Chapter 14 THE MAGNETIC FIELD

The phenomenon of magnetism has been known since antiquity - you yourself have probably seen and handled magnets or magnetic compasses since you were a child. In this chapter we will discover that these magnetic phenomena, like their electrical and gravitational counterparts, can most readily be described in terms of force fields. We will see how to detect a magnetic field, how to measure its value and direction, and even how to create one. Having discovered specific laws which describe how mechanical forces and electrical forces behave, we will now examine a magnetic force law which specifies how moving charged particles interact with these magnetic fields. This interaction is of great practical interest, for it forms the theoretical basis of electrical motors and generators.

PERFORMANCE OBJECTIVES

After completing this chapter, you should:

1. be able to describe the magnetic force between two straight parallel conducting wires in which moving electrons constitute a current.
2. be able to describe the magnetic force field (magnitude and direction) about conductors in which moving electrons constitute a current.
   a. in a straight wire
   b. in a single loop
   c. in a helix or coil.
3. be able to describe the motion of electrons in a uniform magnetic force field for electrons moving perpendicular to the field.
4. be able to experimentally measure the magnetic field strength of a coil as a function of the current which produces the magnetic field.
5. be able to experimentally determine the mass of the electron.

1. Read Section 14-1 The Magnetic Needle page 279
   14-2 Magnetic Fields of Magnets and Currents page 280

   a. When a magnet is suspended so that it can freely rotate in a horizontal plane, which end points north? Check your prediction by observing the two magnets which are suspended so they are free to rotate in a horizontal plane.

   b. Obtain magnetizer and de-magnetizer and learn how to use them.

   c. Like magnetic regions _________ each other while unlike magnetic regions ____________ each other.

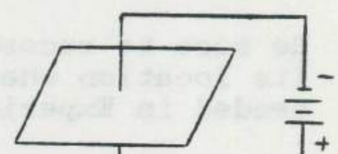
   d. Near a magnet, one finds ___________________. Its direction is determined using ______________ and is in the direction ________________________________.

   e. Create photograph (a) on page 282 using the MAGNETIC PROJECTILE Apparatus and a bar magnet. Repeat using a horseshoe magnet.

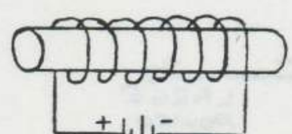
   f. Optional...Place a bar magnet in the center of a piece of paper and trace a few magnetic field lines using a compass.

   g. In finding the direction of the magnetic field around a wire, one uses the _______ hand rule. This is based on the arbitrary choice that the direction of the current is chosen as ____________________________.

   h. Draw (on the diagram at the right) where the wire emerges from the paper, the magnetic field which is caused by the current in the wire.



   i. Determine the direction of the magnetic field inside the coil shown at the right. Indicate the direction with an arrow.



2. Problems: page 280: #1 #2 #3
   284: #4 #5 #6

3. Read: Section 14-3 The Vector Addition of Magnetic Fields page 284

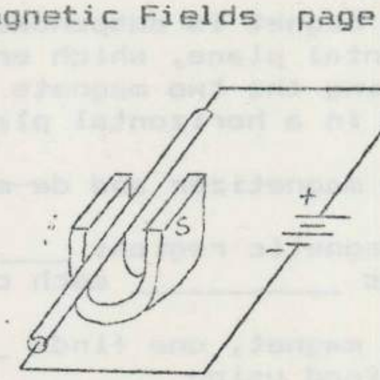
4. Optional...Experiment 20 The Magnetic Field of a Current page 41

   A magnetic compass is used to explore the magnitude and direction of the magnetic field at the center of a loop of wire in which a current is flowing. The experiment will show that magnetic fields add like vectors and are proportional to the current that produces them. Do this experiment only if you wish to verify this for yourself.

5. Problems: page 286: #7 #8 #9
304: #29 #30

6. Read: Section 14-4 Forces on Currents in Magnetic Fields page 286

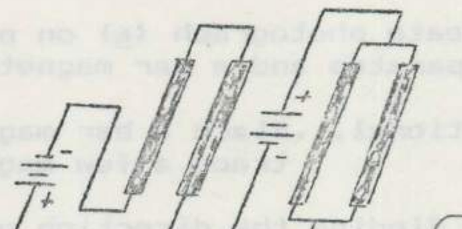
7. a. Predict the direction of the force on the wire in the diagram at the right.



b. Obtain necessary apparatus and check your prediction.

8. Indicate on the two diagrams at the right whether the wires (darkened) will attract or repel each other.

Now obtain necessary apparatus and check your predictions.



9. Problems: page 289: #10 #11 #12
page 304: #31

Exp. 21 THE MEASUREMENT OF A MAGNETIC FIELD IN FUNDAMENTAL UNITS p 44

a. Be sure to record the number of each piece of apparatus used and its location when you set up your experiment. Some of it will be needed in Experiment 22A - THE MASS OF THE ELECTRON.

b. Use the following diagrams in place of Figure 21-2 (in lab guide).

c. Let the length of string be less than 10 cm.

d. Have instructor check all hook-ups before turning on the current.

e. The current in the coil should not exceed 5 amps. To gather data, begin with 1/2 amp in the coil.

f. A graph of the magnetic field in the COIL vs the current through the COIL is a must if you plan to determine the mass of the electron in Experiment 22A.

11. Read: Section 22-5 Meters And Motors page 289

a. Have instructor demonstrate the Barlow Wheel. Are you satisfied that the wheel moves in the direction that you would predict?

b. Have instructor demonstrate the motor principle.

c. Obtain a St. Louis motor, 2 power sources, and hook-up wire. Examine how the motor works when:

(1) magnets are used.

(2) electromagnet is used.

d. Using Overhead Transparency 43-A and 43-B, explain first to your partner and then to your instructor how a galvanometer works.

12. Problems: page 291: #13 #14 #15

13. Read: Section 14-6 Forces on Moving Charged Particles in a Magnetic Field page 291

Text Derivation	Instructors Derivation
Force on wire of length ℓ	
(1) $\vec{F} = \vec{B}_\perp \vec{I}\, \ell$	(1) $\vec{F} = \vec{B}_\perp \vec{I}\, \ell$
Force on 1 elem chg in wire of length ℓ	To show I in terms of q, v, ℓ
(2) $\vec{F}/q = \vec{B}_\perp \vec{I}\, \ell$	(2) $I = q/t$
To show I in terms of N, V, ℓ	(3) $t = \ell/v$
(3) $I = N/t$ (4) $t = \ell/v$	(4) $I = qv/\ell$
(5) $I = Nv/\ell$	Substitute (4) into (1)
Substitute (5) into (2)	(5) $\vec{F} = \vec{B}_\perp vq$
(6) $\vec{F} = \vec{B}_\perp \vec{v} q$	

14. Since $\vec{F}$ is always perpendicular to $\vec{v}$, the type of motion that best describes the motion of charge 'q' would be ________________________.

Thus, $\vec{F}_c$ = ______. Since $\vec{F}_{mag} = \vec{B}_\perp vq$, then r = __________.

15. Problems: Page 295: #16 #17 #18 #19 #20.

16. Read: Section 14-7 Using Magnetic Fields to Measure the Masses of Charged Particles page 295

Complete the following:

	Mechanical Quantities		Electrical Quantities
a. Energy	$E_K = 1/2mv^2$	=	________________
b. Momentum	$p = mv$	=	________________
c. Velocity	$v = 2E_K/p$	=	________________
d. Mass	$m = p/v$	=	________________

17. Experiment 22A The Mass of the Electron page 50

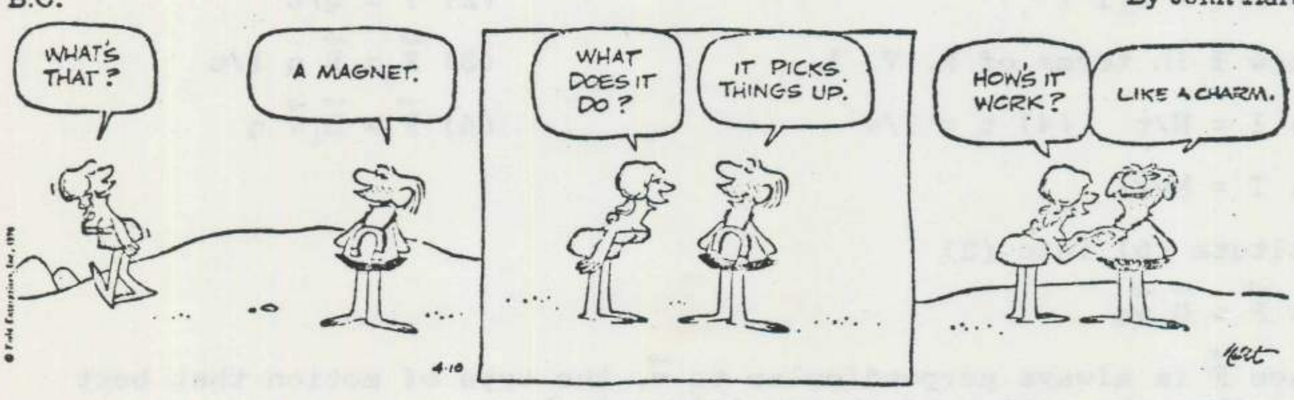
a. Use the same ammeter and power source for the coil that you used in the previous experiment.

b. Have instructor check hook-up before the current is turned on.

18. Read: Section 14-8 The Neutron page 299
14-9 The absorption of Neutrons by Nuclei: Fission p 302

19. Complete the enclosed written exercise and when completed, have it evaluated.

B.C. By John Hart



B.C. By John Hart

ANSWERS CHAPTER 14

1. (a) Information from your text should help (c) repel, attract
   (d) a magnetic field, compass, in the direction that the north seeking region points (g) right, the direction the positive charges in the wire move (or would move)
   (h) counter clockwise (i) to the right

2. (1) (2) S.A.B.
   (3) south magnetic region
   (4) stands up at right angle to the paper
   (5) no - are all closed loops of various shapes
   (6) clockwise in both cases

5. (7) resultant force is 1.41 times the magnitude of the first field
   (8) The field is directly proportional to the magnitude of the current.
   (9)(a) N 60° E (b) $B = B_e$
   (29) S.A.B.
   (30) eight

7. Experimental evidence will provide the answer.

8. Experimental evidence will provide the answer.

9. (10) parallel to the field in either the same or opposite direction.
   (11) downward
   (12) 2.1 newtons
   (31)(a) zero (b) 2.0×10^{-4} N (c) 2.0×10^{-5} kg (d) S.A.B.

12. (13) will read too low
   (14) (15) S.A.B.

14. uniform circular motion, mv^2/r, $mv/B\ q$

15. (16) radius increases as square root of accelerating potential
   (17) (18) S.A.B.
   (19)(a) 6.25×10^{12} elect/s (b) 2.08×10^{6} electron (c) 1.0×10^{-7} N
   (d) 4.8×10^{-14} N
   (20) S.A.B. (Your instructor suggests that it is positive.)

16. (a) $E = Vq$ (b) $p = B_{\perp}qr$ (c) $v = 2V/B_{\perp}r$ (d) $m = B^2qr^2/2V$

Questions from the FLYING CIRCUS OF PHYSICAL PHENOMENA by Jearl Walker

1. Late one night Dr. Redish was stirring some dry, regular (granulated) sugar in a glass, which is kind of a late-at-night type of thing to do anyway. Suddenly the lights went out. Wondering what had happened but continuing to stir, he was amazed in noticing that whenever he happened to press and scrape the sugar against the glass, there was a brief glow of light. What was going on?

2. The next day he happened to be sifting some confectioner's sugar to make some pies. Once again a mysterious thing occurred, for as he continued to sift he saw more and more sugar get thrown out to the sides rather than fall straight down. NOW, what was going on?

3. A phenomenon similar in appearance to that in question 1: Unroll scotch tape in a dark room and you'll see a brief glow at the place where the tape is being ripped up from the roll. Why?

1. Describe how you could determine the polarity of a horseshoe magnet.

2. Draw a small bar magnet. Then show the magnetic field lines as they appear about the magnet.

3. Suppose you were locked inside a room made of glued-together wood. You have a bar magnet and an identical piece of iron, but nothing else. Your instructor will give you a passing grade for the course ONLY if you toss out the magnet and keep the iron bar. How can you be sure your choice will not condemn you to another year of high school physics?

4. A current-carrying wire lies in the north-south direction. A compass magnet placed immediately BELOW the wire points towards the west. In what direction are the ELECTRONS in the wire moving? Describe how you know.

5. Calculate the magnetic force on a wire 3 cm long placed perpendicular to a magnetic field of strength 1.2 N/amp-m. The current in the wire is 2.5 amps.

   a. What is the magnetic force on the wire?

A current of 5 Amps flows through a wire that has 0.5 m of its length in and perpendicular to a uniform magnetic field. The wire experiences a force of 0.25 N. What is the magnetic field?

7. A straight 2-m long segment of a circuit is at 30 degrees to a magnetic field. If the field is 3 N/amp-m and the current is 10 amps,

   a. Find the magnitude of the force on the segment.

   b. Indicate the force direction with the aid of a sketch.

8. Doubly ionized particles in a beam carrying a net positive charge of 2 elementary charges enters a magnetic field of 4.0 E-2 N/amp-m at right angles to the field. The particles have a speed of 9.0 E6 m/s. What force acts on the particle?

(30)

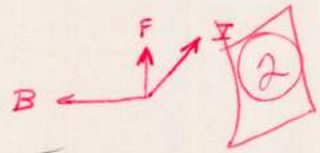
TEST CHAPTER 14 page -1- Name Key

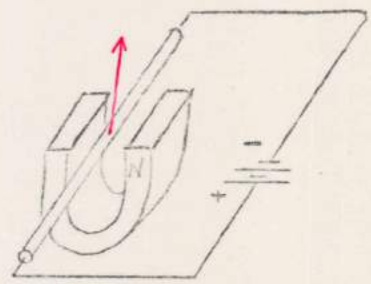
1. Describe the magnetic field around a current-carrying wire.

CIRCULAR

DIRECTION IS (4)

2. Indicate the direction of the force on the current carrying wire shown in the diagram.





3. What ~~three~~ four factors control the force that acts on a wire in a magnetic field?

1. Strength of B
2. Current in wire
3. length of wire in B
4. Angle between

B I l θ

(4)

4. Two parallel wires carrying a current in the same direction are attracted to each other. Why?

(4) $\vec{F} = \vec{B}\vec{I}l$ B of one wire causes force on other wire with current in it.

(4)

5. How would the force on an electron compare with that on a proton moving at the same speed in the same magnetic field. The mass of the electron is 9.1 E-31 kg, of the proton 1.7 E-~~27~~ kg.

$F_e = ?\ F_p$

$v_e = v_p$ $B_e = B_p$

$m_e = 9.1 \times 10^{-31}$ kg

$m_p = 1.7$

$F = Bvq$

$$\frac{F_e}{F_p} = \frac{B_e v_e q_e}{B_p v_p q_p}$$

(3)

$$\vec{F_e} = -\vec{F_p}$$

(2) mag same

(1) dir opposite

17

6. An electron in a T.V. picture tube is moving with a speed of 3.0 E7 m/s in a direction perpendicular to the earth's magnetic field of strength 5.5 E-5 N/amp-m.

a. What is the magnetic force on the electron?

b. What is the acceleration due to this force?

$v = 3\times10^{7}\ \frac{M}{S}$

$B = 5.5\times10^{-5}\ \frac{N}{Amp\cdot M}$

(4) $F = Bvq = 5.5\times10^{-5}\ \frac{N}{Amp\cdot M} \times 3\times10^{7}\ \frac{M}{S} \times 1\ \text{electron} \times \frac{1.6\times10^{-19}\ \text{coul}}{1\ \text{electron}}\ \frac{\text{sec}}{\text{coul}}$

$F = 2.64\times10^{-16}\ N$

(3) $a = \frac{F}{m} = \frac{F}{9.1\times10^{-31}\ Kg} = 2.9\times10^{14}\ \frac{M}{s^2}$

7. A wire 60 cm long is in a magnetic field of 0.4 N/amp-m. The force acting on the wire is 1.8 N. If the angle between the wire and the direction of the magnetic field is 20 degrees, what is the current in the wire

(5) $l = 60\ cm$

$B = 0.4\ \frac{N}{amp\cdot M}$

$F = 1.8\ N$

$\theta = 20^\circ$

$I =$

$\vec{F} = \vec{B}\times\vec{I}\,l$

$F = B I l \sin\theta$

$I = \frac{F}{B l \sin\theta}$

$= \frac{1.8\ N\ (Amp)\cdot M}{0.4\ N} \times \frac{1}{60\ cm} \times \frac{1}{\sin 20^\circ}\ \frac{\text{coul}}{\text{sec}} \times \frac{100\ cm}{1\ M}$

$= \frac{180}{0.4\times60\times\sin 20^\circ}$ amps

$I = 21.9$ amps

12

6 meters = .42 grams)
Thread

IV-9. THE MEASUREMENT OF A MAGNETIC FIELD IN FUNDAMENTAL UNITS

In addition to establishing a unit of magnetic field strength in familiar units, this is the only experiment in which magnetic forces are measured. Consequently, it has a high priority. This experiment can be done after the topic is studied in the text.

The coil calibration determined in this experiment will be needed in Experiment IV-10. The coils should therefore be numbered if their characteristics are different, so they can be identified when used again.

In Fig. 2 of the Laboratory Manual, the loop and coil are shown connected in parallel to the source of current, each having a variable resistor and an ammeter in its circuit to permit independent control of their currents. This arrangement will be most easily understood by students, but if you are short of rheostats and ammeters, the apparatus can be connected in series as shown in Fig. (a). If this circuit is used, it will not be possible to make several determinations of a given field in the coil by varying the current in the loop.

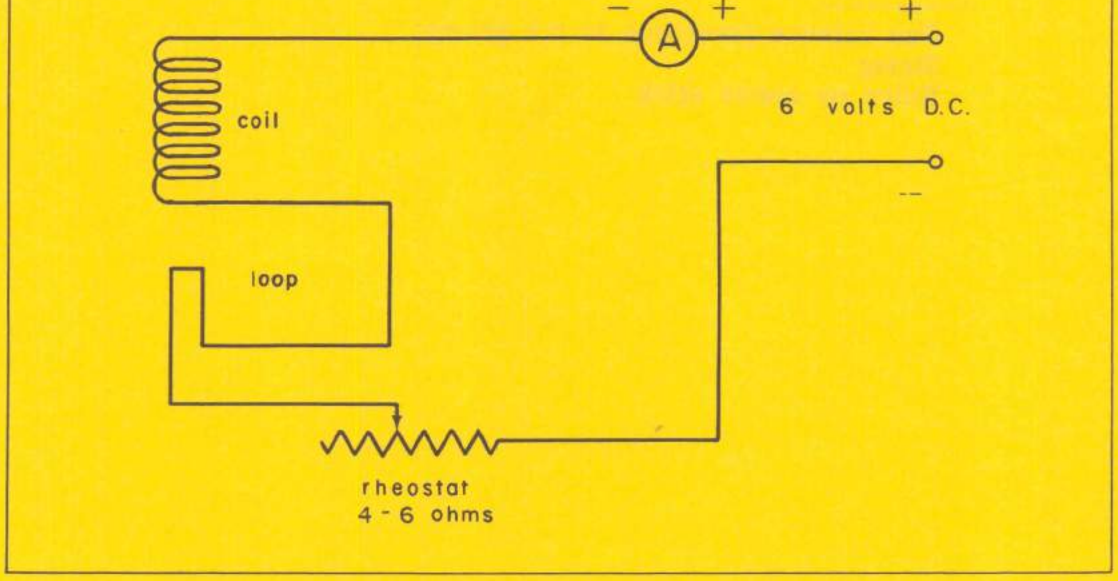


Figure (a)

For the accuracy of the experiment, the wire or string can be assumed to be uniform in cross section, and the mass of the short length of string can be calculated from the mass of several meters of string.

The length L of the straight end of the loop (A in Fig. 1) should be measured as the distance between the centers of the strips forming the sides of the loop.

Notice that a systematic error can occur if the ammeter's calibration is off.

Answers to Questions

The ratio of the field strength of the coil to the current in the coil is constant.

Although the current-carrying loop can be balanced in the magnetic field near a small magnet, the measured value of the field strength will be hard to interpret since the field about the magnet is far from uniform over distances comparable to the dimensions of the loop. We would have no idea at what point near the magnet the field would have the strength we calculated from the balancing force on the loop.

In principle, the balance could be used to measure the field of the earth which is uniform over large distances, but the earth's field is so weak that, without using excessive currents through the balance, the force is too small to measure. Students might try this, however, to see if any motion of the balance can be observed. If more than 5.0 amperes are used in the loop, the contacts will become hot and corroded. A piece of fine sandpaper or emery cloth will clean the contacts.

If iron wire is used in the loop, it becomes magnetized and adds an unknown field to the field being measured.

APPARATUS

1 Air-core solenoid
1 Current balance and contacts
1 DC current source, 0 - 10 amp (6 to 12 volts) this can be used simultaneously for several setups
2 Ammeters, 0 - 10 amp
2 Variable resistors (to regulate the current above)
8 Clip leads, 2' or 3'

Pan balance (sensitive to 0.1 grams)
String
Ruler or meter stick

1. Describe how you could determine the polarity of a horseshoe magnet.

   1. Compass
   2. Current Carrying Wire
   3. Magnet of Known Polarity

2. Draw a small bar magnet. Then show the magnetic field lines as they appear about the magnet.

3. Suppose you were locked inside a room made of glued-together wood. You have a bar magnet and an identical piece of iron, but nothing else. Your instructor will give you a passing grade for the course ONLY if you toss out the magnet and keep the iron bar. How can you be sure your choice will not condemn you to another year of high school physics?

4. A current-carrying wire lies in the north-south direction. A compass magnet placed immediately BELOW the wire points towards the west. In what direction are the ELECTRONS in the wire moving? Describe how you know.

Current ↑
∴ electrons ↓

5. Calculate the magnetic force on a wire 3 cm long placed perpendicular to a magnetic field of strength 1.2 N/amp-m. The current in the wire is 2.5 amps.

   a. What is the magnetic force on the wire?

$l = 3$ cm
$B = 1.2 \frac{N}{Amp \cdot M}$
$I = 2.5$ Amps

$F = BIl$ $\quad 1.2 \frac{N}{Amp \cdot m} \times 2.5 \text{ Amps} \times 3 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}}$

$F = 0.09 N$

6. A current of 5 Amps flows through a wire that has 0.5 m of its length in and perpendicular to a uniform magnetic field. The wire experiences a force of 0.25 N. What is the magnetic field?

$I = 5$ Amps
$\ell = 0.5$ M
$F = 0.25$ N
$B =$

$B = \frac{F}{I\ell} = \frac{0.25 N}{5 Amp \times 0.5 M}$

$B = 0.1 \frac{N}{Amp \cdot M}$ + Direction ⊥ to plane of F & I

7. A straight 2-m long segment of a circuit is at 30 degrees to a magnetic field. If the field is 3 N/amp-m and the current is 10 amps,

a. Find the magnitude of the force on the segment.

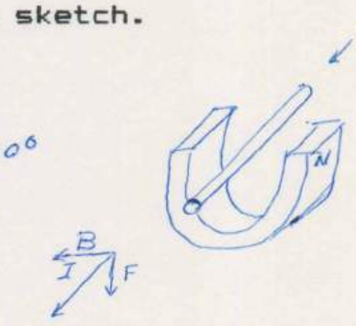
b. Indicate the force direction with the aid of a sketch.

$F = ?$
$B = 3 \frac{N}{AMP \cdot M}$
$I = 10$ AMPS
$\theta = 30°$
$\ell = 2$ M

$F = BI\ell \sin\theta$

$3 \frac{N}{Amp\ M} \times 10\ Amp \times 2 M \times \sin 30°$

$F = 30$ N



8. Doubly ionized particles in a beam carrying a net positive charge of 2 elementary charges enters a magnetic field of 4.0×10^{-2} N/amp-m at right angles to the field. The particles have a speed of 9.0×10^{6} m/s. What force acts on the particle?

$q = 2$ elem chg
$B = 4.0 \times 10^{-2} \frac{N}{Amp\ M}$
$v = 9.0 \times 10^{6} \frac{M}{S}$
$F =$

$F = B_{\perp} v q$

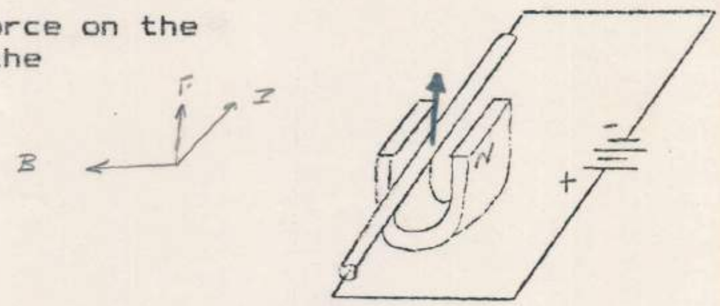
$4.0 \times 10^{-2} \frac{N}{Amp\ M} \times 2\ elem\ chg \times 9.0 \times 10^{6} \frac{M}{S} \times 1.6 \times 10^{-19} \frac{C}{el} \frac{S}{C}$

$F = 1.15 \times 10^{-13}$ N

Written Exercise ~~TEST~~ CHAPTER 14 Test page -1- Name ______________ Shorter.

1. Describe the magnetic field around a current-carrying wire.

2. Indicate the direction of the force on the current carrying wire shown in the diagram.



3. What three factors control the force that acts on a wire in a magnetic field?

   B which wire is in
   I current in wire
   l length of wire in B

4. Two parallel wires carrying a current in the same direction are attracted to each other. Why?

   B of one is in direction such that the current in other has a force towards instruction

5. How would the force on an electon compare with that on a proton moving at the same speed in the same magnetic field. The mass of the electron is 9.1 E31 kg, of the proton 1.7 E27 kg.

F_e vs $F_{,H'}$ $\qquad F = Bvq$

$v_e = v_{,H'}$

$m_e = \qquad m_{,H'} =$

$q = 1 \qquad q = 1$

$B_e = B_{,H'}$

Same magnitude
opposite direction

6. An electron in a T.V. picture tube is moving with a speed of 3.0 E7 m/s in a direction perpendicular to the earth's magnetic field of strength 5.5 E-5 N/amp-m.

   a. What is the magnetic force on the electron?

   b. What is the acceleration due to this force?

$v = 3.0 \times 10^7$ m/s

$B = 5.5 \times 10^{-5} \frac{N}{amp \cdot m}$

$q = 1$ elec chg

$F = Bvq = 5.5 \times 10^{-5} \frac{N}{amp \cdot m} \times 3.0 \times 10^7 \frac{m}{s} \times 1 \text{ elec chg} \times \frac{1 \text{ coul}}{1.6 \times 10^{-19} \text{ elec chg}}$

$a = \frac{F}{m} = \frac{\quad}{9.1 \times 10^{-31} \text{ kg}}$

7. A wire 60 cm long is in a magnetic field of 0.4 N/amp-m. The force acting on the wire is 1.8 N. If the angle between the wire and the direction of the magnetic field is 20 degrees, what is the current in the wire?

$l = 60$ cm

$B = 0.4 \frac{N}{amp \cdot m}$

$F = 1.8$ N

$\theta = 20^\circ$

$F = BIl$

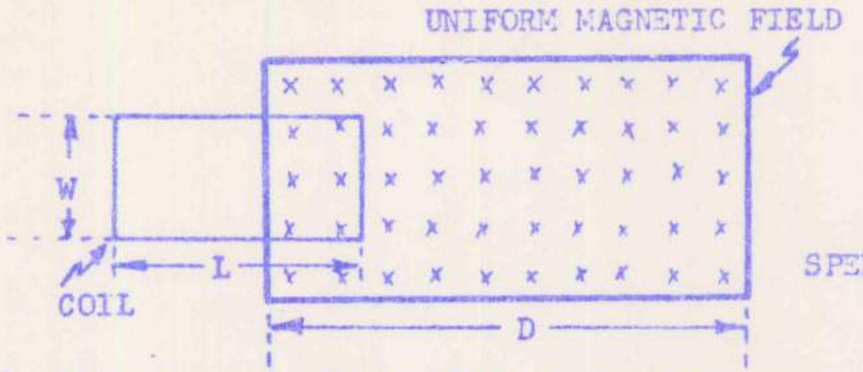
$I = \frac{F}{B l \sin\theta}$

$= \frac{1.8 \text{ N amp} \cdot \text{m}}{0.4 \text{ N } 60 \text{ cm} \times \sin 20^\circ} \times \frac{10^2 \text{ cm}}{1 \text{ m}}$

Physics Quiz No. ______ Name ______________________

Induced EMF Date ______________________

A rectangular coil with resistance R is pulled at a constant speed through a region in which a uniform magnetic field exists.



L = 10 centimeters
W = 4.0 centimeters
R = 16 ohms
D = 25 centimeters
B = 2.0E3 webers/m^2

SPEED OF COIL = 2.0 m/s

1) Plot a graph of the flux through the coil as a function of time. Your graph should begin at the instant the coil enters the magnetic field and end at the instant the entire coil leaves the magnetic field. (3 pts.)

2) Plot a graph of the induced EMF as a function of time over the same time period as used in question 1). How is this graph related to the graph in question 1)? (3 pts.)

3) Plot the power as a function of time over the same time period as above. (2 pts.)

4) If the coil is immursed in the magnetic field and then rotated about an axis through the short side of the coil, plot the graph of the induced EMF versus time for one complete rotation of the coil. (2 pts.)

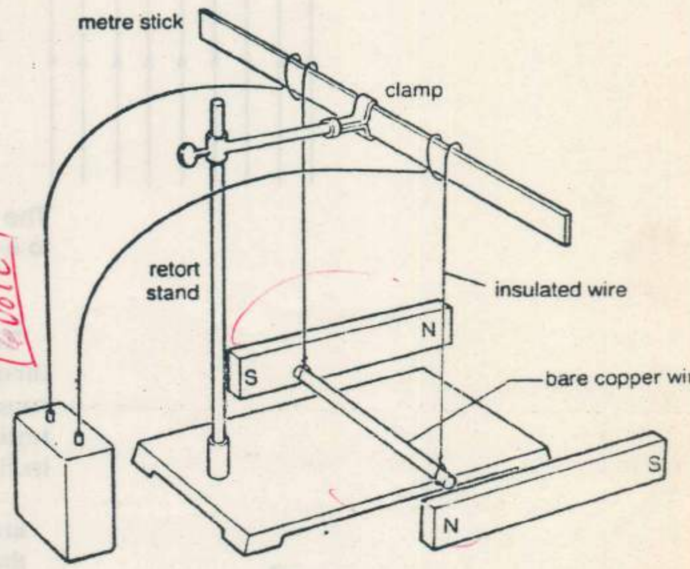
S- 3

Conductor in a Magnetic Field – the Motor Principle

For centuries, scientists had been intrigued with the idea of constructing a device that would be capable of producing continuous motion by using some other form of energy. With Oersted's discovery of electromagnetism, the door was opened for the development of the electromagnetic motor. An Englishman, Michael Faraday (1791-1867), was able to devise such a motor as early as 1821. The next investigation examines the simple principle on which Faraday's motor was based.

Investigation: The Motor Principle

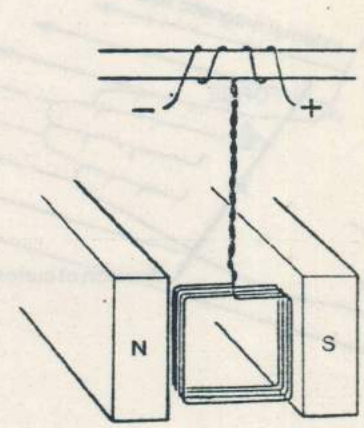
Problem:
Under what conditions does a conductor experience an electromagnetic force?



Materials:
pair of bar magnets
insulated wire (fine)
6 V battery
5 cm length of bare 12-gauge copper wire
retort stand, clamp, and metre stick

Procedure

1. **Using the insulated wire, retort stand, clamp, metre stick, and bare copper wire, set up the apparatus illustrated. Remove some insulation from the wire before attaching it to the bare copper wire.**
2. **Place the bar magnets so that the bare copper wire lies between opposite poles of the magnets, and parallel to a line joining them.**
3. **Connect the battery momentarily and note any effect this has on the conductor.**
4. **Rotate the magnets by 90°, so that the conductor now lies between the poles but perpendicular to the line joining them with one magnet above the conductor and one below it.**
5. **Reconnect the battery and observe any effect this has on the conductor.**
6. **Reverse the poles of the magnets. What effect does this have on the conductor? Reverse the connections to the battery. What effect does this have?**
7. **Wind the wire into a rectangular coil of 10 to 15 turns, as illustrated, and suspend the coil between the poles of the magnets. Connect the battery and notice the effect this has on the coil. Reverse the battery connections and repeat.**



The magnitude of the force on a straight current-carrying conductor in a uniform magnetic field is:

$$F = BIL\sin\theta$$

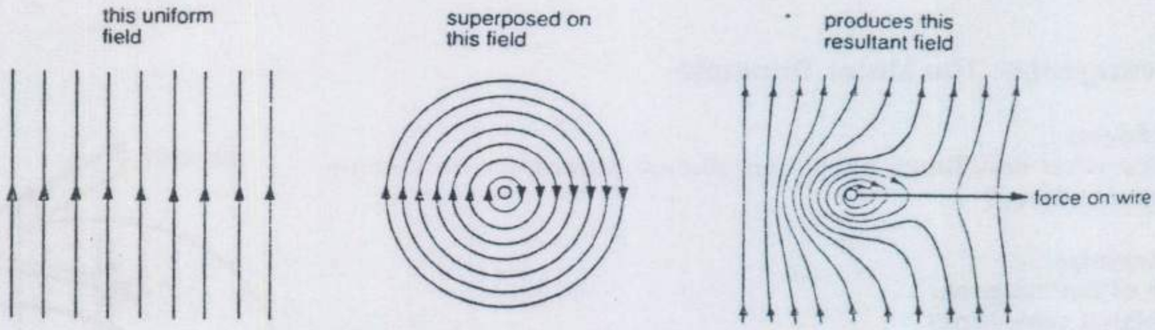
where B is the strength of the uniform magnetic field
L is the length of the conductor in the magnetic field
I is the current flowing through the conductor
θ is the angle between the conductor and the magnetic field lines.

Questions

1. **What happens to a conductor when it is placed in a magnetic field so that it is**
   (a) parallel to the magnetic field lines?
   (b) perpendicular to the magnetic field lines?
2. **On what factors does the direction of the force on the conductor depend?**
3. **What factors do you predict would affect the magnitude of this force?**
4. **What happens to the rectangular coil when current flows through it? Do all four sides of the coil experience a force? Explain, in terms of your answer to question 1.**
5. **What device does this simple coil and magnet simulate?**

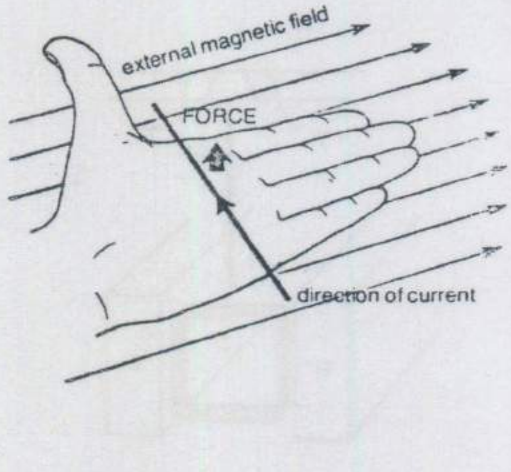
When the current-carrying wire is placed in the magnetic field so that its electrons cut across the magnetic field lines, it experiences a force. When placed parallel to the magnetic field, the conductor experiences no force. The force acts perpendicular both to the direction of the current and to the magnetic field lines. Reversing either the current or the magnetic field causes the force to act in the opposite direction.

The next diagrams help to explain how the direction of this force is related to the magnetic field of the conductor and to the external magnetic field.



The magnetic field pattern due to current in a straight wire at right angles to a uniform field

To the left of the conductor, the field lines point in the same direction and hence reinforce each other, producing a strong magnetic field. To the right, the fields are opposed and, as a result, tend to cancel each other, producing a weak field. This difference in field strength, indicated by the spacing of the field lines, results in a force to the right on the conductor. If either the external field or the direction of the current were to be reversed, the force would act in the opposite direction.



A more detailed investigation would show that the actual magnitude of the force depends on the magnitude of both the current and the magnetic field.

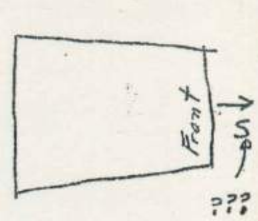
To summarize these effects, in what is called the **motor principle**:

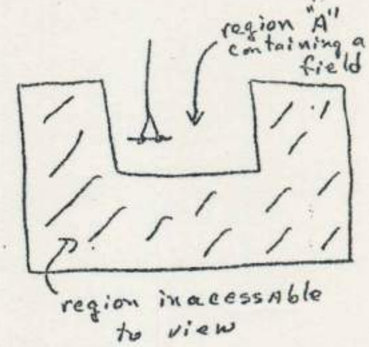
A current-carrying conductor that cuts across external magnetic field lines experiences a force perpendicular to both the magnetic field and the current. The magnitude of this force depends on the magnitude of both the external field and the current.

The direction of the force on the conductor also depends on the direction of the current and the direction of the external magnetic field. It can be determined easily, by using what is called the **left-hand rule for the motor principle**:

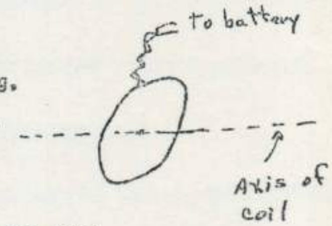
If the fingers of the left hand point in the direction of the external magnetic field lines, and the thumb represents the current direction, the force on the conductor will be in the direction in which the palm faces.

A student finds a compass in a classroom with the end painted gold pointing toward the front of the classroom. He is not familiar with the local directions so he cannot tell north from south. He does find a battery and wire and after appropriate tests he explains, "The front of this room faces South!" Explain what tests he might have made and how he came to his decision.



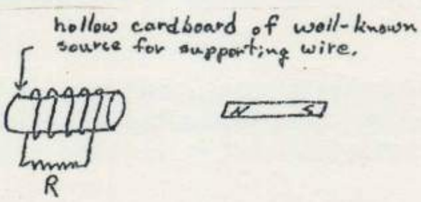


A student suspends a magnetized needle into the space "A" and the north end points to the left. After subsequent tests, <u>with the same needle</u>, the student states region A contains an <u>electric</u> field, not a magnetic field. What tests did he do and why did he reach this conclusion?



After examining the field around the current carrying ring, with a small compass, a student states, "The field (<u>outside</u> the thin space within the ring) is shaped like the field of a disk magnet of the same size." Assuming this is true, where would the north and south poles of this current-carrying loop be? (How did you decide where the poles were with the disk magnet?) Explain.

What direction is the current, if any, thru the resistor R (explain briefly in each case):



A. When the magnet is moved toward the left. ____________________

B. When the magnet is stopped ____________________

C. When the magnet is moved to the right. ____________________