 4H(g)

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(iii)     Use your answer from part (c)(ii) to calculate a value for the mean bond enthalpy of a C–H bond in methane.

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**(5)**

**(Total 10 marks)**

**Q9.**         Methanol, CH3OH, is a convenient liquid fuel.

(a)     An experiment was conducted to determine the enthalpy of combustion of liquid methanol. The energy obtained from burning 2.12 g of methanol was used to heat 150 g of water. The temperature of the water rose from 298 K to 362 K. (The specific heat capacity of water is 4.18 J K–1 g–1)

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

(ii)     Use the data above to calculate a value for the enthalpy of combustion of one mole of liquid methanol.

**(7)**

(b)     Methanol can be synthesised from methane and steam by a process that occurs in two stages.

*Stage 1* CH4(g) + H2O(g)  3H2(g) + CO(g)    Δ*H*~~ο~~ = +206 kJ mol–1

*Stage 2* CO(g) + 2H2(g)  CH3OH(g)                 Δ*H*~~ο~~ = –91 kJ mol–1

(i)      Explain why, in *Stage 1*, a higher yield of hydrogen and carbon monoxide is **not** obtained if the pressure is increased.

(ii)     *Stage 2* is carried out at a compromise temperature of 500K. By considering what would happen at higher and lower temperatures, explain why 500 K is considered to be a compromise for *Stage 2*.

**(5)**

(c)     The standard enthalpies of combustion of carbon monoxide and of hydrogen are
–283 kJ mol–1 and –286 kJ mol–1, respectively. Use these data and the enthalpy change for *Stage 2* to calculate a value for the standard enthalpy of combustion of gaseous methanol.

**(3)**

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**(Total 15 marks)**

**Q10.**          (a)     Explain the meaning of the terms *mean bond enthalpy* and *standard enthalpy of formation*.

*Mean bond enthalpy .....................................................................................*

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Standard enthalpy of formation .....................................................................

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**(5)**

(b)     Some mean bond enthalpies are given below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bond  | N–H | N–N | N≡N | H–O | O–O |
| Mean bond enthalpy/kJ mol–1 | 388  | 163  | 944  | 463  | 146  |

Use these data to calculate the enthalpy change for the following gas-phase reaction between hydrazine, N2H4, and hydrogen peroxide, H2O2

   +   2 H––O––O––H      N ≡ N   +   4 H––O––H

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**(3)**

(c)     Some standard enthalpies of formation are given below.

|  |  |  |  |
| --- | --- | --- | --- |
|   | N2H4(g) | H2O2(g) | H2O(g) |
| ∆*H*f~~ο~~ /kJ mol–1 | +75 | –133 | –242 |

These data can be used to calculate the enthalpy change for the reaction in part (b).

N2H4(g) + 2H2O2(g) → N2(g) + 4H2O(g)

(i)      State the value of ∆*H*f~~ο~~ for N2(g).

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(ii)     Use the ∆*H*f~~ο~~ values from the table to calculate the enthalpy change for this reaction.

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**(4)**

(d)     Explain why the value obtained in part (b) is different from that obtained in part (c)(ii).

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**(1)**

**(Total 13 marks)**

**Q11.**          (a)     Define the term *standard enthalpy of combustion*, ∆*Hc*~~ο~~

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**(3)**

(b)     Use the mean bond enthalpy data from the table and the equation given below to calculate a value for the standard enthalpy of combustion of propene. All substances are in the gaseous state.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Bond | C == C  | C—C  | C—H  | O == O | O == C  | O—H  |
| Mean bond enthalpy/kJ mol–1 | 612  | 348  | 412  | 496  | 743  | 463  |



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**(3)**

(c)     State why the standard enthalpy of formation, ∆*H*f~~ο~~, of oxygen is zero.

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**(1)**

(d)     Use the data from the table below to calculate a more accurate value for the standard enthalpy of combustion of propene.

|  |  |  |  |
| --- | --- | --- | --- |
| Compound | C3H6(g)  | CO2(g)  | H2O(g)  |
| Standard enthalpy of formation, ∆*H*f ~~ο~~/ kJ mol–1 | +20  | –394  | –242  |

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**(3)**

(e)     Explain why your answer to part (b) is a less accurate value than your answer to part (d).

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**(2)**

**(Total 12 marks)**

**Q12.**(a)     Define the term *standard enthalpy of formation*, ∆*Hf*~~ο~~

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**(3)**

(b)     Use the data in the table to calculate the standard enthalpy of formation of liquid methylbenzene, C7H8

|  |  |  |  |
| --- | --- | --- | --- |
| Substance | C(s) | H2(g) | C7H8(l) |
| Standard enthalpy of combustion, ∆*H*c~~ο~~ /kJ mol–1 | –394 | –286 | –3909 |

7C(s) + 4H2(g) → C7H8(l)

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**(3)**

(c)     An experiment was carried out to determine a value for the enthalpy of combustion of liquid methylbenzene using the apparatus shown in the diagram.



Burning 2.5 g of methylbenzene caused the temperature of 250 g of water to rise by 60°C. Use this information to calculate a value for the enthalpy of combustion of methylbenzene, C7H8

(The specific heat capacity of water is 4.18 J K–1 g–1. Ignore the heat capacity of the container.)

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**(4)**

(d)     A 25.0 cm3 sample of 2.00 mol dm–3 hydrochloric acid was mixed with 50.0 cm3 of a 1.00 mol dm–3 solution of sodium hydroxide. Both solutions were initially at 18.0 °C.

After mixing, the temperature of the final solution was 26.5°C.

Use this information to calculate a value for the standard enthalpy change for the following reaction.

HCl(aq) + NaOH(aq) → NaCl(aq) + H2O(l)

In your calculation, assume that the density of the final solution is 1.00 g cm–3 and that its specific heat capacity is the same as that of water. (Ignore the heat capacity of the container.)

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**(4)**

(e)     Give **one** reason why your answer to part (d) has a much smaller experimental error than your answer to part (c).

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**(1)**

**(Total 15 marks)**

**Q13.**          The combustion of hydrocarbons is an important source of energy.

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

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**(3)**

(b)     (i)      Write an equation for the complete combustion of ethane, C2H6.

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(ii)     Use the standard enthalpies of formation given below to calculate the standard enthalpy of combustion of ethane.

|  |  |  |  |
| --- | --- | --- | --- |
| Formula and state of compound | C2H6(g) | CO2(g) | H2O(l) |
| Standard enthalpy of formation (at 298 K)/kJ mol–1 | –85 | –394 | –286 |

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**(4)**

(c)     A container and its contents of total heat capacity 120 J K–1 were heated using a methane burner. Calculate the maximum theoretical temperature rise when 0.10 g of methane was completely burned. The standard enthalpy of combustion of methane is –890 kJ mol–1.

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**(4)**

**(Total 11 marks)**

**Q14.**          (a)     Nitromethane, CH3NO2, is used as an ‘energy rich’ fuel for motor-racing. It burns in oxygen forming three gases.

2CH3NO2(l) + 1½O2(g) → 2CO2(g) + 3H2O(g) + N2(g)

(i)      A 1.00 mol sample of nitromethane was burned in oxygen forming the products shown in the equation above. Calculate the total volume of gases produced at 298 K and 100 kPa (assume that the water is gaseous).

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(ii)     This combustion reaction is very exothermic and reaches a temperature of 1000 K. Determine the total volume of gases when the temperature is raised to 1000 K at a constant pressure.

(If you have been unable to determine a volume in your answer to part (a)(i), you may assume it to be 8.61 × 10–4 m3 but this is not the correct answer).

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**(5)**

(b)     It has been suggested that, instead of releasing it into the atmosphere, the carbon dioxide gas evolved during a combustion reaction can be absorbed by sodium hydroxide solution, as shown by the following equation.

2NaOH(aq) + CO2(g) → Na2CO3(aq) + H2O(l)

(i)      Give two reasons why this reaction might not be suitable for the removal of carbon dioxide from the exhaust gases of an engine.

*Reason 1* ............................................................................................

*Reason 2* ............................................................................................

(ii)     The sodium hydroxide solution for this reaction can be made on an industrial scale, together with chlorine gas and hydrogen gas, by electrolysis of a dilute solution of sodium chloride. Suggest one commercial advantage and one environmental disadvantage of this industrial process.

*Commercial advantage* .......................................................................

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*Environmental disadvantage* ..............................................................

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**(4)**

(c)     Nitrogen forms several different oxides. Calculate the empirical formula of an oxide of nitrogen which contains 26% of nitrogen by mass.

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**(3)**

(d)     Another oxide of nitrogen, N2O, decomposes on warming to produce nitrogen and oxygen. Write an equation for the decomposition reaction.

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**(1)**

(e)     Internal combustion engines burn fuels in air. Suggest one advantage of using air mixed with N2O for this purpose.

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**(1)**

**(Total 14 marks)**

**Q15.**          A group of students devised an experiment which they believed would enable them to investigate the strength of the intermolecular forces between ethyl ethanoate molecules (CH3COOCH2CH3) and trichloromethane molecules (CHCl3).

They mixed exactly 0.10 mol of each of the two liquids in a copper calorimeter and recorded the following results. The starting temperature of both liquids was the same.

|  |  |
| --- | --- |
| Mass of 0.10 mol of ethyl ethanoate / g | 8.80 |
| Mass of 0.10 mol of trichloromethane / g | 11.95 |
| Increase in temperature (∆*T*) on mixing / K | 9.5 |

(a)     (i)      Write an expression for the heat change (*q*) which relates mass (*m*), specific heat capacity (c) and change in temperature (∆*T*).

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**(1)**

(ii)     Calculate the amount of heat required to increase the temperature of 8.80 g of ethyl ethanoate by 9.5 K during the mixing process. (You should assume that *c* for ethyl ethanoate = 1.92 J g–1 K–1)

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**(1)**

(iii)     Calculate the amount of heat required to increase the temperature of 11.95 g of trichloromethane by 9.5 K during the mixing process. (You should assume that *c* for trichloromethane = 0.96 J g–1 K–1)

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**(1)**

(iv)    Using the values from parts (a) (ii) and (a) (iii), calculate the molar enthalpy change in kJ mol–1 for the mixing process.

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**(2)**

(b)     The students deduced that the heat change was due only to the formation of intermolecular forces between ethyl ethanoate molecules and trichloromethane molecules.

Ignoring all experimental errors, give **one** reason why the students may have made an incorrect deduction.

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**(1)**

**(Total 6 marks)**

**Q16.**          Barium can be extracted from barium oxide (BaO) in a process using aluminium.
A mixture of powdered barium oxide and powdered aluminium is heated strongly.
The equation for this extraction process is shown below.

3BaO(s) + 2Al(s) → 3Ba(s) + Al2O3(s)

Some standard enthalpies of formation are given in the table below.

|  |  |  |
| --- | --- | --- |
| Substance | BaO(s) | Al2O3(s) |
| ∆*H*  f ~~ο~~ / kJ mol–1 | –558 | –1669 |

(a)     (i)      State what is meant by the term *standard enthalpy of formation*.

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**(3)**

(ii)     State why the standard enthalpy of formation of barium and that of aluminium are both zero.

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**(1)**

(iii)     Use the data to calculate the standard enthalpy change for the reaction shown by the equation above.

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**(3)**

(b)     (i)      Suggest the major reason why this method of extracting barium is expensive.

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**(1)**

(ii)     Using barium oxide and aluminium powders increases the surface area of the reactants. Suggest **one** reason why this increases the rate of reaction.

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**(1)**

(c)     (i)      Write an equation for the reaction of barium with water.

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**(1)**

(ii)     A solution containing barium ions can be used to test for the presence of sulfate ions in an aqueous solution of sodium sulfate.

Write the **simplest ionic** equation for the reaction which occurs and state what is observed.

Simplest ionic equation

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Observation .........................................................................................

**(2)**

(iii)     State how barium sulfate can be used in medicine. Explain why this use is possible, given that solutions containing barium ions are poisonous.

Use .....................................................................................................

Explanation .........................................................................................

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**(2)**

**(Total 14 marks)**

**Q17.**          Hydrogen gas is used in the chemical industry.

(a)     Tungsten is extracted by passing hydrogen over heated tungsten oxide (WO3).

(i)      State the role of the hydrogen in this reaction.

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**(1)**

(ii)     Write an equation for this reaction.

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**(1)**

(iii)     State **one** risk of using hydrogen gas in metal extractions.

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**(1)**

(b)     Hydrogen is used to convert oleic acid into stearic acid as shown by the following equation.

 + H2  CH3(CH2)16COOH
                     oleic acid                                                               stearic acid

(i)      Use your knowledge of the chemistry of alkenes to deduce the type of reaction that has occurred in this conversion.

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**(1)**

(ii)     State the type of stereoisomerism shown by oleic acid.

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**(1)**

(c)     Hydrogen reacts with nitrogen in the Haber Process. The equation for the equilibrium that is established is shown below.

N2(g) + 3H2(g)  2NH3(g)

(i)      State Le Chatelier’s principle.

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**(1)**

(ii)     Use Le Chatelier’s principle to explain why an increase in the total pressure of this equilibrium results in an increase in the equilibrium yield of ammonia.

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**(2)**

(d)     Hydrogen reacts with oxygen in an exothermic reaction as shown by the following equation.

H2(g) + O2(g) → H2O(g)                ∆*H* = –242 kJ mol–1

Use the information in the equation and the data in the following table to calculate a value for the bond enthalpy of the H–H bond.

|  |  |  |
| --- | --- | --- |
|   | O–H | O=O |
| Mean bond enthalpy / kJ mol–1 | + 463 | + 496 |
|  |  |  |

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**(3)**

**(Total 11 marks)**

**Q18.**          The balance between enthalpy change and entropy change determines the feasibility of a reaction. The table below contains enthalpy of formation and entropy data for some elements and compounds.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   | N2(g) | O2(g) | NO(g) | C(graphite) | C(diamond) |
| Δ*H*f~~ο~~/kJ mol–1 | 0 | 0 | +90.4 | 0 | +1.9 |
| *S*~~ο~~/J K–1 mol–1 | 192.2 | 205.3 | 211.1 | 5.7 | 2.4 |

(a)     Explain why the entropy value for the element nitrogen is much greater than the entropy value for the element carbon (graphite).

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**(2)**

(b)     Suggest the condition under which the element carbon (diamond) would have an entropy value of zero.

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**(1)**

(c)     Write the equation that shows the relationship between Δ*G*, Δ*H* and Δ*S* for a reaction.

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**(1)**

(d)     State the requirement for a reaction to be feasible.

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**(1)**

(e)     Consider the following reaction that can lead to the release of the pollutant NO into the atmosphere.

N2(g) + O2(g)  NO(g)

Use data from the table above to calculate the minimum temperature above which this reaction is feasible.

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**(5)**

(f)      At temperatures below the value calculated in part (e), decomposition of NO into its elements should be spontaneous. However, in car exhausts this decomposition reaction does **not** take place in the absence of a catalyst.
Suggest why this spontaneous decomposition does **not** take place.

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**(1)**

(g)     A student had an idea to earn money by carrying out the following reaction.

C(graphite)  C(diamond)

Use data from the table above to calculate values for Δ*H* and Δ*S*~~ο~~ for this reaction. Use these values to explain why this reaction is **not** feasible under standard pressure at any temperature.

Δ*H*~~ο~~ ...............................................................................................................

Δ*S*~~ο~~ ...............................................................................................................

Explanation ..................................................................................................

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**(3)**

**(Total 14 marks)**

**Q19.**          Comparison of lattice enthalpies from Born-Haber cycles with lattice enthalpies from calculations based on a perfect ionic model are used to provide information about bonding in crystals.

(a)     Define the terms *enthalpy of atomisation* and *lattice dissociation enthalpy*.

Enthalpy of atomisation ...............................................................................

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Lattice dissociation enthalpy ........................................................................

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**(4)**

(b)     Use the following data to calculate a value for the lattice dissociation enthalpy of sodium chloride.



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**(3)**

(c)     Consider the following lattice dissociation enthalpy (Δ*H*L~~ο~~) data.

|  |  |  |
| --- | --- | --- |
|   | NaBr | AgBr |
| Δ*H*L~~ο~~(experimental)/kJ mol–1 | +733 | +890 |
| Δ*H*L~~ο~~(theoretical)/kJ mol–1 | +732 | +758 |

The values of Δ*H*L~~ο~~ (experimental) have been determined from Born–Haber cycles.

The values of Δ*H*L~~ο~~ (theoretical) have been determined by calculation using a perfect ionic model.

(i)      Explain the meaning of the term *perfect* *ionic model*.

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**(2)**

(ii)     State what you can deduce about the bonding in NaBr from the data in the table.

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**(1)**

(iii)     State what you can deduce about the bonding in AgBr from the data in the table.

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**(1)**

**(Total 11 marks)**

**Q20.**         A student devised an experiment to investigate the enthalpies of combustion of some alcohols. The student chose the following series of primary alcohols.

|  |  |
| --- | --- |
| **Name** | **Formula** |
| Methanol | CH3OH |
| Ethanol | CH3CH2OH |
| Propan-1-ol | CH3CH2CH2OH |
| Butan-1-ol | CH3CH2CH2CH2OH |
| Pentan-1-ol | CH3CH2CH2CH2CH2OH |
| Alcohol **X** | CH3CH2CH2CH2CH2CH2OH |
| Heptan-1-ol | CH3CH2CH2CH2CH2CH2CH2OH |

(a)     (i)      Name alcohol **X**.

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**(1)**

(ii)     State the general name of the type of series shown by these primary alcohols.

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**(1)**

(iii)     Draw the displayed formula of the position isomer of butan-1-ol.

**(1)**

(iv)    Using [O] to represent the oxidising agent, write an equation for the oxidation of butan-1-ol to form an aldehyde.

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**(1)**

(v)     Draw the displayed formula of a functional group isomer of this aldehyde.

**(1)**

(b)     The student carried out a laboratory experiment to determine the enthalpy change when a sample of butan-1-ol was burned.
The student found that the temperature of 175 g of water increased by 8.0 °C when 5.00 × 10–3 mol of pure butan-1-ol was burned in air and the heat produced was used to warm the water.

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

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**(3)**

(c)     (i)      Give the meaning of the term *standard enthalpy of combustion*.

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**(3)**

(ii)     Use the standard enthalpy of formation data from the table and the equation for the combustion of butan-1-ol to calculate a value for the standard enthalpy of combustion of butan-1-ol.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   | CH3CH2CH2CH2OH(l) | O2(g) | CO2(g) | H2O(l) |
| Δ*H*f~~ο~~ / kJ mol–1 | –327 | 0 | –394 | –286 |
|  |  |  |  |  |

CH3CH2CH2CH2OH(l) + 6O2(g)  4CO2(g) + 5H2O(l)

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**(3)**

(d)     The student repeated the experiment described in part (b) and obtained an experimental value for the enthalpy of combustion for each alcohol in this series.
These experimental values were then compared with calculated values from standard enthalpies of formation, as shown in the graph below.



(i)      In terms of bonds broken and bonds formed, explain why the calculated values of enthalpies of combustion of these alcohols, when plotted against *M*r, follow a straight line.

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**(2)**

(ii)     Give **two** reasons why the experimental values obtained by the student are lower than the calculated values using the enthalpy of formation data.

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**(2)**

**(Total 18 marks)**

**Q21.**          This question is about the extraction of titanium from titanium(IV) oxide by a two-stage
process.
The first stage in the process produces titanium(IV) chloride. In the second stage,
titanium(IV) chloride is converted into titanium.
The enthalpy change for the second stage can be determined using Hess’s Law.

(a)     Give **one** reason why titanium is **not** extracted directly from titanium(IV) oxide using carbon.

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**(1)**

(b)     Give the meaning of the term *enthalpy change*.

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**(1)**

(c)     State Hess’s Law.

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**(1)**

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

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**(3)**

(e)     The following standard enthalpy of formation data refer to the second stage in the extraction of titanium.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   | TiCl4(g) | Na(I) | NaCl(s) | Ti(s) |
| Δ*H*f~~ο~~/ kJ mol–1 | –720 | +3 | –411 | 0 |
|  |  |  |  |  |

(i)      State why the value for the standard enthalpy of formation of Na(I) is **not** zero.

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**(1)**

(ii)     Use data from the table to calculate a value for the standard enthalpy change of the following reaction.

TiCl4(g) + 4Na(I)  4NaCl(s) + Ti(s)

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**(3)**

(iii)     State the role of sodium in this reaction.

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**(1)**

**(Total 11 marks)**

**Q22.**          The rate of a chemical reaction is influenced by the size of the activation energy. Catalysts are used to increase the rates of chemical reactions but are not used up in the reactions.

(a)     Give the meaning of the term *activation energy*.

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**(2)**

(b)     Explain how a catalyst increases the rate of a reaction.

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**(2)**

(c)     The diagram below shows the Maxwell–Boltzmann distribution of molecular energies, at a constant temperature, in a gas at the start of a reaction.
On this diagram the most probable molecular energy at this temperature is shown by the symbol *E*mpThe activation energy is shown by the symbol *E*a



To answer the questions (c)(i) to (c)(iv), you should use the words **increases**, **decreases** or **stays the same**. You may use each of these answers once, more than once or not at all.

(i)      State how, if at all, the value of the most probable energy (*E*mp) changes
as the total number of molecules is increased at constant temperature.

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**(1)**

(ii)     State how, if at all, the number of molecules with the most probable energy (*E*mp) changes as the temperature is decreased without changing the total number of molecules.

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**(1)**

(iii)     State how, if at all, the number of molecules with energy greater than the activation energy (*E*a) changes as the temperature is increased without c hanging the total number of molecules.

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**(1)**

(iv)    State how, if at all, the area under the molecular energy distribution curve changes as a catalyst is introduced without changing the temperature or the total number of molecules.

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**(1)**

(d)     For each of the following reactions, identify a catalyst and name the organic product of the reaction.

(i)      The fermentation of an aqueous solution of glucose.

Catalyst ..............................................................................................

Name of organic product ....................................................................

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**(2)**

(ii)     The hydration of but-2-ene.

Catalyst ..............................................................................................

Name of organic product ....................................................................

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**(2)**

**(Total 12 marks)**

**Q23.**(a)     Iron is extracted from iron(III) oxide using carbon at a high temperature.

(i)      State the type of reaction that iron(III) oxide undergoes in this extraction.

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**(1)**

(ii)     Write a half-equation for the reaction of the iron(III) ions in this extraction.

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**(1)**

(b)     At a high temperature, carbon undergoes combustion when it reacts with oxygen.

(i)      Suggest why it is **not** possible to measure the enthalpy change directly for the following combustion reaction.

C(s,graphite)    +    O2(g)        CO(g)

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**(1)**

(ii)     State Hess’s Law.

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**(1)**

(iii)    State the meaning of the term *standard enthalpy of combustion.*

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*(Extra space)* ........................................................................................

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**(3)**

(c)     Use the standard enthalpies of formation in the table below and the equation to calculate a value for the standard enthalpy change for the extraction of iron using carbon monoxide.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   | Fe2O3(s) | CO(g) | Fe(l) | CO2(g) |
| ∆*H*f/ kJ mol–1 |
|  – 822– 111+14– 394 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Fe2O3(s) | + | 3CO(g) |  | 2Fe(I) | + | 3CO2(g) |

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*(Extra space)* .................................................................................................

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**(3)**

(d)     (i)      Write an equation for the reaction that represents the standard enthalpy of formation of carbon dioxide.

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**(1)**

(ii)     State why the value quoted in part (c) for the standard enthalpy of formation of CO2(g) is the same as the value for the standard enthalpy of combustion of carbon.

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**(1)**

**(Total 12 marks)**

**Q24.**Methanol (CH3OH) is an important fuel that can be synthesised from carbon dioxide.

(a)     The table shows some standard enthalpies of formation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   | CO2(g) | H2(g) | CH3OH(g) | H2O(g) |
| ∆HfƟ/kJ mol–1 | – 394 | 0 | – 201 | – 242 |

(i)      Use these standard enthalpies of formation to calculate a value for the standard enthalpy change of this synthesis.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| CO2(g) | + | 3H2(g) |  | CH3OH(g) | + | H2O(g) |

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*(Extra space)* ........................................................................................

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**(3)**

(ii)     State why the standard enthalpy of formation for hydrogen gas is zero.

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**(1)**

(b)     State and explain what happens to the yield of methanol when the total pressure is increased in this synthesis.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| CO2(g) | + | 3H2(g) |  | CH3OH(g) | + | H2O(g) |

Effect on yield ................................................................................................

Explanation ....................................................................................................

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*(Extra space)* .................................................................................................

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**(3)**

(c)     The hydrogen required for this synthesis is formed from methane and steam in a reversible reaction. The equation for this reaction is shown below.

CH4(g)   +   H2O(g)      C0(g)   +   3H2(g)           ∆H = +206 kJ mol–1

State and explain what happens to the yield of hydrogen in this reaction when the temperature is increased.

Effect on yield ................................................................................................

Explanation ....................................................................................................

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*(Extra space)* .................................................................................................

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**(3)**

(d)     The methanol produced by this synthesis has been described as a carbon-neutral fuel.

(i)      State the meaning of the term *carbon-neutral*.

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*(Extra space)* ........................................................................................

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**(1)**

(ii)     Write an equation for the complete combustion of methanol.

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**(1)**

(iii)    The equation for the synthesis of methanol is shown below.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| CO2(g) | + | 3H2(g) |  | CH3OH(g) | + | H2O(g) |

Use this equation and your answer to part (d)(ii) to deduce an equation to represent the overall chemical change that occurs when methanol behaves as a carbon-neutral fuel.

Equation ...............................................................................................

**(1)**

(e)     A student carried out an experiment to determine the enthalpy change when a sample of methanol was burned.

The student found that the temperature of 140 g of water increased by 7.5 °C when 0.011 mol of methanol was burned in air and the heat produced was used to warm the water.

Use the student’s results to calculate a value, in kJ mol–1, for the enthalpy change when one mole of methanol was burned.
(The specific heat capacity of water is 4.18 J K–1 g–1).

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*(Extra space)* .................................................................................................

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**(3)**

**(Total 16 marks)**

**Q25.**Hydrazine (N2H4) decomposes in an exothermic reaction. Hydrazine also reacts exothermically with hydrogen peroxide when used as a rocket fuel.

(a)     Write an equation for the decomposition of hydrazine into ammonia and nitrogen only.

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**(1)**

(b)     State the meaning of the term *mean bond enthalpy*.

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**(2)**

(c)     Some mean bond enthalpies are given in the table.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|   |  | N–H | N–N | N≡N | O–H | O–O |
|   | Mean bond enthalpy / kJ mol−1 | 388 | 163 | 944 | 463 | 146 |

Use these data to calculate the enthalpy change for the gas-phase reaction between hydrazine and hydrogen peroxide.



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**(3)**

**(Total 6 marks)**

**Q26.**A student used Hess’s Law to determine a value for the enthalpy change that occurs when anhydrous copper(II) sulfate is hydrated. This enthalpy change was labelled *ΔH*exp by the student in a scheme of reactions.



(a)     State Hess’s Law.

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**(1)**

(b)     Write a mathematical expression to show how Δ*H*exp, Δ*H*1 and Δ*H*2 are related to each other by Hess’s Law.

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**(1)**

(c)     Use the mathematical expression that you have written in part (b), and the data book values for the two enthalpy changes Δ*H*1 and Δ*H*2 shown, to calculate a value
for Δ*H*exp

Δ*H*1 = −156 kJ mol−1
Δ*H*2 = +12 kJ mol−1

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**(1)**

(d)     The student added 0.0210 mol of pure anhydrous copper(II) sulfate to 25.0 cm3 of deionised water in an open polystyrene cup. An exothermic reaction occurred and the temperature of the water increased by 14.0 °C.

(i)      Use these data to calculate the enthalpy change, in kJ mol−1, for this reaction of copper(II) sulfate. This is the student value for Δ*H*1

In this experiment, you should assume that all of the heat released is used to raise the temperature of the 25.0 g of water. The specific heat capacity of water is 4.18 J K−1 g−1.

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**(3)**

(ii)     Suggest **one** reason why the student value for Δ*H*1 calculated in part (d)(i) is less accurate than the data book value given in part (c).

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**(1)**

(e)     Suggest **one** reason why the value for Δ*H*exp **cannot** be measured directly.

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*(Extra space)* .................................................................................................

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**(1)**

**(Total 8 marks)**

**Q27.**This question is about the extraction of metals.

(a)     Manganese can be extracted from Mn2O3 by reduction with carbon monoxide at high temperature.

(i)      Use the standard enthalpy of formation data from the table and the equation for the extraction of manganese to calculate a value for the standard enthalpy change of this extraction.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   |  | Mn2O3(s) | CO(g) | Mn(s) | CO2(g) |
|   | Δ*H*fϴ/ kJ mol−1 | −971 | −111 | 0 | −394 |

Mn2O3(s) + 3CO(g)   2Mn(s) + 3CO2(g)

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**(3)**

(ii)     State why the value for the standard enthalpy of formation of Mn(s) is zero.

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**(1)**

(b)     Titanium is extracted in industry from titanium(IV) oxide in a two-stage process.

(i)      Write an equation for the first stage of this extraction in which titanium(IV) oxide is converted into titanium(IV) chloride.

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**(2)**

(ii)     Write an equation for the second stage of this extraction in which titanium(IV) chloride is converted into titanium.

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**(2)**

(c)     Chromium is extracted in industry from chromite (FeCr2O4).

(i)      In the first stage of this extraction, the FeCr2O4 is converted into Na2CrO4 Balance the equation for this reaction.

.........FeCr2O4 + .........Na2CO 3 + .........O 2   .........Na2CrO4 + 2Fe2O 3 + 8CO2

**(1)**

(ii)     In the final stage, chromium is extracted from Cr2O3 by reduction with aluminium.

Write an equation for this reaction.

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**(1)**

**(Total 10 marks)**

**Q28.**Group 2 metals and their compounds are used commercially in a variety of processes.

(a)     Strontium is extracted from strontium oxide (SrO) by heating a mixture of powdered strontium oxide and powdered aluminium.

Consider these standard enthalpies of formation.

|  |  |  |  |
| --- | --- | --- | --- |
|   |  | SrO(s) | Al2O3(s) |
|   | ***ΔH*fϴ / kJ mol−1** | – 590 | – 1669 |

3SrO(s) + 2Al(s)       3Sr(s)   +   Al2O3(s)

Use these data and the equation to calculate the standard enthalpy change for this extraction of strontium.

The use of powdered strontium oxide and powdered aluminium increases the surface area of the reactants.
Suggest **one** reason why this increases the reaction rate.

Suggest **one** major reason why this method of extracting strontium is expensive.

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**(5)**

(b)     Explain why calcium has a higher melting point than strontium.

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**(2)**

(c)     Magnesium is used in fireworks. It reacts rapidly with oxygen, burning with a bright white light. Magnesium reacts slowly with cold water.

Write an equation for the reaction of magnesium with oxygen.

Write an equation for the reaction of magnesium with cold water.

Give a medical use for the magnesium compound formed in the reaction of magnesium with cold water.

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**(3)**

**(Total 10 marks)**

**Q29.**Ethanol is an important industrial compound.

(a)     Ethanol can be produced by the hydration of ethene.
The equation for the equilibrium that is established is

H2C=CH2(g)   +   H2O(g)       CH3CH2OH(g) Δ*H* = −42 kJ mol−1

The operating conditions for the process are a temperature of 300 oC and a pressure of 7 MPa.
Under these conditions, the conversion of ethene into ethanol is 5%.

(i)      Identify the catalyst used in this process.
Deduce how an overall yield of 95% is achieved in this process without changing the operating conditions.

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**(2)**

(ii)     Use your knowledge of equilibrium reactions to explain why a manufacturer might consider using an excess of steam in this process, under the same operating conditions.

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**(3)**

(iii)    At pressures higher than 7 MPa, some of the ethene reacts to form a solid with a relative molecular mass greater than 5000.

Deduce the identity of this solid.

Give **one** other reason for **not** operating this process at pressures higher than 7 MPa.
Do **not** include safety reasons.

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**(2)**

(b)     Write an equation for the reaction that has an enthalpy change that is the standard enthalpy of formation of ethanol.

...............................................................................................................

**(2)**

(c)     When ethanol is used as a fuel, it undergoes combustion.

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

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**(3)**

(ii)     Consider these bond enthalpy data.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|   |  | C–H | C–C | C–O | O=O | C=O | O–H |
|   | **Bond enthalpy / kJ mol−1** | 412 | 348 | 360 | 496 | 805 | 463 |

Use these data and the equation to calculate a value for the enthalpy of combustion of gaseous ethanol.

CH3CH2OH(g)   +   3O2(g)        2CO2(g)   +   3H2O(g)

...............................................................................................................

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...............................................................................................................

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**(3)**

(d)     Gaseous ethanol can be used to convert hot copper(II) oxide into copper.

(i)      Deduce the role of ethanol in this reaction.

...............................................................................................................

**(1)**

(ii)     Draw the structure of the organic compound with *M*r = 60 that is produced in this reaction.

**(1)**

**(Total 17 marks)**

**M1.**          (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 × C−H = 4 × 413 = +1652
1 × C−C = 1 × 347 = 347
1 × C=O = 1 × 736 = 736
2½ × O=O = 2.5 × 498 = 1245 **(1)**                  = 2735 + 1245 = +3980 **(1)**

*first mark for 4 : 1: 1 or 2735 ignore sign*

(ii)     4 × H−O = -4 × 464 = –1856
4 × C−O = -4 × 736 = –2944 **(1)**                               = –4800 **(1)**

*First mark for 4 : 4*

(iii)     ΔHR = ΣBonds broken − ΣBonds made
       = +3980 − 4800 = −820 **(1)**

*Conseq Mark for incorrect answers in (i) and (ii) as
(i) Answer + (ii) Answer =*

**5**

**[7]**

**M2.**          (a)     (Enthalpy change) when 1 mol **(1)** of a compound is formed
from its constituent elements **(1)** in their standard states **(1)**

**3**

*Allow energy or heat, Ignore evolved or absorbed
Mark each point independently*

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

**1**

(c)     ΔHR = Hf products ‑ Hf reactants **(1)**  = [(3 × -286) + (3 × -394)] ‑ (-248) **(1)**= -1792 **(1)** (kJ mol–1)

*Deduct one mark for each error to zero*

**3**

**[7]**

**M3.**(a)     2AgNO3 + Zn → Zn(NO3)2 + 2Ag **(1)**

*Accept an ionic equation i.e.2Ag+ +Zn → 2Ag + Zn2+*

**1**

(b)     Moles = mv / 1000 **(1) =** 0.20 × 50/1000 = 1.00 × 10–2

**2**

(c)     Heat energy change = mCΔT **(1)** = 50 × 418 × 3.2 J

= 669 J (Ignore signs) **(1)**

*Allow 668, 67.0  0.67kJ*

*Penalise wrong units if given*

**2**

(d)      = 134 kJ mol–1

*Mark one : 2 × (answer to (c))*

*Mark two : Dividing by answers to (b)*

*Allow 133 – 134*

*Penalise incorrect units*

*Mark conseq to equation in (a) for full marks, also to that in (c)*

*If No working is shown and answer is incorrect zero*

**2**

(e)     Incomplete reaction or Heat loss **(1)**

**1**

**[8]**

**M4.**          (a)     Heat energy change **(1)**

*Not energy on its own*

          measured at constant pressure **(1)**

*Mark separately, ignore constant temperature statements*

**2**

(b)     (i)      Enthalpy change when 1 mol of a substance (or compound / product) **(1)**is formed from its constituent elements **(1)** in their standard states **(1)**under standard conditions **(1)**

*Mark separately*

(ii)     2Na(s) + S(s) + 2O2(g) → Na2SO4(s)

*Balanced (1) State symbols (1), but only if all species are correct*

*Allow S8 (s)*

**5**

(c)     Enthalpy change is independent of reaction route **(1)**

*Penalise incorrect additional statements*

**1**

(d)



         –1356 + (2 × 285.8) + (4 × 393.5) + ΔHfC4H4O4 = 0

          ΔHf = –789.6 kJ mol–1

*If answer is incorrect:*

*Score +789.6 two marks*

*Score (× 1); (× 2) and (× 4) for species - one mark*

*If an incorrect negative answer given check for AE for loss of one mark*

**3**

**[11]**

**M5.**(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. CH4*

*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 N2 + 3/2 H2 → NH3 **(1)**

*Ignore s s*

(ii)     ΔH = (Σ)bonds broken – (Σ)bonds formed **(1)**      = 1/2 × 944 + 3/2 × 436 – 3 × 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)**OR (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]**

**M6.**          (a)     C3H6O + 4O2 → 3CO2 + 3H2O **(1)** (or multiple)                                                    1

(b)     (i)       **(1)**  = 0.0250 **(1)**

*allow 0.025
allow conseq on wrong Mr*

*1.45/100, CE;  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)      = –972 (kJ mol–1) **(1)**

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

**5**

(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)**or heat/energy required to vaporise water
or water molecules have more energy in the gaseous state

**3**

(d)     ΔH = ΣΔ*H*reactants – ΣΔ*H*products **(1)**

(or cycle )

= (2 × –394) + (3 × –286) + (–297) – (–1170) **(1)**= –773 **(1)**

*ignore units even if wrong*

*Allow 1/3 for +773*

**3**

**[12]**

**M7.**          (a)     (i)      enthalpy (or heat or heat energy) change when
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*

**3**

(b)     enthalpy change (or enthalpy of reaction) is independent of route **(1)**

          Δ*H* = ΣΔHf prods - ΣΔHf reactants (or cycle) **(1)**minimum correct cycle is:



          Δ*H* = -642 – 286 – (–602 + 2 × –92) **(1)**      = –142 (kJ mol–1) **(1)**

*penalise this mark for wrong units*

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

**4**

(c)     ΔH = *mcT* **(1)**      (or *mcΔT*)
      = 50 × 4.2 × 32 = 6720 J = 6.72J **(1)**

*mark is for 6720 J or 6.72 kJ*

          moles HCl =  × conc =  × 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 Δ*H* = 6.72/0.075 **(1)**                     = –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*

**8**

          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]**

**M8.**          (a)     Δ*H* = Σ(bonds broken) – Σ(bonds formed) (or cycle)

**1**

      = +146 – 496/2 (or 2 × 463 + 146 –(2 × 463 + 496/2)

**1**

      = – 102 (kJ mol–1) **(1)**

*(accept no units, wrong units loses a mark; +102 scores* ***(1)*** *only)*

**1**

(b)     C(s) + 2H2(g) → CH4(g) equation **(1)** Correct state symbols **(1)**

**2**

(c)     (i)      Macromolecular

*(accept giant molecule or carbon has many (4) bonds)*

**1**

(ii)     Δ*H* = ΣΔ*Hf*(products) – ΣΔ*Hf*(reactants) (or cycle)

**1**

      = 715 + 4 × 218 – (–74.9)

**1**

      = 1662 (kJ mol–1)

*(accept no units, wrong units loses one mark,
allow 1660 to 1663, –1662 scores one mark only)*

**1**

(iii)     1662/4 = 415.5

*(mark is for divide by four, allow if answer to (c)(ii) is wrong)*

**1**

**[10]**

**M9.**          (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
*xΔT* (or *mcΔT)*

**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/Mr = 2.12/32 (1)
= 0.0663

**1**

         Δ*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)     (i)      equilibrium shifts to left at high pressure

**1**

because position of equilibrium moves to favour
fewer moles (of gas)

**1**

(ii)     at high temperature reaction yield is low (or at low *T* yield is high)

**1**

at low temperature reaction is slow (or at high *T* reaction is fast)

**1**

therefore use a balance (or compromise) between rate and yield

**1**

(c)     Δ*H* = ΣΔ*H*c~~ο~~(reactants) – *ΣΔH*c~~ο~~ (products) (or correct cycle)

**1**

*ΔH*c~~ο~~ (CH3OH) = *ΔHc~~ο~~*(CO) + 2 × *ΔHc~~ο~~*(H2) – Δ*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)
(note + 764 scores 1/3)*

**1**

**[15]**

**M10.**          (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);
*(or similar)*

**1**

*=* –789;

*(+ 789 scores 1 only)*

**1**

(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;

*(+ 777 scores one only)*

**1**

(d)     mean bond enthalpies are not exact

*(or indication that actual values are different from real values)*

**1**

**[13]**

**M11.**          (a)     enthalpy change/ heat energy change when 1 mol of a substance

**1**

is completely burned in oxygen

**1**

at 298K and 100 kPa or standard conditions

**1**

*(not 1atm)*

(b)     ∆H = ∑ bonds broken – ∑ bonds formed

**1**

= (6 × 412) + 612 +348 + (4.5 × 496) – ((6 × 743) + (6 × 463))

**1**

= – 1572 kJ mol–1

**1**

(c)     by definition ∆*H*f is formation from an element

**1**

(d)     ∆*Hc* = ∑ ∆*Hf* products -∑ ∆*H*f reactants or cycle

**1**

= (3 × – 394) + (3 × –242) – (+20)

**1**

= − 1928 kJ mol–1

**1**

(e)     bond enthalpies are mean/average values

**1**

from a range of compounds

**1**

**[12]**

**M12.**(a)     Enthalpy change when 1 mol of compound (1)

Is formed from it’s elements (1)

All substances in their standard state (1)

**3**

(b)     Δ*H* = ΣΔ*H*~~ο~~c (reactants) – ΣΔ*H*~~ο~~c (products)  (1)

= (7*x* – 394) + (4 *x* – 286) – (– 3909)  (1)

= + 7 kJmol–1 (1)

**3**

(c)     Heat change = m c Δ*T* (1)

                               = 250 × 4.18 × 60 = 62700J = 62.7kJ (1)

Moles C7H8 = 2.5 /92 = 0.0272 (1)

*ΔH* = 62.7 / 0.0272 = – 2307 kJ mol–1 (1)

*(allow –2300 to –2323)*

**4**

(d)     Mass of water heated = 25 + 50 = 75g
Temp rise = 26.5 – 18 = 8.5 °C

*both for* ***(1)*** *mark*

Heat change = 75 × 4.18 × 8.5 = 2665 J = 2.665 kJ (1)

Moles HCl = 0.05 (1)

Δ*H =* – 2.665 / 0.05 = –53.3 kJmol–1 (1)

*(allow –53 to –54)*

**4**

(e)     Less heat loss (1)

**1**

**[15]**

**M13.**          (a)     The enthalpy change when 1 mol of a compound

**1**

is completely burnt in oxygen

**1**

under standard conditions, or 298K and 100kPA

**1**

(b)     (i)      C2H6 + 3½O2 → 2CO2 + 3H2O

**1**

(ii)     ΔH = 2 × ΔHf~~ο~~ (CO2) + 3 × ΔHf~~ο~~ (H2O) – ΔHf~~ο~~ (C2H6)

**1**

= – 788 – 858 – (–85)

**1**

= – 1561 kJ mol–1

**1**

(c)     moles methane =  = 6.25 × 10–3

**1**

kJ evolved = 6.25 × 10–3 × 890 = 5.56

**1**

5.56 × 103 joules = (mc)ΔT

**1**

ΔT =  = 46.4 K

**1**

**[11]**

**M14.**          (a)     (i)      Moles of gas produced = 3

**1**

         *PV* = *nRT*

**1**

*V = nRT/P =* 3 × 8.31 × 298/100000

**1**

= 7.43 × 10–2 m3

**1**

(ii)     7.43 × 10–2 × 1000/298 = 0.249 m3

**1**

(b)     (i)      any two from:

exhaust gases hot so would boil the solution away
solution would splash
reaction might be too slow
would need continuous supply of solution and/or replacement
of products

**2**

(ii)     *Commercial advantage*         could sell chlorine and/or hydrogen

**1**

*environmental disadvantage*         generation of electricity
                                                       likely to lead
                                                       to release of CO2                                                       (or chlorine toxic)

**1**

(c)     % O = 74%

**1**

N:O = 26/14:74/16

**1**

= 1.86: 4.63 = 1:2.5 therefore formula is N2O5

**1**

(d)     2N2O → 2N2 + O2

**1**

(e)     Proportion of O2 increased leading to higher T (or more
complete combustion)

**1**

**[14]**

**M15.**          (a)     (i)      q = mc ΔT

*Ignore case except T*

**1**

(ii)     8.80 × 1.92 × 9.5 = **161** (J) to 160.5(12) (J)

*Credit 0.161 provided it is clear that it is kJ.
Penalise wrong units*

**1**

(iii)     11.95 × 0.96 × 9.5 = **109** (J) to 108.98(4) (J)

*Credit 0.109 provided it is clear that it is kJ.
Penalise wrong units.*

**1**

(iv)    **M1**    Addition of (a)(ii) and (a)(iii)

**M2**    Multiply by 10 and convert to kJ (divide by 1000)
leading to an answer

*Consequential on (a)(ii) and (a)(iii)
Penalise wrong units
Ignore the sign*

         Therefore ΔH = **(–) 2.69 *OR* (–) 2.7(0)** (kJ mol–1)

*Ignore greater numbers of significant figures (2.69496)
Subtraction in M1 is CE*

**2**

(b)     One from:

•        No account has been taken of the intermolecular forces initially
in the two liquids OR each liquid has its own intermolecular
forces in operation before mixing.

•        The liquids may react or reference to reaction or reference
to bonds broken or formed

*Any statement which shows that there are other intermolecular forces to consider.
Ignore heat loss and ignore poor mixing.*

**1**

**[6]**

**M16.**          (a)     (i)      **M1**    The enthalpy change / heat change at constant pressure
          when 1 mol of a compound / substance / product

**1**

**M2**    Is formed from its (constituent) elements

**1**

**M3**    With all reactants and products / all substances in
          standard states
          ***OR***          All reactants and products / all substances in normal
          states under standard conditions / 100 kPa / 1 bar and
          specified T / 298 K

*Ignore reference to 1 atmosphere*

**1**

(ii)     By definition
**OR**Because they are elements

**1**

(iii)     **M1**    Δ*Hf* = ΣΔ*Hf* **(products)** – ΣΔ*Hf***(reactants)**

**1**

**M2**    = –1669 – 3(–558)
(This also scores M1)

**1**

**M3**    = **(+) 5** (kJ mol–1)

*Correct answer gains full marks.
Assume the value is positive unless specifically stated as negative.
Credit 1 mark if – 5 (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; this
     would score 2 marks (M1 and M2)
•    If no AE, check for a correct method; this requires either
     a correct cycle with 3BaO OR a clear statement of M1
     which could be in words and scores only M1*

**1**

(b)     (i)      *One from*

•        Aluminium is expensive (to extract *OR* due to electrolysis)

•        High energy cost

•        The cost of heating strongly

*This requires a clear statement about cost*

**1**

(ii)     *One from*

•        increase collision frequency

•        OR more collisions

•        OR more chance of colliding

*The answer MUST refer to more collisions.*

*Ignore “more available to collide”*

**1**

(c)     (i)      Ba + **2**H2O → Ba(OH)2 + H2

*Ignore state symbols
Allow multiples and correct ionic equations*

**1**

(ii)     **M1**    Ba2+ + SO42– → BaSO4                               (or the ions together)

*Allow crossed out Na+ ions, but penalise if not crossed out*

**1**

**M2**    White precipitate / white solid

*Ignore state symbols
Ignore “milky”*

**1**

(iii)     **M1**    Barium meal or ( internal ) X-ray or to block X-rays

**1**

**M2**    BaSO4 / barium sulfate is insoluble (and therefore not toxic)

*Accept a correct reference to M1 written in the explanation in M2, unless contradictory.*

*For M2   NOT barium ions
     NOT barium
     NOT barium meal and NOT “It”.*

*Ignore radio-tracing.*

**1**

**[14]**

**M17.**          (a)     (i)      Reducing agent

***OR***

Reduce(s) (WO3/tungsten oxide)

OR

electron donor

OR

to remove oxygen (from WO3/tungsten oxide or to form water);

**1**

(ii)     WO3 + **3**H2 → W + **3**H2O

*Or multiples*

**1**

(iii)     *One from*

H2 is

•    explosive

•    flammable or inflammable

•    easily ignited

*Ignore reference to pressure or temperature*

**1**

(b)     (i)      Addition

*Ignore “electrophilic”*

*Penalise “nucleophilic addition”*

***OR***

(catalytic) hydrogenation

OR

Reduction

**1**

(ii)     Geometric(al)

***OR***

cis/trans OR E Z OR E/Z

**1**

(c)     (i)      (If any factor is changed which affects an equilibrium), the
position of equilibrium will shift/move/change/respond/act
so as to oppose the change.

***OR***

(When a system/reaction in equilibrium is disturbed), the
equilibrium shifts/moves in a direction which tends to
reduce the disturbance

*A variety of wording will be seen here and the key part is the last phrase and must refer to movement of the equilibrium.*

***QoL***

**1**

(ii)     **M1 – Statement of number of moles/molecules**There are more moles/molecules (of gas) on the left/of reactants

***OR***

fewer moles/molecules (of gas) on the right./products

***OR***

there are 4 moles/molecules (of gas) on the left and 2 moles/
molecules on the right.

*Ignore “volumes” for M1*

*Mark independently*

**M2 – Explanation of response/movement in terms of pressure**Increase in pressure is opposed (or words to that effect)

***OR***

pressure is lowered by a shift in the equilibrium (from left) to
right/favours forward reaction.

**2**

(d)     ΣB(reactants) – ΣB(products) = Δ*H* (**M1**)

***OR***

Sum of bonds broken – Sum of bonds formed = ΔH (**M1**)

B(H–H) + ½B(O=O) – 2B(O–H) = – 242 (**M1**)

B(H–H) = – 242 – ½(+496) + 2(+463) (this scores **M1** and **M2**)

B(H–H) = (+)436 (kJ mol–1) (**M3**)

Award 1 mark for – 436

Candidates may use a cycle and gain full marks.

*M1 could stand alone*

*Award full marks for correct answer.*

*Ignore units.*

*Two marks can score with an arithmetic error in the working.*

**3**

**[11]**

**M18.**          (a)     Because it is a gas compared with solid carbon

*Mark independently*

**1**

Nitrogen is more disordered/random/chaotic/free to move

**1**

(b)     0 K/–273 C/absolute zero

**1**

(c)     Δ*G* = Δ*H* – *T*Δ*S*

*Allow ΔH = ΔG – TΔS*

*TΔS = ΔH – ΔG*

*ΔS = (ΔH – ΔG)/T*

*Ignore ~~o~~ in ΔG~~o~~*

**1**

(d)     Δ*G* is less than or equal to zero (Δ*G ≤* 0)

*Allow ΔG is less than zero (ΔG < 0)*

*Allow ΔG is equal to zero (ΔG = 0)*

*Allow ΔG is negative*

**1**

(e)     When Δ*G* = 0 *T* = Δ*H*/Δ*S*

**1**

Δ*H* = +90.4

*Allow ΔH = +90*

**1**

Δ*S* = ΣS(products) – ΣS(reactants)

**1**

Δ*S* = 211.1 – 205.3/2 – 192.2/2 = 12.35

**1**

*T* = (90.4 × 1000)/12.35 = 7320 K/7319.8 K

*Allow 7230 to 7350 K (Note 7.32 K scores 4 marks)*

*Units of temperature essential to score the mark*

**1**

(f)      Activation energy is high

*Allow chemical explanation of activation energy*

*Allow needs route with lower activation energy*

*Allow catalyst lowers activation energy*

**1**

(g)     Δ*H* = 1.9 (kJ mol–1)

**1**

Δ*S* = 2.4 – 5.7 = –3.3 (J K–1 mol–1)

*for M1 and M2 allow no units, penalise wrong units*

**1**

Δ*G* is always positive

*This mark can only be scored if ΔH is +ve and ΔS is –ve*

**1**

**[14]**

**M19.**          (a)     Enthalpy change for the formation of 1 mol of gaseous atoms

*allow heat energy change for enthalpy change*

**1**

From the element (in its standard state)

*ignore reference to conditions*

**1**

Enthalpy change to separate 1 mol of an ionic lattice/solid/compound

*enthalpy change not required but penalise energy*

**1**

Into (its component) gaseous ions

*mark all points independently*

**1**

(b)     Δ*H*L = –Δ*H*f + Δ*H*a + I.E. + 1/2E(Cl-Cl) + EA

*Or correct Born-Haber cycle drawn out*

**1**

= +411 + 109 + 494 + 121 – 364

**1**

= +771 (kJ mol–1)

*–771 scores 2/3*

*+892 scores 1/3*

*–51 scores 1/3*

*–892 scores zero*

*+51 scores zero           ignore units*

**1**

(c)     (i)      Ions are perfect spheres (or point charges)

**1**

Only electrostatic attraction/no covalent interaction

*mention of molecules/intermolecular forces/covalent bonds
CE = 0*

*allow ionic bonding only*

*If mention of atoms CE = 0 for M2*

**1**

(ii)     Ionic

*Allow no covalent character/bonding*

**1**

(iii)     Ionic with additional covalent bonding

*Or has covalent character/partially covalent*

*Allow mention of polarisation of ions or description of polarisation*

**1**

**[11]**

**M20.**          (a)     (i)      Hexan-1-ol1

*ONLY*

**1**

(ii)     Homologous (series)

*ONLY*

**1**

(iii)     Displayed formula for butan-2-ol



*All bonds must be drawn out including the O–H bond*

*Ignore bond angles*

**1**

(iv)    CH3CH2CH2CH2OH + [O]  CH3CH2CH2CHO + H2O

*Require this whole equation as written or formulae drawn out*

*Penalise “sticks”*

**1**

(v)     Displayed formula for butanone

(credit possible enols, ethers and cyclic structures for C4H8O)



*All bonds must be drawn out*

*Ignore bond angles*

**1**

(b)     **M1** q = m c ΔT OR calculation 175 × 4.18 × 8

**M2**    = **5852** (J) OR 5.85 (kJ) OR 5.9 (kJ) (This also scores M1)

**M3** 0.005 mol, therefore ΔH = **–1170** (kJ mol–1)

                          OR ΔH = **–1170.4** (kJ mol–1)

                         OR ΔH = **–1200** (kJ mol–1)

*Award full marks for correct answer*

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

*Ignore incorrect units in M2*

*Penalise M3 ONLY if correct answer but sign is incorrect OR value is in J mol–1*

*If m = 5 × 10–3 OR if ΔT = 281, CE and only allow one mark for correct mathematical formula for M1*

*If c = 4.81 (leads to 6734) penalise M2 ONLY and mark on for M3 = –1350 (–1347)*

**3**

(c)     (i)      **M1**    The enthalpy change (or heat change at constant pressure)
when 1 mol of a compound/substance/alcohol

**M2** is burned completely in oxygen

OR burned in excess oxygen

**M3** with all reactants and products/all substances in
standard states

OR

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

*For M3*

*Ignore reference to 1 atmosphere*

**3**

(ii)     **M1    (could be scored by a correct mathematical
expression)**

**M1**    Δ*H* =ΣΔ*H*f (**products**) – .ΣΔ*H*f (**reactants**)

OR a correct cycle of balanced equations

**M2**    = 4(–394) + 5(–286) – (–327)

          (This also scores M1)

**M3**    = **– 2679** (kJ mol–1) OR **–2680** (kJ mol–1)

**Award 1 mark ONLY for (+) 2679 OR (+) 2680**

*Correct answer to calculation gains full credit*

*Credit 1 mark if + 2679 (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; this
     would score 2 marks (M1 and M2)*

*•    If no AE, check for correct method; this requires either
     a correct cycle with 4CO2 and 5H2O OR a clear
     statement of M1 which could be in words and scores
     only M1*

**3**

(d)     (i)      **M1    This is about the change in formula up the series**

          Each alcohol in the series (compared with the previous one)

          increases by/has an extra CH2

OR

          has one more C-C and two more C-H

**M2    This is about the reaction and bond breaking/making**

          Combustion of each alcohol in the series breaks one

          more C-C and two more C-H compared with the previous one
AND forms one more mol CO2 and one more mol H2O

OR

          A statement in which there is the idea that the extra OR
additional OR difference in number of bonds broken
and formed (as the series increases) is the same OR has
the same difference in energy

*N.B. If the first statement here for M2 is given, both marks score*

**2**

(ii)     **For the two marks M1 and M2**

heat loss or heat absorbed by the apparatus

OR

incomplete combustion/not completely burned

OR

The idea that the water may end up in the gaseous state
(rather than liquid) OR reactants and/or products may
not be in standard states.

**2**

**[18]**

**M21.**          (a)     One from

•        Ti is not produced

•        TiC / carbide is produced OR titanium reacts with carbon

•        Product is brittle

•        Product is a poor engineering material

*Penalise “titanium carbonate”*

*Ignore “impure titanium”*

*Credit “titanium is brittle”*

**1**

(b)     Heat (energy) change at constant pressure

***QoL***

**1**

(c)     The enthalpy change in a reaction is independent of
the route taken (and depends only on the initial and final states)

*Credit “heat change at constant pressure” as an alternative to “enthalpy change”*

**1**

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

*For M1, credit correct reference to molecule/s or atom/s*

**M2** is formed from its (constituent) elements

**M3** with all reactants and products / all substances in
standard states

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

*Ignore reference to 1 atmosphere*

**3**

(e)     (i)      Na / it is not in its standard state / normal state under
standard conditions

OR

Standard state / normal state under standard conditions
for Na is solid / (s)

***QoL***

*Ignore “sodium is a liquid or sodium is not a solid”*

**1**

(ii)     **M1 ∆Hr = ∑∆Hf (products) - ∑∆Hf (reactants)**

**M2 ∆Hr** = 4(−411) − (−720) − 4(+3)             = −1644 + 720 − 12             (This also scores M1)

**M3**        = **−936** (kJ mol−1)

*Correct answer gains full marks*

***Credit 1 mark for + 936*** *(kJ mol−1)*

***Credit 1 mark for – 924*** *(kJ mol−1)i.e. assuming value for Na(l) = 0*

*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; this would         score 2 marks (M1 and M2)*

*•        If no AE, check for a correct method; this requires* ***either****a correct cycle with 2Cl2 and 4Na OR a* ***clear complete         statement*** *of M1 which could be in words and scores         only M1*

**3**

(iii)    Reducing agent

*Ignore “reduces titanium”*

OR reductant OR reduces TiCl4

OR electron donor

**1**

**[7]**

**M22.**          (a)     **M1** The activation energy is the minimum / least / lowest energy

*Mark independently*

*Ignore “heat” and ignore “enthalpy”*

**M2** (energy) for a reaction to occur / to go / to start

OR (energy) for a successful / effective collision

*Ignore “breaking the bonds”*

**2**

(b)     **M1** Catalysts provide an alternative route OR an
alternative mechanism OR alternative / different path(way)

**M2** Lowers the activation energy

*Mark independently*

*Ignore reference to “surface”*

**2**

(c)     (i)      Stay(s) the same

**1**

(ii)     Increases

*Credit “increase” or “increased”*

**1**

(iii)     Increases

*Credit “increase” or “increased”*

**1**

(iv)    Stay(s) the same

**1**

(d)     (i)      **M1** yeast or zymase

**M2** ethanol

*Ignore “enzyme”*

*In M2, ignore “alcohol” and ignore any formula*

**2**

(ii)     **M1** (Concentrated) H3PO4 OR (Concentrated) H2SO4

**M2** butan-2-ol

*Credit correct names*

*Ignore “hydrogenphosphate or hydrogensulfate”*

*Ignore “dilute” or “aq”*

*Do not penalise absence of hyphens in name.*

*In M2, ignore any formula*

**2**

**[12]**

**M23.**(a)      (i)     reduction **OR** reduced **OR** redox ***OR*** reduction–oxidation

*Not “oxidation” alone*

**1**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| (ii) | Fe3+ | + | **3**e– |  | Fe |

*Ignore state symbols*

*Do not penalise absence of charge on electron*

*Credit Fe3+      Fe   –****3****e–*

*Credit multiples*

**1**

(b)     (i)      **Because (one of the following)**

CO is not the only product ***OR***

*Reference to “incomplete combustion to form CO” does not answer the question*

(Some) complete combustion (also)occurs ***OR***

CO2 is (also) formed

Further oxidation occurs

**1**

(ii)     The enthalpy change / heat (energy) change at constant pressure in a reaction
is independent of the route / path taken (and depends only on the initial and
final states)

**1**

(iii)    **M1**   The enthalpy change / heat change at constant pressure when 1 molof a compound / substance / element

*For M1, credit correct reference to molecule/s or atom/s*

**M2**   is burned completely / undergoes complete combustion in (excess)
oxygen

**M3**   with all reactants and products / all substances in standard states

*For M3*

*Ignore reference to 1 atmosphere*

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

**3**

(c)     **M1 (could be scored by a correct mathematical expression which must
have all** ∆H **symbols and the ∑)**

*Correct answer gains full marks*

*Credit 1 mark ONLY for –1 (kJ mol–1)*

**M1**   *∆H*r = ∑*∆H*f (**products**) – ∑*∆H*f (**reactants**)

*Credit 1 mark ONLY for – 27 (kJ mol–1) i.e. assuming value for Fe(l) = 0*

       ***OR*** correct cycle of balanced equations with 2Fe, 3C and 3O2

**M2**   *∆Hr*   = 2(+14) + 3(– 394) – (– 822) – 3(–111)

                 = 28 –1182 + 822 + 333

                 (This also scores M1)

**M3**        = **(+) 1** (kJ mol–1)

**(Award 1 mark ONLY for – 1)**

**(Award 1 mark ONLY for – 27)**

*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; this would score 2 marks (M1 and M2)*

*•        If no AE, check for a correct method; this requires either a correct cycle with 2Fe, 3C and 3O2 OR a clear statement of M1 which could be in words and scores only M1*

**3**

(d)     (i)      C(s)     +     O2(g)     CO2(g)

*State symbols essential*

*Possible to include C(s, graphite)*

**1**

(ii)     These two enthalpy changes are for the same reaction / same equation /
same reactants and products

*Penalise reference to CO2 being produced by a different route*

***OR***

They both make one mole of carbon dioxide only from carbon and oxygen
(or this idea clearly implied)

*“both form CO2” is not sufficient (since other products might occur e.g.CO)*

***OR***

The same number and same type of bonds are broken and formed

**1**

**[12]**

**M24.**         (a)      (i)     **M1   (could be scored by a correct mathematical expression which must have
        all** ∆*H***symbols and the** ∑ or SUM)

**M1**      Δ*Hr* = ΣΔ*Hf* **(products)** - ΣΔ*Hf* **(reactants)**

***OR***     a correct cycle of balanced equations with 1C, 3H2 and 1O2

**M2**     Δ*Hr* = – 201 + (– 242) – (– 394)
Δ*Hr* = – 201 – 242 + 394
Δ*Hr* = – 443 + 394
(This also scores M1)

**M3**    = – **49** (kJ mol–1)
**(Award 1 mark ONLY for + 49)**

*Correct answer gains full marks*

*Credit 1 mark ONLY for + 49 (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;
         this would score 2 marks (****M1*** *and* ***M2****)*

*•        If no AE, check for a correct method; this requires either
         correct cycle of balanced equations with 1C, 3H2 and 1O2*

*OR a clear statement of* ***M1*** *which could be in words and
         scores only* ***M1***

**3**

(ii)     It is an element / elemental

*Ignore reference to “standard state”*

**OR**

By definition

**1**

(b)     **M1** (The yield) increases / goes up / gets more

*If M1 is given as “decreases” / “no effect” / “no change” then CE= 0 for clip, but mark on only* ***M2*** *and* ***M3*** *from a blank M1*

**M2**   There are more moles / molecules (of gas) on the left / of reactants
***OR***  fewer moles / molecules (of gas) on the right
/ products
***OR***  there are 4 moles /molecules (of gas) on the left and 2 moles / molecules on the right.
***OR***  (equilibrium) shifts / moves to the side with less moles / molecules

*Ignore “volumes”, “particles” “atoms” and “species” for* ***M2***

**M3: Can only score M3 if M2 is correct**

The (position of) equilibrium shifts / moves (from left to right) to oppose the increase
in pressure

*For* ***M3****, not simply “to oppose the change”*

*For* ***M3*** *credit the equilibrium shifts / moves (to right) to lower / decrease the pressure*

*(There must be a specific reference to the change that is opposed)*

**3**

(c)     **M1**  Yield increases goes up

**M2**   The (forward) reaction / to the right is endothermic OR takes in/ absorbs
heat

***OR***

The reverse reaction / to the left is exothermic OR gives out / releases heat

*If M1 is given as “decrease” / “no effect” / “no change” then CE= 0 for clip, but mark on only* ***M2*** *and* ***M3*** *from a blank* ***M1***

**Can only score M3 if M2 is correct**

**M3** The (position of) equilibrium shifts / moves (from left to right) to oppose the increase
in temperature **(QoL)**

*For* ***M3****, not simply “to oppose the change”*

*For* ***M3****, credit the (position of) equilibrium shifts / moves* ***(QoL)***

*to absorb the heat* ***OR***

*to cool the reaction* ***OR***

*to lower the temperature*

*(There must be a specific reference to the change that is opposed)*

**3**

(d)     (i)     An activity which has no net / overall (annual) carbon emissions to the
atmosphere
***OR***An activity which has no net / overall (annual) greenhouse gas emissions
to the atmosphere.
***OR***There is no change in the total amount / level of carbon dioxide /CO2 carbon /greenhouse gas present in the atmosphere.

*The idea that the carbon /CO2 given out equals the carbon /CO2 that was taken in from the atmosphere*

**1**

(ii)     CH3OH    +    **1**½    O2        CO2     +     **2**H2O

*Ignore state symbols*

*Accept multiples*

**1**

(iii)     **3**H2    +     **1**½    O2          **3**H2O

*Ignore state symbols*

***OR***

*Accept multiples*

**2**H2     +     O2         **2**H2O

*Extra species must be crossed through*

**1**

(e)     **M1**    q = m c ∆T

*Award full marks for correct answer*

*Ignore the case for each letter*

***OR***    q = 140 × 4.18 × 7.5

**M2**    = 4389 (J) OR 4.389 (kJ) OR 4.39 (kJ) OR 4.4 (kJ)(also scores M1)

**M3**    Using 0.0110 mol
therefore ∆H = **– 399** (kJmol–1 )
OR **– 400**

*Penalise* ***M3*** *ONLY if correct numerical answer but sign is incorrect; +399* ***gains 2 marks***

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

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

*If ∆T = 280.5; score q = m c ∆T only*

*If c = 4.81 (leads to 5050.5) penalise* ***M2*** *ONLY and mark on for* ***M3*** *= – 459*

**+399** **or +400 gains 2 marks**

*Ignore incorrect units*

**3**

**[16]**

**M25.**(a)    3N2H4  4NH3 + N2

*Or multiples*

*Ignore state symbols*

**1**

(b)     M1 enthalpy / heat (energy) change / required / needed to break / dissociate a covalent bond (or a specified covalent bond)

*Ignore bond making*

*Ignore standard conditions*

***M2*** *requires an attempt at* ***M1***

M2 average / mean over different molecules / compounds / substances

**2**

(c)     M1
⅀ (bonds broken) − ⅀ (bonds formed) = *ΔH*

***M1*** *could stand alone*

***OR***

Sum of bonds broken − Sum of bonds formed = *ΔH*

*Award full marks for correct answer*

M2 (also scores **M1**)

*Ignore units*

4(+388) + 163 + 2(146) + 4(463) − 944 − 8(463) = *Δ*H
OR broken +3859 (2007) formed − 4648 (2796)

M3

*Δ*H =  **− 789** (kJ mol−1)

*Two marks can score with an arithmetic error in the working*

Award 1 mark for + 789

*Credit* ***one mark only*** *for calculating either the sum of the bonds broken or the sum of the bonds formed provided this is the only mark that is to be awarded*

Students may use a cycle and gain full marks

**3**

**[6]**

**M26.**(a)    The enthalpy change / heat (energy) change (at constant pressure) in a reaction is independent of the route / path taken (and depends only on the initial and final states)

*Ignore the use of ΔH for enthalpy*

**1**

(b)     *ΔHexp + ΔH2 – ΔH1 = 0*

*Any correct mathematical statement that uses all three terms*

***OR***

*ΔHexp + ΔH2 = ΔH1* ***OR*** *ΔH1 = ΔHexp + ΔH2*

***OR***

*ΔHexp= ΔH1 – ΔH2* ***OR*** *ΔHexp = ΔH1 +( – ΔH2 )*

**1**

(c)     *ΔHexp = ΔH1 – ΔH2*

*ΔHexp = −156 −12 =* ***−168*** *(kJ mol−1)*

*Ignore units*

Award the mark for the correct answer without any working

**1**

(d)    (i)      M1 q = m c ΔT OR calculation (25.0 x 4.18 x 14.0)

*Award full marks for correct answer*

M2 = **1463**J OR **1.46** kJ (This also scores **M1**)

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

M3 must have both the correct value within the range specified **and** the minus sign

*Penalise* ***M3*** *ONLY if correct numerical value but sign is incorrect; e.g.* ***+69.5 to +69.7 gains 2 marks***  *(ignore +70 after correct answer)*

For 0.0210 mol, therefore

Δ*H*1 = **− 69.67** to **− 69.52** (kJ mol-1)

**OR** Δ*H*1 = **− 69.7** to **− 69.5** (kJ mol−1)

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

Accept answers to 3sf or 4sf in the range − 69.7 to − 69.5

*ΔT = 287, score q = m c ΔT only*

Ignore -70 after correct answer

*If c = 4.81 (leads to 1684J ) penalise* ***M2*** *ONLY and mark on for* ***M3*** *= − 80.17 (range − 80.0 to − 80.2)*

*Ignore incorrect units*

**3**

(ii)     The idea of heat loss

*NOT impurity*

***OR***

Incomplete reaction (of the copper sulfate)

*NOT incompetence*

***OR***

Not all the copper sulfate has dissolved

*NOT incomplete combustion*

**1**

(e)     Impossible to add / react the exact / precise amount of water

*Not just “the reaction is incomplete”*

***OR***

Very difficult to measure the temperature rise of a solid

***OR***

Difficult to prevent solid dissolving

***OR***

(Copper sulfate) solution will form

**1**

**[8]**

**M27.**(a)     (i)      **M1 (could be scored by a correct mathematical expression which must have all Δ*H* symbols and the ⅀ or SUM)**

*Correct answer gains full marks*

*Credit 1 mark ONLY if* ***–122*** *(kJ mol−1)*

M1        Δ*H* = ⅀Δ*H*f (**products**) - ⅀Δ*H*f (**reactants**)

***OR*** a correct cycle of balanced equations

M2        Δ*H* = 3(−394) − 3(−111) − (−971)
         (This also scores M1)

M3        = **(+) 122**(kJ mol−1)

**Award 1 mark ONLY for –122**

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; this would score 2 marks (****M1*** *and* ***M2****)*

*•        If no AE, check for correct method; this requires either a correct cycle of balanced equations OR a clear statement of* ***M1*** *which could be in words and scores* ***M1 only***

**3**

(ii)     By definition

*Ignore reference to “standard state”*

***OR***

Because it is an element / elemental

**1**

(b)    (i)      TiO2 + **2**Cl 2 + **2**C  TiCl4 + **2**CO

*Allow multiples*

***OR***

TiO2 + **2**Cl 2 + C  TiCl4CO2

*Ignore state symbols*

M1 use of Cl2 and C

M2 a correct balanced equation

**2**

(ii)     TiCl4 + **4**Na  Ti + **4**NaCl

*Allow multiples*

***OR***

TiCl4 + **2**Mg  Ti + **2**MgCl2

*Ignore state symbols*

M1 use of Na ***OR*** Mg

M2 a correct balanced equation

**2**

(c)    (i)      **4** FeCr2O4  +  **8** Na2CO3 + **7**O2  **8**Na2CrO4 + 2Fe2O3 + 8CO2

*Allow multiples*

*Ignore state symbols*

**1**

(ii)     Cr2O3 + **2**Al   Al2O3 + **2**Cr

*Allow multiples*

*Ignore state symbols*

**1**

**[10]**

**M28.**(a)    **M1 (could be scored by a correct mathematical expression**

*Correct answer to the calculation gains all of* ***M1****,* ***M2*** *and* ***M3***

M1 *ΔH* = Σ*ΔHf* (**products**) − Σ*ΔH f* (**reactants**)

*Credit 1 mark for − 101 (kJ mol−1)*

***OR*** a correct cycle of balanced equations

M2 = − 1669 − 3(− 590)
= − 1669 + 1770
(This also scores M1)

M3 = **+ 101** (kJ mol−1)

**Award 1 mark ONLY for − 101**

*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; this would score 2 marks (****M1*** *and* ***M2****)*

*•        If no AE, check for a correct method; this requires either a correct cycle with 3Sr and 2Al OR a clear statement of* ***M1*** *which could be in words and scores* ***only M1***

**M4 - Using powders**Any **one** from

•        To increase collision frequency / collisions in a given time / rate of collisions

•        To increase the surface contact / contact between the solids / contact between (exposed) particles

*Ignore dividing final answer by 3*

*Penalise* ***M4*** *for reference to molecules.*

**5**

**M5 Major reason for expense of extraction**Any **one** from

•        Aluminium is extracted by electrolysis ***OR*** aluminium extraction uses
         (large amounts of) electricity

•        Reaction / process / It / the mixture requires heat

•        It is endothermic

(b)     Calcium has a higher melting point than strontium, because

*Ignore general Group 2 statements.*

**Correct reference to size of cations / proximity of electrons**M1 (For Ca) delocalised electrons closer to cations / positive ions / atoms / nucleus
***OR*** cations / positive ions / atoms are smaller
***OR*** cation / positive ion / atom or it has fewer (electron) shells / levels

*Penalise* ***M1*** *if either of Ca or Sr is said to have more or less delocalised electrons OR the same nuclear charge.*

*Ignore reference to shielding.*

**Relative strength of metallic bonding**M2 (Ca) has stronger attraction between the cations / positive ions / atoms / nucleus and the delocalised electrons
***OR***stronger metallic bonding

(assume argument refers to Ca but credit converse argument for Sr)

***CE= 0*** *for reference to molecules or Van der Waals forces or intermolecular forces or covalent bonds.*

**2**

(c)     **M1** **2**Mg + O2   **2**MgO

**M2** Mg + **2**H2O   Mg(OH)2 + H2

*Credit multiples of the equations.*

**M3** Magnesium hydroxide is used as an antacid / relieve indigestion (heartburn) / neutralise (stomach) acidity / laxative

*Not simply “milk of magnesia” in* ***M3***

**3**

**[10]**

**M29.**(a)     (i)      M1 c(oncentrated) phosphoric acid / c(onc.) H3PO4***OR*** c(oncentrated) sulfuric acid / c(onc.) H2SO4

*In* ***M1****, the acid must be concentrated.
Ignore an incorrect attempt at the correct formula that is written in addition to the correct name.*

M2 Re-circulate / re-cycle the (unreacted) ethene (and steam) / the reactants
***OR*** pass the gases over the catalyst several / many times

*In* ***M2****, ignore “remove the ethanol”.
Credit “re-use”.*

**2**

(ii)     M1
(By Le Chatelier’s principle) the equilibrium is driven / shifts / moves to the right / L to R / forwards / in the forward direction

**M2 depends on a correct statement of M1**The equilibrium moves / shifts to

•        oppose the addition of / increased concentration of / increased moles / increased amount of water / steam

•        to decrease the amount of steam / water

**Mark M3 independently**M3 Yield of product / conversion increase ***OR*** ethanol increases / goes up / gets more

**3**

(iii)    M1 Poly(ethene) / polyethene / polythene / HDPE / LDPE

**M2 At higher pressures**More / higher cost of electrical energy to pump / pumping cost
***OR***Cost of higher pressure equipment / valves / gaskets / piping etc.
***OR*** expensive equipment

*Credit all converse arguments for* ***M2***

**2**

(b)     M1 for balanced equation

M2 for state symbols in a correctly balanced equation

2C(s / graphite) + 3H2(g) + ½O2(g)   CH3CH2OH(l)
(C2H5OH)

*Not multiples but credit correct state symbols in a correctly balanced equation.*

*Penalise C2H6O but credit correct state symbols in a correctly balanced equation.*

**2**

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

*If standard enthalpy of formation* ***CE=0***

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**

(ii)     M1

*Correct answer gains full marks*

ΣB(**reactants**) − ΣB(**products**) = *ΔH*

*Credit 1 mark for (+) 1279 (kJ mol−1)*

OR
Sum of bonds broken − Sum of bonds formed = ΔH
OR
B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O) (LHS)
− 4B(C=O) − 6B(O−H) (RHS) = *ΔH*

M2 (also scores **M1**)
348+360+463+5(412)+3(496) [LHS = **4719**]
                         (2060)   (1488)
− 4(805) − 6(463) [RHS = − **5998**] = *ΔH*(3220)     (2778)
OR using only bonds broken and formed (**4256 − 5535**)

*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; this would score 2 marks (****M1*** *and* ***M2****)*

*•        If no AE, check for a correct method; this requires either a correct cycle with 2C and 6H and 7O OR a clear statement of* ***M1*** *which could be in words and scores* ***only M1***

M3
ΔH= **− 1279** (kJ mol−1)

*Allow a maximum of one mark if the only scoring point is LHS = 4719* ***OR*** *RHS = 5998*

Award 1 mark for +1279

**Candidates may use a cycle and gain full marks**

**3**

(d)    (i)      Reducing agent ***OR*** reductant ***OR*** electron donor
***OR*** to reduce the copper oxide

*Not “reduction”.*

*Not “oxidation”.*

*Not “electron pair donor”.*

**1**

(ii)     CH3COOH

**1**

**[17]**