Forces on currents

* ***show an understanding that a magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets.***
* ***represent a magnetic field by field lines.***
* ***show an appreciation that a force might act on a current-carrying conductor placed in a magnetic field.***
* ***recall and solve problems using the equation***
* ***F = BIl sinθ, with directions as interpreted by Fleming’s left-hand rule.***
* ***define magnetic flux density and the tesla.***
* ***show an understanding of how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance.***
* ***predict the direction of the force on a charge moving in a magnetic field.***
* ***recall and solve problems using F = BQv sinθ.***

# The force between two currents

Set up two strips of foil as shown in the diagram and connect the power supply.



1. First, arrange the connections so the current is passing down both strips of foil. Set the power supply to 1 V. Switch on and describe what happens.

2. Increase the power supply to 2 V. What happens now?

3. Arrange the connections so that the current is passing up both strips of foil. What happens?

4. Finally arrange the connections so the current is passing up one foil and down the other. What is the result?

What you have seen

1. The size of the force between currents depends on the size of the current.

2. The direction of the force depends on the current directions. If they are in the same direction they attract. If they are in opposite directions, they repel. Like currents attract, unlike currents repel.

Practical advice

The main point is that currents experience forces in a magnetic field, which can be due to either a permanent magnet or another current. The size of the force depends on the sizes of the current and the magnetic field.

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| warning | Safety  If the current is too large then the foil will get hot and the forces will be too large and tear the foil. When using two strips of foil be aware that if they touch sparking may occur. Care is needed, and the pd must remain modest |

External reference

This activity is taken from Advancing Physics chapter 15, 290E

Force on a current-carrying wire

Here you measure the force on a current-carrying wire placed in a uniform magnetic field. This is the origin of the ‘motor force’.

You will need:

* two mild steel yokes
* four slab magnets
* rheostat rated at least at 4 A, 6 A is better
* digital multimeter, used as an ammeter
* power supply, 0–12 V
* leads, 4 mm; three are required, two need to be at least 0.5 m long
* mass balance, electronic, 0–2 kg, ± 10 mg
* two retort stands with boss and clamp
* metre rule (used for holding wire in position)
* shaped bare wire, six samples

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| warning | Safety  Large currents will heat the wires and care should be taken when handling them |

What to do



The ‘top pan balance’ is a straightforward way of investigating the factors affecting the force on a wire carrying a current in a magnetic field. The ‘wire’ is clamped so that it remains stationary and the balance measures the ‘change in weight’ of the Magnadur magnets placed on its pan.

The balance will probably be calibrated in grams and milligrams. One gram is equivalent to a weight of 0.0098 N (0.01 N will probably be accurate enough). The balance should also be capable of being ‘tared’ or zeroed with the magnets in place, so that when there is no force the reading is zero.

1. A single straight wire, connected to a dc power supply in series with an ammeter and rheostat, is taped to a metre rule and clamped horizontally at right angles to the field. Vary the current gradually up to about 5 or 6 A. (This will depend on your power supply.)

2. How does the force on the wire (or the change in weight of the magnets) depend on the current in the wire?

3. Plot a graph of force against the current in the wire.

4. To investigate how the length of wire in the field affects the force, the single wire can be replaced by wires of different length. These wires have been shaped so that a short horizontal section can be placed in the field. Investigate how changing the length affects the force on the wire. Make sure that the current is the same each time.

5. There are forces acting on the vertical sections of the wire. Why don’t these affect the reading on the balance?

6. Plot a graph of force against the length of the wire in the field.

If magnets of different strength are available, you should be able to determine how the force depends on the magnetic field strength, although a quantitative relationship may be very difficult to establish.

Outcomes

1. The two graphs should show that the force is proportional both to the current in the wire and to the length of wire in the field.

2. The force is also proportional to the magnetic field strength, although without measurement you may not be convinced.

Practical advice

Several lengths of shaped bare wire are required, about 0.56 mm diameter or thicker. Bare or tinned copper will do. All apart from one should be shaped so that a known length can be inserted into the field between the magnets ranging from 10 mm up to 60 mm. The ends of these wires could be fitted with 4 mm sockets for ease of use.

This is a slick and easy way to do an experiment that has appeared in different forms, primarily as a current balance, which we want to avoid. We do not think the students’ or teacher’s time is rewarded by the effort that is often necessary to get results. The top pan balance provides a simple way of measuring force.

It is well worth preparing a set of wires beforehand, although, if time allows, teachers may wish their students to make them. This will mean that suitable tools, good pliers and possibly a small vice, will need to be available as well as the apparatus listed.

Investigating length and current are straightforward and should not cause too many problems. It would be wise to check what range of currents will provide suitable results.

Changing the magnetic field will be less satisfying, unless you have a wide range of suitable magnets with different, known strengths.

There may be a problem with a 100 Hz ripple affecting either the ammeter or the balance; if this is the case a good smoothing unit should be used.

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| warning | Safety  Large currents will heat the wires and care should be taken when handling them |

External reference

This activity is taken from Advancing Physics chapter 15, 300E

Forces on currents in magnetic fields

µo = 4π × 10-7 N A-2 and g = 9.81 m s-2

1. (a) Write down the formula for the force on a straight wire of length L placed at right angles to a magnetic field of flux density B.

(b) A pivot arrangement using a wire of length 15 cm is placed in a magnetic field. When a current of 4 A is passed through the wire it is found that a mass of 2.0 g must be hung from the wire to return it to a horizontal position. g = 9.81 m s-2

Calculate the magnetic flux density of the magnet.

2. A horizontal wire 6 cm long and mass 1.5 g is placed at right angles to a magnetic file of flux density 0.5 T. Calculate the current that must be passed through the wire so that it is self-supporting

3. A wire of length 0.5 m carrying a current of 2 A is placed at right angles to a magnetic field of 0.2 T. Calculate the force on the wire.

4. What is the force between two wires placed 0.2 m apart in a vacuum each carrying a current of 5 A.

Questions 5 and 6:

A magnetic field exerts a force of 0.25 N on an 8.0 cm length of wire carrying a current of 3.0 A at right angles to the field.

5. Calculate the force the same field would exert on a wire 20 cm long carrying the same current.

6. Calculate the force the same field would exert on three insulated wires, each 20 cm long and held together parallel to each other, each carrying a current of 3.0 A in the same direction.

7. (a) Using the ideas of forces on currents in magnetic fields and the diagram explain the operation of a moving coil loudspeaker.

### N

# S

## Front view

voice coil

tubular magnet

core

paper cone

voice coil

flexible leads

soft iron core

tubular magnet

Side view

(b) Calculate the force on the voice coil of a loudspeaker that has a diameter of 2 cm, a 100 turns and carries a current of 20 mA if the field strength of the tubular magnet is 0.1T.

Questions

A beam of particles passes in a straight line from a source X, to a spot, E, on a fluorescent screen. When the electromagnet shown is switched on, the beam hits the screen at one of the spots A, B, C, D or E.



1. In which direction does the beam bend if the particles are positively charged?

2. Where does it go if the particles are neutral?

3. What happens to the positively charged particles if the magnetic field is reversed?

In one form of mass spectrometer, charged ions in the beam fan out, moving in the paths shown in the diagram. Parts of the paths include a magnetic field whose direction is perpendicular to the plane of the paper.

4. Indicate places where there must be no magnetic field in the direction suggested. Do not use shading.

5. Shade the area where there must be a magnetic field.

6. What is the shape of the path followed by a proton that is projected into a uniform magnetic field at right angles to its velocity? Justify your answer.

The diagram shows the initial path of an electron fired into a uniform magnetic field. The magnetic field is at right angles to the direction of the electron and is directed away from the reader.



7. Add a labelled arrow to the show the direction of the force on the electron.

8. Draw the subsequent path of the electron.

A uniform electric field is produced by maintaining a potential difference of 1000 V across a pair of parallel plates 5 cm apart. An electron enters the field at right angles as shown with a velocity of 4.0  107 m s–1 and emerges from the plates without hitting them.



9. Draw in the path of the electron on the diagram.

10. What name is given to this type of path?

Hints

1. Remember that the left-hand motor rule works for conventional current.

2. Remember that the left-hand motor rule works for conventional current.

Practical Advice

These questions are intended to be straightforward, to reinforce understanding and to build confidence. Students will be required to understand the independence of vertical and horizontal motions, and also motion where the acceleration is constant.

External reference

This activity is taken from Advancing Physics chapter 16, 90S

The cyclotron

Background

In a cyclotron, protons are kept moving in a circular path by a uniform magnetic field at right angles to the plane of the path.



The American physicist E O Lawrence designed and built the first cyclotron in 1930. For this achievement, he was awarded the Nobel Prize for physics in 1939. Only a few centimetres in diameter, the Lawrence cyclotron accelerated protons to energies of 80 keV.

Questions

You will need the following data:

mass of proton = 1.7 x 10–27 kg

charge on proton = 1.6 x 10–19 C

1. What is the velocity of a proton with an energy of 80 keV?

2. The largest possible path had a radius of about 50 mm. What strength of magnetic field must have been used?

3. What would be the radius of the path followed by a proton with half this maximum energy in the same field?

4. How long would it take 80 keV protons to travel once round their path? How long would it take for those with half this energy?

Constructed of two D -shaped chambers (later called ‘dees’ because of their shape), the cyclotron worked by giving particles of any energy, on their respective paths, a push every time they had completed half an orbit.



5. How was it possible for particles of differing energy all to be accelerated together?

Practical advice

This is something more able students may enjoy thinking about.

It is instructive for students to realise that even such a crude and simple device represented a major advance in particle physics, providing a source of high-energy particles that could be fired at atomic nuclei, to probe their structure. Lawrence had done a calculation of the necessary length for a linear accelerator to produce protons with energies of a million eV. He realised his laboratory was too small, and that set him thinking about bending the accelerator so that protons would travel in a spiral. Each time the protons crossed the gap between ‘dees’, they would be accelerated. To make his cyclotron work, he needed a good vacuum in the chambers and very high-frequency electrical oscillator to alternate the polarity of the ‘dee’ chambers.

A key idea, that radius is proportional to speed, is accessible to analysis.

Half a century later Edwin McMillan, another great American particle physicist, said of the cyclotron: ‘I consider this to be the single most important invention in the history of accelerators; it brought forth a basic idea of great power, and one capable of later elaborations and variations … All the big proton synchrotrons are really just an extension of the cyclotron principle.

External reference

This activity is taken from Advancing Physics chapter 16, 100S

Charged particles moving in a magnetic field

Instructions

This question set contains two groups of questions. Answer all the questions in the spaces provided. The following data will be needed:

 magnitude of the electronic charge = 1.6  10–19 C

 mass of electron = 9.1  10–31 kg

Questions 1– 5 are about the motion of charged particles in a bubble chamber.

1. An electron gun in a vacuum accelerates electrons up to a kinetic energy of 2.9  10–16 J. Show that the speed acquired by each electron is 2.5  107 m s–1.

The electron beam enters a region of uniform magnetic field of strength, *B*, perpendicular to the beam. The magnetic field causes the beam to follow a circular path as in the diagram below.



2. Show that the force experienced by the electron is about 8.8  10–15N,

when B is 2.210–3 T.

3. Use your answer to question 2 to find the radius of this circular path.

4. Evidence for the motion of electrons in magnetic fields can be observed from the trail of bubbles they leave as they pass through liquid hydrogen. In these bubble-chamber experiments a single electron tends to produce a track which is a spiral rather than a circle. Explain why.



5. On the diagram below draw the likely path of a proton travelling at the same speed in an identical field.



Questions 6–10 are about the motion of charged particles in magnetic fields and the cyclotron frequency.

6. Explain why a charged particle, moving with a constant speed *v* perpendicular to a uniform magnetic field *B*, will follow a circular path.

7. Show that for a particle of mass *m* and charge *q* the radius of the circular path is given by the expression r = mv/Bq.

8. Using your answer to question 7, show that the frequency of this circular motion, known as the cyclotron frequency, is given by the expression f = qB/2m.

9. Some astrophysicists believe that the radio signals of 109 Hz reaching us from Jupiter are emitted by electrons orbiting in Jupiter’s magnetic field. Assuming the frequency of the radio emission is identical to the cyclotron frequency; find the strength of the magnetic field around Jupiter.

10 The electrons lose energy as they emit radiation. What effect, if any, will this have on the frequency of the radio signals detected? Explain your answer.

Hints

5. Think about the charge and mass of the proton.

10. What happens to the speed of the proton as it loses energy?

Practical advice

Both sets of questions link with work in particle physics. The radio emissions from electrons orbiting in the magnetic field of Jupiter are explained using the idea of cyclotron frequency.

External reference

This activity is taken from Advancing Physics chapter 16, 150S