Belgium esero

CHAMELEON
Virtual Laboratories for Exoplanets and Planet-Forming Disks

# CLOUDS IN SPACE

## 2nd & 3rd grade secondary education
## Teacher guide

**Exploring how clouds form on planets in our solar system and beyond**

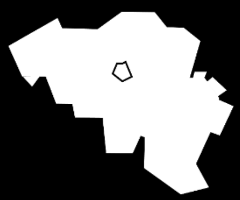
●●●●●● How are clouds generated on Earth ●●●●●
●●●●●● Where do clouds occur and why? ●●●●●●●
●●● Can you simulate clouds in the classroom? ●●●

# OVER ESERO BELGIUM

ESERO is een scholenprogramma van de Europese Ruimtevaartorganisatie ESA. Het doel van dit programma is leraren van basisonderwijs en middelbaar onderwijs helpen om het populaire thema ruimtevaart in de klas te brengen, binnen hun lesopdracht. Dit doen we op drie manieren: **lesmateriaal** (online), **lerarenvormingen**, en **STEM projecten voor scholen**. Het aanbod is volledig gratis voor leraren in beroep en leraren in opleiding, en is afgestemd op de eindtermen in het onderwijs. Hedendaagse en inspirerende ruimtevaartmissies vormen de context diverse schoolvakken.

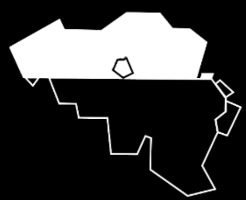
# WWW.ESERO.BE

Nationale coördinator



KU LEUVEN

Vlaamse coördinator



UGENT VOLKSSTERRENWACHT ARMAND PIEN

Frans- en Duitstalige coördinator

ULB
La Scientothèque

ESA Education beheert en coördineert alle ESERO's in Europa. Elke ESERO bestaat dankzij een cofinanciering van ESA en nationale partners. Het federaal wetenschapsbeleid (BELSPO) is de cofinancierende partner voor ESERO Belgium.

esa European Space Agency

belspo

# Clouds in space

## Exploring how clouds form on planets in our solar system and beyond

***Teacher guide***

# Fast facts

| | |
|---|---|
| **Target group** | 15-18 year old students. |
| **Type** | Inquiry based learning (In class student lead experiments) |
| **Lesson time** | 2 x 50 minutes |
| **Needed** | ▪ Warm water<br>▪ Ice<br>▪ Measuring equipment (thermometers, digital camera) |
| **Topics** | ▪ Space<br>▪ Exoplanets<br>▪ Clouds<br>▪ Inquiry learning<br>▪ Hands-on |
| **Learning objectives** | ▪ State what an exoplanet is<br>▪ Explain why clouds are important to exoplanet science<br>▪ Explain how clouds are formed on a planet<br>▪ Identify the variables in an experiment/demonstration.<br>▪ Demonstrate how clouds form<br>▪ Use scientific methods to test and record the effects of systematically changing a variable<br>▪ Present scientific findings to the class |

**Summary**

In this set of six activities students will using inquiry learning methods to discover how clouds form on a planet, and how understanding clouds plays an important role in astronomy. Students will be guided to develop hypotheses about cloud formation and test them using hands-on experiments in groups. The students will then have the opportunity to consolidate their learning by presenting and discussing their findings to the class.

# Colofon

| | |
|---|---|
| **First edition** | January 2023 |
| **Updates** | |
| **Conditions of use** | This resources can be used freely for education purpose. When you copy parts of it, then a correct reference has to be made to the original.<br>The most recent version can be downloaded on www.esero.be > NL > Lesmateriaal. |
| **AUTHORS** | |
| **Oriel Marshall** | Content and didactics, trainer of teachers. |
| **ESERO Belgium** | Support in layout, dissemination and teacher trainings. |
| **Your opinion is important** | ESERO Belgium always keeps working on improved quality. As a user you are encouraged to give us feedback via the contact data on www.esero.be. When your feedback contributes significantly to the new edition, your name will be mentioned in the authors list (colofon). This way, users are helping other, future users to get better resources. |

# CONTENT

# Summary of activities

## ① Introduction Quiz

**Description:** A short presentation quiz that introduces the students to the idea of clouds in space and exoplanets.
**Outcome:** Engage the students, gauge their prior knowledge, and introduce new concepts.
**Requirements:** None.
**Time:** 10 minutes.

## ② Video demonstration of cloud jar

**Description:** Water is poured into the bottom of a glass container, spray a small amount of hair spray into the container, and then place a plate filled with ice on top. A cloud will form inside the container.
**Outcome:** Introduce the class to the demonstration. Illicit intrigue and questions from the class as to how it works.
**Requirements:** Completion of Activity 1
**Time:** 10 minutes.

## ③ List the variables

**Description:** List the variables in the demonstration: Students participate as a class to list the variables that might affect this demonstration.
**Outcome:** Practice of scientific methods and thinking
**Requirements:** Completion of Activity 2.
**Time:** 5 minutes.

## ④ Student experiments

**Description:** Students are split into groups and are provided with the equipment needed to perform the demonstration. Each group is given/chooses one variable to systematically adjust and record the results of.
**Outcome:** Inquiry learning: using scientific methods to explore and understand how clouds are formed
**Requirements:** Completion of Activity 3.
**Time:** 25 minutes.

### Optional break

## ⑤ Presentations of findings

**Description:** Students will present the results of their experiments. They will explain the effects of changing their given variable, and share their hypothesis' about why these effects may have occurred.
**Outcome:** Presenting scientific results and using those results to come to informed conclusions.

| | |
|---|---|
| **Requirements:** | Completion of Activities 1 through 3. |
| **Time:** | 20 minutes. |

## 6 Post-activity discussion

| | |
|---|---|
| **Description:** | The students will apply their knowledge they have learnt about lightning to answer questions about how this information can help astronomers. |
| **Outcome:** | Application of their new knowledge to different situation. This will help to both evaluate and solidify their learning. |
| **Requirements:** | Completion of Activities 1 to 4. |
| **Time:** | 30 minutes. |

# Introduction

Almost everything we know about planets other than our own has been learned through telescope observations. If an alien was living in another solar system and was looking at earth through an alien telescope, a lot of the surface of the earth would be covered by clouds.

*Figure 1: Earth as seen from ESA's Copernicus Sentinel-3 Satellite*

This cloud coverage would make it more difficult for the alien astronomers to observe the surface of the earth. By this same reasoning, our observations of other planets are vastly affected by cloud coverage. In order to understand a planet, its atmosphere and the surface that may be underneath the clouds, it is important that we first understand the clouds themselves.

In this set of activities the students will use inquiry learning methods to understand how clouds form on a planet and what conditions are needed on a planet for it to have clouds. Through this, it will not only help students to understand not only the importance of clouds in astronomy, but also help students to understand the cloud formation process on earth.

Through these activities, students will be encouraged to think about the similarities and differences between planets, and will learn about planets outside of our own solar system (exoplanets). Students will also have opportunities to test their scientific skills, and apply their understanding of cloud formation by using deductive skills to determine what clouds can teach us about all forms of planets from our own out to the furthest reaches of our current telescopes.

# Background

## Cloud formation

Cloud formation requires the same set of physics regardless of the planet the clouds are on, however there are vast differences when it comes to the chemicals and compositions involved in the formation.

The conditions that are required for clouds to form are simply:

1. super saturated portion of atmosphere (eg. A pocket of the atmosphere where the amount of vapor in the pocket exceeds the maximum amount that that pocket of atmosphere can hold so the relative humidity is greater than 100%)
2. An aerosol in the atmosphere for the vapour to condense onto.

On earth, the aerosols that clouds form around can come from many different sources. Some examples of these are smoke from volcanoes, pollution from cars, salt from sea spray, or sand in the air from sand storms.

The relative humidity of a pocket of air depends on the content of vapour in the atmosphere and the temperature of the atmosphere. The higher the temperature of the atmosphere, the more vapor that is needed to achieve super saturation, and vice versa. Super saturation for clouds on earth most commonly occurs when water evaporates from the surface of the earth, thus filling a pocket of air with water vapor. This pocket will then rise through the atmosphere where the air is cooler. As the pocket of air and vapor gets colder, the amount of vapor that the pocket can hold decreases until super saturation is reached. If there are aerosol particles in this pocket of air, the vapor will start to condense onto these particles and this will build up to form clouds.

On other planets, super saturation and aerosols are also both required for cloud formation, but different planet atmospheres will have very different chemical compositions, temperatures and pressures. On terrestrial planets, aerosols may be due to events such as dust storms or volcanos on the planet’s surface but the dust and smoke will likely have an entirely different chemical composition.

## Solar system clouds

All of the planets in our solar system except Mercury have clouds. Mercury does not have any clouds as it does not have an atmosphere. The gas giants have a swirling layer of cloud covering almost their entire surface, and terrestrial planets such as Earth and Mars have clouds coverage more closely resembling that seen on Earth: a variety of cloud patterns, usually with more cloud coverage at the poles and some storms across the planet.

As detailed in the accompanying presentation content, the clouds on other planets in our solar system are formed from a wide range of minerals, ices, gases.

## Exoplanet Clouds

Clouds plays a crucial role in exoplanet research. Astronomers have found more than five thousand planets outside of our own solar system and the many of these planets are believed to have clouds in their atmospheres. Cloud coverage can greatly affect the light that we see from a planet with telescopes, so it is crucial that we can understand clouds and their processes in order to learn more about exoplanets. Clouds affect both the light being reflected by a planet, and the properties of the planet itself. Clouds are insulating so can affect the temperature of a planet. They also have a higher opacity than atmospheric gas and so absorb light from a planets host star and re-emit it at different wavelengths.

Clouds on exoplanets can look very different to clouds in our atmosphere here on Earth. The wide variety of planet sizes, compositions and temperatures can result in clouds or cloud layers of varying heights and thicknesses, made up of a huge variety of minerals, liquids, gases and solids. This makes it possible to have clouds on exoplanets that are made up of molten rock, glass, iron, rubies, sapphires and more!

Along with different compositions and sizes, clouds locations on a planet can also vary drastically on exoplanets. Some exoplanets are ‘tidally locked’, this means that the same face of the planet is always facing its host star, resulting in one side of the planet being eternally daytime and one side having continuous night with a twilight zone running around the middle. On planets like these, the day side is often too hot for clouds to form, but the night side might have a warmer planet surface, but a very cold atmosphere. This means the conditions on the nightside are much more suited for clouds to form, so may result in a planet that is half cloudy and half with clear skies!

# Activity 1
# Introduction to Clouds on other planets

In this activity, students will be introduced to the idea of clouds on other planets. The goal of this activity is to gauge students prior understanding to the topic and to engage them and elicit the students interest. The science behind cloud formation will not be addressed in this activity, instead it will focus on where clouds have been observed, what effects clouds can have, and why it is important for exoplanet scientists and astronomers to understand clouds.

## Equipment

Projector/screen & Digital presentation (provided in attached PowerPoint presentation)

## Exercise 1: Clouds in Space Quiz

Follow the slideshow of quick quiz questions about clouds in space. Students should be given time to discuss each question. If there are many additional and follow up question from the students at this stage, it is suggested to write down these questions so that they can be addressed at the end of the lesson.

## Additional Slide Information

Additional information and tips can be found in Annex 2: Slide Notes.
It is recommended to have these notes accessible during your class

## Discussion

As seen in the quiz questions, many of the exoplanets we have found so far are believed to have clouds, and clouds can introduce difficulties when observing a planet. Therefore, it is important that exoplanet scientists can understand how and where clouds form in order to help them ‘see through’ the effects of the clouds, and learn more about the planet below. Learning about clouds also helps scientists to understand the chemical composition and dynamics of a planets atmosphere. If we know what conditions are needed for clouds to form, then when we observe a planet with clouds we can deduce that those conditions must be met on that planet.

## Exercise 1

What What do you think are the conditions needed for clouds to form?

*There is no set answer for this question at this stage. The goal of this question is to peak the students inquiry. The same question will be asked later in the lesson (Activity 6) and answers will be provided.*

# Activity 2

# Clouds in a Jar

In this activity, you will show a video demonstration of the cloud in a jar experiment. The video can be found at the following link

https://vimeo.com/802277701

## Exercise

During this demonstration it is important that students are only shown the the effect and are not given the explanation yet of what is happening. This is to encourage the curiosity of the students and to encourage them to come up with their own hypotheses during the experiment and exploration phase of the lesson (Activity 4).

## Discussion

The students should see the clouds form in the jar. It is encouraged that they question how this is happening, but that answers are not provided by the teacher at this stage. The students will attempt to develop hypothesis themselves and test them in activity 4.

# Activity 3
# Determining the Variables

In this activity, students will work as a class to determine the variables in this demonstration.

## Equipment

A whiteboard/black board/ screen that all of the students can see

## Exercise 3

As a class, ask the students which variables are present in this demonstration. Theses should be written up on a board or screen that all of the students can see. The teacher may guide the students as needed. It is suggested to use ‘think, pair, share’, or similar, for this activity.

## Results

With guidance from the teacher where necessary, the following variables should be identified by the class.
The variables in **bold** are suggested to be tested in the next activity, so identification of these is highly recommended. The variables not in bold are useful for context and completeness and the identification of these will aide in class discussion. You class may also identify other variables that are not on this list! Not all variables will have a direct parallel to exoplanet atmospheres. This is because all physical analogies and demonstrations will have limitations, as it is not an exact replica of an exoplanet atmosphere.

| Variable In Experiment | Parallel in Exoplanet Atmosphere |
|---|---|
| **Temperature of the water at the bottom of the container** | **Surface temperature of the exoplanet** |
| **Temperature of the water at the top of the container -> air temperature at the top of the container** | **Temperature of the exoplanet’s atmosphere** |
| **Presence/composition of the added particles/aerosol** | **Presence/composition of dust and minerals in the exoplanet's atmosphere** |
| Volume of water at the bottom of the jar | Quantity of surface water on the planet |
| Atmospheric pressure | Atmospheric pressure on the exoplanet |
| Humidity inside the container | Humidity in the exoplanets atmosphere |

# Activity 4

# Exploration/Experimentation

In this activity, students will be split into groups and asked to investigate the effect of a variable on the cloud that is formed in order to try to determine what a planet would need to have clouds.

## Equipment

- One large glass container per group
- A Metal/ceramic plate/bowl that can be used as a lid for the glass containers (one per group)
- A kettle or water bath (one per class)
- A container or beaker for hot water
- Thermometer (at least one per group)
- Hairspray/dry shampoo - unfragranced if possible (one per group)
- A water spray bottle
- Ice
- Washing up liquid soap (or other anti-fog substance for glass)
- An eye test chart (provided in annex 1)

## Health and safety

Caution should be used when using hot water. It should be explained to the class that a quick change in the temperature of a glass container could cause it to smash. This activity involves the use of hairspray, students with asthma should be aware of this and it is a good idea to keep windows open during this activity.

## Exercise

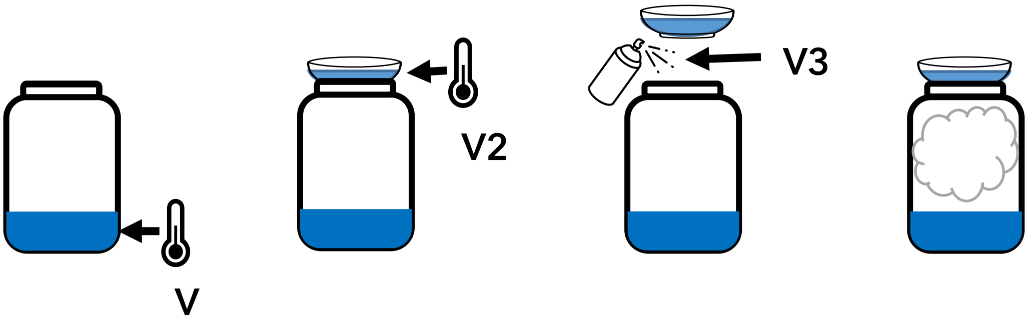
The students should be split into groups of 3 to 5 students for this activity. Each group will choose one variable to investigate. If the groups have trouble deciding on a variable, you may instead assign them one of the following variables:

1. The atmospheric temperature of the exoplanet (the temperature of the water at the top of the jar)
2. The presence/composition of aerosols/minerals in the exoplanet atmosphere (the presence/composition of an aerosol)
3. The surface/liquid temperature on the exoplanet (the temperature of the water at the bottom of the jar)

Suggested temperatures are: Ice water ( 0 °C) ,Room temperature (~ 20 °C), Hot (75 - 80°C)

Suggested aerosols are: No aerosol, water aerosol (from a spray bottle), hairspray

**The suggested optimum combination of variables to create a cloud is:**
**V1 = Hot (75 - 80°C), V2 = Ice water (0 °C), V3 (Aerosol) = hairspray**




When a group is changing one of the variables, it should be suggested that the group keep the other control variables at the optimum values stated above. It is suggested not to allow students to choose the quantity of hairspray as their variable as this will be difficult to control and may cause issues if there is poor ventilation.

If one group finishes testing their suggested variable at the suggested values, they may experiment further to learn more about the topic. This may include changing the amount of water or aerosol, or changing the variable in smaller increments. In order to allow students to practice their scientific skills it is suggested that you allow the students to come up with their own plans for further experimentation and only intervene if their testing is unsafe.

## Recording Results

Students can record their results in any way that they see fit. The suggested method for recording their results is as follows:

Students will set up a digital camera or camera phone so that the eye test chart is visible through the glass container. A photograph will be taken of the container with no cloud as a control. Photos/videos/timelapses will then be taken (with the same lighting, and the camera in the same position) to document the thickness of the cloud. You can keep track of conditions by numbering each test, and including a piece of paper in the photograph with that number drawn on it.

## Discussion

In this activity students are encouraged to think independently and practice their problem solving skills. Students are allows to come up with their own hypothesis' and test them using methods that they deem appropriate and helpful. It is important during this activity that the students are documenting their results in an appropriate and accurate manner.

# Activity 5
# Group Presentations

In this activity, students will present their findings from Activity 4 to the rest of the class. The class will then summarise these findings together in order to determine what variables are needed to form a cloud on a planet..

## Equipment

A whiteboard/black board/ screen that all of the students can see.

## Exercise 5

The groups of students will take turns to present their findings to the rest of the class. This can be done in a manner seen fit by the teacher (eg. Oral presentation, digital presentation, poster etc.)

The students should be encouraged to clearly present the following points:

- The variable they were testing
- Their hypothesis before testing began
- What they found during their testing
- Was their hypothesis confirmed or denied
- After seeing the results of the test, why they think changing their variable had the effect that it did.

## Discussion

You may wish to write brief notes from each group up on the board.

After the students have presented their findings, a discussion can be had as a class to determine what they have found out collectively and try to come up with a list of the conditions needed for clouds to form on a planet.

Students will then be asked to write a short paragraph describing their findings in order to summarise what has been found.

# Activity 6

# Post-activity Discussion

In this activity, students will break down the steps in the experiment to understand what conditions are needed for clouds to form on a planet.

For this activity, students are introduced to the concepts of humidity, saturation and condensation. These concepts can be explained using the relevant slides in the presentation.

## Some background on saturation and condensation

All The amount of vapour (for example, water vapour) that a pocket of air in a planet's atmosphere can hold is related to the temperature of the air. If the air is warmer, then it can hold more vapour, if it is colder it can hold less.

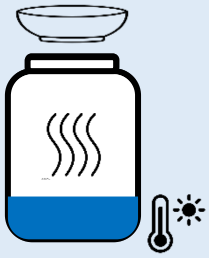
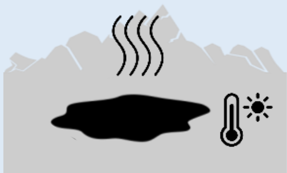
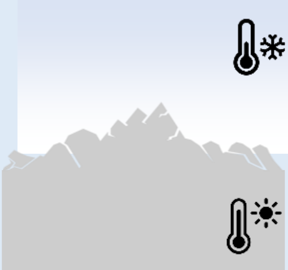
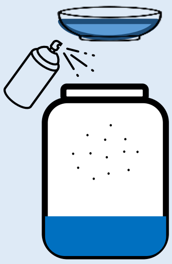
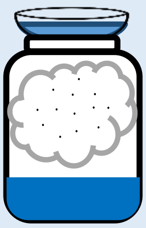
When a pocket of air is holding as much vapour as is possible at a given temperature it is **saturated** (relative humidity = 100% ). If more vapour is added past this saturation point, then the extra vapour will condense onto any surface that it can so that the air remains at saturation point. You can see this in action when there is a car full of people breathing out water vapour and it starts to condense onto the windows.

If there is no surface available for the vapour to condense onto, then the vapour has to stay in the air. This results in the air being **super saturated** (relative humidity is more than 100%).

In an exoplanet atmosphere, vapour in the atmosphere can condense onto small aerosol particles suspended in the air. These might be dust, or very tiny pieces of rock or other minerals that are in the atmosphere.

**Cloud condensation nuclei:** Also known as 'Cloud seeds'. This is the name given to aerosols and particles in the atmosphere that, when they are in a supersaturated pocket of air, vapour from the air will condense onto to form clouds.

## Exercise 6.1: Suggested Answers

| | Experiment Diagrams | Exoplanet Atmosphere (complete the diagrams) | Scientific Processes (add written descriptions) |
|---|---|---|---|
| **Step 1** |  |  | Liquid on the surface is hot enough to evaporate into the air<br>=> The humidity of the atmosphere/container increases |
| **Step 2** |  |  | The top of the atmosphere is cold<br>=> The amount of vapor that the air can hold decreases<br>=> The relative humidity increases, and the air becomes super saturated |
| **Step 3** |  |  | Small particles in the air become aerosols<br>=> These are cloud condensation nuclei |
| **Step 4** |  |  | The moisture from the saturated air condenses onto the cloud condensation nuclei and clouds form |

**A Note on Gaseous Planets** Both gaseous and rocky/terrestrial exoplanets can have clouds. Terrestrial planets (like earth or mars) have a rocky surface, there may be liquids on this surface that can evaporate into the atmosphere to form clouds. Gaseous planets (like Jupiter and Saturn) do not have a solid surface this means that the vapour to form the cloud must already be in the atmosphere. Similarly with dust and aerosols: rocky planets may have dust and other particles on the surface that will be blown up into the atmosphere, whereas with gaseous planets the aerosol particles must form within the atmosphere.

## Exercise 6.1 : Suggested Answers

**Q1**

Imagine you hear in the news that astronomers have found evidence of clouds on an exoplanet. From this information, what can you predict/deduce about the planet in question?

*If an exoplanet has clouds on it then this means that the conditions for clouds to form must be met. This means that the planet must have:*

- *An atmosphere*
- *Vapor in the air (if it is a terrestrial planet, this could be from the ground being hot enough for liquid on the surface to evaporate, if it is a gaseous planet, then the vapour will remain in the atmosphere)*
- *A cool enough atmosphere for the relative humidity of the exoplanet atmosphere to be above 100% (super saturation)*
- *Aerosols/particles in the air (dust, volcanic ash, small minerals or rock particles)*

**Q2 (extension question)**

Some exoplanets are tidally locked to their star. This means that the same side of the planet is always facing the star, just like how the moon is tidally locked to the earth so that we only see one face of the moon. This results in one side of the planet being in constant daytime, and the other side of the planet in constant night. It is predicted that these planets will often have clouds only on one side, why do you think this might be?

*Certain temperature constraints must be met for clouds to form. On terrestrial planets, the ground must be hot enough for liquid to evaporate, but the atmosphere above must be cool enough for super saturation to occur. Tidally locked planets have very extreme temperatures. The day side is always very hot in comparison to the night side.*

*For a planet that is close to its star, the day side may be so hot that the air never gets cool enough for super saturation to occur so no clouds could form, as condensation would not occur. The night side may have a heated surface due to the planet being heated by the sun, so liquid may evaporate into the air, and the cold atmosphere on the night side would allow saturation to be reached, and clouds to form.*

*For a planet that is far away from its star, the day side might have the correct temperature conditions to form clouds, but the night side might be too cold for liquids to vapourise into the atmosphere.*

# Links

**ESA resources**
ESERO Belgium: classroom resources, teachers trainings and STEM projects for schools: www.esero.be
Teach with Exoplanets: https://www.esa.int/Education/Teach_with_Exoplanets
ESA classroom resources: www.esa.int/Education/Classroom_resources
ESA Kids homepage: www.esa.int/kids

**NASA recources**
NASA Video - Exoplanet Clouds: 'Jewels' of New Knowledge:
https://exoplanets.nasa.gov/news/1709/exoplanet-clouds-jewels-of-new-knowledge/

**Extra information**
CHAMELEON Marie Curie Exoplanet Research Network
https://chameleon.iwf.oeaw.ac.at/

# Annex 1

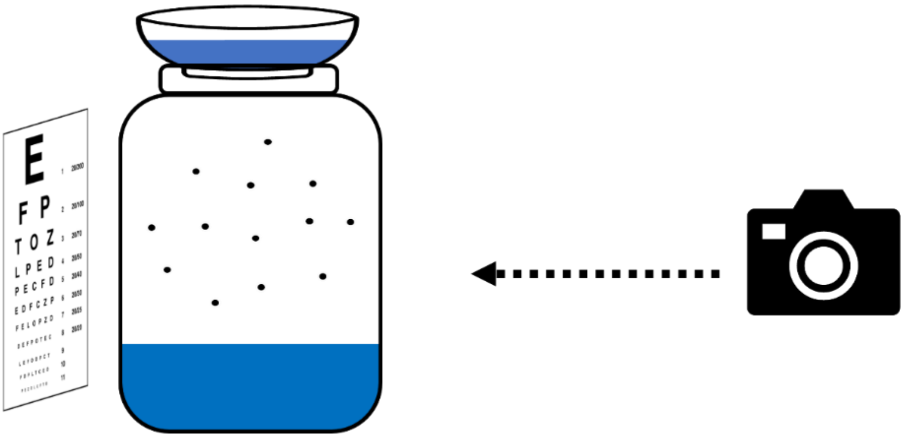
# Eye test chart

This is used to assess the opacity of the cloud. Credit: commons.wikimedia.org

| | | |
|---|---|---|
| E | 1 | 20/200 |
| F P | 2 | 20/100 |
| T O Z | 3 | 20/70 |
| L P E D | 4 | 20/50 |
| P E C F D | 5 | 20/40 |
| E D F C Z P | 6 | 20/30 |
| F E L O P Z D | 7 | 20/25 |
| D E F P O T E C | 8 | 20/20 |
| L E F O D P C T | 9 | |
| F D P L T C E O | 10 | |
| P E Z O L C F T D | 11 | |

# Annex 2

# Demonstration Instructions



**Step 1:** Clean and dry the glass container. Apply a very small amount of dish soap to a paper towel and wipe this around the inside of the glass container leaving a very thin (but invisible) film. This will help the glass to not fog up.

**Step 2:** Place or stick the eye test chart (provided in Annex 1)  to the back of the container so that it is visible to the students though the container. This will be used as a way of assessing the thickness of the cloud.

**Step 3:** Pour approximately 2-3cm of hot water (between 75 and 80 degrees C) into the bottom of the container. This water should be hot but should not have visible clouds of steam or fog up the glass. If it does fog up the class or if there is visible steam, leave the lid off the container until it is cooled enough that the steam is no longer visible.

**Step 4:** Fill the 'lid' with ice and a few centimeters of water and place it on top of the glass container. It should be the same shape as the hole of the jar that the air inside the jar is sealed in.

**Step 5:** Remove the lid, add a small spray of hairspray into the container then replace the lid.

**Step 6:** A cloud should begin to form within the jar. As the cloud forms, the lettering on the eye test should become gradually obscured as the cloud forms.