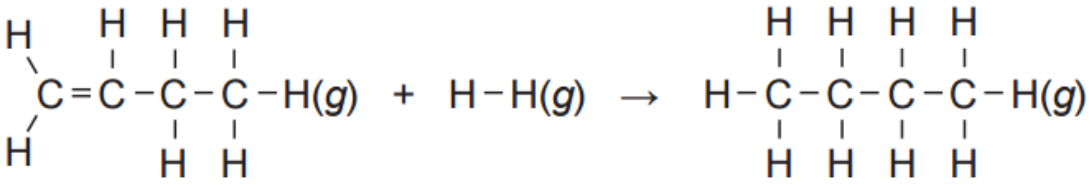
QUESTIONS

QUESTION 1 (2016:3)

(iii) Pentane combustion: $C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(l)$ $\Delta_r H^o = -3509$ kJ mol^{-1}
Hexane, C_6H_{14}, like pentane, will combust (burn) in sufficient oxygen to produce carbon dioxide gas and water. Hexane combustion: $2C_6H_{14}(l) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(l)$ $\Delta_r H^o = -8316$ kJ mol^{-1},
Justify which alkane – pentane or hexane – will produce more heat energy when 125 g of each fuel is combusted in sufficient oxygen. $M(C_5H_{12}) = 72.0$ g mol^{-1} $M(C_6H_{14}) = 86.0$ g mol^{-1}

QUESTION 3 (2016:3)

(c) Calculate the enthalpy change, $\Delta r\ H°$, for the reaction of but-1-ene gas, $C_4H_8(g)$, with hydrogen gas, $H_2(g)$, to form butane gas, $C_4H_{10}(g)$. Use the average bond enthalpies given in the table below.

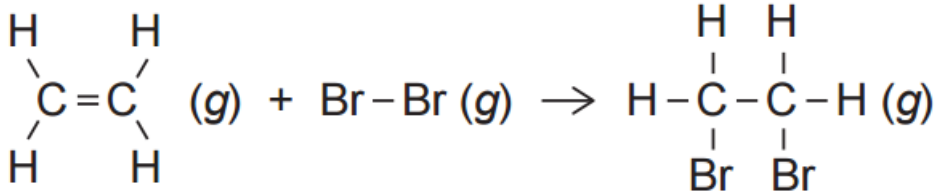


Bond	Average bond enthalpy / kJ mol^{-1}
C=C	614
C–C	346
C–H	414
H–H	436

Show your working and include appropriate units in your answer.

QUESTION (2015:1)

(d) Ethene gas, $C_2H_4(g)$, reacts with bromine gas, $Br_2(g)$, as shown in the equation below.



Calculate the enthalpy change, $\Delta_r H°$, for the reaction between ethene and bromine gases, given the average bond enthalpies in the table below. Show your working and include appropriate units in your answer.

Bond	Average bond enthalpy/kJ mol^{-1}
Br–Br	193
C–C	346
C=C	614
C–Br	285
C–H	414

QUESTION (2015:2)

(a) Hand warmers contain a supersaturated solution of sodium ethanoate which, when activated, crystallises and releases heat. Circle the term that best describes this reaction.

exothermic endothermic

Give a reason for your choice.

(b) (i) Glucose is made in plants during photosynthesis when carbon dioxide gas, $CO_2(g)$, and water, $H_2O(l)$, react to produce glucose, $C_6H_{12}O_6(aq)$, and oxygen gas, $O_2(g)$. The photosynthesis reaction can be represented by the following equation: $6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$ $\Delta_rH° = 2803$ kJ mol^{-1}

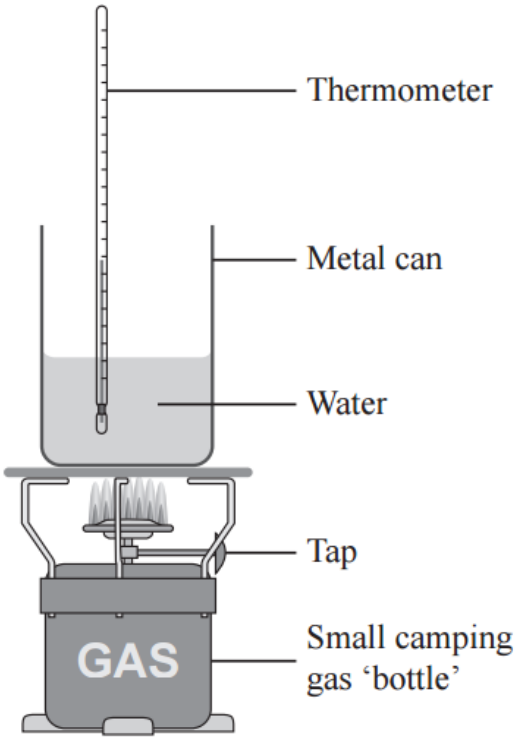
Circle the term that best describes this reaction.

exothermic endothermic

Give a reason for your choice.

(ii) Calculate how much energy is absorbed or released in the photosynthesis reaction if 19.8 g of carbon dioxide gas, $CO_2(g)$, reacts completely with excess water, $H_2O(l)$, to form glucose, $C_6H_{12}O_6(aq)$, and oxygen gas, $O_2(g)$. Show your working and include appropriate units in your answer. $M(CO_2) = 44.0$ g mol^{-1}.

(c) A small camp stove containing butane gas, $C_4H_{10}(g)$, is used to heat some water, as shown in the diagram below. A student measures the temperature change in the water and calculates that when 3.65 g of butane is combusted, 106 kJ of heat is released.



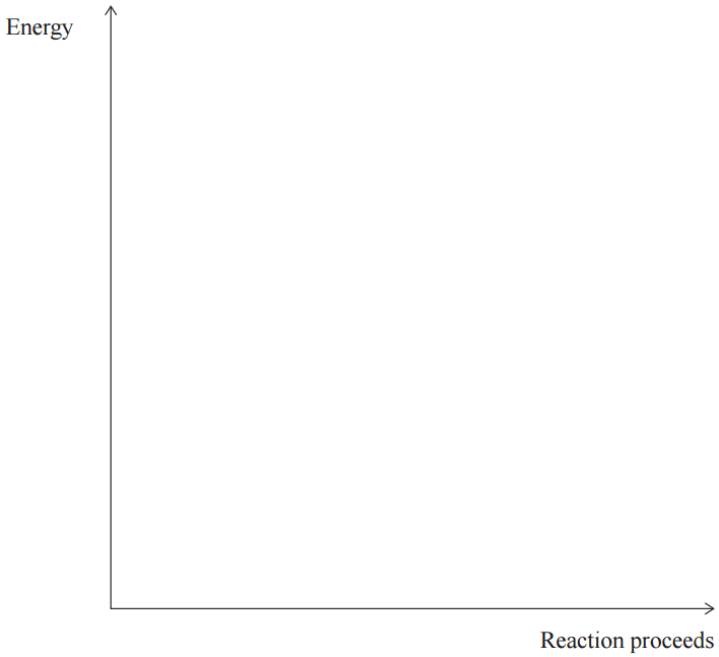
The reaction for the combustion of butane is shown in the equation below.

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l)$$

(i) Calculate the enthalpy change (Δ_rH) for this reaction, based on the above measurements. $M(C_4H_{10}) = 58.0$ g mol^{-1}.

(ii) The accepted enthalpy change for the combustion reaction of butane gas, $C_4H_{10}(g)$, is $\Delta_rH = -5754$ kJ mol^{-1}. Explain why the result you calculated in part (c)(i) is different to the accepted value. In your answer, you should include at least TWO reasons.

(iii) Complete, including labels, the energy diagram for the combustion of butane gas showing reactants, products, and the change in enthalpy.



(iv) Butane gas is a useful fuel because when it undergoes combustion, energy is released. Explain why energy is released in this reaction, in terms of making and breaking bonds. No calculations are required

QUESTION (2014:1)

(d) Hydrogen gas, $H_2(g)$, reacts with oxygen gas, $O_2(g)$, as shown by the following equation

$$H_2(g) + ½\ O_2(g) \rightarrow H_2O(g) \quad \Delta_r H^o = -242\ kJ\ mol^{-1}$$

Given the average bond enthalpies in the table below, calculate the average bond enthalpy of the **O – H** bond in H_2O.

Bond	Average bond enthalpy / kJ mol^{-1}
H – H	436
O = O	498

QUESTION (2014:3)

(a) (i) When solid sodium hydroxide is added to water, the temperature increases.

Circle the term that best describes this reaction.

Exothermic Endothermic

Give a reason for your choice.

(ii) The freezing of water to form ice can be represented by the following equation.

$$H_2O(l) \rightarrow H_2O(s)$$

Circle the term that best describes this reaction.

Exothermic Endothermic

Explain your choice.

(c) Methanol and ethanol can both be used as fuels. Their combustion reactions can be represented by the following equations:

Methanol combustion: $2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$ $\Delta_r H^o = -1450\ kJ\ mol^{-1}$

Ethanol combustion: $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ $\Delta_r H^o = -1370\ kJ\ mol^{-1}$

Justify which fuel, methanol or ethanol, will produce more heat energy when 345 g of each fuel is combusted in excess oxygen.

$$M(CH_3OH) = 32.0\ g\ mol^{-1}$$

$$M(C_2H_5OH) = 46.0\ g\ mol^{-1}$$

QUESTION (2013:2)

(c) Chlorine reacts with methane to form chloromethane and hydrogen chloride, as shown in the equation below.

$$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$$

Use the following bond enthalpies to calculate $\Delta_r H°$ for this reaction.

Bond	**Bond enthalpy / kJ mol^{-1}**
H – Cl	431
C – H	414

C – Cl	324
Cl – Cl	242

QUESTION (2013:3)

(a) Dissolving ammonium nitrate in a beaker containing water can be represented by the following equation:

$$NH_4NO_3(s) \rightarrow NH_4^+(aq) + NO_3^-(aq) \quad \Delta_rH° = 25.1 \text{ kJ mol}^{-1}$$

Circle the term below that best describes this process.

exothermic endothermic

Circle the description below that best describes what you would observe happening to the beaker during this process.

gets colder stays the same gets warmer

Explain your choices.

(b) Glucose is an important source of energy in our diet. The equation below shows the combustion of glucose to form carbon dioxide and water.

$$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) \quad \Delta_rH° = -2820 \text{ kJ mol}^{-1}$$

(i) Circle the term below that best describes this process.

exothermic endothermic

Give a reason for your choice.

(ii) Females who are moderately active need 9 800 kJ of energy per day.

Calculate the number of moles of glucose that would provide this daily energy requirement.

(c) (i) Many portable BBQ and camping gas canisters contain butane, C_4H_{10}. Butane is a gas at room temperature, and has a boiling point of – 0.5°C. The gas canisters contain both gas and liquid butane. As the gaseous butane is used, some of the liquid evaporates.

Circle the term below that best describes this process.

exothermic endothermic

Give a reason for your choice, and use your knowledge of structure and bonding, and energy changes, to explain the changes occurring as the liquid evaporates.

(ii) The equation below shows the combustion of butane.

$$C_4H_{10}(g) + 13/2\ O_2(g) \rightarrow 4CO_2(g) + 5H_2O(g)$$

When 100 g of butane undergoes combustion, 4960 kJ of energy is released.

Calculate the enthalpy change when 1 mole of butane undergoes combustion.

$$M(C_4H_{10}) = 58.1 \text{ g mol}^{-1}.$$

(d) The iron oxides Fe_3O_4 and Fe_2O_3 react with aluminium as shown below.

$$3Fe_3O_4(s) + 8Al(s) \rightarrow 4Al_2O_3(s) + 9Fe(s) \quad \Delta rH° = -3348 \text{ kJ mol}^{-1}$$

$$Fe_2O_3(s) + 2Al(s) \rightarrow Al_2O_3(s) + 2Fe(s) \quad \Delta rH° = -851 \text{ kJ mol}^{-1}$$

Justify which iron oxide, Fe_3O_4 or Fe_2O_3, will produce more heat energy when 2.00 kg of iron is formed during the reaction with aluminium.

Your answer should include calculations of the heat energy produced for the given mass of iron formed. M(Fe) = 55.9 g mol^{-1}.

QUESTION (2012:3)

(a) Some Bunsen burners use methane gas, CH_4, as a fuel. The reaction for the combustion of methane in a Bunsen burner is shown in Equation One below.

Equation One: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ $\Delta_rH = -889$ kJ mol^{-1}.

When this reaction occurs, bonds are broken and bonds are formed.

State which bonds are broken and which bonds are formed during the reaction.

Bonds broken:

Bonds formed:

(b) Calculate the energy released when 128 g of methane is burnt.
M (CH_4) = 16.0 g mol^{-1}.

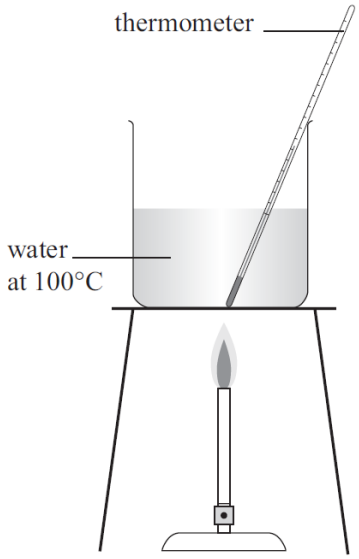
(c) The equation for water boiling at 100°C is shown below in Equation Two.

Equation Two: $H_2O(l) \rightarrow H_2O(g)$ $\Delta_rH = 40.7$ kJ mol^{-1}

Explain why this equation is endothermic.

You should relate the energy changes that are occurring to the specific bonds being broken or formed.

(d) A student heats 72.0 g of water to 100°C using a Bunsen burner.



The student then boils the water.

Calculate the mass of methane gas, CH_4, that would need to be combusted in a Bunsen burner to boil the 72.0 g of water.

M (H_2O) = 18.0 g mol^{-1}.

In your answer you will need to:

- use **Equation Two** to determine the amount of energy required to boil the water

- use **Equation One** to determine the mass of methane needed to produce the required amount of energy
- assume that no energy is lost to the surrounding environment.

QUESTION (2011:4)

(a) For each of the following, circle the correct word to indicate whether it is an exothermic or endothermic change.

Give a reason for your choice.

(i) $NH_4NO_3(s) \rightarrow NH_4^+(aq) + NO_3^-(aq)$ $\Delta_r H = +25.7$ kJ mol^{-1}

exothermic **endothermic**

Reason:

(ii) Water vapour condensing, forming rain.

exothermic **endothermic**

Reason:

(b) The overall reaction occurring in many disposable hand warmers can be represented by:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s) \quad \Delta_r H = -1652 \text{ kJ mol}^{-1}$$

(i) Calculate the energy released when 1.00 mol Fe_2O_3 is produced.

(ii) Calculate the mass of Fe that would be required to release 185 kJ of energy.

M(Fe) = 55.9 g mol$^{-1.}$

(iii) Many types of hand warmers are reusable. When these hand warmers are activated, heat is generated during the rapid crystallisation from liquid to solid. They can be "recharged" by putting them in a pot of boiling water for ten minutes.

Explain, in terms of thermochemical principles, how hand warmers can be recharged by heating.

(c) Hydrogen and methane can be used as fuels.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) \quad \Delta_r H = -570 \text{ kJ mol}^{-1}$$

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l) \quad \Delta_r H = -890 \text{ kJ mol}^{-1}$$

Determine which of the fuels, hydrogen or methane, provides the most energy per gram of fuel burned. Justify your answer with calculations.

$M(H_2) = 2.00$ g mol^{-1} $M(CH_4) = 16.0$ g mol^{-1}

QUESTION (2010:3) (parts (a) and (c))

(a) Classify the following reactions, by writing in the box below the word '**Exothermic**' or '**Endothermic**'.

	Exothermic or Endothermic
$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$ $\Delta_r H = -48.0$ kJ mol^{-1}	
$H_2O(g) \rightarrow H_2O(l)$	
$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$ 206 kJ of energy is absorbed.	
When zinc powder reacts with copper sulfate solution, the temperature rises.	

(c) When a 12.2 g sample of ammonia is burned, 275 kJ of energy is released.
Calculate the energy released for the reaction below, when four moles of ammonia are burned.

$4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(l)$

$M(NH_3) = 17.0\ g\ mol^{-1}$

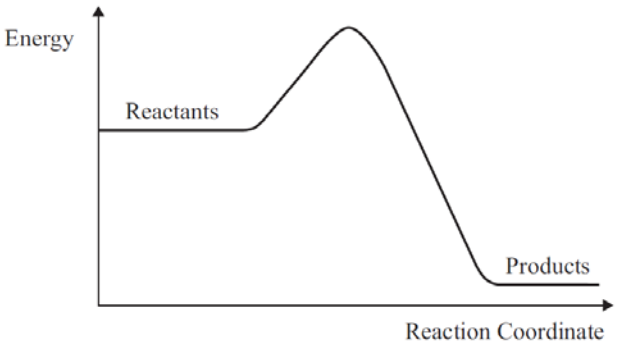
QUESTION (2009:2)

(a) For the reaction $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$,
the enthalpy of reaction is $\Delta_r H = -950\ kJ\ mol^{-1}$.

The reverse reaction is $4NO(g) + 6H_2O(g) \rightleftharpoons 4NH_3(g) + 5O_2(g)$

Two energy diagrams are shown below. One is for the forward reaction and one is for the same reaction in the reverse direction.

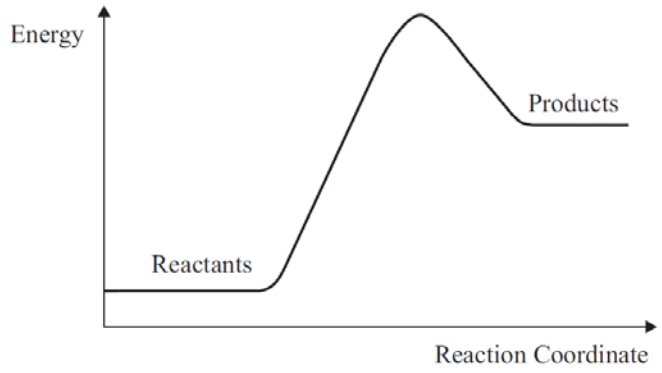
Diagram One



Exothermic or **Endothermic**
(*circle one*)

Forward or **Reverse**
(*circle one*)

Diagram Two



Exothermic or **Endothermic**
(*circle one*)

Forward or **Reverse**
(*circle one*)

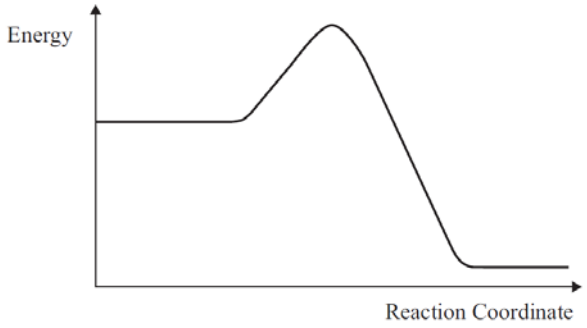
(i) For each diagram, **circle** the correct answer to indicate whether the diagram is for an **exothermic** reaction or an **endothermic** reaction.

(ii) For each diagram, **circle** the correct answer to indicate whether the diagram is for the **forward** reaction or for the **reverse** reaction.

(iii) On the diagrams for **both** reactions, also label the following:
- enthalpy of reaction, $\Delta_r H$
- Activation Energy, E_a.

(iv) Determine the value for the enthalpy of reaction ($\Delta_r H$) for the reaction shown in **Diagram Two**.
Explain how you determined this value.

(b) The energy diagram below represents a reaction carried out at 20°C.



(i) On the same axes, redraw the energy diagram to show the same reaction carried out at a higher temperature.

(ii) Explain any changes to

- enthalpy of reaction, $\Delta_r H$
- Activation Energy, E_a
- energy of the reactants
- energy of the products.

(c) The equation for the reaction between calcium oxide, CaO, and water can be represented as

$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(aq)$ $\Delta H = -82.0$ kJ mol^{-1}

M(CaO) = 56.0 g mol^{-1}

Calculate the mass of calcium oxide required to release 287 kJ of energy.

QUESTION (2008: 5)

When an 18.4 g sample of ethanol is burned, 546 kJ of energy is released.

Determine the enthalpy change, ΔrH, for the reaction when one mole of ethanol is burned.

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

M(C_2H5OH) = 46.0 g mol^{-1}

QUESTION (2007:4)

(a) Classify the following reactions as exothermic or endothermic by writing in the box the word that best represents each equation.

		Exothermic or Endothermic
(i)	$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O$ A temperature increase occurs.	
(ii)	$N_2(g) \rightarrow 2N(g)$ $\Delta_r H = +934$ kJ mol^{-1}	
(iii)	$H_2(g) + I_2(g) \rightarrow 2HI(g)$ A temperature decrease occurs.	
(iv)	$2H_2(g) + CO(g) \rightarrow CH_3OH(g)$ $\Delta_r H = -128$ kJ mol^{-1}	

(b) Dissolving of ammonium nitrate in water is an endothermic process.

$NH_4NO_3(s) \rightarrow NH_4^+(aq) + NO_3^-(aq)$

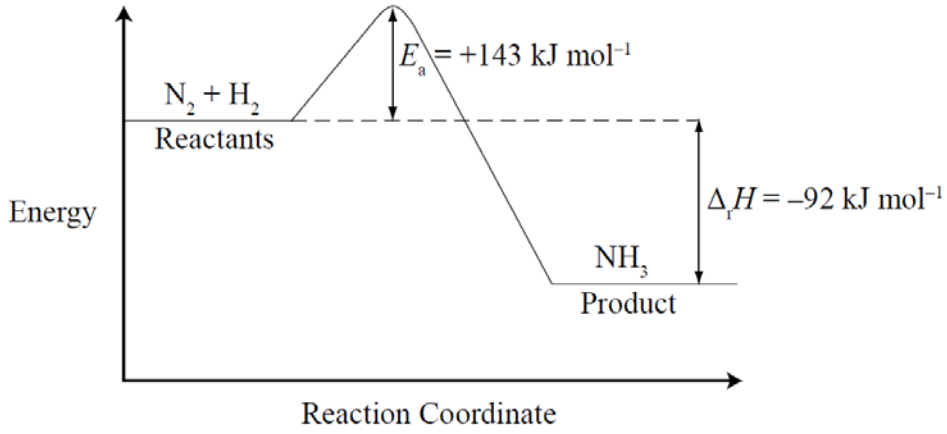
(i) When 1.80 g of ammonium nitrate was dissolved in 50.0 g of water, the temperature decreased by 2.70°C. The heat capacity of water is 4.18 J g^{-1} $°C^{-1}$. $M(NH_4NO_3)$ = 80.0 g mol^{-1}

Calculate the enthalpy change when one mole of ammonium nitrate dissolves completely in water.

(ii) Calculate the mass of ammonium nitrate that would be required to absorb 1.25 kJ of energy.

QUESTION (2007:6) (parts (b) & (c))

For the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$,
the enthalpy of reaction Δ_rH = –92 kJ mol^{-1}, and the activation energy E_a = +143 kJ mol^{-1}.
An energy diagram for this chemical reaction is shown below.

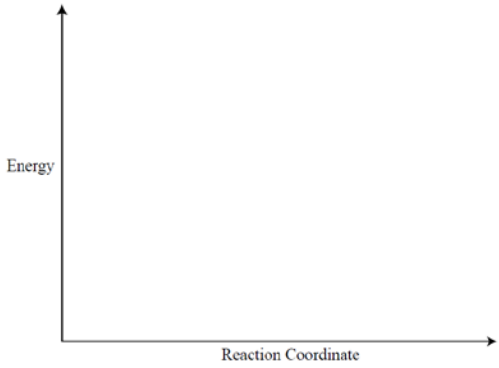


The reverse reaction is $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)$

(b) State the values for Δ_rH and E_a for this reverse reaction.

Δ_rH = _____kJ mol^{-1} E_a = _____ kJ mol^{-1}

(c) Draw the energy diagram below for this reverse reaction.
Label the diagram with the four labels from the key list.
KEY LIST: $N_2 + H_2$ NH_3 Δ_rH E_a



ANSWERS

QUESTION 1 (2016:3)

(iii) Pentane combustion: $C_5H_{12}(l) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(l)$ $\Delta_r H^o = -3509$ kJ mol^{-1}
Hexane, C_6H_{14}, like pentane, will combust (burn) in sufficient oxygen to produce carbon dioxide gas and water. Hexane combustion: $2C_6H_{14}(l) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(l)$ $\Delta r H^o = -8316$ kJ mol^{-1},
Justify which alkane – pentane or hexane – will produce more heat energy when 125 g of each fuel is combusted in sufficient oxygen. $M(C_5H_{12}) = 72.0$ g mol^{-1} $M(C_6H_{14}) = 86.0$ g mol^{-1}

n (pentane) = 125 g / 72.0 g mol^{-1} = 1.74 mol
n (hexane) = 125 g / 86.0 g mol^{-1} = 1.45 mol

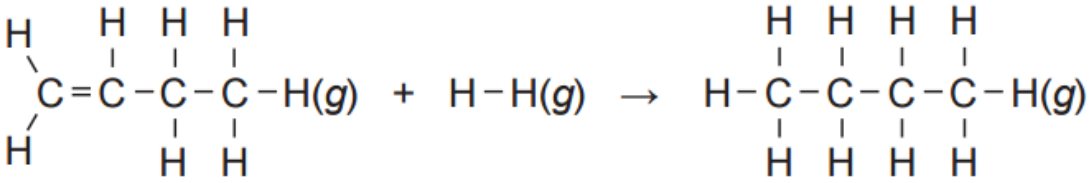
If 1 mole of pentane releases 3509 kJ energy, then 1.74 mol of pentane
1.74 × 3509 = 6106 kJ energy released.

If 2 moles of hexane release 8316 kJ energy,
then 1 mole of hexane releases 4158 kJ energy. So 1.45 mol of hexane
1.45 × 4158 = 6029 kJ energy releases.

So pentane releases more energy (77.0 kJ) than hexane, per 125 g of fuel.

QUESTION 3 (2016:3)

(c) Calculate the enthalpy change, Δr H°, for the reaction of but-1-ene gas, $C_4H_8(g)$, with hydrogen gas, $H_2(g)$, to form butane gas, $C_4H_{10}(g)$. Use the average bond enthalpies given in the table below.



Bond	Average bond enthalpy / kJ mol^{-1}
C=C	614
C–C	346
C–H	414
H–H	436

Show your working and include appropriate units in your answer.

Bond breaking
C=C 614
C–C × 2 692
C–H × 8 3312
H–H 436

Bond making
C–C × 3 1038
C–H × 10 4140
5178 kJ mol^{-1}

5054 kJ mol^{-1}

$\Delta_r H°$ = Bond breaking – bond making

$\Delta_r H°$ = 5054 kJ mol^{-1} – 5178 kJ mol^{-1}

$\Delta_r H°$ = –124 kJ mol^{-1}

OR

Bond breaking		Bond making	
C=C	614	C–C	346
H–H	436	C–H × 2	414 × 2
	1050 kJ mol^{-1}		1174 kJ mol^{-1}

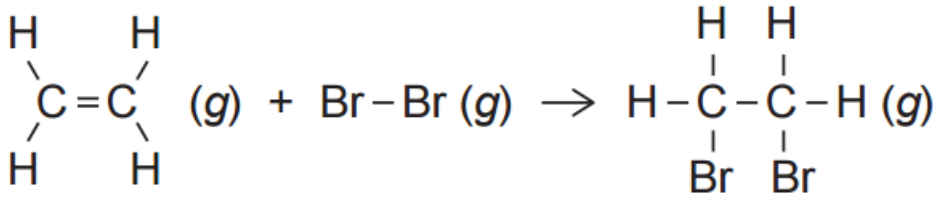
$\Delta_r H°$ = Bond breaking – bond making

$\Delta_r H°$ = 1050 – 1174

$\Delta_r H°$ = –124 kJ mol^{-1}

QUESTION (2015:1)

(d) Ethene gas, $C_2H_4(g)$, reacts with bromine gas, $Br_2(g)$, as shown in the equation below.



Calculate the enthalpy change, $\Delta_rH°$, for the reaction between ethene and bromine gases, given the average bond enthalpies in the table below. Show your working and include appropriate units in your answer.

$C_2H_4(g) + Br_2(g) \rightarrow C_2H_4Br_2(g)$

Bonds broken		Bonds formed	
C=C	614	C–C	346
Br–Br	193	C–Br	2×285
	807		916

Δ_rH^o = ΣBond energies(bonds broken) – ΣBond energies(bonds formed)
= 807 – 916 (or 2463 – 2572)
= –109 kJ mol^{-1}

(*Alternative calculation that includes the breaking and reforming of four C-H bonds will also be accepted to Excellence level.*)

QUESTION (2015:2)

(b) Hand warmers contain a supersaturated solution of sodium ethanoate which, when activated, crystallises and releases heat. Circle the term that best describes this reaction.

exothermic endothermic

Give a reason for your choice.
Exothermic because the temperature of the solution increases / heat is released / particles slow down / bonds are formed

(b) (i) Glucose is made in plants during photosynthesis when carbon dioxide gas, $CO_2(g)$, and water, $H_2O(l)$, react to produce glucose, $C_6H_{12}O_6(aq)$, and oxygen gas, $O_2(g)$. The photosynthesis reaction can be represented by the following equation: $6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$ $\Delta_rH° = 2803$ kJ mol^{-1}
Circle the term that best describes this reaction.

exothermic endothermic

Give a reason for your choice.
Endothermic because the Δ_rH^o value is positive / it uses the sun's energy

(ii) Calculate how much energy is absorbed or released in the photosynthesis reaction if 19.8 g of carbon dioxide gas, $CO_2(g)$, reacts completely with excess water, $H_2O(l)$, to form glucose, $C_6H_{12}O_6(aq)$, and oxygen gas, $O_2(g)$. Show your working and include appropriate units in your answer. $M(CO_2) = 44.0$ g mol^{-1}.

$n(CO_2) = m/M = 19.8/44.0$

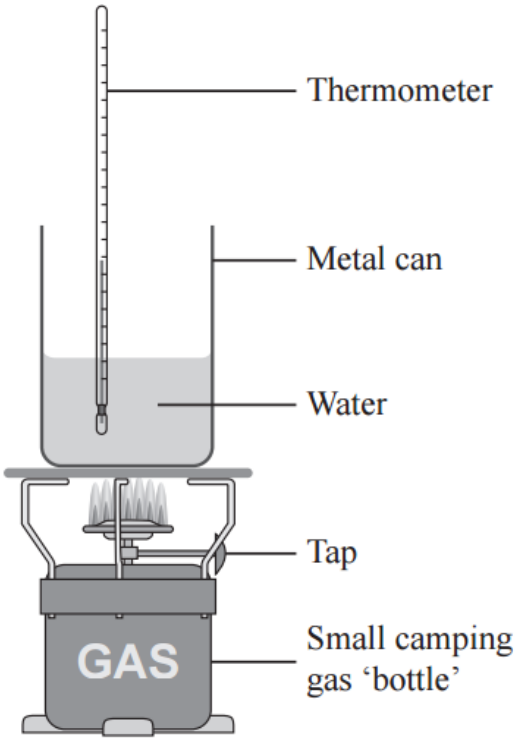
$n(CO_2) = 0.450$ mol

Since 6 moles of CO_2 reacting requires 2803 kJ of energy

then 1 mole of CO_2 reacting requires 2803/6= 467.2 kJ of energy

and 0.450 moles of CO_2 requires $467.2 \times 0.450 = 210$ kJ of energy absorbed.

(d) A small camp stove containing butane gas, $C_4H_{10}(g)$, is used to heat some water, as shown in the diagram below. A student measures the temperature change in the water and calculates that when 3.65 g of butane is combusted, 106 kJ of heat is released.



The reaction for the combustion of butane is shown in the equation below.

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l)$$

(i) Calculate the enthalpy change (Δ_rH) for this reaction, based on the above measurements. $M(C_4H_{10}) = 58.0$ g mol^{-1}.

$n(C_4H_{10}) = 3.65/58.0 = 0.0629$ mol

If 0.0629 moles of C_4H_{10} releases 106 kJ of energy

Then 1 mole of C_4H_{10} releases 106/0.0629 = 1685 kJ of energy

And 2 moles of C_4H_{10} releases $1685 \times 2 = 3370$ kJ of energy (3368) ($\Delta_rH = -3370$ kJ mol^{-1})

(ii) The accepted enthalpy change for the combustion reaction of butane gas, $C_4H_{10}(g)$, is $\Delta_rH = -5754$ kJ mol^{-1}. Explain why the result you calculated in part (c)(i) is different to the accepted value. In your answer, you should include at least TWO reasons.

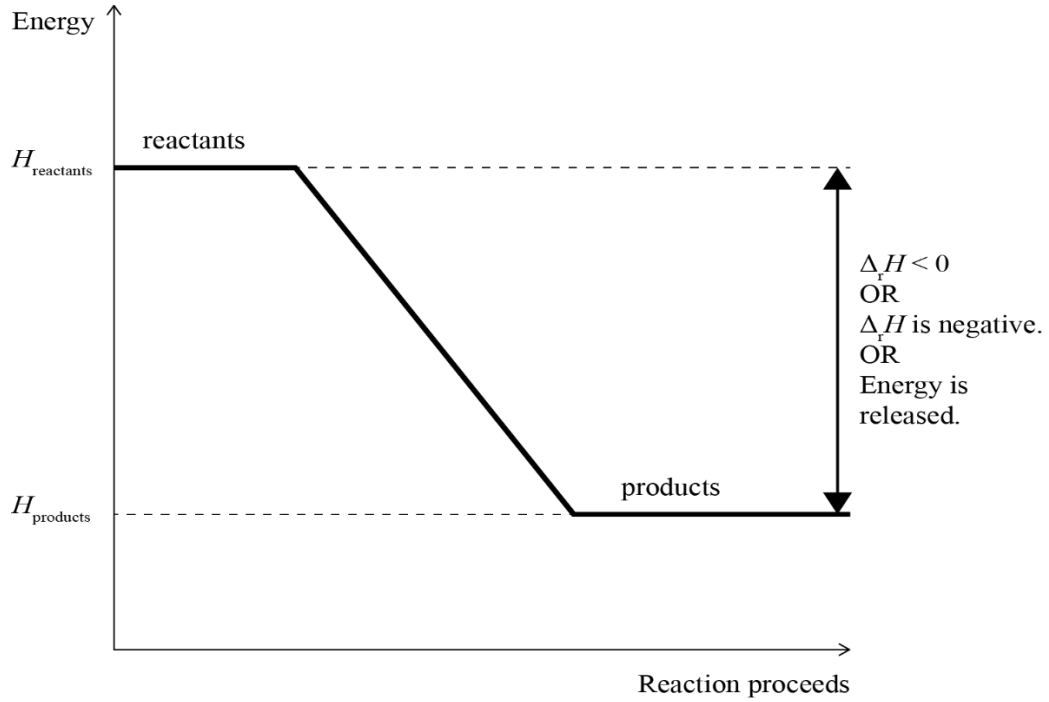
The results from this experiment are less than the accepted results, due to errors in the experimental design. The errors could include:

1. Some energy is used to heat the metal can and the air surrounding the experiment / the experiment was not conducted in a closed system
2. Incomplete combustion of butane.

3. Some butane may have escaped before being ignited.
4. The butane in the gas canister was impure.
5. Some water evaporated
6. Some energy was converted to light and sound
7. Not carried out under standard conditions

Therefore, not all of the energy released by the combustion of butane was transferred to heating the water.

(iii) Complete, including labels, the energy diagram for the combustion of butane gas showing reactants, products, and the change in enthalpy.



(v) Butane gas is a useful fuel because when it undergoes combustion, energy is released. Explain why energy is released in this reaction, in terms of making and breaking bonds. No calculations are required.

When butane undergoes combustion, heat is released, so it is an exothermic reaction. Bond-making is an exothermic process / releases energy and bond-breaking is endothermic / requires energy. For the overall reaction in the combustion of butane to release energy, more energy is given out as bonds are made (when the products, CO_2 and H_2O are formed) than the energy being used to break the bonds (in the reactants, C_4H_{10} and O_2)

QUESTION (2014:1)

(d) Hydrogen gas, $H_2(g)$, reacts with oxygen gas, $O_2(g)$, as shown by the following equation

$$H_2(g) + \tfrac{1}{2}\, O_2(g) \rightarrow H_2O(g) \quad \Delta_r H^o = -242 \text{ kJ mol}^{-1}$$

Given the average bond enthalpies in the table below, calculate the average bond enthalpy of the **O – H** bond in H_2O.

Bond	Average bond enthalpy / kJ mol^{-1}
H – H	436
O = O	498

$\Delta_r H^o$ = ∑(bonds broken) – ∑(bonds formed)

Bonds broken

H–H = 436 and ½ × O=O = ½ × 498

Total = 685 kJ

Bonds formed

2 × O–H

∑(bonds formed)= ∑(bonds broken) – $\Delta_r H^o$ = 685 – (– 242) = 927 kJ

2 × O–H = 927 kJ and so **O–H** = 464 (463.5) kJ mol^{-1}

QUESTION (2014:3)

(a) (i) When solid sodium hydroxide is added to water, the temperature increases.

Circle the term that best describes this reaction.

Exothermic **Endothermic**

Give a reason for your choice.

Exothermic, as the temperature increases, which shows energy is being released.

(ii) The freezing of water to form ice can be represented by the following equation.

$H_2O(l) \rightarrow H_2O(s)$

Circle the term that best describes this reaction.

Exothermic **Endothermic**

Explain your choice.

Exothermic, weak intermolecular attractions form between the water molecules, this releases energy.

(c) Methanol and ethanol can both be used as fuels. Their combustion reactions can be represented by the following equations:

Methanol combustion: $2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$ $\Delta_r H^o$ = -1450 kJ mol^{-1}

Ethanol combustion: $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ $\Delta_r H^o$ = -1370 kJ mol^{-1}

Justify which fuel, methanol or ethanol, will produce more heat energy when 345 g of each fuel is combusted in excess oxygen.

$M(CH_3OH)$ = 32.0 g mol^{-1}

$M(C_2H_5OH)$ = 46.0 g mol^{-1}

$n(CH_3OH) = m / M = 345 / 32 = 10.78$ mol

$n(C_2H_5OH) = m / M = 345 / 46 = 7.50$ mol

2 mol CH_3OH releases 1 450 kJ of energy

1 mol CH_3OH releases 725 kJ of energy

10.78 mol CH_3OH releases 725 kJ $\times$ 10.78 = 7 816 kJ of energy

1 mol C_2H_5OH releases 1 370 kJ of energy

7.5 mol C_2H_5OH releases 1 370 kJ $\times$ 7.5 = 10 275 kJ of energy

Therefore C_2H_5OH releases more energy when 345 g of fuel are combusted.

QUESTION (2013:2)

(c) Chlorine reacts with methane to form chloromethane and hydrogen chloride, as shown in the equation below.

$$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$$

Use the following bond enthalpies to calculate $\Delta_r H°$ for this reaction.

Bond	Bond enthalpy / kJ mol^{-1}
H – Cl	431
C – H	414
C – Cl	324
Cl – Cl	242

Bonds broken C-H x 1 & Cl-Cl x 1 414 + 242 = 656

Bonds formed C-Cl x 1 & H-Cl x 1 -324 + -431 = -755

656 + -755 = -99.0 kJ mol^{-1}.

OR

Bonds broken C-H x 4 & Cl-Cl x 1 1656 + 242 = 1898

Bonds formed C-Cl x 1 & & C-H x 3 H-Cl x 1 -324 + -1242 + -431 = -1997

1898 + -1997 = -99.0 kJ mol^{-1}.

QUESTION (2013:3)

(a) Dissolving ammonium nitrate in a beaker containing water can be represented by the following equation:

$$NH_4NO_3(s) \rightarrow NH_4^+(aq) + NO_3^-(aq) \quad \Delta_r H° = 25.1 \text{ kJ mol}^{-1}$$

Circle the term below that best describes this process.

exothermic **endothermic**

Circle the description below that best describes what you would observe happening to the beaker during this process.

gets colder **stays the same** **gets warmer**

Explain your choices.

The process is endothermic since the enthalpy change ($\Delta_r H°$) is positive, which indicates that energy is absorbed by the system as the ammonium nitrate dissolves. Since heat energy is absorbed by the system from the surroundings (water & beaker), the **water or beaker** will get cooler as they lose heat energy.

(b) Glucose is an important source of energy in our diet. The equation below shows the combustion of glucose to form carbon dioxide and water.

$$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) \quad \Delta_r H° = -2820 \text{ kJ mol}^{-1}$$

(i) Circle the term below that best describes this process.

exothermic **endothermic**

Give a reason for your choice.

The reaction is exothermic because the enthalpy change ($\Delta_r H°$) is negative; indicating that heat energy is produced during the reaction.

(ii) Females who are moderately active need 9 800 kJ of energy per day.

Calculate the number of moles of glucose that would provide this daily energy requirement.

9800 kJ / 2820 kJ mol^{-1} = 3.48 mol

(c) (i) Many portable BBQ and camping gas canisters contain butane, C_4H_{10}. Butane is a gas at room temperature, and has a boiling point of – 0.5°C. The gas canisters contain both gas and liquid butane. As the gaseous butane is used, some of the liquid evaporates.

Circle the term below that best describes this process.

exothermic **endothermic**

Give a reason for your choice, and use your knowledge of structure and bonding, and energy changes, to explain the changes occurring as the liquid evaporates.

Heat energy is needed to change the butane from a liquid to a gas; the energy is used to break the weak intermolecular forces between the butane molecules.

(ii) The equation below shows the combustion of butane.

$$C_4H_{10}(g) + 13/2\ O_2(g) \rightarrow 4CO_2(g) + 5H_2O(g)$$

When 100 g of butane undergoes combustion, 4960 kJ of energy is released.

Calculate the enthalpy change when 1 mole of butane undergoes combustion.

$M(C_4H_{10}) = 58.1 \text{ g mol}^{-1}$.

n(C_4H_{10}) = 100 g / 58.1 g mol^{-1}

= 1.7212 mol

-4960 kJ / 1.7212 mol = -2882 kJ mol^{-1}

(d) The iron oxides Fe_3O_4 and Fe_2O_3 react with aluminium as shown below.

$$3Fe_3O_4(s) + 8Al(s) \rightarrow 4Al_2O_3(s) + 9Fe(s) \quad \Delta r H° = -3348 \text{ kJ mol}^{-1}$$

$$Fe_2O_3(s) + 2Al(s) \rightarrow Al_2O_3(s) + 2Fe(s) \quad \Delta r H° = -851 \text{ kJ mol}^{-1}$$

Justify which iron oxide, Fe_3O_4 or Fe_2O_3, will produce more heat energy when 2.00 kg of iron is formed during the reaction with aluminium.

Your answer should include calculations of the heat energy produced for the given mass of iron formed.

$M(Fe) = 55.9 \text{ g mol}^{-1}$.

$n(Fe) = 2000 \text{ g} / 55.9 \text{ g mol}^{-1} = 35.78 \text{ mol}$

Fe_3O_4: $3348 \text{ kJ} / 9 = 372 \text{ kJ mol}^{-1}$

$372 \text{ kJ mol}^{-1} \times 35.78 \text{ mol} = 13\,310.16 \text{ kJ}$

$= 1.33 \times 10^4 \text{ kJ}$ (produced / released)

Fe_2O_3: $851 \text{ kJ} / 2 = 425.5 \text{ kJ mol}^{-1}$

$425.5 \text{ kJ mol}^{-1} \times 35.78 \text{ mol} = 15\,224.4 \text{ kJ}$

$= 1.52 \times 10^4 \text{ kJ}$ (produced / released)

Therefore Fe_2O_3 produces more heat energy when 2 kg iron is formed.

QUESTION (2012:3)

(a) Some Bunsen burners use methane gas, CH_4, as a fuel. The reaction for the combustion of methane in a Bunsen burner is shown in Equation One below.

Equation One: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \ \Delta_rH = -889 \text{ kJ mol}^{-1}$.

When this reaction occurs, bonds are broken and bonds are formed.

State which bonds are broken and which bonds are formed during the reaction.

Bonds broken: C–H and O=O

Bonds formed: C=O and O–H

(b) Calculate the energy released when 128 g of methane is burnt.

M (CH_4) = 16.0 g mol^{-1}.

$128 \text{ g} / 16.0 \text{ g mol}^{-1} = 8.00 \text{ mol}$

$8.00 \text{ mol} \times 889 \text{ kJ mol}^{-1} = 7112 \text{ kJ}$

(c) The equation for water boiling at 100°C is shown below in Equation Two.

Equation Two: $H_2O(l) \rightarrow H_2O(g) \ \Delta_rH = 40.7 \text{ kJ mol}^{-1}$

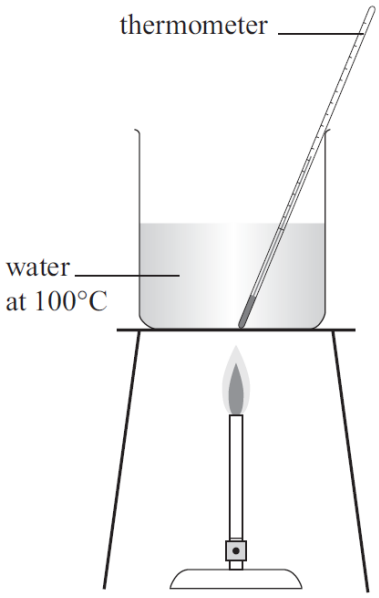
Explain why this equation is endothermic.

You should relate the energy changes that are occurring to the specific bonds being broken or formed.

The reaction is endothermic, as ΔH is positive and because the water is absorbing energy from the flame. During this reaction the weak intermolecular forces between water molecules are broken

Energy is needed to break these attractive forces so the reaction is endothermic.

(d) A student heats 72.0 g of water to 100°C using a Bunsen burner.



The student then boils the water.

Calculate the mass of methane gas, CH_4, that would need to be combusted in a Bunsen burner to boil the 72.0 g of water.

M (H_2O) = 18.0 g mol^{-1}.

In your answer you will need to:

- use **Equation Two** to determine the amount of energy required to boil the water
- use **Equation One** to determine the mass of methane needed to produce the required amount of energy
- assume that no energy is lost to the surrounding environment.

72.0 g / 18.0 g mol^{-1} = 4.00 mol of water being boiled.

Energy required to do this 4.00 mol × 40.7 kJ mol^{-1} = 162.8 kJ

This is the amount of energy that the combustion of methane in the Bunsen is required to produce.

162.8 kJ / 889 kJ mol^{-1} = 0.183 mol of methane to be combusted.

Mass of methane = 0.183 mol × 16.0 g mol^{-1} = 2.93 g.

QUESTION (2011:4)

(a) For each of the following, circle the correct word to indicate whether it is an exothermic or endothermic change.

Give a reason for your choice.

(i) $NH_4NO_3(s) \rightarrow NH_4^+(aq) + NO_3^-(aq)$ $\Delta_r H$ = +25.7 kJ mol^{-1}

exothermic **endothermic**

Reason: positive: value

(ii) Water vapour condensing, forming rain.

exothermic **endothermic**

Reason: bonds form OR energy released

(b) The overall reaction occurring in many disposable hand warmers can be represented by:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s) \quad \Delta_r H = -1652 \text{ kJ mol}^{-1}$$

(i) Calculate the energy released when 1.00 mol Fe_2O_3 is produced.

1652 / 2.00 = 826 kJ mol^{-1} (kJ)

(ii) Calculate the mass of Fe that would be required to release 185 kJ of energy.

M(Fe) = 55.9 g $mol^{-1.}$

4 mol Fe releases 1652 kJ of energy so (4 x 185)/1652 mol of Fe would be needed = 0.448 mol

m(Fe) = nM= 0.448 mol × 55.9 g mol^{-1} = **2**5.0 g

(iii) Many types of hand warmers are reusable. When these hand warmers are activated, heat is generated during the rapid crystallisation from liquid to solid. They can be "recharged" by putting them in a pot of boiling water for ten minutes.

Explain, in terms of thermochemical principles, how hand warmers can be recharged by heating.

Bonds broken OR Melting is endothermic

(c) Hydrogen and methane can be used as fuels.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) \quad \Delta_r H = -570 \text{ kJ mol}^{-1}$$

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l) \quad \Delta_r H = -890 \text{ kJ mol}^{-1}$$

Determine which of the fuels, hydrogen or methane, provides the most energy per gram of fuel burned. Justify your answer with calculations.

$M(H_2)$ = 2.00 g mol^{-1} $M(CH_4)$ = 16.0 g mol^{-1}

$m(H_2) = nM = 2mol \times 2 \text{ g mol}^{-1} = 4$ g

$n(H_2)$ in 1 g = m/M = ½ = 0.5 mol

Energy per mol (H_2) = 570/2 = 285 kJ $mol^{-1.}$

Energy per g(H_2) = 285 x 0.5 = 143 kJ $g^{-1.}$

$m(CH_4) = nM = 1mol \times 16 \text{ g mol}^{-1} = 16$ g

$n(CH_4)$ = m/M = 1/16 = 0.0625 mol

Energy per g (CH_4) = 0.0625 x 890 = 55.6 kJ $g^{-1.}$

H_2 provides the most energy per gram of fuel

QUESTION (2010:3) (parts (a) and (c))

(b) Classify the following reactions, by writing in the box below the word '**Exothermic**' or '**Endothermic**'.

	Exothermic or Endothermic
$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g) \quad \Delta_r H = -48.0 \text{ kJ mol}^{-1}$	exothermic
$H_2O(g) \rightarrow H_2O(l)$	exothermic
$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$ 206 kJ of energy is absorbed.	endothermic
When zinc powder reacts with copper sulfate solution, the temperature rises.	exothermic

(c) When a 12.2 g sample of ammonia is burned, 275 kJ of energy is released.

Calculate the energy released for the reaction below, when four moles of ammonia are burned.

$$4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(l)$$

$M(NH_3) = 17.0 \text{ g mol}^{-1}$

$n(NH_3)$ in 12.2 g sample = 12.2 / 17.0 = 0.718 mol (3s.f.)

4 mol releases 4 × 275 / 0.718 = 1530 kJ (3s.f.)

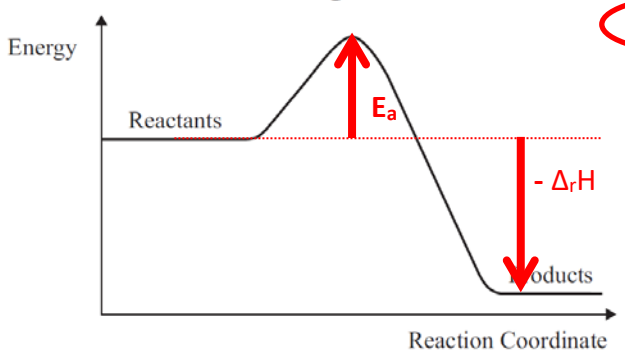
QUESTION (2009:2)

(c) For the reaction $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$,
the enthalpy of reaction is $\Delta_rH = -950 \text{ kJ mol}^{-1}$.

The reverse reaction is $4NO(g) + 6H_2O(g) \rightleftharpoons 4NH_3(g) + 5O_2(g)$

Two energy diagrams are shown below. One is for the forward reaction and one is for the same reaction in the reverse direction.

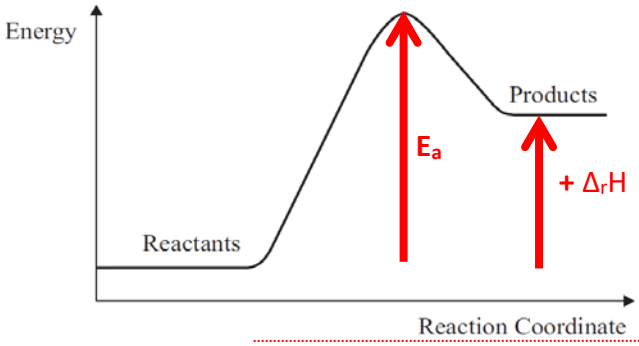
Diagram One



Exothermic or **Endothermic**
(circle one)

Forward or **Reverse**
(circle one)

Diagram Two



Exothermic or **Endothermic**
(circle one)

Forward or **Reverse**
(circle one)

(i) For each diagram, **circle** the correct answer to indicate whether the diagram is for an **exothermic** reaction or an **endothermic** reaction.

(ii) For each diagram, **circle** the correct answer to indicate whether the diagram is for the **forward** reaction or for the **reverse** reaction.

(iii) On the diagrams for **both** reactions, also label the following:

enthalpy of reaction, Δ_rH

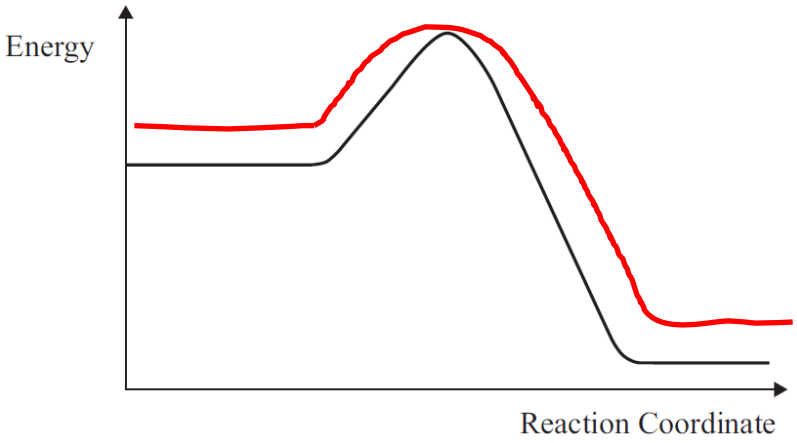
Activation Energy, E_a.

(iv) Determine the value for the enthalpy of reaction ($\Delta_r H$) for the reaction shown in **Diagram Two**.
Explain how you determined this value.

$\Delta_r H$ = + 950 kJ mol^{-1}

Because the same amount of energy is being gained / absorbed / taken in (it is an endothermic reaction) so the $\Delta_r H$ is positive.

(d) The energy diagram below represents a reaction carried out at 20°C.



(i) On the same axes, redraw the energy diagram to show the same reaction carried out at a higher temperature.

(ii) Explain any changes to

- enthalpy of reaction, $\Delta_r H$
- Activation Energy, E_a
- energy of the reactants
- energy of the products.

Diagram redrawn showing the reactants and products having a higher energy, $\Delta_r H$ remains the same, with a smaller E_a.

Explanation:

The energy of the reactants and products is higher because with increased temperature the particles have more (kinetic) energy.

The activation energy gap is reduced because the particles have more energy to start with so require less energy for effective / successful collisions.

The $\Delta_r H$ will remain the same, this is still the same reaction so regardless of what temperature / how much energy the reactants start with the same amount of energy is released.

(c) The equation for the reaction between calcium oxide, CaO, and water can be represented as

$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(aq)$ $\Delta H = -82.0$ kJ mol^{-1}

M(CaO) = 56.0 g mol^{-1}

Calculate the mass of calcium oxide required to release 287 kJ of energy.

n(CaO) = 287 / 82.0 = 3.50

m(CaO) = 3.50 × 56.0 = 196 g

QUESTION (2008: 5)

When an 18.4 g sample of ethanol is burned, 546 kJ of energy is released.

Determine the enthalpy change, ΔrH, for the reaction when one mole of ethanol is burned.

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

$M(C_2H_5OH) = 46.0\ g\ mol^{-1}$

$n(C_2H_5OH) = 18.4/46.0 = 0.400\ mol$

$1\ mol\ releases\ 546/0.400 = 1365\ kJ\ mol^{-1}$

$\Delta H = -1365\ kJ\ mol^{-1}$

QUESTION (2007:4)

(a) Classify the following reactions as exothermic or endothermic by writing in the box the word that best represents each equation.

		Exothermic or Endothermic
(i)	$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O$ A temperature increase occurs.	Exothermic
(ii)	$N_2(g) \rightarrow 2N(g)$ $\Delta_r H = +934\ kJ\ mol^{-1}$	Endothermic
(iii)	$H_2(g) + I_2(g) \rightarrow 2HI(g)$ A temperature decrease occurs.	Endothermic
(iv)	$2H_2(g) + CO(g) \rightarrow CH_3OH(g)$ $\Delta_r H = -128\ kJ\ mol^{-1}$	Exothermic

(b) Dissolving of ammonium nitrate in water is an endothermic process.

$$NH_4NO_3(s) \rightarrow NH_4^+(aq) + NO_3^-(aq)$$

(i) When 1.80 g of ammonium nitrate was dissolved in 50.0 g of water, the temperature decreased by 2.70°C. The heat capacity of water is $4.18\ J\ g^{-1}\ °C^{-1}$. $M(NH_4NO_3) = 80.0\ g\ mol^{-1}$

Calculate the enthalpy change when one mole of ammonium nitrate dissolves completely in water.

$50.0\ g \times 2.70°C \times 4.18\ J\ g^{-1}\ °C^{-1} = 564.3\ J$

$n(NH_4NO_3) = 1.80\ g \div 80\ g\ mol^{-1} = 2.25 \times 10^{-2}\ mol$

Energy absorbed when 1 mol dissolves

$= 564.3\ J \div 2.25 \times 10^{-2}\ mol = 25\ 080\ J$

$\Delta_r H = +25.1\ kJ\ mol^{-1}$

(ii) Calculate the mass of ammonium nitrate that would be required to absorb 1.25 kJ of energy

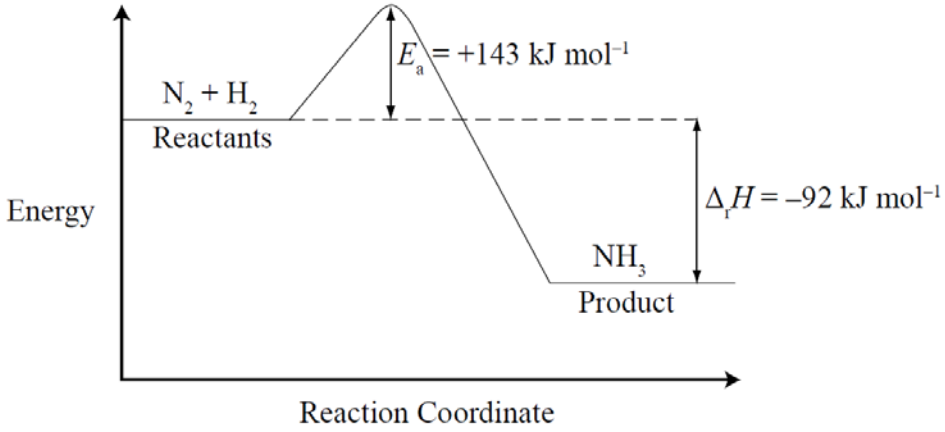
1.25/25.1 = 0.0498 mol

0.0498 mol × 80.0 g mol^{-1} = 3.98 g (or 3.99 g)

(or other correct method)

QUESTION (2007:6)(parts (b) & (c))

For the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$,
the enthalpy of reaction Δ_rH = –92 kJ mol^{-1}, and the activation energy E_a = +143 kJ mol^{-1}.
An energy diagram for this chemical reaction is shown below.



The reverse reaction is $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)$

(b) State the values for Δ_rH and E_a for this reverse reaction.

Δ_rH = +92 kJ mol^{-1} E_a = = 235 kJ mol^{-1} (143 + 92)

(d) Draw the energy diagram below for this reverse reaction.
Label the diagram with the four labels from the key list.
KEY LIST: $N_2 + H_2$ NH_3 Δ_rH E_a