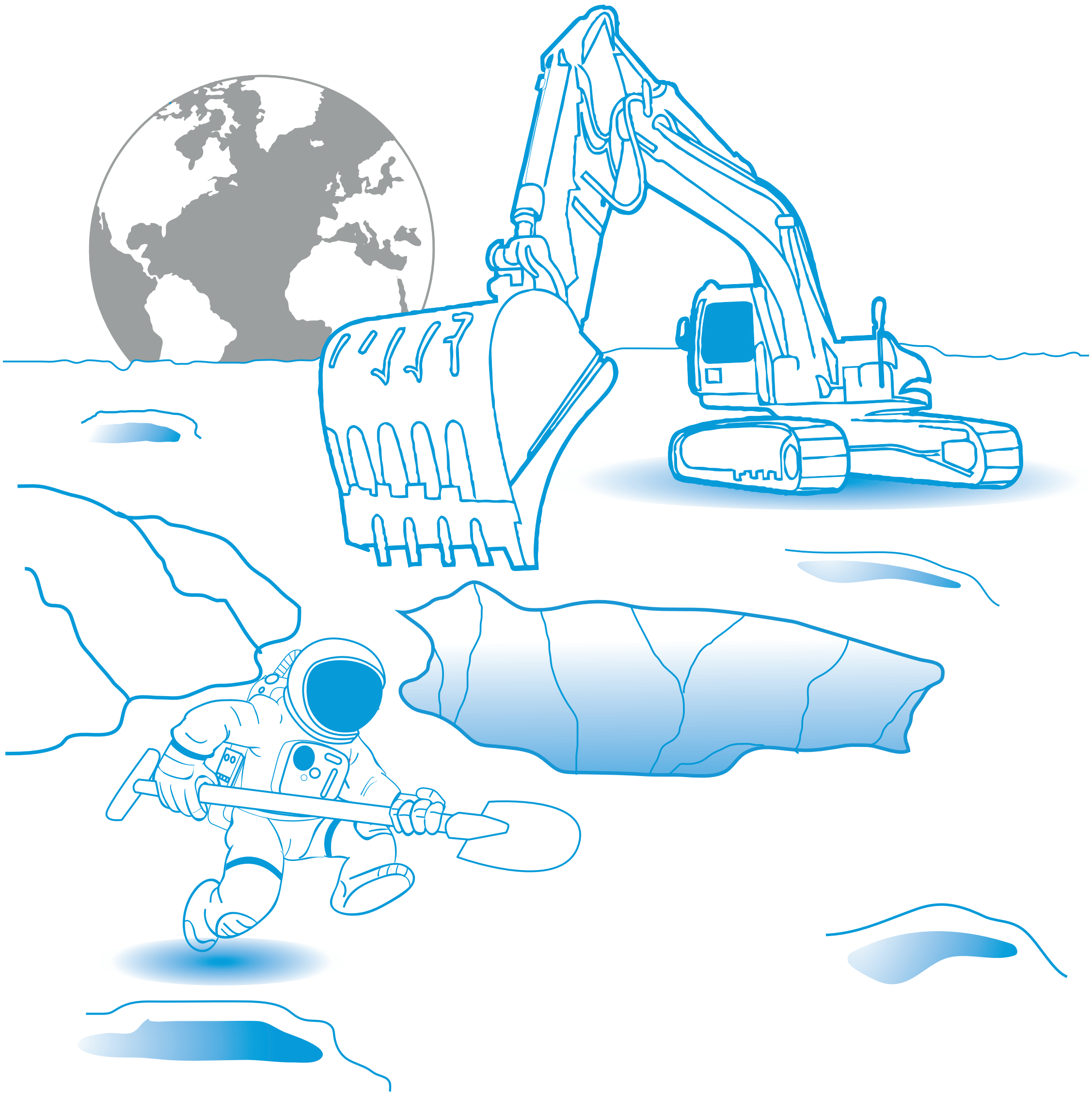
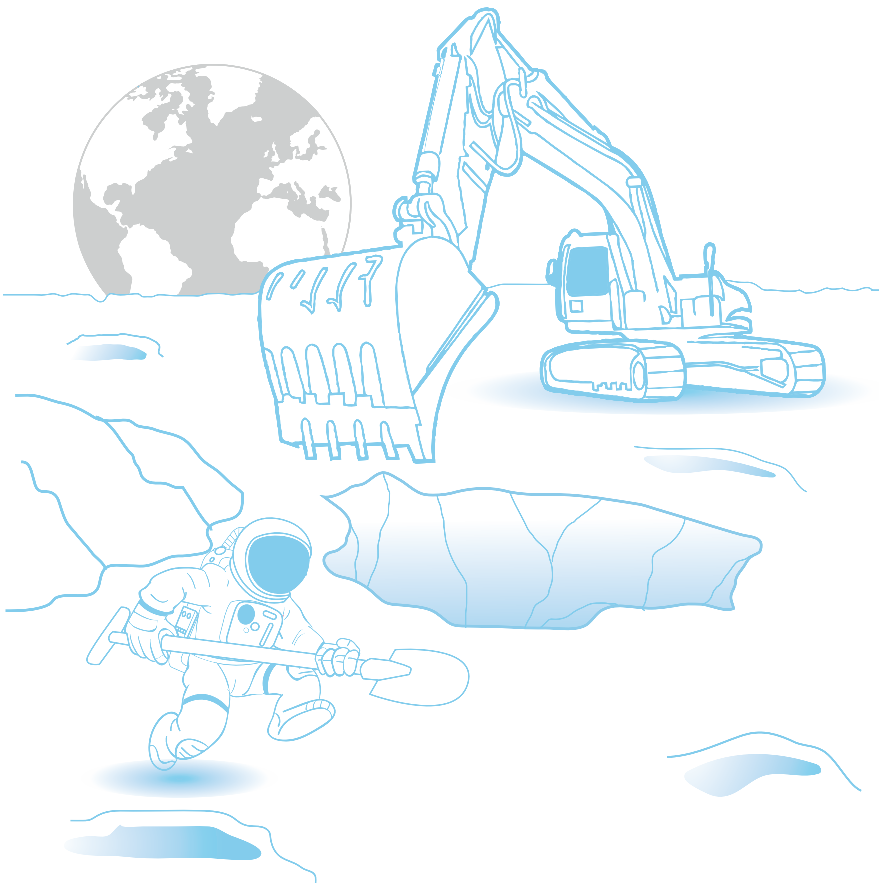
teach with space

→ EXTRACTING WATER FROM LUNAR SOIL

Learning about filtration and distillation





teach with space – extracting water from lunar soil | C10
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→ EXTRACTING WATER FROM LUNAR SOIL

Learning about filtration and distillation

Fast facts

Subject: Chemistry, Physics

Age range: 12-16 years old

Type: laboratory activity

Complexity: medium

Teacher preparation time: 30 minutes

Lesson time required: 1 hour and 20 minutes

Cost: low – all equipment should be available in a school science laboratory

Location: laboratory

Includes the use of: pre-prepared blocks of ice mixed with sand

Keywords: Moon exploration, Filtration, Distillation, States of matter, Phase transitions.

Brief description

In this resource, students will learn about changes of state of matter using water on the Moon as an example. They will interpret data from a pressure vs. temperature graph for water to enable a discussion about how changes of state are different on the Moon compared to what we are used to on Earth. They will then compare two methods for separating mixtures, in the context of extracting water from lunar soil. They will be given pre-prepared lunar soil analogue blocks and compare simple distillation to filtration and decide which is most efficient on Earth and on the Moon.

Learning objectives

- Learning how changes of state vary depending on pressure and temperature.
- Understanding changes of state in terms of the particle model.
- Learning to use distillation equipment to separate mixtures.
- Using filtration to separate mixtures.
- Carrying out experiments appropriately, having due regard for the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations.
- Evaluating methods and suggesting possible improvements and further investigations.
- Interpreting percentages and percentage changes as a fraction or a decimal.

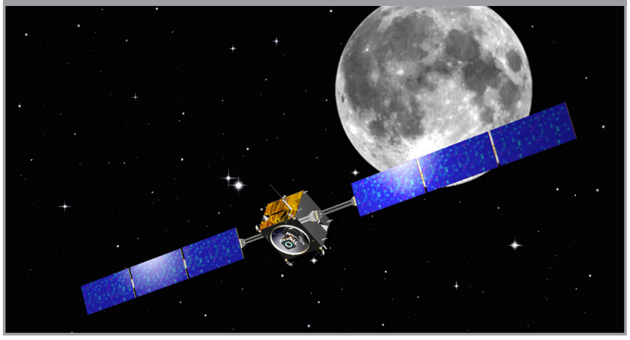
→ Summary of activities

Summary of activities					
	Title	**Description**	**Outcome**	**Requirements**	**Time**
1	Is water different on the Moon ?	Identifying the water phases. Analysing a pressure vs. temperature graph for water in the context of the Moon.	Learn how the extraction of water could be carried out on the Moon.	None	20 minutes
2	Filtration or distillation?	Comparing filtration and distillation processes for "lunar ice cores".	Plan and carry out an experiment in filtration and distillation.	Completion of activity 1 is advised	1 hour

➔ Introduction

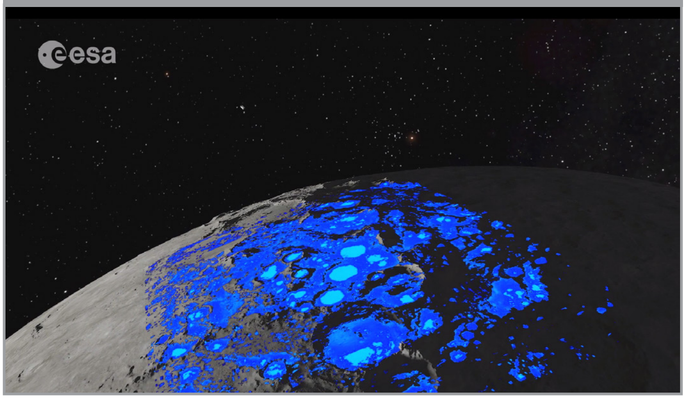
Between 1969 and 1972, twelve astronauts visited the Moon. These lunar missions were the only time humans walked on a world other than Earth. Since then several satellites and robotic missions have studied the Moon. One of those missions was SMART-1, which orbited the Moon between November 2004 and September 2006. SMART-1 took detailed images of the surface and studied what the rocks are made of. The mission ended with a deliberate crash into the lunar surface.

Figure 1



↑ ESA's SMART-1 was Europe's first Moon orbiter

Figure 2



↑ Map of the lunar south pole of where water ice would be stable buried in the top 1 metre (dark blue), and on the surface (light blue).

In 2009, the presence of water on the lunar poles was discovered. However, water only exists on the Moon in the form of ice. The Moon has no atmosphere, so the pressure at the surface is extremely low. At low pressures, water can only exist in the form of a solid (ice) or a gas. In a permanently shadowed crater, where the temperature can be as low as -248°C, the water exists as ice. When the surface of the Moon is heated by the Sun it can reach temperatures of up to 123°C. Because of the low pressure on the Moon, when water ice reaches -40°C it will change state directly from ice (solid) to water vapour (gas). Nowadays ESA, in collaboration with other Space Agencies, is planning to send robotic missions and astronauts to explore the surface of the Moon once more.

In the future, if we wish to build a settlement on the Moon, we will need to consider how to extract the ice from the lunar regolith (soil).

In this set of activities students will have to imagine, they are on a lunar mission and will have to extract water from "lunar" ice cores.

→ Activity 1: Is water different on the Moon?

In this activity, students will investigate the water states and water phase transitions. Students will analyse the phase diagram for water and conduct a simple experiment to learn that pressure and temperature affect the state of water. Lastly, students will relate what they learn to Moon exploration and how water might be extracted from regolith on the Moon.

Equipment

- Syringe
- Hot water
- Printed student worksheets for each student

Exercise

Distribute the student worksheets to each student. Students are first asked to name (identify) the changes of state:

- Sublimation is where a solid changes to a gas (no liquid phase).
- Deposition is where a gas changes to a solid (no liquid phase).
- Freezing is where a liquid changes to a solid.
- Melting is where a solid changes to a liquid.
- Evaporation is where a liquid changes to a gas.
- Condensation is where a gas changes to a liquid.

Students will also have to draw the particle model for the three states of matter.

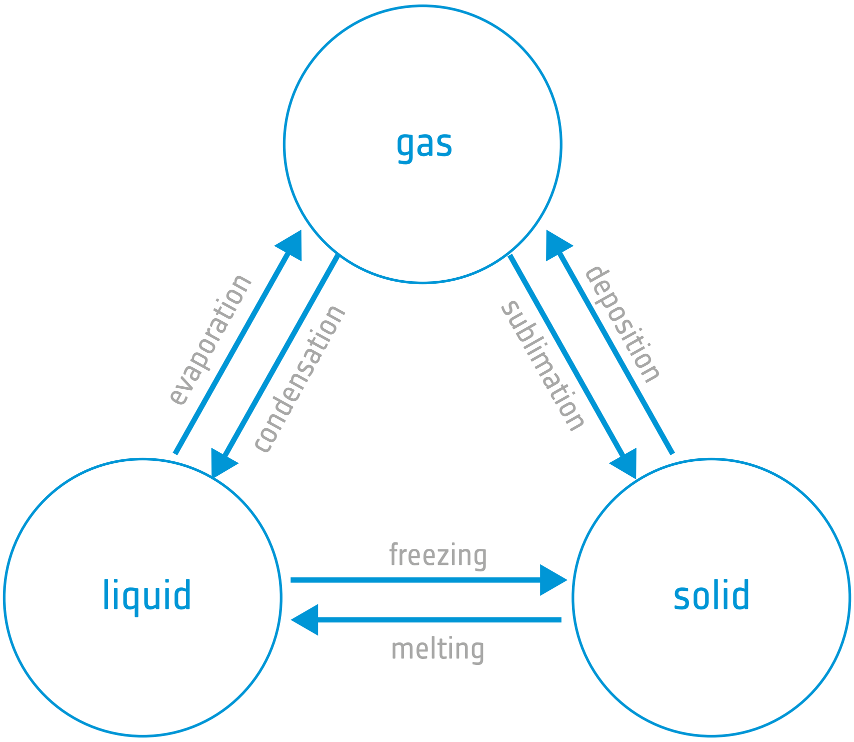
In question 3 students will have to relate the changes of state of water with temperature and pressure. You can provide familiar examples like going diving (pressure increases) and going to the top of a mountain (pressure decreases).

When pressure decreases, water boils at a lower temperature. In question 4 b) students can test the hypothesis they presented in question 4 a), using a syringe to create an environment with lower pressure.

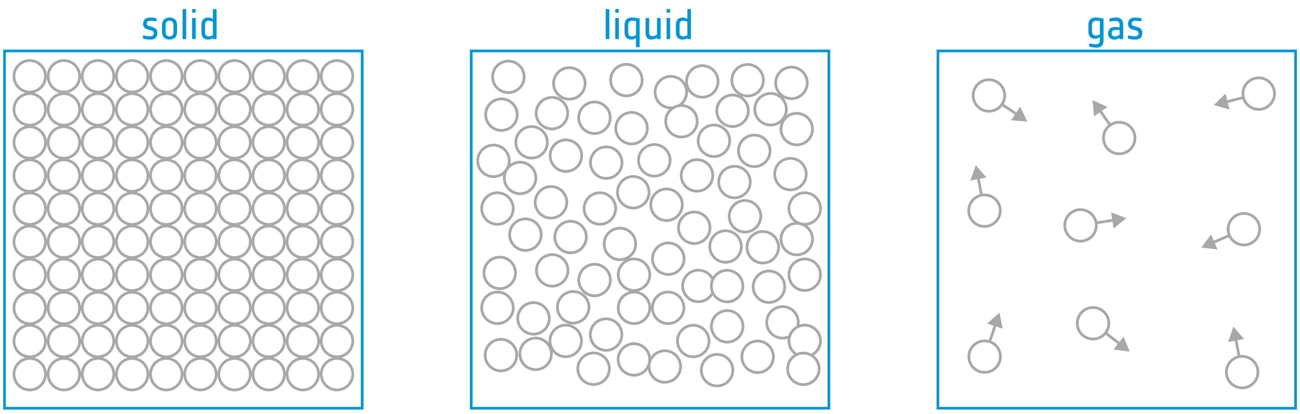
In question 5 we ask the students to apply the concepts they have learned to the Moon environment. You can start by relating some of the previous examples with the Moon: on top of a mountain on Earth air pressure is lower because there is less atmosphere there. On the Moon there is no atmosphere, so the pressure is very low.

Consult the results section for complete answers to the student worksheet questions.

Results



2.



3.

Water state	Temperature range (K)	Pressure (atm)
Solid	<273	1
Liquid	273-373	1
Gas	>373	1

4. a. The boiling point of water decreases as the pressure decreases. At very low pressure (~0.01 atm) water cannot exist in a liquid state.

   b. The pressure in the syringe decreases. Even though the water temperature is below 100°C , the water reaches boiling point and should begin to evaporate.

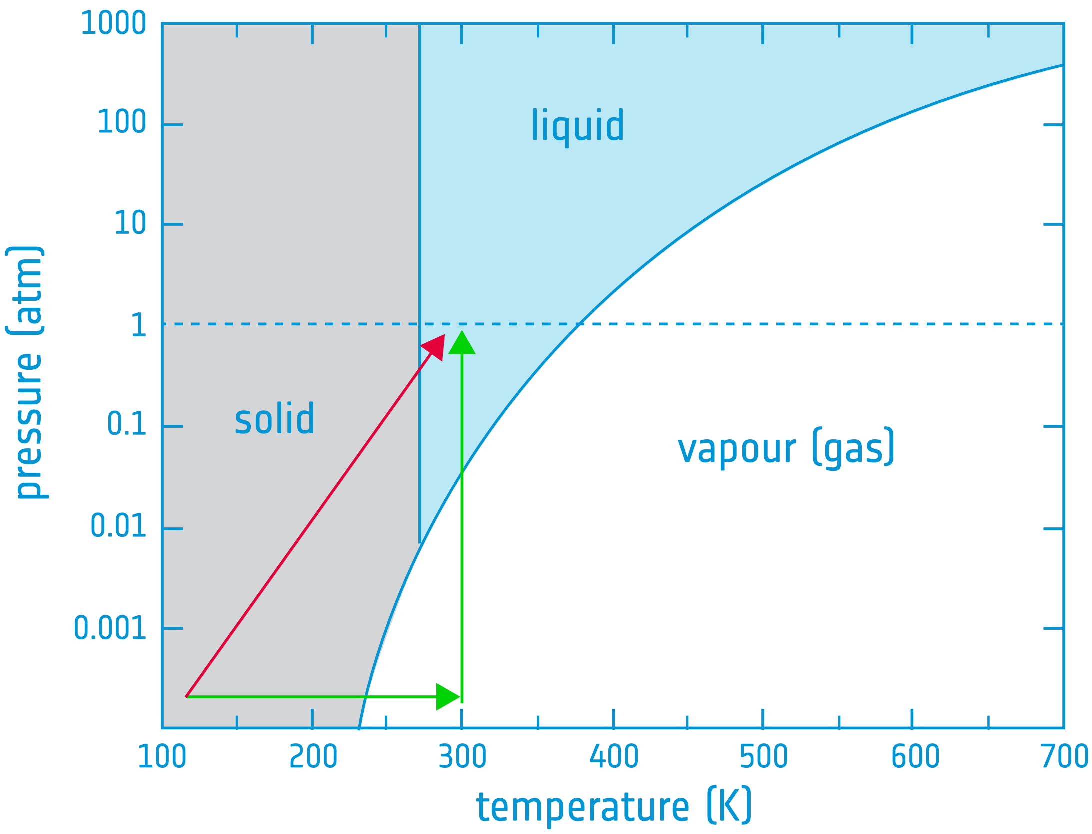
5. a. Figure A2 shows that at very low pressures (close to 0 atm), independent of temperature, water does not have a liquid phase. The Moon has no atmosphere, at the surface the pressure is approximately 0 atm and so the water ice will sublimate, transitioning straight between solid and gas.

   b. Solid (ice)

   c. If you remove the ice from the crater the temperature will increase. When the water ice heats up it will begin to sublimate. If the ice is not kept in a sealed container it will dissipate into a gas and you will lose all the water you collected. This could be counteracted by keeping the ice in a sealed container.

   d. To obtain liquid water you have to increace the temperature and presurre.

   e. Below are a few examples of correct answers.



Example 1 (green) : Heating in sunlight on lunar surface, then pressurising inside Moon base.

Example 2 (red): Pressurising and heating simultaneously. This would occur if the samples were taken directly into a pressurised environment.

→ Activity 2: Filtration or distillation?

In this activity, students will compare two methods of separating water from sand: filtration and distillation. They will be given simulated lunar ice/soil cores to use in their experiment and calculate the percentage mass of water extracted in each case.

Equipment

- Printed student worksheets for each group
- Pre-prepared ice-cores (see Annex)
  - Weighing scales
  - Sand and water
  - Test-tube packaging or similar

Filtration equipment

- Conical flask
- Measuring cylinder
- Filter paper
- Funnel
- Bunsen burner (optional, to melt the ice cores)

Distillation equipment

- Bunsen burner or hotplate/boiling ring
- Conical flask
- Tripod
- Bung with hole for plastic/rubber tubing
- Large tin with a hole in the side
- Ice cubes (for cooling the tubes)
- Small piece of copper tubing (optional – improves cooling)
- Measuring cylinder

Preparation of distillation equipment

The copper tubing (if available) and as much as possible of the plastic/rubber tubing should be inserted into the tin and covered with ice. There should be an air-tight seal between all parts of the tubing.

Health and Safety

Students should wear safety glasses when heating the ice/sand mixture.

If using the bunsen burner: the conical flask used for filtration should be allowed to cool for at least 5 minutes, after removing the heat source, before handling. The flask should then only be held at the top by the neck.

All parts of the distillation equipment, including the measuring cylinder will become hot and could cause burns if handled.

The measuring cylinder used for distillation should be allowed to cool for at least 5 minutes, after removing the heat source, before handling.

If steam or excessive water vapour is coming through the end of the tubing, the Bunsen burner should be moved temporarily away from the conical flask.
If moving the Bunsen burner during the distillation experiment, then it should be held by the base only and changed to a safe flame.

As soon as the mixture inside the conical flask starts bubbling then the heat source must be removed to prevent the glassware from overheating.

Exercise

Divide the students into groups of four. Each group will try both methods: filtration and distillation. The students should plan each investigation before carrying it out. Their plan should be checked and the equipment set up before they are given the ice cores.

The key elements that students should include are as follows:

Filtration

1. Read safety notes and plan accordingly.
2. Set up the filtration equipment, as in the diagram.
3. Measure the mass of the ice cores inside the tray and record the value.
4. Remove the ice cores from the tray and place in conical flask.
5. Measure the mass of the empty tray (take this from the total mass in step 3).
6. Melt the ice cores.
7. Filter mixture.
8. Measure the volume of water recovered.
9. Calculate the percentage mass of water recovered.

Distillation

1. Read safety notes and plan accordingly.
2. Set up distillation equipment, as in the diagram.
3. Measure the mass of the ice cores inside the tray and record the value.
4. Remove the ice cores from the tray and place in conical flask.
5. Measure the mass of the empty tray (take this from the total mass in step 3).
6. Boil mixture until dry.
7. Measure the volume of water recovered.
8. Calculate the percentage mass of water collected.

Students should compare their results and discuss which method recovers the most water, and what they think the reason for this is. They should talk about how water could be lost with both methods. They should conclude that:

- Through the filtration method, water still remains in the sand and in the filter paper.
- With distillation, water can be lost through water vapour, and some will remain in the tubes.

The distillation process is most energy intensive when carried out in the lab. This would not necessarily be the case on the Moon, as distillation (or more precisely sublimation) could take place at low temperatures when in a very low-pressure environment, see Figure A2 of Activity 1, the water vapour will then condense as a liquid in a pressurised environment.

Results

2. Discuss the health and safety requirements for the activity and ensure all points in the Health and Safety section are covered.
3. Below are some examples of advantages and disadvantages of filtration and distillation.

Discuss with the students how energy is used in each and which requires more. This is a small example of the experiment so you can also have discussions around how easy it would be to scale the experiments up to a practical level.

	Advantages	Disadvantages
Filtration	• Energy efficient • Cost effective • Simple apparatus • Scalable	• Slow • Equipment is dependent on the mixture • Some of the liquid will remain in the residue
Distillation	• Kills harmful bacteria • Adaptable by changing temperature for different mixtures • Scalable	• Uses more energy for heating • More complicated setup

4. The students must measure the mass of the ice cores before carrying out the procedure.
5. The students must measure the mass of water extracted from the ice cores.
6. An example of how much water is recovered for the different methods:

$$\frac{\text{mass of water}}{\text{mass of ice core}} * 100$$

Mass of ice cores (g)	Filtration		Distillation	
	Mass of water (g)	% recovered	Mass of water (g)	% recovered
100	19	19%	36	36%

7. Encourage discussions around where water may have been lost during the experiment and the differences between the two processes. This creates a good opportunity to ask how the experiments could be improved in the future.
8. Discuss ways to test cleanliness of the water (inspection by eye is probably the easiest) and where impurities/bacteria/contaminants could be present.

9. a. On Earth, distillation requires more heat energy to boil the cores compared with melting the cores for filtration. Distillation requires two phase changes compared with only one for filtration.

   b. On the Moon, the methods would require approximately an equal amount of energy as they would both require an increase in heat and pressure to obtain liquid water.

10. On the Moon, the pressure is too low for liquid water to exist. If you attempted this investigation on the Moon without being in a pressurised environment you would not retrieve liquid water. As you heat the ice cores the ice would sublimate and the gas would escape leaving you without any water. You would have to use a sealed pressurised container.

11. Any relevant ideas from the students.

12. Example from results above:

Distillation is the most efficient as it recovered 36% compared to 19% by filtration.

$$\frac{36}{100} * 1\text{ kg} = 0.36\text{ kg}$$

$$1\text{ kg} = 1\text{ l} \text{ so } 0.36\text{ kg} = 0.36\text{ l} = 360\text{ ml}$$

13. First, do the calculation to find the mass of water per day for one astronaut:

$$\frac{6}{0.36} = 16.7\text{ kg}$$

For 6 astronauts: $16.7 * 6 = 100.2\text{ kg}$

Conclusion

Students should conclude that, on Earth, distillation uses a lot more energy than filtration. However, on the Moon, the low pressure due to the lack of atmosphere means that both methods will require pressurisation and heating to extract liquid water. They should also come to a conclusion about which method they used was the most efficient. Students should realise that we will require a lot of water to survive on the Moon and this presents a big challenge that space agencies are working to overcome.

→ EXTRACTING WATER FROM LUNAR SOIL

Learning about filtration and distillation

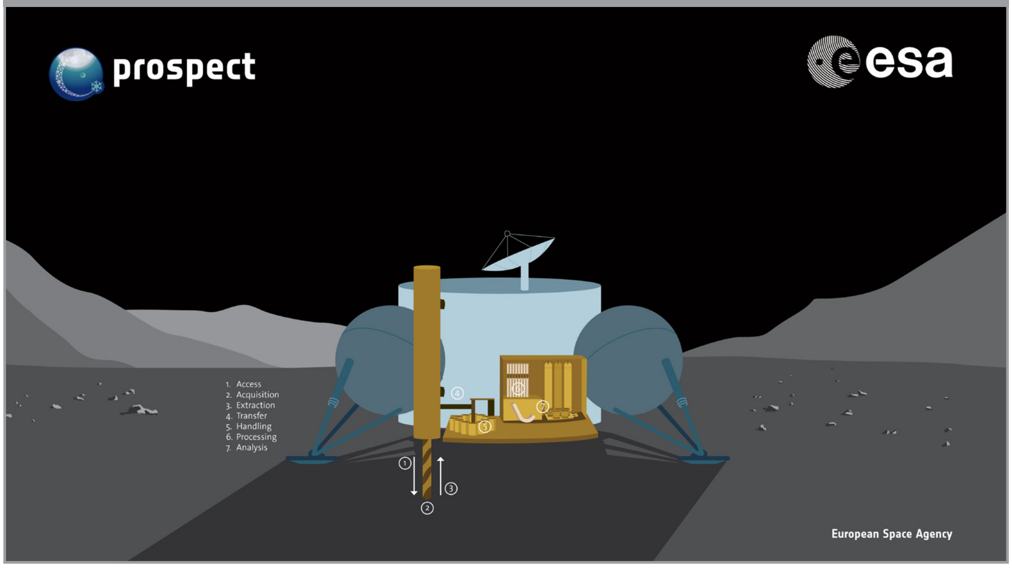
Introduction

Liquid water is an abundant substance on Earth covering 71% of the Earth's surface, but water is actually extraordinary. It is the only common substance known to exist as a solid, liquid, and gas in normal terrestrial conditions and has the ability to dissolve more solid substances than any other liquid. Water is also vital for all known forms of life!

On the Moon, water has been detected in the form of ice. In the future, water ice could be mined to provide liquid water on the Moon for astronauts to drink and for growing plants. The water could also be split into hydrogen and oxygen to provide breathable oxygen and rocket fuel.

ESA is developing the PROSPECT system that will be part of the Luna 27 mission. It will drill into the surface of the Moon to retrieve valuable resources, including water, to support future exploration missions.

Figure A1



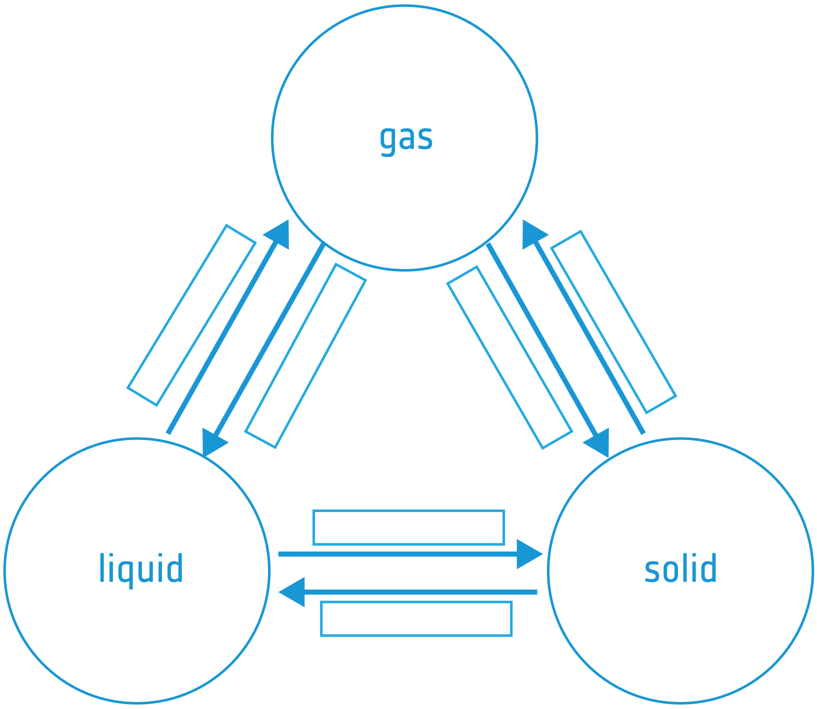
↑ The PROSPECT system concept and its functions.

→ Activity 1: Is water different on the Moon?

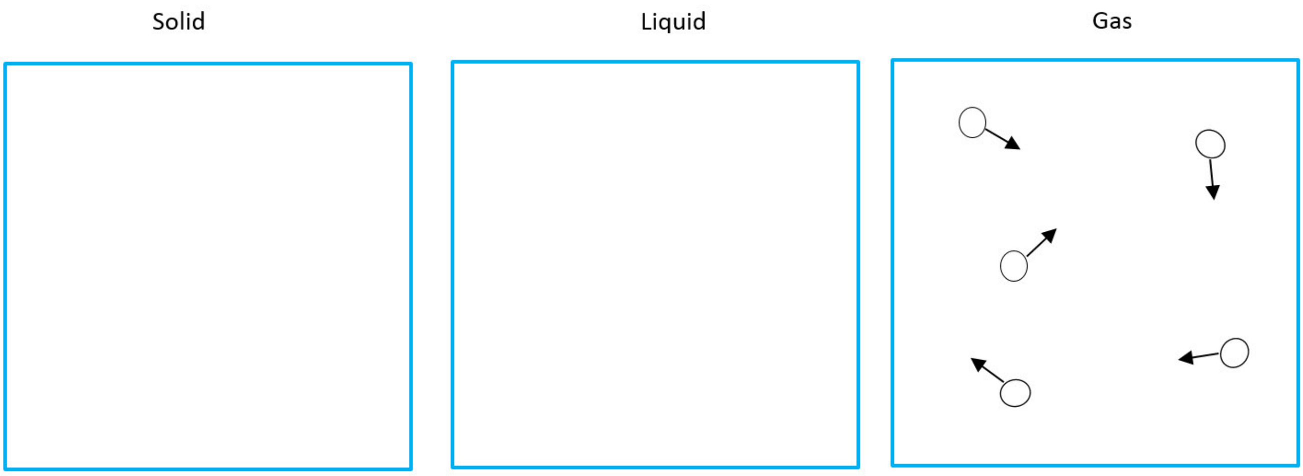
To extract water on the Moon we need to know about states of matter and phase transitions.

Exercise

1. Fill in the dashed boxes with the different phase transitions:



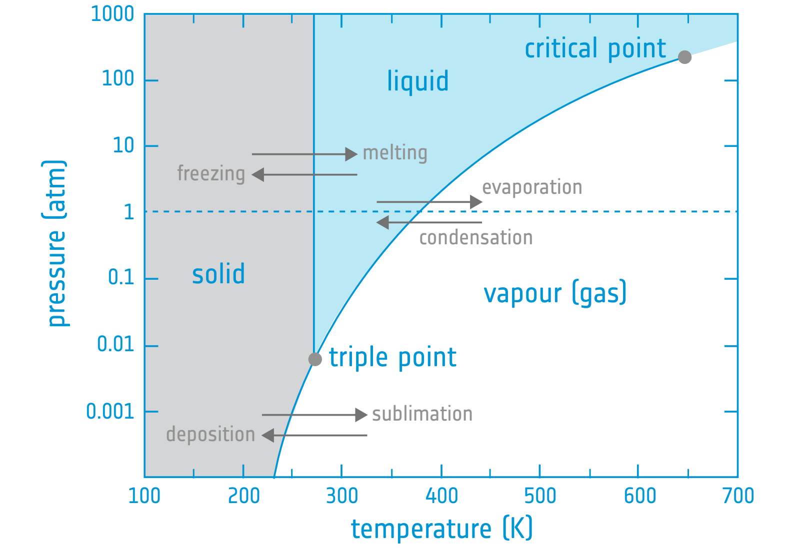
2. Draw the structure of the particles in each of the three states of matter in the boxes below. The particle model for the gaseous state has been done for you.



3. Phase transitions are not only dependant on temperature. They are also dependant on pressure.

The phase diagram below (Figure A2) shows the state of water as a function of both temperature and pressure. It is divided in three regions: solid, liquid and vapour (gas).

Figure A2



↑ Phase diagram for water. The diagram is divided in three regions: solid, liquid and gas. At room temperature (approx. 300 K) and atmospheric pressure (1 atm), we see that water is in its liquid state.

Use Figure A2 to complete the table below:

Water state	Temperature range (K)	Pressure (atm)
Solid		1
Liquid		1
Gas		1

4. a. What happens to the boiling point of water as the pressure decreases? Explain.

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b. Test your hypothesis. Use a syringe to suck up approximately 1 ml of hot water (lukewarm or hotter). Place your finger at the tip and pull the syringe back as shown in Figure A3.

Figure A3

What happens to the water in the syringe?

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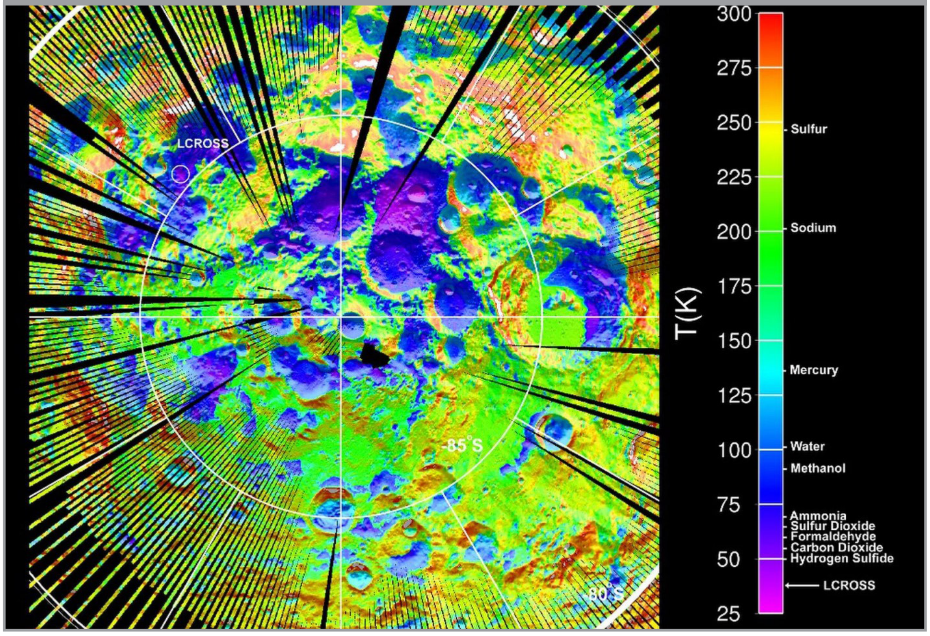
____

5. The Moon does not have an atmosphere, so the pressure on the surface is approximately 0 atm. Temperatures on the Moon are extreme, ranging from -248°C to 123°C depending on where you are on the surface and if it is daytime or night time.

Figure A4



↑ LRO Diviner surface temperature map of the south polar region of the Moon during daytime. The map shows the locations of several permanently shadowed craters that are potential locations for water ice.

a. Use Figures A2 and A4 to explain why water is not found in a liquid state on the surface of the Moon.

b. Imagine that you have extracted water from a permanently shadowed crater which has a temperature of 100 K. What state would the water be in in this crater?

c. What would happen to your water sample from question 5 b if you tried to transport it out of the crater?

d. How could you obtain liquid water from ice on the Moon?

e. Draw arrows on the phase diagram to show your solution in question 5 d.

→ Activity 2: Filtration or distillation?

Any water ice extracted from the surface layers of the Moon will be trapped in the lunar regolith (lunar soil). In this activity you will have to find a way of separating the water from the regolith analogue. You will receive frozen "lunar" ice-cores and your task is to compare two ways of extracting the water from the simulated Moon regolith.

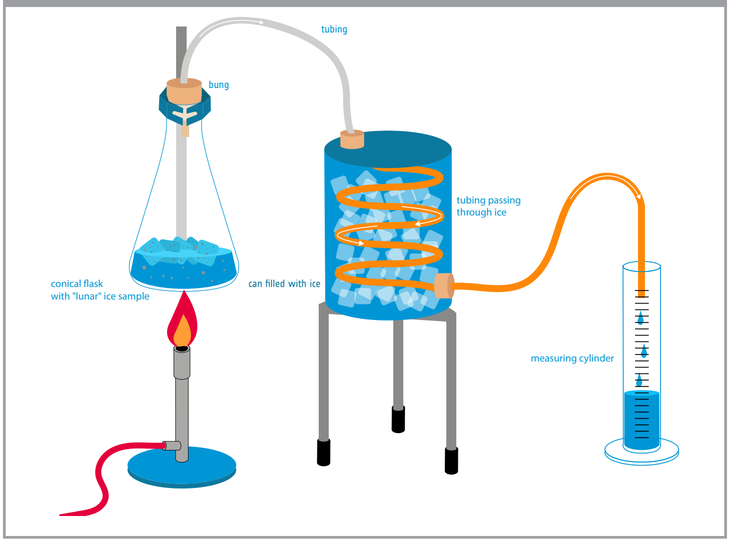
Experiment

Compare two methods for extracting water from lunar regolith: filtration and distillation. **Distillation** is the process of separating substances from a liquid mixture by boiling the liquid and cooling the vapour to form a condensate. **Filtration** separates solids from fluids by adding a medium through which only the fluid can pass.

Distillation equipment

- Bunsen burner or hotplate/boiling ring
- Conical flask
- Tripod
- Bung with hole for plastic/rubber tubing
- Large can with a hole in the side
- Ice cubes (for cooling the tubes)
- Small piece of copper tubing (optional – improves cooling)
- Measuring cylinder

Figure A5

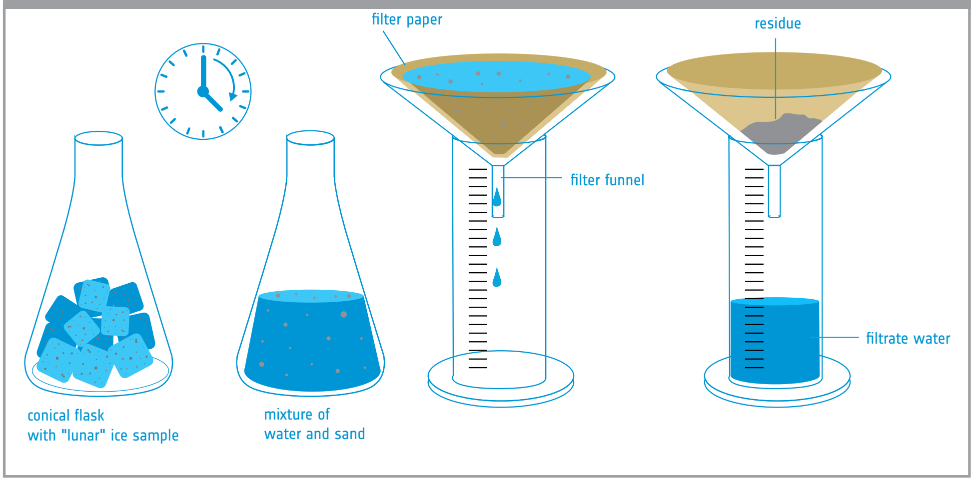


↑ Experimental setup for distillation

Filtration equipment

- Conical flask
- Measuring cylinder
- Filter paper
- Funnel
- Bunsen burner (optional, to melt the ice cores)

Figure A6



↑ Experimental setup for filtration

Your task is to compare the percentage mass of water extracted from the distillation process and the filtration process.

1. Given the information above, and the equipment available, prepare an investigation plan to compare both extraction methods.

2. Which safety concerns should you take into consideration?

3. What do you think the advantages and disadvantages of filtration and distillation are?

4. What will you need to measure **before** carrying out the procedure?

5. What will you need to measure **after** carrying out the procedure?

6. Fill in the table with your results.

Mass of ice cores (g)	Filtration Mass of water (g)	% recovered

Mass of ice cores (g)	Distillation Mass of water (g)	% recovered

7. Which method yields the highest volume of water? Why do you think this is?

8. Which method do you think yields the cleanest water?

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9. a. Which method do you think is the most energy intensive on Earth? Explain.

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b. And on the Moon? Explain.

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____

10. What problems would you encounter if you tried to do this investigation on the Moon?

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11. Can you think of other ways to extract water from the regolith?

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____

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Did you know?

Astronauts on the International Space Station recycle most of the water that they use – about 75%. The Water Recovery System can recover water from astronauts' urine and from their breath. This is filtered and cleaned and can be used again. On average, an astronaut on the International Space Station uses 90% less water than that of a person on Earth.

12. For the most efficient method, how many litres of water do you recover per kilogram of lunar ice? (To help with your analysis you can use the fact that 1 litre of water has a mass of 1 kilogram).

13. Assume that we need 6 litres of water per day per astronaut on the Moon. How many kilograms of lunar ice would you have to extract every day to supply a crew of 6 astronauts?

→ Links

ESA resources

Moon Camp Challenge
esa.int/mooncamp

Moon animations about 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

ESA missions

ESA PROSPECT project is studying a lunar drill for sample collection of lunar ice
exploration.esa.int/moon/59102-about-prospect

ESA Smart-1, Europe's first Moon orbiter
sci.esa.int/smart-1

Extra information

The Moon, ESA's interactive guide
lunarexploration.esa.int

Airbus Foundation Discovery Space, water on the Moon
youtube.com/watch?v=wHJ3F7eIxEM

Sample collection of water ice and other icy volatiles
lunarexploration.esa.int/#/library?a=293

Water and volatiles on the Moon
lunarexploration.esa.int/#/library?a=252

→ Annex: Preparation of ice cores

Ice cores should be prepared the day before the practical activity. In this example, packaging material for test-tubes was used but any container that will produce pieces of ice small enough to fit into the conical flasks will do. The total volume of the container should be measured by filling the container with water and pouring into a measuring cylinder. The container should then be filled half with sand by volume, and half with water. The container should then be placed on a level surface in the freezer.

Ice cores should not be taken out of the freezer until immediately before use – this is because the sand side of the mixture can quickly melt and remain in the container.