Calculating energy changes from burning fuels

TEACHERS' AND TECHNICIANS' NOTES

Specification reference: C3.3.1 Energy from reactions

(a) The relative amounts of energy released when substances burn can be measured by simple calorimetry, eg by heating water in a glass or metal container.

Learning objectives

- To find out how much energy different fuels produce by a calorimetric method
- To identify a potential relationship between the number of carbon atoms and the energy produced
- To calculate the energy released per mole of fuel (**HT**)
- To calculate the theoretical energy released per mole based on bond energy data (**HT**)

Description of activity

This is a practical activity that students can carry out in small groups depending on availability of equipment. Students should first consider how the energy given out from a fuel can be measured.

The basis for comparison of fuels should be considered such as mass of fuel to achieve a particular temperature change, energy per gram of fuel or energy per mole of fuel, depending on the ability of the group.

A suggested method for the activity is on the accompanying worksheet, with a range of tasks for handling results to provide extension activities.

How Science Works

The following aspects can be addressed:

- Being able to make their own predictions (4.1.1a)
- Being able to test their own predictions (4.1.1b)
- Identifying some possible hazards in practical situations (4.2.1a)
- Managing risks (4.2.1b)
- Considering the precision of the measured data (4.3.2e)
- Recognising and identifying the cause of systematic errors (4.5.2d)
- Describing the relationship between two variables (4.5.3a)
- Evaluating methods of data collection (4.5.4d)
- Considering whether or not any prediction made is supported by the evidence (4.6.1a)

Resources

- Spirit burners (one or two per fuel to be used)
- Heat proof mats (several per group)
- Clamp and stand
- Top pan balance
- Thermometers
- 100 cm^3 measuring cylinders
- Metal calorimeters (cans with the label removed will do)
- Fuels: methanol, ethanol, propanol, butanol, pentanol

Practical tips

- Since the fuel soaks the wick of the spirit burner, these should not be refilled with a different fuel, but groups can collect a pre-filled burner for their experiment. If different groups do the fuels in a different order, one or two of each should be sufficient.
- Weigh the burner immediately before and after using to reduce evaporation of fuel from the wick.
- It is best not to heat the water much above 60 ºC, so as to reduce heat loss and risk of burning fingers.
- The practical provides a good opportunity to discuss and evaluate errors. It is clear heat is lost to the surroundings and is used to hear the calorimeter and thermometer. Evaporation of water and fuel from the wick are also sources of error. As the chain length increases the evidence of incomplete combustion is also increasingly obvious as there is a lot of soot produced.

Health and safety issues

- The alcohols are highly flammable (see CLEAPSS Hazcards 40A and B, 84A, B and C), so use a small volume in each spirit burner and have lids on when not in use. Keep bottles away from naked flames (eg in the prep room).
- Take care with hot apparatus.

Timing

- Approximately 45 min (if completed in groups)

Different approaches

Support students by getting them to plot a bar chart of the temperature rise produced by each sample.

Extend students by getting them to complete the energy calculations shown on the students' worksheet.

Answer to energy calculations

Energy used in breaking bonds = 347 + 358 + 464 + (5 × 413) + (3 × 498) = 4728 kJ/mol

Energy produced in making bonds = (4 × $^{-}$805) + (6 × $^{-}$464) = – 6004kJ/mol

Overall energy change = 4728 + – 6004 = –1276 kJ/mol (exothermic)

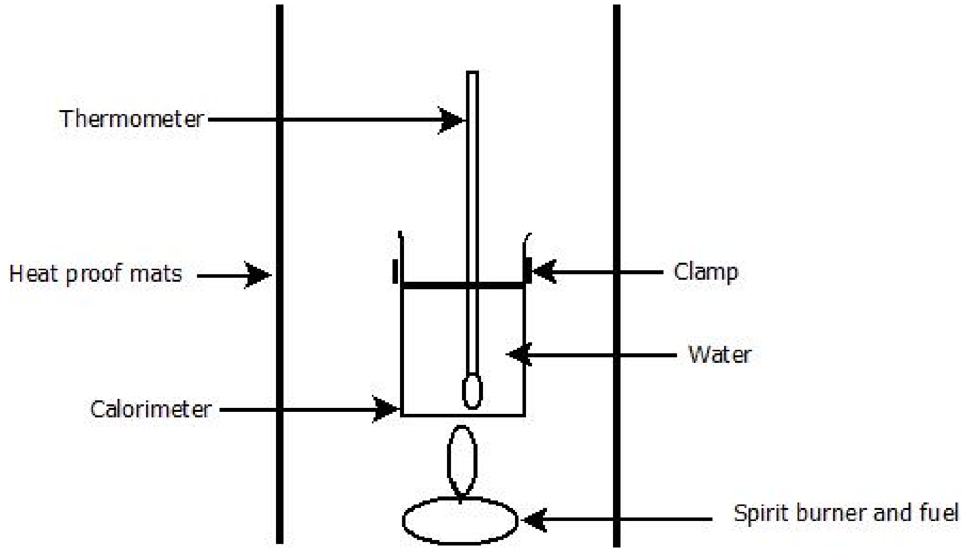
Calculating energy changes from burning fuels

STUDENTS' WORKSHEET

Aim

- To find out how much energy different fuels produce by a calorimetric method
- To identify a potential relationship between the number of carbon atoms and the energy produced
- To calculate the energy released per mole of fuel (**HT**)
- To calculate the theoretical energy released per mole based on bond energy data (**HT**)

Method



1. Weigh the spirit burner (including fuel).
2. Measure out 100 cm^3 of water into the calorimeter and measure the temperature.
3. Set up the burner with heatproof mats at each side to cut down on draughts. Allow a distance of about 5 cm between the top of the wick and the base of the calorimeter.
4. Light the burner and heat the water until the temperature reaches about 60° C. Stir with the thermometer to ensure the water is heated evenly.
5. When you have finished heating, put the lid on the burner to extinguish the flame and re-weigh it as soon as possible.
6. Repeat the procedure with a different fuel.
7. Record your results in the table below.

Health and safety

☒ The alcohols are highly flammable, so use a small volume in each spirit burner and have lids on when not in use. Keep bottles away from naked flames.

☒ Take care with hot apparatus.

Results

Name of fuel	Chemical formula	Molecular mass in grams	Mass of burner in grams			Temperature in °C		
			Before	After	Difference	Before	After	Difference

Evaluation questions

1 Which fuel do you think gives out the most heat? Give a reason for your answer.

2 One way to compare fuels is to find the temperature change per gram of fuel. To do this divide the temperature change by the mass of fuel used. Write your results into the table below.

Name of fuel	Temperature change per gram in °C

3 Why might this not be a very helpful way of comparing fuels?

4 The **energy** given out by a fuel can be calculated by using the following equation:

Energy given out = mass of water heated × temperature change × specific heat capacity of water

Since water has a density of 1g/cm^3, the mass is the same as the volume you used (ie 100g). The specific heat capacity of water is 4.2 J/g/°C.

Calculate the energy given out for each fuel and write your results in the table below.
(You may wish to convert the energy into kilojoules by dividing by 1000.)

Name of fuel	Energy produced in kilojoules

5 The **energy density** of a fuel is the energy given out per gram.

Calculate the energy per gram for each fuel and write your results in the table below.

Name of fuel	Energy density in kilojoules per gram

6 The energy given out per mole of fuel can be calculated in the following way:

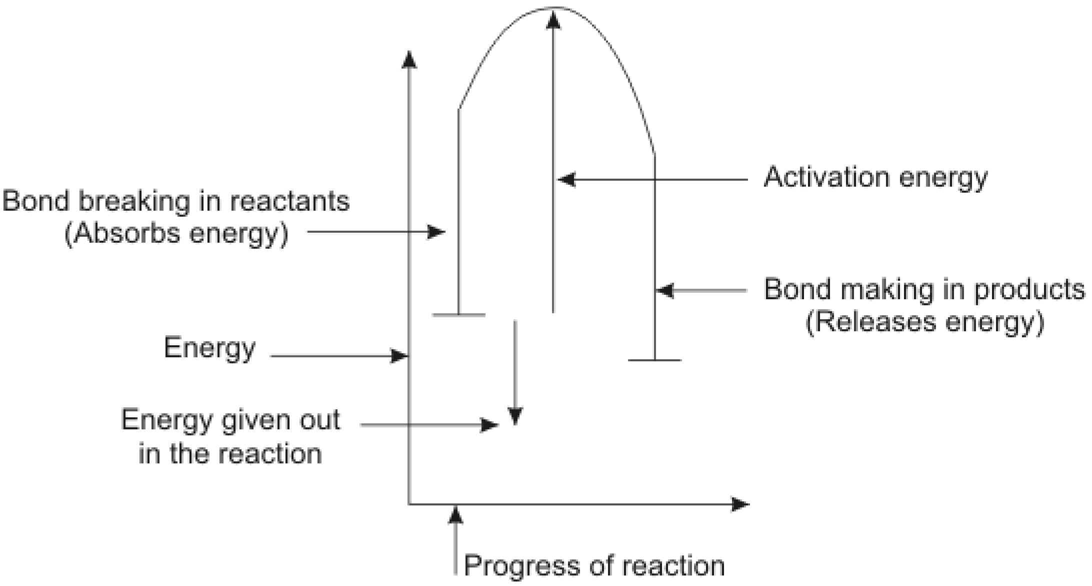
Energy per mole = energy density x relative molecular mass

Calculate the energy per mole for each fuel and write your results in the table below.

Name of fuel	Energy density in kilojoules per mole

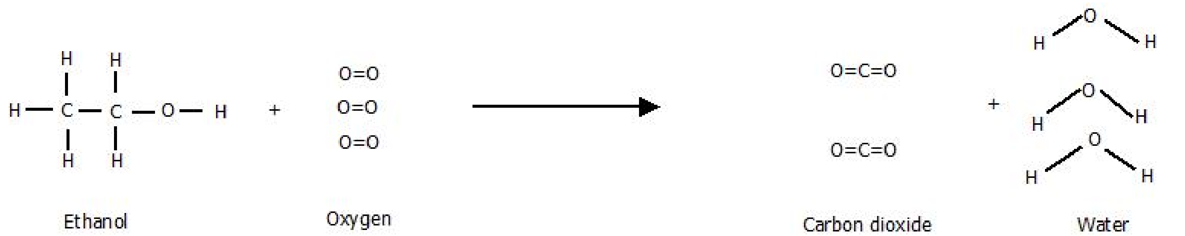
Extension work: Making and breaking bonds

It is possible to calculate how much energy **should** be produced when a fuel is burned by considering which bonds are broken or made.



By referring to bond energy data and adding up the energy used to break all the bonds in the reactants and the energy released in making all the bonds in the products, you can calculate the energy change when ethanol burns.

$$CH_3CH_2OH + 3\,O_2 \rightarrow 2\,CO_2 + 3\,H_2O$$



Overall energy change = energy used in breaking bonds + energy produced in making bonds
(positive) (negative)

1. Calculate the energy change when ethanol burns using the bond energy data below.
2. Compare your calculated value with the result for your experiment. Give some reasons why the two results are so very different.
3. Plot a suitable graph of the number of carbon atoms in the fuel and the energy given out.
4. What relationship can you see and can you explain it?

Type of bond	Bond energy in kJ/mol
C-H	413
C-C	347
C-O	358
O-H	464
O=O	498

C=O	805