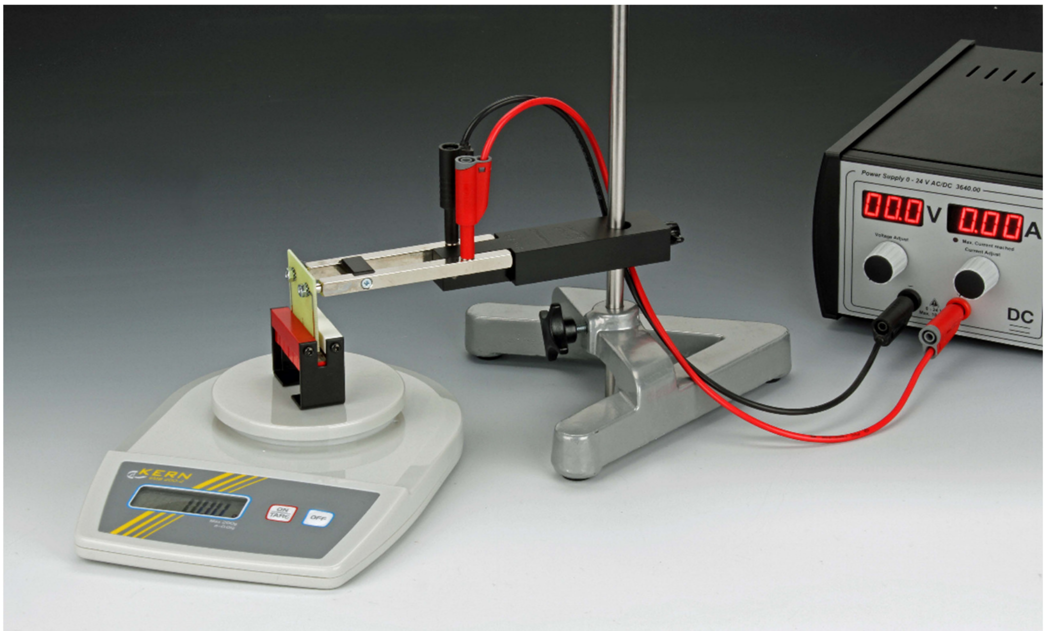
The magnetic force on a conductor

Experiment number	137230-EN	*Topic*	Electromagnetism				
Version	2017-05-23 / HS	*Type*	Student exercise	*Suggested for*	grade 9-10+	*p.*	1/4



Objective
To examine the force on a current carrying conductor in a magnetic field.
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. The size of the force on the magnet is equal to the force on the conductor and has the opposite direction (action = reaction). The reading of the scales can therefore be used to find the force on the conductor.

The power supply 364000
The short piece of conductor used in the setup has a very low resistance and will by and large act like a short circuit.

Therefore the button *Current Adjust* is used to define the current while the button *Voltage Adjust* simply should be turned halfway up.

Equipment
(*Detailed list on p. 4.*)

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

The current can be read off the power supply's built-in ammeter.

In case *a power supply other than 364000* is used, is can be necessary to insert a resistor into the circuit. Use 1 Ω, 50 W (420505).

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

Procedure

(Ask your teacher which of the following section you must complete.)

1 – Varying the current

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

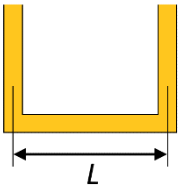
In case the scales used is sensible to magnetic fields, increase the distance to the magnetic system with e.g. a small block of polystyrene foam.

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

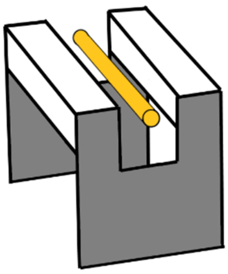
Repeat with currents of approx. 2, 3, 4 and 5 A.

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.

(The following two parts should only be completed if you are instructed to do so.)

3 – Varying the magnetic field

Setup as in part 1. Use the single sides PCB with the longest horizontal conductor.

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.

The magnetic field can be changed by changing the number N of the magnets.

Cut the current and zero the scales each time – then turn on and read the scales with the current running.

Start with all magnets in the holder. Turn off, zero, turn on, read.

Remove one magnet from the holder and distribute the rest evenly. Turn off, zero, turn on, read.

Repeat, until only one magnet is left.

Write the results down in a table like this:

I =		A
Measured		Calculated
N	m / g	F / mN

4 – Varying the length of the conductor

Use the same kind of setup as in part 1. Chose 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.

Theory

When an electric current runs in a conductor, perpendicular to a magnetic field, the conductor experiences a force given by

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

where B is the strength of the magnetic field, I is the current, and L is the length of the conductor.

(This formula is called Laplace's force law and is a special case of Lorentz' force law.)

Three useful special cases

If B and L are constant we have:

$$F = constant \cdot I$$

If I and L are constant we have:

$$F = constant \cdot B$$

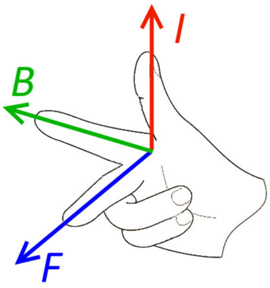
If B and I are constant we have:

$$F = constant \cdot L$$

The direction of the force

The direction of the force on the conductor can be found by a right hand rule (figure).

F is perpendicular to both the current in the conductor and the magnetic field.



Your textbook may mention "Fleming's left-hand rule for motors" – which gives the same result. Learn ***one*** of these.

Measuring force with the scales

The force of gravity on a mass m is given by

$$F = m \cdot g \ ,$$

where g is the acceleration due to gravity.

The scales read m when it experiences a force F.

Remember the action = reaction rule: Assume that the scales experiences a *downward* force of 1 N – then the conductor experiences an *upward* force of 1 N.

Be careful with units everywhere! It can be advantageous to consistently convert to SI units first (i.e. m instead of cm or mm, kg instead of g, etc.)

Calculations etc.

Recommended: Use a computer with a spreadsheet.

"Weight" must always be converted to force.

1 – Varying current

Plot the force as a function of the current in a coordinate system. (x axis: I , y axis: F)

Draw the best straight line through the data points.

2 – The direction of the force

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

(Continue only if you completed part 3 and 4.)

3 – Varying magnetic field

Plot the force as a function of the number of magnets in a coordinate system. (x axis: *number* , y axis: F)

Draw the best straight line through the data points and (0,0).

4 – Varying length

Plot the force as a function of the length of the conductor in a coordinate system. (x axis: L, y axis: F)

Draw the best straight line through the data points and (0,0).

Discussion and evaluation

According to theory, the force F increases in step with the current I. Does it match your results?

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 they not matter?

(Continue only if you completed part 3 and 4.)

According to theory, the force F increases in step with the magnetic field B.

Does this match your results? Compare with the (good or bad) match in part 1.

It is also predicted that the force F should grow in step with the length L of the conductor.

Does it match your results? Compare with how good or bad the results fit in Part 1 and Part 3.

Bonus assignment for the fast and skilled: Find the size of B in parts 1 and 4. Are the two values the same? Should they be that?

Teacher's notes

Everybody should complete part 1 and 2. Let the most skilled (and fastest) students carry on as the time allows

Concepts used

Current
Magnetic field
Force
Action = reaction
Right hand rule

Mathematical skills

Linear relationship
Using a spreadsheet

About the equipment

The current balance 456500 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 – 3 cm thick block of Styrofoam between the scales and the magnet assembly.

A more advanced approach to the same topic (including the angle dependency of the force) can be found as experiment *137240-EN Laplace's force law*.

Detailed equipment list

Specifically for the experiment

456500 Current balance

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.)