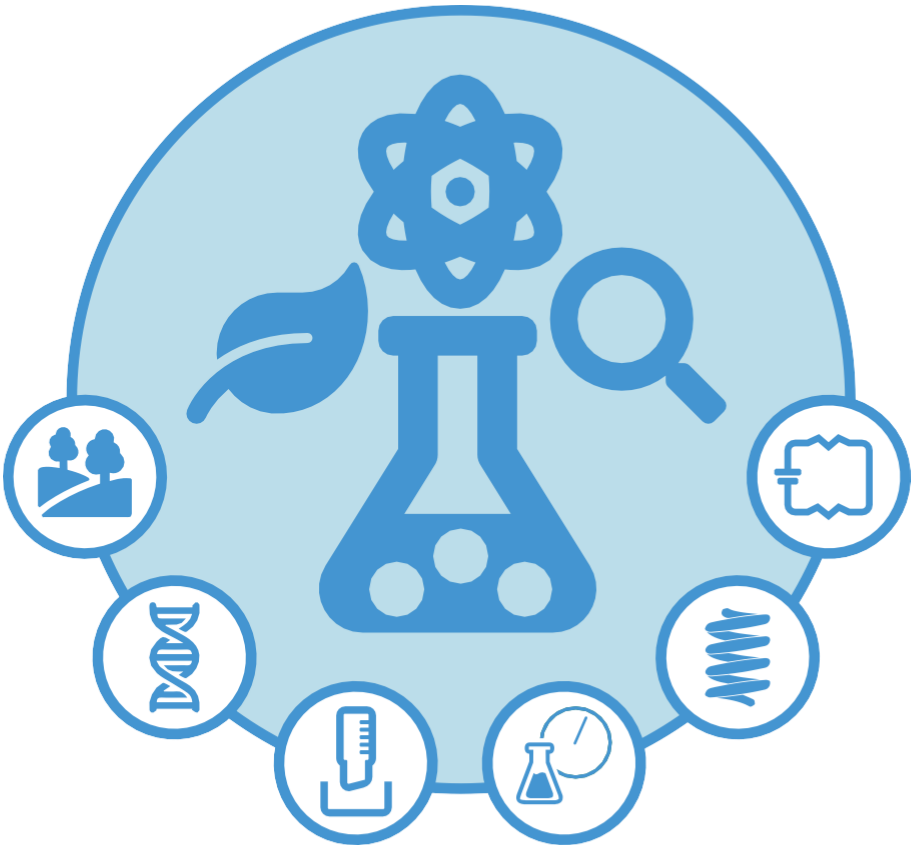
EXEMPLAR LESSON

OpenSTEM Africa

CALORIMETRY:
COMBUSTION OF ALCOHOLS



Acknowledgements

Ministry of Education

The Ministry of Education, Ghana, for their oversight, support and guidance which has been essential in ensuring that OpenSTEM Africa aligns with and complements other education initiatives and programmes.

CENDLOS, Ghana, for their collaboration and innovation in providing essential avenues for OpenSTEM Africa to reach learners and teachers.

Ghana Education Service, and the expert SHS science teachers, for their expertise in producing materials that are rooted in the Ghanaian school context, accessible and useful to learners and teachers.

For information on OpenSTEM Africa see: www.open.edu/openlearncreate/OpenSTEM_Africa

OPITO for their generous support, which has made OpenSTEM Africa and the development of the Virtual Laboratory and these materials possible.

Contents

Exemplar lessons for the OpenSTEM Africa Virtual Laboratory applications

All the exemplar lessons are examples of lessons which could be used both individually and by whole classes of Senior High School (SHS) students in the elective sciences of Biology, Chemistry and Physics. Each of the lessons is linked specifically to one of the applications in the OpenSTEM Africa Virtual Laboratory. The exemplar lesson is created to give, both to SHS students and to SHS teachers, a clear example of the ways in which the applications can be used in the learning and teaching of practical science. There is a focus throughout the lesson on the student's development of the practical and experimental skills which, along with knowledge and understanding, are integral to the profile of learning, teaching and assessment in SHS sciences.

The 'you' in this lesson is 'you', the Senior High School student. Remember that you can repeat the experiments and activities in this lesson as often as you have time for in class. This freedom to repeat experiments and activities is also important if you are accessing the lesson outside the classroom, for example for homework. Every application in the OpenSTEM Africa Virtual Laboratory contains real data – the experiments are real experiments. This means you might make mistakes the first or second or third time you try an experiment or an activity – and that is exactly what often happens in the real world in the sciences. So, it is helpful for you as a student to share in some of the real-world trial and error of science as you develop your skills as a scientist.

The exemplar lesson also contains a set of teaching notes at the end of this document for 'you' the SHS science teacher, to suggest how you might want to set up this particular lesson with one of your classes. Hopefully it will also generate ideas for other lessons on the same topic, or other lessons which use the same OpenSTEM Africa Virtual Laboratory application.

Calorimetry: combustion of alcohols

Lesson objectives

By the end of this lesson, you will be able to:

- Understand the terms ‘chemical energy’ and ‘enthalpy change’.
- Differentiate between exothermic and endothermic reactions and understand the energy transfer involved in a combustion reaction.
- Write balanced chemical equations for the combustion of alcohols.
- Determine the heat of combustion of alcohols using calorimetry experiments.

The following practical and experimental skills will be developed:

- Taking measurements of mass and temperature
- Recording quantitative data
- Carrying out enthalpy change calculations
- Interpreting results
- Identifying sources of errors in a calorimetry experiment.

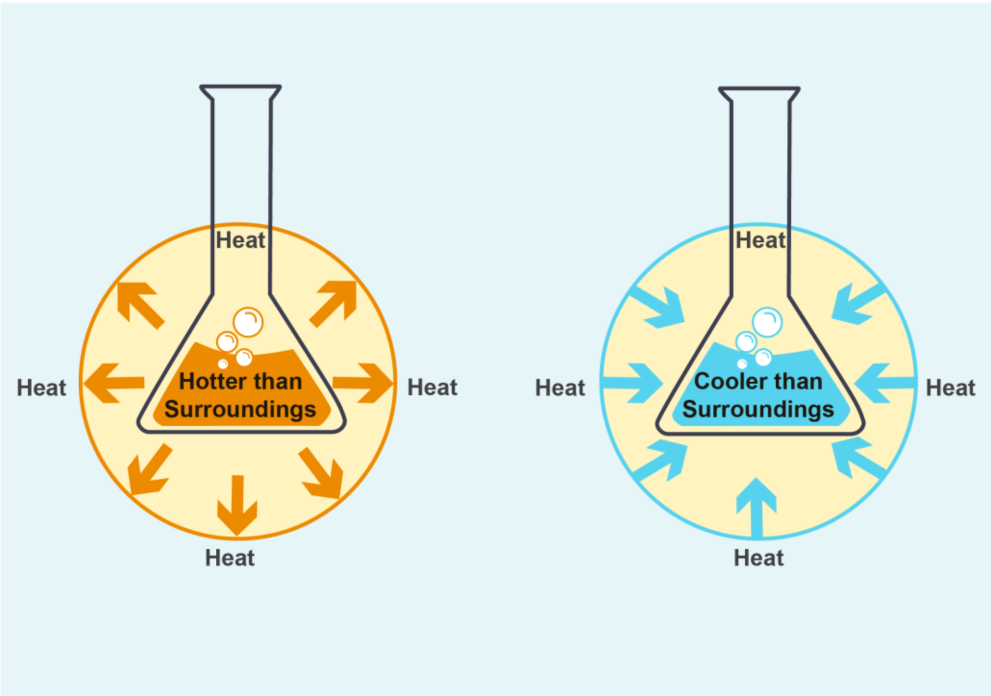
Background

Chemical reactions and energy changes

In our everyday lives we depend on chemical reactions to provide our energy needs: burning fuels for heating, transport and cooking, and in our bodies where a multitude of chemical reactions keep us alive.

A chemical reaction involves a substance undergoing a change which alters its chemical composition. During a chemical reaction, bonds are broken in the reactants and new bonds are formed in the products. Breaking bonds requires energy whereas making bonds releases energy. The net difference between the bond-breaking and bond-making processes accounts for the energy changes during the chemical reaction.

If more energy is released when the bonds are made than is required to break bonds, energy will be released into the environment – these are called **exothermic** reactions. If the opposite is true and more energy is required to break the reactant bonds than is released when the product bonds are formed, energy must be absorbed from the environment. These are called **endothermic** reactions. Figure 1 illustrates the difference between exothermic and endothermic reactions in terms of heat energy.



(a) (b)

Figure 1. (a) An exothermic reaction releasing energy (in the form of heat) to surroundings, and (b) an endothermic reaction absorbing energy from surroundings.

Think of examples of exothermic and endothermic reactions
Go to Appendix 3 for the answer.

Enthalpy changes of chemical reactions

The chemical energy involved in reaction is called **enthalpy change**. For a given substance the **enthalpy** can be thought of as a kind of energy store that provides, or accepts, energy in the form of heat. The symbol for enthalpy of a substance is written as H.

For a chemical reaction the heat released, or absorbed, is a measure of the difference in energy between reactants and products (under the same conditions of temperature and pressure). The enthalpy change of a chemical reaction is written as ΔH, where Δ (the upper-case Greek letter delta) means 'change of' and can be calculated as:

$$\Delta H = H(\text{products}) - H(\text{reactants})$$

This equation says that the heat released, or absorbed, by the chemical reaction is equal to the difference between the enthalpy of the products and the enthalpy of the reactants. Since an enthalpy change represents the heat transferred in a chemical reaction, the appropriate SI unit is the **joule** (J).

In an exothermic reaction, the products have lower energy than the reactants and the reaction releases energy in the form of heat to the surroundings. Therefore, ΔH is negative ($\Delta H < 0$) for an exothermic reaction. Figure 2 shows a schematic representation of the energy changes occurring in both exothermic and endothermic reactions.

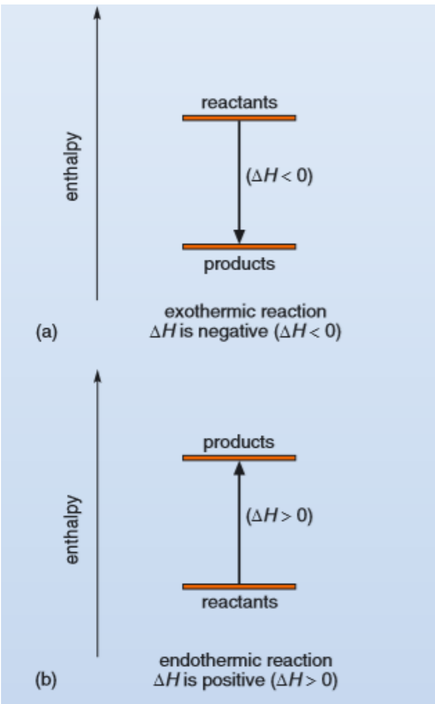


Figure 2. Enthalpy diagrams for (a) an exothermic reaction, where ΔH is negative, and (b) an endothermic reaction, where ΔH is positive. The vertical axes represent enthalpy (H), increasing upwards, and the enthalpies of reactants and the enthalpies of products are represented by different levels on the axes.

Combustion of alcohols

Alcohols are **organic compounds** containing the **hydroxyl** (-OH) **group** that are widely used in our lives and are among the most abundantly produced chemicals in industry.

Alcohols can be classified as primary, secondary, and tertiary depending on the position of the hydroxyl group. The hydroxyl group is attached to a carbon with at least two hydrogen atoms in a primary alcohol, to a carbon with only one hydrogen atom in a secondary alcohol, and to a carbon with no hydrogen atoms in a tertiary alcohol (as shown in Figure 3).

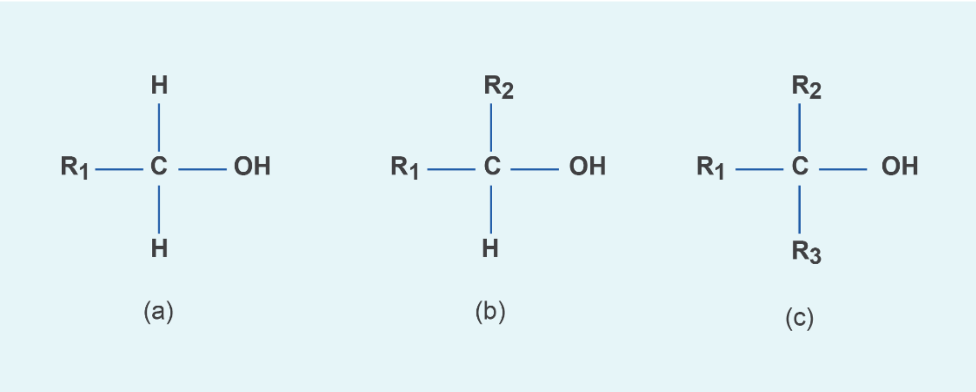
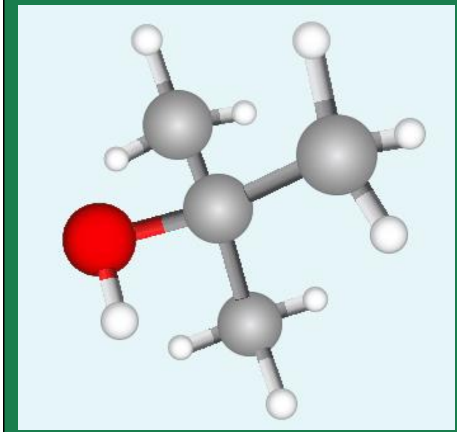


Figure 3. Generic structural formula of (a) primary alcohol, (b) secondary alcohol, and (c) tertiary alcohol. The letter R represents an atom or group of atoms.

You may have come across the term **alkanol**. Alkanol is a type of alcohol with very specific R groups; the Rs are alkane compounds in alkanols. **Alkanes** are compounds containing only carbon-carbon single bonds and carbon-hydrogen bonds (examples are methane, ethane, propane). The classification of alcohols shown in Figure 3 also applies to alkanols.

When naming the simple alcohols in this lesson, you should start by identifying the longest straight carbon chain containing the hydroxyl group. The name of the alkane corresponding to the longest chain is used without the final '-e' and adding instead the suffix '-ol'. The carbon atoms in the chain should be given a number considering that the carbon attached to the hydroxyl group should have the lowest possible number. If any branch (or group of atoms) is identified of the main chain, you will indicate it in the name of the alcohol as well as its position.

Name the tertiary alcohol below. The image shows its ball and stick model with carbon atoms represented by grey balls, hydrogen atoms by white balls and the oxygen atom by a red one.



Structure 1

Go to Appendix 3 for the answer.

Complete the table below.

Alcohol	**Molecular formula**	**Structural formula**	**Type of alcohol**
Methanol			
Ethanol			
Propan-1-ol			
Propan-2-ol			
Butan-1-ol			
2-methylbutan-2-ol			

Table 1 Chemical formulas of different types of simple alcohols

Go to Appendix 3 for the answer.

What are the differences between propan-1-ol and propan-2-ol?

Go to Appendix 3 for the answer.

Alcohols are of interest as alternatives to conventional non-renewable fossil fuels (such as coal, crude oil and natural gas). Alcohols are highly flammable and can undergo **combustion**. Combustion is a reaction in which a substance reacts with oxygen to give carbon dioxide (CO_2), water (H_2O) and heat energy. All combustion reactions are exothermic.

In particular, low **molecular weight** alcohols (such as methanol and ethanol) are considered attractive alternatives to fossil fuels because they can be produced at low cost (e.g., methanol can be synthesised industrially from biomass like plants, fruits and animal waste using bacteria). Additionally, alcohol-fuels are a more environment friendly energy source and their use will help to reduce emissions of **greenhouse gases** and toxic gases (mitigating climate change). These alcohols have the potential to become the transportation fuel instead of gasoline.

Write the balanced chemical equation for the complete combustion of ethanol, CH_3CH_2OH.
Go to Appendix 3 for the answer.

Calorimetry

Enthalpy changes can be measured experimentally. The amount of heat energy being transferred during a chemical reaction can be measured using a **calorimeter**. The basic principle of **calorimetry** is that energy transferred during a reaction (as heat) causes the water in the surroundings to increase its temperature (for exothermic reactions) and decrease its temperature (for endothermic reactions).

In the OpenSTEM Africa Calorimetry application you will use a simple calorimeter to compare the heat energy released from burning various alcohols. The efficiency of alcohol fuels will be investigated by measuring how much alcohol is required to raise the temperature of a fixed volume of water by a number of degrees Celsius.

The calorimeter consists of a conical flask containing a known volume of water over an alcohol burner (Figure 4). The change in the temperature of water during combustion is measured using a thermometer and it is a direct measure of the alcohol energy content. The alcohol burner is weighed before and after the combustion to calculate the mass of alcohol burned in order to heat the water.

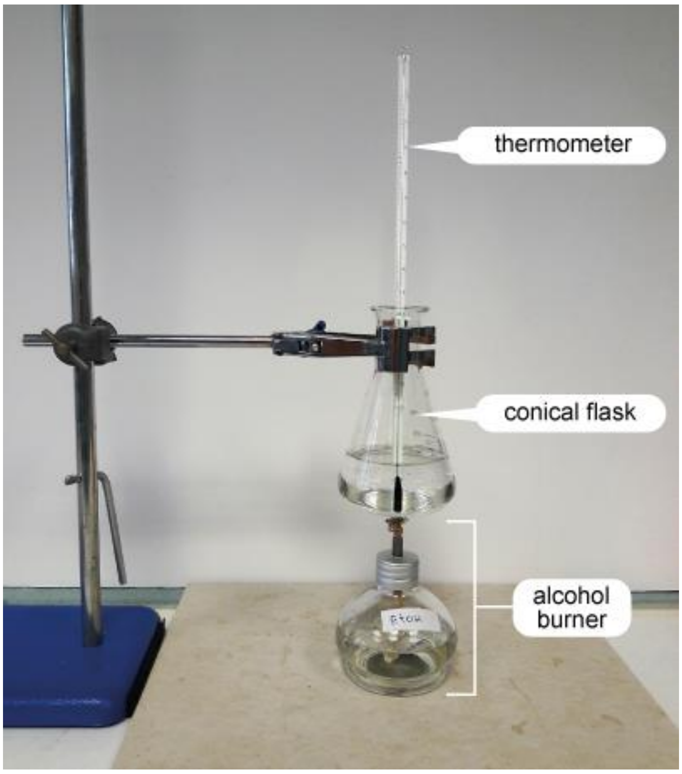


Figure 4. Simple calorimeter used to determine heat energy released in the combustion of alcohols.

Think about the major source of error when using the simple calorimeter shown in Figure 3.
Go to Appendix 3 for the answer.

Calculating enthalpy changes

To calculate the energy transferred from the combustion of alcohols to the water (q) you will use the equation:

$$q = m\,c\,\Delta T$$

where m is the mass of water in the conical flask, c is the **specific heat capacity** of water (4.18 J g^{-1} $^{o}C^{-1}$) and ΔT is the increase in the temperature of water.

Remember that the density of water is 1 kg/l so if you are using a volume of 100 ml of water in your experiment, this volume is equal to 100 g of water.

The experimental enthalpy of combustion of an alcohol (ΔH) will be calculated dividing the energy transferred to the water (q) by the moles of alcohol burned in the reaction (n):

$$\Delta H = -\,q/\,n$$

Why does the energy change (ΔH) for combustion have a negative value?
Go to Appendix 3 for the answer.

Now work through an example calculation to check your understanding of the steps require to determine experimental values of enthalpy of combustion.

A spirit burner with ethanol (C_2H_5OH) was used to heat 100.0 ml of water. When the temperature of water had increased 40.0°C, the mass of the burner and ethanol has decreased by 0.980 g. Calculate the experimental enthalpy change of combustion for ethanol.
Go to Appendix 3 for the answer.

Practical activity

In this online experiment you will determine the energy released in the combustion of various alcohols.

Task 1: You will perform a series of calorimetry experiments for 4 alcohols: methanol, ethanol, propan-2-ol and butan-1-ol.

Task 2: Using the data of your calorimetry experiments, you will compare the heat energy released from burning different alcohols.

Task 1: Calorimeter experiments

You will now carry out your calorimetry experiments. Remember that all your data should be recorded in your laboratory notebook. The change in the temperature of water during combustion is measured using a thermometer and it is a direct measure of the alcohol energy content. The alcohol burner is weighted before and after the combustion to calculate the mass of alcohol burned to heat the water.

Detailed instructions are provided within the experiment. In preparation for the experiment read and reflect on the following summary of the steps you will need to take:

1. Choose an alcohol from the list provided.
2. Weigh the burner containing the selected alcohol (with its cap on) and record the initial mass.
3. Place the burner under the flask and remove its cap.
4. Add 100 ml of tap water into the conical flask.
5. Record initial temperature of the water.
6. Use the lighter to light the wick.
7. Gently stir the water with the thermometer to ensure uniform temperature throughout.
8. When the temperature of water has increased by a number of degrees, the flame is extinguished by placing the cap on the burner. Note that the increase in temperature of water should be kept constant for all your trials; any increase by 20 to 60 ^oC will provide you with suitable data.
9. Record the final temperature of water.
10. Reweigh alcohol burner (with its cap on) and record the final mass.
11. Repeat steps 1–10 at least twice for each alcohol. The water in the conical flask will be refreshed each time. Keep the increase of water temperature by a constant number of degrees in your trials. In this interactive screen experiment you do not need to worry about other variables that are already kept constant (such as the volume of water added to the conical flask and the distance between the wick and the bottom of the conical flask).

Planning your experimental work will help your experiments to run smoothly in the virtual laboratory.

Table 2 shows a template you could use to record your observations.

Alcohol	**T water at start / °C**	**T water at end / °C**	**ΔT / °C**	**Mass of alcohol plus burner at start / g**	**Mass of alcohol plus burner at end / g**	**Mass alcohol burned / g**
Methanol						
trial 1						
trial 2						
Ethanol						
trial 1						
trail 2						
Propan-2-ol						
trial 1						
trial 2						
Butan-1-ol						
trial 1						
trial 2						

Table 2 Calorimeter data for combustion of alcohols.

Calorimetry: combustion of alcohols

Go to the OpenSTEM Africa Virtual Laboratory.

Click on the icon to access the Calorimetry application homepage.

Watch the introductory video before entering the experiment.

Task 2: Data analysis and discussion

Use your data from Task 1 to calculate your experimental values of enthalpy change of combustion for those different alcohols. Table 3 shows a template you could use to record your values.

ΔT = °C		
Alcohol	**Mass burned/g**	**ΔH combustion/ KJ mol^{-1}**
Methanol		
Ethanol		
Propan-2-ol		
Butan-1-ol		

Table 3 Experimental values of enthalpy change of combustion for various alcohols.

Now let's discuss your enthalpy change of combustion values for different alcohols and compare your data of enthalpy change of combustion to those in the Handbook of Chemistry and Physics (the largest comprehensive physical science data source available).

Compare the experimental combustion enthalpy values for all four alcohols. Can you explain the pattern observed in your data?
Go to Appendix 3 for the answer.

Which are more efficient fuels shorter or longer chain alcohols?
Go to Appendix 3 for the answer.

Predict the energy during combustion of propan-1-ol
Go to Appendix 3 for the answer.

Table 4 shows handbook data for the enthalpy changes in the combustion of various alcohols. Compare these values to your experimental values and calculate the efficiency (in %) of the simple calorimeter used in this investigation.

Table 4 Combustion enthalpy changes for alcohols

Alcohol	**ΔH combustion/ KJ mol^{-1}**
Methanol	-715
Ethanol	-1371
Propan-2-ol	-2010
Butan-1-ol	-2673

Data from CRC Handbook of Chemistry & Physics

Suggest improvements that you could be made to the experiment set-up to obtain experimental values closer to the theoretical values in Table 4.

Go to Appendix 3 for the answer.

Summary

The basic principle of calorimetry instrumentation is that energy produced during combustion is absorbed by water and thus increases its temperature. The overall energy required to break and make bonds (also known as enthalpy) can be measured using a calorimeter.

In this experiment you have used a simple calorimeter to compare the heat energy from burning various alcohols. The change in the temperature of water during combustion is measured using a thermometer and it is a direct measure of the alcohol energy content. The alcohol burner is weighted before and after the combustion to calculate the mass of alcohol burned to heat the water.

You calculated the experimental enthalpy changes in the combustion of an alcohol dividing the energy transferred to the water by the moles of alcohol burned in the reaction, and by comparing your experimental data from various alcohols you will be able to determine the efficiency of these fuels.

Quiz

Answer the questions, then search for the correct answers in Appendix 4.

Question 1

For each of the questions below select the correct answer:

1. Which of the following is an example of exothermic reaction?

    a) Photosynthesis

    b) Melting ice

    c) Combustion

2. Which of the following alcohols is an alkanol?

    a) 1-propenol

    b) Ethanol

    c) Phenol

3. Which of the following reaction is balanced combustion reaction of propan-1-ol?

    a) $2\ C_4H_9OH(l) + 12\ O_2(g) \rightarrow 8\ CO_2\ (g) + 10\ H_2O(g)$

    b) $C_3H_7OH(l) + 5\ O_2(g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O(g)$

    c) $2\ C_3H_7OH(l) + 9\ O_2(g) \rightarrow 6\ CO_2\ (g) + 8\ H_2O(g)$

Question 2

How many moles of propanol are in 1.42 g of propanol? Complete the paragraph below by selecting one option to fill in the gap.

There are ______moles of ethanol in 1.42 g of propanol.

[0.0237, 0.237, 85.2]

Question 3

Which of the following statements is correct?

1. The enthalpy change of a chemical reaction is positive for exothermic reactions.
2. The experimental enthalpy change of the combustion of an alcohol is calculated dividing the heat energy transferred to the water by the grams of alcohol burned in the reaction.
3. Enthalpy changes can be determined experimentally using a calorimeter.

Glossary

Alcohol – Organic compound containing the hydroxyl (-OH) group.

Alkanes – Organic compounds containing only carbon-carbon single bonds and carbon-hydrogen bonds.

Alkanol – Type of alcohol derived from alkanes.

Calorimeter – Device used to determine the energy involved in a chemical process.

Calorimetry – Field of science that measures the heat given out or taken in by a chemical process.

Combustion reaction – Fuel is burned and reacts with oxygen to release energy.

Endothermic reaction – Chemical reaction that takes energy from the surroundings.

Enthalpy – Chemical energy store in a given substance.

Enthalpy change – Chemical energy involved in a reaction or difference in chemical energy between reactants and products.

Exothermic reaction – Chemical reaction that transfer energy to the surroundings.

Fuel – Substance that reacts exothermically with oxygen releasing energy when it burns.

Greenhouse gases – Gases (such as carbon dioxide, methane, nitrous oxide, ozone) responsible for trapping heat in Earth's atmosphere.

Homologous series – Family of organic compounds that have the same functional group and similar chemical properties.

Hydroxyl group – Group of atoms or functional group (-OH) determining the main chemical properties of alcohols.

Isomers – Molecules with the same number but a different arrangement of atoms.

Joule – SI unit of energy or work, written as J.

Molecular weight – mass of a molecule of a substance, calculated in practice by summing the atomic weights of the atoms making up the substance's molecular formula.

Organic compounds – Large class of chemical compounds in which one or more atoms of carbon are covalently linked to atoms of other elements (most commonly hydrogen, oxygen, or nitrogen).

Specific heat capacity – Amount of energy needed to raise the temperature of 1 Kg of substance by 1 ^{o}C.

Appendix 1: Teacher notes – organisation of the lesson

Teaching notes for the Combustion of alcohols application and the exemplar lesson on enthalpy change of combustion for various alcohols.

Combined with using the Calorimetry: Combustion of alcohols application, this lesson links to the following units in the Teaching Syllabus for Chemistry:

- SHS 1 Section 1 Introduction to chemistry, Unit 2: Measurement of Physical quantities
- SHS 1 Section 4 Conservation of matter and stoichiometry, Unit 3: Stoichiometry and chemical equations
- SHS 2 Section 1 Energy and energy changes, Unit 1: Energy changes in physical and chemical processes
- SHS 2 Section 1 Energy and energy changes, Unit 2: Energy cycles and bond enthalpies
- SHS 2 Section 6 Chemistry of carbon compounds, Unit 9: Alkanols
- SHS 3 Section 1 Chemistry, Industry and environment, Unit 4: Environmental pollution

Ideas for organising this exemplar lesson link directly to activities and teaching examples in the OpenSTEM Africa CPD units *Organising practical work, Collaborative learning*, *Linking Science to everyday life* and *Using ICT to support learning***.**

Overview

If it can be arranged through your Head of Science and the Head of ICT, this lesson should take place in the ICT Lab in your school. If the lesson takes place in the ICT Lab, it may be possible for each student to work individually at a computer; otherwise divide the class so that students are in small groups at a computer.

If it isnot possible to use the ICT Lab for this lesson, then try to set up this lesson in your classroom. You may be lucky enough in your school to have a set of 'empty' tablets or mobile phones which students can use. Or you may be able to bring a laptop connected to the internet or to your school intranet – and perhaps connected to a projector to make it possible for the whole class to view at once. If access to ICT is a real challenge in your school but you want your students to view an experiment, you might be able demonstrate it to small groups of your students at a time using your own mobile phone.

Whatever way(s) you set up the class, it would still be helpful to the students to be able to work in pairs or small groups for at least some of the lesson. Do remember as well that students need desk space to be able to write in their notebooks and to draw diagrams.

Steps in Organising the lesson

Step 1: This takes place in the lesson before the one where you and your class access the OpenSTEM Africa Virtual Laboratory Calorimetry (Combustion of alcohols). Have students work in pairs to pre-read the Background section of the exemplar lesson. They should ask each other the questions in the Background section and check with each other that each understands the answers. You may want students to complete their reading of the Background section for homework or continue into a second lesson. If you do allocate more than one lesson to the Background work, consider changing the pairs of students around. In that way each student can check their understanding of what they have learned with a new partner. While they are doing so, you may want to walk round the class, checking they understand the terms chemical energy, enthalpy change and distinguish between exothermic versus endothermic reactions. It is important that students can identify alcohols and understand combustion reactions. Understanding how to determine the enthalpy changes of combustion using data from calorimetry experiments is essential for successful completion of the lesson.

Step 2: At the beginning of this exemplar lesson, check students' understanding of relevant chemistry by asking (again!) the questions in the Background section. You could organise the class to work in the same pairs as in the previous lesson or change them again. Have each person in the pair create the tables for their experimental data in their own laboratory notebook in preparation for their data collection from the practical activity.

Step 3: Within each pair, have them check each other's work and that each has set the tables out correctly with the correct headings.

Step 4: Make sure that each pair has access to/can see the computer screen to begin the actual investigation and observation and carry out the calorimeter experiments. Ensure that each pair knows how to perform the experiments – or if you are using a laptop/projector, that you draw on the expertise of the class as you go through each step of the investigation, weighting the burners, recording values of temperature of water, selecting a constant increase of temperature of water, running at least two trials per alcohol – i.e., ask them what the next step is.

Step 5: Have the class follow the instructions. Make sure, if working in a pair on a PC, that each student in the pair gets to follow all the steps; if working in a group on a PC, have the group leader ensure that everyone in the group is involved.

Step 6: Ten minutes before the end of the lesson, tell the students to complete the quiz.

Appendix 2: Teacher notes – outputs from the lesson

Task 1

Initial weight of each alcohol burner will be slightly different for each student. Table below summarizes data of mass of alcohol burned for different increases of temperature (any increase between 20 to 60 ^{o}C will provide students with suitable data).

Due to lab safety issues and/or deviations from the procedure that could introduce experimental error, there are some alerts appearing in the application and advising students in various situations (e.g., lighting the wick without water in conical flask, water getting too hot if temperature goes above 85 ^{o}C, moving alcohol burner with lighted wick, water not being stirred before taking temperature readings and keeping cap off burner without lighted wick for over 1 minute).

Expected range of calorimeter data for combustion of alcohols at different increases of temperature.

Alcohol	ΔT / ^{o}C	*Mass alcohol burned / g
methanol		
	20	0.71
	40	1.43
	60	2.06
ethanol		
	20	0.56
	40	1.12
	60	1.59
propan-2-ol		
	20	0.51
	40	0.95
	60	1.42
butan-1-ol		
	20	0.43
	40	0.82
	60	1.28

**Average values for five trials*

Students should supply data from at least two replicates and present average of theses for their selected increase of temperature.

Task 2

Students will calculate the ΔH combustion value for each alcohol.

Expected set of experiment data for the combustion of alcohols (at ΔT of 20 ^oC).

Alcohol	**ΔH combustion/ KJ mol^{-1}**
Methanol	380
Ethanol	697
Propan-2-ol	1045
Butan-1-ol	1393

Students should comment on the disparity between their experimental data and the data published in the Handbook of Chemistry and Physics. Ensure students discuss the limitations of the simple experimental set up identifying the major source of errors and suggesting some improvements.

Appendix 3: In-text question answers

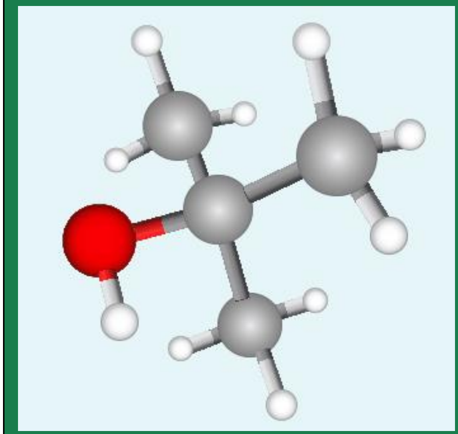
Think of examples of exothermic and endothermic reactions

Answer:

Exothermic reactions releases energy to the surroundings in the form of heat; some examples of exothermic reaction are burning of a substance, explosions, rusting of iron, nuclear fission, cellular respiration.

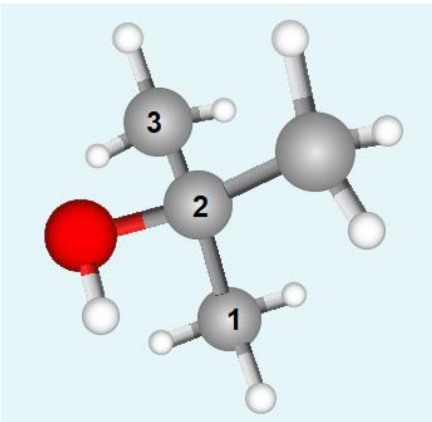
On the other hand, endothermic reactions absorb energy from the surroundings in the form of heat; some examples of endothermic reaction are evaporating liquids, melting solids, photosynthesis,

Name the tertiary alcohol below. The image shows its ball and stick model with carbon atoms represented by grey balls, hydrogen atoms by white balls and the oxygen atom by a red one.



Structure 1

Answer: 2-methylpropan-2-ol

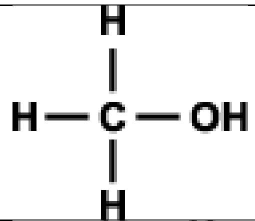
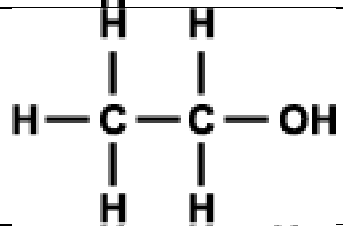
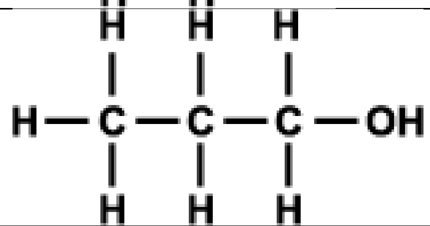
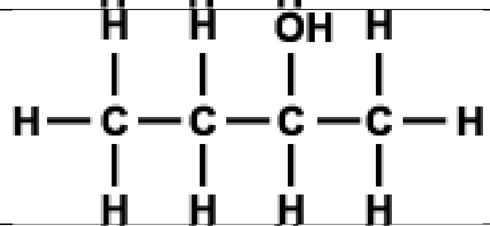
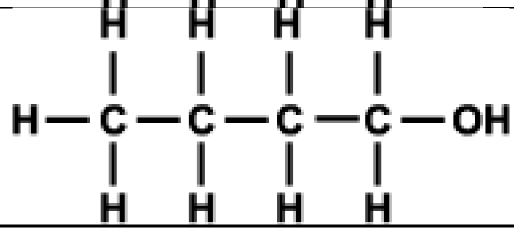


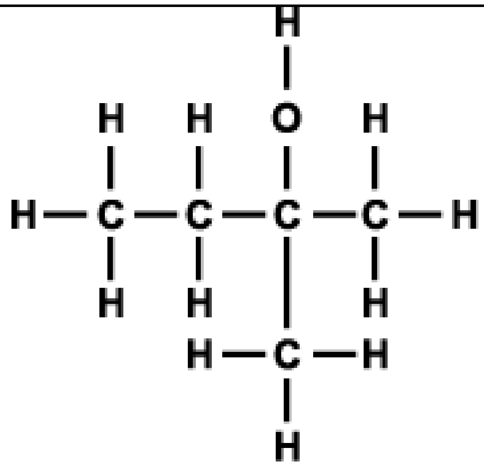
Complete the table.

Table 1 Chemical formulas for some simple alcohols.

Alcohol	Molecular formula	Structural formula	Type of alcohol
Methanol			
Ethanol			
Propan-1-ol			
Propan-2-ol			
Butan-1-ol			
2-methylbutan-2-ol			

Answer:

Alcohol	Molecular formula	Structural formula	Type of alcohol
Methanol	CH_3OH		Primary
Ethanol	C_2H_5OH		Primary
Propan-1-ol	C_3H_7OH		Primary
Propan-2-ol	C_3H_7OH		Secondary
Butan-1-ol	C_4H_9OH		Primary

2-methylbutan-2-ol	$C_5H_{11}OH$		Tertiary

What is the differences between propan-1-ol and propan-2-ol?

Answer:

Propano-1-ol and propan-2-ol are alcohols with the same molecular formula but they have a different arrangement of atoms in the molecule and consequently different chemical properties. They are **isomers**.

Write the balanced chemical equation for the complete combustion of ethanol, CH_3CH_2OH.

Answer:

$CH_3CH_2OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$

Think about the major source of error when using the simple calorimeter shown in Figure 2.

Answer:

Heat loss to the surroundings is a large source of error in this experiment. More sophisticated, commercially available calorimeters have a thermally insulated container to avoid this.

Why does the energy change (ΔH) for combustion have a negative value?

Answer:

The combustion of alcohols is an exothermic reaction and energy is given out and transferred to the surroundings; so the enthalpy change of this reaction has a negative value.

A spirit burner with ethanol (C_2H_5OH) was used to heat 100.0 ml of water. When the temperature of water had increased 40.0°C, the mass of the burner and ethanol has decreased by 0.980 g. Calculate the experimental enthalpy change of combustion for ethanol.

Answer: The energy transferred to the water is calculated as:

$q = m\ c\ \Delta T$

where m is the mass of water in the conical flask, c is the specific capacity of water (4.18 J $g^{-1}\ {}^{o}C^{-1}$) and ΔT is the increase in the temperature of water.

$q = 100.0\ g \times 4.18\ J\ g^{-1}\ {}^{o}C^{-1} \times 40.0\ {}^{o}C = 16720\ J = 16.72\ KJ$

In the experiment 0.980 g of ethanol burned. The amount of ethanol burned should be converted from grams into moles.

Molar mass of $C_2H_5OH = (12 \times 2) + (1 \times 5) + 16 + 1 = 46\ g\ mol^{-1}$

Number of moles of C_2H_5OH burned $= 0.980\ g / 46\ g\ mol^{-1} = 0.0213$ moles of ethanol

Next the enthalpy of the combustion is calculated as:

$\Delta H = -q/\ n$

$\Delta H = -16.72\ KJ/\ 0.0213\ moles = -784.98\ KJ\ mol^{-1}$

(Due to the uncertainty of the measurements, the value should be reported with only three significant figures, $\Delta H = -785$ KJ/mol).

Compare the experimental combustion enthalpy values for all four alcohols. Can you explain the pattern observed in your data?

Answer:

The difference in the combustion enthalpy between the alcohols in the series (methanol, ethanol, propan-2-ol and butan-1-ol) is very similar. This constant increase in the heat energy is due to the extra $-CH_2$ unit inserted in the chain as you pass through the series.

Which are more efficient fuels shorter or longer chain alcohols?

Answer:

The higher the number of carbon and hydrogen atoms per molecule of alcohol, the higher the combustion enthalpy – consequently the fuel is more efficient. You need to burn less mass of a longer chain alcohol to increase the temperature of a fixed volume of water by a certain number of degrees.

Predict the energy during combustion of propan-1-ol

Answer:

Propan-2-ol and propan-1-ol are isomers. Consequently, the net energy difference between the bond-breaking and bond-making processes in the combustion of both alcohols is very similar.

Table 4 shows handbook data for the enthalpy changes in the combustion of various alcohols. Compare these values to your experimental values and calculate the efficiency (in %) of the simple calorimeter used in this investigation.

Table 4 Combustion enthalpies changes for alcohols

Alcohol	**ΔH combustion/ KJ mol^{-1}**
Methanol	-715
Ethanol	-1371
Propan-2-ol	-2010
Butan-1-ol	-2673

Data from CRC Handbook of Chemistry & Physics

Suggest simple improvements that you could be made to the experiment set-up to obtain experimental values closer to the theoretical values in Table 4.

Answer:

In the example calculation for the combustion of ethanol previously discussed, the energy value obtained was -785 KJ mol^{-1}. According to the handbook, the energy value for ethanol should be closer to -1371 KJ mol^{-1}.

The efficiency of the simple calorimeter used here is calculated as:

% efficiency = (-785 KJ mol^{-1}/-1371 KJ mol^{-1}) x 100 = 57.3%

As discussed, the heat loss is a major source of error in this experiment (energy will be radiated away and used to heat up the container itself and the air). Additionally, the combustion of alcohol is not always complete and small quantities of the alcohol may also evaporate.

You could improve the experiment set-up by using a metal instead of glass beaker; metals (such as copper) are good heat conductors and would transfer more heat to the water. Putting a lid on the beaker would reduce heat lost after it has been transferred to the water. Enclosing the set-up or using screens would reduce the heat lost by elimination any drafts in the laboratory. Optimising the distance between the wick and the bottom of the conical flask could be also explored.

Appendix 4: Quiz answers

Correct answers are **highlighted in green**.

Question 1

For each of the questions below select the correct answer:

1. Which of the following is an example of exothermic reaction?

   a) Photosynthesis

   b) Melting ice

   c) **Combustion**

2. Which of the following alcohols is an alkanol?

   a) 1-propenol

   b) **Ethanol**

   c) Phenol

3. Which of the following reaction is balanced combustion reaction of propan-1-ol?

   a) $2\ C_4H_9OH(l) + 12\ O_2(g) \rightarrow 8\ CO_2\ (g) + 10\ H_2O(g)$

   b) $C_3H_7OH(l) + 5\ O_2(g) \rightarrow 3\ CO_2\ (g) + 4\ H_2O(g)$

   c) **$2\ C_3H_7OH(l) + 9\ O_2(g) \rightarrow 6\ CO_2\ (g) + 8\ H_2O(g)$**

Question 2

How many moles of propanol are in 1.42 g of propanol? Complete the paragraph below by selecting <u>one</u> option to fill in the gap.

There are _____moles of ethanol in 1.42 g of propanol.

[**0.0237**, 0.237, 85.2]

Feedback

Worked calculation:

Molar mass of propanol (C_3H_7OH) = (12 x 3) + (1 x 7) + 16 + 1 = 60 g mol^{-1}

Number of moles of propanol burned = 1.42 g / 60 g mol^{-1} = 0.0237 moles

Question 3

Which of the following statements is correct?

1. The enthalpy change of a chemical reaction is positive for exothermic reactions.
2. The experimental enthalpy change of the combustion of an alcohol is calculated dividing the heat energy transferred to the water by the grams of alcohol burned in the reaction.
3. **Enthalpy changes can be determined experimentally using a calorimeter.**

ACKNOWLEDGEMENTS

Grateful acknowledgement is made to the following sources:

- Ministry of Education logo, used with permission from Ghana Ministry of Education
- CENDLOS logo, used with permission from CENDLOS
- OPITO logo, used with permission from OPITO

Every effort has been made to contact copyright owners. If any have beeninadvertently overlooked, the publisher will be please to make necessary arrangements at the first opportunity.

OpenSTEM Africa