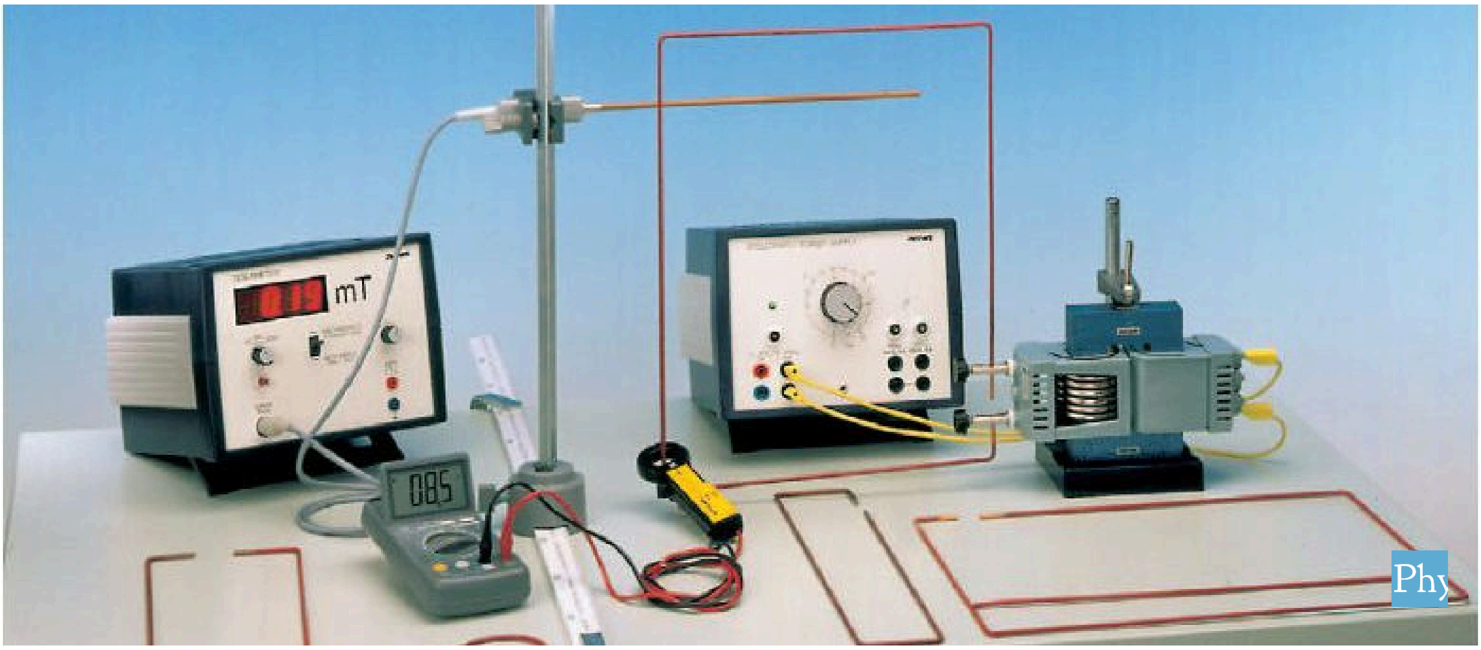
# Magnetic field outside a straight conductor



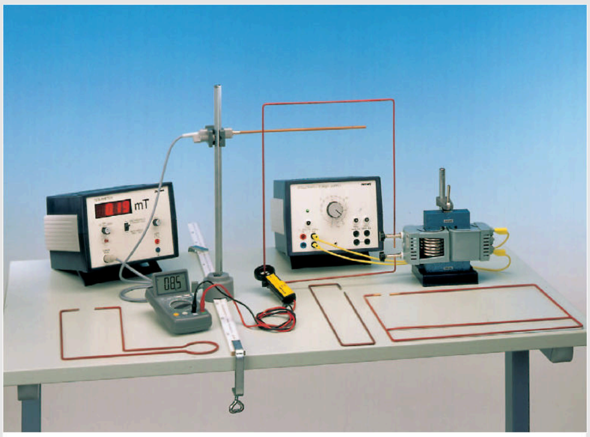
The goal of this experiment is to investigate the magnetic field around a straight conductor.

Physics › Electricity & Magnetism › Magnetism & magnetic field

| Difficulty level | Group size | Preparation time | Execution time |
|---|---|---|---|
| hard | 2 | 10 minutes | 10 minutes |

# General information

## Application



Setup

Moving electric charges result in a magnetic field. The magnetic field around a straight conductor is the fundamental form, that such a magnetic field takes.

This experiment tries to determine the form of such a magnetic field.

## Other information (1/2)

**Prior knowledge**

No prior knowledge is required.

**Scientific principle**

A current which flows through one or two neighbouring straight conductors produces a magnetic field around them. The dependences of these magnetic fields on the distance from the conductor and on the current are determined.

## Other information (2/2)

**Learning objective**

The goal of this experiment is to investigate the magnetic field around a straight conductor.

**Tasks**

Determination of the magnetic field

1. of a straight conductor as a function of the current,
2. of a straight conductor as a function of the distance from the conductor,
3. of two parallel conductors, in which the current is flowing in the same direction, as a function of the distance from one conductor on the line joining the two conductors,
4. of two parallel conductors, in which the current is flowing in opposite directions, as a function of the distance from one conductor on the line joining the two conductors.

# Theory (1/3)

Maxwell's 1st equation for the case when electric fields $\vec{E}$, variable with time, are absent,

$$\int_C \vec{B} \cdot d\vec{s} = \mu_0 \int_A \vec{j} \cdot d\vec{A} \qquad (1)$$

together with Maxwell's 4th equation,

$$\int_A' \vec{B} \cdot d\vec{A} = 0 \qquad (2)$$

provides the relationship between steady electric current I flowing through the area A,

$$I = \int_A \vec{j} \cdot d\vec{A}$$

and the magnetic field $\vec{B}$ which it produces.

# Theory (2/3)

C is the boundary of A, $A'$ is the enclosed area, $\vec{j}$ is the electrical current density, $\mu_0$

is the magnetic field constant, $\mu_0 = 1.26 \cdot 10^{-6}$ Vs/Am .

From (1) and (2) one obtains for a long straight conductor

$$|\vec{B}| = \frac{\mu_0}{2\pi} \cdot \frac{I}{|\vec{r}|} \qquad (3)$$

where $\vec{r}$ is the distance of the conductor from the point at which the magnetic field is measured.

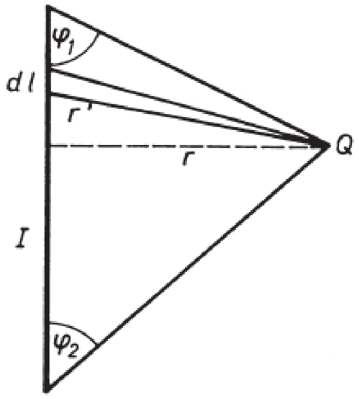


Fig. 1: Contribution of a conductor section dl to the magnetic field at point Q.

## Theory (3/3)

The direction of $\vec{B}$ is $\perp$ both to $\vec{r}$ and to $\vec{j}$.

For a finite conductor one obtains, with the notation of Fig. 1:

$d\vec{B} = \frac{1}{4\pi}\mu_0 \frac{I}{r^3} d\vec{l} \times \vec{r}$ (Biot-Savart)

and from this

$|\vec{B}| = \frac{\mu I}{4\pi r}(\cos\phi_1 - \cos\phi_2)$

# Equipment

| Position | Material | Item No. | Quantity |
|---|---|---|---|
| 1 | Current conductors,set of 4 | 06400-00 | 1 |
| 2 | Coil, 6 turns | 06510-00 | 1 |
| 3 | Coil, 140 turns, 6 tappings | 06526-01 | 1 |
| 4 | Clamping device for iron cores | 06506-00 | 1 |
| 5 | Iron core, I-shaped, laminated | 06500-00 | 1 |
| 6 | Iron core, U-shaped, laminated | 06501-00 | 1 |
| 7 | PHYWE power supply, variable DC: 12 V, 5 A / AC: 15 V, 5 A | 13540-93 | 1 |
| 8 | PHYWE Teslameter, digital | 13610-93 | 1 |
| 9 | Hall probe, axial | 13610-01 | 1 |
| 10 | Current transformer/Clamp Ammeter adaptor | 07091-10 | 1 |
| 11 | Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C… 760°C | 07122-00 | 1 |
| 12 | Meter scale, l = 1000 mm | 03001-00 | 1 |
| 13 | Barrel base expert | 02004-00 | 1 |
| 14 | Support rod, stainless steel, 500 mm | 02032-00 | 1 |
| 15 | Right angle clamp expert | 02054-00 | 1 |
| 16 | G-clamp | 02014-00 | 2 |
| 17 | Connecting cord, 32 A, 500 mm, yellow | 07361-02 | 2 |
| 18 | Universal clamp | 37715-01 | 1 |

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# Setup and Procedure

## Setup and Procedure (1/2)

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The experimental set-up is arranged as shown in Fig. 2. The current transformer is used to measure the secondary current (20 A…120 A). Since the primary and secondary current have a linear relationship, the primary current can also be measured. However, a calibration curve for primary/secondary current should then be recorded for each conductor.
Because of the heating of the conductors, the current must be readjusted or a “warm-up time” must be allowed to elapse.

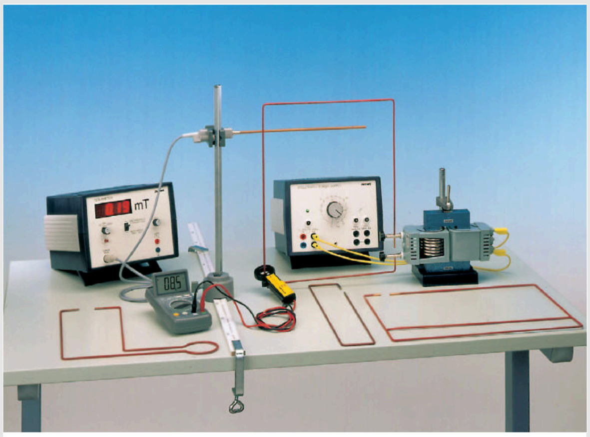

Fig. 2: Experimental setup

## Setup and Procedure (2/2)

A phase displacement can occur between the “construction-kit” transformer and the magnetic field meter, giving the illusion of a “negative” magnetic field (minimum of the magnetic field indicator with increasing current). This can be eliminated by reversing the polarity of the primary of the transformer.

Higher short-time secondary currents can be achieved by connecting the constant and variable voltage in series on the power unit. Attention should be paid to the correct phase angle.

# Evaluation

# Results (1/5)

From the regression line to the measured values of Fig. 3 with the exponential statement

$Y = A \cdot X^B$

the exponent $B = 0.97 \pm 0.01$

and the slope $A = 52.91 \pm 0.01$ A/mT

with (3) this gives $\mu_0 = 1.3 \cdot 10^{-6}$

Because of the small zero-deflection due to the instrument and the effect of the other conductor and the “construction kit” transformer, it is appropriate to carry out the measurement with small distances (up to approx. 3 cm) and with large currents (approx. 100 A).

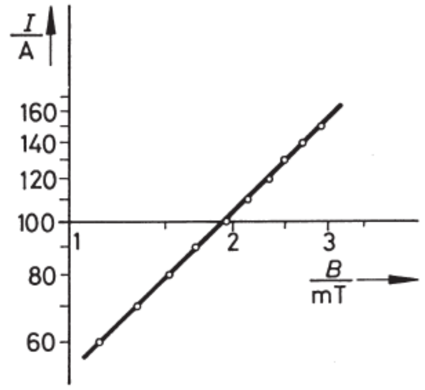

Fig. 3: Relationship between current value and magnetic field of a long conductor (distance between conductor and measuring point: 1.1 cm).

# Results (2/5)

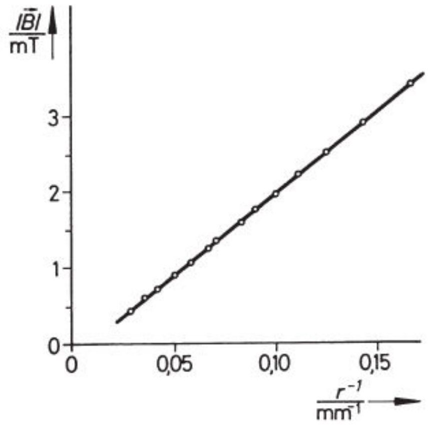

Fig. 4: Magnetic field of a long conductor as a function of distance (I = 100 A).

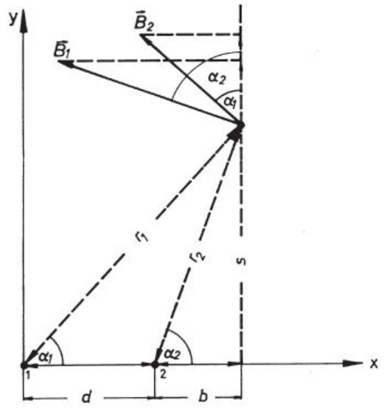

Fig. 5: Magnetic field of two conductors 1 and 2.

## Results (3/5)

For the case of two parallel conductors in the z-direction, both carrying the same current I in the same direction (p = 1) or in opposite directions (p = −1), the superposition of the magnetic fields gives the components $B_x$ and $B_y$ of the magnetic field at point Q with the notation of Fig. 5.

$$B_x = |\vec{B}_1|\sin\alpha_1 + p\cdot|\vec{B}_2|\sin\alpha_2 = \frac{\mu_0 l}{2\pi\cdot s}\cdot(\sin^2\alpha_1 + p\cdot\sin^2\alpha_2)$$

$$B_y = |\vec{B}_1|\cos\alpha_1 + p\cdot|\vec{B}_2|\cos\alpha_2 = \frac{\mu_0 l}{2\pi}\cdot(\frac{1}{b+d}\cos^2\alpha_1 + p\cdot\frac{1}{b}\cdot\cos^2\alpha_2)$$

For Q on the x-axis, one obtains ($\alpha_1 = \alpha_2 = 0$)

The peak at the minimum of the magnetic field originates from the reflection of the negative magnetic field as positive values, since the measuring instrument only indicates the absolute value of the magnetic field. The different values of the magnetic field at r = −5 mm and r = +5 mm occur because of the additive or subtractive superimposition of the magnetic fields of conductors 1 and 2.

## Results (4/5)

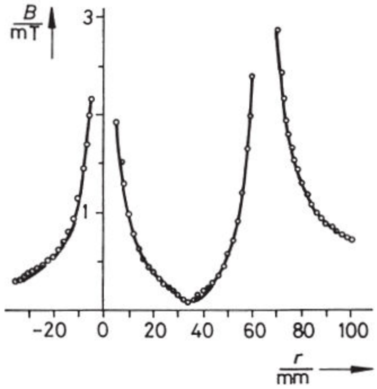

Fig. 6: Magnetic field component $B_x$ of two parallel conductors on the x-axis as a function of the distance from one conductor, if the current in both conductors is in the same direction.

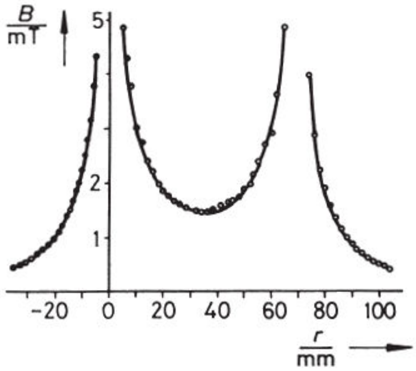

Fig. 7: Magnetic field component $B_y$ of two parallel conductors on the x-axis as a function of the distance from one conductor, if the current in the two conductors is in opposite directions (I = 107 A).

## Results (5/5)

The increase in the field at conductor 2 in comparison with conductor 1 at r = 65 mm as compared with r = 5 mm occurs because of the higher current density in conductor 2, which results from the resistance of the connecting piece between conductors 1 and 2. Finally, beyond conductor 2 (r = 75 mm), the effect of conductor 3 becomes noticeable.
This is parallel to conductors 1 and 2, but the current in it flows in the opposite direction to that in conductors 1 and 2 and thus reinforces the magnetic field of 1 and 2 in this area.

The strengthening of the fields can be clearly seen in the space between the two conductors, compared with the reduction in the area beyond the two conductors.