The Earth's Magnetic Field

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1 | Summary

Why is it so important to know the values of the Earth's magnetic field? Why is the ESA's three-satellite Swarm mission studying its changes?

The Earth's magnetic field is responsible for the presence of the auroras in the polar regions and the beneficial deflection of the solar winds. We can call this magnetic field the Earth's safeguard against cosmic radiation and charged particles.

The terrestrial magnetic field can be measured using different methods, but in this unit the students can compare their measurements of the magnetic field using two Helmholtz coils and a real compass or a smartphone compass application with a direct measurement using the smartphone's magnetic sensor.

- **Keywords:** the Earth's magnetic field, Helmholtz coils, declination
- **Disciplines:** physics, mathematics, ICT, geography
- **Age level of students:** 12-19 years
- **Android apps:** Smart Compass, Sensor Kinetics, Compass
- **iOS apps:** Compass, Magnetometer

2 | Conceptual introduction

The Earth's magnetic field is more or less like a bar magnet tilted 11 degrees from the spin axis of the Earth. It seems that the electric currents in the Earth's core and their dynamo effect are responsible for the presence of this magnetic field. The Earth's magnetic field changes continually in terms of both magnitude and direction, and the poles' position changes at the same time. The World Magnetic Model calculated at the National Geophysical Data Center is updated every five years. According to the NGDC, in the year 2010 the magnetic pole coordinates of the World Magnetic Model were 84.97°N, 132.35°W for the South magnetic pole and 64.42°S, 137.34°E for North magnetic pole.

The Earth's magnetic field B is measured in the SI units microtesla (μT) or nanotesla (nT), and its value varies from 24μT to 66μT.

The purpose of this experiment is to measure the horizontal component of the Earth's magnetic field using a pair of Helmholtz coils, a compass and a smartphone with a sensor for magnetic fields.

This unit fits in well with the physics curricula in each European country (every physics student learns about the static magnetic field and the DC magnetic effect).

3 | What the students do

The students determine the magnitude of the horizontal component of the Earth's magnetic field. To do this, the students first have to assemble the electric circuit. Note that the power supply has to be far away from the coils due to its own magnetic field. If your school doesn't have a pair of Helmholtz coils, you can easily build them together with your students (see the instructions on how to make a Helmholtz coil in the iBook or at www.science-on-stage.de/iStage2-downloads). The device produces a homogeneous magnetic field in the mid-plane between the two circular coils. For this experiment the coils have to be aligned in a North–South direction and be in a vertical position, so that the Helmholtz coils' magnetic field (B_H) is perpendicular to the horizontal component of the Earth's magnetic field (B_E). A compass or a smartphone (with a compass app) placed in the central position of the device will point in the direction of the vector sum of the two components of the magnetic field, as shown in FIG. 1.

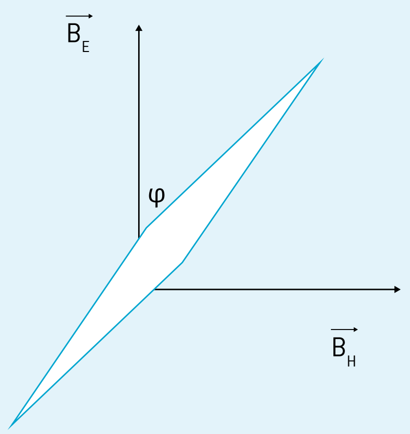
Obviously, $\tan \varphi = \frac{B_H}{B_E}$

Note: If your smartphone's magnetic sensor is inaccurate, it needs to be recalibrated. Move and twist your smartphone for a few seconds until the correct values can be obtained again. Also make sure that no magnet is near your smartphone.

3 | 1 Level 1

Turn the power supply knob to adjust the current in such a manner that the angle φ becomes 45°.

FIG. 1



In this case, $\tan \varphi = 1$
and the magnitude of the magnetic field produced by the device equals the horizontal component of the Earth's magnetic field: $B_H = B_E$.

FIG.2 **Screenshot Compass app**

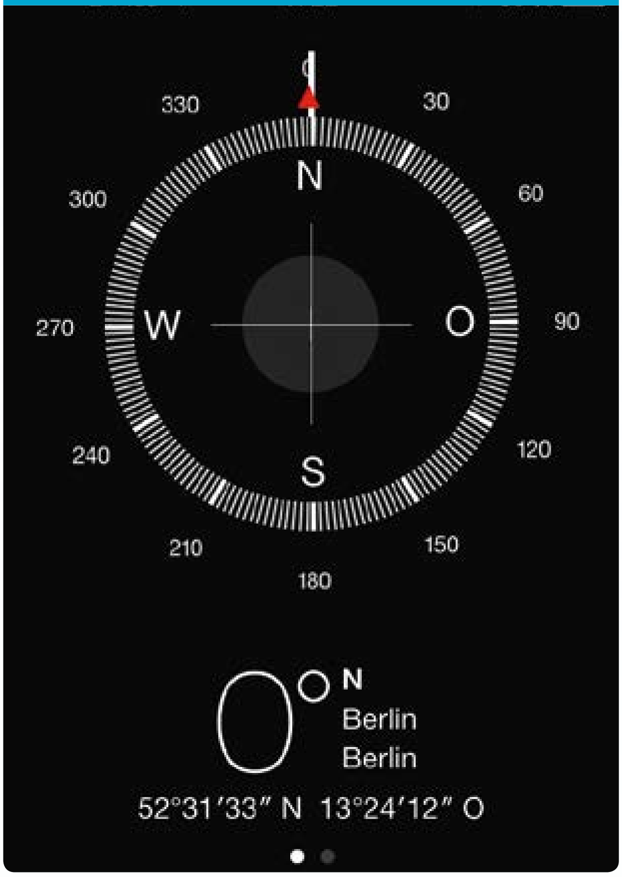
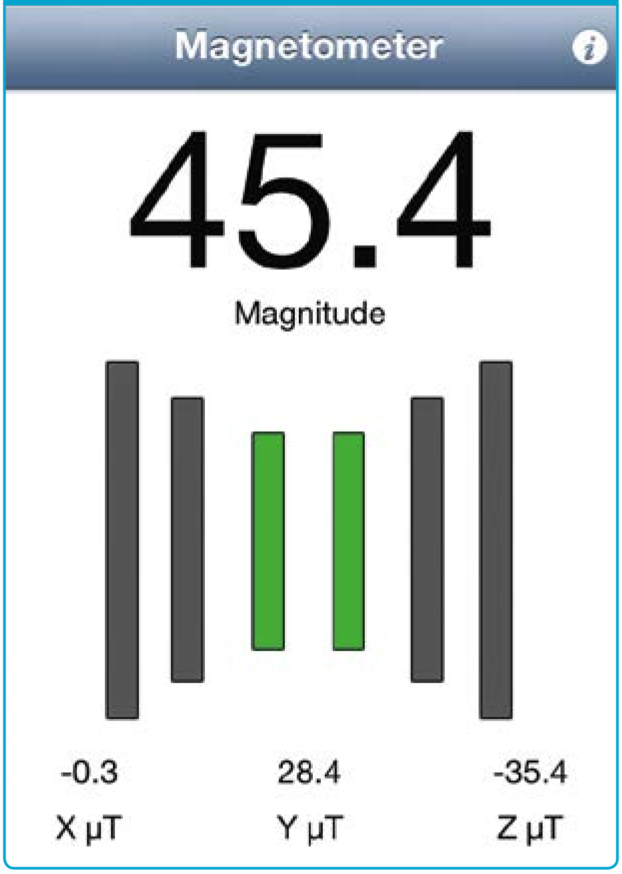


FIG.3 **Screenshot Magnetometer**



Read the value of the current. You can calculate the Helmholtz coils' magnetic field by using the following formula:

$$B_H = \mu_0 \cdot \frac{8 \cdot N \cdot I}{R \cdot 5\sqrt{5}},$$

where N is number of turns in each coil (20 in our case), I is the current through the coils in amperes, R is the radius of the coils in meters (20 cm in our case), and

$$\mu_0 = 4\pi \cdot 10^{-7}\,\frac{V \cdot s}{A \cdot m}$$

is the magnetic permeability in a vacuum.

To compare the value obtained from the formula, use a smartphone app. Lay your smartphone on a flat surface and align your smartphone parallel to the North–South direction by using the compass app of your smartphone or a magnetic needle (see **FIG. 2**). Use an app to measure the magnetic field in three dimensions. In this case (see **FIG. 3**) one of the components (B_X) should be almost zero. The other one shows the horizontal component (B_Y). B_Z then shows the vertical component of the magnetic field.

3|2 **Level 2:**

Turn the power supply knob to produce the suggested values of the electric current through the coils, resistor and ammeter. The values are written as in **FIG. 4**.

FIG.4

I (mA)	φ (°)	tan (φ)
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		

Measure the deflection of the compass and write down these angles. Calculate and fill in the third column.

Plot the two graphs:

- $\varphi = f(I)$ $\varphi(I)$
- $tg\,\varphi = f(I)$, which is a linear function $\tan\varphi(I)$

Draw the line that best fits the measurement points of the $\tan\varphi(I)$ graph, choose two points from that line and write down their values. With the slope k of the linear curve, calculate the magnitude of the horizontal component as follows:

$$\tan\varphi = \underbrace{\frac{\mu_0 \cdot N \cdot 8}{B_E \cdot R \cdot 5\sqrt{5}}}_{\text{slope k}} \cdot I \quad \text{and} \quad B_E = \frac{\mu_0 \cdot N \cdot 8}{k \cdot R \cdot 5\sqrt{5}}\,.$$

Compare the values obtained by the measurement with your smartphone measurement shown in Level 1. Also compare your values with the estimated values for the Earth's magnetic field at your location at http://www.ngdc.noaa.gov/geomag-web/. The latitude and longitude can be obtained from your smartphone.

FIGS. 5-7 show examples of our measurements with R = 20 cm and N = 20.

FIG.5

φ (°)	I (mA)	tan (φ)
0	0	0.00
9	28	0.16
17	59	0.31
25	92	0.47
31	120	0.60
37	153	0.57
41	180	0.87
45	210	1.00
49	241	1.15
52	276	1.28
56	320	1.48

The value for the slope is k = 0.00451/mA and therefore B_E = 19.98μT.

FIG.6

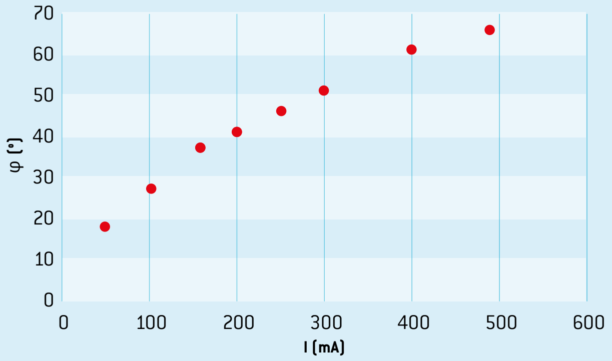
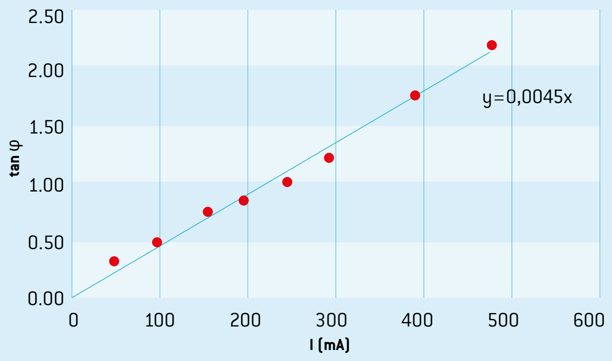


FIG.7



3|3 Further experiments

3|3|1 Observe the change in the Earth's magnetic field over a long period of time (about three months).

Students can measure the horizontal and the total magnitude of the Earth's magnetic field over a period of time. At this stage the students only need to use their smartphones and the Magnetometer app (Sensor Kinetics—Android). The measurement has to be made in the same place every time in order to obtain comparable values. After this the students can record the data in a graph and discuss the fluctuation.

3|3|2 Compare the magnetic field's values with the latitude

Students from different schools can be involved in a common project. For this they have to measure the horizontal magnetic field in their home town and note their latitude. After recording this data the students will realise that the Earth's magnetic field is changing a little every day, and also that there is an important gradient in the horizontal component of the Earth's magnetic field going from the equator to the North Pole (in the northern hemisphere). Data for this experiment can be obtained from the database (Find the link to the moodle database at www.science-on-stage.de/istage2-downloads).

4 | Cooperation option

Take part in a European science project

As part of this teaching unit we have created a database where you can upload your measurements of the horizontal component of the Earth's magnetic field. Please also enter the date of your measurement, your location and your global position coordinates. Link info at www.science-on-stage.de/istage2-downloads. You will have to register to enter data there.

Here you will also have access to the values recorded previously by other participants, both teachers and students.

5 | Conclusion

This unit helps students to understand that the accuracy of the analogue measurement (with a pair of Helmholtz coils and a compass) is just as good as that of the digital measurement (with a smartphone).

The students will observe how modern technology improves scientific research. The duration of the measurement process has changed dramatically. In addition, the smartphone is a multipurpose measuring device.

The students can compare their results to current data and immediately see how accurate they are and share their results.

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