Current balance – Force acting on a current-carrying conductor (Item No.: P2410601)

Curricular Relevance

Area of Expertise: Physics → **Education Level:** University → **Topic:** Electricity and Magnetism → **Subtopic:** Magnetic Field and Magnetic Forces → **Experiment:** Current balance – Force acting on a current-carrying conductor

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	20 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Uniform magnetic fields, magnetic induction (formerly magnetic- flux densitiy), Lorentz force, moving charges, current

Introduction

Overview

The force acting on a current-carrying conductor loop in a uniform magnetic field (Lorentz force) is measured with a balance. Conductor loops of various sizes are suspended in turn from the balance, and the Lorentz force is determined as a function of the current and magnetic induction. The uniform magnetic field is generated by an electromagnet. The magnetic induction can be varied with the coil current.

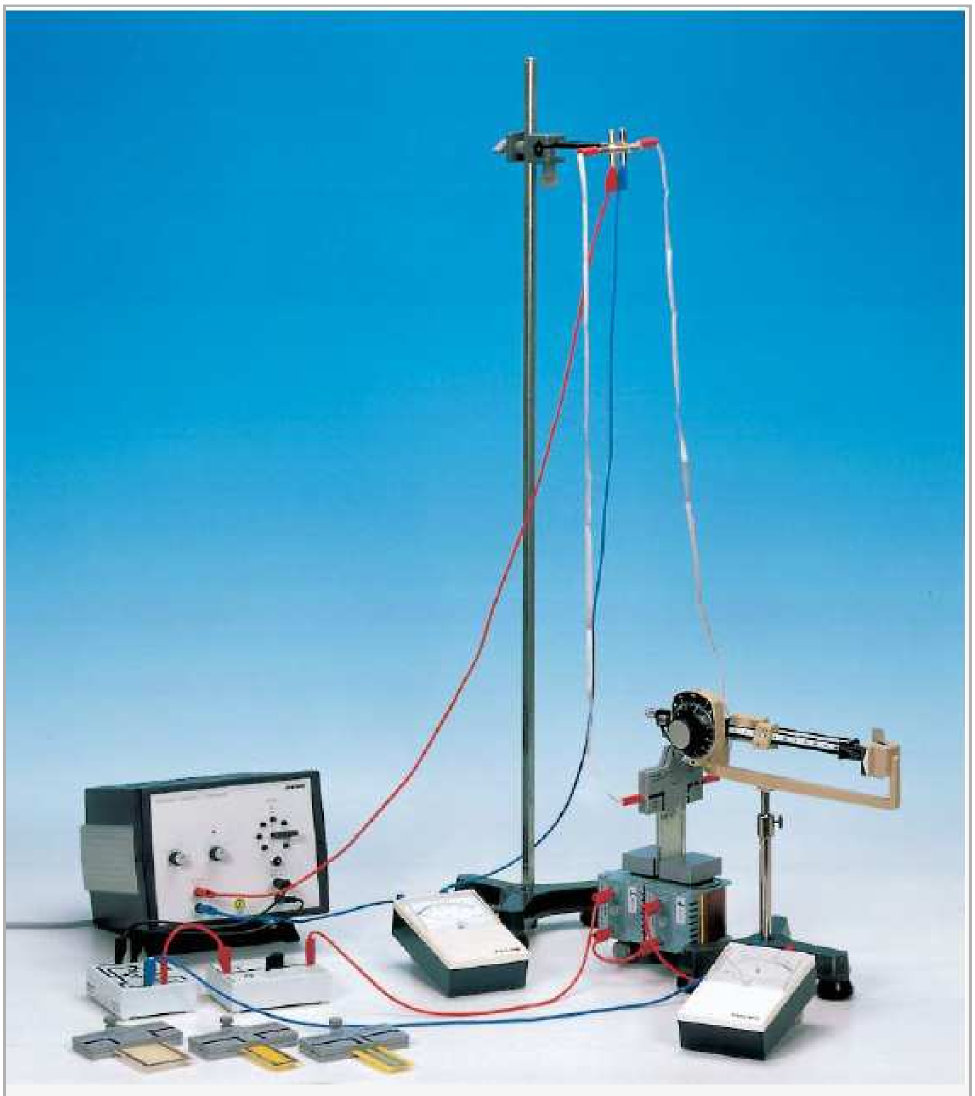
Fig. 1: Experimental set-up: Current balance. Force acting on a currentcarrying conductor.

Note

If a magnetic-field measuring instrument is available, then, in the third of the above tasks, the Lorentz force can be measured directly as a function of the magnetic induction.

Equipment

Position	Material	Bestellnr.	Menge
1	Current balance consisting of	11081-88	1
2	Balance LGN 310, on rod	11081-01	1
3	Pole pieces, rectangular, 1 pair	11081-02	1
4	Wire loop, l = 12.5 mm, n = 1	11081-05	1
5	Wire loop, l = 25 mm, n = 1	11081-06	1
6	Wire loop, l = 50 mm, n = 2	11081-07	1
7	Wire loop, l = 50 mm, n = 1	11081-08	1
Further equipment:			
8	Iron core, U-shaped, laminated	06501-00	1
9	Coil, 900 turns	06512-01	2
10	Metal strip, with plugs	06410-00	2
11	Distributor	06024-00	1
12	Bridge rectifier, 230 V AC/5 A DC	06031-11	1
13	On/off switch	06034-01	1
14	Power supply, universal	13500-93	1
15	Ammeter 1/5 A DC	07038-00	2
16	Tripod base -PASS-	02002-55	2
17	Stand tube	02060-00	1
18	Support rod -PASS-, square, l = 1000 mm	02028-55	1
19	Right angle clamp expert	02054-00	1
20	Connecting cord, l = 100 mm, red	07359-01	1
21	Connecting cord, l = 250 mm, black	07360-05	2
22	Connecting cord, l = 250 mm, blue	07360-04	2
23	Connecting cord, l = 500 mm, red	07361-01	2
24	Connecting cord, l = 500 mm, blue	07361-04	1
25	Connecting cord, l = 1000 mm, red	07363-01	1
26	Connecting cord, l = 1000 mm, blue	07363-04	1
Recommended accessories	for measuring the magnetic field:		
27	Teslameter, digital	13610-93	1
28	Hall probe, tangent., prot. cap	13610-02	1

Tasks

1. The direction of the force is to be determined as a function of the current and the direction of the magnetic field.
2. The force F is to be measured, as a function of the current I_L in the conductor loop, with a constant magnetic induction B and for conductor loops of various sizes. The magnetic induction is to be calculated.
3. The force F is to be measured, as a function of the coil current I_M, for a conductor loop. In the range being considered, the magnetic induction B is, with sufficient accuray, proportional to the coil current I_M.

Set-up and procedure

The experiment is set up as in Fig. 1. The coils of the electromagnet are connected in series and are connected to the alternating voltage output of the power unit via an ammeter, a switch and a bridge rectifier. For the first two parts of the experiment, a fixed voltage of 12 V AC is selected and the associated current I_M in the coils is measured.

The conductor loops are connected via two light flexible metal stripes, first of all to a distributor, and then via an ammeter to the direct voltage output of the supply unit. The distance between the metal strips should be as large as possible and they should only sag slightly, so that no forces from the magnetic field act on them.

1. The pole shoes are first placed on the electromagnets in such a way as to produce an air gap of about 4 cm. The conductor loop with $l = 25\,\mathrm{mm}$ is suspended from the balance with its horizontal section perpendicular to the lines of the magnetic field.

   The balance is trimmed with no current flowing through the conductor, and a conductor current of $I_\mathrm{L} = 5\,\mathrm{A}$ is then set. The direction and magnitude of the force are determined as a function of the direction of the current and are observed with the magnet rotated about a horizontal axis. Without a magnetic field, the position of the balance is observed both with and without current flowing through the conductor loop.

2. The pole shoes are placed on the electromagnet with their edges parallel and with an air gap of 1 cm.

   The conductor loop with $l = 12.5\,\mathrm{mm}$ is hung on the balance. The horizontal section of the conductor runs perpendicular to the field lines and − with the balance trimmed − is in the middle of the uniform field (fine adjustment with screw on tripod). The current in the conductor is raised in steps of 0.5 A with the knob on the power unit. The mass m_0 of the conductor loops is determined with the magnetic field switched off. The magnetic field is then switched on, the (apparently increased) mass m is measured, and the Lorentz force calculated from the difference between the two readings. The measurement is made in a similar way for the other three conductor loops.

3. The procedure is essentially as described in 2 above, only with conductor loop $l = 50\,\mathrm{mm}$, $n = 2$.

   The current in the conductor is $I_\mathrm{L} = 5\,\mathrm{A}$. The current I_M in the coils is varied by means of the applied voltage. The Lorentz force F on each occasion is determined from the readings.

Theory and evaluation

In a magnetic field with a magnetic induction $\vec{B}$, a force $\vec{F}$ (Lorentz force) acts on a moving charge carrier with charge q and velocity $\vec{v}$:

$$\vec{F} = q \cdot \left(\vec{v} \cdot \vec{B}\right) \tag{1}$$

The force vector $\vec{F}$ is perpendicular to the plane occupied by $\vec{v}$ and $\vec{B}$. In this experiment $\vec{v}$ and $\vec{B}$ are also at right angles to each other, so that the following relationship holds for the values of the vectors:

$$F = q \cdot v \cdot B \tag{2}$$

The velocity of the charge carriers (electrons) is measured via the electric current I_L in the conductor. The total charge of the electrons in the section of the conductor of length l must be formulated for q:

$$q \cdot v = I_\mathrm{L} \cdot l \tag{3}$$

The following is therefore obtained for the Lorentz force:

$$F = I_\mathrm{L} \cdot l \cdot B \tag{4}$$

1. Observations show that the direction of the force vector is dependent on the direction of travel of the electrons and the direction of the magnetic field.

   In the field lines are parallel to the direction of travel, a force acts on the conductor loops. At a magnetic induction of $B = 0$, the balance changes its position only slightly when the current I in the conductor loop is switched on. At $I_\mathrm{L} = 5\,\mathrm{A}$, however, the change in the force is quite measureable. The explantation of this effect is that two conductors carrying a current are mutually attracted. When a current flows, the flexible metal strips change their position slightly and can thereby affect the position of the balance.

2. In the two vertical sections of the conductor loop the electrons travel in opposite directions, and the two forces acting on them cancel each other out. Only the horizontal section of the conductor loop, whose length l is stated on the loop, therefore affects the measured Lorentz force. One of the conductor loops has two turns ($n = 2$), each with a horizontal lenght of 50 mm. The Lorentz force on these conductor loops is exactly equivalent to that on a single loop of twice the lenght ($l = 100\,\mathrm{mm}$, $n = 1$).

   The experimental results are shown in Fig. 2, where

$$F \sim I_L .$$

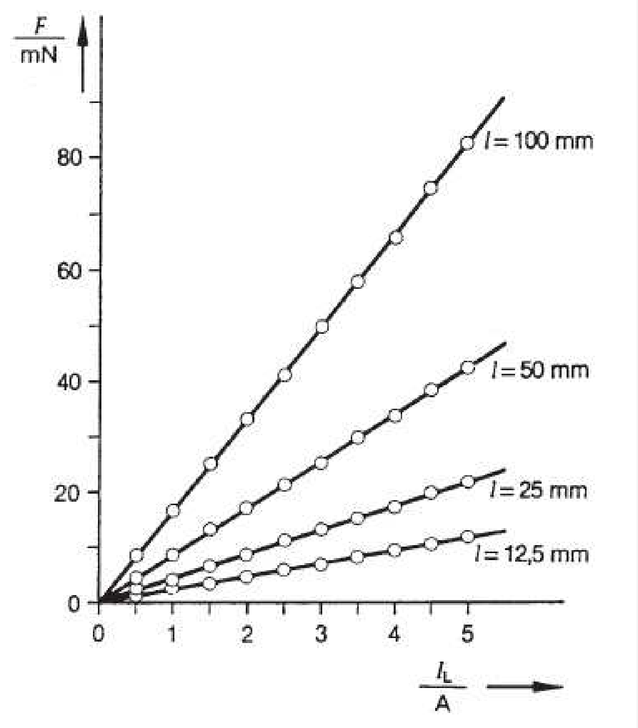

Fig. 2: Lorentz force F as a function of the current I_L in the conductor loop. Coil current I_M = 870 mA. Parameter: length l.

Using the respective parameter, the value of the magnetic induction B can be obtained from the slope of the regression line in Fig. 2 with a standard deviation s_B:

conductor loop length l in mm	magnetic induction B in mT	standard deviation s_B in mT
12.5	184	1
25	173	1
50	168	1
100	164	1

The small value of the standard deviation indicates that the measured values fit nicely on a straight line. The scatter of the values determined for the magnetic induction is due to the stray field at the edge of the uniform magnetic field, which exerts forces on the horizontal part of the leads to the conductor loop. Their effect is greater with short conductor loops than with long ones, since the Lorentz forces measured are small.

In Fig. 3 the Lorentz force F for a fixed current $I_L = 5\,\mathrm{A}$ is plotted against the conductor length l. We obtain:

$$F \sim I_L .$$

As a result of the influence of the stray field described above, the linear graph in Fig. 3 does not pass exactly through the origin.

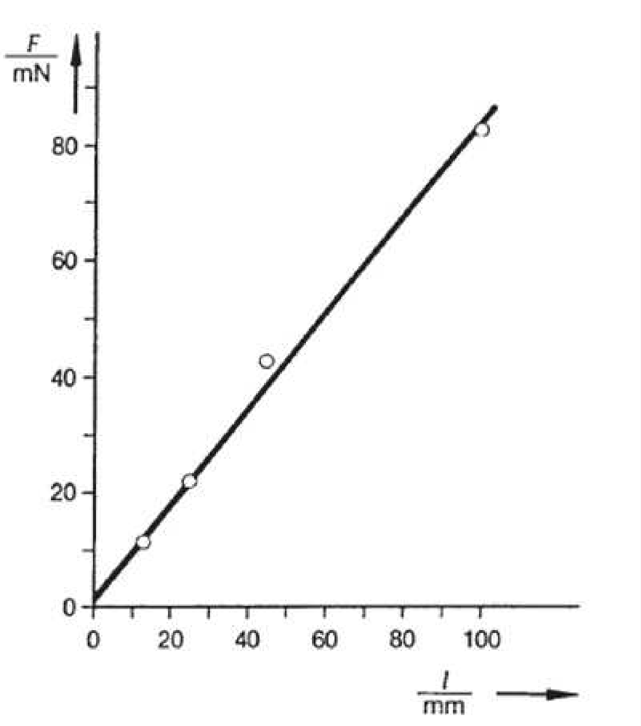

Fig. 3: Lorentz force F as a function of the conductor length l for I_L = 5 A. Coil current 870 mA.

3. The experimental results are shown in Fig. 4. The Lorentz force F is proportional to the current I_{M} in the coils of the electromagnet:

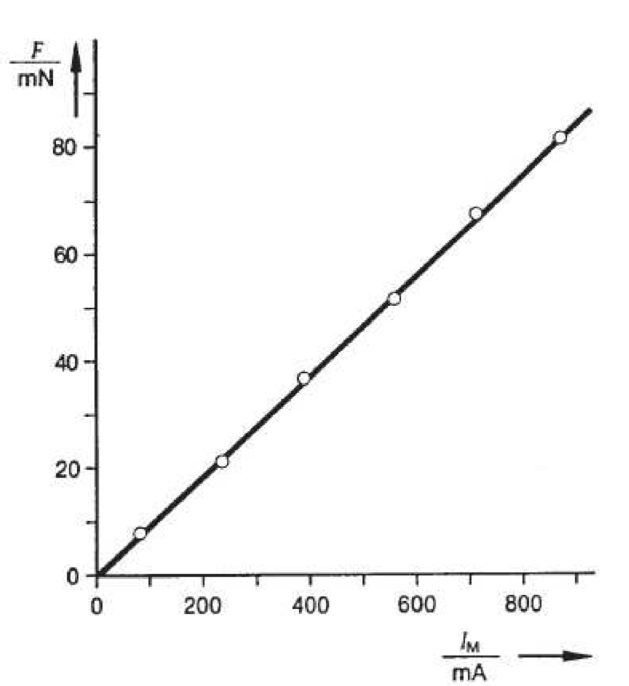

Fig. 4: Lorentz force F as a function of current I_M in the coils for conductor loop l = 100 mm.

Note

If a magnetic-field measuring instrument is available, the magnetic induction can be measured as a function of the coil current. The measurements show that the magnetic induction B and the coil current I_{M} are proportional in the range under consideration.

Together with the results from Fig. 4, we therefore obtain

$$F \sim B\,.$$

With a coil current of $I = 870\,\mathrm{mA}$, the magnetic induction in the 1 cm air gap is $B = 168\,\mathrm{mT}$, in good agreement with the values calculated from the slope of the regression lines in Fig. 2.