NAROM | ANDØYA SPACE CENTER

Co-funded by the Erasmus+ Programme of the European Union

ROCK STAR

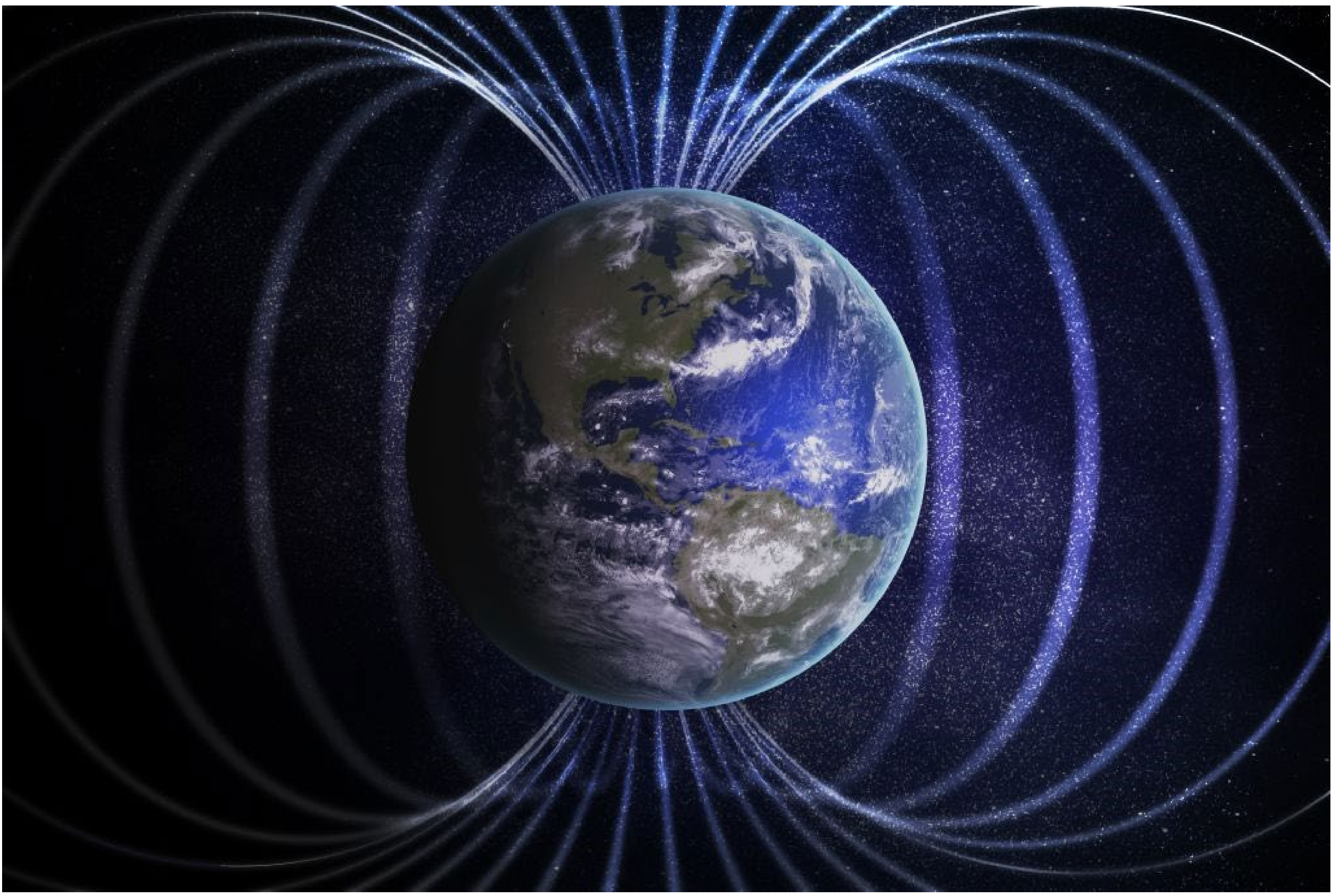
ENHANCING STEM EDUCATION

MAGNETIC FIELD TASK

Task Box: The Sun-Earth Connexion

Summary

The exercise provides an understanding about the measurements of the magnetic field can give valuable information about the Northern Lights.



Content

Overview	
Purpose	This exercise will provide students with an understanding of how measurement of magnetic fields can provide valuable information about the Northern Lights.
Duration	Two hours
Location	NAROM Lab / Local schools
Equipment	Computer and Honeywell magnetometer, calculator, stretched long wire that can withstand multiple amps continuous current, power supply that can supply at least 10 A.
Safety issues	None
Background	It is beneficial to have learned how large magnetic fields near an "infinitely" long straight wire with electric current running through it are and which way they point.
Literature	Included
Software	Mobile Phone Apps to measure magnetic field

Learning objectives

Gain increasing knowledge about:

- using the scientific methodology
- using media tools to obtain and analyse data
- the Earth magnetic field
- how the Earth magnetic field can be influenced by external currents.

21st Century skills:

- Work in international groups using English as communication language
- Problem solving skills
- Critical thinking
- Collaboration
- Communication
- Information and media literacy

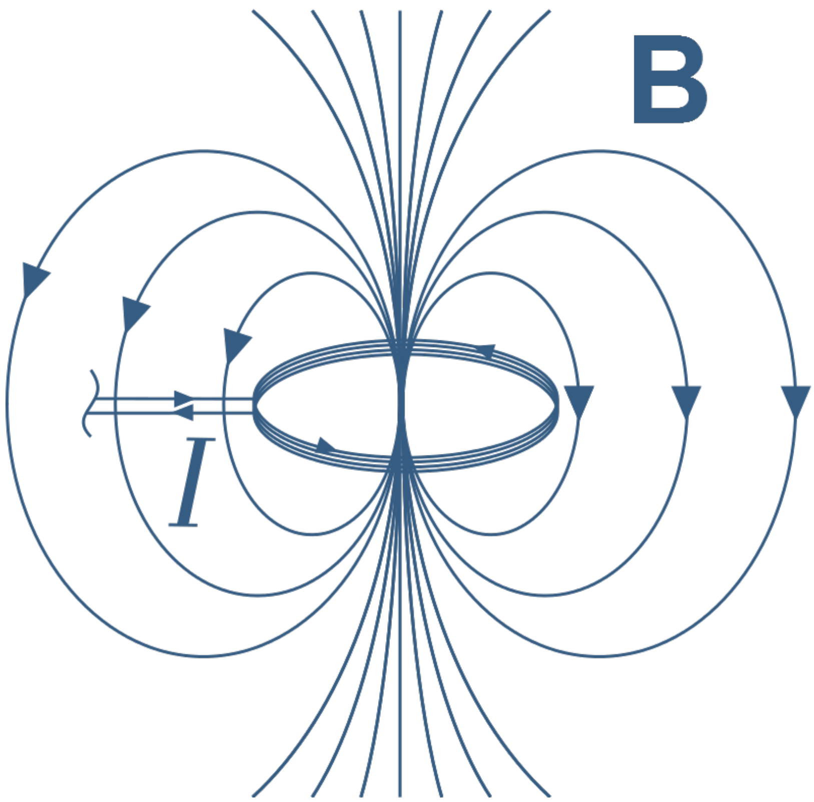
Theory: background

General introduction

In this exercise we will look at the three components of Earth’s magnetic field using a magnetometer. We will also see how a battery can affect a compass needle based on the magnetic field around the wire. Lastly, we will create an artificial aurora using direct current and measure it using a magnetometer.

The Earth has a magnetic field and we know how to take advantage of this when we navigate with a compass. The compass needle turns around to point north. The magnetic field must therefore have an orientation. Earth's magnetic field has a size and it is between 40 and 70 μT (micro tesla), which is quite weak compared to the field we have just outside a regular fridge magnet, which is approximately 10 to 60,000 μT (like 0.01 to 0.06 T, tesla).

In physics, physical properties are called vectors when they have both a size and an orientation. However, Earth’s magnetic field is not actually oriented the same way as an ordinary compass needle. Earth's magnetic field at our latitudes points north, but also partially downward into Earth. In compasses used for orienteering in the Northern hemisphere, an added an extra weight is used that makes the compass needle remain horizontal even though the Earth's magnetic field points downward. This extra weight makes our compasses built for the Northern hemisphere useless in for example Australia, where the Earth's magnetic field partially points up from the ground (and north). You can wonder why it works well with regular ship compasses, how it works well almost anywhere, but not very close to the magnetic North Pole or South Pole.



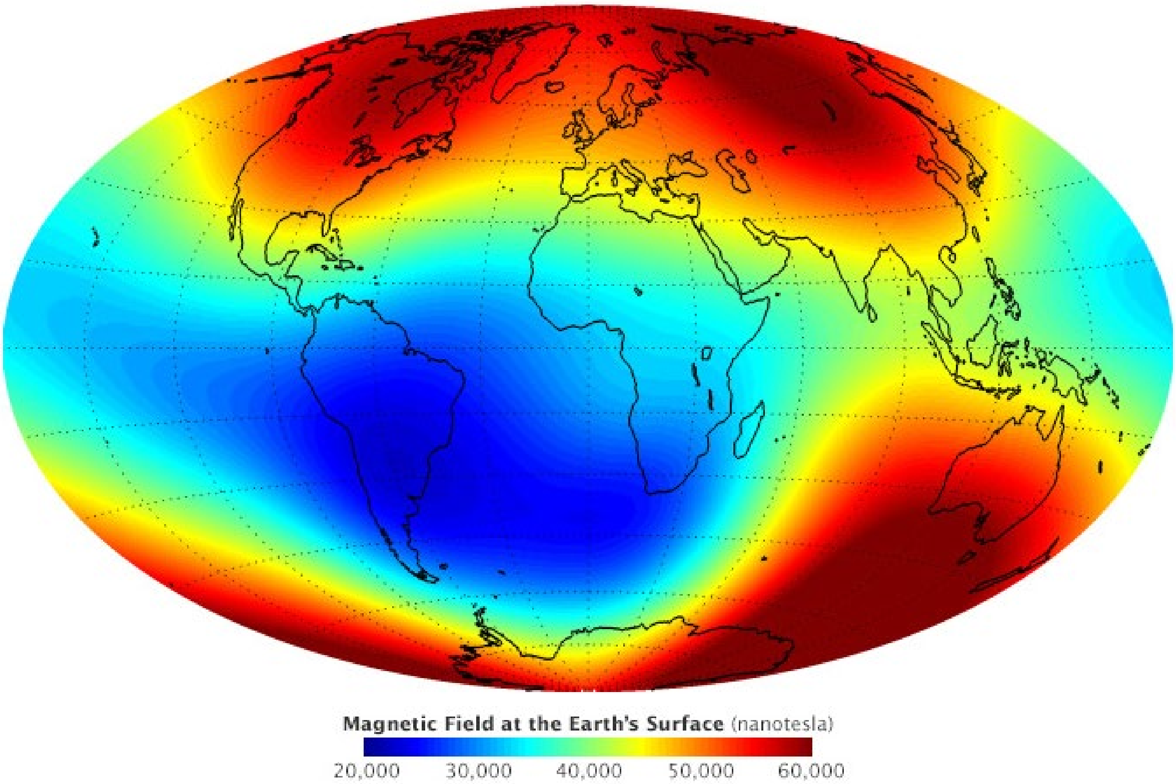


Figure 1: Source: http://Earthobservatory.nasa.gov

It is a bit strange to think that it really is the magnetic South Pole, which lies far to the true North and the magnetic North Pole far to the south. The field lines point from the magnetic North Pole to the magnetic South Pole. The compass' North Pole then points towards magnetic South, i.e. towards true North.

Earth's magnetic field changes over hundreds of thousands of years. It is also commonly believed that the magnetic North and South Pole have moved around a few times throughout Earth's history. In the course of a day or a week, the changes are too small to notice.

Nevertheless, with sensitive magnetic field meters, often called magnetometers, we can record weak changes in the Earth's magnetic field in a matter of seconds and minutes. These changes are not due to changes inside the Earth, but due to an additional magnetic field caused by electric currents in the atmosphere. We also have magnetic fields caused by human activity, such as tram, metro, railway, electric cars, other vehicles, power lines, heating, motors, cookers etc. We will concentrate on the magnetic fields that nature itself creates.

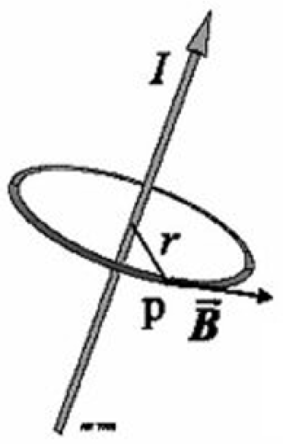
It is thus such that Northern Lights are formed by electrically charged particles that have traveled with the solar wind from the Sun. The same electrically charged particles create magnetic fields in the atmosphere. Severe particle flows can cause a lot of Northern Lights and relatively large magnetic disturbances near the Earth's surface. The orientation of the total magnetic field can temporarily change, and it has been reported that compasses can point up to 10 degrees from the normal direction during strong Northern Lights. Powerful particle flows provide what we call a "magnetic storm". This is split up into individual events (fluctuations) called "magnetic substorms." All this means that if we can measure magnetic fields, we also get an idea of when Northern Lights will occur and discover more about where the they appeared.

Alternative explanation: When Northern Lights stretch like an arc across the sky, they will have a relatively short extension in the North-South direction but may extend for thousands of kilometers in East-West direction. Northern Lights particles cause ionization along the arc and thus high electrical conductivity. Electric fields in the ionosphere will then be able to drive a significant electrical current (called electrojet) along the arc. From the ground, it may seem as if we have an approximate straight-line current overhead.

The magnetic field decreases with the distance from where the current flows, which means we have to be nearby to prevent too much noise. We cannot follow Southern Lights in the Antarctic with measuring instruments in Norway. However, we have sensitive enough instruments for example to detect magnetic fields from powerful Northern Lights straight above Andøya, up to Svalbard and down to Trondheim. The highest effect will always be measured from the ground straight under the Northern Lights, which in our example would be Andøya.

The magnetic field from an electric current

We can use the Biot-Savart law to calculate the magnetic field from an arbitrary current distribution. Sometimes we can model the physics in a simpler manner: If the electrical current flows approximately as a straight line anywhere near the place in which we measure the magnetic field, we can use a simplified calculation. The field B (in μTesla) is given as (*with I in Ampere and r in meter)*:



$$B = \frac{0{,}2[I]}{[r]}\ \mu\text{T}$$

Figure 2: B in μTesla, I in Ampere and r in meter

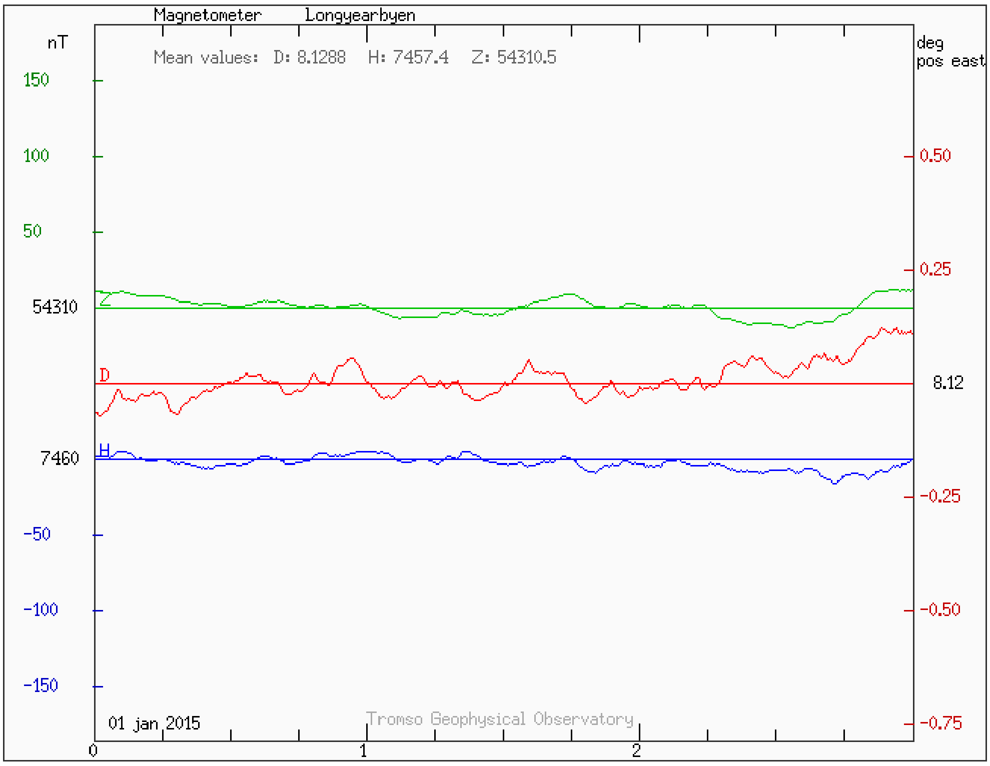
The magnetic field at a point p a distance away from the electric current will be directed tangentially in relation to a circle through the point p, where the circle has center in the line and is perpendicular to it. Which way the tangent will point we will find out from the "right hand rule": If we grasp the wire with our thumb in the direction of flow, the magnetic field revolves around the wire in the same direction as the other four fingers point. The magnetic field is also inversely proportional to the distance. This means that the field is down to half if the distance to the line is increased to the double.

If we measure the magnetic field in three orthogonal directions (X, Y, Z), we can find the direction and magnitude of the magnetic field. However, this is not enough to determine exactly where the electric current flows. We can find the direction of the electric current, but we cannot determine the distance to the electric current.

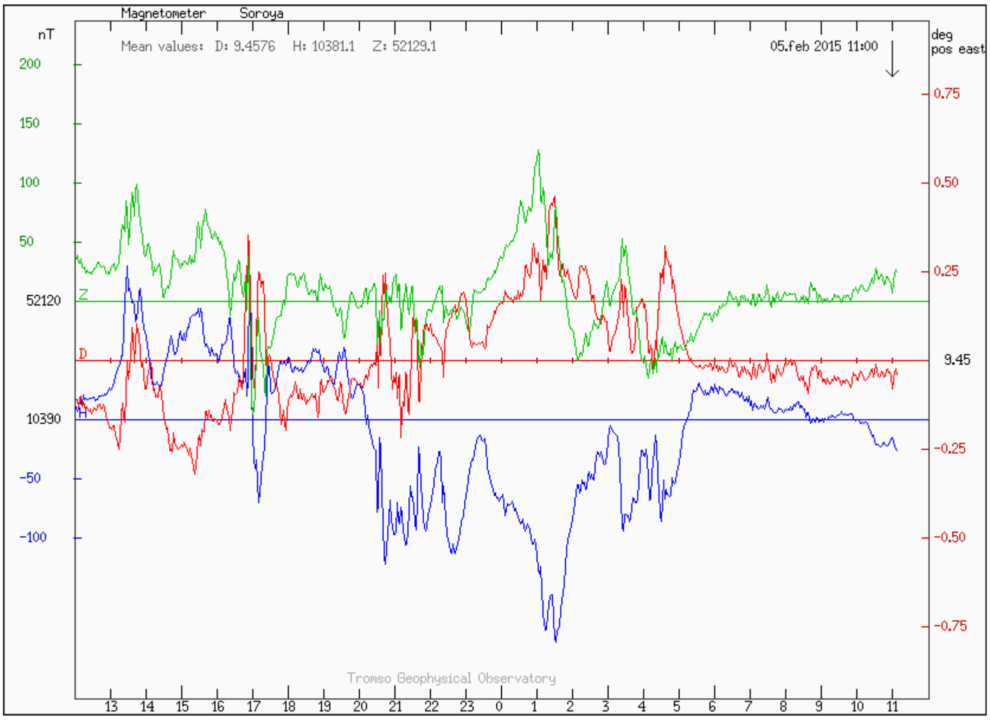
If, however, we measure the magnetic field simultaneously at two different locations on Earth (and not too far apart), we could determine the direction from these two locations and get an intersection. This means that we can determine the position and, as soon as we have the position, we can determine the strength of the electrical current.

There is a national and international network of magnetometers which are running steadily 24/7. An excerpt of these data are freely available over the internet. Go to the websites of the Auroral Observatory in Tromsø at http://geo.phys.uit.no and select "The geomagnetic page".

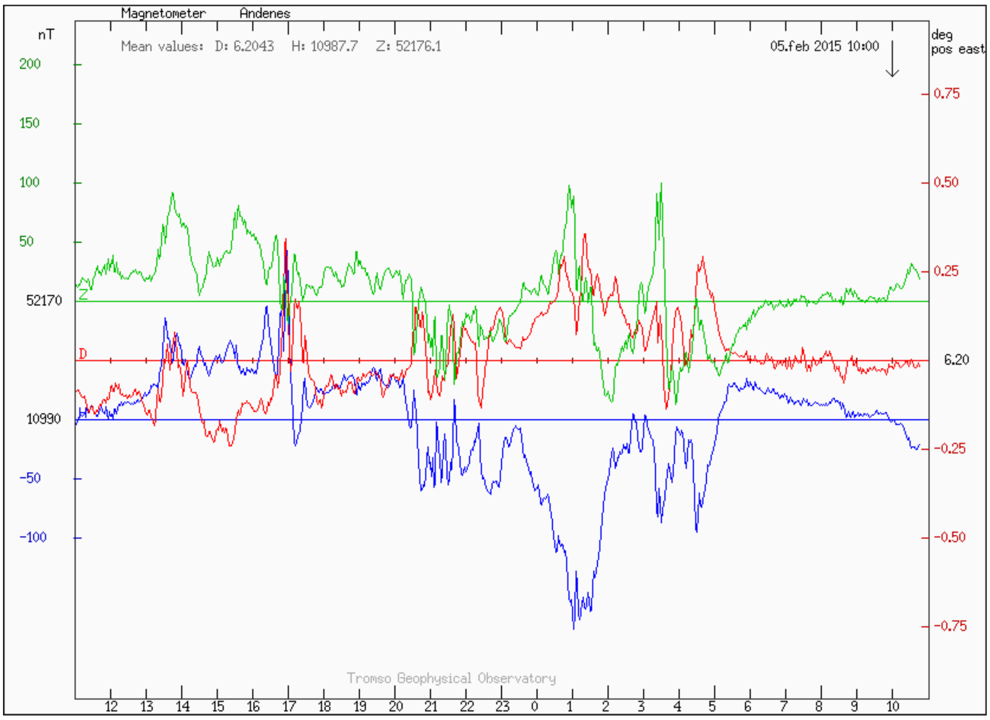
Examples of the detected variations in the magnetic field are shown below. Here, it is not the X, Y, Z components that are displayed, but the horizontal (H) and vertical (Z) components of the magnetic disturbances the Earth's magnetic field experiences. In addition, the declination (D), i.e. the angle between true North and magnetic North is shown:



Longyearbyen

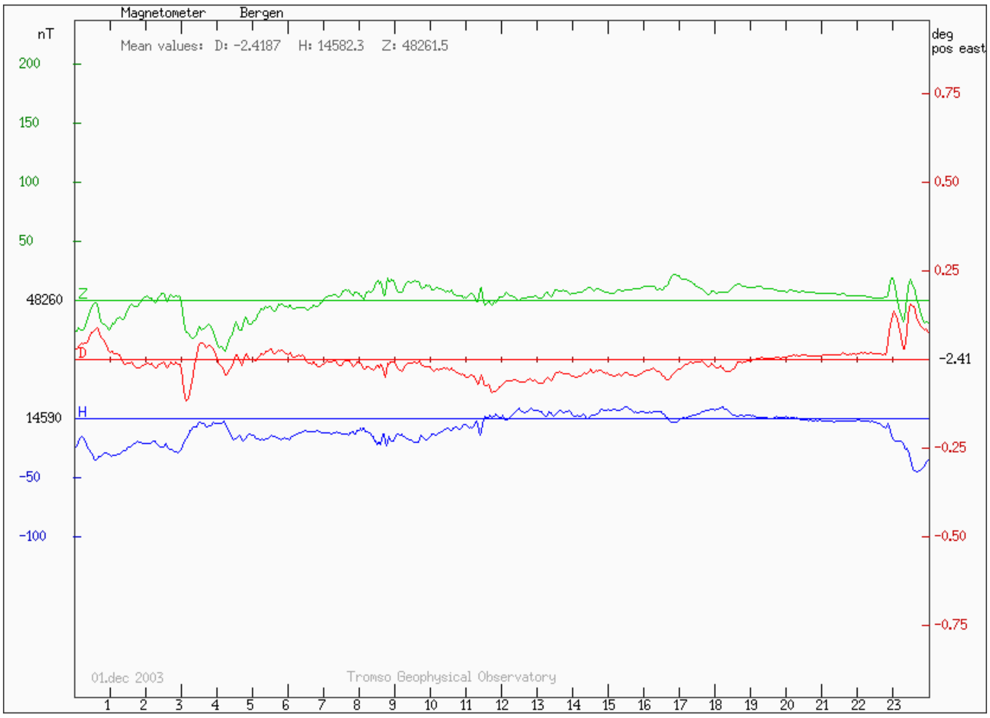


Sørøya



Andenes

Rørvik



Bergen

Although the total variations in the Earth's magnetic field is less than 2%, the magnetic field can fluctuate quite a lot in the time period shown in the charts above. The largest fluctuations occur at Sørøya, but much less in Bergen. Each peak, either upward or downward, corresponds to a number of charged particles passing high up in the atmosphere, this time the most near Sørøya.

The currents can be substantial (and it must be for it to be measured) when Northern Lights and charged particles are located about 100 km up into the atmosphere. Trying to measure magnetic fields from regular power lines would not be possible at such a distance. There are two reasons why the current is as great as it gets. Current is defined as charges passing an imaginary surface pr. second. A major current can be achieved by either having many charged particles per volume (high charge density), and/or charges that passes by at high speed. Our particles have a speed of about the same magnitude as the light. The speed is therefore very high and when it has a considerable charge density, the current is high.

Do you want to know more?

The formula in figure 2 above also applies to the case where the current is not focused within a thin line (channel, wire). Although the charges are distributed over a large cross section, we get the same formulas as above, if the charge distribution is what we call "cylindrically symmetrical" and assuming that the particle flow does not reach all the way to the ground.

We mentioned earlier that the simple formula applied only if the current line is straight anywhere near that point we measure the magnetic field in. This is an insufficient wording. Instead, say something like: If the closest distance to the electric current is h, the current must follow a straight line anywhere within a distance of about 5h, maybe even a little more. There is of course no exact limit here. There is a gradual transition and the limit is determined by how precise we want to be.

Occasionally, particle currents flow into the Earth in such a way that it generates a "surface current" which is approximately equal everywhere on an entire surface. In that case, the above formula does not apply. We get a magnetic field given by:

$B = 0.63 * s$ (in μT)

Where s is current density (the electric current per unit area of cross section) in the plane the current flows. The magnetic field will then be horizontal and perpendicular to the direction of the current (again determined by the right-hand rule). If the surface current covers a large area that encompasses several observation stations, the magnetic field changes on the respective stations will be horizontal, parallel and have approximately the same size. We will not use models based on surface currents for analysing magnetic-field fluctuations in this exercise.

Summary

Earth's magnetic field can be described using vectors and points partially downward and to the north at our latitude. The magnetic field at the Earth's surface is mainly due to currents of liquid iron in Earth's interior, however particle currents from the Sun towards our atmosphere also creates a magnetic field. This latter magnetic field may vary in seconds and minutes. We may use simultaneous magnetic field measurements from several observation stations to determine the particle flows and their strength. When we calculate the data, we often use a simplified model that provides a magnetic field from a "straight wire" as shown in figure 2 earlier in this guide. Occasionally it may be better to analyse the data under the assumption that the particle currents occur in large horizontal planes. However, we will not use such a model in this exercise.

Activity 1: Earth's magnetic field and the compass

We need to measure the Earth's magnetic field and find the angle it forms respect to the horizontal plane.

a) Place the compass on a flat surface where there are no metal objects nearby (1-2m should be enough). Find and take note of the magnetic South.
b) Then place the magnetometer with the x-direction parallel to the compass needle. Remove the compass and read the value from the three (xyz) components.
c) What is the total magnetic field (B), in μT (micro Tesla)?

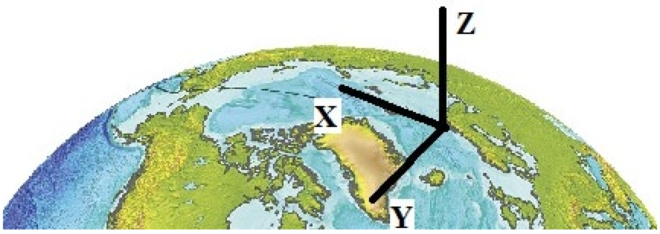


Figure 3: The three (xyz) component

d) What is the angle (I) between the magnetic field and the horizontal plane? Draw a figure.

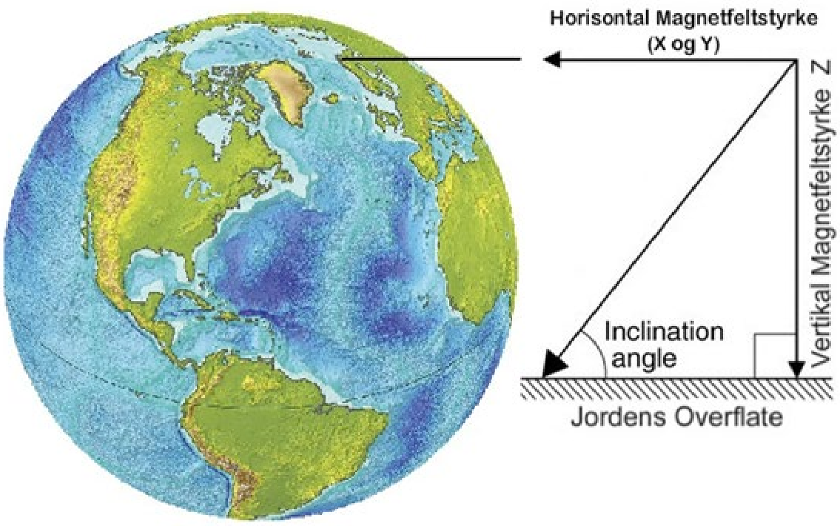


Figure 4: The angle (I) between the magnetic field and the horizontal plan

e) One of the most famous adventurers in Norway today is considering buying a measuring instrument just like the one you are using in this exercise to be certain that he will be able to find the South Magnetic Pole. How would you have used the instrument to navigate to the magnetic pole?

Activity 2: Direct current can affect the compass needle

Here we will show that direct current through a wire can affect a compass needle, in other words, repeat Ørsted's famous experiment. To achieve this, we must compete with the Earth's magnetic field. From exercise 1 above, you already know the horizontal component of the Earth's magnetic field at your location.

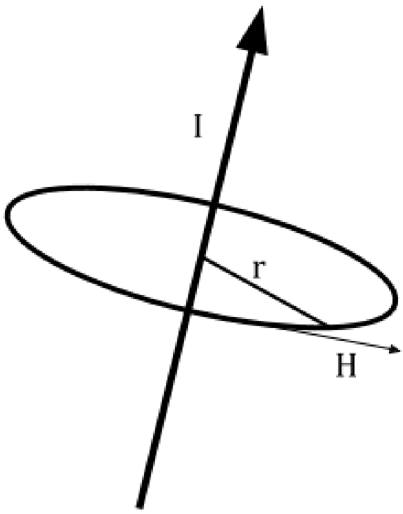
If you want to get the compass needle to move by passing a current through a wire, the current must be large enough, so that the magnetic field you generate becomes as powerful as the horizontal component of the Earth's magnetic field.

a) Calculate how strong the current needs to be to get a sufficiently strong magnetic field in order move the compass needle.

Suppose you do keep the wire 1 cm away from the compass needle. Use Biot–Savart's law and find **I**. The magnetic field (B) in which we will use in this formula is only the horizontal magnetic field strength (H).

$$H = \left(\frac{0,2 \times I}{r}\right)$$

I is measured in ampere, **r** in meters and **H** in microtesla.



Figur 5: Magnetic flux density

How much current do you need to compete with the Earth's magnetic field? Is it enough by using a battery at such a distance?

b) Place the compass on a flat horizontal surface a good distance away from metal objects. Now try to hold the wire horizontally just above the compass, first with the wire across the compass needle, and then along the compass needle. Keep the rest of the wire as far as possible away from the compass.

Connect a 9V battery to the wire at each of the two ends of the wire, while observing the compass. (You are short-circuiting the battery, so try not to keep the wire connected to the battery longer than necessary).

Explain your observations based on the *right-hand rule*. Use the figures below.

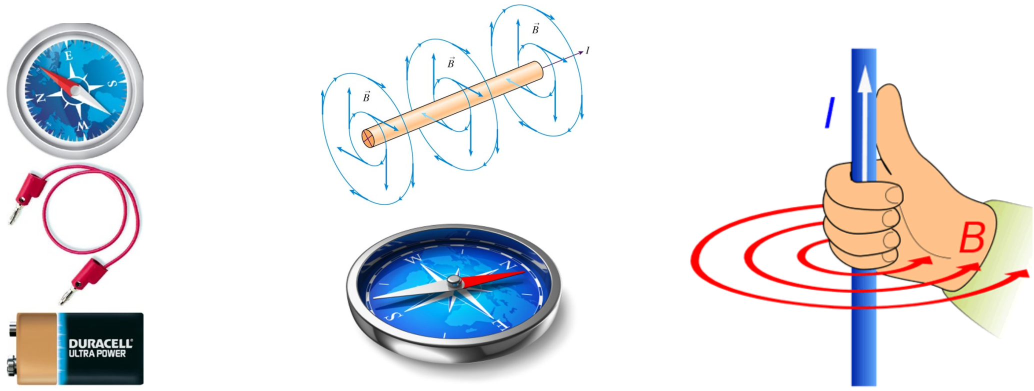


Figure 6: The right-hand rule

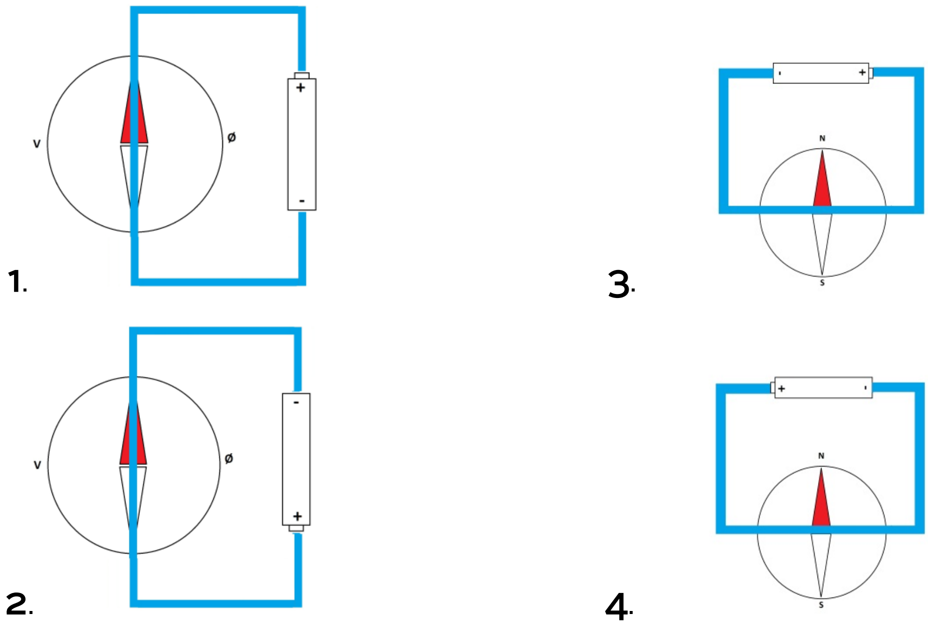


Figure 12: Influencing a compass needle with 9V battery and a wire

Draw in which way the red part of the needle will point:

	1	2	3	4
Expected				
Actual				

Activity 3: Measuring the magnetic field of an "artificial aurora" using a magnetometer

We cannot create Northern Lights manually, so we must "simulate" aurora in this exercise.

Since we are only concerned with the magnetic field generated by the Northern Lights, we can simulate this magnetic field using a long, straight wire where a direct current is sent through for a given time period. Two people hold the wire at each end to stretch it and we will make measurements with and without current. Make sure that the distance between the wire and the magnetometer is stable throughout all measurements.

Place the magnetometer with the x-direction parallel to the wire just below the wire and mark the position. To obtain good measurement data, the distance to the wire should not be too long (10-20 cm).

a) Measure the three components of the Earth's magnetic field without compromising any electrical power in the wire. Record the data in the table in the table 1 below.

b) Measure the distance between the wire and the magnetometer before reading the values. Let the instructor switch on the current and repeat the measurements for two different current values. This will simulate that there are a far stronger currents in the atmosphere associated with an aurora.

Table 1: Magnetic-field measurements with or without current

	No current	Current 1	Current 2	Difference 1	Difference 2
Bx (μT)					
By (μT)					
Bz (μT)					

c) Once you have the measurements written down in the table 1, find the difference and then calculate the total magnetic field B for the difference values. Finally, use these differences and find I for both currents. Discuss the results.

Table 2: Estimated current

	Current 1	Current 2
I (A)		

d) If the current does not match what the instructor conducted through the wire, what might be the cause?

RockStar methodology

The goal with this task is to complete the 3 stages that complement RockStar methodology: (1) to complete the task in the local school, (2) to discuss the results from the different schools, (3) to complete the task during the Gathering in Andøya and compare the results with those obtained at home.

The goal of the phase 2 and 3 is to work with 21st century skills by activating international collaboration between students for making discussion together, building conclusions based on criticism, and presenting results to others.

Phase 1: School

The first step is done at the local school and lead by the local teacher. In case of planned future collaboration with other schools, it is convenient to complete the task the same day.

Outcomes: Groups of 3-4 students write a **report** describing what has been done, presenting a discussion and analysis of the results obtained. This report will be used afterwards to compare the results with other groups from other schools/countries.

Phase 2: Comparison on-line of the results.

The goal for this step is to share and discuss the results obtained by different schools in different countries. 2 or 3 classes meet in virtual classrooms using, eg, *jitsi*[1]. The teacher selected as main responsible of the event presents the goals of the activity, how the students will be organised and what they need to achieve. The initial large group is divided in **IWG** (international working groups) with the presence of 2,3 students per country. Using different computers, the different students are distributed in other virtual classrooms where they go through a collection of guidelines to help with the work to achieve: these will include to compare the results, discuss the similarities and differences, discuss if this is what was expected and why, and write together their conclusions.

Outcomes: When the different IWG finish (around 30 minutes session), the responsible ask them to meet again in the common virtual classroom. Each IWG choose a couple of representants who **present** to the others IWG their conclusions.

Phase 3: Gathering.

The activity will be done again as part of the gathering in Andøya. Due to the high latitude of the island, different results are expected to be obtained. If the phase 2 has not been able to achieve before the gathering, the students from the different schools will present to the rest their local results.

[1] For a description about the procedure, read the document "The expanded classroom in RockStar"

Outcome: The students will work in **IWG** to compare the different local results with the results obtained in the gathering. The IWG prepare a **report** with the description, analysis and discussion of the procedure and comparison of the results.