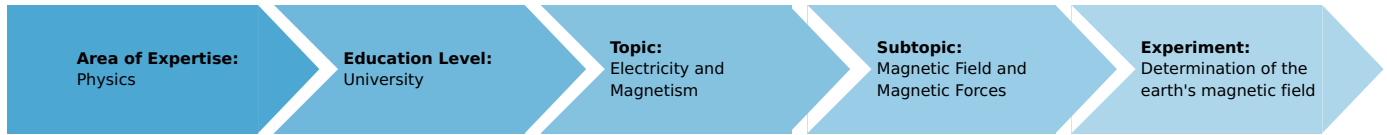


# Determination of the earth's magnetic field

(Item No.: P2430100)

## Curricular Relevance



### Difficulty



Difficult

### Preparation Time



1 Hour

### Execution Time



2 Hours

### Recommended Group Size



2 Students

### Additional Requirements:

### Experiment Variations:

### Keywords:

magnetic inclination, magnetic declination, isoclinic lines, isogonic lines, inclinometer, magnetic flux density, Helmholtz coils

## Overview

### Short description

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.



Fig. 1: Experimental set-up to determine the earth's magnetic field.

## Equipment

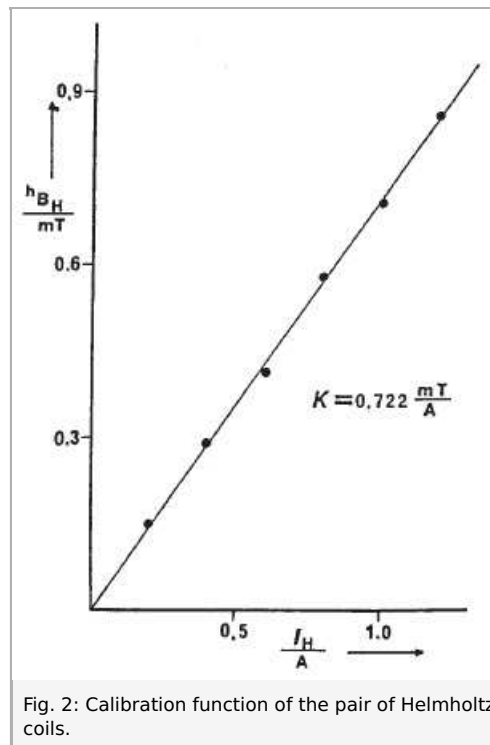
Position No.	Material	Order No.	Quantity
1	Helmholtz coils, one pair	06960-00	1
2	PHYWE power supply, universal DC: 0...18 V, 0...5 A / AC: 2/4/6/8/10/12/15 V, 5 A	13504-93	1
3	Rheostat, 100 Ohm , 1.8A	06114-02	1
4	Teslameter, digital	13610-93	1
5	Hall probe, axial	13610-01	1
6	Digital multimeter 2005	07129-00	1
7	Magnetometer	06355-00	1
8	Barrel base PHYWE	02006-55	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

## 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.

## Set-up and procedure

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  $K = {}^h B_H / I_H$  is determined through the appertaining graphic representation. (See Fig. 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 be slightly 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  ${}^h B_E$  of the earth-magnetic field, the deflection angle  $\alpha$  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.

The angle  $\varphi$  (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  $\vartheta_1$ . Make sure that the spin axis is consistent with the direction "north/south". In order to check on  $\vartheta_2$ , the magnetometer is turned by  $180^\circ$  and thus replaced on the vertical plane.

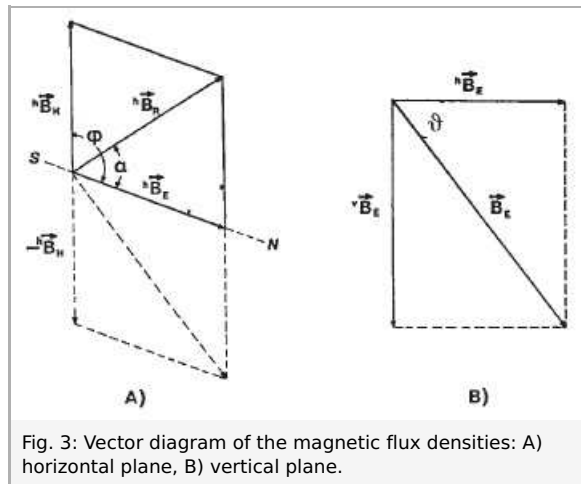


Fig. 3: Vector diagram of the magnetic flux densities: A) horizontal plane, B) vertical plane.

## Theory and evaluation

For currentless coils, the magnetic needle of the magnetometer aligns 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  $\alpha$  and will point in the direction of the resulting  ${}^h B_R$ . 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:

$$\frac{\sin \alpha}{\sin \beta} = \frac{\sin \alpha}{\sin(\varphi - \alpha)} = \frac{{}^h B_H}{{}^h B_E} \quad (1)$$

In the special case where the coil axis is perpendicular to the direction "north/south" ( $\varphi = 90^\circ$ ), the following applies:

$${}^h B_E = {}^h B_H \cot \alpha \quad (2)$$

By means of the calibration

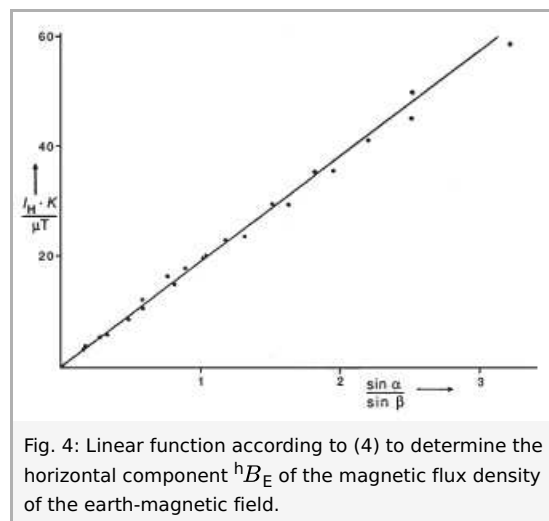
$${}^h B_H = I_H \cdot K \quad (\text{see Fig. 2}) \quad (3)$$

we get from (1):

$${}^h B_E \cdot \left( \frac{\sin \alpha}{\sin \beta} \right) = I_H \cdot K \quad (4)$$

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.

$${}^h B_E = 19.2 \mu\text{T}$$



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

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

$${}^v B_E = {}^h B_E \tan \vartheta = 46.3 \mu\text{T} \quad (5)$$

The total flow density  $B_E$  is calculated to

$$|B_E| = \sqrt{({}^v B_E)^2 + ({}^h B_E)^2} = 50.2 \mu\text{T} \quad (6)$$

Reference values for Göttingen, Germany:

$${}^h B_E = 19.06 \mu\text{T}$$

$${}^v B_E = 43.96 \mu\text{T}$$

$$\vartheta = 66.57^\circ$$

$$B_E = 47.91 \mu\text{T}$$

## 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.

## Abbreviations

${}^h B_H$  horizontal flux density in the center of the Helmholtz arrangement (external field)

${}^h B_E$  horizontal component of the earth-magnetic field

${}^h B_R$  resulting flux density

${}^v B_E$  vertical component of the earth-magnetic field

$I_H$  Helmholtz coil current

$K$  calibration factor