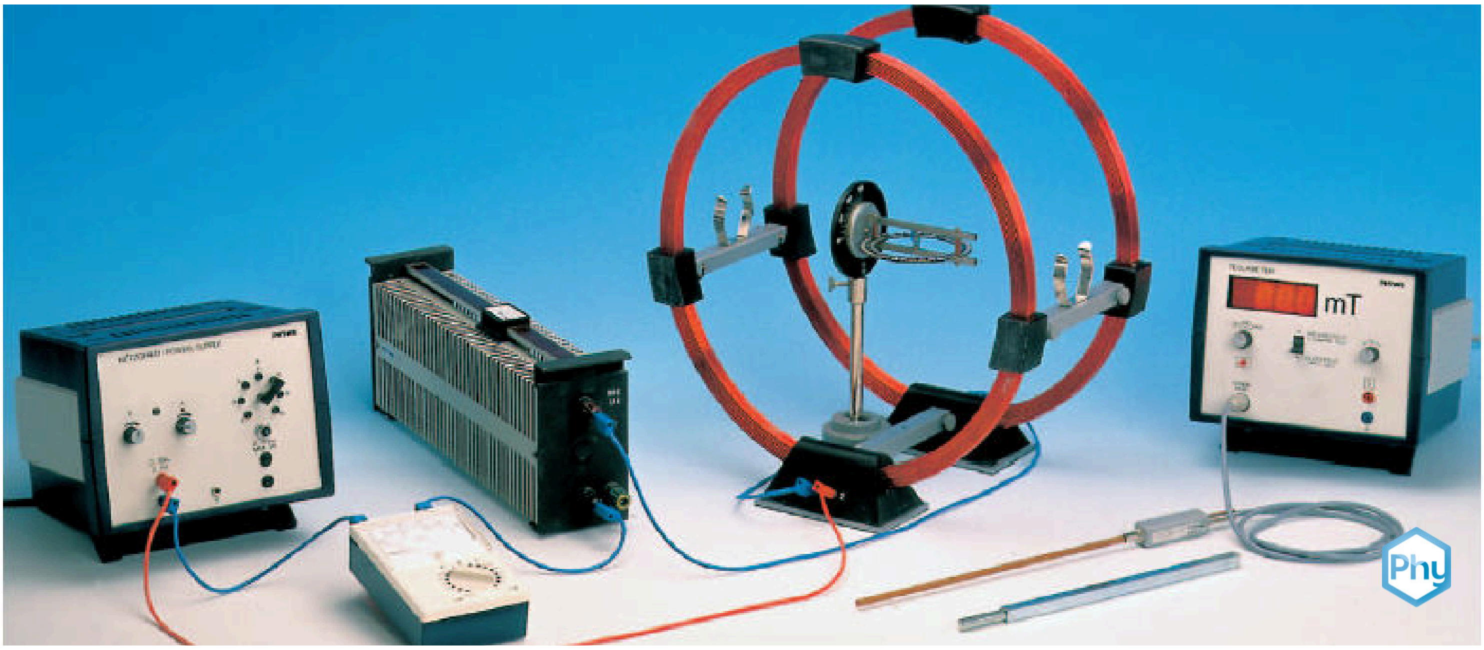
Determination of the earth's magnetic field



Physics | Electricity & Magnetism | Magnetism & magnetic field

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/6013eb1ae60a490003a0f1cc

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

General information

Application

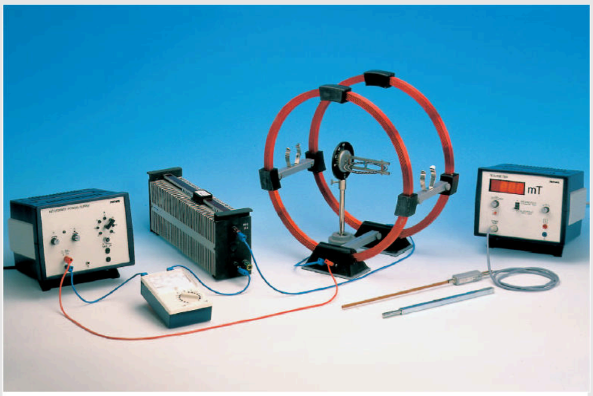


Fig.1: Experimental set-up

The magnetic field of the earth protects the planet from cosmic radiation. Exact knowlege about its precise form alows for the calibration of measurment tools, that are used to measure other magnetic fields.

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Other information (1/2)

PHYWE

Prior knowledge

The prior knowlege required for this experiment is found in the theory section.

Main principle

A constant magnetic field, its magnitude and direction known, is superimposed on the unknown earth-magnetic field. The earth-magnetic field can then be calculated from the magnitude and direction of the resulting flux density.

Other information (2/2)

PHYWE

Learning objective

The goal of this experiment is to measure the magnetic field of the earth.

Tasks

1. The magnetic flux of pair of Helmholtz coils is to be determined and plotted graphically as a function of the coil current. The Helmholtz system calibration factor is calculated from the slope of the line.
2. The horizontal component of the earth-magnetic field is determined through superimposition of the Helmholtz field.
3. The angle of inclination must be determined in order to calculate the vertical component of the earth-magnetic field.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Theory (1/2)

For currentless coils, the magnetic needle of the magnetometer alligns itself with the horizontal component ${}^{h}B_{E}$ (direction "north/south") of the earth-magnetic field. If an additional magnetic field ${}^{h}B_{H}$ is superimposed on this component through the Helmholtz coils, the needle will be turned around the angle α and will point in the direction of the resulting ${}^{h}B_{H}$.In Fig. 3A), the field components for the general case $\varphi \neq 90^{\circ}$ are represented. The components drawn by a broken line represent the resulting conditions of the polarity of the coil current is reversed. By means of the sine-theorem, we obtain:

$$\frac{\sin\alpha}{\sin\beta} = \frac{\sin\alpha}{\sin(\varphi - \alpha)} = \frac{{}^{\mathrm{h}}B_{\mathrm{H}}}{{}^{\mathrm{h}}B_{\mathrm{E}}} \quad (1)$$

Theory (2/2)

In the special case where the coil axis is perpendicular to the direction “north/south” $\varphi = 90^{\circ}$, the following applies:

$$ {}^{\mathrm{h}}B_{\mathrm{E}} = {}^{\mathrm{h}}B_{\mathrm{H}} \cot\alpha \quad (2)$$

By means of the calibration

$$ {}^{\mathrm{h}}B_{\mathrm{H}} = I_{\mathrm{H}} \cdot K \quad (3)$$

we get from (1):

$$ {}^{\mathrm{h}}B_{\mathrm{E}} \cdot \left(\frac{\sin\alpha}{\sin\beta}\right) = I_{\mathrm{H}} \cdot K \quad (4)$$

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Equipment

Position	Material	Item No.	Quantity
1	Helmholtz coils, one pair	06960-06	1
2	PHYWE Power supply, universal DC: 0...18 V, 0...5 A / AC: 2/4/6/8/10/12/15 V, 5 A	13504-93	1
3	Rheostat, 100 Ohm, 1.8 A	06114-02	1
4	PHYWE Teslameter, digital	13610-93	1
5	Hall probe, axial	13610-01	1
6	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C… 760°C	07122-00	1
7	Magnetometer	06355-00	1
8	Barrel base expert	02004-00	1
9	Right angle clamp expert	02054-00	1
10	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
11	Stand tube	02060-00	1
12	Connecting cord, 32 A, 1000 mm, red	07363-01	1
13	Connecting cord, 32 A, 1000 mm, blue	07363-04	4

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

PHYWE

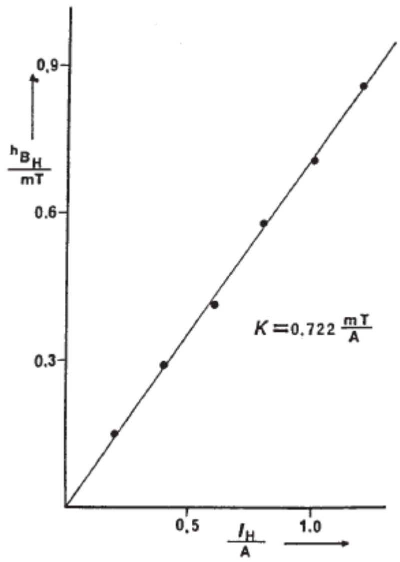
Setup and Procedure

Setup

PHYWE

The experiment composition is as depicted in Fig. 1. The Helmholtz coils, complete with mounted space-holders, are connected in series (linkage of equally-numbered connections) and connected with the DC generator by the rheostat and the multimeter used as ammeter. The Hall probe is to be fixed on the support rod with barrel base pointing inward toward the coil axis in the center of the Helmholtz arrangement. In this arrangement, the horizontal flux density ${}^{h}B_{H}$ of the pair of coils is to be determined as a function of the coil current I_{H}. The calibration factor $K = {}^{\mathrm{h}}B_{\mathrm{H}}/I_{\mathrm{H}}$ is determined through the appertaining graphic representation. (See Fig. 2).

Fig. 2: Calibration function of the pair of Helmholtz coils.



PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Procedure (1/2)

Note: Before measuring begins, the zero-point position of the teslameter must be set precisely.

By means of barrel base, stand tube and optic judgement, the magnetometer (with a leveled graduated circle) is placed between the coils so that the center of the graduated circle is approximately identical with the center of the pair of coils.

First, the direction “north/south” is noted on the graduated circle for currentless coils. In order to secure the direction “north/south” of the magnetic needle, the needle should beslightly turned away from its resting position several times. Possible friction resistance can be reduced by gently tapping the instrument. In order to determine the horizontal component ${}^hB_E$ of the earth-magnetic field, the deflection angle α of the magnetic needle is measured from its resting position as a function of small coil currents. If the polarity of the coil current is reversed, the measuring series must be repeated. In determining the exact angle, the indications from both needle tips must be considered.

Procedure (2/2)

The angle φ (Fig. 3A) between the direction “north/south” and the axis of the pair of coils is obtained through maximal needle deflection when the resistor is short-circuited the ammeter eliminated and the coil current set to approximately 4 A.

In conclusion, and for currentless coils, the graduated circle of the magnetometer is turned to the vertical plane so that the magnetic needle now indicates the inclination angle ϑ_1.Make sure that the spin axis is consistent with the direction “north/south”. In order to check on ϑ_2, the magnetometer is turned by 180° and thus replaced on the vertical plane.

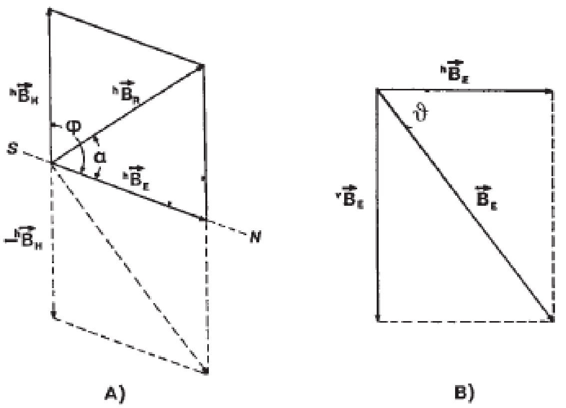


Fig. 3: Vector diagram of the magnetic flux densities: A) horizontal plane, B) vertical plane.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Evaluation

Results (1/2)

If $I_H \cdot K$ is represented as a function of $\frac{\sin\alpha}{\sin\beta}$ (Fig. 4), the horizontal component of the earth-magnetic field is obtained from the slope.

$${}^{\mathrm{h}}B_{\mathrm{E}} = 19.2\,\mu\mathrm{T}$$

From Fig. 3 B) follows the vertical component ${}^{\mathrm{v}}B_{\mathrm{E}}$ and the measured angle of inclination.

$$\vartheta = \frac{1}{2}(\vartheta_1 + \vartheta_2) = \frac{1}{2}(67^\circ + 68^\circ) = 67.5^\circ$$

$${}^{\mathrm{v}}B_{\mathrm{E}} = {}^{\mathrm{h}}B_{\mathrm{E}} \tan\vartheta = 46.3\,\mu\mathrm{T} \quad (5)$$

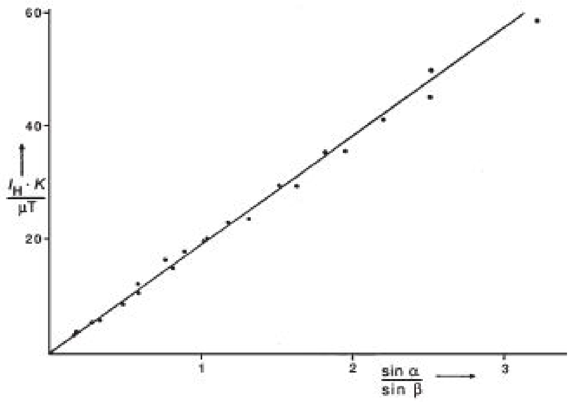


Fig. 4: Linear function according to (4) to determine the horizontal component ${}^{h}B_{E}$ of the magnetic flux density of the earth-magnetic field.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Results (2/2)

The total flow density B_E is calculated to

$$|B_\mathrm{E}| = \sqrt{({}^\mathrm{v}B_\mathrm{E})^2 + ({}^\mathrm{h}B_\mathrm{E})^2} = 50.2\,\mu\mathrm{T} \quad (6)$$

Reference values for Göttingen, Germany:

$${}^\mathrm{h}B_\mathrm{E} = 19.06\,\mu\mathrm{T}$$

$${}^\mathrm{v}B_\mathrm{E} = 43.96\,\mu\mathrm{T}$$

$$\vartheta = 66.57^\circ$$

$$B_\mathrm{E} = 47.91\,\mu\mathrm{T}$$

Note

Acceptable measuring results are only obtainable if the influence of perturbing magnetic fields (for example: pieces of iron close to the measuring site) is avoided.

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de