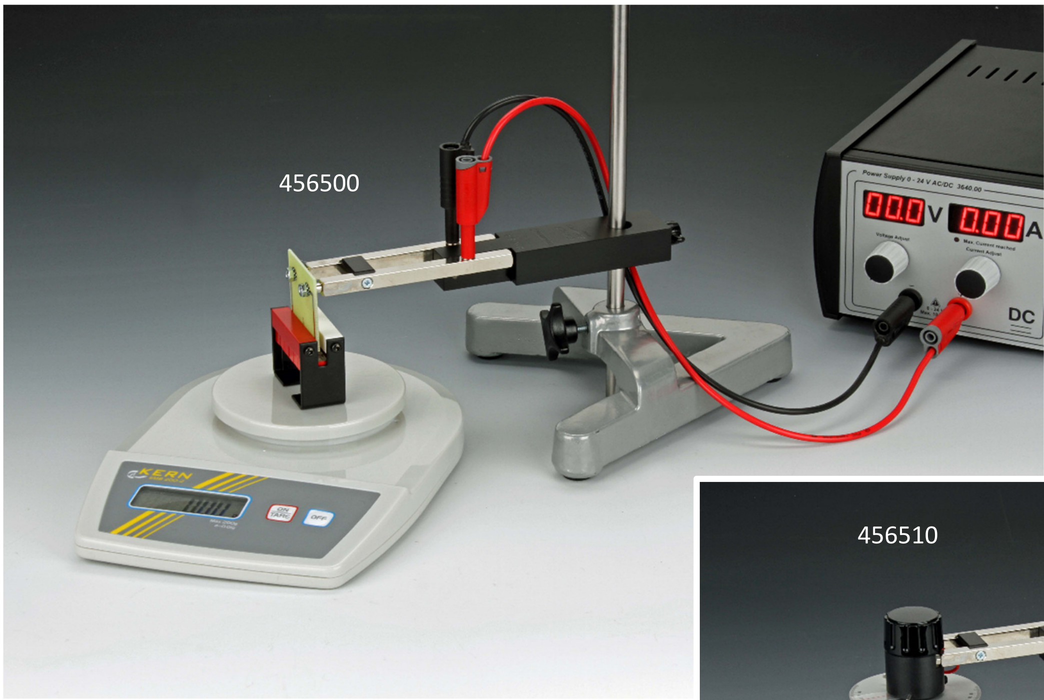
Laplace's force law

Experiment number	137240-EN	*Topic*	Electromagnetism				
Version	2017-07-13 / HS	*Type*	Student exercise	*Suggested for*	grade 12+	*p.*	1/4



Objective

To examine the force on a current carrying conductor in a magnetic field including the angle dependency.

To confirm the theoretical expression for the force (Laplace's force, Lorentz force).

Principle

We use the magnetic fields from a permanent magnet placed on a digital scales. According to Newton's 3rd law, the force on the magnet and the force on the conductor are of equal size, but of opposite directions. Reading the scales can therefore be used to find the force on the conductor.

Equipment

(*Detailed list on p. 4.*)

456500 Current balance
456510 Current balance, angle dependent
364000 Power supply
Lab leads
Stand material
Digital scales 200 g / 0,01 g

The power supply 364000

The short piece of conductor used has a very low resistance, effectively working as a short circuit.

Use therefore the button *Current Adjust* for setting the current while the *Voltage Adjust* button should simply be turned e.g. halfway up.

The current is read on the built-in meter on the power supply.

In case another power supply than 364000 is used, it may be necessary to add a series resistor between the power supply and the conductor. Use 1 Ω, 50 W (420505).

In case the power supply doesn't have a built-in ammeter, an external instrument must be used.

Procedure

1 – Varying the current

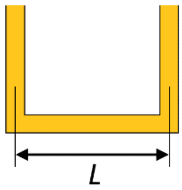
Build the setup as shown on the large picture on p. 1.

In case the scales used is sensible to magnetic fields, increase the distance to the magnetic system with e.g. a small block of polystyrene foam.

The conductor used is placed on a replaceable piece of printed circuit board. Some of these are double-sided, allowing the current to run at both sides.

The conductor holder (blank metal) can be tilted; you can change the conductor without moving the magnet assembly.

Start with the single-sided board with the longest horizontal conductor.



Measure the length (L) of the horizontal part.

Adjust the height to make the conductor at the height of the centre of the pole shoes of the magnet.

Turn down *Current Adjust* completely and turn *Voltage Adjust* halfway up. Both meters on the power supply should read 0 now. Zero ("tare") the scales.

Turn up the current I to approx. 1 A – read the precise value. Read the scales: m.

Write down the measurements in a table like this.

Note: If the scales show a negative number, write down the current as negative as well.

L = mm		
Measured		*Calculated*
I / A	m / g	F / mN

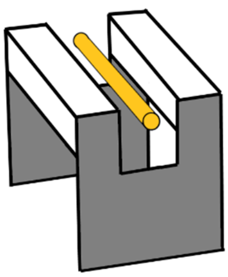
Repeat with currents of approx. 2, 3, 4 and 5 A.

Reverse the current by swapping the leads at the power supply. Measure once more at five different currents – remember the sign.

2 – The direction of the force

The magnetic field runs from the red north pole to the white south pole. The current runs from plus to minus.

Draw a sketch like this of the magnet assembly and the horizontal part of the conductor.



Indicate the magnetic poles, the direction of the current and whether the scales read positive or negative in this situation.

3 – Varying the length of the conductor

Use the same kind of setup as in part 1. Choose the direction of the current that gives positive readings on the scales.

In this part, the current should be approx. 5 A – write down the precise value and use the same current through all measurements. The easiest is to adjust once and not touch the *Current Adjust* button any more.

The current can be turned on and off with the *Voltage Adjust* button.

Use each of the single-sided boards and fill out a table like this:

I = A		
Measured		*Calculated*
L / mm	m / g	F / mN

Don't forget to zero the scales (with no current running) each time you have changed the conductor

Go on with the two double sided PCBs; multiply the measured length by 2 to obtain L.

4 – Varying the angle

Place the accessory 456510 on the holder and change the magnet assembly. (Small image on p. 1)

Adjust the height again to centre the lower horizontal part of the wire in the magnetic field.

Turn the black button to find the limits of rotation. Place the button approx. in the middle of this interval.

Zero the scales (with zero current).

Turn up to approx. 5 A.

Rotate *the magnet assembly* relative to the conductor until the scales read 0 – fine-tune on the black button.

Keep the conductor fixed while rotating the plastic sheet until the red indicator coincides with 0 on the angle scale (see image). This way the angle 0° correspond to 0 gram on the scales. The setup is now ready.

Vary the angle θ in steps of 10° and note each time the reading of the scales. Write the angles with sign. If possible, measure from -100° to +100°.

Measured	
θ / °	m / g

5 – Varying the field

Change back to the first magnet assembly. Complete a measurement series with the conductor used in part 1 and 5 A current, but vary the number of magnets in the holder.

Theory

When a current runs in a conductor placed in a homogeneous magnetic field, the conductor experiences a force given by

$$F = B \cdot I \cdot L \cdot \sin(\theta)\ ,$$

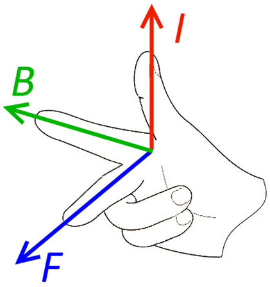
where B is the magnetic flux density, I is the current, L is the length of the conductor and θ is the angle between the conductor and the direction of the field.

(This expression is known as Laplace's force law and is a special case of Lorentz' force law.)

If the conductor is perpendicular to the magnetic field, this reduces to

$$F = B \cdot I \cdot L\ .$$

The direction of the force on the conductor is found from a right-hand rule (see figure). F is perpendicular to both the conductor and the magnetic field.



Newton's 3rd law used on this system:

$$F_\mathrm{M} = -F_\mathrm{L}$$

- i.e.: The force on the magnet assembly from the conductor is *directed opposite* the force on the conductor from the magnet assembly; their sizes are equal.

The scales as a force meter: The force of gravity on the mass m is given by

$$F = m \cdot g$$

The scales read m when it experiences the force F.

Careful with units everywhere! It may be an advantage to consistently convert to SI units first.

Calculations etc.

It can be an advantage to use a computer with a spreadsheet. In part 4 it is almost a necessity.

Everywhere, the "weight" must be converted to force.

1 – Varying current

Plot the force as a function of the current.

Draw the best straight line approximation to the data points and find the slope of the line. Calculate, from the slope, the size of B.

2 – Direction of the force

Explain the direction of the force on the conductor based on the sketch and notes. Does it match the theory?

3 – Varying length

As a start, work with the *single-sided* PCBs only.

Plot the force as a function of the length of the conductor.

Draw the best straight line approximation to the data points, including (0,0) and determine its slope.

From the slope, find the size of B.

Repeat this with the two double-sided PCBs. Call the value now found B_2.

4 – Varying the angle

Use a spreadsheet for this analysis.

No matter how careful you have zeroed the angle scale, a small error of constant size may have slipped in. Let us call this small offset $\Delta\theta$. Use a cell in the spreadsheet for this value; place a 0 here initially.

Introduce a column for $\sin(\theta+\Delta\theta)$ – careful: The spreadsheet probably assumes angles to be in radians!

Measured		Calculated	
θ / °	m / g	$\sin(\theta+\Delta\theta)$	F / mN

When also the force column has been completed, the force F must be plotted as a function of $\sin(\theta+\Delta\theta)$.

According to theory, the result should be a straight line (as B, I and L are all constant).

Her it may be necessary to adjust the value of $\Delta\theta$ ± a few degrees until the points approximate a straight line closely.

5 – Varying field

Plot the force as a function of the number of magnets.

Do the points lie on a straight line through (0,0)?

Discussion and evaluation

Comment on the correlation between theory and observations in part 2.

We have not mentioned the *vertical* parts of the conductor so far. Why do not they matter?

Explain in detail what type of graph is expected in parts 1 and 3 and describe how well it matches the measured results.

How does the size of B match in part 1 and part 3?

In Part 3 you also found a value for the field, which was called B_2. Compare this with the previously found value for B. Explain a possible deviation.

Describe the outcome of part 4 in conjunction with the theory.

Can the value for B found in part 4 be compared to the field in part 1? Explain the answer.

Discuss the result of Part 5.

Teacher's notes

Concepts used

Current
Magnetic flux density (B field)
Force
Newton's 3rd law
Right hand rule

Mathematical skills

Linear relationship
Using a spreadsheet (exceeding the beginner level in part 4.)

About the equipment

The current balance 456500 (and 456510) has a nominal maximum current of 5 A, but this can exceeded at no risk for a short time.

To find out if a specific digital scales is suited for this experiment, try the following:

Build the setup as for part 1 in this manual.

Zero the scales (with zero current).

Use a current of approx. 5 A; read the scales, then reverse the direction of the current without changing its size. Read again.

The two weights read must be approximately the same just with opposite signs. Deviations of 1 to 2 % are acceptable.

If necessary, try to place a 2 to 3 cm thick block of Styrofoam between the scales and the magnet assembly.

A more elementary approach to the same topic (without the angle dependency of the force) can be found as experiment *137230-EN Magnetic force on a conductor*.

Detailed equipment list

Specifically for the experiment

456500	Current balance
456510	Current balance, angle-dependent

Standard lab equipment

364000	Power supply
105720	Safety cable 50 cm, sort
105721	Safety cable 50 cm, red
000100	Stand base
000850	Retort stand rods, 25 cm
102964	Kern scales 200 g / 0,01 g, or similar (102950, 103245, 102905 etc.)

Ruler or caliper gauge

Alternative power supplies

As mentioned, when using a power supply without a current limiter, a series resistor must be added to the setup:

420505	Resistor 1 ohm 50 W 5%
105711	Safety cable 25 cm, red

If the power supply doesn't have an ammeter, we recommend this sturdy analog instrument:

381570 Ammeter

(Beware that cheap multimeters may not allow high currents for an extended time.)