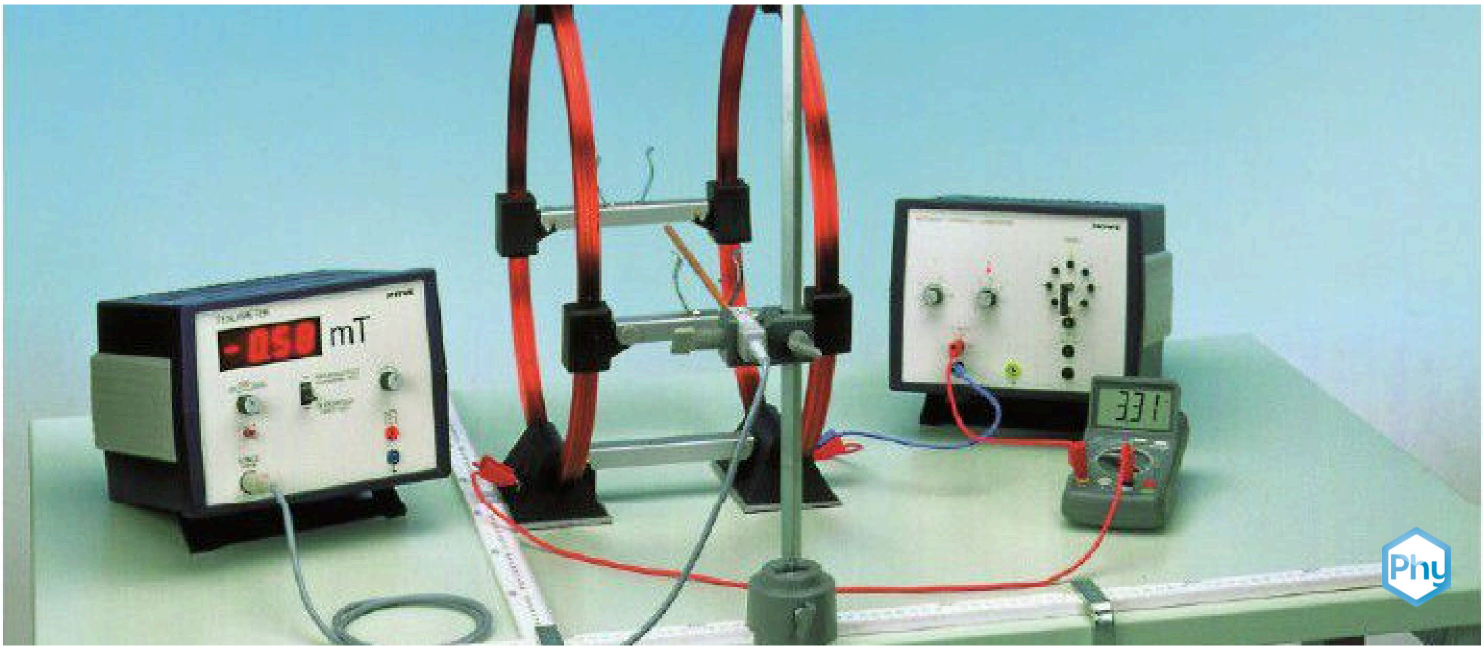
Magnetic field of paired coils in a Helmholtz arrangement with a teslameter



Physics | Electricity & Magnetism | Magnetism & magnetic field

Difficulty level	Group size	Preparation time	Execution time
easy	2	20 minutes	30 minutes

This content can also be found online at:

http://localhost:1337/c/601435d438ab09000357d9c8

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General information

Application

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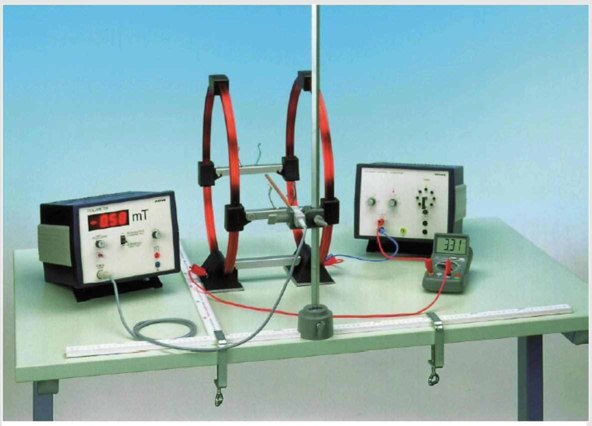

Fig.1: Experimental set-up

Magnetic fields are widely used in different fields. From the magnets used on junkyards to transport old cars up to their use in particle accelerators magnetic fields produced by coils have many applications.

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Other information (1/2)

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Prior knowledge

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

Main principle

The spatial distribution of the field strength between a pair of coils in the Helmholtz arrangement is measured. The spacing at which a uniform magnetic field is produced is investigated and the superposition of the two individual fields to form the combined field of the pair of coils is demonstrated.

Other information (2/2)

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Learning objective

The goal of this experiment is to investigate the magnetic field produced by paired coils.

Tasks

1. Measure the magnetic flux density along the z-axis of the flat coils when the distance between them a = R (R = radius of the coils) and when it is greater and less than this.
2. Measure the spatial distribution of the magnetic flux density when the distance between coils a = R, using the rotational symmetry of the set-up:
   a. measurement of the axial component B_z
   b. measurement of radial component B_r
3. Measure the radial components B'_z and B''_z of the two individual coils in the plane midway between them and to demonstrate the overlapping of the two fields at $B_r = 0$

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Theory (1/4)

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From Maxwell's equation

$\int_K \vec{H} d\vec{s} = I + \int_F \dot{\vec{D}} d\vec{f}$ (1)

where K is a closed curve around area F, H is the magnetic field strength, I is the current flowing through area F, and D is the electric flux density, we obtain for direct currents ($\dot{D} = 0$), the magnetic flux law:

$\int_K \vec{H} d\vec{s} = I$ (2)

With the notations from Fig. 2, the magnetic flux law (2) is written in the form of Biot-Savart's law:

$d\vec{H} = \frac{I}{4\pi} \frac{d\vec{l} \times \rho}{\rho^3}$ (3)

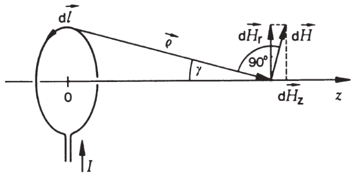

Fig. 2: Drawing for the calculation of the magnetic field along the axis of a wire loop.

Theory (2/4)

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The vector $\overrightarrow{\mathrm{d}l}$ is perpendicular to $\vec{\rho}$ in addition to this $\vec{\rho}$ and $\mathrm{d}\vec{H}$ lie in the plane of the drawing, so that

$dH = \frac{I}{4\pi\rho^2} dl = \frac{I}{4\pi} \frac{dl}{R^2+z^2}$ (4)

$\mathrm{d}\vec{H}$ can be resolved into a radial $\mathrm{d}H_r$ and an axial $\mathrm{d}H_z$ component.

The $\mathrm{d}H_z$ components have the same direction for all conductor elements $\overrightarrow{\mathrm{d}l}$ and the quantities are added; the $\mathrm{d}H_r$ components cancel one another out, in pairs.

Therfore, $H_r(z) = 0$ (5)

and $H(z) = H_z(z) = \frac{I}{2} \frac{R^2}{(R^2+z^2)^{3/2}}$ (6)

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Theory (3/4)

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along the axis of the wire loop, while the magnetic flux density

$$B(z) = \frac{\mu_0 \cdot I}{2R} \cdot \frac{1}{\left(1+\left(\frac{z}{R}\right)^2\right)^{3/2}} \qquad (7)$$

The magnetic field of a flat coil is obtained by multiplying (6) by the number of turns N. Therefore, the magnetic flux density along the axis of two identical coils at a distance α apart is

$$B(z, r=0) = \frac{\mu_0 \cdot I \cdot N}{2R} \cdot \left(\frac{1}{\left(1+A_1^2\right)^{3/2}} + \frac{1}{\left(1+A_2^2\right)^{3/2}}\right) \qquad (8)$$

where $A_1 = \frac{z+\alpha/2}{R}$

Theory (4/4)

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When z = 0, flux density has a maximum value when $\alpha < R$ and a minimum value when $\alpha > R$. The curves plotted from our measurements also show this (Fig. 3); when $\alpha = R$, the field is virtually uniform in the range

$$-\frac{R}{2} < z < +\frac{R}{2}$$

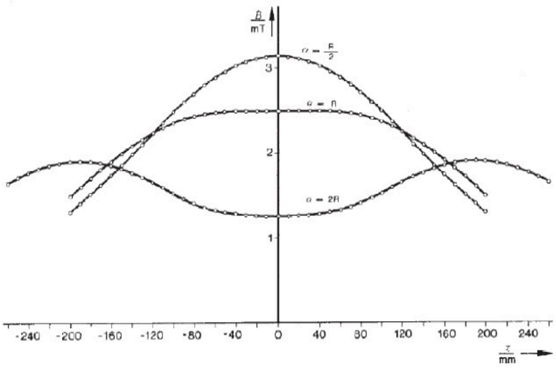

Fig. 3: $B\,(r = 0)$ as a function of z with the parameter α.

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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	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C… 760°C	07122-00	1
4	PHYWE Teslameter, digital	13610-93	1
5	Hall probe, axial	13610-01	1
6	Meter scale, l = 1000 mm	03001-00	2
7	Barrel base expert	02004-00	1
8	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
9	Right angle clamp expert	02054-00	1
10	G-clamp	02014-00	3
11	Connecting cord, 32 A, 500 mm, blue	07361-04	2
12	Connecting cord, 32 A, 500 mm, red	07361-01	2
13	Universal clamp	37715-01	1

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Setup and Procedure

Setup (1/2)

Connect the coils in series and in the same direction, see Fig. 4; the current must not exceed 3.5 A (operate the power supply as a constant current source). Measure the flux density with the axial Hall probe (measures the component in the direction of the probe stem).

The magnetic field of the coil arrangement is rotationally symmetrical about the axis of the coils, which is chosen as the z-axis of a system of cylindrical coordinates (z, r, ϕ). The origin is at the centre of the system. The magnetic flux density does not depend on the angle ϕ, so only the components $B_\mathrm{z}\ (z,\ r)$ and $B_\mathrm{r}\ (z,\ r)$ are measured.

Clamp the Hall probe on to a support rod with barrel base, level with the axis of the coils. Secure two rules to the bench (parallel or perpendicular to one another, see Figs. 5–7). The spatial distribution of the magnetic field can be measured by pushing the barrel base along one of the rules or the coils along the other one.

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Setup (2/2)

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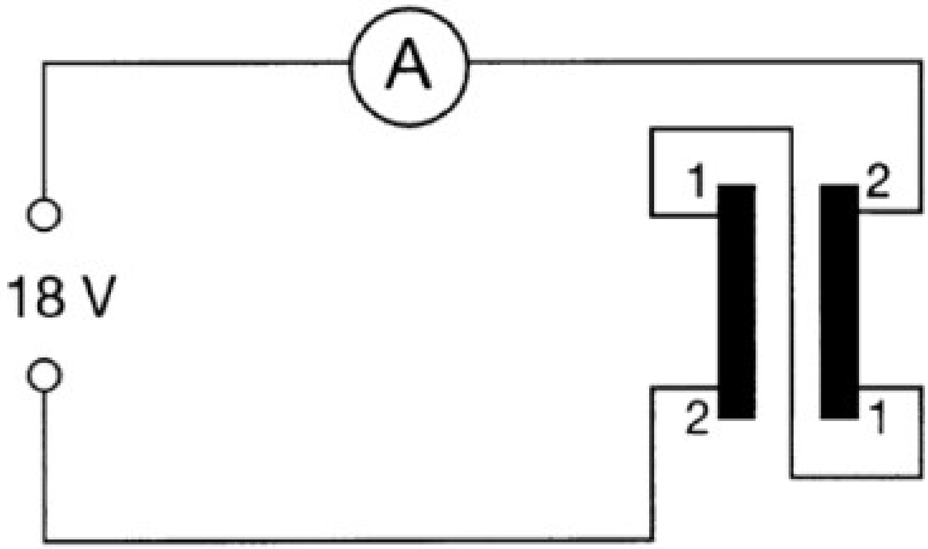

Fig. 4: Wiring diagram for Helmholtz coils.

Procedure (1/3)

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- Along the z-axis, for reasons of symmetry, the magnetic flux density has only the axial component Bz. Fig. 5 shows how to set up the coils, probe and rules. (The edge of the bench can be used instead of the lower rule if required.) Measure the relationship B (z, r = 0) when the distance between the coils a = R and, for example, for a = R/2 and a = 2R.

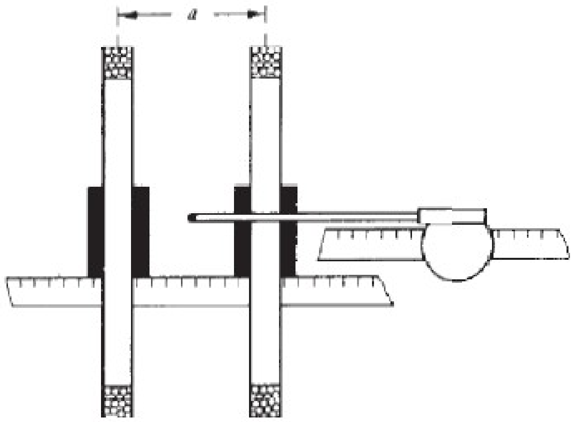

Fig. 5: Measuring $B\,(z,\, r = 0)$ at different distances a between the coils.

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Procedure (2/3)

- When distance a = R the coils can be joined together with the spacers. a) Measure Bz (z, r) as shown in Fig. 6. Set the r-coordinate by moving the probe and the z-coordinate by moving the coils. Check: the flux density must have its maximum value at point (z = 0, r = 0). b) Turn the pair of coils through 90° (Fig. 7). Check the probe: in the plane z = 0, B_z must = 0.

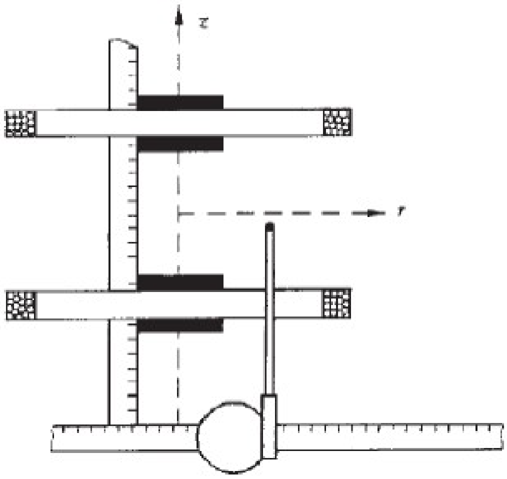

Fig. 6: Measuring B_z (*z*, *r*).

Procedure (3/3)

- Short-circuit first one coil, then the other. Measure the radial components of the individual fields at z = 0.

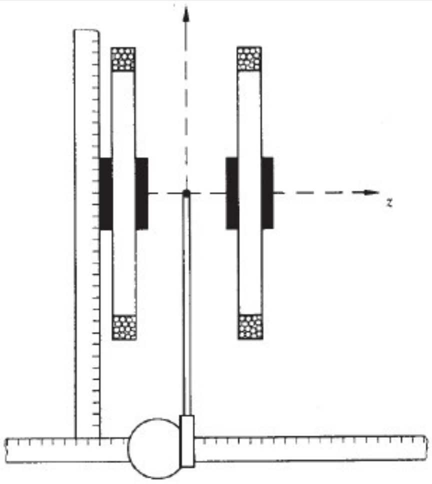

Fig. 7: Measuring B_r (*z*, *r*).

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Evaluation

Results (1/2)

Magnetic flux density at the mid-point when$\alpha = R$:

$$B(0.0) = \frac{\mu_0 \cdot I}{2R} \cdot N \cdot \frac{2}{\left(\frac{5}{4}\right)^{\frac{3}{2}}} = 0.716\, \mu_0 \cdot N \cdot \left(\frac{I}{R}\right)$$

when N = 154, R = 0.20 m and I = 3.5 A this gives:

B (0.0) = 2.42 mT.

Our measurements gave B (0.0) = 2.49 mT.

Figs. 8 and 9 shows the curves Bz (z) and Br (z) measured using r as the parameter; Fig. 10 shows the super-position of the fields of the two coils at $B_r = 0$ in the centre plane z = 0.

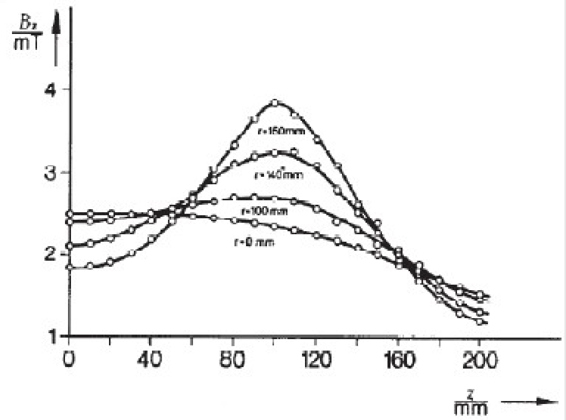

Fig. 8: $B_z(z)$, parameter *r* (positive quadrant only).

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Results (2/2)

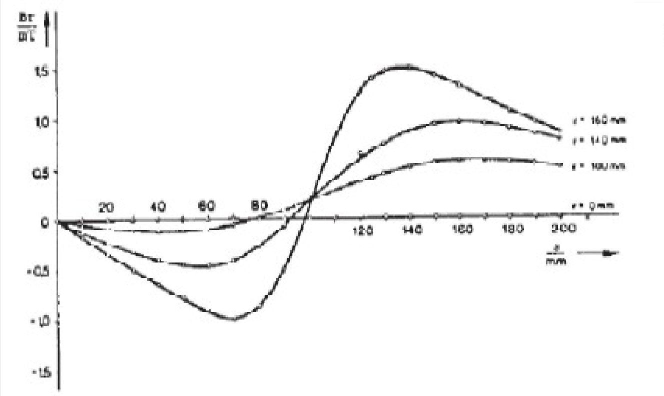

Fig. 9: $B_z(z)$, parameter r (positive quadrant only).

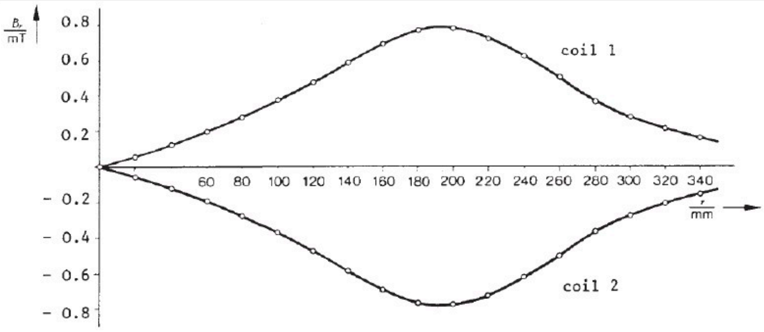

Fig. 10: Radial components B_r'(r) and $B_r''(r)$ of the two coils when z = 0.

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