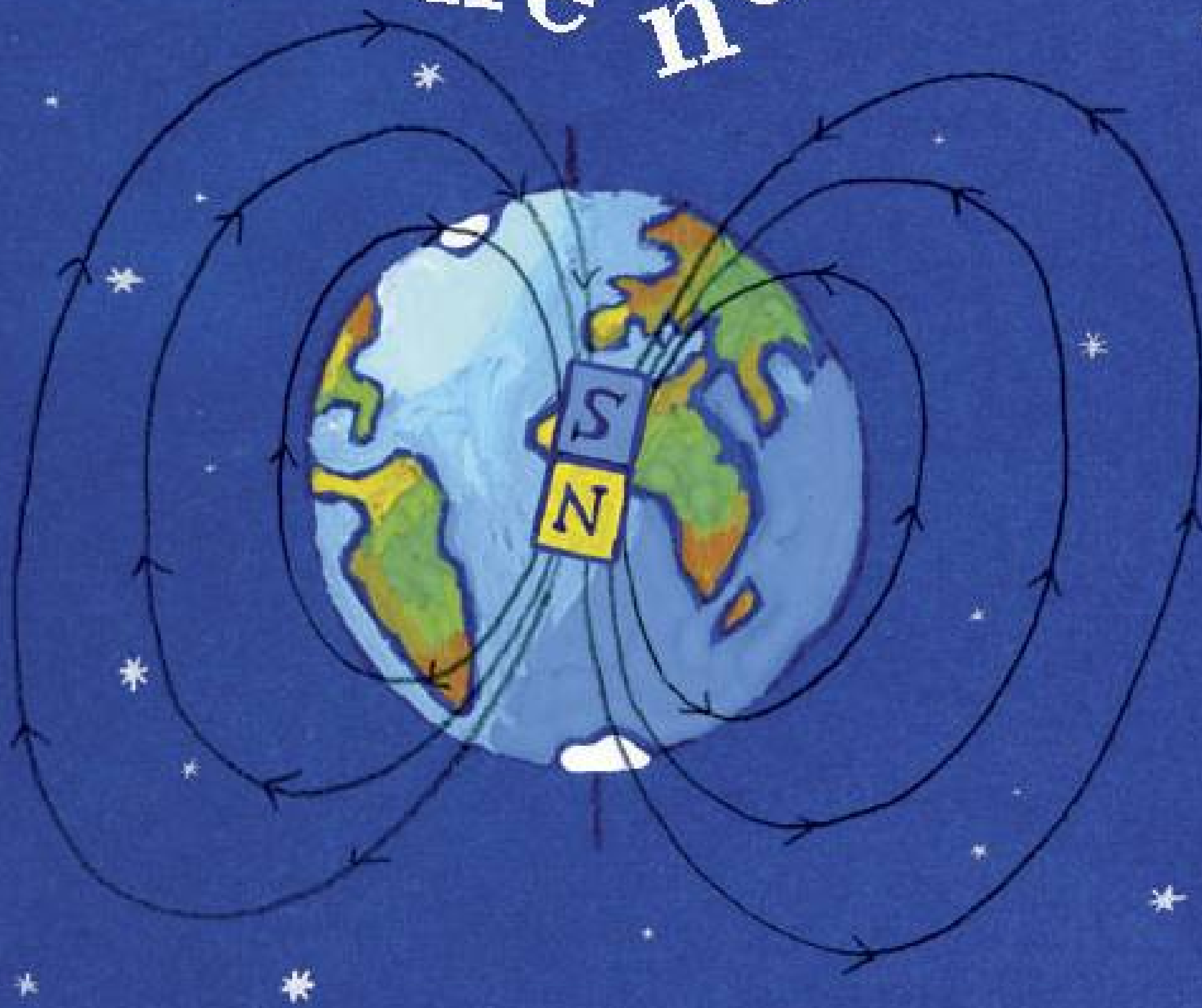
looking for the north



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looking for the north

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EU-UNAWE, 2012

The Spanish National Research Council (CSIC) is the largest public institution in Spain devoted to scientific research and technological development. It aims to encourage, develop and disseminate scientific and technological research in order to contribute to the advancement of knowledge and to economic, social and cultural development. The CSIC is an institution which promotes science education and supports the work of UNAWE and EU-UNAWE programmes, which are especially designed for young people from all Spanish-speaking countries.

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EU-UNAWE is an educational project of the European Union, based on the UNAWE programme. Both projects use the beauty and grandeur of the Universe to encourage young children, particularly those from underprivileged communities, to take an interest in science and technology, and to foster their sense of global citizenship from an early age. UNAWE was founded in 2005. It is already active in over 40 countries and comprises a global network of more than 500 astronomers, teachers and educators.

In three years, EU-UNAWE will implement Universe awareness-raising activities in six countries: Germany, Italy, the Netherlands, Spain, United Kingdom and South Africa. The project includes the organization of teacher training workshops and the development of learning resources for children. In the long term, EU-UNAWE will help produce the next generation of engineers and scientists in Europe and encourage children from underprivileged areas to realize that they are part of a much larger global community.

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Introduction

In astronomy, we often use the compass to help us orient our instruments and even to correctly position certain models. The direction indicated by the compass nearly coincides with the meridian direction, i.e. the north-south direction. As the deviation is really small, the compass turns out to be the most convenient instrument for orientation if we do not need perfectly accurate measurements.

But why does the compass always point north, along the line of the local meridian? The answer lies in the magnetic field generated by our planet. This is also closely related, for example, to the spectacular aurora borealis and australis (figure 1). The magnetic field protects us from the ionized particles that come from the Sun through solar wind and from cosmic rays, thus making life possible on our planet.

Terrestrial magnetism is rarely taught in schools as a chapter of astronomy. However, as the compass is often used in astronomy, it is useful to explain the relationship between the rotation axis of the Earth and the Earth's magnetic field. Compasses are used to orient sundials which are governed by the apparent motion of the Sun around the world axis, to orient the axis of an equatorial telescope in accordance with the Earth's rotation axis in relation to which we see the entire sky turning, and it is also used in many teaching models that require orientation. To explain scientifically how a compass works, we first need to introduce a simplified presentation of the terrestrial magnetism.

Figure 1: Northern lights in Lapland. We can distinguish the Big Dipper among the reddish lights of the aurora (Sakari Ekko, Finland).

Why are there magnetic fields and how does a magnet work?

If we wish to explain to schoolchildren the origin of magnetic force and of the related magnetic field, we can start by talking about atoms. Imagine that we could go on and on dividing a biscuit in halves, increasingly smaller. At some point we would get a tiny piece that we could no longer divide. We may think that the smallest structure of the objects that surround us is the atom. It consists of small particles. Basically, these are the neutrons and the protons, which are bound to each other forming a nucleus, plus the electrons that spin around it (figure 2). We now know that these particles consist of other smaller particles. However, these details are not indispensable to explain magnetism, so we can safely ignore them for our purpose.

Two of these particles have a property called electric charge. Electrons have a negative and protons have a positive charge; neutrons have no charge. It appears that, in general, bodies and objects have the same number of electrons and protons, so that charges compensate each other. Therefore, bodies have no overall charge. Sometimes, however, we can add electrons to an atom which therefore acquires a negative charge, i.e. more electrons than protons. Or sometimes we can remove electrons, so the atom acquires a positive charge, as there are more protons than electrons. The majority of the atoms are hardly free around us, because they merge in pairs or groups. These unions occur by releasing electrons, as does the iron, or by sharing, as other elements do.

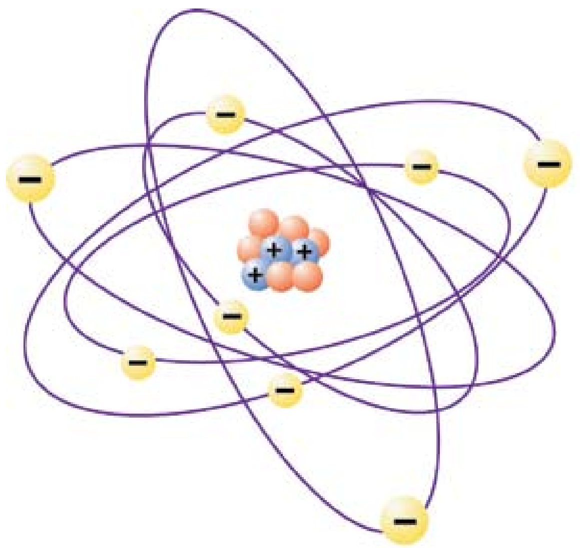


Figure 2: The structure of an atom.

When two iron atoms merge both of them release electrons. These form an electron cloud around the atoms.

When an electrically charged atom, or one of these isolated electric charges, is in motion, it generates around it a region where the so-called magnetic effects become apparent. This region is called a magnetic field, like those generated by magnets. In fact a magnet is nothing else but a material that has many charges moving around and generating what is known as a magnetic field, or magnetism. This is totally invisible to our eyes and imperceptible to our senses. However, there is a simple way to detect this invisible magnetic force, and this is by observing its effects. A magnet generates a force of attraction that can be visualized by displaying around it iron filings.

As we saw, when the iron atoms merge together they release electrons around the atoms. This cloud of electrons can move creating an electric current, thereby generating a magnetic field, which can interact with the magnetic fields generated by magnets.

Experiment 1: The battery that attracts iron filings

Moving charges generate a magnetic field. To visualize this phenomenon we can do a small experiment.

Material:
A 9-volt battery, or several batteries that together reach 9 volt (as seen in the picture)
Electrical wire
Iron filings
A nail

Method:
We wind an electrical wire around a nail and connect the two poles of the battery with the two ends of the wire. We then bring it closer to the iron filings. The current flowing through the wire gives rise to a movement of electrons. These generate a magnetic field of which we can see the effects as it makes the iron filings move when current goes through, i.e. when there is a flow of electrons.

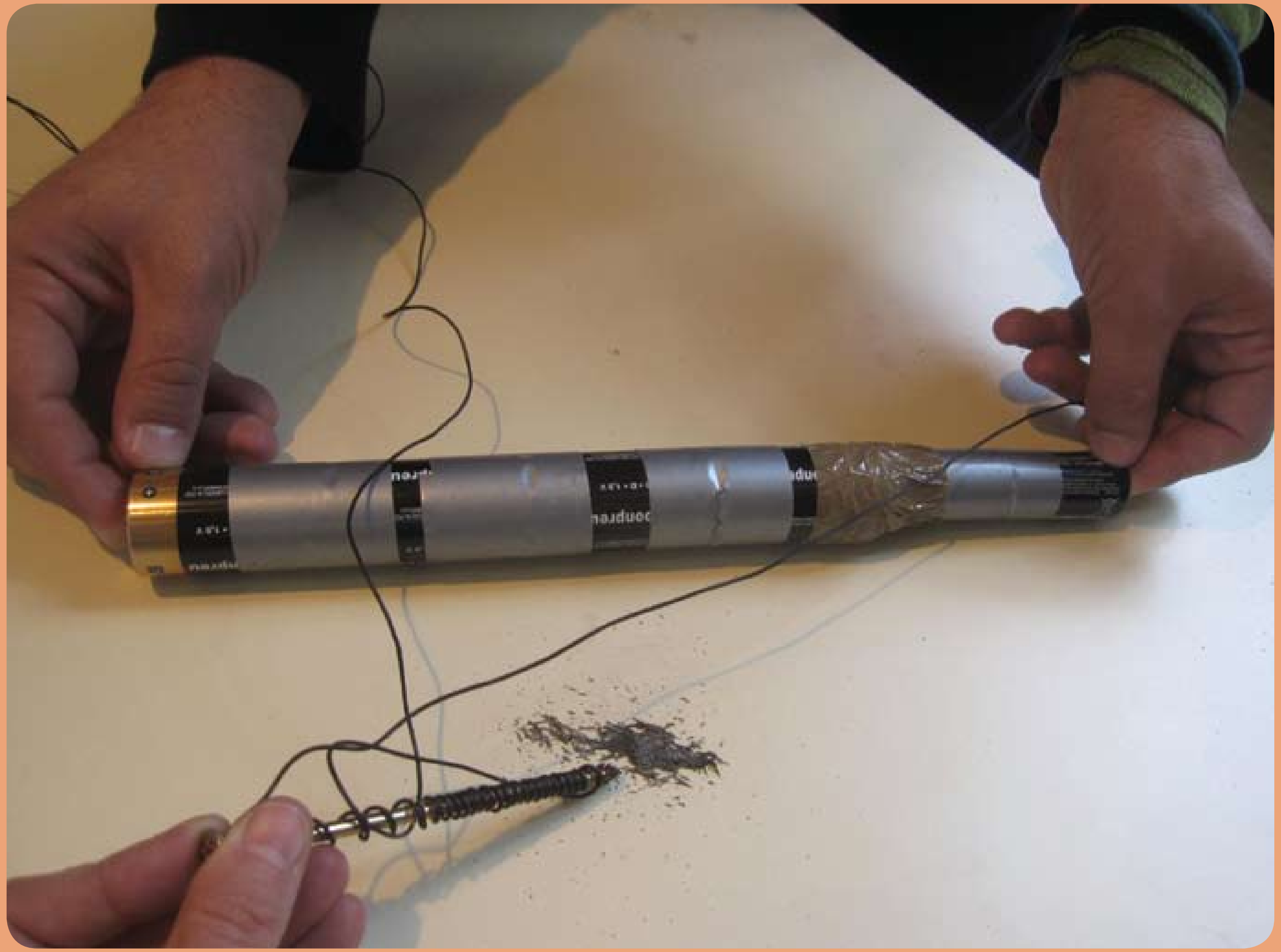


Figure 3: Several batteries connected to an electrical wire to show the movement of the iron chips when current flows.

How do magnets attract?

The movements of electrons around the atomic nucleus are simply small circular currents which generate a weak magnetic force called a magnetic dipole.

If electrons spin anticlockwise (to the left in figure 4), the magnetic force points upwards. If the negative charges spin clockwise around the atomic nucleus, the magnetic force points downwards (to the right in figure 4).

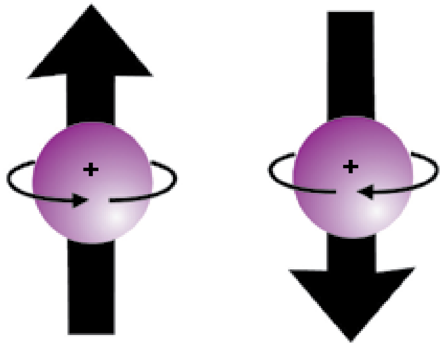


Figure 4: If electrons spin anticlockwise, the magnetic force points upwards. If the negative charges rotate clockwise, the magnetic force points downwards.

In general, the orientations of the magnetic dipoles are randomly distributed so that the forces balance each other out (figure 5). The overall result is that bodies around us do not usually create a magnetic field, except for magnets (figure 6).

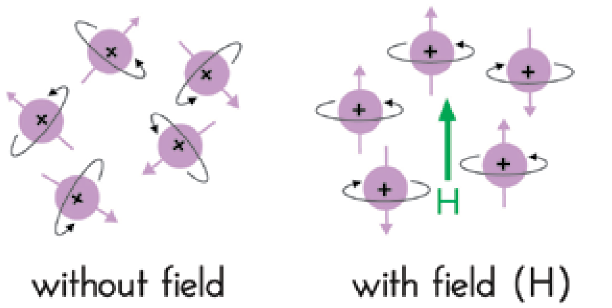


Figure 5: A material which is not magnetized. The magnetic dipoles offset each other, resulting in a null magnetic field.

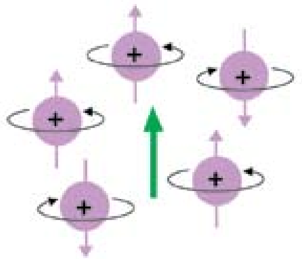


Figure 6: A magnet. Dipoles are oriented in a particular direction, resulting in a global magnetic field.

What is the peculiarity of magnets? In their case, these small currents of electrons around the atomic nucleus do not have a random orientation. The vast majority spin in the same direction, so that the small magnetic forces that are generated do not offset but reinforce and amplify each other, resulting in a magnetic force. This is the case of magnetite, a mineral that can be found in nature and which behaves like a magnet.

When the magnetite, or a magnet, is in the vicinity of a piece of iron, the magnetic field that it generates aligns the electric currents of the iron creating a magnetic field. All the iron magnetic dipoles line up in the same direction. It behaves like a magnet for some time, until the dipoles lose direction again and acquire random orientations so that they compensate again the small magnetic forces that they generate (figure 7).

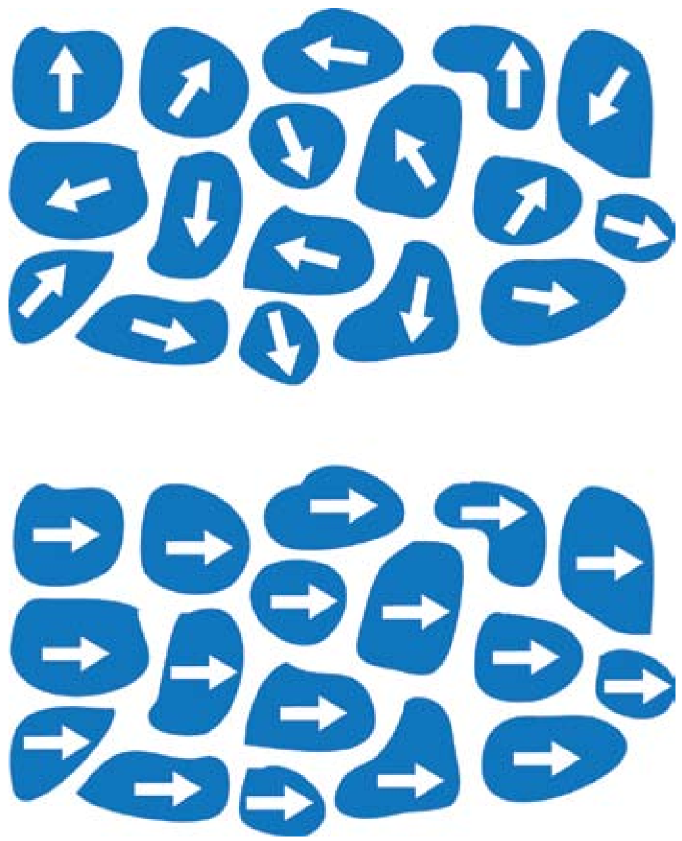


Figura 7: Top, disoriented dipoles, bottom oriented dipoles.

Experiment 2: Attracting a paper clip first with a piece of magnetite and then with a magnet

Show the effects of the magnetic field on a paper clip: first with a piece of magnetite and then with a magnet.

Material:
A magnet
Magnetite
A metal paper clip

Method:
Bring a paper clip close to a piece of magnetite or to a magnet. In fact, if you rub the paper clip and the magnet together the paper clip gets magnetized and starts to behave like a magnet.

Figure 8: Clips attracted by a piece of magnetite

As noted, if a magnet is in the vicinity of an iron bar all dipoles change direction and line up in accordance with the magnetic field created by the magnet. However, when the magnet is removed, the iron dipoles return to their original state. We say that the iron has no memory, and all the dipoles are randomly oriented as they were beforehand.

To create an artificial magnet heat an iron bar so that the atoms find it easier to line up in accordance with the magnetic field. When the iron cools down dipoles keep pointing in the same direction. A magnet was created.

What are poles? Why do opposite poles attract and like poles repel?

In analogy to dipoles, which indicate the direction of the field, magnets (which are nothing else but many dipoles oriented in the same direction) are also often described by indicating the direction of the field. The magnetic field has one direction, but there are also areas that behave differently from the rest. These areas are the so-called magnetic poles (figure 9). They are called north and south by analogy with the geographic north and south.

Figure 9: The direction of the magnetic field generated by a magnet.

If we have two magnets and put them together, they will behave in such a way that their magnetic fields have a common direction. Opposite poles tend to get closer to each other while similar poles tend to repel and get as close as possible to the opposite pole of the other magnet (figure 10).

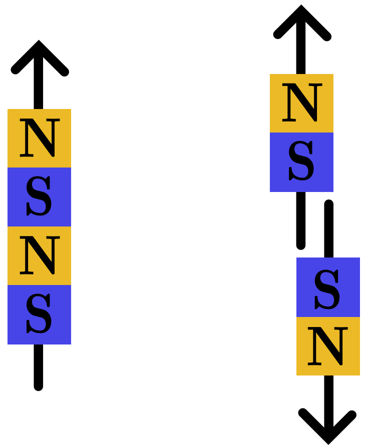


Figure 10: The direction of the two magnetic fields coincides when we bring the north pole close to the south pole, but when we bring together the two south poles, they repel because the two directions of the field are opposite.

What are lines of force and how do you detect a magnetic field?

The magnetic field is the region of space where the magnetic effects are present. Magnetic fields are typically represented by so-called field lines, which indicate the position adopted by iron particles that would surround a magnet.

There are an infinite number of lines of force, although only a few of them are visible, as shown by the experiment in figure 11. Lines are formed because the lines of the filings can only have the width of a particle of iron, and when a line is formed, it repels the other. Therefore, the number of lines that are visible and the distance in between depend on the size of the iron particles. The field lines of a magnet come out of the so-called north pole and go into the south pole (figure 12). This means that if we spread iron filings around a magnet they will line up along lines that are similar to those in the Figure. Through the magnetic field lines we can determine where exactly the magnetic force is stronger. Indeed, it can be very intense, as happens in the poles, where the field lines are very dense, or very weak in the middle, where the field lines are far apart.

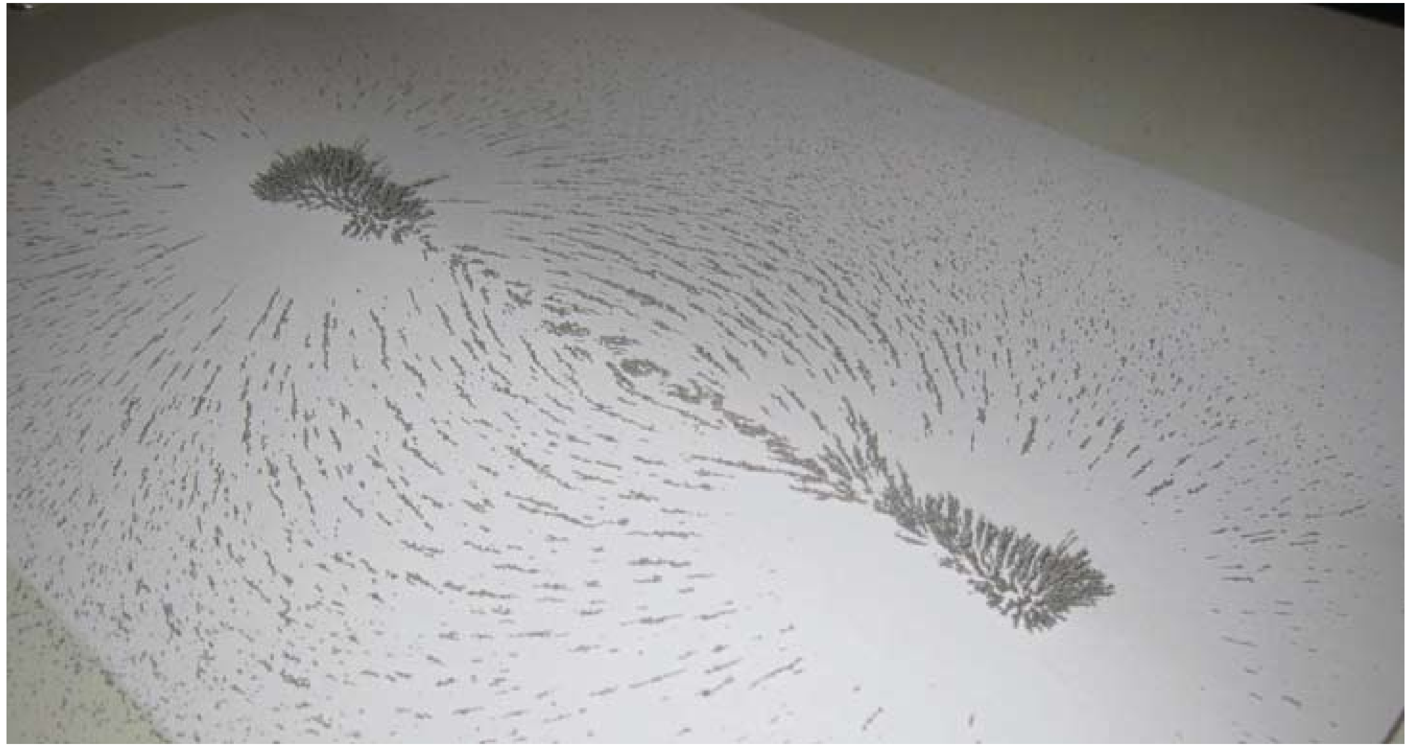


Figure 11: We can see that the lines of force of a magnet are separated by spaces because the iron filings attract or repel when they get magnetized because of the magnetic field of the magnet.

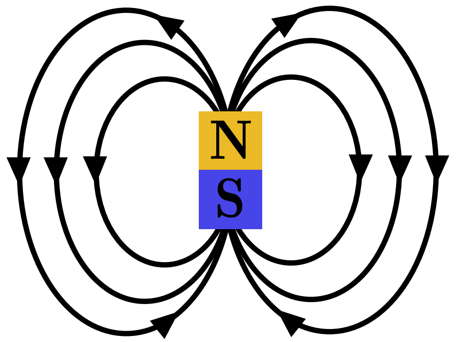


Figure 12: The field lines indicate the way iron particles distribute around a magnet.

Experiment 3: How to detect magnetic poles

By means of a round magnet and iron filings we can show that there are two peculiar areas on the magnet: these are the poles. We use a round magnet because it has no ends and its poles are not immediately obvious.

Material:
A round magnet
Iron filings

Method:
We hold the magnet with our fingers and spread over iron filings. We will see that there are two points which clearly accumulate filings and where the lines of force are visible. These are the two poles. It is clear that the magnetic field is stronger at the poles than at the equator.

Figure 13: The poles correspond to the area attracting more filings, as this is the area with the highest density of lines of force.

Why does the Earth have a magnetic field and how can we detect it?

The core of the Earth is formed by molten metals, which suggests it is loaded with electrical charges. This core does not stay still, but rotates together with the Earth. Therefore, these moving electric charges generate around them a very powerful magnetic field, extending thousands of kilometres inside the Earth and hundreds of kilometres into space (figure 14). This is very easy to detect. The Earth's magnetic field is strongest at the poles, and weakest around the equator (figure 14). In fact, the magnetic and geographic poles do not coincide exactly, as the inner core of the Earth is not liquid but solid - due to the huge pressure exerted on it and on its liquid part by the outer layers - and it is not exactly in the centre, but a little off. That is why the magnetic and geographic poles do not coincide.

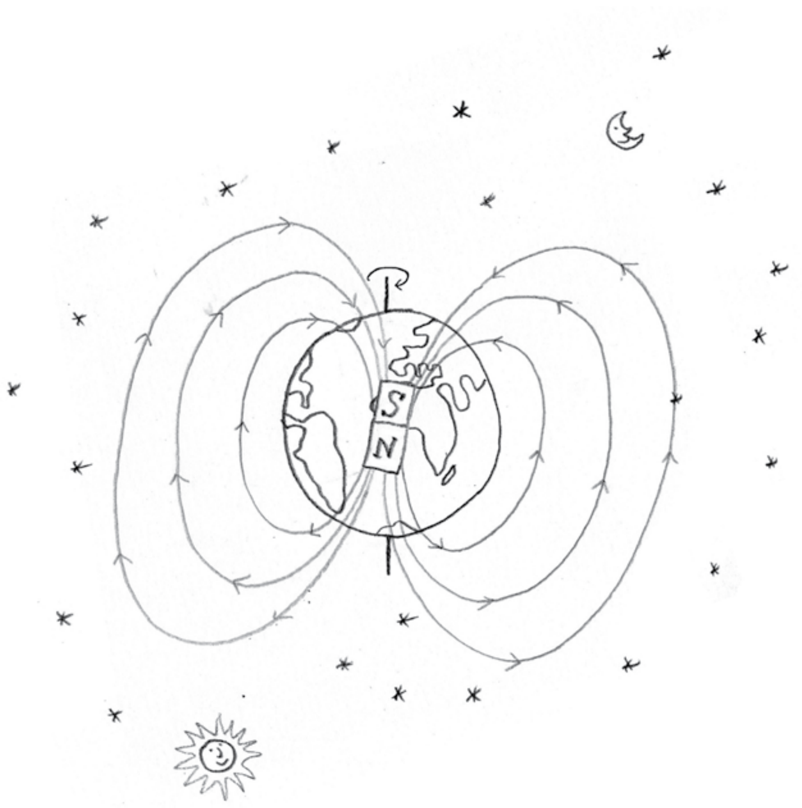


Figure 14: Earth's magnetic field. Interestingly, the magnetic south pole points towards the north.

Experiment 4: Polystyrene Earth with inner magnet

Let us create a model of the Earth's magnetic field.

Material:
A ball of polystyrene
A sufficiently large spherical magnet
Iron filings
Tape

Method:
Cut the polystyrene ball in half and pierce it on both sides to fix the magnet inside securely. Next, place the magnet inside the ball and stick the two halves together using adhesive tape. We now have our Earth model with its magnetic field. To ascertain this, we can spread iron filings across its surface. You can see how they stick to the poles of the Earth, i.e. the magnet's poles area, while at equator there are no filings.

Figure 15 and 16: The iron filings around the magnetized Earth indicate the direction of the poles. As they collect many more filings in this area compared to the equator we can deduce that the magnetic field is stronger at the poles than at the equator.

Experiment 5: Detect the Earth's magnetic field with a magnet that can move freely

To detect the Earth's magnetic field, use a magnet that can move freely.

First example: A teaspoon with a magnet (The Chinese compass).

Material:
A teaspoon
A cylindrical neodymium magnet to better suit the teaspoon

Method:
Take the teaspoon and bend the handle a little bit upwards. Next, place the magnet on the end of the spoon, so that one of its poles points towards the handle. Place the spoon upon a smooth, flat and metal free surface and make it spin. When it stops rotating, the handle will indicate the north-south direction.

Figure 17: Magnetic spoon.

Second example: A magnet floating on water.

Material:
A bowl
A piece of polystyrene
An elongated magnet with the two poles painted in different colours
Water

Method:
Glue the magnet to the polystyrene piece and let it float freely on the water in the bowl. Your little "boat" will keep spinning until the magnet gets in line with the north-south direction of the Earth's magnetic field. The direction indicated by the teaspoon and the polystyrene magnet is the direction of the magnetic field of the earth.

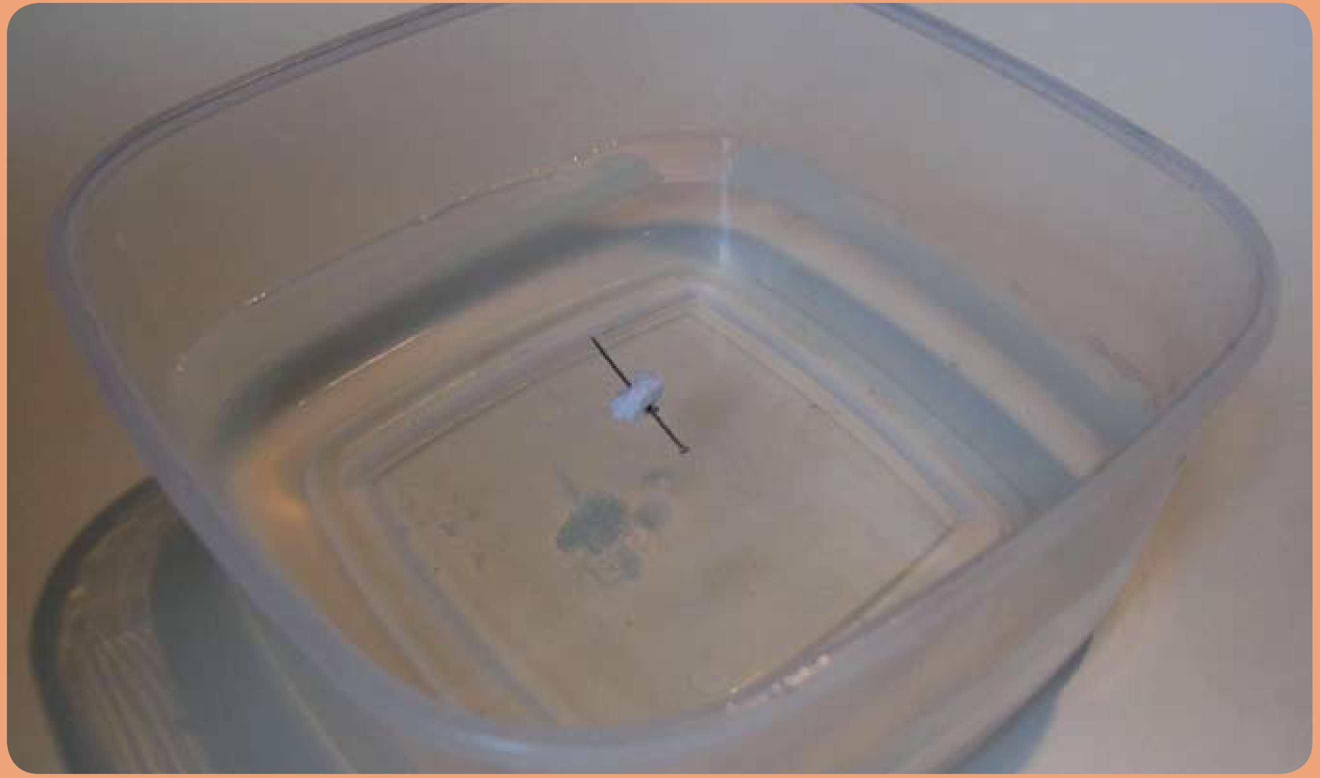
Figure 18: Floating magnet.

Third example: Compass needle.

Material:
A bowl
A piece of polystyrene
A needle
A magnet
Water

Method:
Rub the needle and the magnet together until the needle is magnetized. Then fix it on a piece of polystyrene and place it on water. When the needle stops rotating, it will mark the north-south direction.

Figure 19: Magnetic needle.



Auroras and the Earth's magnetic field

In addition to producing light, the Sun also generates a stream of particles called solar wind. The particles that travel at high speed are dangerous because they have high energy and high penetrating power in the skin, damaging the cells' DNA. The Earth's magnetic field is responsible for diverting these very energetic and dangerous particles away, preventing them from reaching the surface. Without it there would be no life on Earth. It is our shield which also offers beautiful natural events such as the auroras.

To understand more fully the phenomenon of the aurora we need to consider a fourth state of matter, in addition to those that we already know, i.e. solid, liquid and gas. This state is called plasma. It is the most common state of matter in the universe, and can be found in stars, as well as in the interstellar and in the intergalactic medium. All around us, although we may have not noticed it before, there is matter in this state. Examples are lightning, the inside of the fluorescent and energy saving lamps, some monitors or TV screens as well as plasma balls.

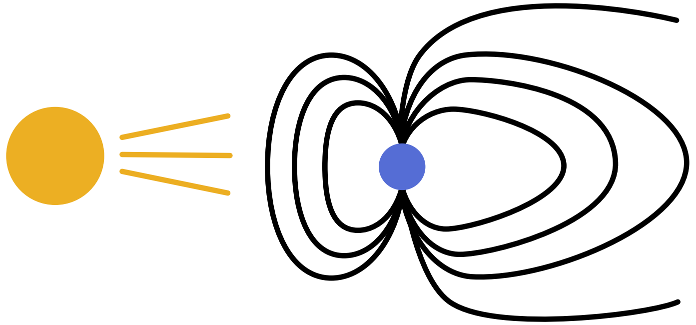


Figure 20: Earth's magnetic field interacts with solar wind particles.

Figure 21: Lightning (Marcel Costa).

Figure 22: Plasma ball filaments.

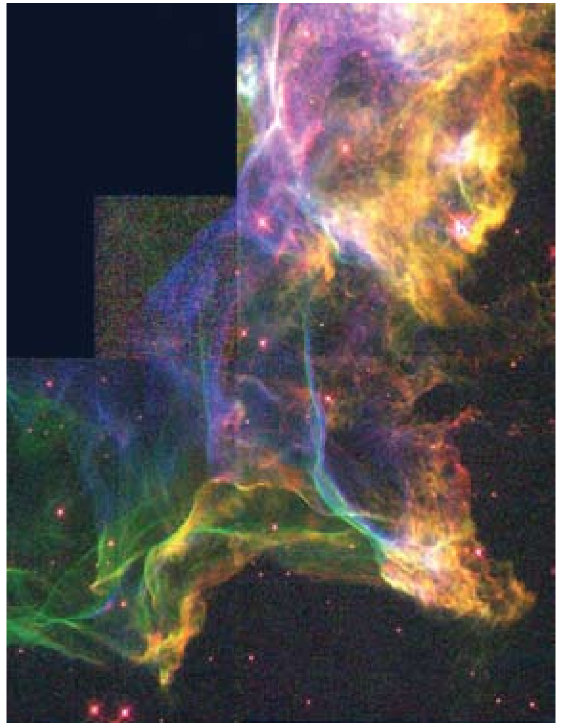


Figure 23: Swan Nebula veil that displays the interstellar material as filaments (Hubble Space Telescope).

Experiment 6: Homemade plasma

The flame of a candle is not solid, nor liquid, nor gas .... It is plasma! Plasma is the most common state of matter in the universe, but a less frequent one on our planet and in our daily life. The flame is a handy example of plasma. It is formed by electrically charged particles moving at high speed, and therefore sensitive to magnetic fields. You can check this very easily.

Material:

A flat neodymium magnet
A teaspoon
Tape
A burning candle

Method:

Fix the neodymium magnet to the handle of the spoon with a bit of adhesive tape. Slowly move the spoon towards the candle flame, and pay attention to what happens. You will notice how it deviates, attracted or repelled by the magnetic field of the magnet. Similarly, the solar wind plasma is deflected by the Earth's magnetic field.

Figure 24: Vertical candle flame without a magnet. Figure 25: Diverted flame with a magnet nearby.

Experiment 7: Plasma Ball

A plasma lamp is a transparent glass sphere filled with a mixture of several gases at low pressure, and driven by high frequency and high voltage alternating current.
It throws "lightning bolts" (actually, ionized gas) that extend from the inner electrode to the walls of the glass sphere, giving rise to multiple constant beams of coloured light.

Material:
A plasma lamp

Method:
The placement of a hand near the crystal alters the electric field causing a thicker beam inside the sphere close to the contact point.

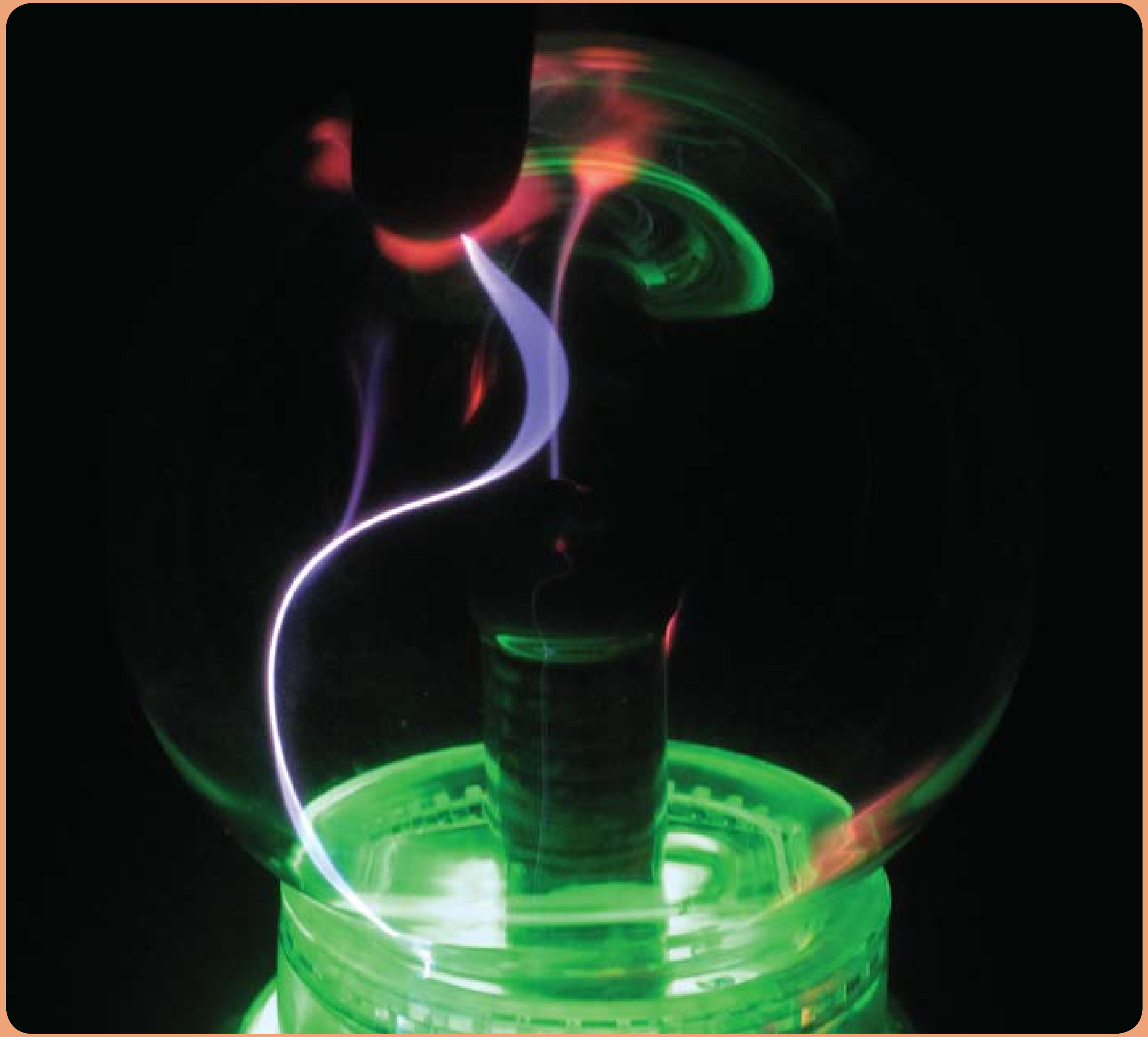


Figure 26: A hand on a plasma ball.

The solar wind is another example of plasma. Gas particles move freely. When their energy is very high, gas atoms lose their structure to form a new state, namely plasma. Particles in this state move freely. When they collide with each other, at high speeds, they give rise to spectacular phenomena. Just like gas, plasma does not have definite shape and volume. However, unlike gas, plasma is affected by magnetic fields, as seen in the previous experiment. Under its influence, it may form structures such as filaments and lightning.

The solar wind particles travelling at high speed collide with the Earth's magnetic field and can be captured. These particles accumulate at the poles and collide with molecules in the upper atmosphere. These collisions release the streaks of light that form auroras.

Auroras occur and are visible mainly in the polar regions, where the magnetic field is most intense and where the plasma particles captured by the field are concentrated. For this reason, they are called aurora borealis if they occur in the northern hemisphere and aurora australis in the southern hemisphere.

There are periods when many auroras occur and periods with fewer, depending on the activity on the Sun's surface. Our star is not always equally active. It goes in cycles of about 11 years, when the Sun is more active and more particles emerge from the surface eruptions. They are also more energetic, and upon reaching the Earth's magnetic field they produce a higher number of auroras.

It should be mentioned, in addition to the beauty of their various colours, that auroras move and dance across the sky dome. It really is one of the most spectacular natural events. In addition, it is another proof of the Earth's magnetic field.

Figure 27: Aurora borealis. The lines indicate the direction of arrival of the electrons along the lines of force of the terrestrial magnetic field (Sakari Ekko, Finland).

Appendix: Ferromagnetic meteorites

Atmosphere is not only hit by solar wind particles, but also by many small meteorites. Just like in the case of solar wind particles, when getting in contact with the gases of the atmosphere, meteorites heat up and disintegrate, releasing a large amount of energy and streaks of light. These are so-called shooting stars. Some of these small meteorites collide with the Earth's crust. In fact, the Earth is daily hit by several tons of them.

Experiment 8: Extraterrestrial meteorites hunt

In a simple way, we can detect and pick up some of these micrometeorites that collided with the Earth's crust coming from the tail of a comet or an asteroid belt. How can we do that? Well, by taking advantage of the fact that some are ferromagnetic, meaning that a magnet detects and attracts them. You can exploit this property and become a hunter of micrometeorites, following the steps that we describe below.

Material:

A magnet
A plastic bag
A wooden stick
A magnifying glass or a microscope

Method:

Place the magnet inside the white bag, and make sure that its bottom, where the magnet is located, is taut and smooth. It is better if the magnet has a wide flat base. With the magnet inside the bag, within an inch of the soil, you have to comb areas where these micrometeorites may accumulate, for example roofs, outdoor areas with little human activity, or areas where rain water accumulates, such as the bottoms of valleys, streams, river banks, etc.

After some time, on the white base of your bag, where the magnet is, tiny dark spots appear. Gently remove the magnet and make sure that the objects you captured fall into a container. If you watch them under the microscope or under a powerful magnifying glass, you'll notice a wide variety of forms. Some of the captured particles are irregularly shaped, while other are elongated like a thread. You may also find some spherical or drop-shaped particles. These are very likely to be micrometeorites, rounded by the friction of our atmosphere, while the others are just industrial debris etc.

Good luck with your search!

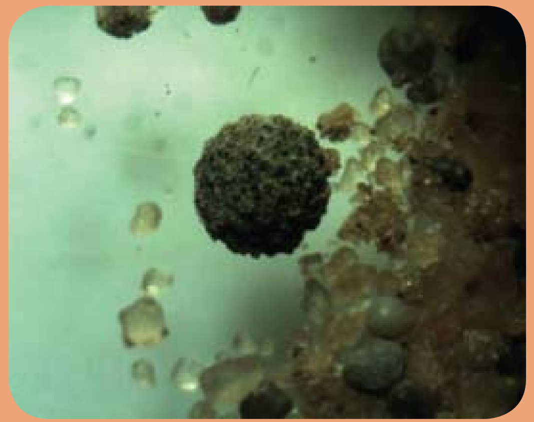


Figure 28: You can perfectly recognize the spherical meteorite against the grit background.

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The aim of UNAWE is that children from all countries may have a personal, enjoyable relationship with astronomy. EU-UNAWE is the European branch of this global project and involves Germany, Italy, the Netherlands, Spain, United Kingdom and South Africa. Through experiences and emotions related to stargazing children begin to understand that they are also part of the universe and they have a world in front of them ready to be explored.