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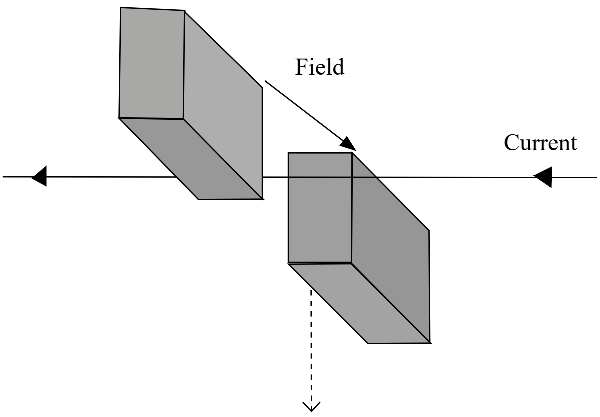
Physics Factsheet

Investigate how the force on a wire varies with flux density, current, and length of wire using a top pan balance

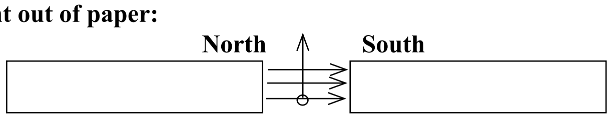
The Motor Effect
When two magnetic fields combine, each will interact with the other. A moving charge has an associated electromagnetic field which will interact with a permanent magnetic field. If a current carrying wire is placed in a permanent magnetic field, there will be a force to be exerted on the wire. A series of electrical charges are moving through the magnetic field and so the force is exerted on the wire due to the electron flow.



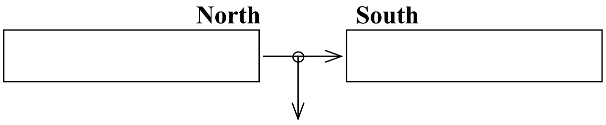
Flemings' Left-hand Rule
Hold the first and second fingers and thumb of the left hand mutually perpendicular so that the **F**irst finger points in the direction of the **F**ield; the se**C**ond finger points in the direction of the conventional **C**urrent, then your **T**humb will point in the direction of the **T**hrust or force on the conductor.

Applying Flemings' left-hand rule to a current carrying conductor placed between the poles of a magnet:

Current out of paper:



Current into paper:



Quick Question 1
Would you choose an alternating current or a direct current when designing an experiment to show the motor effect? Give a reason for your answer.

Answer
A direct current. The direction of electron flow is constant so the direction of the force on the conductor will be constant. With an alternating current of 50 cycles per second the direction of the force would vary 50 times per second giving no observed net force.

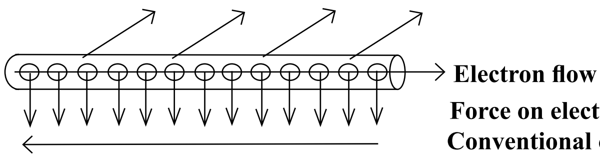
A simple demonstration of the motor effect can be seen by mounting a wire between the poles of a U-shaped horseshoe bar magnet and passing a small direct current through the wire. The wire would be seen to move. The effect can be increased by:
- Increasing the length of wire which is experiencing the magnetic field
- Increasing the magnetic field strength
- Increasing the current in the wire.

The quantitative value of magnetic field strength is termed 'magnetic flux density' (symbol B).

For a wire carrying a current through a magnetic field, the force (F in Newtons N) exerted equals the current I (amps A) × length L (in metres m) × the magnetic field strength B (in teslar T) × sin θ, where θ is the angle between the magnetic field and the direction of the current. The current I is charge q (in coulombs C) transferred ÷ time t (in seconds s) taken.

$$F = ILB \sin\theta = \frac{q}{t} LB \sin\theta$$

If electrons move along a wire (shown below) from left to right, the force exerted by a magnetic field at right angles and into the page on the electrons is down the page.



This then corresponds to a conventional current going from right to left. As the force on the wire is downwards, this force can be measured by mounting the wire on a top pan balance.

Definition of the Tesla (T)
A tesla is the magnetic flux density if a wire of length 1 metre carrying a current of 1 amp has a force exerted on it of 1 newton in a direction at right angles to both the flux and the current.

Quick Question 2
A wire 5 cm long and carrying a current of 0.5 amps is positioned at right angles to a magnetic field of 3×10^{-2} Tesla. Find the force in Newtons exerted on the length of wire by the magnetic field.

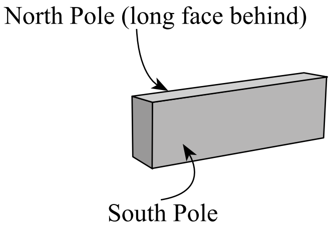
Answer
The angle between the field and the length of wire is 90° and so sin θ = sin 90° = 1 and F = length of wire × current × magnetic field = 5×10^{-2}m × 0.5 A × 3×10^{-3} = T

The force on a charged particle moving through a *vacuum* in a magnetic field may be expressed

F = Bqvsinθ   where v = L ÷ t

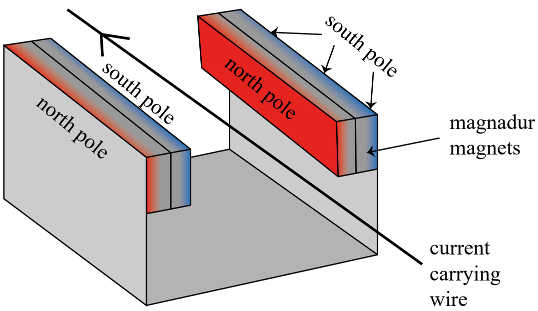
Magnadur Magnets

A suitable form of magnet for this type of investigation is a magnadur magnet. These are ceramic magnets which have ferro magnetic properties. The north and south poles are on the large flat and long surfaces of the magnet:



They can be arranged to stand on the bench or more conveniently are attached to an iron yoke.

Experimental setup of four magnadur magnets (2 sets of 2 mounted on an iron yoke) with a current carrying copper wire parallel to the centre of the long edge of the magnets and equidistant between them



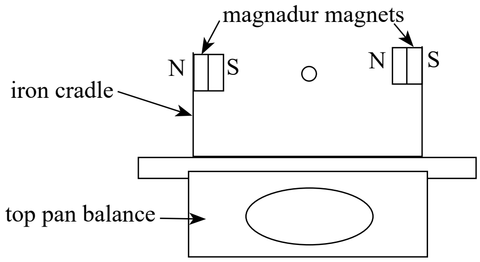
force on cradle is downwards

Use Fleming's left-hand rule to verify that the force on the cradle is downwards.

Quick Question 3
Use Fleming's left-hand rule to find the effect of reversing the current direction.

Answer
The force on the cradle will be upwards.
The force on the cradle can be measured by mounting the cradle on a top pan balance.

Mounting the Cradle on the Top Pan Balance



The copper wire must be secured at each end, for example by clamps on clamp stands.

Quick Question 4
Give a reason why the wire should be held rigidly so that it cannot move.

Answer
When a current flows through the wire there will be a force on the wire and an equal and opposite force on the top pan balance. For accurate measurement of the force on the balance the wire must remain in a constant position.

Quick Question 5
In which direction must the current flow be for a downwards force on the top pan balance.

Answer
Current flowing out of paper.

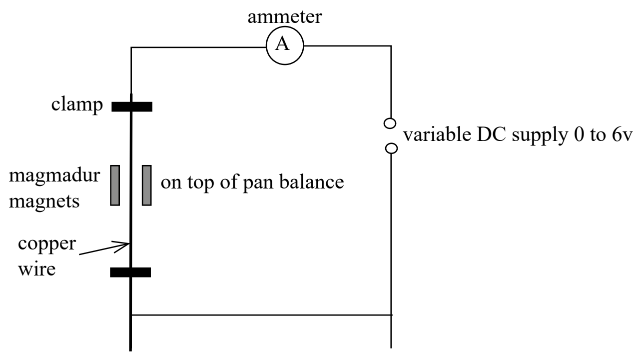
Safety

The current flowing through the copper wire will cause it to get hot (especially at the higher currents), so care must be taken.

Ensure that the top pan balance readings can be easily seen without bending over the apparatus.

Ensure that the iron yoke and magnadur magnets are stable when mounted on the top pan balance. Allow for any movement that will occur when the force is exerted on the balance due to the current through the copper wire.

The Electric Circuit



Analogue vs. Digital Instruments
- Analogue instruments have a non-linear scale, and so the percentage reading errors are higher in the region where the scale is more cramped. This may result in substantial errors in the lower readings, and so the chance of error in your experiment is higher.
- Digital instruments do not have these observational errors and give more consistent accuracy.

- Analogue instruments are often used because they are less expensive, lighter in weight, and more easily portable than digital instruments.
- Analogue instruments use more power than digital instruments.

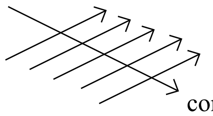
Experimental Procedure

1. Set the top pan balance to zero (with no current flowing).
2. Set the voltage to give the maximum current on the ammeter (for example 5.0 A).
3. Note the mass recorded by the top pan balance.
4. Repeat steps 1 to 3 for successive values of current for example 4.0A, 3.0A, 2.0A, 1.0A, and note the successive values of mass.
5. Repeat steps 1 to 4 three times and note the readings obtained.
6. Find the mean value for each of your values of current.
7. Plot a graph to show the mean value of mass m against current I.
8. Draw a line of best fit and record the gradient = m ÷ I.
9. Find the length of the magnetic field by measuring the length L of the magnadur magnets (ignore end effects).
10. Find the value of the force on the wire as recorded by the top pan balance, that is mass (kg) multiplied by the value of g = 9.81 Nkg^{-1}.
11. The length of wire in the field is equal to the length L of the magnadur magnets.
12. Put the force on the wire into the relationship: Force = magnetic flux density B in Tesla x current I in amps × length L in metres = mg ÷ 1000.
13. Rearrange to give B = mg ÷ (I × L × 1000) = gradient × g ÷ (L × 1000).
14. Put your values for gradient of your graph and length L of magnadur magnets into your expression for B. The value obtained should be of the order of 5×10^{-2} Tesla.

Practice Questions

1. Define the term magnetic flux density and state its unit.
2. Draw an arrow on the diagram to show the direction of the force on the current carrying wire.

Magnetic field



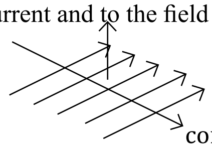
conventional current

3. Give the expression for the force when the angle, θ between the current, I and the field, B is not 90°.
4. Why should the copper wire be firmly clamped?
5. Explain why a graph is drawn with a line of best fit and the gradient taken, rather than working out each value of m÷I and finding an average.
6. The reading error of an analogue ammeter varies with current. Explain why.
7. Explain the difference between accuracy and precision. Would you expect the precision to be greater when using an analogue instrument or when using a digital instrument.
8. Explain the difference between repeatability and reproducibility.

Answers to Practice Questions

1. The force acting per unit current per unit length of wire when a current flows at right angles to the field. The direction of the magnetic field is at right angles to the force and to the current and is given by Fleming’s left-hand rule. The unit of magnetic flux density is the tesla, T.
2. At right angles to the current and to the field and upwards.

Magnetic field



conventional current

3. F = magnetic field x current x length of wire x sin θ.
4. When a current flows the copper wire will experience a force. In order that the reading of the top pan balance is accurate the wire must remain in a constant position.
5. Any anomalous results can be more easily seen and checked by being repeated (or possibly excluded).
6. The scale is not linear, that is the division per amp is smaller for lower values, thus the percentage error is higher for lower values of current.
7. Accuracy refers to the closeness to the actual value. Precision is the agreement obtained between repeated results. The precision relates to the repeatability of readings and so would be higher for a digital instrument, as there is no reading error.
8. Repeatability refers to repeats of the same experiment on the same occasion. A repeatable experiment gives the very similar results each time. Reproducibility refers to the same measurements taken by different people using different instruments over a period of time.

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