Name: _____

3.1 Energetics

Date:

Time:

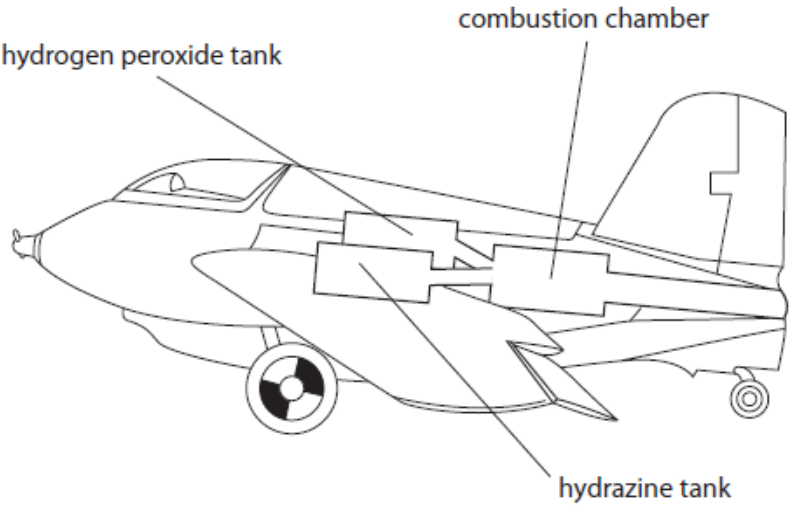
Total marks available:

Total marks achieved: _____

Questions

Q1.

During the Second World War, engineers developed a rocket-powered aircraft.



The aircraft carried these two liquids

- hydrazine, N_2H_4
- hydrogen peroxide, H_2O_2

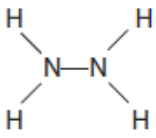
When these two liquids mix in the combustion chamber, they evaporate and then react rapidly to form nitrogen gas, N_2, and steam, H_2O

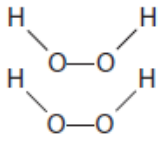
The reaction is exothermic.

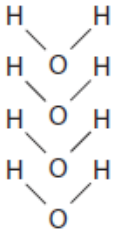
The equation for the reaction is

$$N_2H_4 \quad + \quad 2H_2O_2 \quad \rightarrow \quad N_2 \quad + \quad 4H_2O$$

The displayed formulae for the reactants and products are







(a) The tables give the bond energies for the bonds broken in the reactants and the bonds made in the products.

Bonds broken	
bond	bond energy in kJ/mol
N—N	159
N—H	391
O—O	143
O—H	463

Bonds made	
bond	bond energy in kJ/mol
N≡N	945
O—H	463

(i) Use the data in the tables to calculate the total amount of energy required to break all of the bonds in the reactants.

(1)

energy required = ... kJ

(ii) Use the data in the tables to calculate the total amount of energy released when all of the bonds in the products are made.

(1)

energy released = ... kJ

(iii) Calculate the enthalpy change, ΔH, in kJ/mol, for the reaction. Include a sign in your answer.

(3)

ΔH = ... kJ/mol

(b) Explain, in terms of bonds broken and bonds made, why this reaction is exothermic.

(2)

.....

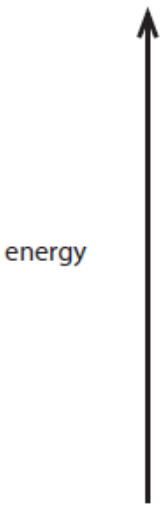
.....

.....

.....

(c) Draw an energy level diagram for the reaction between N_2H_4 and H_2O_2

(3)

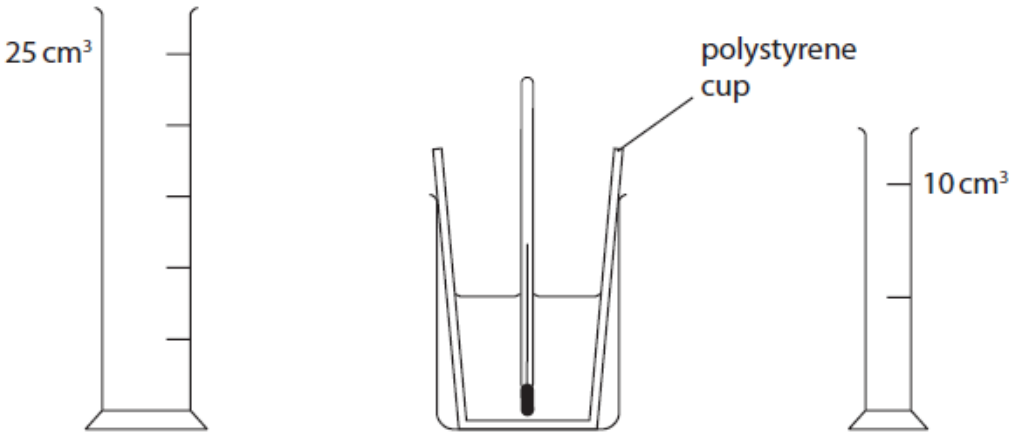


(Total for question = 10 marks)

Q2.

When aqueous solutions of potassium hydroxide and nitric acid are mixed together, an exothermic reaction occurs.

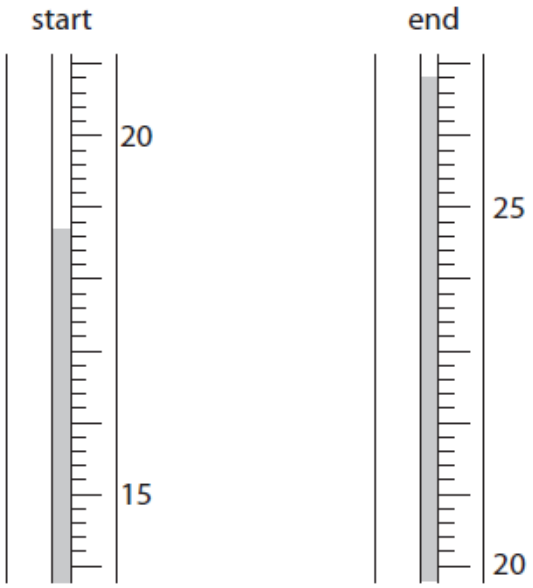
The diagram shows the apparatus used in an experiment to measure the temperature increase.



This is the student's method.

- use the larger measuring cylinder to add 25 cm^3 of aqueous potassium hydroxide to the polystyrene cup.
- record the steady temperature.
- use the smaller measuring cylinder to add 5 cm^3 of dilute nitric acid to the cup, stir the mixture with the thermometer.
- record the highest temperature of the mixture.
- continue adding further 5 cm^3 portions of dilute nitric acid to the cup, stirring and recording the temperature, until a total volume of 35 cm^3 has been added.

(a) The diagram shows the thermometer readings at the start and at the end of one experiment.



Complete the table to show:

- the thermometer reading at the start of the experiment
- the temperature rise in the experiment.

(2)

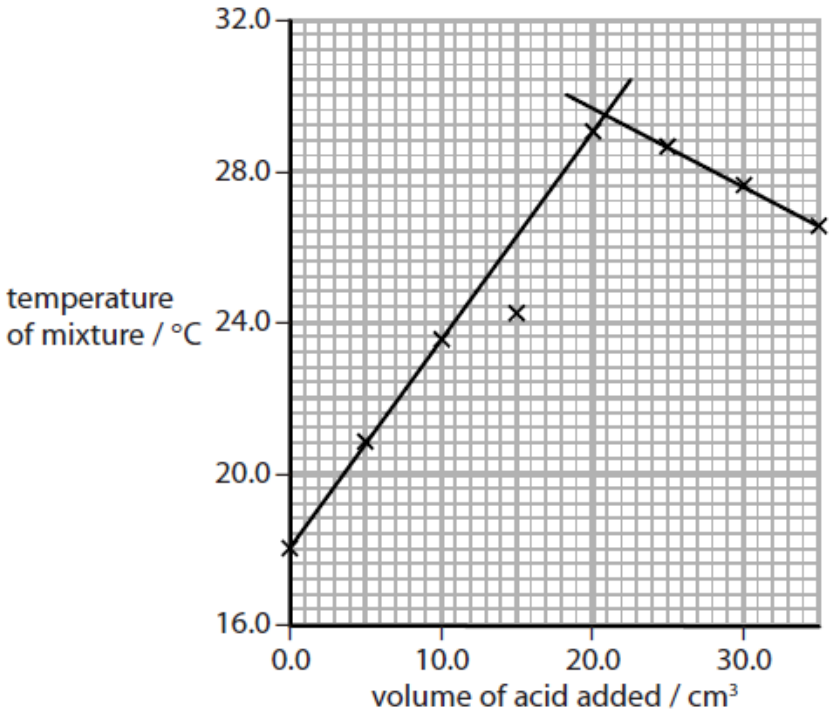
thermometer reading at end / °C	26.8
thermometer reading at start / °C	
thermometer rise / °C	

(b) Another student uses the same method, adding the dilute nitric acid from a burette.

The table shows his results.

volume of acid added / cm^3	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0
temperature of mixture / °C	18.0	20.8	23.5	24.2	29.0	28.6	27.6	26.5

This is the student's graph.



The point where the lines cross represents complete neutralisation.

(i) Identify the maximum temperature reached during the experiment.

(1)

maximum temperature = ... °C

(ii) Identify the volume of dilute nitric acid that exactly neutralises the 25 cm^3 of aqueous potassium hydroxide.

(1)

volume = ... cm^3

(c) Another student records these results.

volume of aqueous potassium hydroxide	= 20.0 cm^3
starting temperature of aqueous potassium hydroxide	= 18.5 °C
maximum temperature of mixture	= 30.0 °C
volume of dilute nitric acid	= 20.0 cm^3

Calculate the heat energy released in this experiment.

c = 4.2 J/g / °C

mass of 1 cm^3 of mixture = 1 g

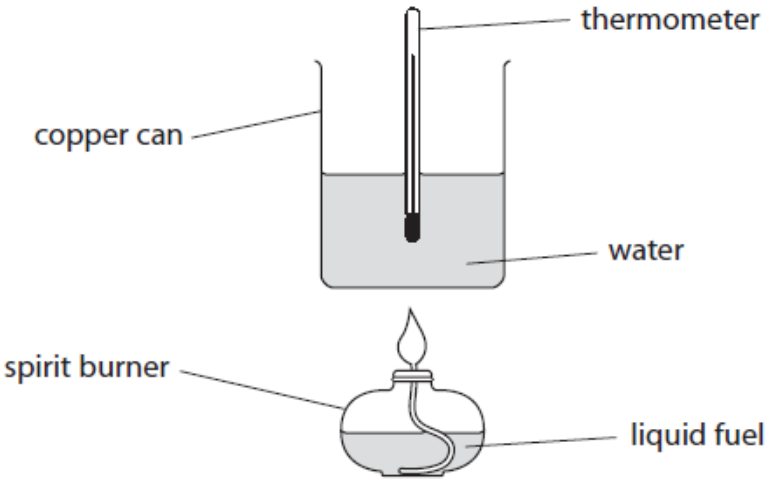
(4)

heat energy = ... J

(Total for question = 8 marks)

Q3.

A student uses this apparatus to investigate the heat energy released when a liquid fuel is burned.



This is the student's method.

- measure the mass of the spirit burner and fuel
- add 100 cm^3 of water to the copper can
- record the temperature of the water
- use the spirit burner to heat the water until the temperature rises by 30 °C

- immediately measure the new mass of the spirit burner and fuel

(a) Suggest why the student measures the mass of the spirit burner and fuel immediately after heating the water.

(1)

.....

.....

.....

(b) When the fuel is burned, the student notices that a black solid forms on the bottom of the copper can.

(i) Identify the black solid.

(1)

.....

(ii) Explain why the black solid forms.

(2)

.....

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.....

(c) (i) Show that the heat energy change, Q, to raise the temperature of 100 cm^3 of water by 30 °C is approximately 13 kJ.

[mass of 1.0 cm^3 of water = 1.0 g]

[c for water = 4.2 J/g/ °C]

(3)

(ii) The student burns 0.96 g of methanol, CH_3OH

Calculate the molar enthalpy change, ΔH, in kJ/mol, for the combustion of methanol.

Include a sign in your answer.

[M_r of methanol = 32]

(3)

ΔH = ... kJ/mol

(d) The table shows data book values for the molar enthalpy change, ΔH, for the combustion of

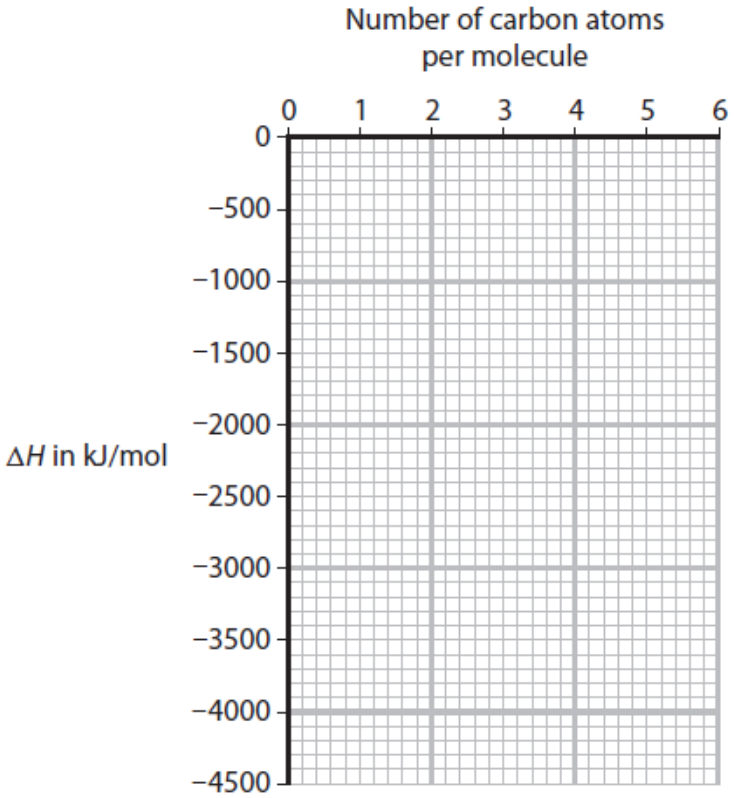
some alcohols with different numbers of carbon atoms per molecule.

Number of carbon atoms per molecule	1	2	3	4	5
Molar enthalpy change, ΔH, in kJ/mol	−730	−1370	−2020	−2680	−3320

(i) Plot the data values from the table on the grid.

Draw a straight line of best fit.

(2)



(ii) Deduce the value of ΔH for an alcohol with six carbon atoms per molecule.

Show on the graph how you obtained your answer.

(2)

ΔH = ... kJ/mol

(iii) State the relationship between ΔH and the number of carbon atoms per molecule.

(1)

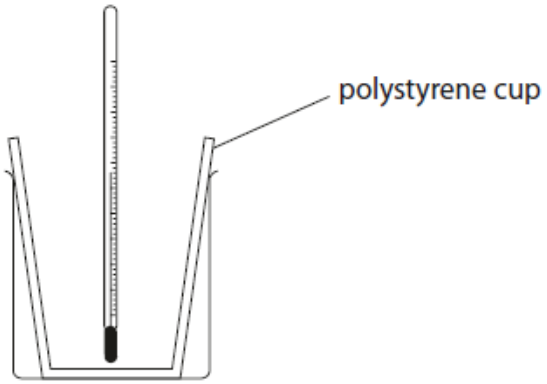
.....

.....

(Total for question = 15 marks)

Q4.

A student uses this apparatus to investigate the temperature change that occurs when ammonium nitrate is dissolved in water.



She uses this method.

- put 100 cm^3 of water into the polystyrene cup and measure the initial temperature of the water
- add 8.00 g of ammonium nitrate and stir
- record the lowest temperature reached by the solution

The table shows her results.

Initial temperature of water in °C	20.0
Lowest temperature of solution in °C	14.2

(a) Use the results of the experiment to explain what type of reaction is taking place when ammonium nitrate is added to water.

(2)

.....

.....

.....

.....

(b) Show that the heat energy change, Q, is about 2400 J.

[mass of 1.00 cm^3 of solution = 1.00 g]

[for the solution, c = 4.18 J/g/ °C]

(3)

Q = ... *J*

(c) Use your answer to part (b) to calculate the enthalpy change, Δ*H*, in kilojoules per mole of ammonium nitrate.

[M_r of ammonium nitrate = 80.0]

Include a sign in your answer.

(4)

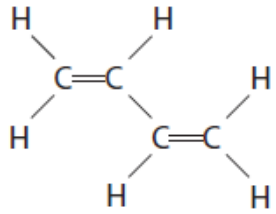
Δ*H* = ... kJ/mol

(Total for question = 9 marks)

Q5.

The organic compound butadiene is a colourless gas used in the manufacture of synthetic rubber for tyres.

The displayed formula of butadiene is



(a) Explain why butadiene is described as an unsaturated hydrocarbon.

(3)

.....

.....

.....

.....

.....

.....

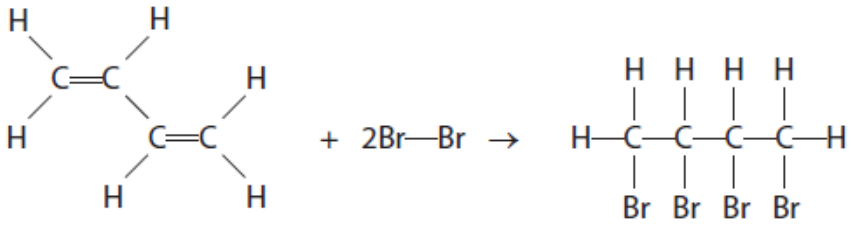
(b) (i) Butadiene reacts with bromine water.

State the colour change that occurs during this reaction.

(1)

from ..... to
.....

(ii) The equation for the reaction between butadiene and bromine can be shown using displayed formulae.



The table gives some bond energies.

Bond	C—H	C=C	Br—Br	C—C	C—Br
Bond energy in kJ/mol	412	612	193	348	276

Use this information to calculate the enthalpy change, ΔH, for the reaction.

Include a sign in your answer.

(4)

ΔH = ... kJ/mol

(c) A scientist does an investigation to find out if butadiene would be a good fuel.

He burns a sample of butadiene gas and observes that carbon forms as black soot.

(i) Complete the equation to explain the scientist's observation.

(1)

$$2C_4H_6 + 7O_2 \rightarrow .....C + 4CO + 2CO_2 + ...H_2O$$

(ii) Explain how one of the products, other than carbon, may cause a problem.

(2)

.....

.....

.....

.....

(iii) The equation for the combustion of butadiene in excess oxygen is

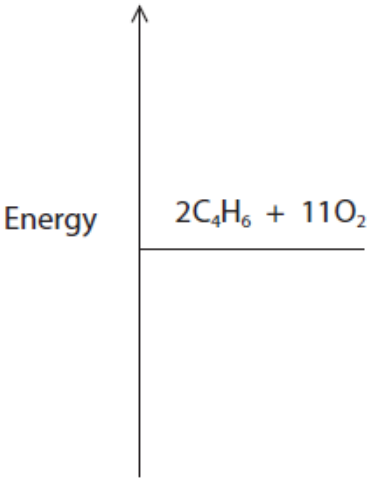
$$2C_4H_6 + 11O_2 \rightarrow 8CO_2 + 6H_2O$$

The enthalpy change for this reaction, ΔH, is – 3446 kJ/mol.

Complete the energy profile diagram for the reaction.

Label the enthalpy change for this reaction, ΔH, and the activation energy.

(4)



(Total for question = 15 marks)

Q6.

Oxygen can be prepared from hydrogen peroxide using a catalyst.

(a) Which is a correct statement about oxygen?

(1)

☒ **A** it burns with a squeaky pop

☒ **B** it relights a glowing splint

☒ **C** it turns blue litmus red

☒ **D** it turns limewater milky

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

(2)

.....

.....

.....

.....

(c) The equation for the preparation of oxygen from hydrogen peroxide is

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

This equation can also be written using displayed formulae to show all the covalent bonds in the molecules.

$$2H{-}O{-}O{-}H \rightarrow 2H{-}O{-}H + O{=}O$$

The table gives the bond energies for these bonds.

Bond	H—O	O—O	O═O
Bond energy in kJ/mol	463	143	498

(i) Use the values in the table to calculate the enthalpy change, ΔH, for the reaction.

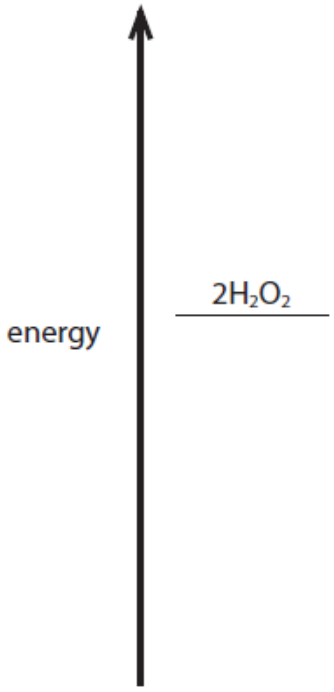
Include a sign in your answer.

(3)

ΔH = ... kJ

(ii) Complete the energy level diagram to show the position of the products and the enthalpy change, ΔH, for the reaction.

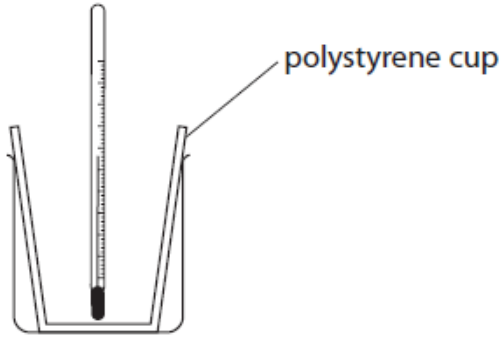
(2)



(Total for question = 8 marks)

Q7.

A student uses this apparatus to find the temperature change when sodium hydroxide solution reacts with dilute hydrochloric acid.



This is the student's method.

- pour 20 cm^3 of sodium hydroxide solution into a polystyrene cup
- record the temperature of the sodium hydroxide solution
- add 20 cm^3 of dilute hydrochloric acid and stir the mixture
- record the highest temperature of the mixture

(a) (i) Give the formula of the ion that causes sodium hydroxide solution to be alkaline.

(1)

.....

(ii) Suggest a pH value for the dilute hydrochloric acid.

(1)

.....

(b) Explain why a polystyrene cup is used in this experiment.

(2)

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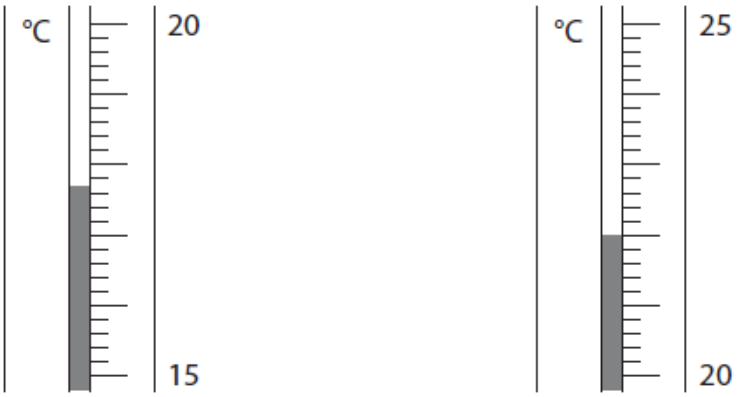
.....

(c) The diagram shows the thermometer readings at the start and at the end of the experiment.



Use the readings to complete the table, giving all values to the nearest 0.1 °C.

(3)

temperature in °C at end	
temperature in °C at start	
temperature change in °C	

(d) Another student does the experiment, but uses 25 cm^3 of sodium hydroxide solution and 25 cm^3 of dilute hydrochloric acid.

She records a temperature change of 5.2 °C.

Calculate the heat energy (Q) in kilojoules (kJ) released in this reaction.

[mass of 1.0 cm^3 of solution = 1.0 g]

[for the solution, c = 4.2 J / g / °C]

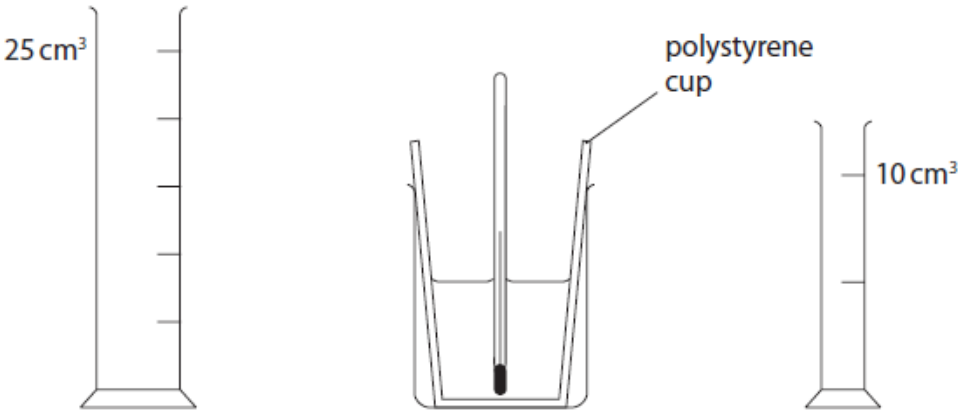
(4)

Q = ... kJ

(Total for question = 11 marks)

Q8.

When aqueous solutions of potassium hydroxide and nitric acid are mixed together, an exothermic reaction occurs. The diagram shows the apparatus used in an experiment to measure the temperature increase.



This is the student's method;

- use the larger measuring cylinder to add 25 cm^3 of aqueous potassium hydroxide to the polystyrene cup
- record the steady temperature
- use the smaller measuring cylinder to add 5 cm^3 of dilute nitric acid to the cup, stir the mixture with the thermometer
- record the highest temperature of the mixture
- continue adding further 5 cm^3 portions of dilute nitric acid to the cup, stirring and recording the temperature, until a total volume of 35 cm^3 has been added.

(a) A teacher advises the student to use a 50 cm^3 burette instead of the 10 cm^3 measuring cylinder.

Suggest **two** reasons why it would be better to use a burette instead of a measuring cylinder to add the acid in this experiment.

(2)

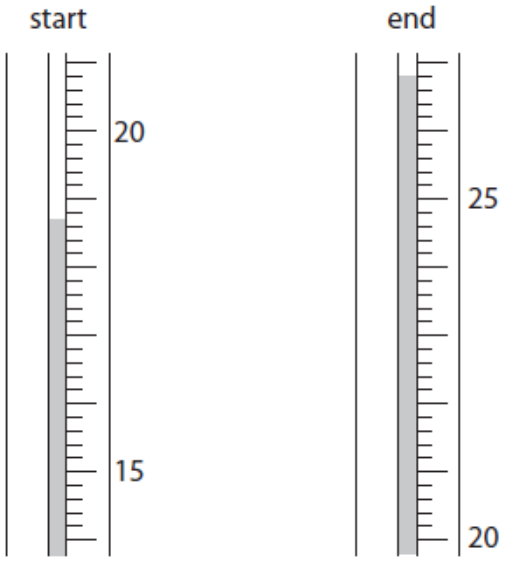
1 .....

.....

2 .....

.....

(b) The diagram shows the thermometer readings at the start and at the end of one experiment.



Complete the table to show:

- the thermometer reading at the start of the experiment
- the temperature rise in the experiment.

(2)

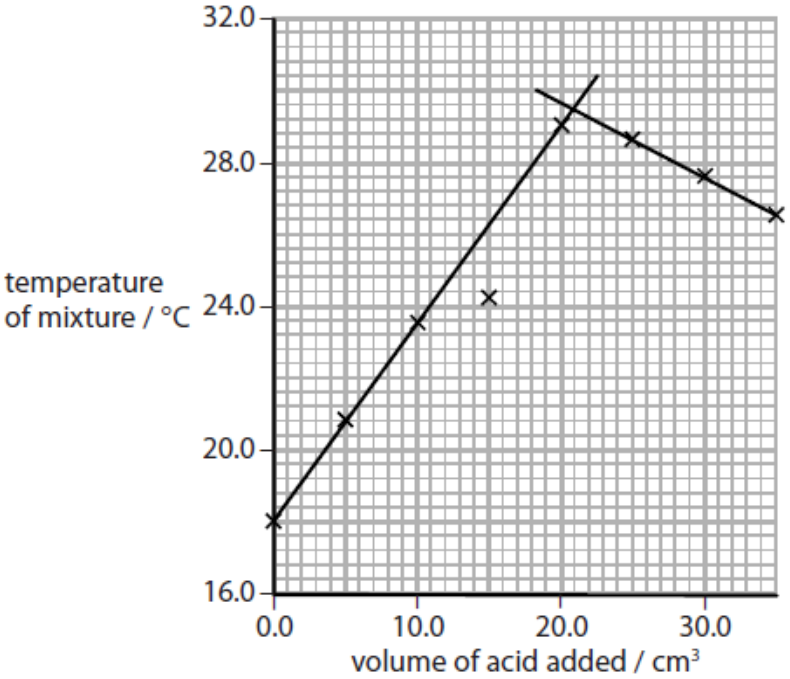
thermometer reading at end / °C	26.8
thermometer reading at start / °C	
thermometer rise / °C	

(c) Another student uses the same method, adding the dilute nitric acid from a burette.

The table shows his results.

volume of acid added / cm^3	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0
temperature of mixture / °C	18.0	20.8	23.5	24.2	29.0	28.6	27.6	26.5

This is the student's graph.



The point where the lines cross represents complete neutralisation.

(i) Identify the maximum temperature reached during the experiment.

(1)

maximum temperature = ... °C

(ii) Identify the volume of dilute nitric acid that exactly neutralises the 25 cm^3 of aqueous potassium hydroxide.

(1)

volume = ... cm^3

(d) Another student records these results.

volume of aqueous potassium hydroxide	= 20.0 cm^3
starting temperature of aqueous potassium hydroxide	= 18.5 °C
maximum temperature of mixture	= 30.0 °C
volume of dilute nitric acid	= 20.0 cm^3

Calculate the heat energy released in this experiment.

c = 4.2 J/g / °C

mass of 1 cm^3 of mixture = 1 g

(4)

heat energy = ... J

(e) In another experiment, the heat energy released is 1600 J when 0.040 mol of potassium hydroxide is neutralised.

Calculate the value of ΔH, in kJ/mol, for the neutralisation of potassium hydroxide.

(2)

ΔH = ... kJ/mo

(Total for question = 12 marks)

Q9.

A student investigates the reaction between magnesium and hydrochloric acid.

He uses this method.

Step 1 add 25 cm^3 of dilute hydrochloric acid to a polystyrene cup

Step 2 record the temperature of the acid

Step 3 find the mass of a 10 cm strip of magnesium ribbon

Step 4 add the magnesium ribbon to the hydrochloric acid

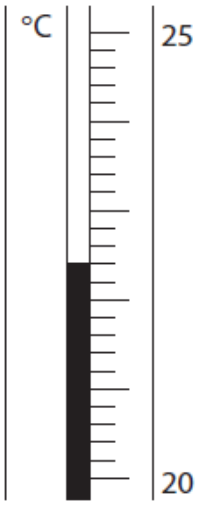
Step 5 when all the magnesium has reacted, record the highest temperature reached

(a) Complete the word equation for the reaction.

(1)

magnesium + hydrochloric acid → ..... + ...

(b) The thermometer shows the temperature of the acid at the start of the experiment.



(i) Complete the table by giving the temperatures to the nearest 0.1 °C.

(2)

temperature of the acid at the start in °C	
highest temperature reached in °C	
temperature rise in °C	20.8

(ii) Show that the heat energy change (Q) for this reaction is about 2200 J.

[mass of 1.0 cm^3 of solution = 1.0 g]

[for the solution, c = 4.2 J/g/°C]

(2)

(iii) The mass of magnesium used by the student was 0.12 g.

Calculate the value of the enthalpy change (ΔH), in kilojoules per mole of magnesium, for the reaction between magnesium and hydrochloric acid.

Include a sign in your answer.

(4)

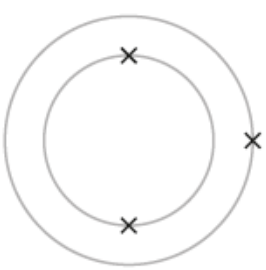
ΔH = ... kJ/mol

(Total for question = 9 marks)

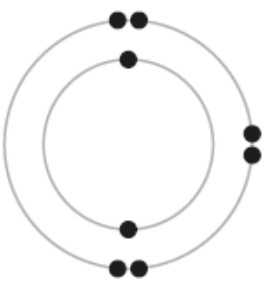
Q10.

This question is about lithium oxide.

(a) The diagram shows the electron configurations of an atom of lithium and an atom of oxygen.



lithium



oxygen

Describe the changes in electronic configuration when lithium and oxygen react to form lithium oxide, Li_2O

(3)

.....

.....

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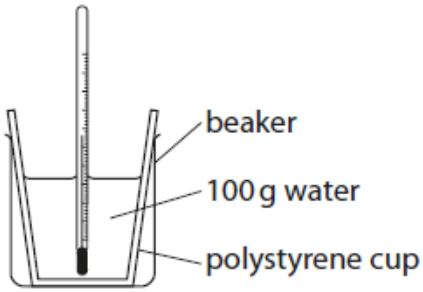
.....

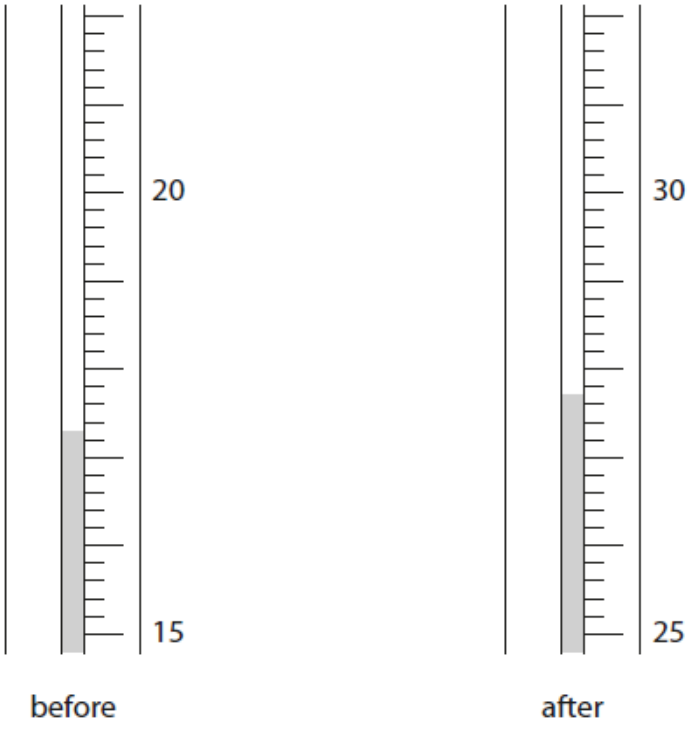
(b) Lithium oxide reacts with water to form lithium hydroxide as the only product.
A scientist uses this apparatus to measure the temperature change of the reaction.



This is the scientist's method.

- pour 100 g of water into a polystyrene cup
- record the temperature of the water
- add the lithium oxide and stir the mixture
- record the maximum temperature reached

The diagram shows the thermometer readings before and after adding the lithium oxide.



(i) Complete the table, giving all values to the nearest 0.1 °C.

(2)

temperature in °C after adding the lithium oxide	
temperature in °C before adding the lithium oxide	17.3
temperature rise in °C	

(ii) Calculate the heat energy change in the reaction.

Give your answer to two significant figures.

[c = 4.2 J / g / °C]

(4)

heat energy change = ... J

(iii) In another experiment the scientist obtains these results.

amount of lithium oxide in mol	0.0580
heat energy change in J	5210

Calculate the molar enthalpy change (ΔH) in kJ / mol.

Include a sign in your answer.

(3)

ΔH = ... kJ / mol

(iv) Give a reason why the scientist does the experiment in a polystyrene cup.

(1)

.....

.....

.....

(Total for question = 13 marks)