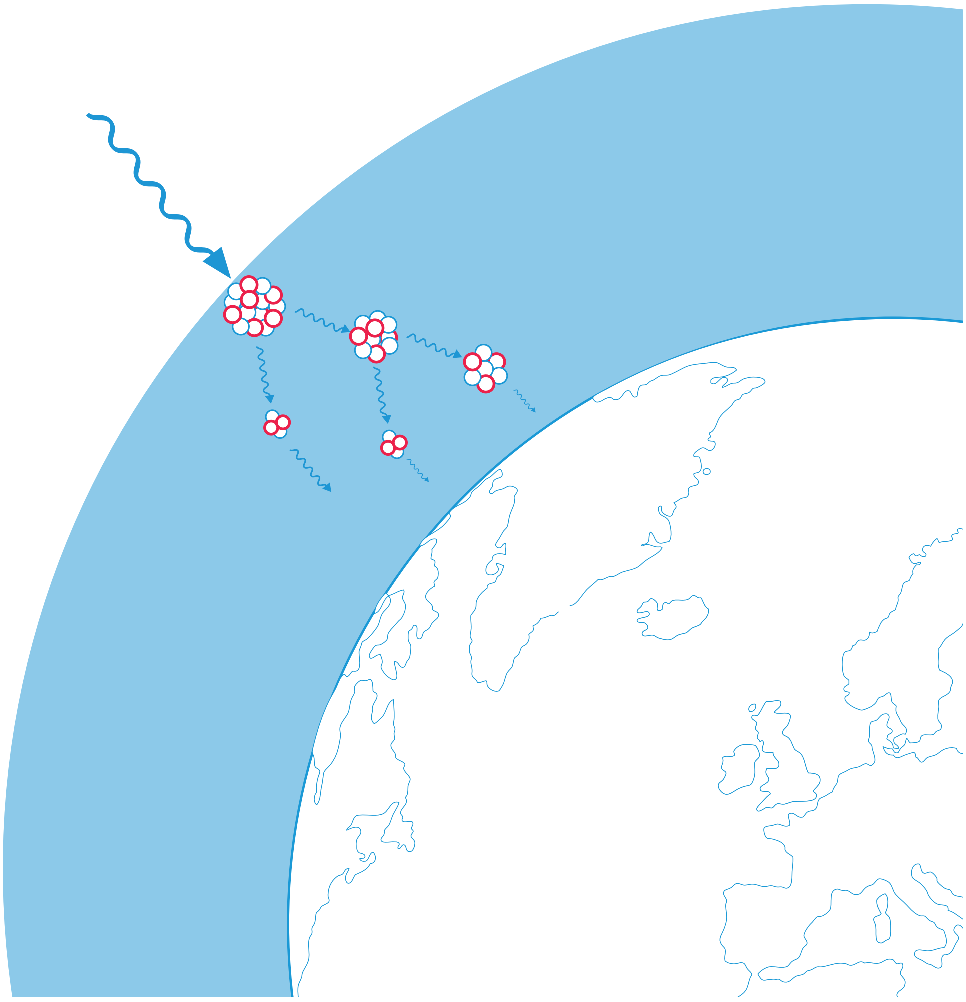
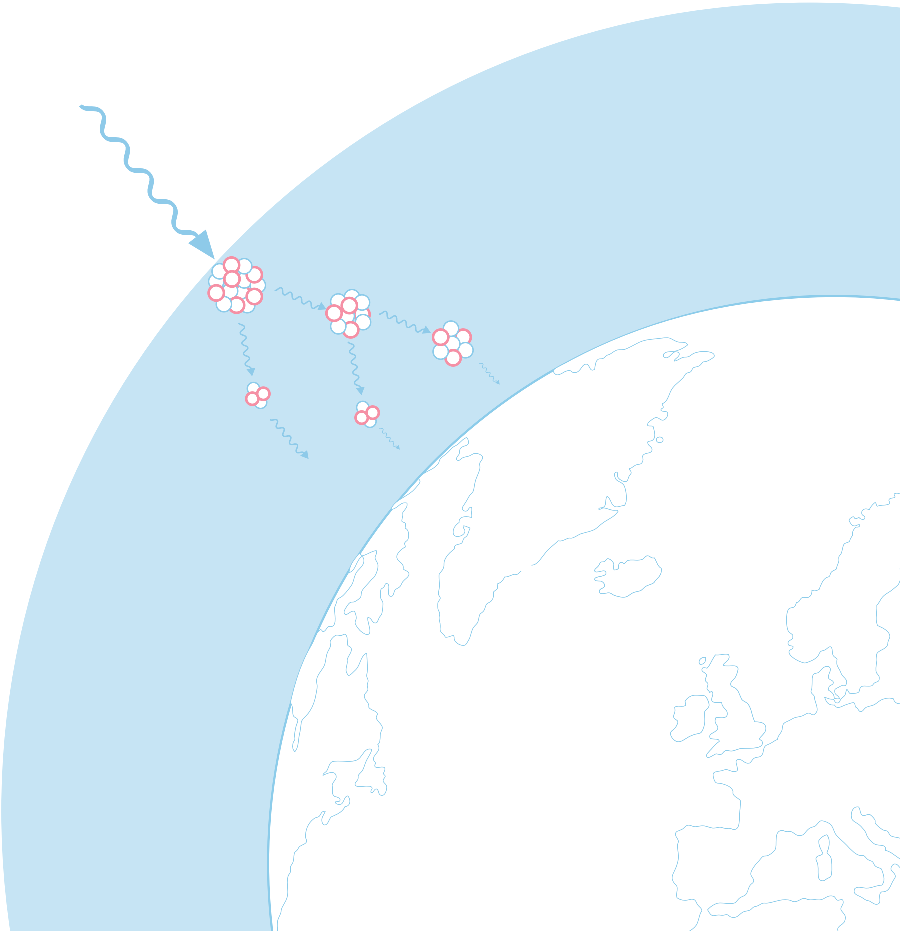
# teach with space

## → CLOUD CHAMBER

### Radioactivity in a cosmic setting





# → CLOUD CHAMBER

## Radioactivity in a cosmic setting

## FAST FACTS

**Age range:** 14-18 years old

**Type:** teacher demonstration/group practical

**Complexity:** medium

**Teacher preparation time:** 5 minutes per cloud chamber

**Lesson time required:** 1 hour

**Cost per kit:** medium (5-25 euros per cloud chamber)

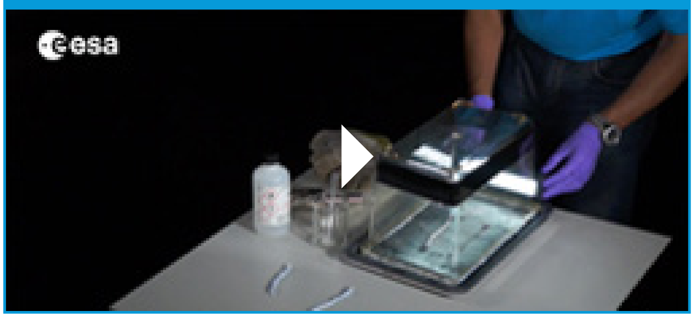
**Location:** small indoor space

**Includes use of:** low level radiation source, dry ice (solid $CO_2$), alcohol

## Students will learn

- Fundamental particles
- Particle interactions
- Atomic number, mass number
- Radiation and radioactive decay
- Radioactive decay as a power source for spacecraft
- The negative effects of ionising radiation on electronics
- Interactions between charged particles and magnetic fields
- Cosmic rays including their interactions with the atmosphere

## You also need



↑ Cloud chamber video (VP03). See Links section.

## Outline

Cloud chambers are boxes specially made to detect charged particles and radiation. In this activity, a cloud chamber is used to observe alpha and beta particles, the charged products of the radioactive decay of thorium-232. Students should already have been introduced to the concept of radioactive decay and the differences between alpha and beta radiation. This experiment will assist students in their understanding by providing a physical demonstration of radioactive decay.

Students will observe the condensation trails that charged particles leave in their wake in a cloud chamber, and learn to identify particles based on the trail properties. Trails made by cosmic rays can be seen in the cloud chamber, which could provide a starting point for introducing cosmic rays and their deflection by the Earth's magnetic field. Students will practice calculating and writing radioactive decay equations. Implications of radiation for ESA are discussed, including the negative effects of radiation on circuits, and the use of radioactive decay as a power source.

## Students will improve

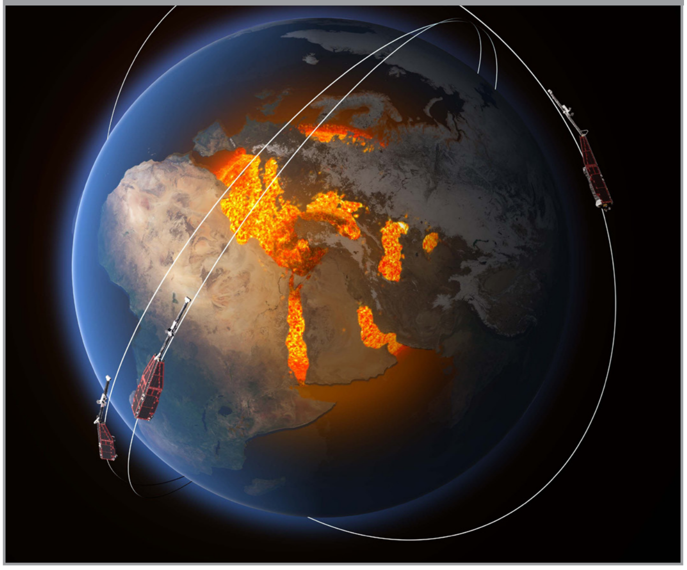
- General experimental skills including using equipment appropriately and making and recording observations.
- The communication and discussion of results, through asking relevant questions to expand understanding and knowledge of a subject.
- Their application of knowledge gained through experimental observations to solve theoretical problems.

# → BACKGROUND

With the invention of the first cloud chamber, a new branch of physics was born: the study of particles and their interactions. Cloud chambers allow us to observe charged particles to determine their properties so we can understand them in more detail.

Inside the chamber, alcohol molecules in vapour form are ionised when charged particles pass close to them. This causes the alcohol vapour to condense into liquid droplets, resulting in a visible condensation trail (contrail) where the charged particle interacted with the alcohol. The length and thickness of this trail depends on the mass of the particle.

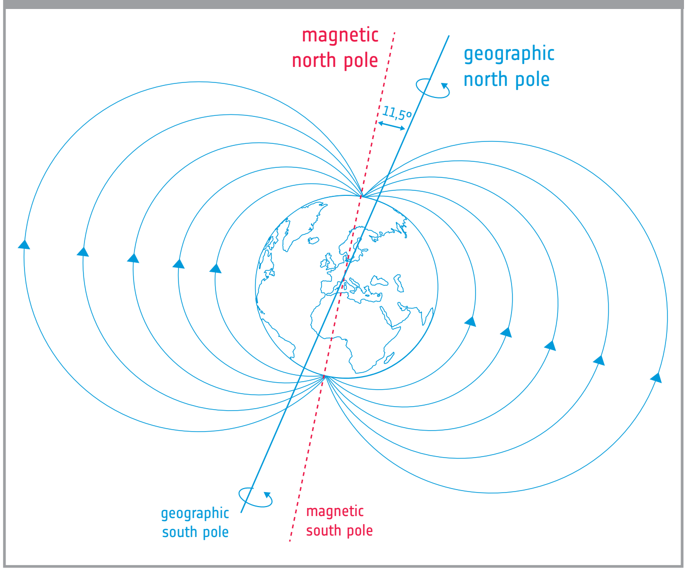
Figure 1



↑ ESA's Swarm satellites orbit the Earth, studying its magnetic field.

These charged, ionising particles come from a range of sources including materials undergoing radioactive decay. During radioactive decay, unstable atoms break up into smaller, more stable atoms, releasing either alpha radiation (a particle made up of two neutrons and two protons) or beta radiation (an electron or a **positron***).

Figure 2



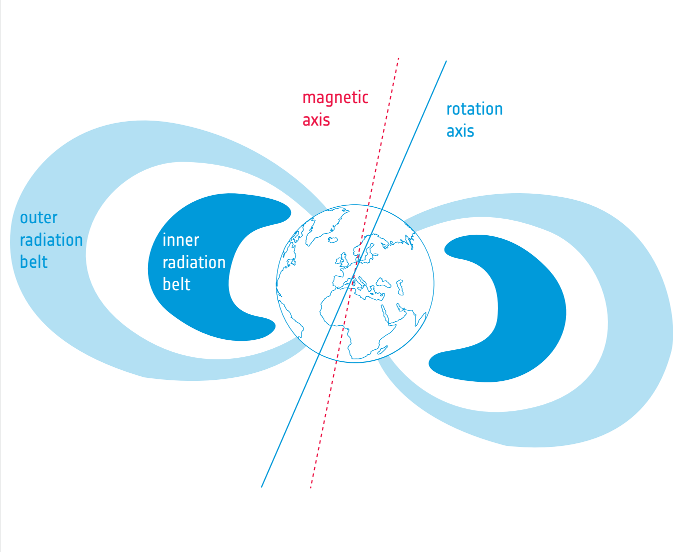

↑ Earth's magnetic field. Note that the rotation axis and the magnetic field axis are aligned differently and they do not intersect at the centre of the Earth

As well as arising from radioactive decay, a lot of ionising radiation is present in space, originating from sources such as **cosmic rays***, the **solar wind***, and **coronal mass ejections***. Moving charged particles are deflected by magnetic fields, so the Earth is largely shielded from ionising space radiation by its own magnetic field, the magnetosphere, which is currently being studied by ESA's Swarm (Figure 1) and Cluster satellites. The magnetosphere is generated by the motion of the magnetic elements iron and nickel in the Earth's core. The magnetic field lines of the Earth are shown in Figure 2.

* **Positron:** a particle with the same mass as an electron, but with the opposite charge.
**Cosmic rays**: very high-energy particles, mostly protons and atomic nuclei, originating from the Sun and objects outside the Solar System.
**Solar wind**: a stream of charged particles emitted from the Sun – mainly electrons and protons.
**Coronal mass ejection**: a burst of electromagnetic radiation, particles, and magnetic fields ejected from the solar corona into space.

Charged particles and radiation can get trapped within the Earth's magnetic field lines which are concentrated in the inner and outer **Van Allen radiation belts*** depicted in Figure 3. This can have an adverse effect on electronic equipment on board spacecraft orbiting the Earth. However, radiation can also be used for good. Spacecraft can be powered via the Seeback effect; a temperature difference between two electrical conductors (induced by heating one with radiation) can produce a voltage difference between the two, causing current to flow.

Figure 3




↑ Van Allen radiation belts. Two doughnut-shaped rings that circle the Earth and contain trapped charged particles.

A cloud chamber can be developed further by including a magnetic field, which deflects moving charged particles. The direction and amount of deflection depends on the charge of the particle. This fact was instrumental in the discovery of antimatter in 1932 when Carl Anderson used a cloud chamber with a magnetic field to observe cosmic rays, charged particles from space, and found that some of the particles were deflected in the opposite direction to what was expected of them.

* **Van Allen radiation belts**: layers of energetically charged particles held in place around the Earth by the magnetic field. The altitude ranges from about 1000 to 60000 km above the Earth's surface.

# → EXPERIMENT PREPARATION

The teach with space - cloud chamber | VP03 video, available on ESA's Education website, shows the complete set-up and use of the cloud chamber. This video can be used to guide students on setting up their chambers, to explain what they are observing, or simply as an alternative to building cloud chambers in the classroom.

## Equipment for each experiment

To prepare in advance
- Medium-sized plastic fish tank
- Adhesive-backed felt (or normal felt and glue appropriate for felt and plastic)

To perform the experiment
- Two thoriated tungsten welding rods (or other alpha/beta source)
- About 2.5 kg dry ice (solid $CO_2$)
- 20 ml isopropyl alcohol, also known as isopropanol (or ethanol if this is unavailable)
- A plastic fish tank with pre-attached felt
- Two metal trays (baking trays work well)
- One piece of black card or laminated black paper (to line trays if they are not dark)
- One or two intense light sources (e.g. an LED light strip, torch, or slide projector light)
- A sheet of paper to wrap around one rod
- Poster putty or reusable adhesive
- A pipette
- Thermal protective gloves
- Safety glasses (one pair per person)

## Set-up

1. Cut strips of felt to a width of approximately 4 cm and the length of the tank sides.

2. With the fish tank open face up, line each of the four sides of the fish tank with the felt strips (they should be near the top of the chamber when in use – see figure on student worksheet). Felt that comes with an adhesive on the back is easiest, but glue can be used to attach the felt. The alcohol will act as a solvent, so any adhesives should be tested before use.

3. Instructions on how to carry out the experiment are provided in the student activties document (teach with space - cloud chamber | P03b).

## Health & Safety

Refer to your school's policy and the national safety guidelines for your country and complete a risk assessment.

**Isopropanol (and other alcohol if used):**

- Isopropanol is highly flammable and an irritant. Do not use near fire and wear goggles.
- Ensure the room is well ventilated and the lid is immediately replaced on the propanol bottle.

**Dry Ice:**

- Ensure the room is well ventilated to avoid high carbon dioxide levels.
- Extensive inhalation of cold vapours can result in lung damage/asthma attacks.
- Wear eye protection and thermally insulated gloves to avoid cold burns from direct contact with the dry ice or cold equipment. If a dry ice burn is obtained, treat as a normal burn - soak under cold water for 10 minutes and seek further medical assistance if necessary.
- Dry ice should NOT be stored in a fully sealed container, as carbon dioxide gas will build up. The container should be clearly labelled.

**Thoriated tungsten rods – radiation source:**

- The thoriated tungsten rods contain thorium oxide, an emitter of alpha particles. It has a very low penetration and therefore is safe to handle when taking appropriate precautions.
- It is recommended that large numbers of rods are stored in a metal box with a radioactive warning on, and stored along with other radioactive sources in your school.
- If the rod is showing signs of flaking or disintegrating it should be disposed of appropriately.
- No part or the rod should be ingested. Whilst this is very unlikely, in the event of ingestion of any part of the rod, seek medical attention before following your school's radioactive substances policy.

# → ANSWERS TO DISCUSSION QUESTIONS

1. **Where do most of the contrails seem to originate?**
   They mostly originate from the two thoriated tungsten rods.

2. **We are observing the radioactive decay of thoriated rods. What could the contrails be showing?**
   The contrails are showing the paths taken by alpha and beta particles produced in the radioactive decay of thorium-232 in the welding rods.

3. **Are there differences between contrails from each of the thoriated rods?**
   From the unwrapped rod, both long thin tracks and short thick tracks can be seen. From the wrapped rod, only long thin tracks can be seen.

4. **What is the difference between alpha and beta decay?**
   Radioactive decay is the process by which the nucleus of an unstable atom loses energy by emitting ionising radiation in order to correct the ratio of protons to neutrons in its nucleus. There are two main types of radioactive decay: alpha and beta.

   In alpha decay, two protons and two neutrons are emitted. This leaves a daughter particle with a mass number that is four less and an atomic number that is two less than the original atom. For example, uranium-238 decays by alpha emission, losing two protons and two neutrons, to become thorium-234.

   For beta decay, there are two options:
   $\beta^-$: A neutron transforms into a proton, emitting an electron in the process.
   $\beta^+$: A proton transforms into a neutron, emitting a positron in the process.

5. **Could the differences between alpha and beta decay have any effect on the contrails that you see?**
   Alpha particles are physically bigger and more ionising than beta particles because they have a charge of +2 from the two protons. They have a relatively short journey before all of their kinetic energy is transferred. This means that contrails from alpha particles are the shorter, thicker trails, about 2-5 cm in length. As they have a weaker charge, beta particles are less ionising and so they travel further before losing all of their energy. They produce longer trails of up to 10 cm.

   Only beta particles are observed from the rod wrapped in paper. This is because alpha particles give away all of their energy to the paper particles by ionising them, before they can reach the alcohol vapour. Beta particles are less strongly ionising and so they travel straight through the paper surrounding the rod without interacting with it. The very short penetrating distance of alpha radiation is clear – alpha particles lose all of their energy in a short distance.

Figure 4


↑ A thoriated rod emitting alpha and beta radiation.

6. **How are contrails formed in a cloud chamber?**
   Alcohol in the felt is very volatile and quickly forms a vapour at the top of the cloud chamber. As the bottom of the cloud chamber reaches a low temperature due to the dry ice, the alcohol vapour cools rapidly as it falls. The alcohol would naturally condense into a liquid at this lower temperature, as it is below its boiling point.

However, in order to condense, particles of gas need a 'seed', or a small particle or disturbance on which they can grow. As there are no seeds in the chamber, a thin 'super-saturated' layer of alcohol that is unable to condense gathers around the bottom of the cloud chamber.

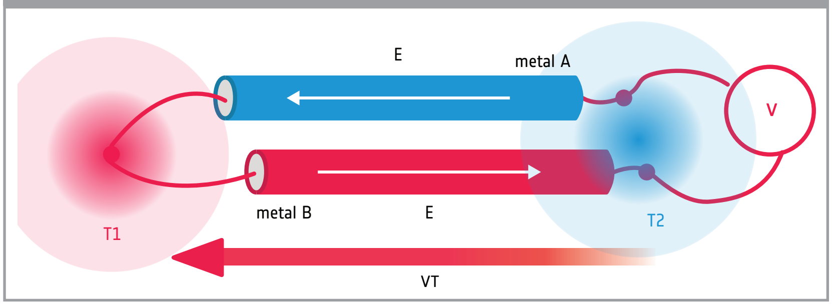
A charged particle (such as an alpha particle produced through radioactive decay) passing through the chamber ionises alcohol molecules in its path. These ionised alcohol molecules act as a seed for the surrounding neutral alcohol molecules, allowing them to condense into droplets, which form the contrail that can be seen in the chamber. Soon after the droplets are formed, they fall to the bottom of the cloud chamber and disperse; the contrail is only visible for a couple of seconds.

7. **Cosmic rays are high energy particles from space. How do we observe them?**
Occasionally you may see contrails that do not appear to originate from the thoriated tungsten rods. While these can be the products of random radioactive decays outside of the chamber, they are more commonly the result of cosmic rays from the Sun and other objects in the Universe such as stars and galaxies. Cosmic rays from space enter the atmosphere and interact with atmospheric particles. These interactions firstly create particles called **pions***. Pions decay very quickly, often into **muons***. These muons can be observed as extremely long, thin, straight trails in the cloud chamber.

8. **What could be the effects of radiation on spacecraft?**
Ionising radiation can knock electrons loose within electric circuits, leading to interference with electrical systems on Earth-orbiting satellites. In most cases this effect is simply observed as a reduction in the quality of the data, but effects are magnified during events such as coronal mass ejections due to an increased intensity of ionising particles. This can lead to excess current through a circuit, which can result in damage or destruction of equipment. As a result, satellite and spacecraft engineers have to protect delicate circuits from harmful space radiation. The simplest approach to this is to shield them with specially designed material containing atoms with a high atomic number, and therefore many protons and neutrons that can absorb much of the space radiation.

9. **How can radioactive decay be used as a power source in space?**
Radioactive decay produces energy, which causes material to heat up. The Seeback effect makes use of this; it is a phenomenon in which a temperature difference between two different electrical conductors can produce a voltage difference between the two. One conductor is heated by radioactive decay, whilst the other conductor is kept cool, for example by exposing it to the cold space environment. Heated electrons will flow from the hotter conductor to the cooler conductor. If the conductors are connected through an electrical circuit, direct current will flow within the circuit (Figure 5). This method of power production has been used in many spacecraft, like ESA's Ulysses mission and the ESA/NASA/ASI Cassini-Huygens mission.

Figure 5

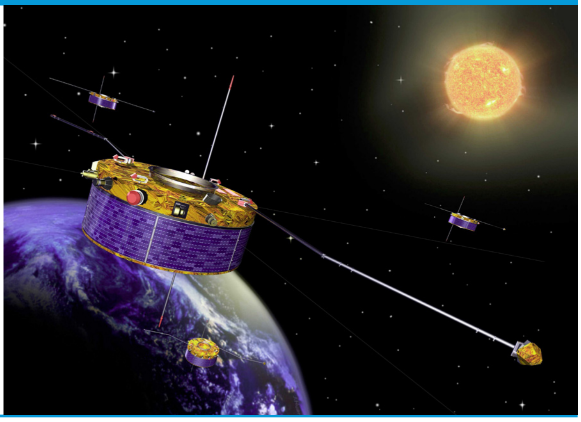



↑ The Seeback effect.

* **Pion (Pi meson):** a type of particle much smaller than an atom. There are three different pions; $\pi^0$, $\pi$+, and $\pi$-.
**Muon**: a particle with the same charge as an electron but with much more mass.

## Did you know?

ESA's Cluster mission studies how the constant stream of charged atoms and electrons from the Sun affects the Earth's magnetosphere. This stream of particles is called the solar wind and gusts of solar wind have the potential to affect power supplies here on Earth (a strong gust could stop all electronic devices from working!). Solar wind can also harm the electronics on-board satellites. Cluster studies phenomena that can cause damage in this way - it assists us in preparing for sudden, potentially dangerous, bursts of solar energy!



# → ANSWERS TO STUDENT ACTIVITIES

1. Decay reactions

a. α **decay**

$$^{238}_{92}U \xrightarrow{\alpha} {}^{234}_{90}Th$$

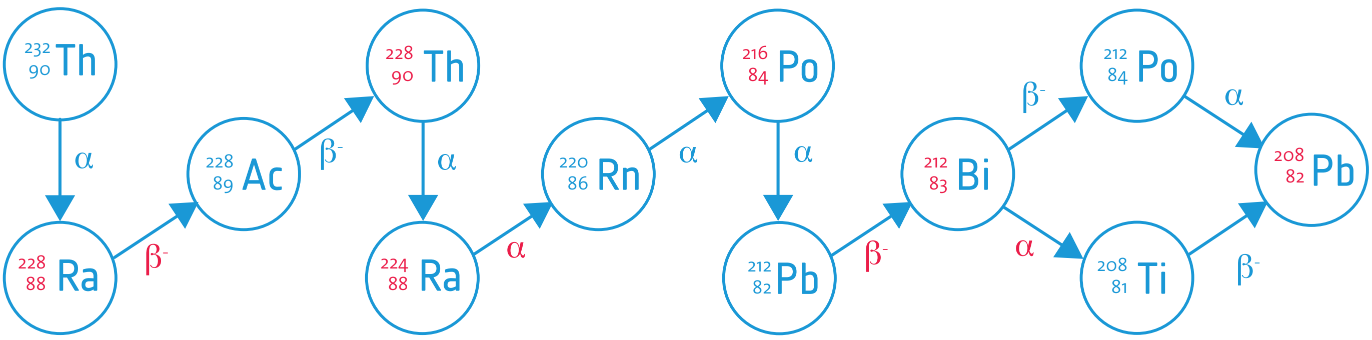
b. β⁻ **decay (electron emission):**

$$^{14}_{6}C \xrightarrow{\beta^-} {}^{14}_{7}N$$

c. β⁺ **decay (positron emission):**

$$^{15}_{8}O \xrightarrow{\beta^+} {}^{15}_{7}N$$

2. Thorium decay




3. The stable element produced at the end of the decay chain is **lead**.

# Links

## Teach with space collection

ESA teach with space - cooking a comet video | VP03: www.esa.int/spaceinvideos/Videos/2014/07/Cloud_chamber_-_classroom_demonstration_video_VP03

## ESA related missions and science

ESA Cassini-Huygens mission: www.esa.int/Our_Activities/Our_Activities/Space_Science/Cassini-Huygens
Cassini's solstice mission: saturn.jpl.nasa.gov/
ESA Ulysses mission: www.esa.int/Our_Activities/Space_Science/Ulysses_overview
ESA Swarm mission: www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/Swarm
ESA Cluster mission: www.esa.int/Our_Activities/Space_Science/Cluster/Science_objectives

## ESA radioactive decay articles

Radioactive decay of titanium powers supernova remnant: www.esa.int/Our_Activities/Space_Science/Radioactive_decay_of_titanium_powers_supernova_remnant
Radioactive iron: www.esa.int/Our_Activities/Space_Science/Integral/Radioactive_iron_a_window_to_the_stars

**teach with space – cloud chamber | P03a**
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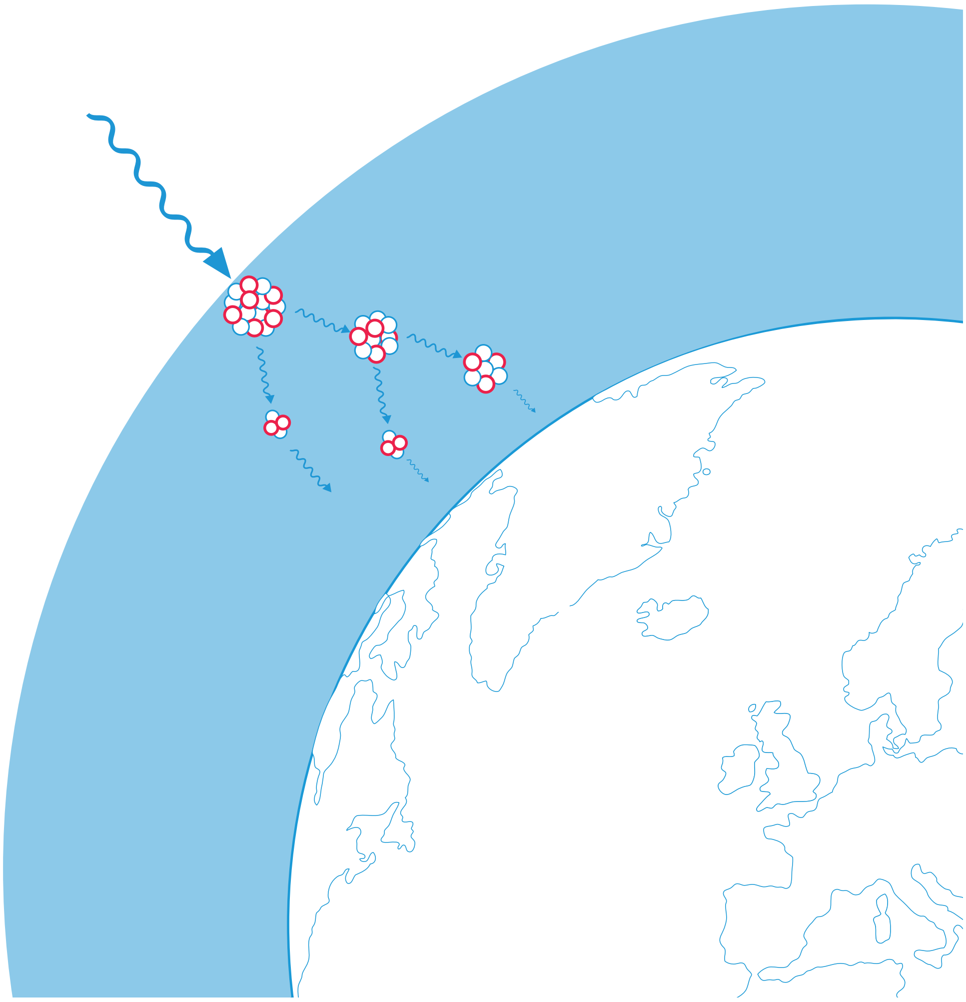
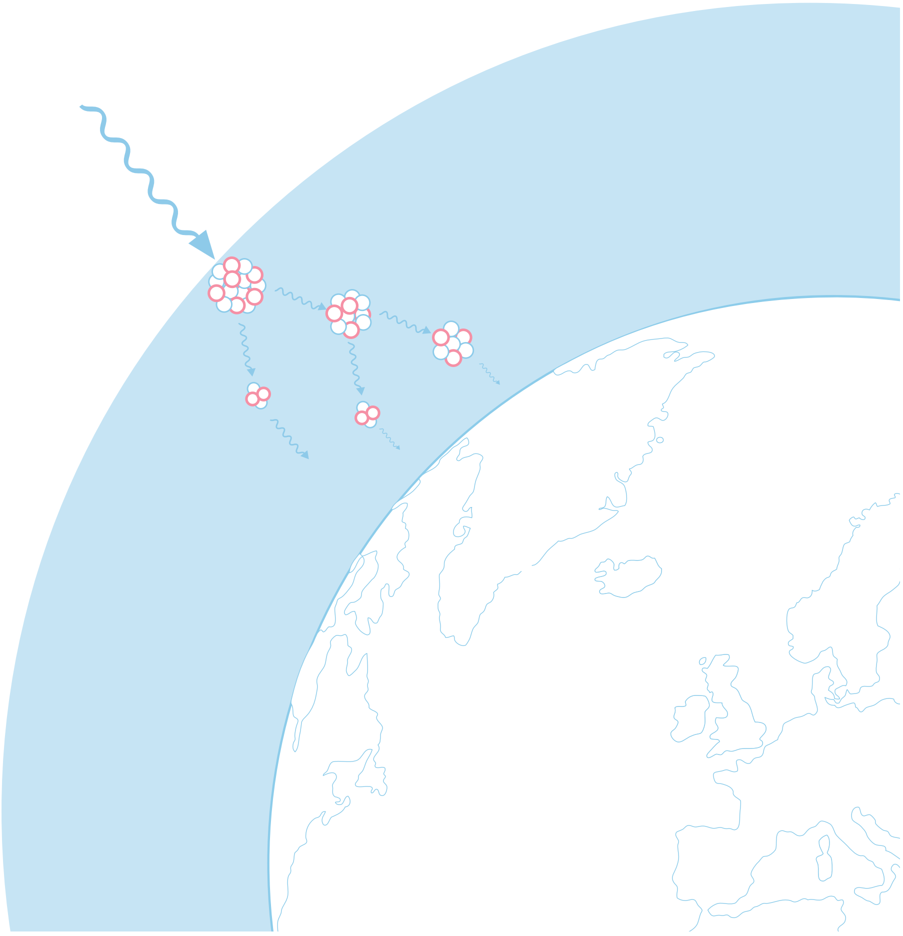
# teach with space

## → CLOUD CHAMBER

### Radioactivity in a cosmic setting

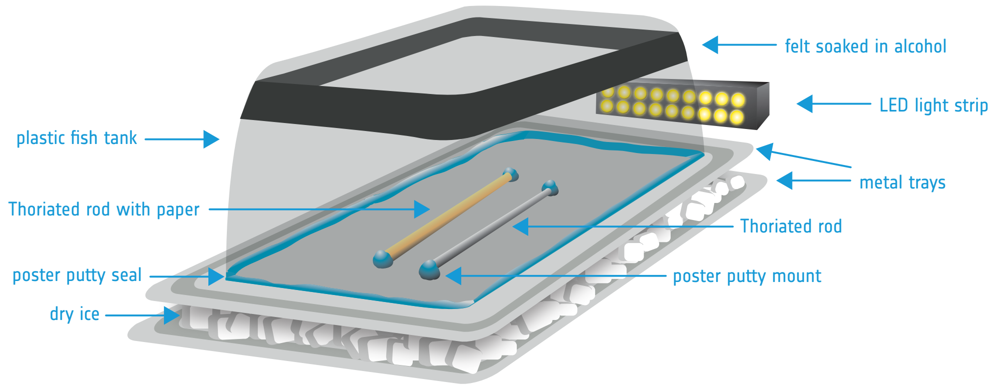




## Building a cloud chamber

In this experiment you will build a cloud chamber, which is a radiation detection device. This will allow you to observe the radioactive decay of thorium-232, a radioactive thorium isotope. Alpha and beta emission can be observed in the form of condensation trails (contrails) in the alcohol vapour inside the chamber, allowing us to better understand radioactive decay.

Figure A1




↑ Experimental setup.

## Equipment

- Two thoriated tungsten welding rods (or other alpha/beta source)
- About 2.5 kg dry ice (solid $CO_2$)
- 20 ml isopropyl alcohol, also known as isopropanol (or ethanol if this is unavailable)
- A plastic fish tank with pre-attached felt
- Two metal trays (baking trays work well)
- One piece of black card or laminated black paper (to line trays if they are not dark)
- One or two intense light sources (e.g. an LED light strip, torch, or slide projector light)
- A sheet of paper to wrap around one rod
- Poster putty or reusable adhesive
- A pipette
- Thermal protective gloves
- Safety glasses (one pair per person)

## Health & Safety

**Isopropanol (and other alcohol if used):**
- Isopropanol is highly flammable - do not use near naked flames.
- Safety glasses must be worn at all times.
- Ensure that you immediately replace the top on the propanol bottle.

**Dry Ice:**
- Wear safety glasses and thermal protective gloves when handling dry ice and anything that has been in contact with dry ice, including the metal trays. If a dry ice burn is obtained, treat it as a normal burn - soak under cold water for 10 minutes and seek further medical assistance if necessary.
- Inhalation of cold vapours can cause lung damage and asthma attacks in asthma sufferers.

**Thoriated tungsten rods – low level radiation source:**
- Keep the rod away from your mouth.
- Warn your teacher if the rod is showing signs of flaking or disintegrating.

## Carrying out the experiment

1. Using the gloves, line one tray with a thin layer of dry ice and place the other tray on top, allowing them both to cool before the experiment.

2. Use a pipette to apply alcohol all along the felt in the plastic tank. Put approximately 6 ml on each of the long sides, and 3 ml on the short sides.

3. Roll out four cylindrical strips of poster putty to the length of the sides of the tank. Completely line the edges of the open face of the tank. This will create a seal when the tank is later turned over to stop air currents disturbing the saturated atmosphere.

4. Take two thoriated tungsten rods and wrap some paper around only one of them. You can use some tape to keep this in place. Attach a small ball of poster putty to both ends of each rod.

5. Using the gloves, take the top tray off of the bottom tray and add more dry ice to the bottom tray until it is almost full.

6. Attach the thoriated tungsten rods to the centre of the base of the empty top tray, as shown in Figure A1. Put them on top of black card if the tray is not very dark.

7. Turn the fish tank over. Place it on the tray with the rods, pressing down to seal it from air currents.

8. Using the gloves, place the top tray onto the bottom tray.

9. Switch on the light source and place it to the side, shining directly into the chamber. Wait a few minutes for the cloud chamber to 'settle', then look down from above to observe against a dark background. You could take photos of what you see in order to examine it in more detail.

## Discussion

Whilst carefully observing the contrails (the white tracks) in the cloud chamber, think about the following questions.

1. Where do most of the contrails seem to originate?
2. We are observing the radioactive decay of thoriated rods. What could the contrails be showing?
3. Are there differences between contrails from each of the thoriated rods?
4. What is the difference between alpha and beta decay?
5. Could the differences between alpha and beta decay have any effect on the contrails you see?
6. How are contrails formed in a cloud chamber?
7. Cosmic rays are high energy particles from space. How could we observe them?
8. What could be the effects of radiation on spacecraft?
9. How could radioactive decay be used as a power source in space?

You can then discuss these points as a class. Throughout or after the discussion, write notes in the boxes on the sheet provided.

State the two main radioactive decay processes, and describe how they work.

Explain how each of the following components of a cloud chamber allow us to see particles.

Plastic tank:

Thoriated rod:

Dry ice:

Alcohol:

Describe how the following properties of a particle would affect how its contrail looks.

Size:

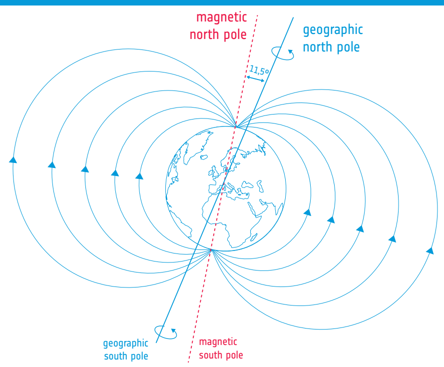
Charge:

Name the particles that produce other contrails (not the results of alpha or beta decay) and give some examples of where they could have come from.

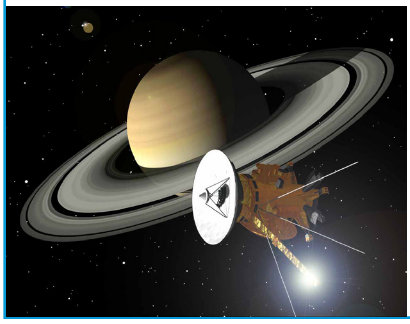
List the positive and negative implications of radioactive decay for spacecraft.

# Test your knowledge of radioactive decay

## Did you know?



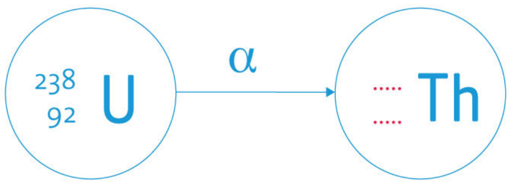

On Earth we are protected from charged cosmic rays by a magnetic field, the magnetosphere, which is generated by the motion of magnetic elements in the Earth's core. The magnetic field extends almost twice the distance of the Moon but the further from the Earth, the weaker it is and so there is less protection from ionising space particles.



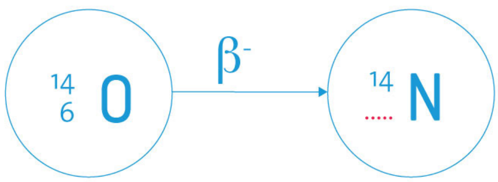
The NASA/ESA/ASI Cassini-Huygens mission to Saturn had to cope with this cosmic radiation as it ventured far beyond the edge of the magnetosphere. Once Cassini-Huygens reached its destination, it was protected by Saturn's own powerful magnetic field.

1. Fill in the gaps to complete the following simple decay reactions. Remember that alpha decay is the emission of two protons and two neutrons, beta decay is the emission of an electron or a positron when a neutron transforms into a proton or a proton into a neutron. Figure A2 shows examples of the alpha and beta decay of atomic nuclei.

a. α **decay**




b. $\beta^-$ **decay (electron emission):**




c. $\beta^+$ **decay (positron emission):**

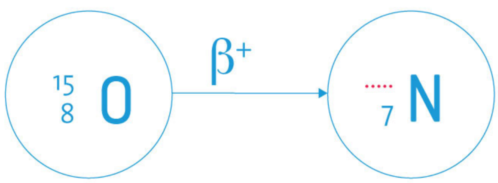
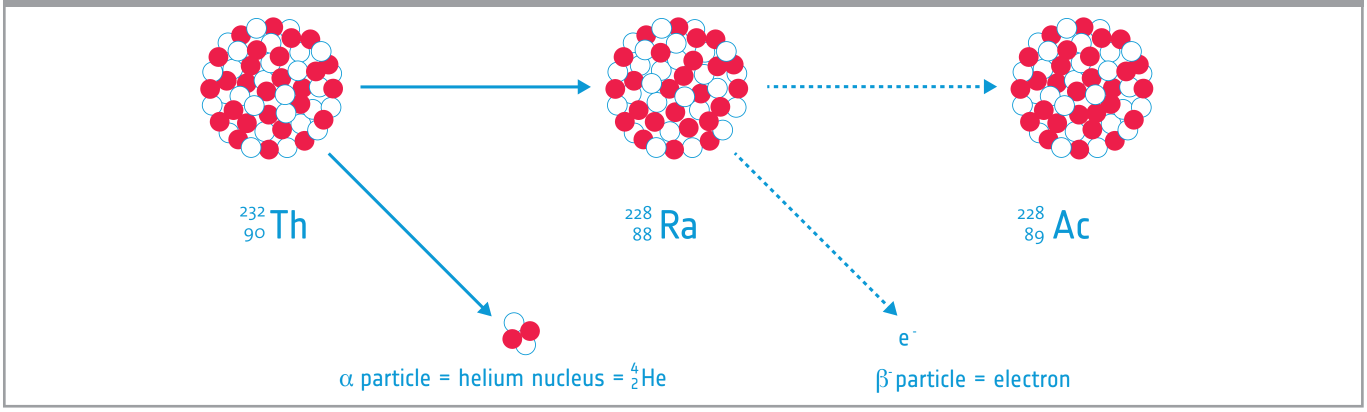
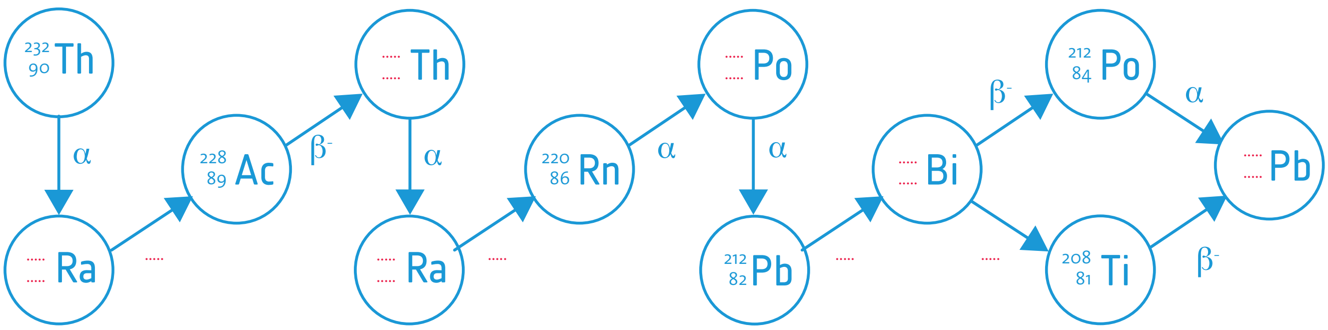


**Figure A2**




↑ The decay chain for thorium, demonstrating α and $\beta^-$ decay.

2. This is the decay chain for thorium-232, the radioactive substance in the tungsten rods in the cloud chamber. A series of alpha and beta decays move through a series of unstable elements to finally obtain a stable element. Fill in the gaps to complete the decay chain.




3. Name the stable element produced at the end of the thorium-232 decay chain:

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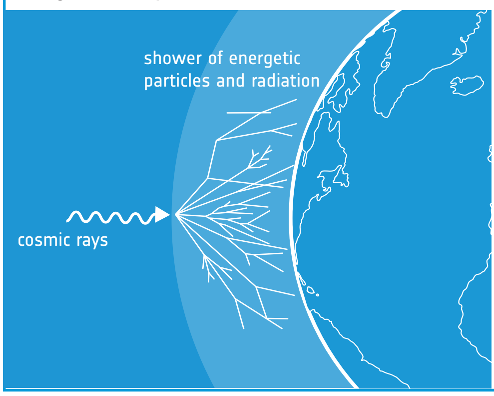
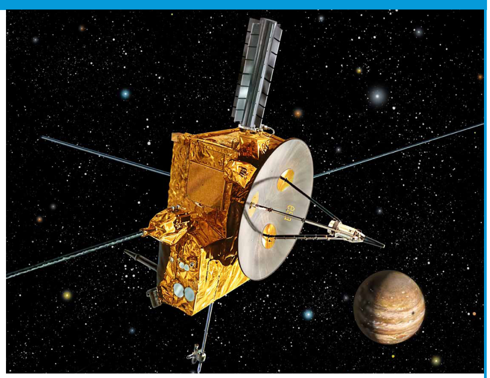
## Did you know?

Cosmic rays are very high energy particles that originate from the Sun and other objects outside the Solar System. ESA's Ulysses spacecraft travelled to the poles of the Sun to study these energetic particles. Once they have left the Sun, many cosmic rays head towards the Earth, entering our atmosphere and interacting with atmospheric molecules to create new particles called pions. Pions decay very quickly, often into muons, which can be observed in a cloud chamber. This is one way in which we can study astronomical objects.



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