# Magnetic Field of the Earth

## DETERMINE THE HORIZONTAL AND VERTICAL COMPONENTS OF THE EARTH'S MAGNETIC FIELD.

- Measure the angle of rotation of a compass needle initially aligned parallel with the horizontal component of earth's magnetic field when a second horizontal magnetic field is superimposed with the help of a pair of Helmholtz coils.
- Determine the horizontal component of the earth's magnetic field.
- Measure the inclination and vertical component and calculate the overall magnitude of the earth's magnetic field.

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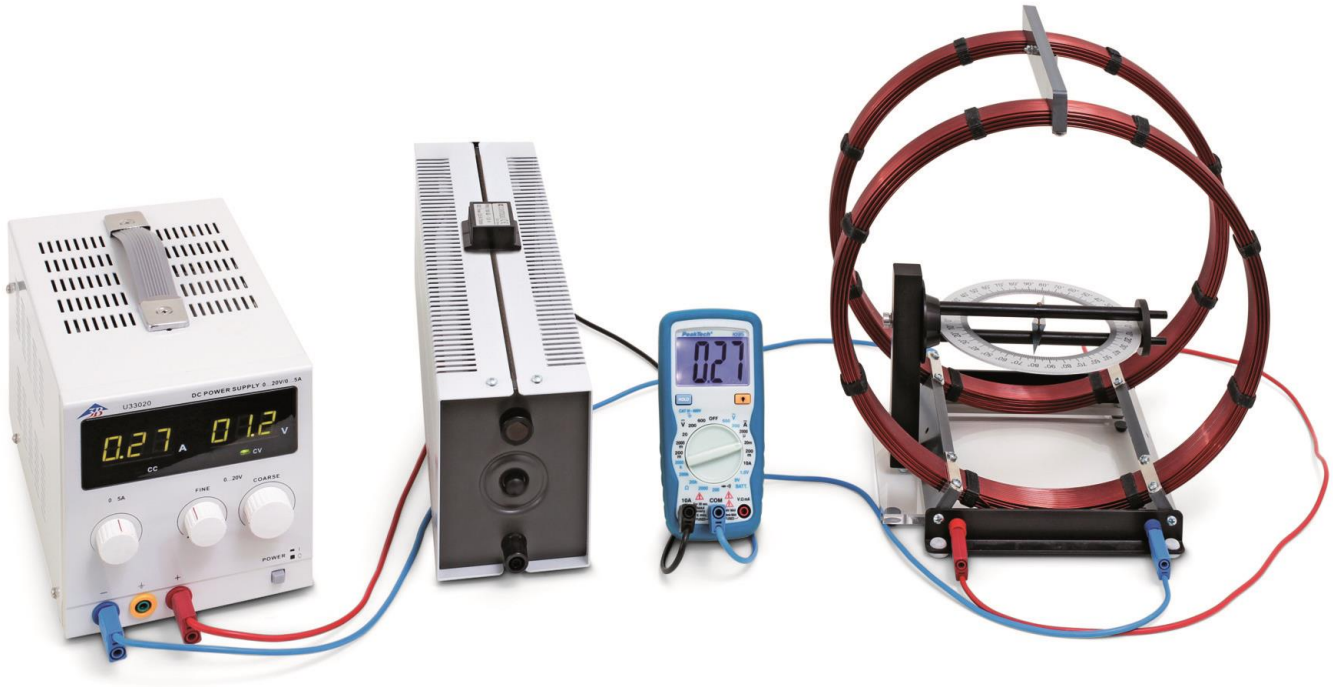

Fig. 1: Measurement set-up.

## GENERAL PRINCIPLES

**The earth is surrounded by a magnetic field generated by a so-called geo-dynamo effect. Close to the surface of the earth, this field resembles that of a magnetic dipole with field lines emerging from the South Pole of the planet and circling back towards the North Pole. The angle between the actual magnetic field of the earth and the horizontal at a given point on the surface is called the inclination. The horizontal component of the Earth's field roughly follows a line running between geographical north and south. Because the earth's crust exhibits magnetism itself, there are localised differences which are characterised by the term declination.**

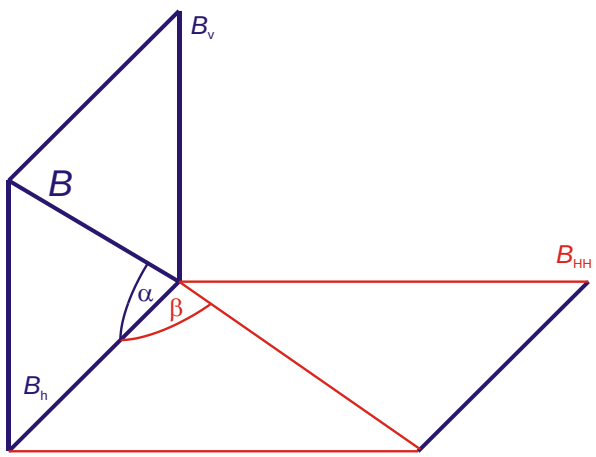


Fig. 2: Diagram of components of the magnetic fields observed in the experiment and definition of the corresponding angles.

This experiment involves measuring the inclination and the absolute magnitude of the Earth's magnetic field along with the horizontal and vertical components of it at the point where the measurement is made.

The following relationships apply (Fig. 2):

(1) $B_v = B_h \cdot \tan\alpha$

$\alpha$: inclination
$B_h$: horizontal component
$B_v$: vertical component

and

(2) $B = \sqrt{B_h^2 + B_v^2}$ .

It is therefore sufficient to determine the values $B_h$ and $\alpha$, since the other values can simply be calculated.

The inclination $\alpha$ is determined with the aid of an dip needle. In order to obtain the horizontal component $B_h$, the dip needle is aligned in horizontal plane in such a way that its needle points to 0° when parallel to the horizontal component 0°. An additional horizontal magnetic field $B_{HH}$, which is perpendicular to $B_h$, is generated by a pair of Helmholtz coils and this field causes the compass needle to turn by an angle $\beta$. According to Fig. 2 the following is then true:

(3) $\frac{B_{HH}}{B_h} = \tan\beta$

In order to improve the accuracy, this measurement is carried out for a variety of angles $\beta$.

## LIST OF EQUIPMENT

| | | |
|---|---|---|
| 1 | Helmholtz Coils 300 mm | 1000906 (U8481500) |
| 1 | DC Power Supply 0-20 V, 0-5 A @230V | 1003312 (U33020-230) |
| or | | |
| 1 | DC Power Supply 0-20 V, 0-5 A @115V | 1003311 (U33020-115) |
| 1 | Digital Multimeter P1035 | 1002781 (U11806) |
| 1 | Inclination Instrument E | 1006799 (U8495258) |
| 1 | Rheostat 100 Ω | 1003066 (U17354) |
| 1 | Set of 15 Safety Experiment Leads, 75 cm | 1002843 (U138021) |

## SET-UP AND PROCEDURE

**Note:**
Set up the experiment on a flat, horizontal surface at a location which is not affected by any interfering magnetic fields from the environment.

### Determining the horizontal component $B_h$

- Turn the hand wheel on the inclination instrument such that the plane of the ring scale and the compass needle are situated parallel to the work surface.

This ensures the compass needle is always aligned along the horizontal component of the Earth's magnetic field.

- Turn the inclination instrument at its base until the 0°-marking of the ring scale aligns with the direction of the compass needle.
- Shift the Helmholtz coils using the inclination instrument such that it is positioned in the middle between the two coils (Fig. 1) and the axis of the Helmholtz coils is oriented perpendicular to the direction of the compass needle.
- Connect the Helmholtz coils, the digital multimeter and the rheostat in series to the power supply unit (Fig. 1).
- Set the rheostat to 100 Ω.
- Switch on the DC power supply and increase the current by raising the voltage with the fine adjustment controller of the DC voltage until the direction pointed to by the compass needle aligns with the 5° marking of the ring scale. Enter the deflection angle $\beta$ = 5° into Tab. 1. Take the current reading on the multimeter and enter this value into Tab. 1 as well.
- Gradually increase the current incrementally until the deflection angle goes up to $\beta$ = 75° in 5° steps. Enter each deflection angle and current value into Table 1. If fine adjustment controller for DC voltage reaches limit stop, continue to increase the current by reducing the resistance on the rheostat.

### Determining inclination α

- Turn the hand wheel on the inclination instrument such that the plane of the ring scale and the compass needle are parallel to the work surface.

This ensures the compass needle is always aligned along the horizontal component of the Earth's magnetic field.

- Turn the inclination instrument at its base until the 0°-marking of the ring scale aligns with the direction of the compass needle.
- Turn the hand wheel on the inclination instrument so that the plane of the ring scale and the compass needle are perpendicular to the work surface.
- Wait unit the compass needle is steady.
- Take a reading of the inclination angle $\alpha_1$ on the ring scale of the inclination instrument and enter the value into Tab. 2.
- Turn the inclination instrument by 180 ° by turning the hand wheel.
- Wait until the compass needle is steady.
- Take a reading of the inclination angle $\alpha_2$ on the ring scale of the inclination instrument and enter it into Tab. 2.

## SAMPLE MEASUREMENT AND EVALUATION

Tab. 1: Deflection angle β, set currents *I* and calculated magnetic fields $B_{HH}$ of the Helmholtz coils in accordance with Equation (5).

| β | *I* / mA | $B_{HH}$ / μT |
|---|---|---|
| 5° | 2.37 | 1.79 |
| 10° | 5.16 | 3.90 |
| 15° | 8.00 | 6.05 |
| 20° | 10.1 | 7.63 |
| 25° | 13.9 | 10.51 |
| 30° | 17.3 | 13.08 |
| 35° | 21.5 | 16.25 |
| 40° | 25.2 | 19.05 |
| 45° | 30.3 | 22.90 |
| 50° | 36.7 | 27.74 |
| 55° | 43.0 | 32.50 |
| 60° | 52.6 | 39.76 |
| 65° | 67.2 | 50.80 |
| 70° | 84.1 | 63.57 |
| 75° | 114.0 | 86.17 |

Tab. 2: Determine the inclination α based on the average value of the two measured values $\alpha_1$ and $\alpha_2$.

| $\alpha_1$ | $\alpha_2$ | $\alpha = \frac{\alpha_1 + \alpha_2}{2}$ |
|---|---|---|
| 65° | 56° | 60.5° |

### Determining the horizontal component $B_h$

From equation (3) the following can be deduced:

(4) $B_{HH} = B_h \cdot \tan\beta$

The horizontal component $B_h$ is therefore equivalent to the gradient of a line through points plotted on a graph of $B_{HH}$ against tanα.

The magnetic field of the Helmholtz coils $B_{HH}$ can be determined easily. Inside the pair of coils it is highly uniform and is proportional to the current *I* through either of the coils:

(5) $B_{HH} = k \cdot I$ where

$$k = \left(\frac{4}{5}\right)^{\frac{3}{2}} \cdot 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot \frac{N}{R}$$

*N* = 124: number of windings
*R* = 147.5 mm: radius

- Compute the magnetic field $B_{HH}$ of the Helmholtz coil pairs for all set currents *I* (Tab. 1) in accordance with Equation (5) and enter the results in Tab. 1.

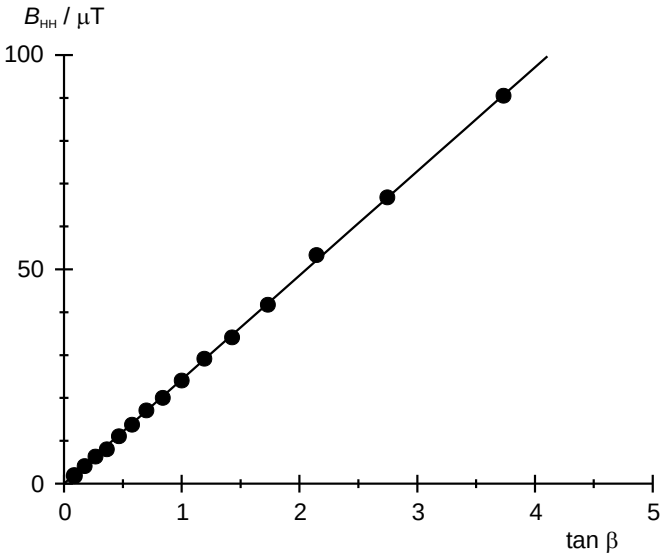


Fig. 3: $B_{HH}$ – tanα - Graph to determine the horizontal component of the earth's magnetic field.

- Plot the magnetic filed $B_{HH}$ versus tanβ in a graph and fit a straight line (Fig. 2).
- Deduce the horizontal component $B_h$ directly from the slope of the line.

(6) $B_h = 23\ \mu\text{T}$

### Determining the vertical component $B_v$ from the inclination α

- Determine the inclination α from the average value of the two measured values $\alpha_1$ and $\alpha_2$ (Tab. 2) and enter the results into Tab. 2.
- Use Equation (1) to determine the vertical component.

(7) $B_v = B_h \cdot \tan\alpha = 23\ \mu\text{T} \cdot \tan 60.5° = 41\ \mu\text{T}$

### Determine the overall magnetic field

- Determine the overall magnitude of the Earth's magnetic field *B* with the aid of Equation (2).

(8) $B = \sqrt{(23\ \mu\text{T})^2 + (41\ \mu\text{T})^2} = 47\ \mu\text{T}$

The values for the horizontal and vertical components determined from the measurement are in very good agreement with the values found in the literature for Central Europe $B_h$ = 20 μT and $B_v$ = 44 μT.