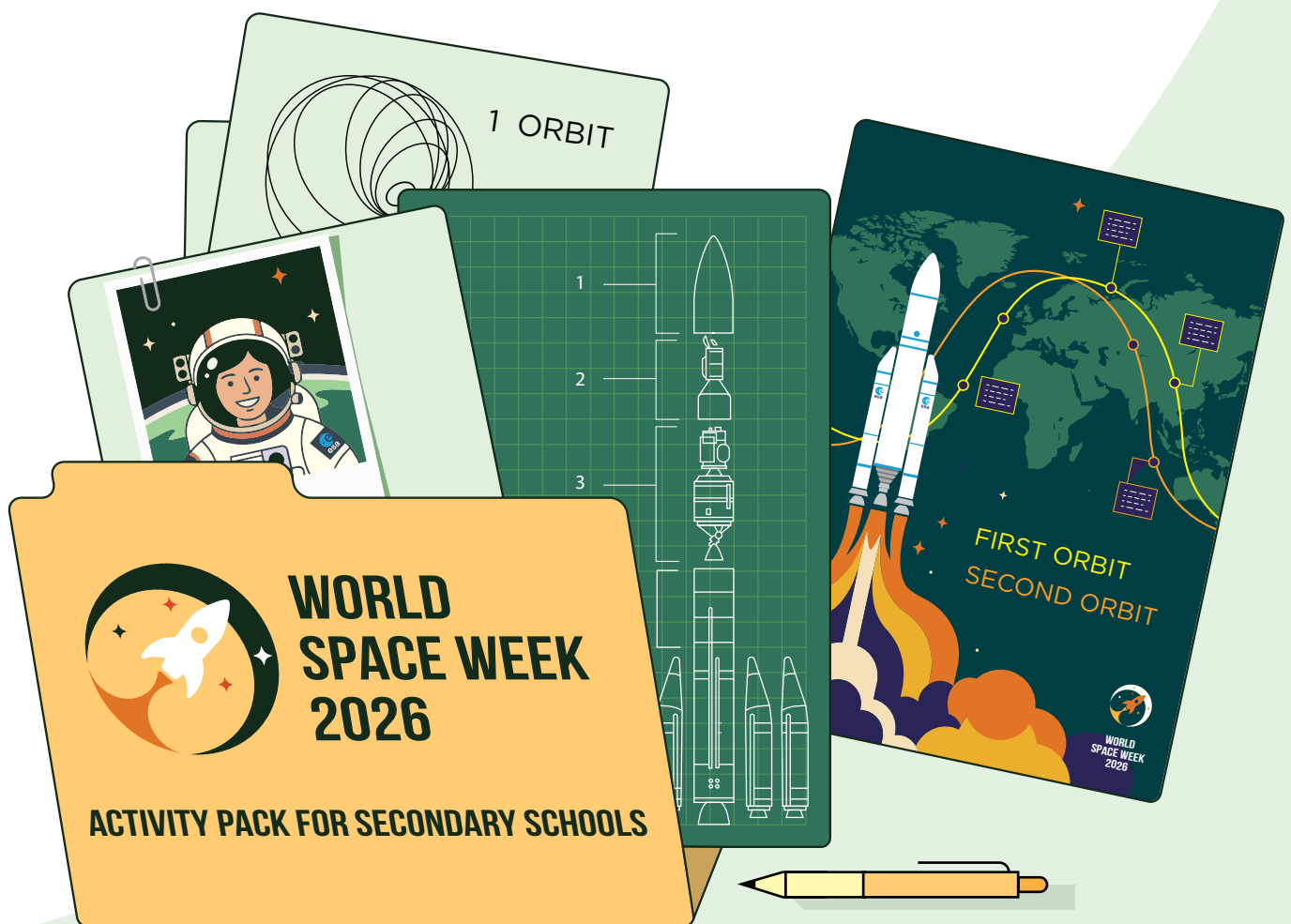


ESERO Ireland Space Week 2026 Second Level Schools & Youthreach



What is World Space Week?

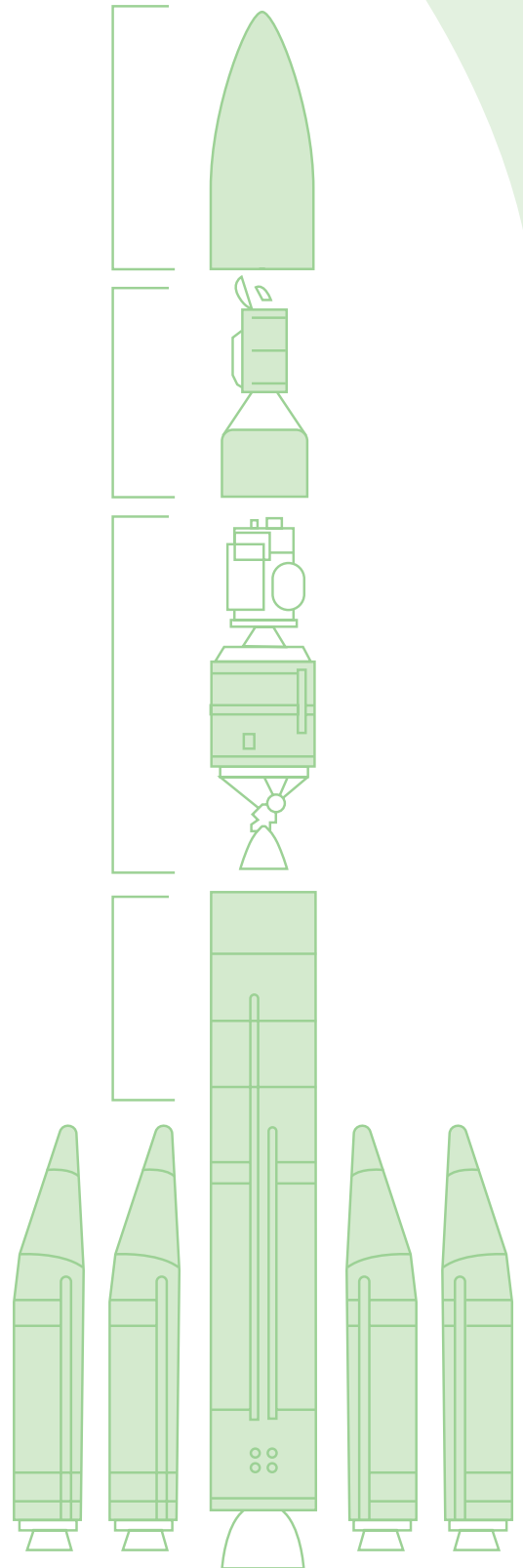
World Space Week happens every year on the 4th – 10th of October. It is the largest annual space event on Earth, celebrating humanity's achievements in space science and technology.

World Space Week consists of space education and outreach events held by space agencies, aerospace companies, schools, planetaria, museums, and astronomy clubs around the world to celebrate space, science, and the wonderful things we can discover in our Universe. Each year has a theme.

This year's theme is
'Rocket Revolution'.

This ESERO Ireland Space Week Activity Pack contains everything you need to know about Space Week 2026, from events you can be part of and projects you can get involved in, to activities you can try out in your own class.

Discover more and check for up to date Space Week event listings at esero.ie/spaceweek2026



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Working in Space



There are a huge variety of careers related to space, from astrophysicists to geologists, programmers, engineers, communicators, and designers.

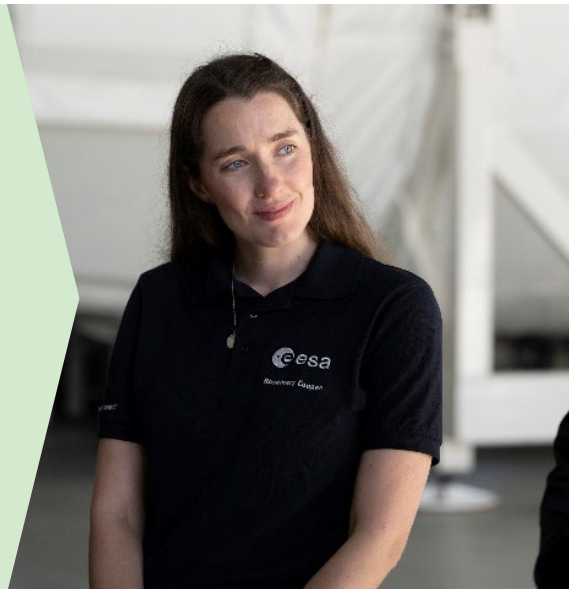
To begin to get to grips with the possibilities, explore the ESERO Ireland video series spotlighting inspiring stories from people who are helping shape the space sector. From research and innovation to industry and education, learn about their paths, passion, and the impact they're making through their work.

See esero.ie/space-career-videos.



Watch this interview with **ESA Astronaut Rosemary Coogan**, born in Belfast and soon to be soaring above Earth, she tells us how she got to where she is now and what she was interested in as a teenager.

[Interview with ESA Astronaut Rosemary Coogan](#)



The Space Industry is bursting with endless possibilities and career paths, with a lot of Irish involvement through researchers and space companies in Ireland building everything from satellite components, and software for space exploration.

Discover inspiring career stories at esero.ie/profiles and see how these professionals are shaping the future of the Space sector, and see careers that might be for you!

What's on for Space Week 2026?



ESERO & Dream Space LIVE for Space Week

Celebrating World Space Week and this year's theme, Rocket Revolution, experts from ESERO Ireland are delighted to join the Dream Space team for Dream Space LIVE.

Together, students will explore how gravity and thrust affect a rocket, consider the purpose of different rocket features and make their own engineering choices as they design a rocket for the journey from Earth into space, and get to grips with coding as they create a simple rocket game of their own!

The session is designed for upper primary and lower post-primary students, is run online and free for classes to join.

Find out more and register to take part at esero.ie/dream-space-live-2026



ESERO Space Careers Roadshow

Our roadshows showcase the incredible diversity of careers that are available in the space industry. Astronauts, scientists, engineers, artists, and countless other professionals will show you what their dream job entails, and the path you can take to follow in their footsteps.

Find out more and sign up at esero.ie/spaceweek2026



Big Screen Cosmic Adventure with ESERO Ireland

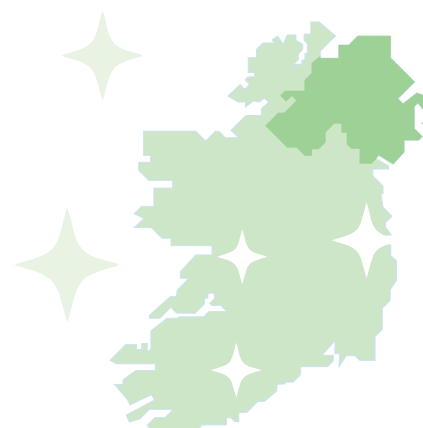
Join us for a space show with a difference. Taking place in the Lighthouse Cinema Dublin, the ESERO Ireland Team will take you on a journey through space, exploring our solar system and getting you up to speed on a range of ESA missions.

Spaces limited, find out more and register to attend at esero.ie/big-screen-cosmic-adventure



Space Week Events around Ireland

For more details and to book any of these events, and to see more, go to esero.ie/super-space-week-events-26



UCD C-Space Talk with Professor Kate Robson Brown

Location: University College Dublin

Date/Time: 6th October 14:00-15:00

Professor Kate Robson Brown, Vice-President for Research, Innovation, and Impact at UCD, and president of the European Low Gravity Research Association (ELGRA), will discuss her career journey and research to date involving life science and bioengineering in space. The talk will end with a Q&A session, so get your questions ready.



UCD C-Space Talk: A Career at the European Space Agency (ESA): Opportunities, Pathways, and the Journey to Space

Location: University College Dublin

Date/Time: 7th October 18:00-19:00

Dr. Loris Franchi, Space Systems Engineer at Redu Space Services and ESA, will share his background and career journey before exploring the wide range of opportunities available to students and graduates at ESA, from internships and graduate programmes to ESA Academy training and beyond. ESA encourages applicants from a wide range of academic backgrounds, so come along to discover where your skills and interests could take you in the European space sector.



Stargazing at Dublin Zoo

Location: Dublin Zoo

Date/Time: 3rd October 18:00-21:00

Look up and discover the wonders of the night sky at Dublin Zoo this World Space Week. Join us for an evening of space, science and stargazing, featuring an inspiring line-up of speakers, celestial explorers and expert stargazers.

For more details and to book any of these events, and to see more, go to esero.ie/super-space-week-events-26

Space is not Just for Space Week...



We can all enjoy and explore space any time of the year, not just during Space Week!

You can get your students involved with the ESA School Projects and take a trip to a space and astronomy focused spot in your area. Keep reading to find out more.....

Space as a Tool for Teaching STEM

Bring STEM learning to life in your classroom with these exciting, hands-on projects from the European Space Agency (ESA) that inspire curiosity, problem-solving, and innovation. Each project offers students the opportunity to engage with real-world science and technology challenges, fostering inquiry-based learning and developing 21st-century skills. Whether it's coding for the International Space Station, designing a lunar habitat, investigating local climate issues, or building a mini satellite, these projects will captivate learners and provide valuable cross-curricular learning experiences.

Below are details on each project, complete with resources and instructions on how to get your students involved.

To find out more and register for the projects, go to esero.ie/projects/



Astro Pi Challenge

Engage Your Students with Real Coding in Space!

The European Astro Pi Challenge, created by ESA and the Raspberry Pi Foundation, offers an incredible opportunity for your students to send their code to the International Space Station (ISS). This project helps students gain hands-on experience with scientific experimentation in space and practise logical thinking and computing skills, using Python programming language

This project is ideal for introducing coding, data analysis, and space science in an engaging and practical way. Teachers can access lesson plans and activity guides to integrate the challenge into their classroom.

For registration and additional information, visit esero.ie/astro-pi



CanSat

Let Your Students Build and Launch Their Own Satellite.

Introduce your students to the exciting world of aerospace engineering with the CanSat project. This ESA competition challenges students to design, build, and launch a mini-satellite—a CanSat—that fits into the size of a drinks can. It's a hands-on experience that brings space technology and engineering to life. Students will

- **Design and Build a CanSat**
- **Launch and Collect Data**
- **Analyse and Present Data**

This is a perfect project for students in TY and senior cycle or equivalent in schools, Youthreaches, and youth clubs interested in electronics, coding, and engineering, providing a practical introduction to space missions.

For registration and additional information, visit esero.ie/cansat



Climate Detectives

Investigate Climate Change with Your Students!

Empower your students to tackle real-world climate issues with the Climate Detectives project by ESA. This initiative allows students to become young climate scientists. They can complete Earth related activities, collect evidence and earn Detectives badges.

For registration and additional information, visit esero.ie/climate-detectives



Moon Camp Challenge

Help Your Students Design Space Habitats!

Get your students thinking about space exploration with the Moon Camp Challenge, a project run by ESA and the Airbus Foundation. In this challenge, students will design a lunar base capable of sustaining human life on the Moon, or a space base further afield in our Solar System. They will explore the challenges of living in extreme environments and then create a model of their solution.

For registration and additional information, visit esero.ie/moon-camp



ESERO Space Education Confluence 2026

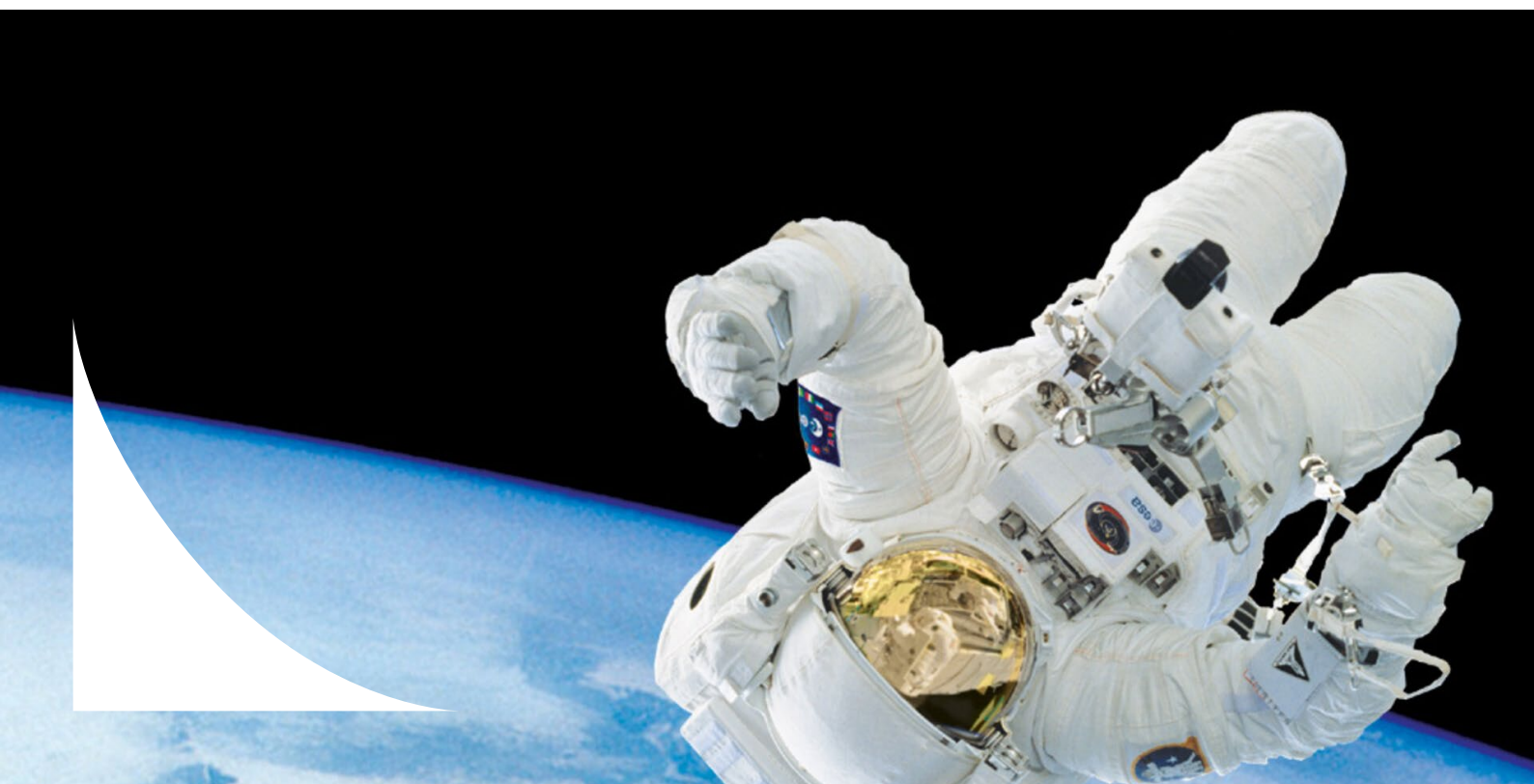
To continue exploring space and using it as a gateway to teaching STEM even after Space Week, join ESERO Ireland for our Space Education Confluence 2026.

With partners in Blackrock Castle Observatory and Oide, as well as a special guest speaker, we will focus on the Junior Cycle curriculum with workshops activities and discussion sessions.

Fully online and interactive, this is a chance for teachers and educators to learn more about space research and resources available for your class activities.

The ESERO Ireland Space Education Confluence 2026 will take place online on Saturday 24th October from 09:30 to 12:30.

Check esero.ie/news-events for details and registration.



Places near you to explore Space

Across Ireland, from Cork to Armagh and Dublin to Mayo, there are amazing places to go and explore space and astronomy. Find one near you below and contact them to plan a trip!



DIAS Dunsink Observatory, Dublin

www.dunsink.dias.ie

DIAS Dunsink Observatory is a historic astronomy centre located in Dublin. The observatory has several telescopes and is connected to astronomy research and education in Ireland. It is also famous for being the workplace of mathematician and astronomer William Rowan Hamilton. Today, Dunsink is an important part of Ireland's astronomy history and helps people learn more about space and science.



MTU Blackrock Castle Observatory, Cork

www.bco.ie

MTU Blackrock Castle Observatory brings together the castle's rich history with the fascinating worlds of astronomy and space. Whether you're planning a visit, or simply want resources to elevate your day-to-day teaching, Blackrock Castle Observatory has everything you need for all things Space.



Mayo Dark Sky Park

www.mayodarkskypark.ie

Wild Nephin National Park becomes **Mayo Dark Sky Park** at night. The site is completely free to access anytime, day or night and they have 3 signature viewing sites for you to choose from where the night sky is very dark because there are very few artificial lights. Mayo Dark Sky gives people the chance to enjoy and learn about space while experiencing the beauty of the night sky.



Armagh Observatory and Planetarium

<https://armagh.space>

Armagh Observatory and Planetarium is a space and science centre in Armagh, Northern Ireland. Visitors can watch shows about space inside a special dome that looks like the night sky. The planetarium also has activities and displays about astronomy and science. Armagh Planetarium is a great place for people who are interested in astronauts, planets, stars and exploring the universe, and also supports astronomy education and research.



Birr Castle Demense, Offaly

www.birrcastle.com

Birr Castle was home to the largest telescope in the world in the 19th and 20th century, called the Leviathan telescope. Scientists used it to study stars, planets and galaxies, and to discover details about spiral galaxies. Today, a state-of-the-art radio telescope, I-LOFAR is also at Birr Castle and visitors can see both telescopes and learn about how people studied space in the past, and how they do so today too!

Activities

Time to get hands-on
and be part of the World
Space Week 2026 **Rocket
Revolution!**

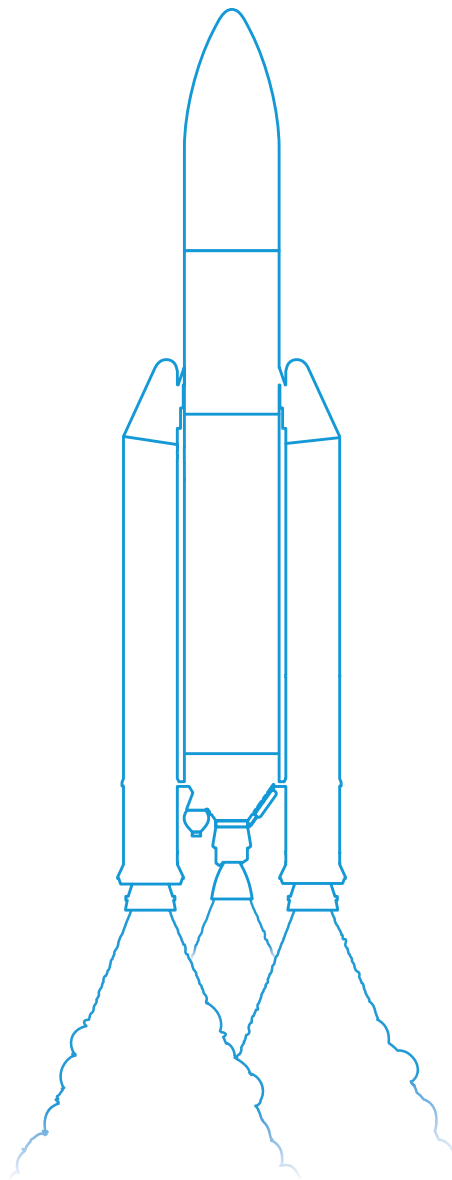
Here are detailed activity plans to build a
rocket and to explore propulsion and what
makes a rocket fly.

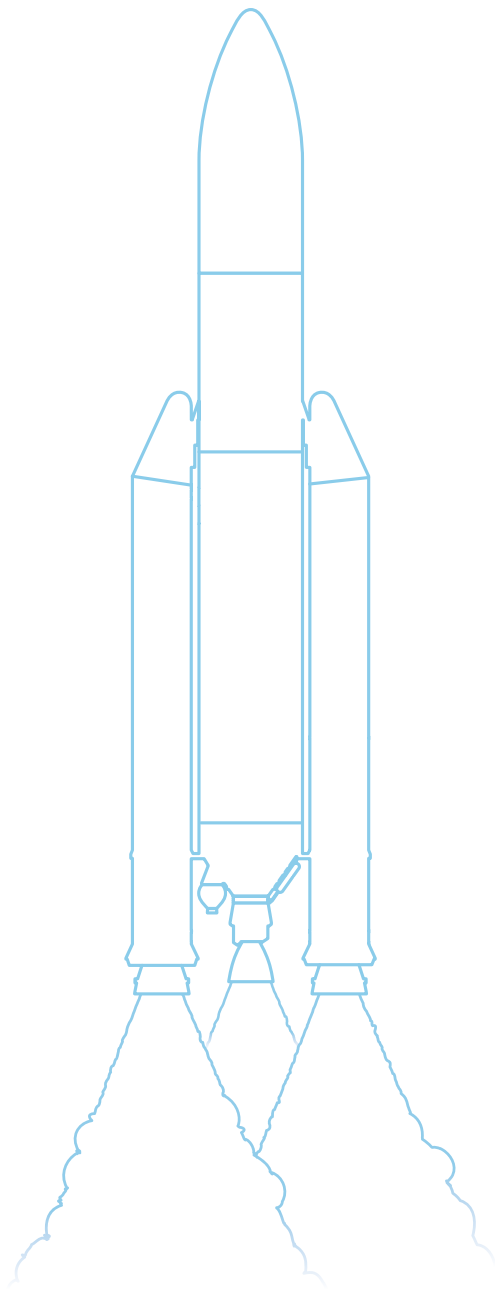


teach with space

→ WHOOSH BOTTLE

Applying Newton's laws to rockets





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Activity 2: Applying Newton's second law to rockets	page 7
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→ WHOOSH BOTTLE

Applying Newton's laws to rockets

FAST FACTS

Age range: 14-17 years old

Type: Practical demonstration or student activity

Complexity: Easy

Teacher preparation time required: 20 minutes to read through activity

Lesson time required: 45 minutes

Location: Laboratory

Includes use of: Highly flammable fuels (ethanol or other alcohol)

Outline

In this activity, alcohol and air are mixed in a large plastic water bottle before being ignited, to simulate the physics principles of chemical rocket engines. The activity can either be run as a teacher demonstration or a student activity, for which there are separate protocols. The students will observe a rapid reaction accompanied by a dramatic “whoosh” sound and flames. They will discuss the similarities and differences between the laboratory reaction and the reaction that occurs in rocket engines. Students will finish the activity by mathematically applying Newton’s laws of motion to what they have seen.

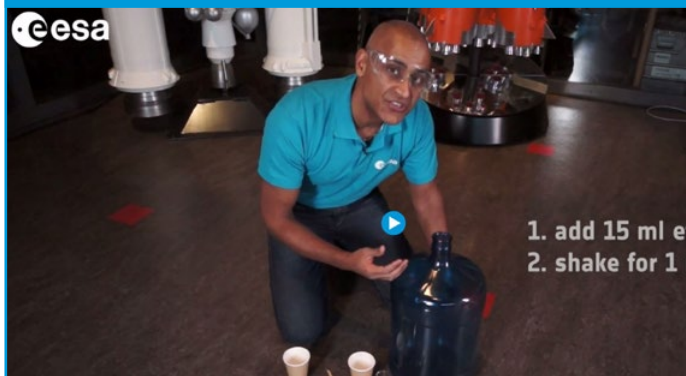
Students will learn

- How chemical rocket engines work
- How to apply Newton’s three laws of motion to rocket engines
- The relationship between thrust and acceleration
- Calculations related to forces

Students will improve

- Their ability to apply knowledge gained through experimental observations to solve theoretical problems
- Their ability to work safely in a laboratory

You will also need



↑ Whoosh bottle – Classroom Demonstration Video.
See links section.

Curriculum links

- Physics – rocket launches, action/reaction forces, Newton’s laws
- Chemistry – combustion reactions

→ ACTIVITY 1: BURN FUEL, BURN!

In this activity, a mixture of air and alcohol is ignited inside a plastic bottle, simulating what happens during the ignition of fuels in a rocket launch. Students will see a rapid reaction, accompanied by a dramatic “whoosh” sound and flames, demonstrating the large amount of energy released in combustion reactions. Chemical rocket engines use the high pressures and temperatures of combustion to accelerate the exhaust gases and to push the rocket upwards.

Experiment preparation

The Whoosh bottle Classroom Demonstration Video, available on ESA’s Education website, shows the complete set-up of this activity, and describes how to carry it out. The protocol presented in this teacher guide provides information on the equipment and instructions for you to do the activity as a teacher demonstration (Figure 1). For students to do this activity as a laboratorial activity they should use small plastic bottles as suggested in the protocol in the students’ activity sheet.

This demonstration is best performed in a dark room.

Equipment

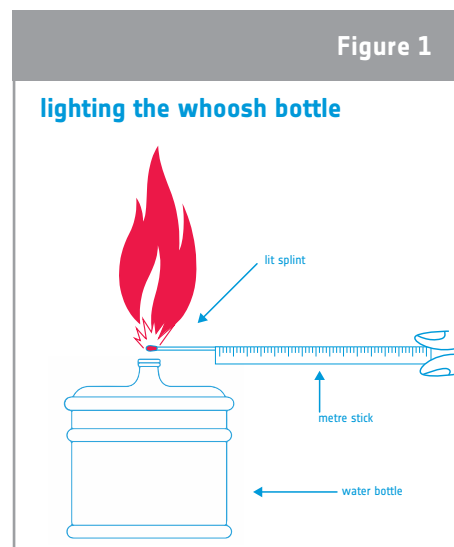
- 1 or more large plastic water bottles as used in water coolers (approximately 20 litres)
- 15 ml of industrial methylated spirit (cheaper) or pure ethanol (more expensive)
- Match and splint
- Metre ruler (the splint should be taped to the ruler to maintain a safe distance when lighting the large bottle)
- Safety glasses
- 1 pair of heavy duty gloves

Health & safety

- Ethanol (and other alcohol if used) 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 the bottles are not damaged. If any cracks are present, use a different bottle.
- Always wear gloves when lighting the bottle. Do not hold your body over the top of the bottle.
- Warn all students and observers about the possible noise levels and ask those with sensitive hearing to cover their ears.
- Do not conduct the demonstration upside down in an attempt to launch the whoosh bottle.
- Follow the general safety control measures in the laboratory.

Exercise

1. Put on safety glasses.
2. Remove the lid from the water bottle and ensure the bottle is completely dry.
3. Pour about 15 ml of fuel into the bottle. Suitable fuels include methylated spirits, methanol, ethanol, propan-1-ol and propan-2-ol.
4. Replace the lid and shake well for at least one minute. The shaking will help to vaporise the alcohol.
5. If any fuel is left at the bottom of the bottle, pour it out and replace the lid. Make sure that students see this being done.
6. Attach a splint to the end of a metre ruler and hold it at a slight downward angle. Light the splint, remove the seal of the bottle, and hold the end of the ruler so that the burning splint is over the neck of the bottle (Figure 1).
7. The reaction happens fast and is loud! Once the reaction is complete, tip the bottle upside down to show students the drops of colourless liquid that fall out. The bottle can be passed around amongst the students for them to feel how warm it is – particularly on the top surface.
8. If more bottles are available, it can be interesting to repeat the experiment with other fuels. Alternatively the same bottle can be reused after recycling the air using a vacuum pump run in reverse, or after pumping fresh air in to the bottle using a bicycle pump.



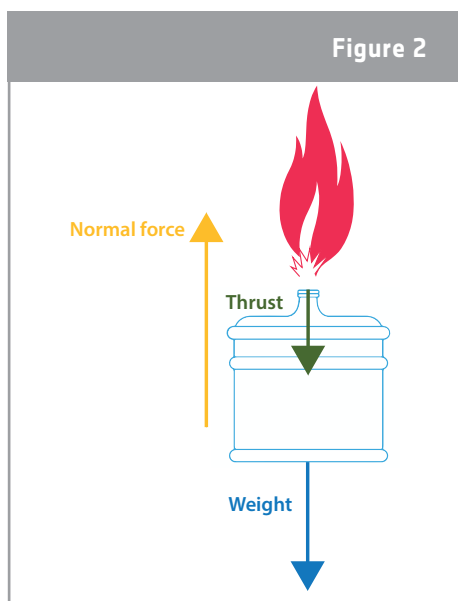
↑ Whoosh bottle set-up (for teacher demonstration)

Answers to discussion questions

1. Explain why the bottle should be shaken after adding the alcohol.
To help vaporise the alcohol.
2. The reaction was accompanied by a whoosh sound. Explain where this sound came from.
The whoosh sound is a result of the exhaust gases being forced rapidly out of the narrow opening of the bottle. This is a consequence of the expansion of hot gas inside the bottle.
3. Considering Newton's third law, identify the forces that act on the bottle during the combustion reaction.
The three forces are:
 - The weight of the bottle
 - The normal force (from the ground)
 - The thrust produced by the exhaust gases (carbon dioxide and water vapour). These gases are expelled upward out of the bottle, thus Newton's third law tells us that the equal and opposite reaction force on the bottle is directed downwards into the floor.

4. Draw a force diagram showing the forces acting on the bottle during the combustion reaction.

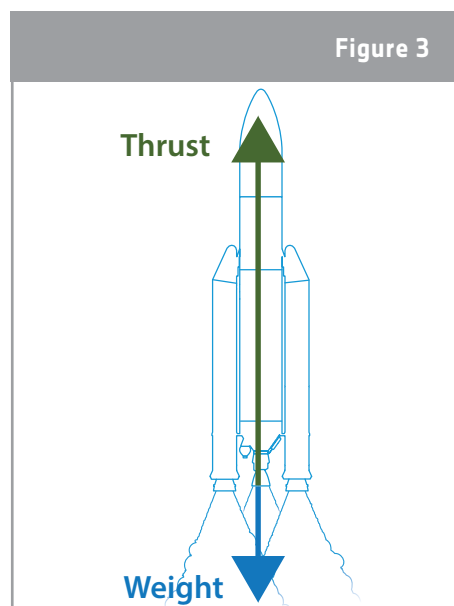
Note that the arrow for the normal force should be approximately equal to the combined size of the weight and thrust arrows (Figure 2).



↑ Forces acting on the whoosh bottle during the combustion reaction

5. Draw a force diagram showing the forces acting on a rocket at the moment of launch, immediately after it has left the ground. Ignore air resistance.

Note that the arrow for the thrust should be bigger than the arrow for the weight (Figure 3).



↑ Forces acting on a rocket during launch

6. Describe the similarities and differences between the two diagrams you have drawn.

The forces that are similar are the weight and the thrust. However, on the bottle the thrust generated by the exhaust gases is directed downwards into the floor, whereas in the rocket the thrust is directed upwards.

7. Explain the effects of the forces in the two examples (the whoosh bottle and the rocket).

The whoosh bottle is effectively an inverted version of a rocket launch. In this case, the exhaust gases produce a downward force (thrust) due to Newton's third law. Because the bottle is placed on the ground or on a table, this thrust is actually acting on the entire mass of the Earth meaning that it does not have any effect.

In the case of a rocket, the thrust is directed upwards and acts only on the mass of the rocket, therefore accelerating it at a relatively high rate (Newton's first and second laws). As the rocket accelerates through the lower atmosphere, there will be considerable aerodynamic drag, especially in the first two or three minutes after launch when velocities are high and the atmosphere is still relatively dense. Above altitudes of 120 km, the atmospheric drag becomes minimal. Although gravitational forces diminish with distance, they never completely disappear.

→ ACTIVITY 2: APPLYING NEWTON'S SECOND LAW TO ROCKETS

To launch a rocket into space there needs to be enough thrust to counteract gravity. In this activity, students apply Newton's second law to rockets to calculate the amount of fuel a rocket needs to create the necessary thrust to launch.

Answers to exercise

1. An Ariane 5 ECA rocket is on the launch pad in Kourou, French Guiana. The lower section of Ariane 5 ECA consists of the main cryogenic core stage (EPC) and the two solid propellant boosters (EAP) (see Figure 4). The thrust generated from its engines is 960 kN from the main EPC cryogenic stage and 6450 kN from each of the two solid propellant boosters attached to it. The total mass of the rocket on the Launchpad is 777 tonnes.

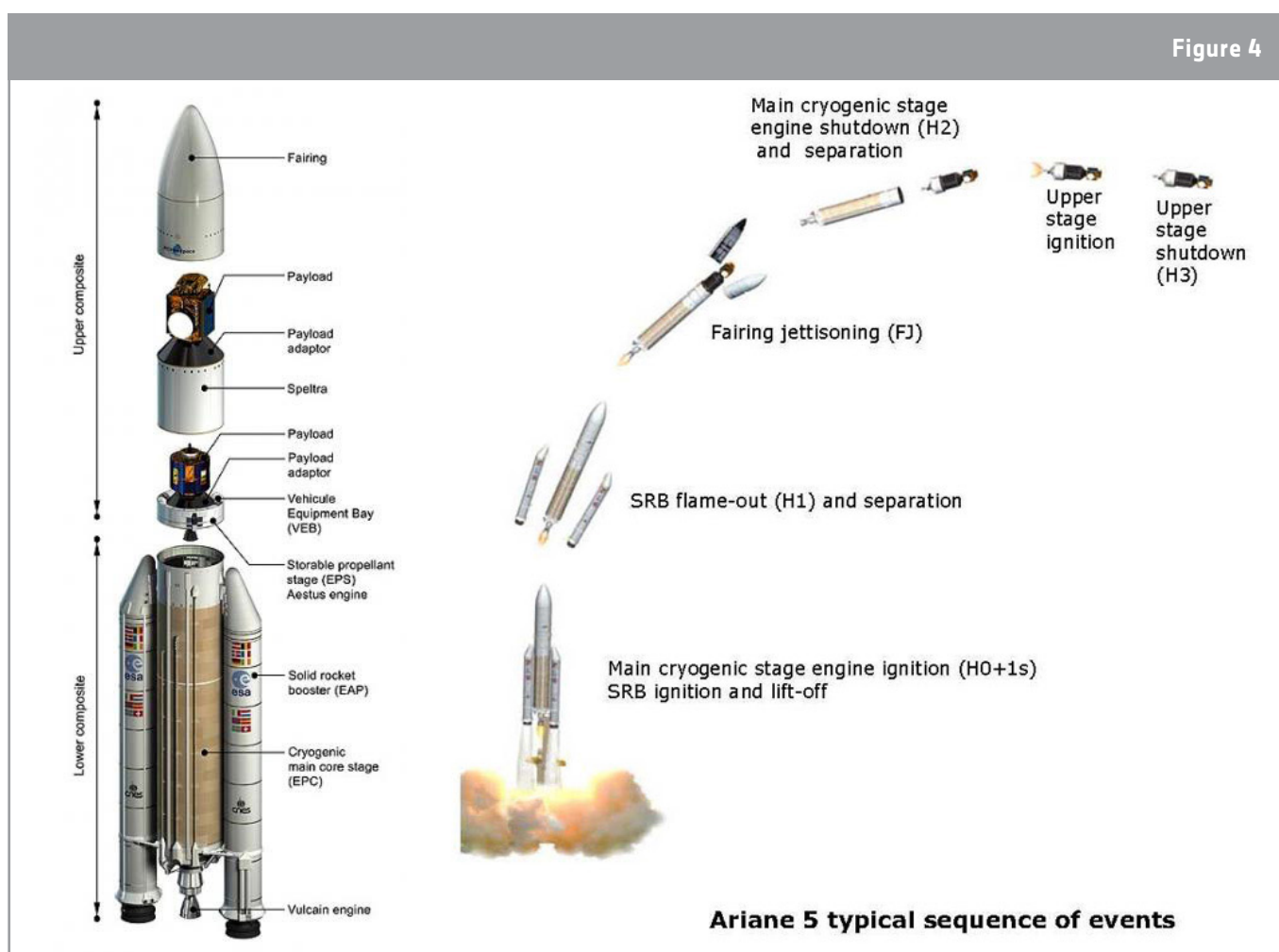
Take the acceleration due to gravity (g) as 9.8 N/kg or 9.8 m/s².

a. Calculate the resultant force on the rocket. It can be useful to draw a force diagram. Ignore air resistance.

Resultant force on rocket = 6.25 MN

b. Calculate the acceleration of the rocket at the moment of launch.

Acceleration = 8.04 m/s²



↑ Typical launch sequence of an Ariane 5 rocket.

2. Assume the rocket rises vertically for the first twenty seconds. Each EAP booster uses 1.8 tonnes of propellant per second and the EPC main stage uses 0.3 tonnes of propellant per second.
- a. Calculate the mass of the rocket after 20 seconds and hence calculate its acceleration at this time.

Mass of the rocket after 20 seconds:

$$777\,000\text{ kg} - (2 \times 1.8\text{ t} \times 1000\text{ kg} \times 20\text{ s}) - (0.3\text{ t} \times 1000\text{ kg} \times 20\text{ s}) = 699\,000\text{ kg}$$

Instantaneous acceleration:

$$\text{Thrust} = 13\,860\,000\text{ kg m/s}^2$$

$$\text{Weight} = 699\,000\text{ kg} \times 9.8\text{ m/s}^2 = 6\,850\,200\text{ kg m/s}^2$$

$$\text{Resultant force} = 13\,860\,000\text{ kg m/s}^2 - 6\,850\,200\text{ kg m/s}^2 = 7\,009\,800\text{ kg m/s}^2$$

$$\text{Acceleration} = \text{force/mass} = 10.03\text{ m/s}^2$$

- b. In reality the rocket's acceleration at this time would be different to the acceleration you have calculated. Do you think the actual value would be higher or lower? Explain your answer. A new force diagram may help you with this.

As the rocket accelerates through the atmosphere its velocity increases and, as a result, atmospheric drag also increases. This is because the force of atmospheric drag is proportional to the density of the air and also to the square of the velocity. This means that as velocity through the atmosphere increases, atmospheric drag plays an increasingly important role. As a result, after 20 seconds of flight, the effect of the drag force is that the resultant force (thrust – drag – weight) will be less than the resultant force would be without the drag (thrust – weight) and so the acceleration will be smaller than previously calculated. As the rocket continues through the atmosphere, air density reduces progressively and at the same time the speed (and acceleration) of the rocket increases as the weight of the rocket diminishes due to the propellants' consumption in the engine(s).

3. The Ariane 5 User Manual gives two figures for the thrust of the EPC main stage (which runs for nine minutes):
 - 960 kN at sea level
 - 1390 kN in vacuum

Explain why these figures are different.

The thrust that a rocket engine produces depends on the velocity of the expelled gases from the combustion chamber. The pressure difference between the gases in the combustion chamber and the surrounding external atmosphere is what drives the exhaust gases out of the combustion chamber and produces thrust. This difference will be maximal in a vacuum. This is why the vacuum thrust is always greater than the thrust at sea level.

→ LINKS

ESA resources

Whoosh bottle – Classroom Demonstration Video (VP01):

http://www.esa.int/spaceinvideos/Videos/2014/07/Whoosh_bottle_-_classroom_demonstration_video_VP01

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_o.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

teachers@esa.int

Concept developed for ESA by the National Space Academy (NSA, UK)

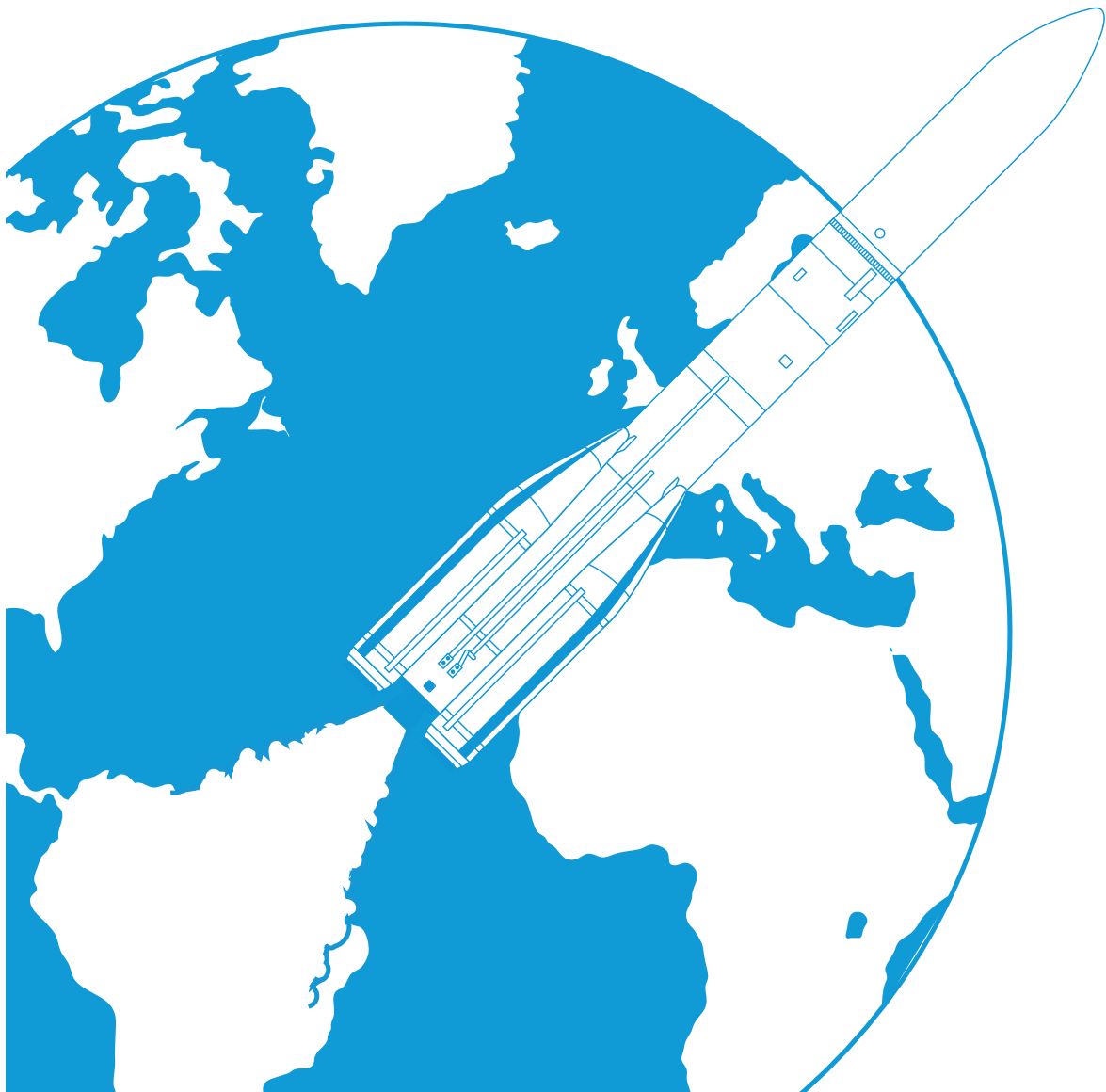
An ESA Education production

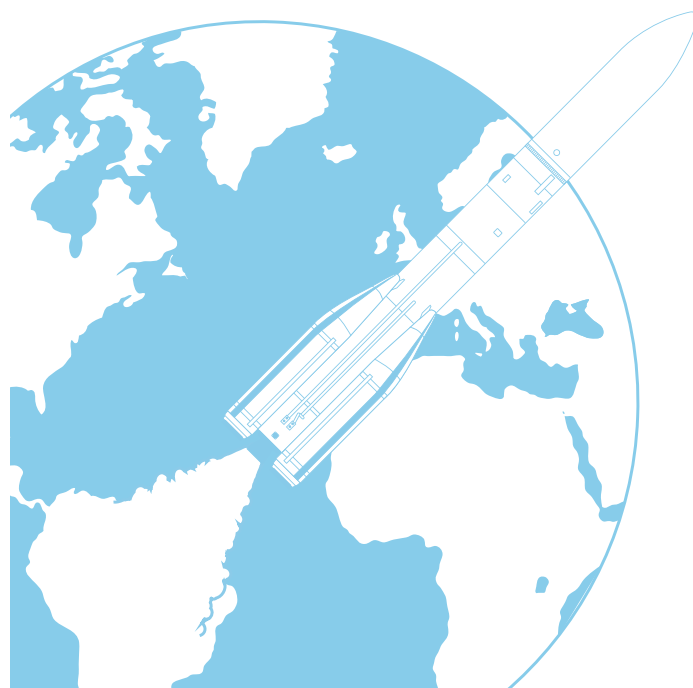
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teach with space

→ 3...2...1 LIFT-OFF!

Building your own paper rocket





Teacher Guide

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The ESA Education Office welcomes feedback and comments
teachers@esa.int

Activity concept developed by ESERO Nordic and ESERO Poland

An ESA Education production
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→ 3...2...1 LIFT-OFF!

Building your own paper rocket

Fast facts

Subject: Physics

Age range: 14-16 years old

Type: student activity

Complexity: medium

Lesson time required: 2 hours

Cost: low (5-10 euros)

Location: Indoors and outdoors

Includes the use of: Self build launch system
(see Annex 1 + 2)

Keywords: Physics, Rockets, Parabolic motion, Aerodynamics, Centre of mass, Centre of pressure, Escape velocity, Orbital velocity, Velocity, Acceleration

Outline

In this set of 3 activities students will design and build their own paper rockets and launch them. They will learn what it takes in order for a rocket to be stable and they will calculate the rocket's trajectory and velocity. They will learn about the velocity required to leave Earth in a rocket and uncover why the Moon has the potential to be a stepping stone for further space exploration. Lastly, they will calculate the acceleration of their rocket at launch and put this into a context of the G-force experienced by astronauts during launch.

Students will learn

- Learning about the centre of mass and centre of pressure.
- Investigating projectile motion and parabolas.
- Calculating velocity and acceleration.
- Understanding forces.
- Improving scientific thinking and ability to work as a team.

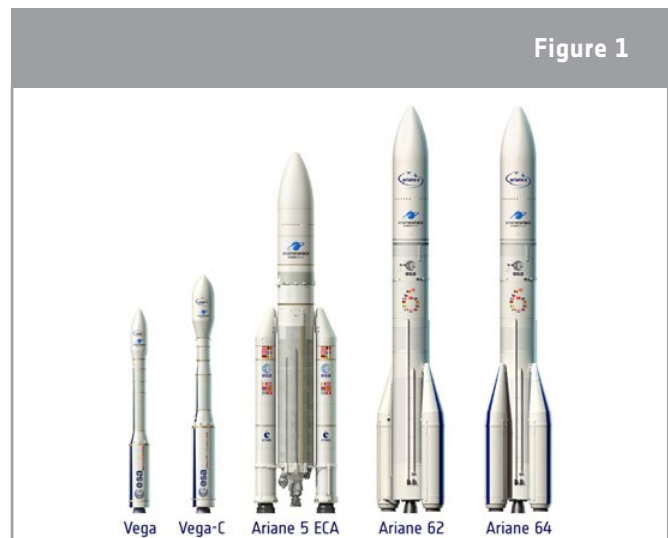
→ Summary of activities

Summary of activities					
	Title	Description	Outcome	Requirements	Time
1	Build your own paper rocket	Design and build a paper rocket.	Learning about rockets, aerodynamics, centre of mass and centre of pressure and what makes a rocket stable.	none	30 minutes
2	Launch your rocket	Launching the rocket, calculating the initial speed as it leaves the launch platform. Relate this to the escape velocity of Earth and the Moon.	Learning about forces, projectile motion, velocity and escape velocity.	Completion of Activity 1. A launch system (Annex 1 or 2). The launch has to be done in an open space, preferably outdoors.	45 minutes
3	Human Spaceflight	Calculate the acceleration of the paper rocket as it blasts off. Relate with the G-force experienced by astronauts.	Learning about acceleration and G-force.	Completion of Activity 2.	45 minutes

→ Introduction

Space agencies use rockets on a regular basis; to send crews to the International Space Station (ISS), to carry probes that will explore our Solar System, and to launch satellites into orbit around Earth. Rockets vary in size, design and type of fuel they use, all depending on their purpose.

ESA's family of launch vehicles includes the Vega, Vega-C and Ariane 5. A new, more efficient rocket is being developed to launch satellite missions and probes: the Ariane 6 (which will come in the form of Ariane 62 and Ariane 64). These launch vehicles are able to launch a huge range of missions into space - from communication satellites to Solar System missions. Their powerful engines provide the energy needed to escape Earth's gravity.



↑ ESA'S 'Family' of launch vehicles.

ESA launches their rockets from their spaceport located in French Guiana in South America, which is only 500 km north of the equator. The Earth's rotation is fastest at the equator and rockets can profit from the 'slingshot' effect. This increases the rocket's speed by 460 m/s, which saves fuel and money. This location is also ideal for launches into geostationary transfer orbit as few changes have to be made to a satellite's trajectory. Safety is also taken into consideration for launch sites. French Guiana is scarcely populated and 90% of the country is covered by equatorial forests. In addition there is no risk of cyclones or earthquakes. All of these factors make ESA's spaceport an optimal launch site.



↑ Orion with European Service Module

In order to get to the Moon with a crewed mission, we have to launch a powerful rocket! One of the most powerful rockets ever launched was the Saturn V, which took humans to the Moon as part of the Apollo program in the 60s and 70s. Humans have not set foot on the Moon since that time.

NASA's Orion spacecraft in combination with the European Service Module, being developed by ESA, will be launched on a new generation of rockets. They will allow astronauts to reach further into space, beyond the Moon to asteroids and even Mars.

In this set of activities, students will be rocket scientists and design and launch their own rocket to go back to the Moon!

→ Activity 1: Build your own paper rocket

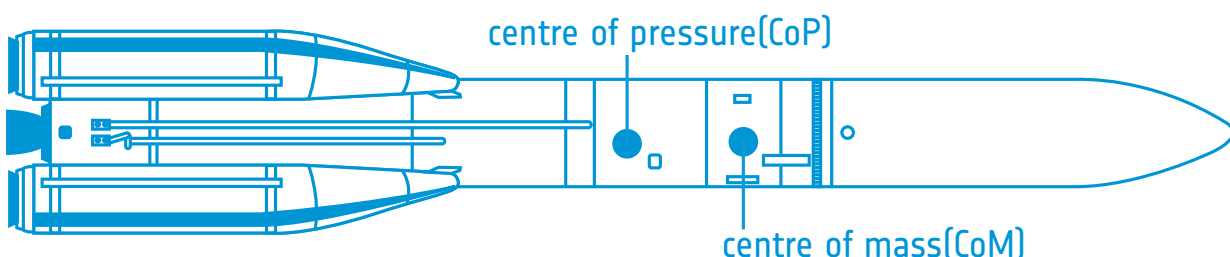
In this activity, students will build a paper rocket. They will find the centre of mass and the centre of pressure and try to make their rockets as aerodynamic as possible. They will test the stability of their rocket and consider which variables in their rocket design will influence the performance of their rocket.

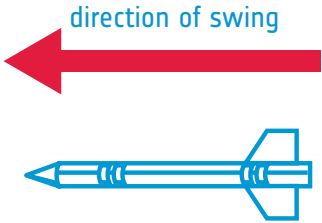
Equipment per group

- Printed student worksheet
- 2 A4 sheets of paper
- Scissors
- Sticky tape
- Plasticine
- Cardboard
- Fins and nose template (optional) – Annex 3

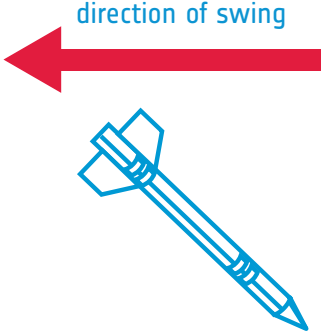
Exercise

1. Divide the class into groups of up to three students and ask them to build a rocket out of the materials provided. It is important to emphasise that the rocket body has to fit on the launch system you have prepared. The students should be creative with their design of the rocket and decide themselves the size and number of fins. However, in Annex 3, you will find a template for fins and nose-cone as inspiration.
2. Ask the students to find the centre of mass (CoM) of their rockets. The CoM is the average position of all the mass in a system so they can find the point by balancing their rocket using a string. Note: some sources will interchange CoM with “centre of gravity”.
3. Ask the students to find the centre of pressure (CoP) of their rocket. The centre of pressure is the geometric centre of the rocket where all of the aerodynamic forces act. If the rocket was homogeneous inside, the CoM and CoP would coincide. We can find the CoP by adding up the individual forces acting on the wings, tail surfaces, drag, etc., but this can be difficult to calculate. A simple way to find an approximate point is by cutting out the silhouette of the rocket in cardboard and balancing it on a ledge. This allows the balance of the projected area to be found.
4. The students should mark both CoM and CoP on their rocket and reflect over the connection between these important points. Ask the students to perform a swing test and evaluate how the position and relation between CoM and CoP affects the stability of their rocket.
5. Example of how the CoM and the CoP should be located in order to have a stable paper rocket.

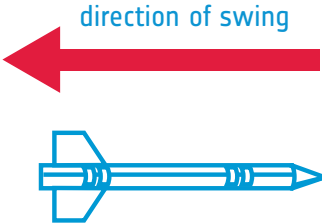


- 6.
- 

Stable flight, nose forward.
CoM is in front of CoP. The example presented would be in this situation, which is the ideal configuration.



Cartwheeling. CoM is too close to CoP



Rocket flying backwards. CoP is in front of CoM

7. In the table are some of the variables that can be changed in the design and launch of the rocket.

Variable	How will changing this variable influence the performance of your rocket?
Number of fins	It will affect the centre of mass, as more weight is added in the back of the rocket. It might also change the location of the centre of pressure if the surface area changes. If the number of fins is asymmetrical, it can also affect the stability and drag.
Size and shape of fins	Bigger fins will move the centre of pressure backwards.
Weather conditions	Different weather conditions will benefit or complicate launches differently depending on the design. For example, a rocket with large fins will be more subjectable to strong winds. Generally paper rockets perform poorly in wind and especially in rain.
Length of the rocket	The length of the rocket will affect the centre of pressure. The rocket can also be so short that the aerodynamic abilities are lost. Or it can be so long that the structure cannot hold itself (since the rocket is made of paper).
Weight of the rocket	The weight distribution of the rocket will determine the centre of mass. A heavy nose-cone will move the CoM forward. This can be done by putting plasticine in the nose cone.

Note: If your class has access to computers, you can download the free rocket simulation tool <http://openrocket.info/>. In this simulation, the students can play around with the dimensions and design of their rockets, and investigate the relationship between the centre of mass and centre of pressure.

→ Activity 2: Launch your rocket

In this activity the students will uncover that mathematics is an integral part of rocket science. They will learn about forces and have to draw free-body diagrams. Both before and after launch they will have a look at the trajectory of the rocket and do calculations involving velocity.

Equipment

- Printed student worksheet per group
- Launch system (see Annexes 1 and 2)
- Self-build paper rocket
- Long measuring tape
- Protractor (optional)

Health and Safety

Ensure that the launch area is clear of people. Do not aim the rocket at anyone. Eye protection is advisable.

Exercise

When launching the rockets remember to have a lot of space and a flat surface (a football field would work well). If you use the launch platform from Annex 2, the rockets may fly 100 m or more! Instruct the students that the maximum pressure should not be above 7 bar.

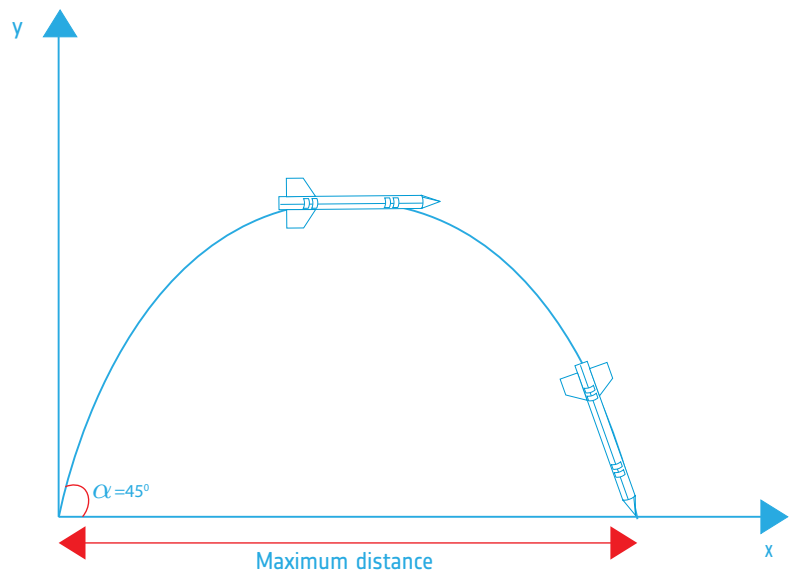
Let the students debate at which angle is best to launch. Later in the discussion section you can talk about the optimal angle in order to gain maximum distance. You can have the students all launch at the same angle to compare which team's rocket is best or you can allow the students to trial their rocket, launching them at different angles to find the optimum angle.

You can make the launch a competition and reward the teams with the furthest travelling rockets. We have provided you with a table in Annex 3 to note down how far each rocket went (this information will be needed later).

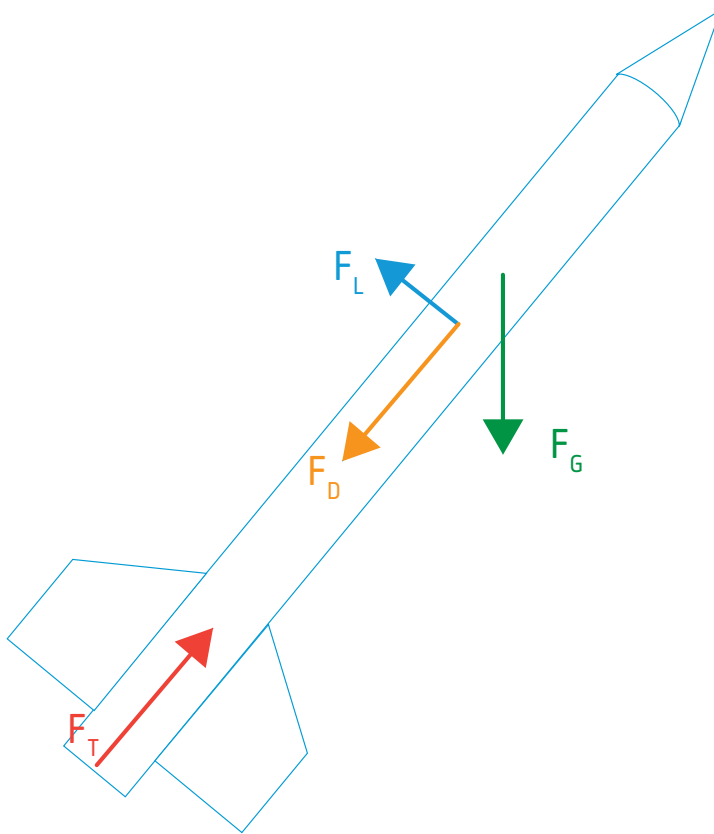
After the launch, talk about how rockets accelerate upwards and why they follow a parabolic path. Introduce Newton's three laws of motion and the force due to gravity. Introduce the concepts of escape velocity and orbital velocity and compare the launch of the paper rockets with launching an actual rocket to the Moon.

Results

1. Scheme of the trajectory that the rocket will follow.
2. To maximise the distance travelled the launch should be done at an angle of 45° .
4. Possible initial conditions which may impact the trajectory of your rocket.
 - Wind
 - Initial velocity given to the rocket
 - Angle of launch



5. Force diagram showing the forces that act on the rocket shown above in the thrust phase.



$F_T = \text{Thrust}$

The thrust force from the rocket will only work for a very short time during launch, giving the rocket a push. This force is what makes the rocket fly.

$F_G = \text{Gravitational force}$

The gravitational force will be approximately constant throughout the whole flight.

$F_D = \text{Drag force}$

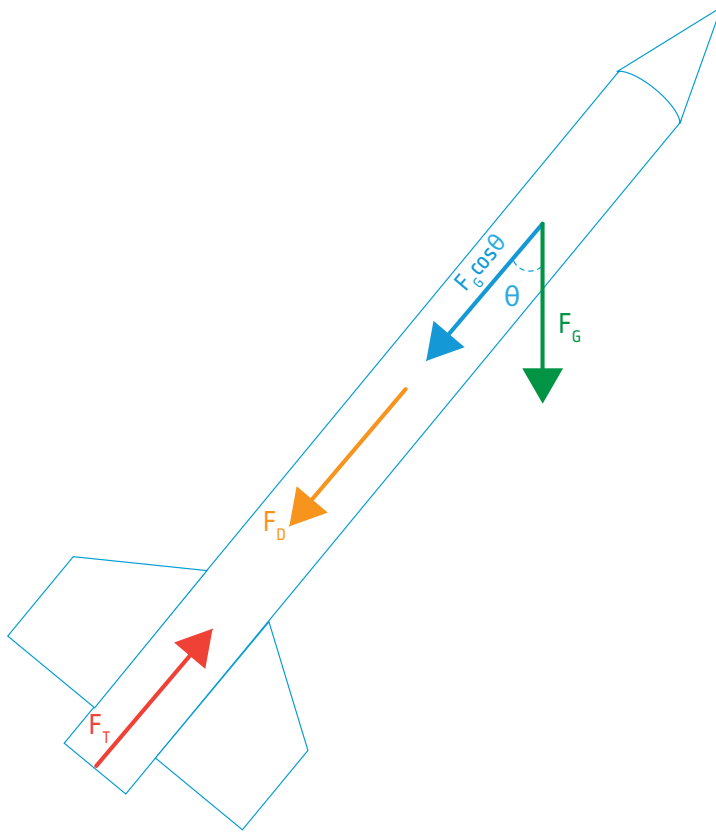
The drag force is dependent on the density, viscosity and compressibility of the air, as well as the velocity, shape and inclination of the rocket.

$F_L = \text{Lift force}$

The lift force is dependent on the density, viscosity and compressibility of the air, as well as the velocity, shape and inclination of the rocket. For this activity we will consider the lift force negligible.

6.
 - a. In a real ESA rocket (e.g. Ariane 5) this phase will last a few minutes, whereas in our paper rocket it lasts barely a second.
 - b. In the direction of motion the resultant of forces, F , is given by:

$$F = -F_D + F_T - F_G \cos \theta$$



Where F is: $F=ma$, m is the mass and a is the acceleration.

Where F_T is: $F_T=-u_e \frac{dm}{dt}$, u_e is the exhaust velocity of the gases with respect to the rocket and $\frac{dm}{dt}$ is the rate of change of the mass of the rocket.

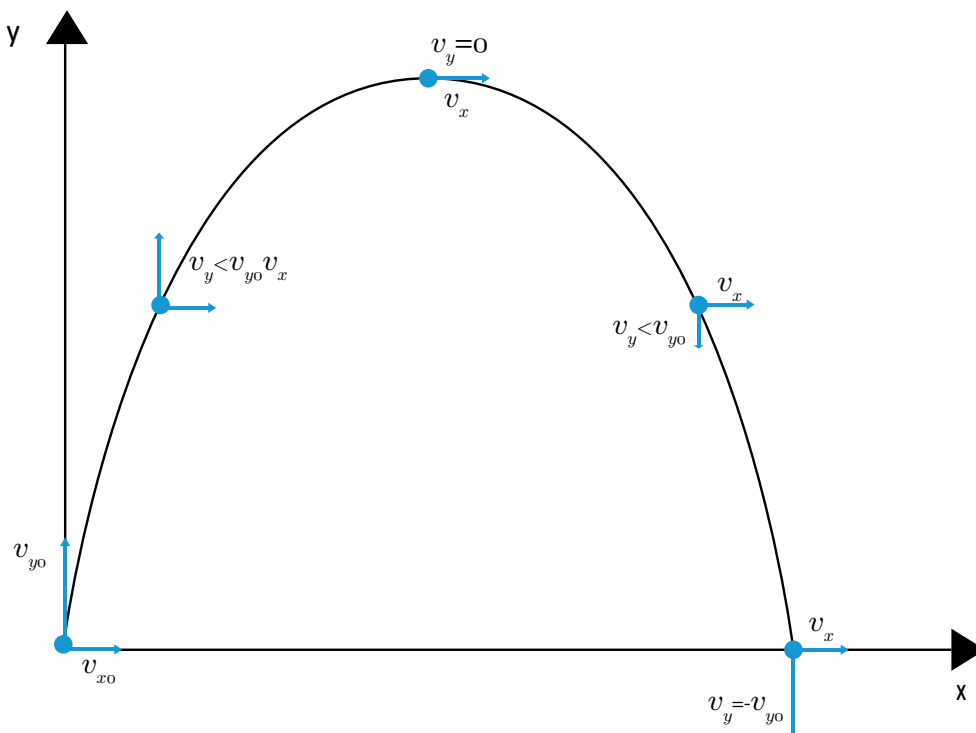
Where $F_G \cos\theta$ is the force due to gravity in the direction of motion of the rocket. $F_G=mg$, m is the mass and g is the gravitational acceleration and θ is the angle between the direction of motion of the rocket and direction of F_G .

Where F_D is the drag force.

- c. Substituting these terms and dividing by m we get the acceleration:

$$a = -\frac{F_D}{m} - \frac{u_e}{m} \frac{dm}{dt} - g \cos(\theta)$$

7. a. Graph with the horizontal and vertical velocity components. Students are encouraged to consider the forces acting on the rocket at each point and why that results in the parabolic motion we see.



7. b. The rocket is quickly accelerated during the thrust phase while on the launch pad. Once the rocket leaves the launch pad there is no longer any thrust. Ignoring drag, this means that there is no force working on the rocket in the x-axis, so from Newton's first law the x-velocity component (v_x) is constant. In the y-axis, we have the gravitational force working on the rocket in the direction of the centre of the Earth (perpendicular to the surface), hence the y-velocity component (v_y) will change.

8. Isolating velocity in the equation:
$$v = \sqrt{\frac{d \cdot g}{\sin(2\alpha)}}$$

9. Using a distance $d = 40 \text{ m}$, angle $\alpha = 45^\circ$:
$$v = \sqrt{\frac{40 \times 9.81}{\sin(2 \times 45^\circ)}}$$

$$v = \sqrt{\frac{392.40}{1}} = 19.81 \text{ m/s}$$

10.
$$v = \left(\frac{19.81}{1000}\right) \times 60 \times 60 = 71.3 \text{ km/h}$$

11. Escape velocity of Earth can be calculated like below:

$$v_e = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{6.371 \times 10^6}} = 1.12 \times 10^4 \text{ m/s} = 4.03 \times 10^4 \text{ km/h}$$

12. Velocity required to put a spacecraft in orbit around the Earth at 300 km above the Earth's surface.

$$v_{\text{orbital}} = \sqrt{\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{6.371 \times 10^6 + 3.00 \times 10^5}} = 7.73 \times 10^3 \text{ m/s} = 2.78 \times 10^4 \text{ km/h}$$

Where r is the orbit radius (from centre of the Earth) so $6371 \text{ km} + 300 \text{ km}$.

13. Comparing to the example in question 9 this is $2.78 \times 10^4 / 71.3 = 390$ times faster than the velocity of the self-built rocket
14. The escape velocity from the Moon is much smaller, as the Moon has considerably less mass for its radius, when compared to Earth.
15. The escape velocity of the Moon can be calculated like below:

$$v_e = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{1.737 \times 10^6}} = 2.38 \times 10^3 \text{ m/s} = 8.57 \times 10^3 \text{ km/h}$$

16. Because the escape velocity of the Moon is lower it needs much less energy (and thereby fuel) to launch a spacecraft from the Moon, making it easier to launch big payloads from the surface of the Moon.

Discussion

Summarise the results in class. What did each group do to make their rocket go further? Did it work? Why or why not?

Ask the students why it could be useful to launch rockets from the Moon, when going further into space – like Mars? Help them understand that since both the orbital velocity and the escape velocity are so much smaller on the Moon, than on Earth, we would need less fuel, meaning it would cost much less to launch. You can also discuss why rockets are launched from locations near the equator using the information in the introduction.

Talk about the simplifications and assumptions that you made in the calculations. For example, we did not take into account any deceleration due to drag force. The drag force will increase as the velocity increases. Discuss when and where they think the drag force will have most effect on the rocket. The required escape and orbital velocity is higher on Earth than what was calculated. Talk about how this is another benefit on the Moon, since there is no atmosphere there is no air resistance and so it is easier to escape.

→ Activity 3: Human spaceflight

In this activity, students will learn about acceleration, forces and G-force. They will explore why there needs to be some extra precautions when launching manned rockets.

Exercise

Start the activity by asking the class how rockets accelerate upwards. This is an excellent opportunity to talk about Newton's three laws of motion and the force due to gravity.

Results

1. Rearranging for time (**t**) in equations (1) and (2) and equating gives:

$$\frac{2s}{u+v} = \frac{v-u}{a}$$

Then rearranging for **a** gives:

$$a = \frac{v^2 - u^2}{2s}$$

2. The initial velocity of the rocket is $u = 0 \text{ m/s}$. If we use the launch velocity calculated in Activity 2, question 9, then we will get:

$$a = \frac{19.81^2 - 0^2}{2 \times 0.3} = \frac{392.4}{0.6} = 654 \text{ m/s}^2$$

3. The students are asked to calculate the G-force of the rocket at launch. A G-force is not a force, but rather a ratio of the total acceleration acting upon an object to the acceleration due to the gravity of the Earth. Using the answer above, we get:

$$G_{\text{force}} = \frac{654}{9.81} = 67$$

This is equivalent to 67 times the force due to Earth's gravity.

Discussion

Discuss in class why they think that an astronaut usually does not experience more than 3 to 6 G's while the number is so high for their rocket?

A human cannot tolerate a G-force as high as 67 G in real life. How much G force a human can sustain also depends on how long they are exposed to the forces: from a few seconds to minutes. Remind the students that this depends on the **acceleration** not the velocity. The acceleration is the change of velocity per time. For a crewed mission, the acceleration is smaller and the spacecraft takes a lot longer to reach the required velocity.

On completion of the three activities you can ask the students to write an individual report on their experiment. They should use the knowledge they have gained during these activities and evaluate how it went and what improvements could be made if they were to do them again.

→ 3...2...1 LIFT-OFF!

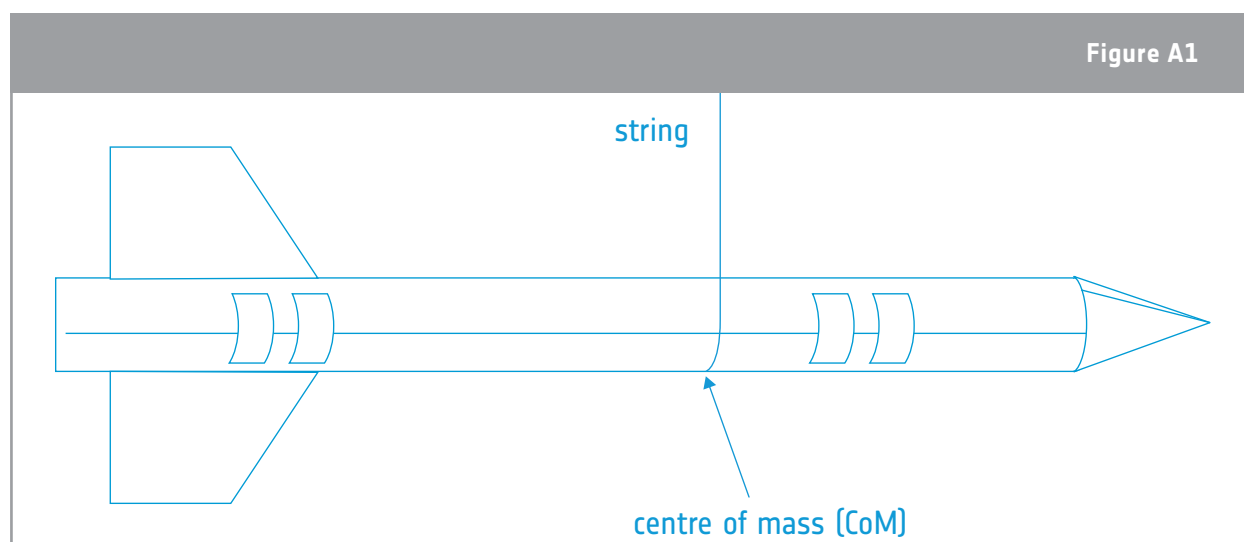
Building your own paper rocket

→ Activity 1: Build your own paper rocket

The basic principles behind rocketry are the same for a simple paper rocket as for space rockets. In this activity, you will design and build your own paper rocket and use it to investigate some of the variables in the design that may affect the stability and performance of your rocket.

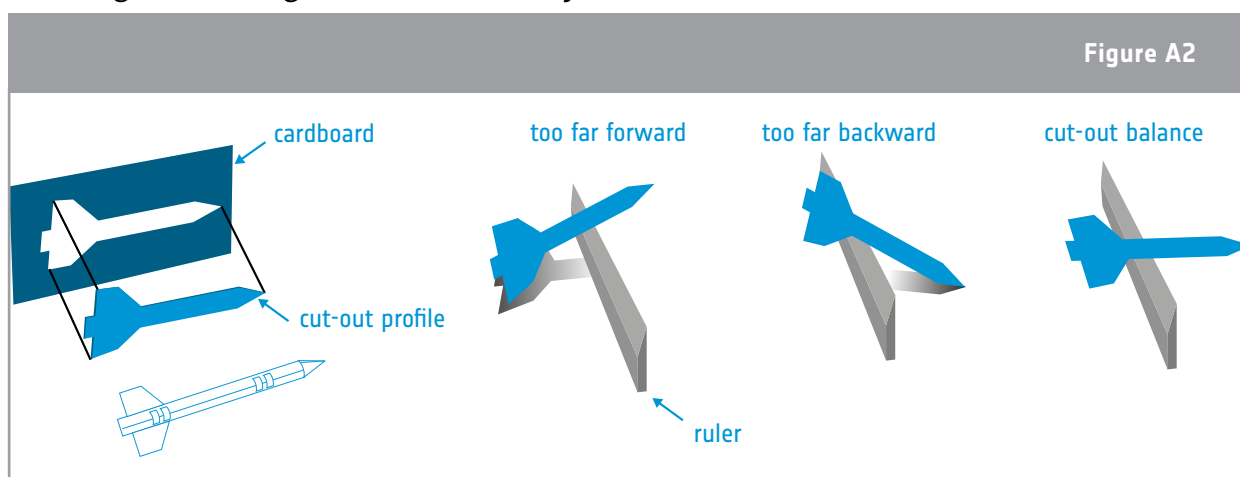
Exercise

1. Build a paper rocket using the equipment provided by your teacher. You can build your rocket anyway you like, but be sure that it fits on the launch system that you will use.
2. Find the centre of mass (CoM) of your rocket. This is the point representing the mean position of the mass in a body or system. You can do this by tying a piece of thread around your rocket and balancing it as shown on the drawing below. Mark where you think the CoM lies with a pencil.



↑ Illustration of how to find the centre of mass of a paper rocket: The rocket is balanced, hanging from a string - the centre of mass (CoM) is where the string is tied.

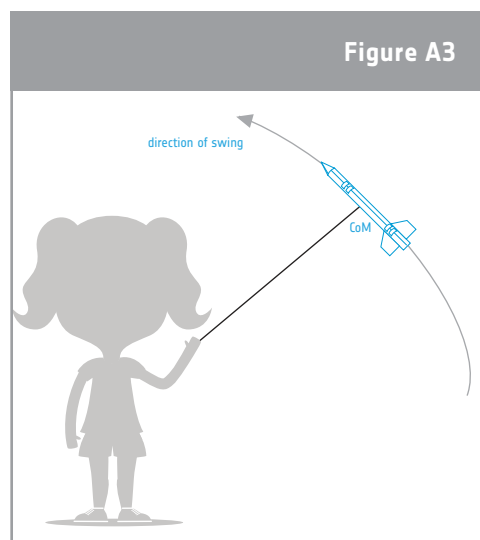
3. Find the centre of pressure (CoP) of your rocket. This is the average location of the pressure acting on the rocket and, in this case, can be found by locating the balance of the rocket's projected area. You can find the CoP by cutting out a silhouette of your rocket in cardboard and balancing it on an edge. Mark the CoP on your rocket.



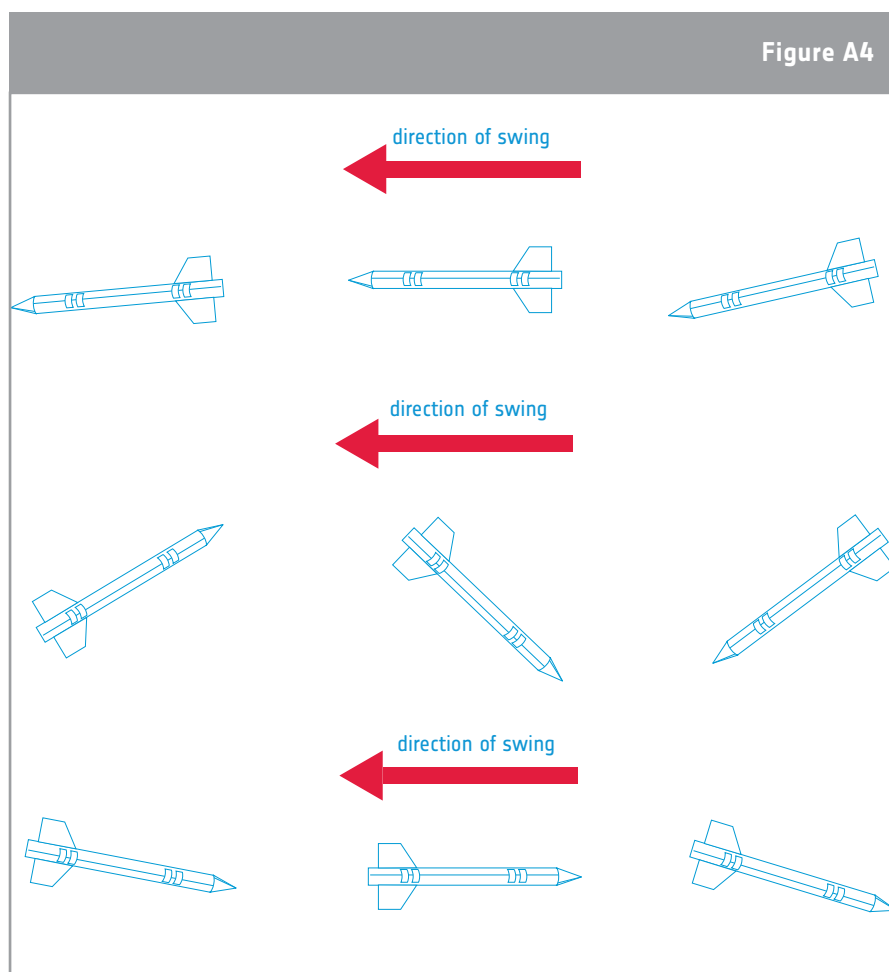
↑ Illustration of how to find the centre of pressure of a paper rocket. A silhouette of the rocket is cut out in cardboard. The centre of pressure is found where the cardboard silhouette is balanced on a ruler.

4. What is the distance between the centre of mass and the centre of pressure? _____ cm
5. Is the centre of pressure in front of the centre of mass? Yes / No
6. You can simulate a wind tunnel test by performing a swing test: Tie a piece of string to the centre of mass and swing the rocket around in a circle like on the illustration below:

Analyse the stability of your rocket and the rockets of your classmates and try to play around with the centre of mass by putting some weight in the nose cone or in the back. What do you think the relative position of the centre of mass (CoM) is in relation to the centre of pressure (CoP) in the three examples below?



↑ Illustration of swing test. The string is tied to the centre of mass and the rocket is swung around.



Relative position of CoM to CoP:

Relative position of CoM to CoP:

Relative position of CoM to CoP:

↑ Illustration of possible behaviors of the paper rocket during the swing test.

7. Was your rocket aligned with the direction of travel throughout the swing test? If not, what do you think you should change?

8. Add more variables to the table and consider how you can change the variable in order for your rocket to be more stable.

Table A1	
Variable	Description
Number of fins	
Size and shape of fins	

↑ Variables in rocket design and their influence on stability.

9. Give your rocket a cool name: _____

Did you know?

A rocket is divided into multiple smaller rockets (called stages). Each smaller rocket has its own engine and its own fuel reserve. The front of the rocket, called nose fairing, transports the payload, usually satellites or astronauts.

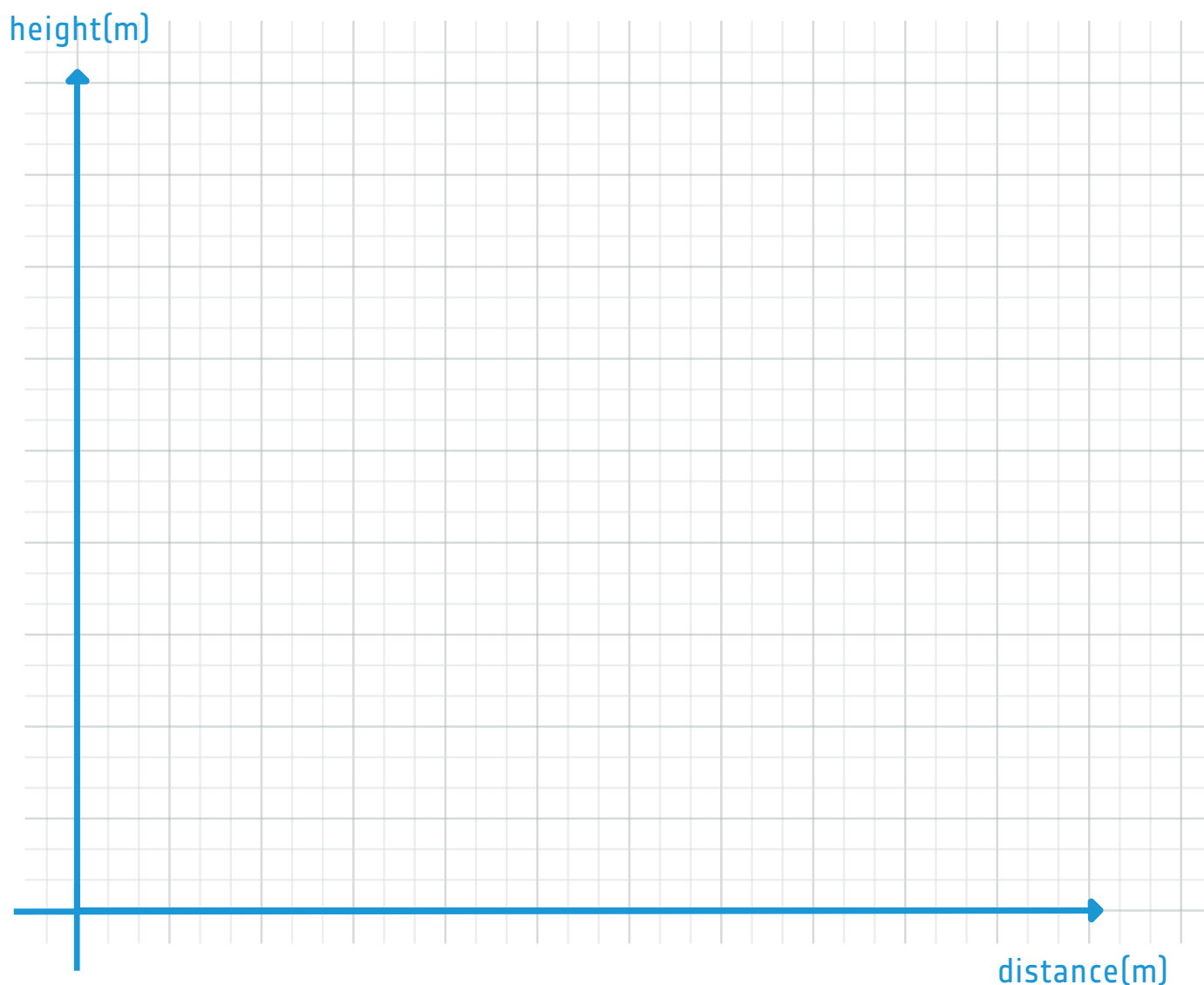


→ Activity 2: Launch your rocket

You are now ready to launch your rocket! A well-built paper rocket can achieve flight distances of 30 m or more! In this activity, you are going to use your results from your rocket launch to calculate its velocity and discover how fast it would have to go in order to go to the Moon.

Exercise

1. Before launching, draw the trajectory that you predict your rocket will follow when you launch it from the ground.



2. At what angle should you launch your rocket with respect to the ground to maximise the distance travelled?

3. How far from the launch pad did your rocket land, in meters?

4. Did your rocket follow the trajectory that you expected? **Yes / No**

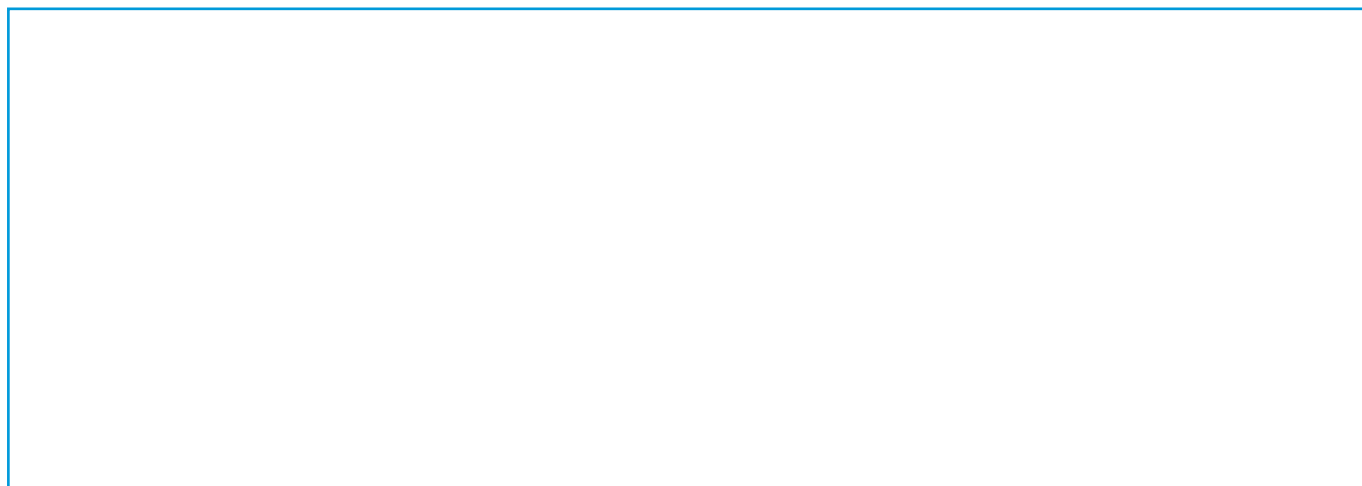
From your results, identify three possible initial conditions that affected the trajectory of your rocket launch.

a. _____

b. _____

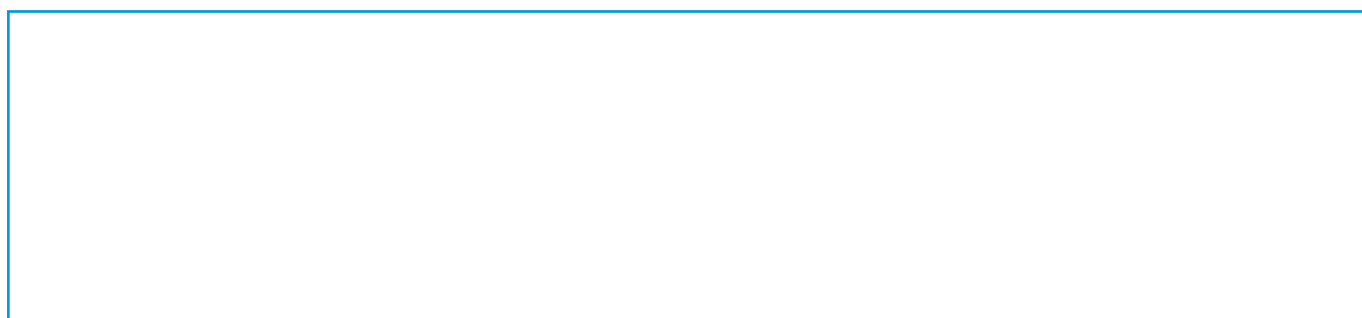
c. _____

5. Draw a force diagram showing the forces that you think would act on a rocket during the powered ascent phase (when propulsion is effective).



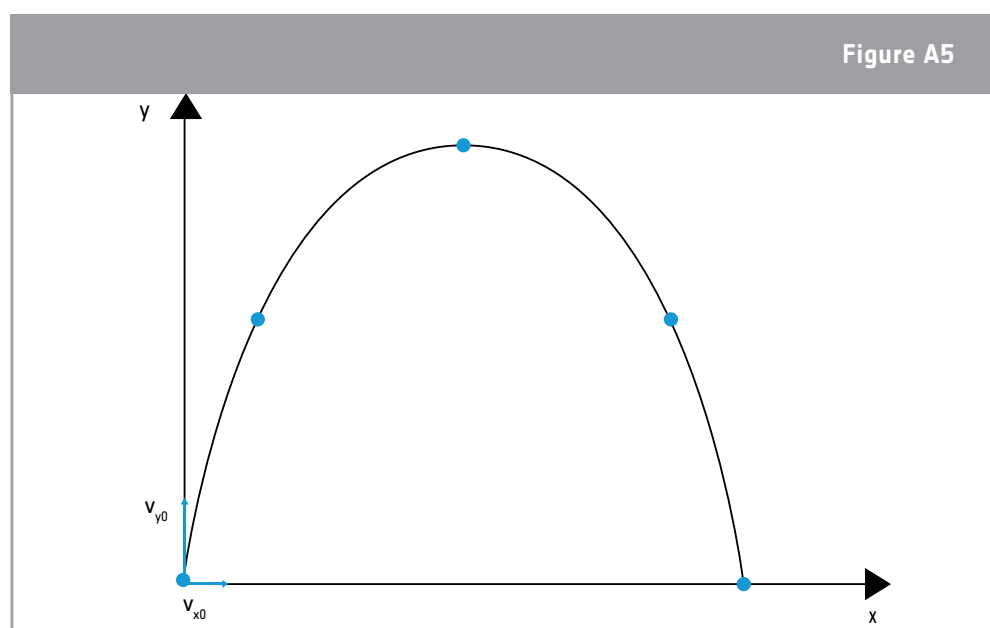
6. a. How long do you think the powered ascent phase lasts in a real rocket? And in your paper rocket?

- b. Write the resultant force equation of the rocket (taking into account only forces in the rocket's direction of motion).



c. Find an expression for the rocket's acceleration.

7. a. Complete the graph with the horizontal velocity component (v_x), and the vertical velocity component (v_y) of the rocket in the points marked on the parabola below. We have helped you by drawing the initial velocity vectors v_{x0} and v_{y0} . You should also consider the forces acting on the rocket throughout the flight and think about why it follows the trajectory it does. We are neglecting the effect of air-resistance (drag) in this question.



↑ Illustration of the parabolic motion of the paper rocket.

b. Describe the variation of velocity on the graph.

8. For an object to follow a parabolic trajectory near Earth's surface (where we can assume the gravitational field to be uniform), it is possible to show that distance, velocity and launch angle depend on each other as follows:

$$d = \frac{v^2 \sin(2\alpha)}{g}$$

where:
 d = distance [m]
 v = velocity [m/s]
 α = angle of launch
 g = gravitational acceleration in [m/s²]

Rearrange the above equation for velocity:

9. Use the measurement for your rocket's flight distance (in meters) from the last exercise. Use the equation from question 8 to calculate the velocity as it leaves the launch pad. Use $g=9.81 \text{ m/s}^2$.

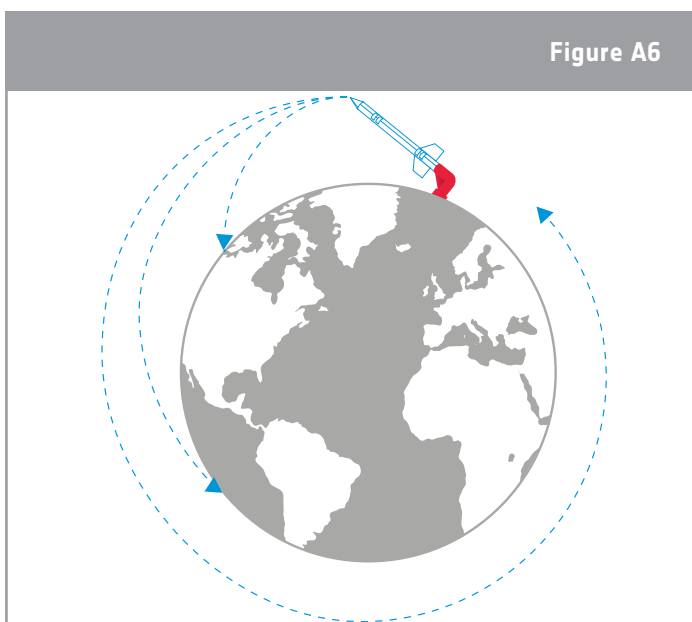
10. Convert the result to km/h? _____
11. Now that you have the velocity of your rocket, let's investigate how to get to the Moon! You have to reach **escape velocity** which is defined as:

$$v_e = \sqrt{\frac{2GM}{r}}$$

G being the gravitational constant, $G = 6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$,
M being the mass of the Earth, $M = 5.97 \times 10^{24} \text{ kg}$,
r being the radius of the Earth, $r = 6371 \text{ km}$.

Calculate the escape velocity of Earth.

Because the escape velocity of Earth is high, we currently launch rockets into orbits, before performing manoeuvres to travel further into space. If we launch the rocket straight up, it will quickly fall back to Earth. Instead, we should launch the rocket with a large tangential velocity (velocity parallel to the surface of the Earth).



↑ Illustration of launching with a large tangential velocity (velocity parallel to the surface of the Earth). When launching with a high enough velocity, the rocket can reach Earth orbit.

12. The higher the velocity of the rocket the further it gets before falling down to Earth. At some point, we shoot so fast that it never falls back down! It goes into orbit! The velocity required for this to happen is called orbital velocity. Orbital velocity can be calculated with this equation:

$$v = \sqrt{\frac{GM}{r}}$$

G = gravitational constant

r = radius of the orbit (add the radius of Earth to the altitude of the orbit)

M = the mass of Earth

Calculate the velocity we need to put a spacecraft in orbit around the Earth at 300 km above the Earth's surface.

13. How many times more is this than the velocity of your rocket?

14. After landing on the Moon we would like to either return home to Earth, or use the Moon to travel further into space. This requires being able to take off from the Moon. Escape velocity is directly proportional to the mass of the object and inversely proportional to the radius of the object.

$$M_{\text{Moon}} = 7.35 \times 10^{22} \text{ kg}$$

$$r_{\text{Moon}} = 1737 \text{ km}$$

Is the escape velocity of the Moon bigger or smaller than Earth's? _____

15. Calculate the escape velocity of the Moon:

16. Discuss why it is convenient to use the Moon as a stepping stone for traveling further into space.

Did you know?

Europe's Spaceport is situated in French Guiana in South America, near the equator. The Earth's rotation is fastest at the equator and rockets can profit from the 'slingshot' effect. This increases the rocket's speed by 460 m/s, which saves fuel and money. This location is also ideal for launches into geostationary transfer orbit as few changes have to be made to a satellite's trajectory.



→ Activity 3: Human Spaceflight

In this activity you will explore how acceleration and forces are important for human spaceflight.

Exercise

Let's now further analyse the launch of the paper rocket. In Activity 2, question 9, you calculated the speed, v , of the rocket when it leaves the launch pad. Before the launch, the rocket was still on the launch pipe, this means that its initial speed, u , is 0 m/s. We will now estimate the acceleration of the rocket over this very short period of time.

$$(1) \quad a = \frac{v-u}{t}$$

where

u = initial velocity
 v = launch velocity
 a = acceleration
 t = time

However, it is hard to measure the time it takes for the rocket to leave the pipe.

So we would like to rewrite the equation without including t . We can use the approximation that the distance travelled (s , which in this case corresponds to the length of the launch pipe) equals the average speed multiplied by time:

$$(2) \quad s = \frac{(u+v)}{2} t$$

1. Use equations (1) and (2) to find an expression for the acceleration, a .

2. Assuming constant acceleration, use the equation to calculate the acceleration of the rocket just before it leaves the launch platform. Consider the length of the 'launch pipe' (s) to be 30 cm and use the velocity calculated in Activity 2 (if you have not calculated a value for velocity use the value 19.81 ms^{-1}).

Did you know?

A G-force is not a force, but rather a ratio of the total acceleration of an object to the acceleration due to the gravity of Earth. Exposure to high G-forces can affect us in different ways. For example, a slap on the face may briefly impose hundreds of G locally and do little damage but constant exposure to 16 G for a minute can be deadly. Usually during launch, astronauts can experience between 3 G and 6 G! They are able to handle such high G forces by training in a centrifuge like the one in the picture.



3. Calculate the G-force an astronaut in your paper rocket would experience during launch. You can do this by dividing the acceleration you calculate in question 2 by $g = 9.81\text{m/s}^2$.

→ Links

ESA resources

Model of a simple launch elbow that can be 3D printed
<https://esamultimedia.esa.int/docs/edu/1PBL.zip>

Moon Camp Challenge
esa.int/Education/Moon_Camp

Animations about how to get to the Moon
esa.int/Education/Teach_with_the_Moon/Travelling_to_the_Moon

ESA classroom resources
esa.int/Education/Classroom_resources

How rockets work
esa.int/kids/en/learn/Technology/Rockets/How_does_a_rocket_work

ESA missions

Orion
esa.int/Our_Activities/Human_and_Robotic_Exploration/Orion

ESA Launch vehicles
esa.int/Our_Activities/Space_Transportation/Launch_vehicles/Europe_s_launchers

ESA Space Transportation
esa.int/Our_Activities/Space_Transportation

Ariane 6
ariane6.esa.int

Europe's spaceport
blogs.esa.int/spaceport

Extra information

Open rocket, a free rocket simulation tool
<http://openrocket.info>

To space! But on which rocket?
esa.int/spaceinimages/Images/2019/06/To_space!_But_on_which_rocket

→ Annex 1: Preparing a simple launch system

Use a plastic bottle and a 3D printed launch elbow to build a launch platform that the students can use to launch a paper rocket. You will need to use a 3D printer to print an elbow which attaches the bottle to the rocket. To print this (<https://esamultimedia.esa.int/docs/edu/1PBL.zip>), you can use either: your own 3D printer; a 3D printer at a MakerSpace (or equivalent); or an online service which can print an object from a file. This elbow can be replaced by a DIY version for example using cardboard or a plastic pipe elbow.

Equipment

- 1 A4 sheet of paper
- 1 3D printed launch elbow
- 1 500ml plastic water bottle

Assemble the simple launch system

1. Roll up the piece of paper into a tight cylinder.
2. Insert the cylinder into the launch elbow and release it so that it unravels to be the same size as the hole in the launch elbow.
3. Screw the water bottle onto the other side of the launch elbow.
4. Your rocket launch system is ready.

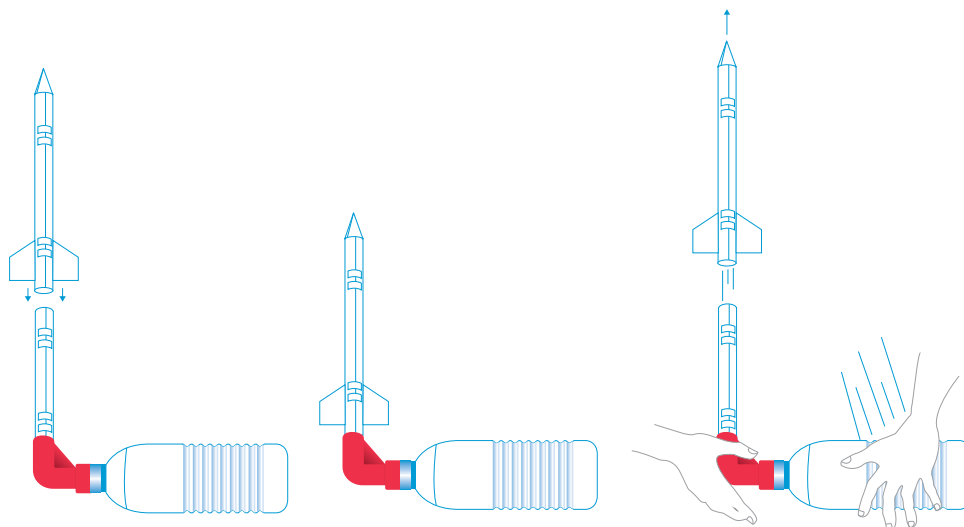


Figure 1

↑ Rocket launch system

Using the launch system

1. Slide your rocket onto the paper pipe connected to the launch elbow.
2. Place the rocket launch system and the rocket on the floor.
3. Step or press hard on the bottle to launch your rocket.



→ Annex 2: Preparing a pressurised launch platform

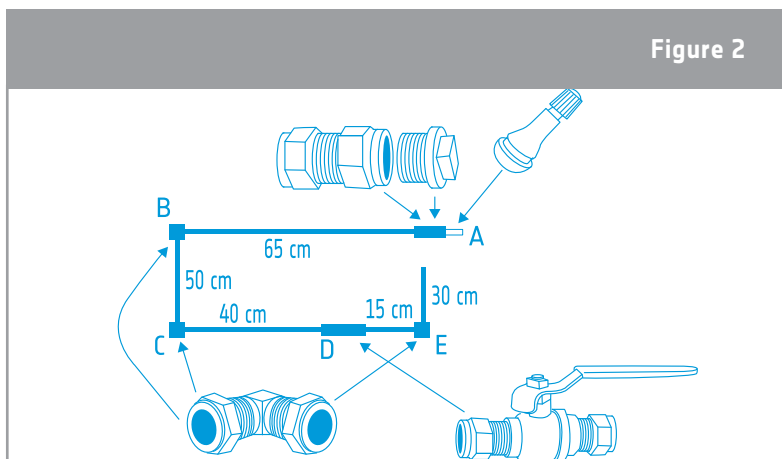
Instructions for building a compressed-air rocket launch pipe platform.

Equipment

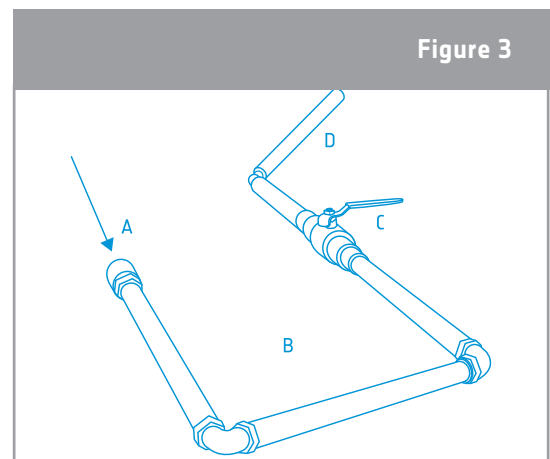
- Copper pipes (diameter: 22 mm, lengths: 65 cm, 50 cm, 40 cm, 30 cm, 15 cm)
- 3 angle connectors
- 1 Pipe junction (regular connector on one end and internal connection on the other)
- 1 pipe plug
- 1 ball valve
- 1 air valve
- Air pump or air compressor

Assemble the pressurised launch platform:

1. Drill a hole in the pipe plug and insert the valve.
2. Connect the valve to the pipe junction.
3. Do not tighten the third angle connector too much as this will allow you to change the angle of the rocket launch pad.
4. Connect the rest of the pipes and pipe junctions as shown below:



↑ Representation of the assembled rocket launch system. A – connection of the straight fitting, plug and tyre valve; B – elbow fitting; C – elbow fitting; D – ball valve, to release the pressure within the launch pad; E – third elbow fitting



↑ Diagram of the assembled rocket launch system.

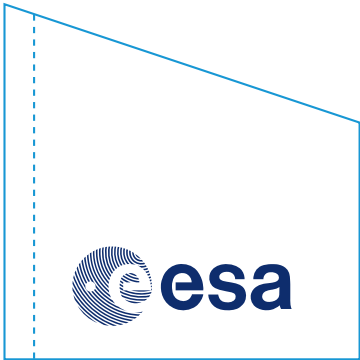
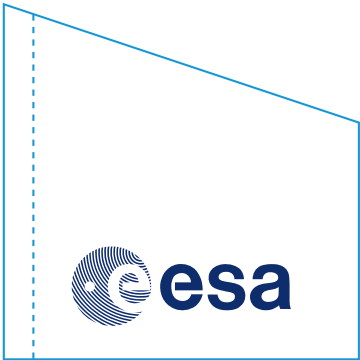
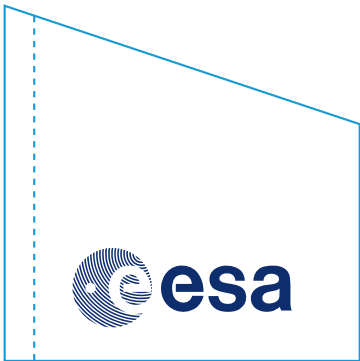
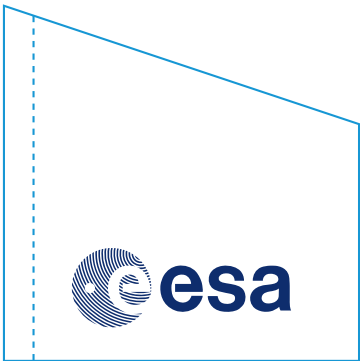
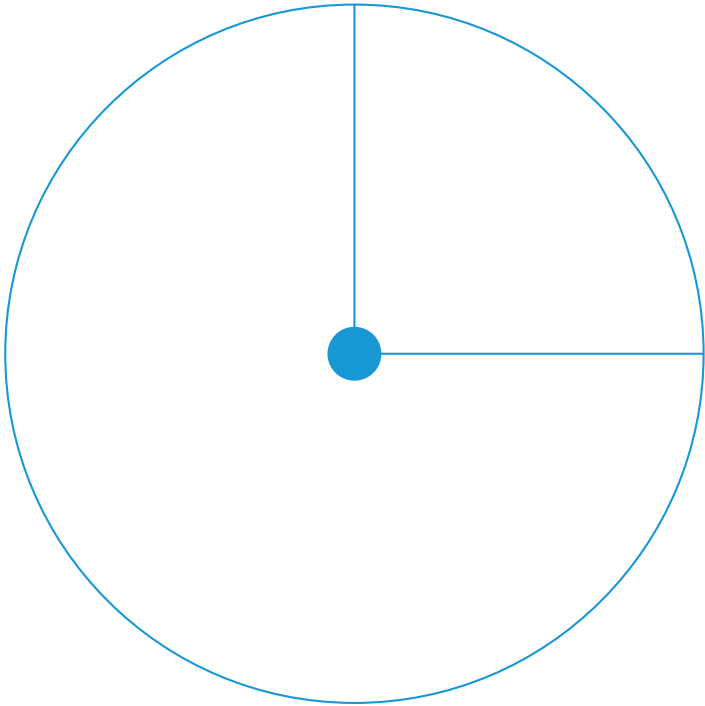
Using the launch system

1. Adjust the angle of the launch pad.
2. Close the valve so no air can escape.
3. Pump the system to a maximum of 7 bar using a bike pump.
4. Open the valve and let the compressed air into the system (this launches the rocket).

Health and Safety

- Check and tighten the pipe connections regularly as they might untighten with use.
- Keep a foot on the launch pad to keep it from moving.
- Make sure no one is standing in front of the launch pad when it is pressurised.
- Maximum pressure on the launch is 7 bar or 101 psi.

→ Annex 3: Fins and nose cone for Activity 1



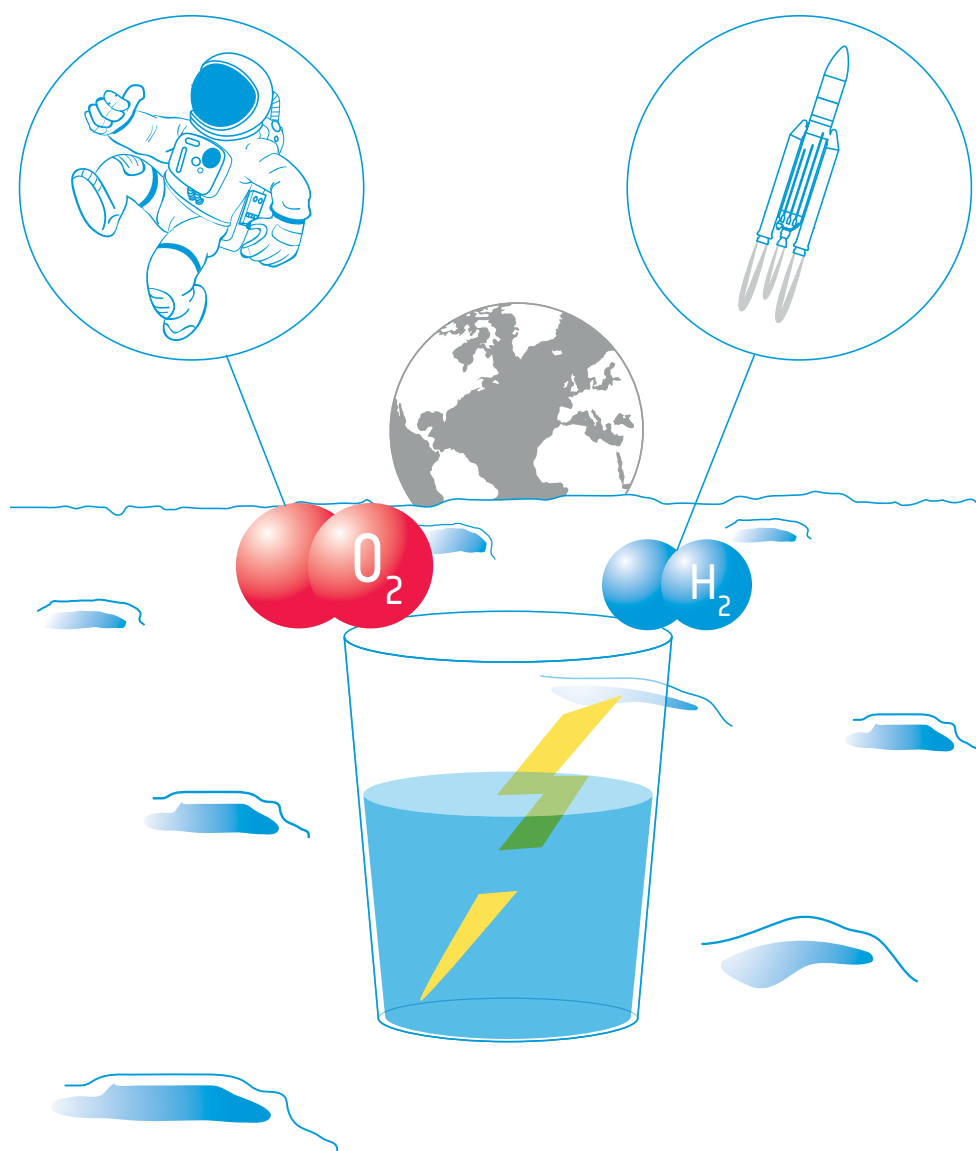
→ Annex 4: Table for recording flight distance

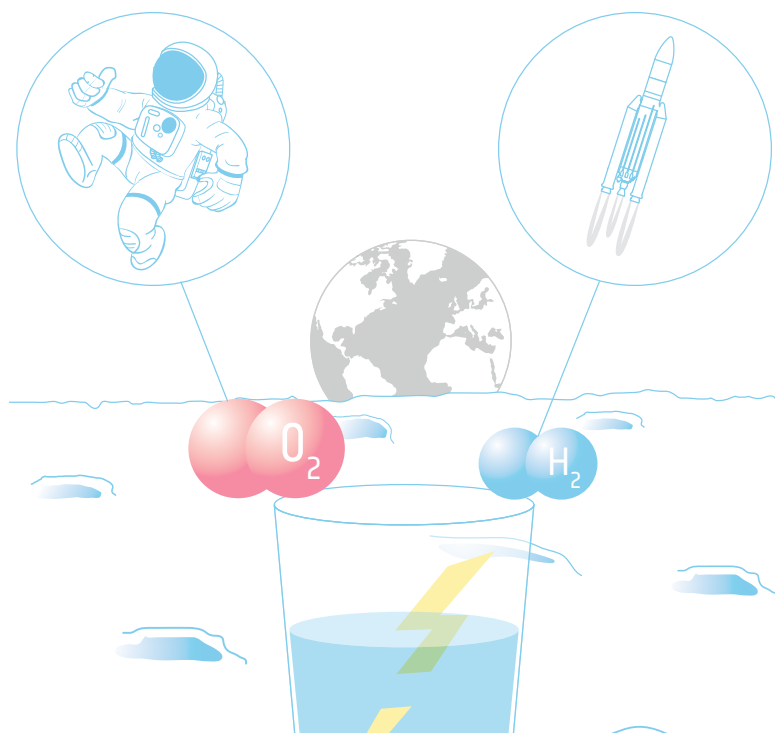
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teach with space

→ POWER FROM WATER

How to produce oxygen and hydrogen on the Moon





Teacher guide

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→ POWER FROM WATER

How to produce oxygen and hydrogen on the Moon

Fast facts

Subject: Chemistry and Physics

Age range: 14-16 years old

Type: laboratory activity

Complexity: medium

Teacher preparation time: 1 hour

Lesson time required: 2 hours

Cost: medium (5-25) euros for activity 1 and 2
and high (50-100 euros) for activity 3

Location: laboratory

Includes the use of: Zinc and copper plates

Keywords: Chemistry, Physics, Moon, Electrochemistry, voltaic pile (battery), Electrolysis, Fuel cells

Brief description

In this set of three activities, students will learn about electrochemistry. In the first activity they will build a voltaic pile – a simple battery. This invention marked the beginning of electrochemistry. Students will then study electrolysis. Electrolysis uses electric current to split water into its components: hydrogen and oxygen. These products can be used as propellants for spacecraft and/or to provide oxygen to support a crew. In the last activity, students examine and use a fuel cell.

Learning objectives

- Understanding how a battery works.
- Performing an experimental activity to confirm that certain chemical reactions can create electricity.
- Performing an experimental activity to confirm that electricity can make certain chemical reactions take place.
- Studying water electrolysis and its applications.
- Investigating fuel cells and their applications.
- Writing balanced equations for REDOX chemical reactions.
- Using equipment appropriately to make and record observations.

→ Summary of activities

Summary of activities					
	Title	Description	Outcome	Requirements	Time
1	Build your own battery	Building a voltaic pile.	Introduction to electrochemistry; learning how a battery works.	None	45 minutes
2	Water electrolysis	Building an electrolyser and performing water electrolysis.	Learning about water electrolysis and its applications.	Completion of activity 1 is advised.	45 minutes
3	Fuel cell	Investigating a fuel cell.	Learning about fuel cells and their applications.	Completion of activity 2 is advised.	30 minutes

→ Introduction

Human exploration of the Moon requires resources: water, oxygen, food, materials, propellant, etc. Bringing everything from Earth would be very inefficient and expensive, so instead mission designers are investigating how to use resources already available on the Moon. One of the most important resources is water. Scientists found evidence that water may exist in some areas towards the Moon's poles. On a future Moon mission, this water could be used to produce hydrogen and oxygen for propulsion and oxygen for breathable air for the crew.

In this set of activities, we are going to investigate how to store energy in batteries and how to generate oxygen and hydrogen from water. In order to do so we need to learn about electrochemistry!

Electrochemistry is the branch of science that studies the relationship between electricity and chemistry. Certain chemical reactions can create electricity, as is the case in a battery. The opposite is also possible: electricity can make certain chemical reactions happen that wouldn't happen spontaneously.

In this resource students will be guided through the principles and chronology of electrochemistry, from the invention of the first battery (the voltaic pile) to the modern use of fuel cells.

In this resource the students will build the following devices:

1. **Battery:** A device that generates electricity from chemical reactions.
2. **Electrolyser:** A device that uses electricity to make certain chemical reactions take place. In this case we will work with water electrolysis and break the bonds that hold the components of water molecules together
3. **Fuel Cell:** A device that produces electricity and heat from a chemical reaction.

→ Activity 1: Build your own battery

The voltaic pile was the first battery ever invented by Alessandro Volta in 1800. Batteries generate electricity from chemical reactions, and the invention of the voltaic pile marked the beginning of electrochemistry.

Batteries are often used on spacecraft as a means of electricity (power) storage and distribution. Traditional batteries contain all their usable energy and can only be discharged. Batteries used on space missions are often re-chargeable. They can be recharged with power from other sources, for example by solar energy. Batteries are crucial because they can provide electricity during periods with no access to other power sources (for example, when it is not in direct sunlight).

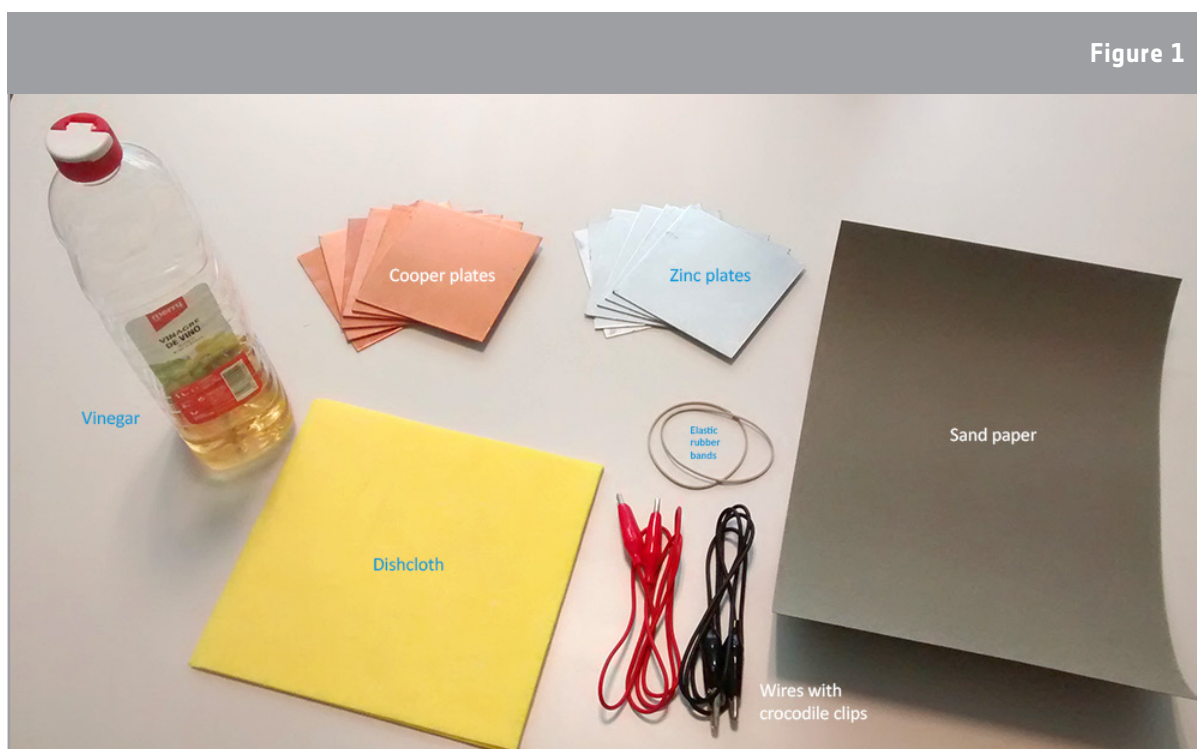
In this activity, students will construct a voltaic pile – a simple battery from metal plates, dishcloth and vinegar. A voltaic pile uses a spontaneous chemical reaction to create electricity.

Health and safety

The voltaic piles should not be left connected in a closed container or unventilated room.

Equipment

- 6 zinc plates (per group)
- 6 copper plates (per group)
- 1 dishcloth (per group)
- Scissors
- Vinegar
- Sandpaper
- 2 elastic rubber bands
- Wires with crocodile clips
- Multimeter
- (optional) AA Batteries



↑ Equipment needed for building a voltaic pile

Exercise

Start by introducing the concept of electrochemistry and the definition of electrical potential difference.

Building one voltaic cell

Divide the class into groups of 3 to 4 students. The students should follow the instructions 1 and 2 in their student worksheet to assemble a simple voltaic cell. After assembling the cell they should connect a multimeter and measure the electrical potential difference.

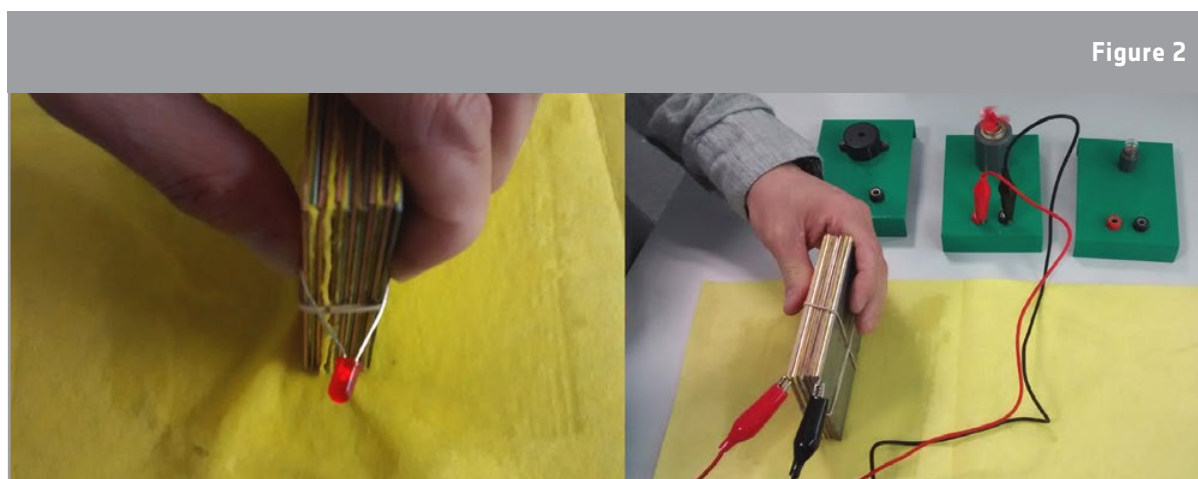
Ask the students to explain why they get an electrical potential difference and to explain what the function of each layer is in the voltaic cell. Have the students write down the ionic equations of the reactions that occur in the voltaic cell. Ask them to answer question 4 to 7 in their student worksheet.

Building a voltaic pile

Now students should pile several voltaic cells to get a voltaic pile. Students should measure the electrical potential difference of the pile once per minute for 10 minutes and record the measurements in Table 1 in their student worksheets. In between measurements they should answer the related questions in their student worksheets.

Ask the students to plot the electrical potential difference of the voltaic pile as a function of time. They should discover that the electrical potential difference decreases with time. Ask the students why they think this is happening.

To demonstrate that the voltaic pile can generate current you can use it to light a LED or make a motor run as seen in Figure 2 and investigate how long the voltaic pile is able to power the actuator.



↑ Making an LED light up using a voltaic pile (left) and powering a motor with a voltaic pile (right).

Ask the students to compare their voltaic pile with a normal AA battery. Talk about how a normal battery works and what the limitations of the voltaic pile are. If time permits, let the students connect the battery and the voltaic pile to different electrical appliances and measure the current in the circuit.

Results

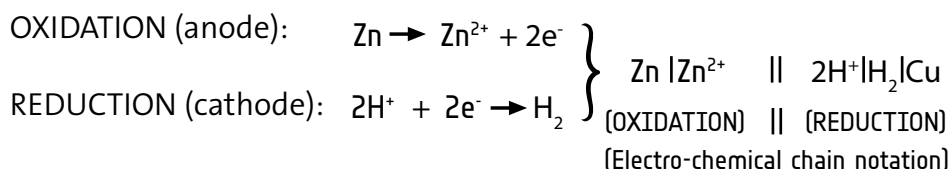
These are the answers to the student worksheet activity 1:

3. From one voltaic cell you should obtain approximately 1 V.

4. The net ionic equation is:



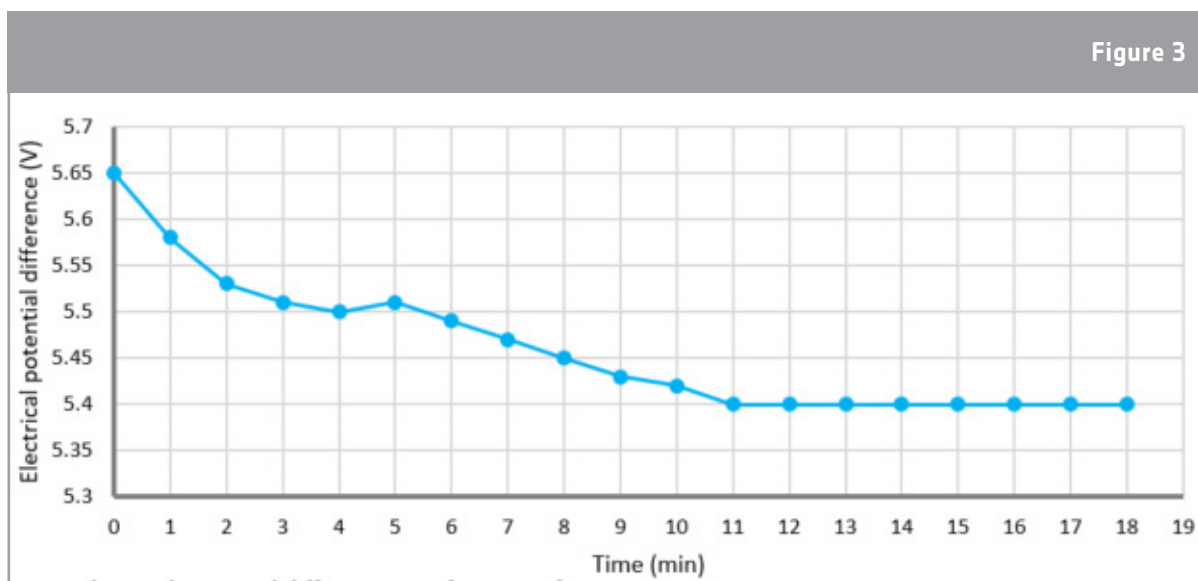
The redox half reactions for the two half cells are:



The copper metal plate only serves as a "chemically inert" noble metallic conductor for the transport of electrons in the circuit and does not chemically participate in the reaction. The copper plate could be replaced by any sufficiently metallic conductor.

5. Zinc is oxidised and releases electrons (anode). hydrogen (hydronium = H_3O^+) is reduced and gains electrons (cathode).
6. An oxidised layer accumulates on the plate's surface (which makes the metal look dull). This decreases the useful area for ion exchange. Sanding removes the oxidised layer.
7. Vinegar is an electrolyte. It allows the exchange of ions between the plates and increases the electrical potential difference. All acids, like vinegar, release H^+ ions that are necessary for the reaction. Even water releases H^+ ions, but in a very low quantity. Adding a salt or an acid increases conductivity. We could use any other substance that acts as an electrolyte (salt or acid)

10. Example result obtained from a voltaic pile consisting of six voltaic cells



↑ Electrical potential difference as a function of time.

11. The voltage drops with time because the internal resistance of pile increases. The zinc surface is oxidized, which results in the reaction surface area being reduced. Vinegar (and other acids) also cause oxidation. Furthermore, in the voltaic pile, hydrogen bubbles are accumulating on the copper surface (polarization). Commercial batteries use very different materials, which oxidise far less than zinc. Some types of batteries use a substance that removes the accumulated hydrogen or vents it off. For these reasons, commercial batteries can continue operating much longer.
12. An AA battery usually has an electrical potential difference of 1.5V unless otherwise specified by the manufacturer. In our example we obtain 1V from one voltaic cell and we obtain 5.5V with the voltaic pile (six voltaic cells). When we increase the number of cells, we increase the total contact surface for ion exchange. The limiting factor to the current output is the internal resistance (which is high).
13. Batteries would be useful for Moon exploration as a way to store energy. Batteries used on space missions are often re-chargeable from other sources, for example by solar energy. Batteries are crucial because they can provide electricity during periods without access to any other power source (for example, when there is no direct sunlight). Bringing non-rechargeable batteries as the only power supply would be both heavy, inefficient and not sustainable.

Discussion

Discuss with the students the importance of the invention of the voltaic pile. How would our lives be without batteries? Could we design a limitless battery? Discuss the reasons for inefficiencies: weight and limited lifetime versus storing capability and power output.

Talk about how energy can only be transformed, not lost or created. Discuss why we still talk about losing energy (because heat is a difficult form of energy to use).

The voltaic pile can be reset by cleaning the metal plates with sandpaper and soak the dishcloth with the electrolyte again. Discuss if any rechargeable battery can be recharged indefinitely.

→ Activity 2: Electrolysis

Electrolysis uses electricity to make chemical reactions occur that would not happen spontaneously. In this activity, students will build an electrolyser: a device that introduces an electric current into a liquid using two electrodes. They will use the device for water electrolysis and discover that it is possible to split water into its components: oxygen and hydrogen.

Health and safety

When testing the gases be sure to keep a safe distance and use long matches or splints to avoid being burned.

Equipment (per group)

- Plastic container with lid (with two holes – see preparation)
- 2 test tubes
- 2 steel push pins
- 2 beakers
- Copper wire
- Battery (optional: a solar cell)
- 400 cm³ distilled water + 12 g NaOH (3% dissolution)
- Distilled water
- Gloves

Figure 4



↑ Equipment needed for building an electrolyser

Preparation

Drill two small holes in the bottom of the container and two holes in the lid (with the diameter of the test tubes) as shown in Figure 5.



↑ Preparation of box for electrolyser

Exercise 1

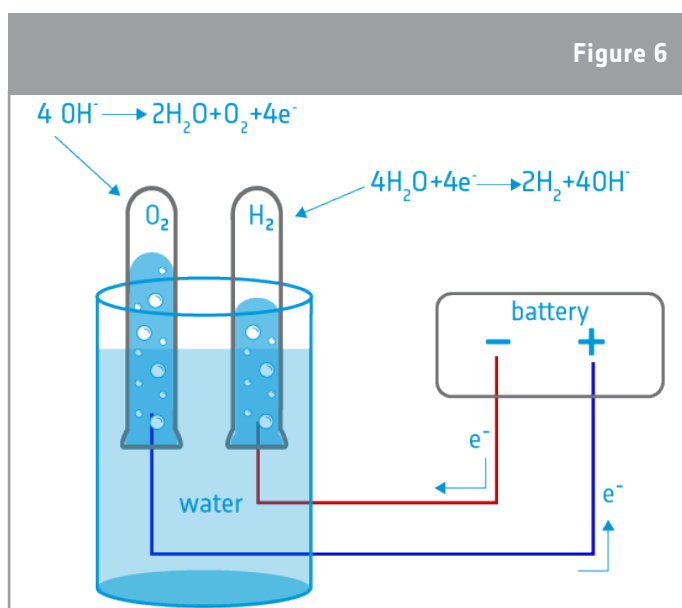
Have the students balance the global equation for the water electrolysis process. Then help them write and understand the oxidation and reduction reactions.

An illustration of the electrolysis setup can be seen in Figure 6.

Let them build their own electrolyser following the instructions in Annex 1. Remind them to time the electrolysis process in order to later calculate the production rate of oxygen. Ask the students to answer question 5 to 7 in their student worksheet about the electrolysis process.

Relate the experiment with oxygen production for space missions. Ask the students to answer questions 8 and 9 in their student worksheet to investigate if their electrolyser could produce enough oxygen for astronauts on the Moon.

If you wish to extend the exercise, students can do the experiment with distilled water, tap water (containing salts) and water with electrolyte.

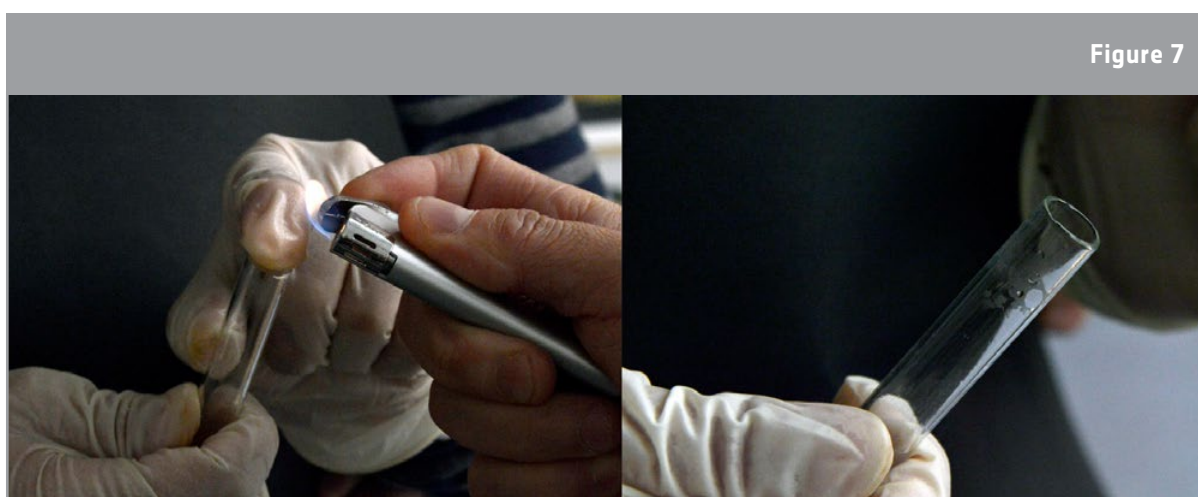


↑ Illustration of the electrolysis setup and process

Identifying the gases

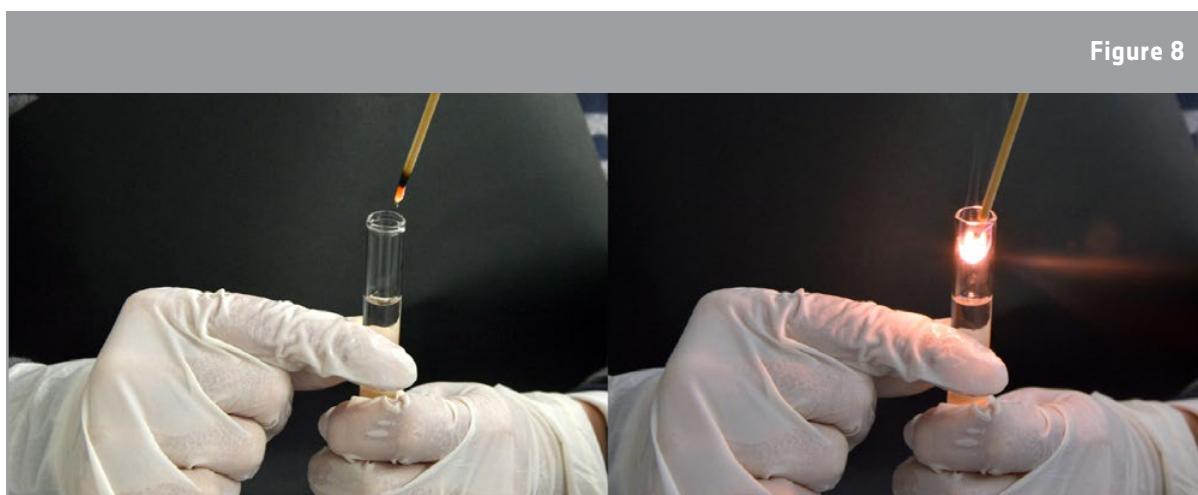
You can do this test as a classroom demonstration or let the students test it themselves. Before performing the test, ask the students if they have any ideas how they could test the gases in the tubes.

Hydrogen test: Place a finger on the opening of the test tube to prevent the hydrogen from escaping, then turn the test tube around and place a long match (or lighter) at the opening of the tube (see Figure 7). You should hear a squeaky pop which confirms the presence of hydrogen (the sound indicates a mini explosion). The reaction $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{L})$ will produce a small amount of water at the bottom of the test tube.



↑ Testing for hydrogen with lighter (left) and presence of water in the test tube (right)

Oxygen test: Place a finger on the opening of the test tube to prevent the oxygen from escaping, then turn the test tube around and place a lit splint at the opening of the tube (see Figure 8). The presence of oxygen will reignite the stick.



↑ Testing for oxygen with lit splint (left). Splint re-ignites in the presence of pure oxygen (right)

Results

These are the answers to the student worksheet activity 2:

1. The global reaction of water electrolysis:
 $2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$
2. Anode oxidation:
 $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$
3. Cathode reduction:
 $4\text{H}_2\text{O} + 4\text{e}^- \rightarrow 2\text{H}_2 + 4\text{OH}^-$
6. NaOH is an electrolyte. Adding an electrolyte speeds up electrolysis because it increases the electrical conductivity of water (i.e. decreases resistance to electricity). Salt, acid or base could be used as an electrolyte. For the specific case of alkaline water electrolysis, a strong base like sodium hydroxide (or potassium hydroxide) is used as the electrolyte, thus avoiding the corrosion problems caused by acid electrolytes (corrosion of metallic electrodes).
7. In the equation $2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$ the products are two hydrogen atoms for each oxygen atom. For that reason, we observe twice the amount of hydrogen than oxygen.
8. Using a voltaic pile of six voltaic cells with an electrical potential difference of 6 V, it is possible to produce 3ml of O_2 in 4 hours = 18 ml/day of molecular oxygen (O_2).
9. Obtaining 18 ml/day is equivalent to $1.8 \cdot 10^{-5} \text{ m}^3/\text{day}$. We can use the ideal gas law to calculate the number of mole of O_2 , and from that the mass:

$$P \cdot V = n \cdot R \cdot T$$

$$n = \frac{P \cdot V}{R \cdot T} = \frac{101325 \text{ Pa} \cdot 1.8 \cdot 10^{-5} \text{ m}^3}{8.314 \frac{\text{J}}{\text{K} \cdot \text{mol}} \cdot 293 \text{ K}} = 7.48 \cdot 10^{-4} \text{ mol}$$

$$m = n \cdot M = 7.48 \cdot 10^{-4} \text{ mol} \cdot 32 \frac{\text{g}}{\text{mol}} = 0.0239 \text{ g}$$

This is the same as $2.4 \cdot 10^{-5} \text{ kg}$ and hence only supplies:

$$\frac{2.4 \cdot 10^{-5} \text{ kg}}{0.84 \text{ kg}} \cdot 100\% = 0.0028\%$$

of the amount needed by one astronaut per day.

10. We could make the production go faster by increasing the electrolyte concentration (in this case the concentration of NaOH) or by using a more powerful battery.
11. Oxygen is vital in order for the astronauts to breathe on the Moon. Hydrogen in combination with an oxidant (for example oxygen) can be used as a source of fuel to propel spacecraft going further into space or to propel rovers to explore the lunar surface and expand human presence. If we had to bring the oxygen and hydrogen we would need containers and a lot of mass and volume. This would be very expensive. In order to make an outpost on the Moon sustainable we need to recycle as much as possible and transform waste products (for example CO_2 , urine, sweat, food waste, metabolic waste etc.) into O_2 and water that can be used again. This is what Life Support Systems are designed to do and technologies for optimizing recycling are being tested on the International Space Station. However, to be more independent from Earth re-supplying the outpost we also have to learn to produce most of what we need on the Moon (in-situ resource utilization).

→ Activity 3: Fuel cell

In this activity, students will use the products of water electrolysis (H_2 and O_2) in a fuel cell. They will investigate how fuel cells produce electricity and heat from a chemical reaction. Students will consider the possibilities and limitations of fuel cells for Moon exploration.

This exercise can be done either as a demonstration or if time permits as a hands-on activity. The experiment requires a fuel cell, which can be acquired online¹.

Equipment

A Fuel cell car science kit¹ or:

- A fuel cell
- A syringe
- Deionized & distilled water
- Power supply (battery, solar cell)
- Silicon tubing and caps
- 30 ml beakers and inner containers (see annex 2)
- Wires with connectors
- Actuators (Motor, LEDs, car etc.)

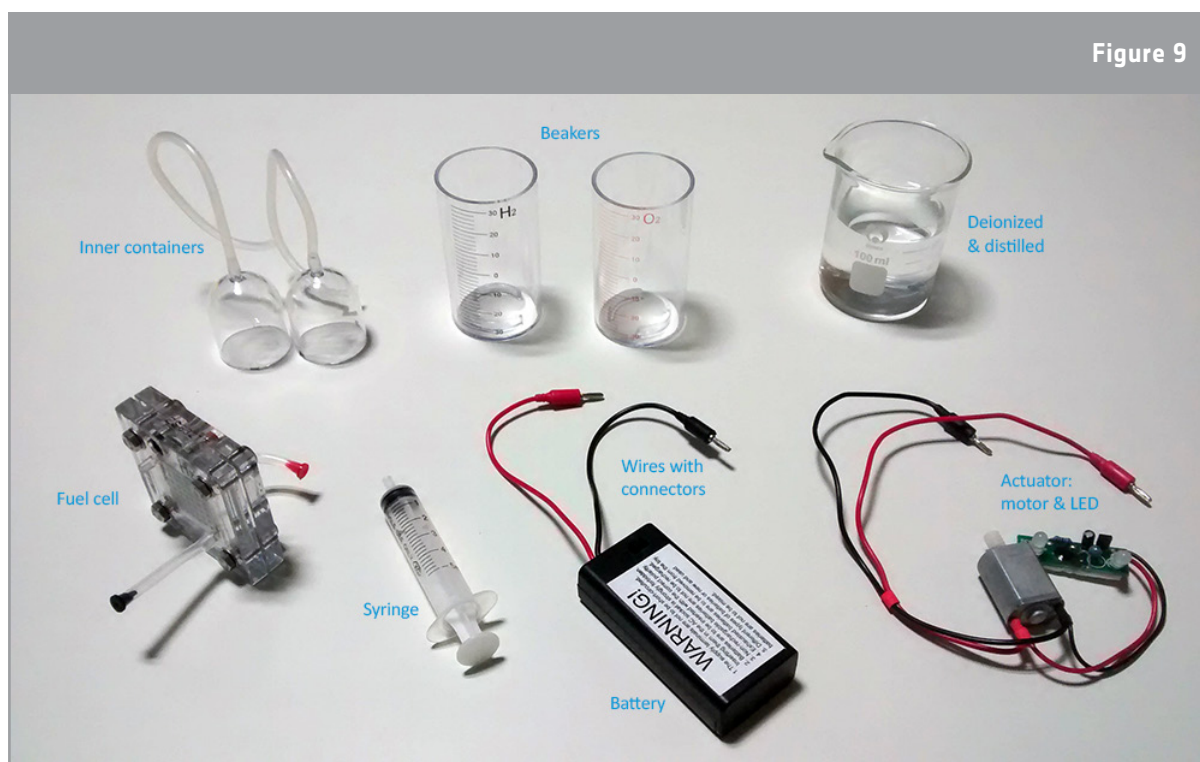


Figure 9

↑ Equipment needed for building a fuel cell system.

Exercise

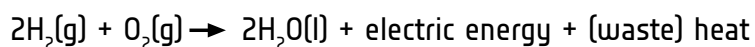
Start by introducing fuel cells to the students. Fuel cells build on the knowledge of water electrolysis and the voltaic pile and offers an opportunity to wrap up the resource.

Ask the students to follow the instructions in Annex 2 (or prepare the experiment beforehand for a demonstration). Ask the students to fill in questions 1 to 5 in their student worksheets and reflect on the advantages and limitations of fuel cells.

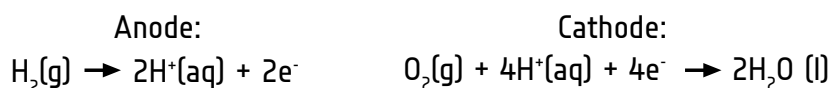
¹ This resource uses the Fuel cell car science kit that can be bought online
<http://www.horizonfuelcellshop.com/europe/product/fuel-cell-car-science-kit/>.

Results

1. Overall reaction in the fuel cell:



2. Anode and cathode reactions



3. A fuel cell is a cheap and clean energy source if oxygen and hydrogen are readily available. It does not pollute: it only produces water and energy. This makes it a potential solution for clean energy on Earth. If we need to produce H_2 and O_2 with electrolysis before we can run the fuel cell, or if H_2 and O_2 are valuable and limited, then fuel cells might not be the optimal solution. We will lose energy since we need another power source in the first place to create the components for the reaction. However, if we combine fuel cell technology with a renewable energy source (for example solar energy) then we can use fuel cells without polluting.
4. Both the voltaic pile, the electrolysis and the fuel cell are examples of electrochemistry in practice. A voltaic pile uses a chemical reaction to generate electricity, water electrolysis uses electricity to make a chemical reaction happen that would not otherwise occur, and a fuel cell reverses the electrolysis reaction and generates electricity again from the products of the electrolysis.

→ POWER FROM WATER

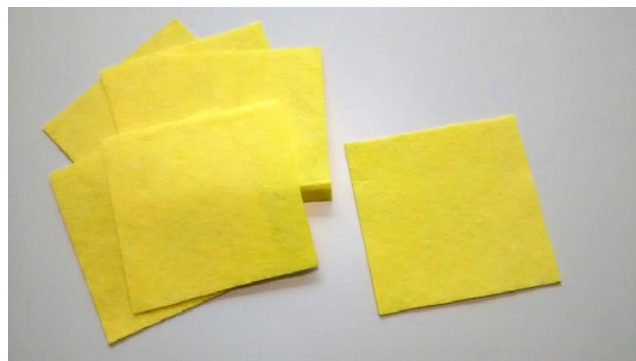
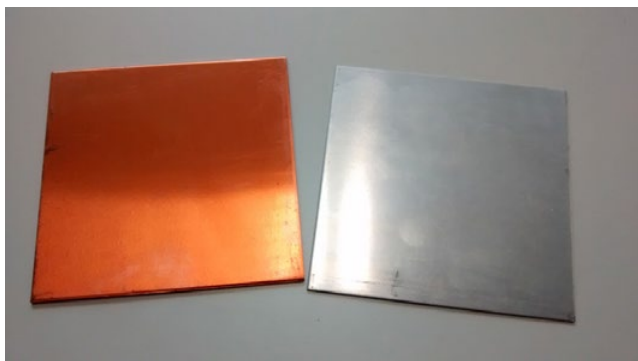
How to produce oxygen and hydrogen on the Moon

→ Activity 1: Build your own battery

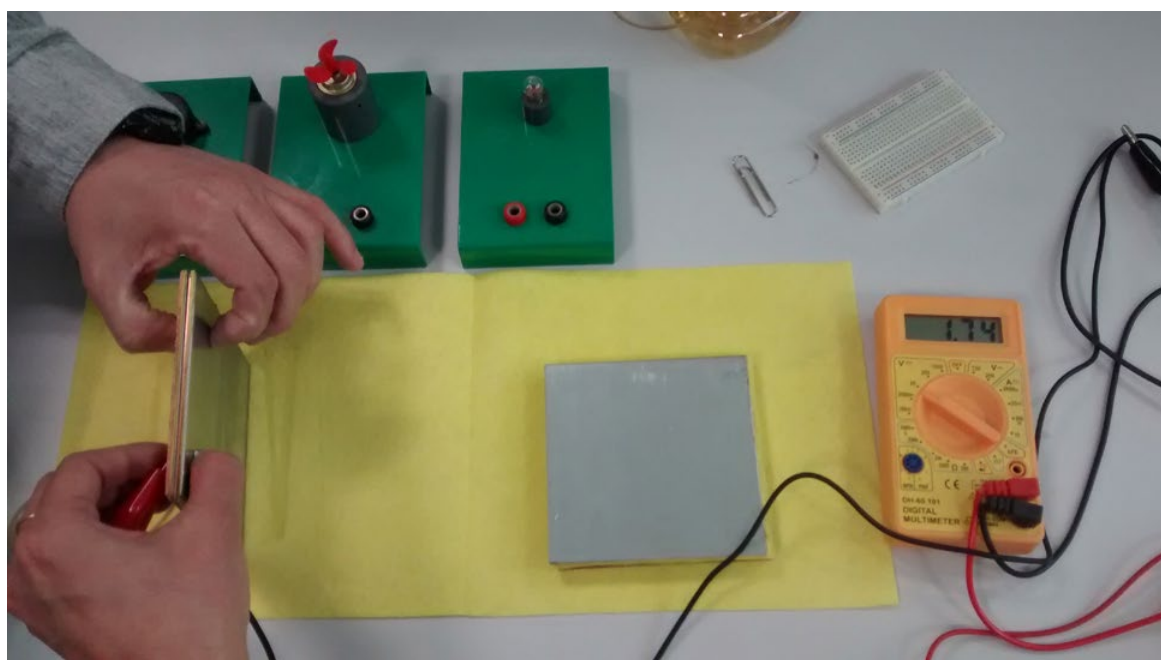
In 1800 Alessandro Volta, one of the pioneers of electricity and power, invented the first battery: the “voltaic pile”. With this invention, he proved that certain chemical reactions can create electricity. Now you will follow in his footsteps and build your own voltaic pile.

Exercise 1

1. Sand both sides of the zinc and copper plates with sandpaper and cut 6 squares from the dishcloth in the same size as the plates.



2. Place one dishcloth square on top of a zinc plate and soak it in vinegar. Then place one copper plate on top of the dishcloth. You now have one voltaic cell. Connect the wires with the crocodile clips to the first and last plate, then connect to a multimeter.



3. What is the electrical potential difference from one voltaic cell? _____ V

4. Write down the net ionic equation, which shows the overall process occurring in the cell:

5. Which component is oxidised and which one is reduced in this reaction?

6. Why is it a good idea to sand the metal plates?

7. Why do we soak the cloth in vinegar? Could we use another substance? Explain.

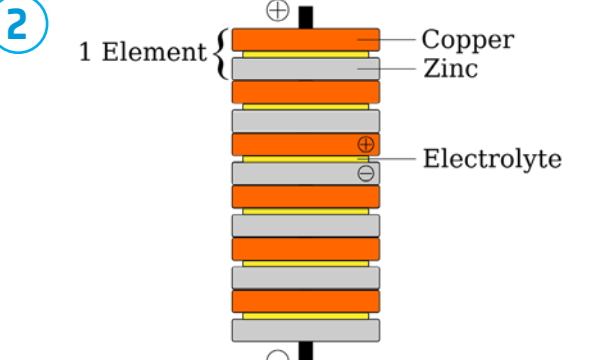
Did you know?

ESA's Huygens probe, which landed on the surface of Titan (Saturn's largest moon), relied on non-rechargeable lithium sulphur dioxide batteries. These were chosen because they could be left inactive during the seven-year trip to Saturn, but still retain sufficient capacity for the landing on Titan.

[Artist impression of the Huygens probe on the surface of Titan.→](#)



8. Follow the instruction below to build a voltaic pile.

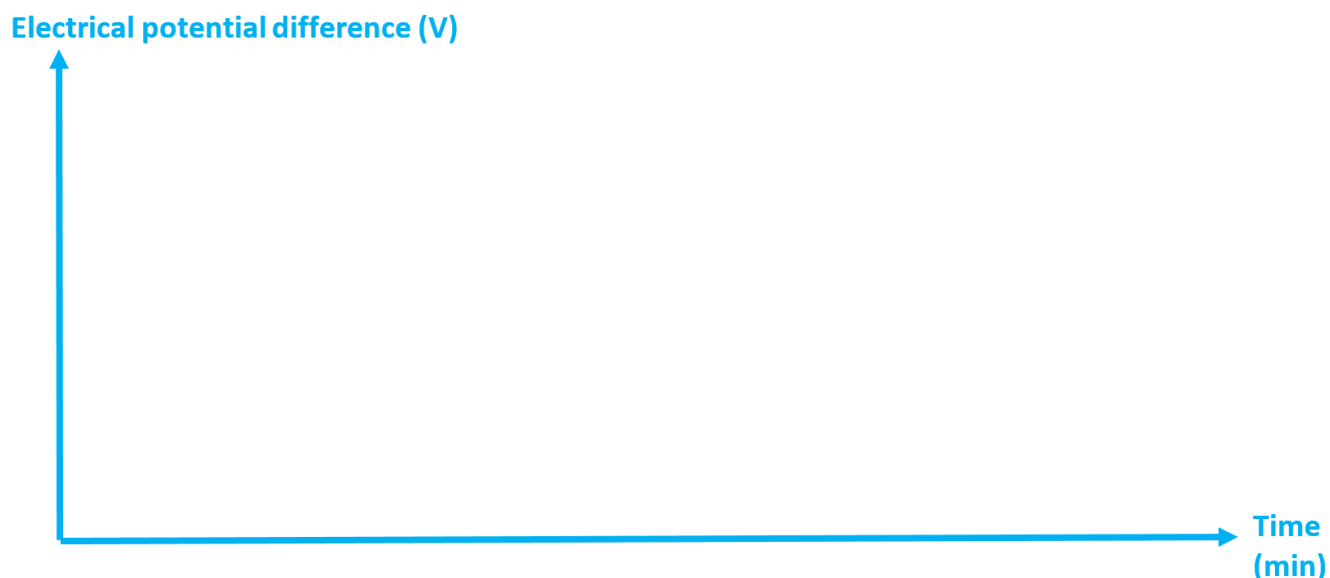
1 	2 
Create six voltaic cells following the instructions from exercise 1	Stack the cells in the order shown
3 	4 
Tie elastic rubber bands around the pile to keep the pile in place.	Connect the wires with the crocodile clips to the first and last plate and connect to a multimeter.

9. Measure the electrical potential difference of the voltaic cell immediately after you have finished assembling it. Take measurements every minute for 10 minutes and record your measurements in Table 1.

Table 1	
Time (min)	Electrical potential difference (V)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

↑ Recordings of electrical potential difference for 10 minutes.

10. Draw a graph of electrical potential difference as a function of time.



11. What do you observe? Explain.

12. What is the electrical potential difference of the voltaic pile compared to a normal AA battery?

13. How could batteries be used for Moon exploration? What are the advantages and disadvantages of batteries?

→ Activity 2: Water electrolysis

Exercise

1. Balance the global reaction below:



2. Write the equation of the reaction that takes place in the anode:

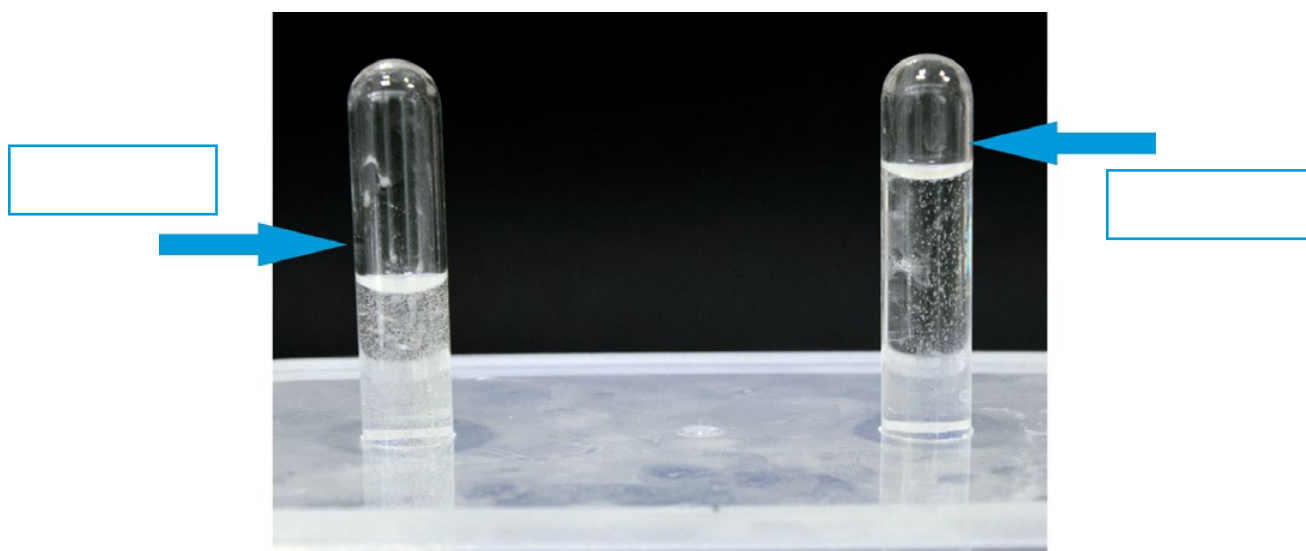
3. Write the equation of the reaction that takes place in the cathode:

4. Build your own electrolyser by following the steps in Annex 1. When starting the electrolysis make sure to start a stopwatch too. You will need the time of the electrolysis to calculate the oxygen production.

5. Describe what happens during the electrolysis.

6. What is the function of dissolving NaOH in the water?

7. Which of the tubes contains oxygen and which hydrogen? How do you know?



8. Measure how much oxygen you have produced and calculate your production rate per minute.

9. Assume that one astronaut breathes 0.84 kg of molecular oxygen (O_2) per day. Can your electrolysis system supply the required oxygen?

10. How can you produce more oxygen per day?

11. What are the advantages and disadvantages of using water electrolysis on the Moon?

Did you know?

Electrolysis of water is the main method of generating oxygen on board the International Space Station (ISS). Water is collected from urine, wastewater, and condensation and split into oxygen and hydrogen in the Oxygen Generation System (OGS). The station's football-field-sized solar arrays are the power source. A similar system could be used on the Moon.

[The international Space Station \(ISS\) orbiting Earth →](#)



NASA, ESA, JAXA and Roscosmos.

→ Activity 3: Fuel cell

Fuel cells can be used to power rovers or space ships or anything in between. Fuel cells do the opposite of electrolysis: they combine H_2 and O_2 and produce H_2O (water) and energy.

After observing how a fuel cell works, answer the questions below:

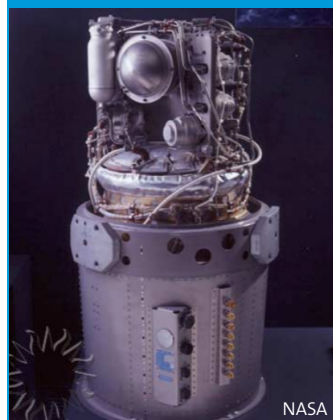
1. Balance the global reaction:



2. Write the chemical reactions occurring at the anode and the cathode:

3. What are the advantages and disadvantages of fuel cells? How can we use them for missions to the Moon?

Did you know?



Fuel cells were the primary source of electric power on the Apollo programme that landed humans on the Moon. Apollo fuel cells used oxygen and hydrogen, stored as liquids at extremely cold temperatures, that when combined chemically yielded electric power and water for drinking. Fuel cells were also used on the Space Shuttle fleet as one component of the electrical power system. The space shuttle fleet flew 135 missions between 1981 and 2011.

← Apollo fuel cell.

4. What are the differences and similarities between the voltaic pile, electrolysis and the fuel cell?

→ Links

ESA resources

Moon Camp Challenge

esa.int/Education/Moon_Camp

Moon animations about the basics of living on the Moon.

esa.int/Education/Moon_Camp/The_basics_of_living

ESA classroom resources:

esa.int/Education/Classroom_resources

Extra information

Voltaic cell:

youtube.com/watch?v=gOVtk6G2TnQ

Electrolysis:

youtube.com/watch?v=dRtSjJCKklo

Fuel cells:

youtube.com/watch?v=OmVnllgDA7o

Fuel cell car science kit:

<https://www.horizeducational.com/fuel-cell-car-science-kit/p1232>

→ Annex 1: Electrolyser

1. Use push pins to fasten the wires to the box



2. Dissolve NaOH in water (3%) and fill the container



3. Raise the test tubes over the punch pins (make sure they stay filled with water). Place the lid on top to keep the tubes in place

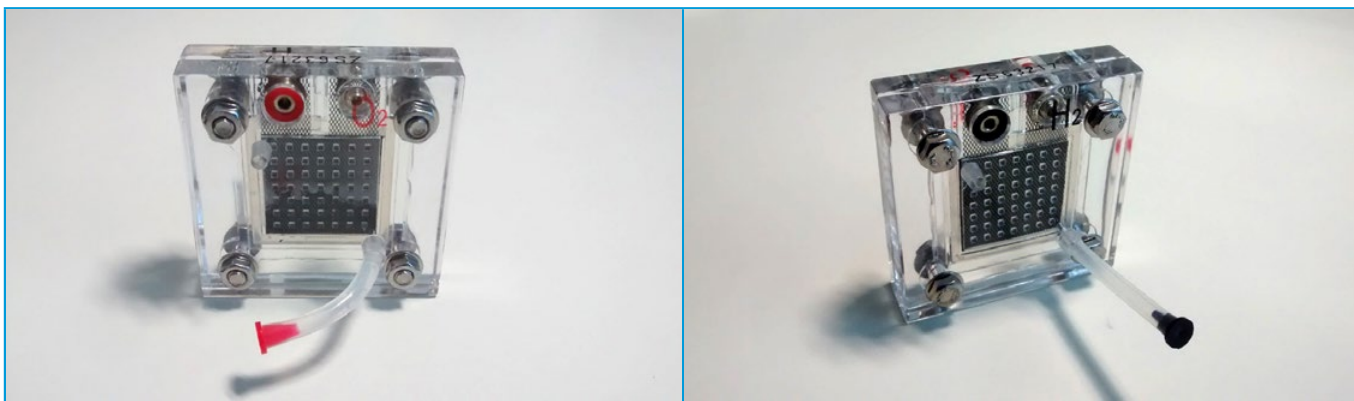


4. Connect the power source and start the electrolysis. Start a timer and record how long the process takes.



→ Annex 2 – Fuel cell

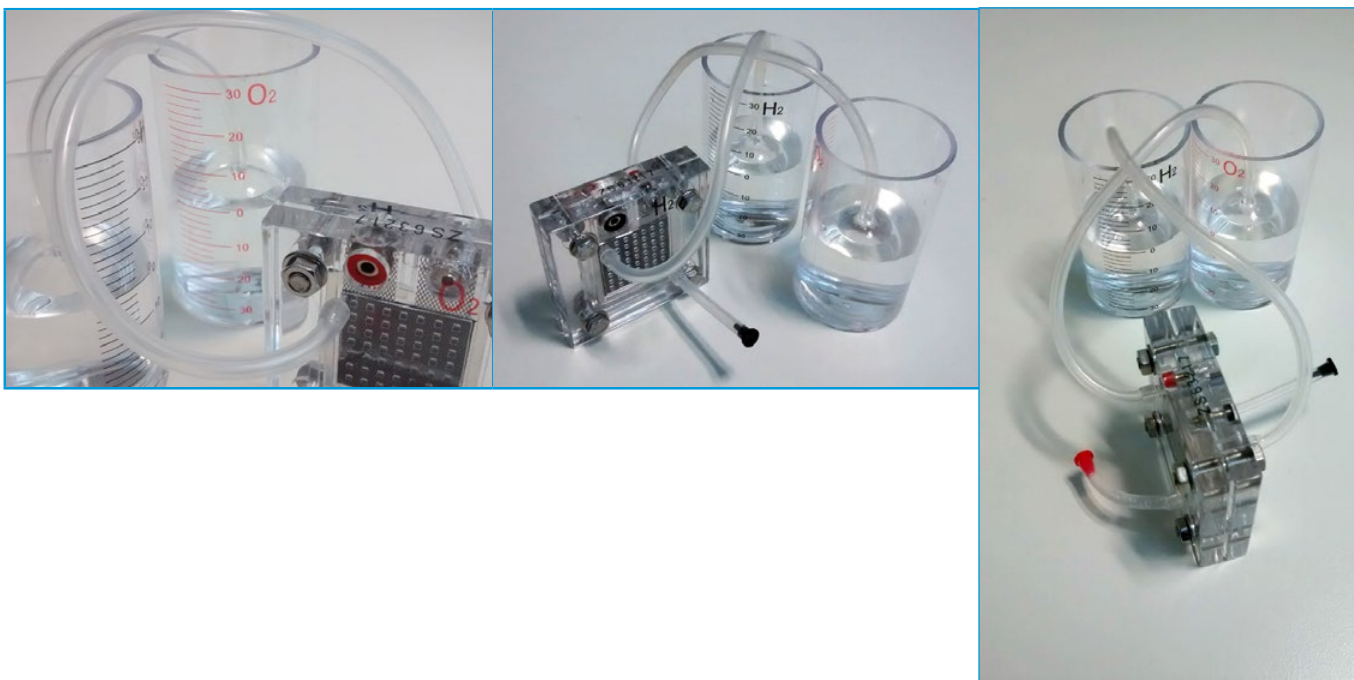
1. Connect two silicon tubes (4cm) to the nozzles on the fuel cell located on the lower section on both sides of the fuel cell.



2. Remove the red cap from the tube connected to the oxygen side of the fuel cell. Using the syringe, inject distilled water into the fuel cell until the fuel cell is half filled with water
3. Place the dome shaped inner containers into the beakers and add water up to the “0” ml (the water should almost cover the inner container). Make sure there is no air trapped inside the inner containers.



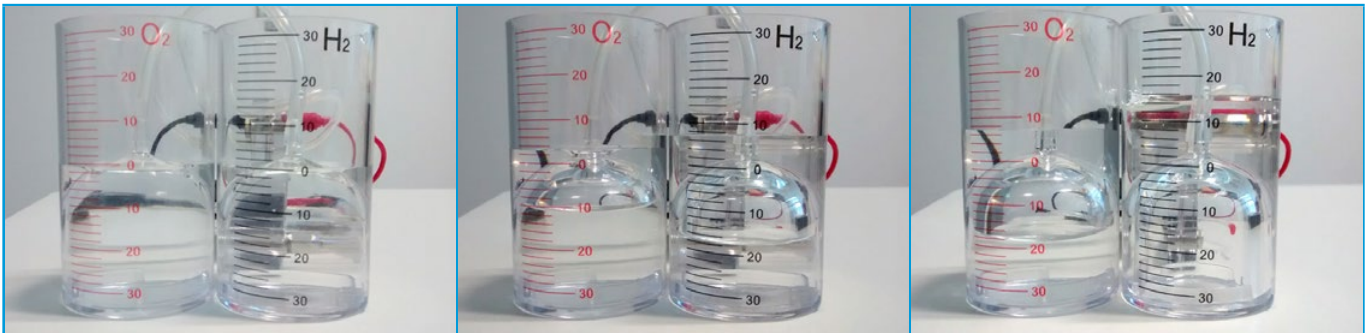
4. Connect the silicon tubes to the upper nozzles of both the O_2 and H_2 side of the fuel cell.



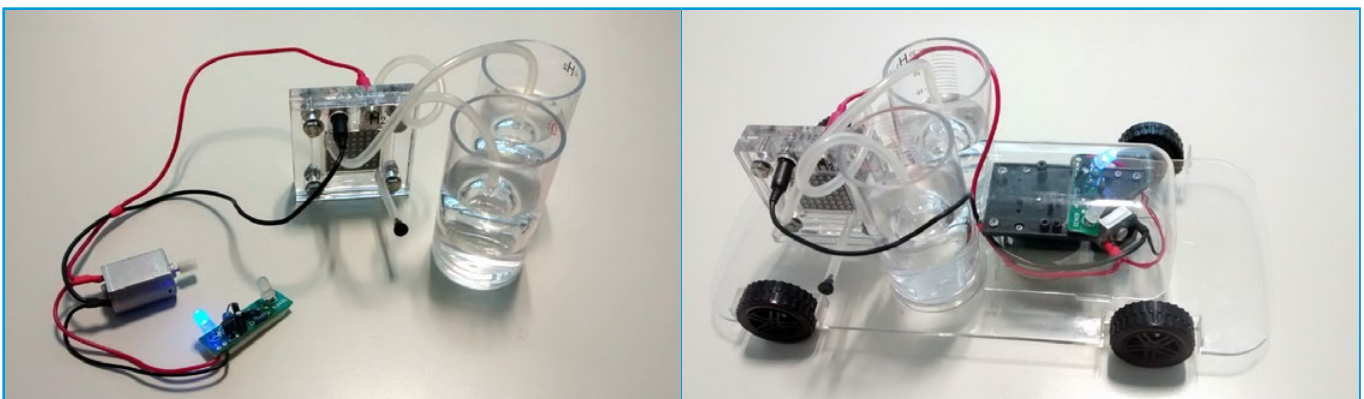
5. Connect the battery pack as seen below. Switch the battery pack to the “on” position and electrolysis should begin.



6. Observe how H_2 and O_2 start to fill the inner containers. When H_2 begins to bubble out of the container the tank is full.



5. Disconnect the battery and connect an actuator (car, motor, LED etc.). H_2 and O_2 combines again producing H_2O and energy to power the motor.



Who are we?



What is ESERO Ireland?

ESERO Ireland is an education project of the European Space Agency (ESA) that is co-funded by Research Ireland while also working with national collaborators. Our aim is to spark young people's passion for STEM (science, technology, engineering, maths) through the exciting world of space, build their skills, and empower them to pursue careers in space. We also raise awareness of the vital role space research, exploration, and applications play in shaping modern society, using engaging resources and creative teaching methods, and inspiration from role models.

Find out more at esero.ie, and follow us on social media **@ResearchIreland**.

