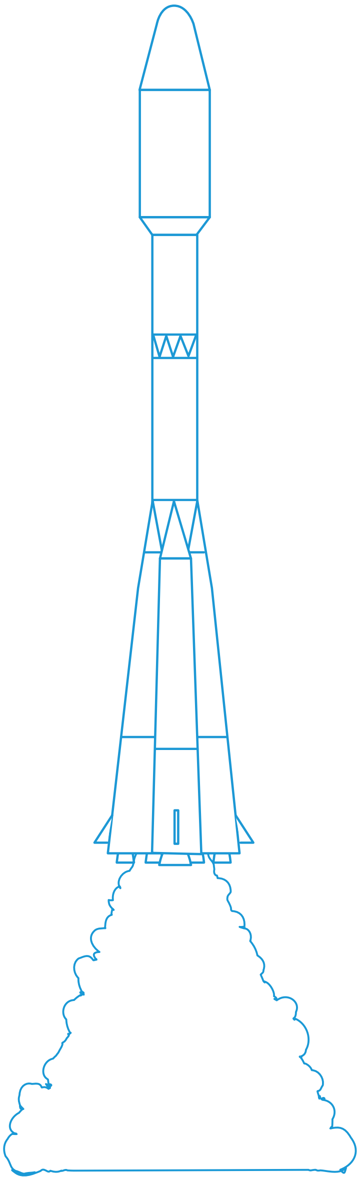
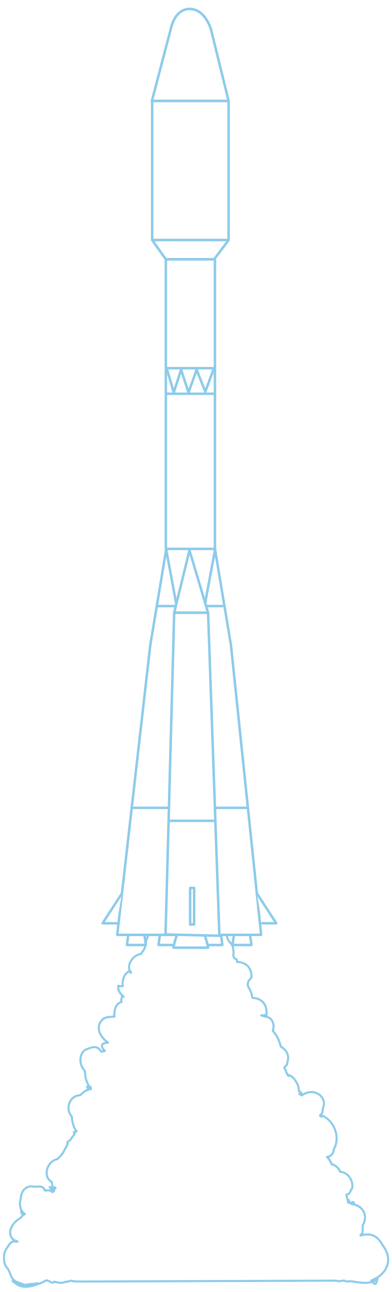
teach with space

→ MINI-WHOOSH BOTTLE

Using rockets to understand combustion reactions





→ MINI-WHOOSH BOTTLE

Using rockets to understand combustion reactions

FAST FACTS

Age range: 14-17 years old
Type: Practical activity
Complexity: Easy
Teacher preparation time: 20 minutes, to read through activity
Lesson time required: 45 minutes
Cost: Low (€0-5 per mini-whoosh bottle)
Location: Laboratory
Includes the use of: Highly flammable fuels (ethanol or other alcohols)

Outline

In this practical investigation, students will perform a combustion reaction using a mixture of alcohol and air in a plastic water bottle. The students will observe a rapid reaction accompanied by a dramatic 'whoosh' sound, simulating what happens when fuels are lit during a real rocket launch. Through answering a series of discussion questions, students will first conclude that combustion reactions are exothermic, before identifying the reactants and products of the reaction and considering different fuels. Students will also practice balancing chemical equations.

Students will learn

- How chemical rocket engines work
- That combustion is an exothermic reaction that requires fuel and an oxidiser
- How to write balanced equations for combustion reactions

Students will improve

- Their ability to apply knowledge gained through experimental observations to solve theoretical problems
- Their general experimental skills, including using equipment appropriately and making and re-cording observations
- Their ability to work safely in a laboratory

You will also need

↑ Mini-whoosh bottle – Classroom Demonstration Video

Curriculum links

- Chemistry – combustion reactions
- Physics – rocket launches, action/reaction forces

→ ACTIVITY 1: LIGHT YOUR BOTTLE

In this practical activity, students will set up a 'mini-whoosh bottle' to simulate the combustion reactions that take place in real rockets. Students will use small plastic bottles to do this safely, but the experiment can also be performed as a teacher demonstration, using a large water cooler type bottle.

The 'Mini-whoosh bottle – Classroom Demonstration Video (VC01)', available on ESA's Education website, shows how to set up and carry out this activity. This video can be used as a guide for students to set up their whoosh bottles. One option is to test many different fuels and compare their combustion. Ethanol works best as a fuel because it is more volatile than other types of alcohol with larger molecular weights (such as propanol or butanol). A related physics activity - 'Whoosh Bottle Classroom demonstration video (VP01)' is also available on ESA's Education website.

Equipment

(for one mini-whoosh bottle)

- 1 small plastic bottle (250 – 330 ml). It is important that each bottle has a lid. Empty water bottles are ideal.
- 1 ml of a fuel such as ethanol (and other alcohols if desired)
- Safety glasses for each student
- 1 pair of heavy duty gloves and long matches (only to be used by you)
- Heat proof mats

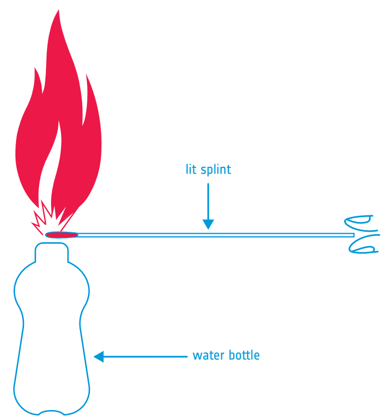
Health & safety

- Alcohol is highly flammable. Do not use near naked flames.
- Ensure that flammable chemicals, including all alcohols, are kept in stoppered containers when not in use.
- Safety glasses must be worn at all times.
- Verify that bottles are not damaged and do not appear to be brittle. If any cracks are present, use a different bottle.
- Always wear gloves when lighting the bottles. Do not hold your body over the top of the bottle.
- Follow the general safety control measures in the laboratory

Exercise

1. Issue students (or groups of students) with equipment.
2. Students should follow the instructions on their student activity sheets.
3. Travel around the classroom, lighting students bottles (Figure 1). Students should observe and consider what happens.
4. Students can repeat the experiment with different fuels to observe the differences during combustion. They could also repeat the experiment using a different plastic bottle.

Figure 1



↑ Lighting the mini-whoosh bottle

Answers to discussion questions

1. Explain why you think it is necessary to vaporise the alcohol first.
   Alcohol molecules that are in the vapour phase combust quicker than molecules that are in the liquid phase. This is because they are spread further apart in the container and have a much greater surface area for the reaction.

2. Describe what you see in the bottle at the end of the experiment.
   A colourless liquid.

3. State what substance you think this is. Without tasting or smelling anything, explain how you would test for this substance.
   The products of a complete combustion reaction are water and carbon dioxide. Since carbon dioxide is a gas and all the liquid fuel remaining was poured out of the bottle before the combustion took place, the liquid must be water.
   To test whether this liquid is water, add white anhydrous copper (II) to the liquid, which will turn it blue.

4. Write a word equation for this reaction.
   ethanol + oxygen ⟶ carbon dioxide + water

5. State whether this reaction is exothermic or endothermic. Justify your answer.
   Exothermic, because we observe light (flame) and hear the sound (whoosh) so we know energy is given off. Students can also carefully touch the bottle after the experiment to see that heat has been released during the reaction. The flame of the match provides the activation energy required for the reaction.

6. Identify the limiting factor in this reaction?
   The fuel.

7. Explain why you cannot repeat this experiment immediately after it has finished.
   The oxygen in the bottle will have been mostly used up in the reaction. So the bottle now contains the nitrogen left from the air and the carbon dioxide produced during the reaction. Neither of these supports combustion, so the reaction cannot be performed again straight away. It would be necessary to wait until the air in the bottle is recycled.

8. Explain how you could control or stop the combustion.
   The combustion process can be controlled or stopped by controlling the amount of fuel available, the amount of oxygen available, or the source of heat.

9. Discuss the similarities and differences of the reaction that occurs in the bottle to the reaction that occurs in rocket engines. Help yourself with this activity sheet, the internet, or you own knowledge.
   A rocket engine and the whoosh bottle both need a fuel and a chemical that plays the role of an oxidiser. The oxidiser is the chemical that reacts with the fuel in an exothermic manner (energy is given out during the reaction). For the whoosh bottle, the fuel (ethanol) is oxidised by oxygen in the air. The rocket engine has to operate outside the atmosphere and so must carry its own oxidiser. Rocket engines may use a variety of different solid and liquid propellants. A common fuel/oxidiser combination is liquid hydrogen and liquid oxygen, as used in the Ariane 5 Vulcain 2 engine. Both of these substances are normally gases at room temperature and therefore must be cooled to very low temperatures (cryogenic) before they become liquids.

→ ACTIVITY 2: COMBUSTION REACTION STUDY

In this activity, students will answer a series of questions to mathematically investigate the combustion reaction that they saw in activity 1.

Answers to questions

The following questions refer to the complete combustion reaction of ethanol, starting with 1 ml of ethanol. Assume that all of the fuel is used up in the reaction and ρ(ethanol) = 0.789 g/ml.

[Relative atomic masses: C = 12; H = 1.01; O = 16]

1. Write down the names of the reactants and products of the reaction.
   Reactants: ethanol and oxygen
   Products: carbon dioxide and water

2. Write a balanced symbol equation for this reaction.
   $C_2H_5OH_{(g)} + 3O_{2\,(g)} \longrightarrow 2CO_{2(g)} + 3H_2O_{(l)}$

3. What is the mass of the ethanol used in this reaction.
   m (ethanol) = 0.789 g

4. Calculate how many moles of each of the reactants and products are involved in this process.
   n (ethanol) = 0.01713 mol, n (oxygen) = 0.05139 mol
   n (carbon dioxide) = 0.03426 mol, n (water) = 0.05139 mol

5. Calculate the masses of each of the reactants and products.
   m (ethanol) = 0.789 g, m (oxygen) = 1.644 g
   m (carbon dioxide) = 1.507 g, m (water) = 0.926 g

6. Is the total mass of reactants and products the same? Explain your answer.
   m (reactants) = 2.433 g, m (products) = 2.433 g
   The law of mass conservation states that mass can neither be created or destroyed, so the total mass in reactants and products must be equal. (A slightly different value can be found due to rounding errors.)

7. In the real-life version of this experiment, explain whether the total mass of the products would be the same as the value you found in question 6.
   The law of conservation of mass is valid in closed systems. Considering that the mini-whoosh bottle is not a closed system (energy and matter are being transferred to the surroundings through steam) we would not find the same value for the mass of the products and for the initial mass of the reactants.

→ LINKS

ESA resources

Mini-whoosh bottle – Classroom Demonstration Video (VC01):
www.esa.int/spaceinvideos/Videos/2014/07/Mini_whoosh_bottle_-_classroom_demonstration_video_VC01

ESA classroom resources:
www.esa.int/Education/Classroom_resources

Solid and liquid fuel rockets:
www.esa.int/Education/Solid_and_liquid_fuel_rockets

ESA Kids introduction to rockets:
www.esa.int/esaKIDSen/SEMYWIXJD1E_Technology_0.html

Introduction to the Ariane 5 rocket:
www.esa.int/Our_Activities/Launchers/Launch_vehicles/Ariane_5

Ariane 5 resources

Information about the Ariane 5 rocket:
www.arianespace.com/vehicle/ariane-5/

Wikipedia entry for Ariane 5:
en.wikipedia.org/wiki/Ariane_5

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www.esa.int/education

The ESA Education Office welcomes feedback and comments
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