Unit 1
(Magnetism)

Magnetism

Magnetism is the force of attraction or repulsion in and around a material.

Magnetism is present is all materials but at such low levels that it is not easily detected.

Certain materials such as magnetite, iron, steel, nickel, cobalt and alloys of rare earth elements, exhibit magnetism at levels that are easily detectable.

Magnets

A magnet is any piece of material that has the property of attracting iron (or steel).

Magnetite, also known as lodestone, is a naturally occurring rock that is a magnet.

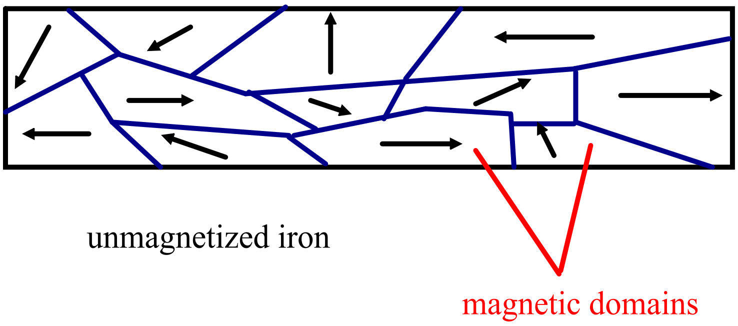
Ferromagnetic materials like iron, nickel, cobalt, chromium dioxide, and alnico (Al-Ni-Co alloy) can be magnetized.

Magnetic Domains

A magnetic domain is a region in which the magnetic fields of atoms are grouped together and aligned. You can think of magnetic domains as miniature magnets within a material.

unmagnetized object - magnetic domains are pointing in different directions

magnetized object - all like magnetic poles line up and point in the same direction



LINK

SPIT

Steel
permanent
reorientation difficult

iron
temporary
reorientation is easy

domains

Magnetic Field Lines

Since no isolated poles are known to exist (ie/ no magnetic monopoles), magnetic field lines have to be drawn so that they are associated with both poles of the magnet.

Activity

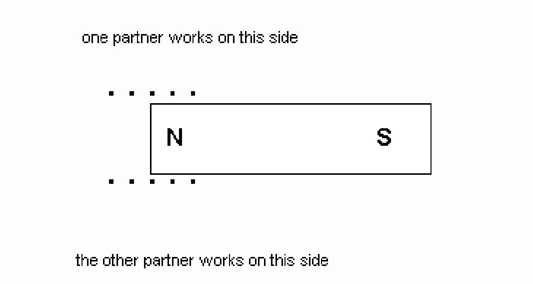
J.31/13

Plotting magnetic field lines using a compass

Place your bar magnet in the center of the poster paper.

Trace the magnet shape onto the paper and label the positions of the magnet's N and S poles on the paper. At this point, don't move the magnet until you've completed the field mapping.

Starting near a corner of the N end of the magnet, place 5 tic marks spaced 4 millimeters apart down the long axis of the bar magnet. (See the figure.)



Now take your compass and place it such that one of the tic marks lies on the circumference of the compass while at the same time the S end of the needle points directly to the tic mark. With a pencil, make another tic mark on the opposite side of the compass, i.e., at the place to which the N end of the compass needle points. See Figure 1. This works best with a small diameter compass. If you have a large compass, make the best of it.

Figure 1

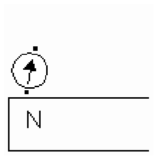
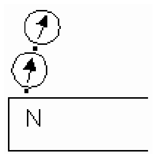


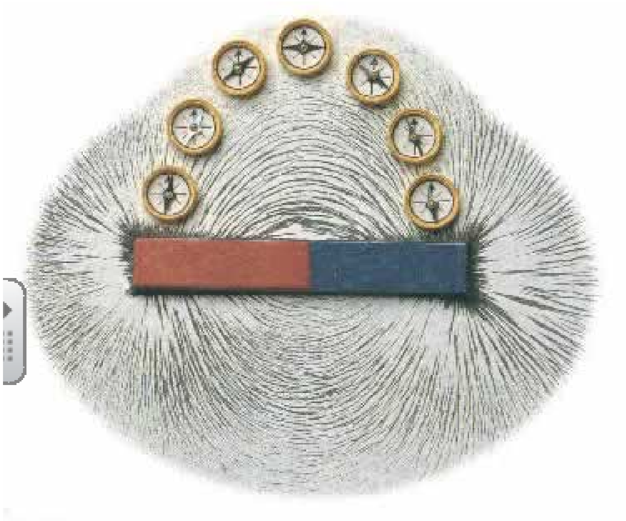
Figure 2



Now move the compass so that the S end of the needle points at the new tic mark you just made. Again make a new tic mark on the opposite side of the compass, at the place to which the N end of the compass needle points. (See Figure 2.) Keep repeating this process until the trail of tic marks reaches the edge of the paper or returns to the south end of the magnet.

Connect the tic marks with a smooth curve to produce a magnetic field line. Draw an arrow on the line to indicate the direction of the field.

Repeat for each of the remaining tic marks at the N end of your side of the magnet. Your partner, if you have one, will do the same thing on the opposite side.



Magnetic Fields

The direction of the magnetic field at a particular location is defined as the direction in which the N-pole of a compass would point when placed at that location. The magnetic field lines leave the N-pole of a magnet, enter the S-pole and continue to form a closed loop inside the magnet. The magnetic field lines outside the magnet are more concentrated at the poles of the magnet, where the magnetic field is greatest.

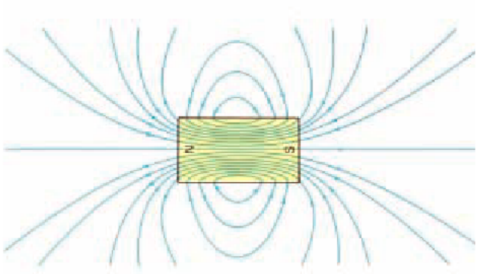
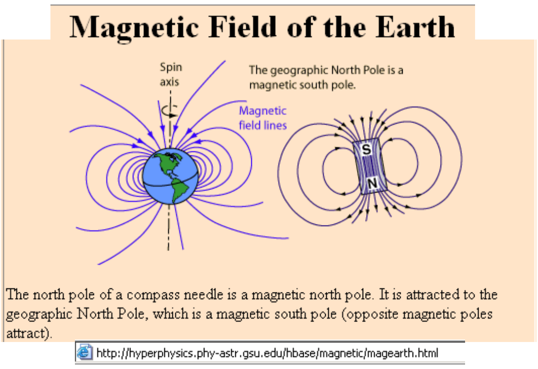


Figure 14.12 The magnetic field lines are closed loops leaving the N-pole of the magnet and entering the S-pole.



Magnetic Field of the Earth

The north pole of a compass needle is a magnetic north pole. It is attracted to the geographic North Pole, which is a magnetic south pole (opposite magnetic poles attract).

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magearth.html

Field Lines for Like Poles

Field Lines for Unlike Poles

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Iron Filings and Magnetic Fields

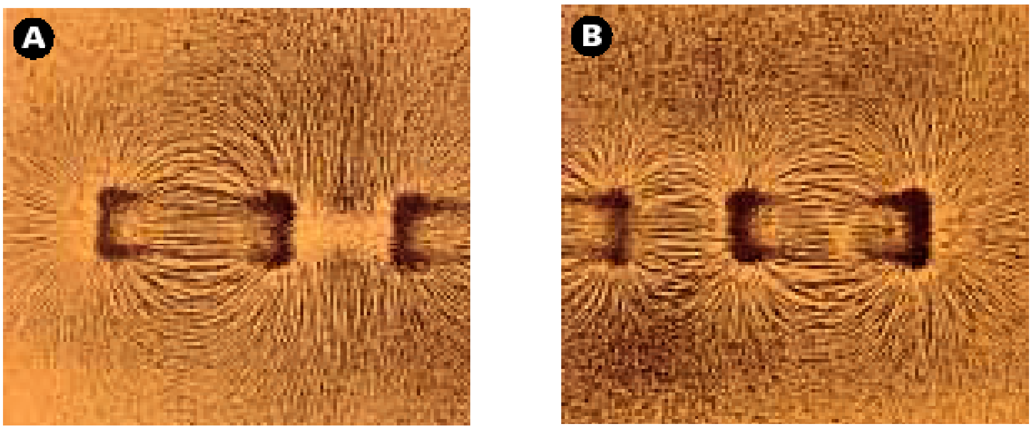

Figure 14.13 The field lines for **(A)** like poles and **(B)** unlike poles

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Oersted's Discovery

In 1819, a Danish physicist, Hans Christian Oersted (1777–1851), was demonstrating the heating effects of an electric current in a wire to some friends and students. On his table he had some compasses ready for a demonstration he was doing later that day in magnetism. He noticed that when he closed the circuit, the needles of the compasses were deflected at right angles to the conductor. He kept this to himself until he had a chance to explore it further. It did not seem to make sense that the compass needle was neither attracted nor repelled by the current but deflected at right angles to it. Oersted had discovered that a current-carrying conductor caused the needle of a magnetic compass to deflect at right angles to the conductor. When he published his findings, it set off a flurry of research into the newly discovered phenomenon called **electromagnetism**. That is, moving electrons produce a magnetic field and a changing magnetic field will cause electrons to move.

Right-hand Rule #1

Oersted's experiments convinced him that each point of a current-carrying conductor created a magnetic field around itself. The field lines were a set of concentric closed circles on planes perpendicular to the direction of the current. The direction of the field lines and thus the direction of the field could be determined using a "right-hand rule" (see Figure 16.4).

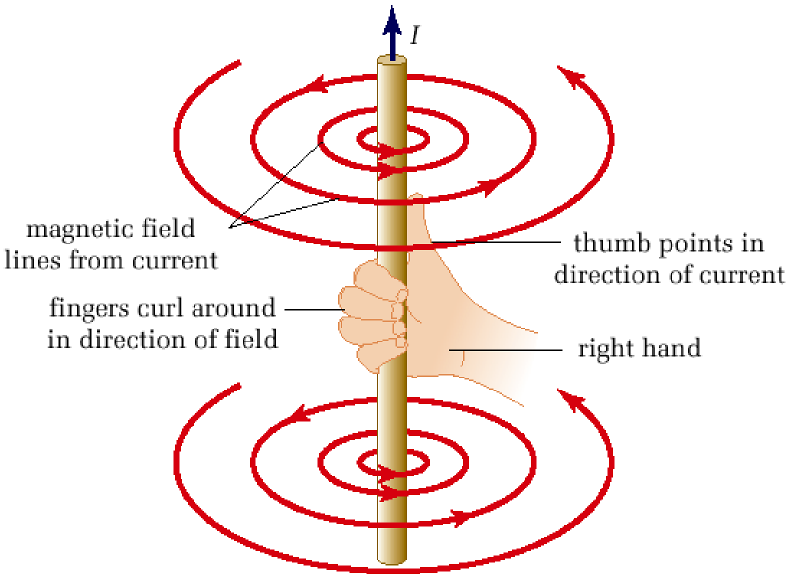
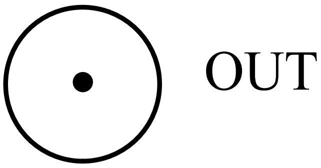


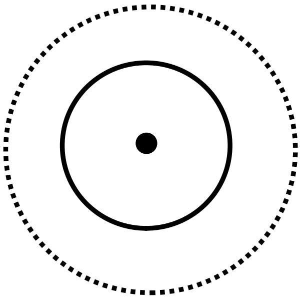
Figure 16.4 **Right-hand rule #1** If you grasp a current-carrying conductor with your right hand so that the thumb lies along the conductor in the direction of the current. then the fingers of your hand will be encircling the cc

NOTE: Currents flowing into or out of the page are indicated using the symbols below.

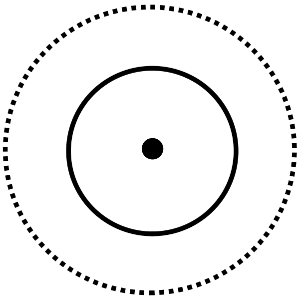
current flowing out of the page



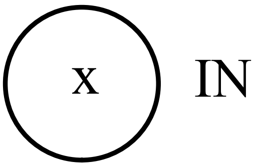
RHR #1
conventional current



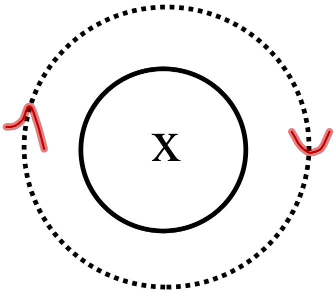
LHR #1
electron flow



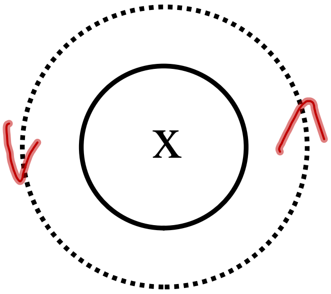
current flowing into the page



RHR #1
conventional current



LHR #1
electron flow



Science 122

Solenoid or Electromagnet

A **solenoid** is a long coil of wire in the shape of a helix. If the wire is wound so that the turns are packed close to each other and the solenoid is long compared to its diameter, the magnetic field lines have the appearance shown in the drawing. The field inside the solenoid and away from its ends is nearly constant in magnitude and directed parallel to the axis. A solenoid can be imagined to be a bar magnet. Solenoids are often referred to as **electromagnets**. Electromagnets have advantages over permanent magnets. For one thing, the strength of the magnetic field can be altered by changing the current and/or the number of turns per unit length. Also, the north and south poles of an electromagnet can be readily switched by reversing the current.

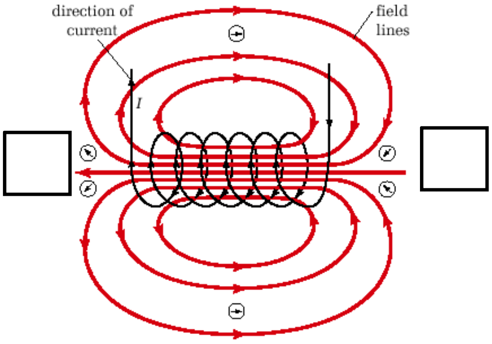


Figure 16.9 The pattern of the magnetic lines of force around a solenoid is very similar to the pattern of lines of force around a bar magnet.

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The N-pole and S-pole of the electromagnet are located using the Right-hand Rule #2.

Right-hand Rule #2

Grasp the coil with the right hand. Curl your fingers around the loops in the direction of the conventional current flow. Your thumb points towards the N-pole of the electromagnet.

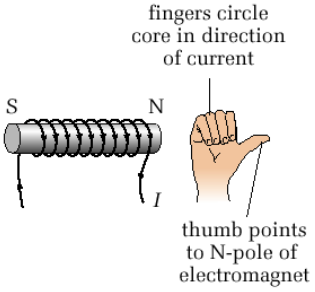

Figure 16.12 Right-hand rule #2 is used to locate the N-pole of an electromagnet.

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Right Hand Rule #3 is used to determine the direction of the force exerted on a conductor by a magnet's magnetic field.

Right-hand Rule #3

Align the thumb along the conductor pointing in the direction of the current and the fingers pointing in the direction of the magnetic field from the magnet that is passing the conductor. The palm is facing the direction of the force that the field from the magnet exerts on the conductor. The palm "pushes" in the direction of the force on the conductor. This phenomenon is called the motor effect since it is the driving force that makes electric motors run.

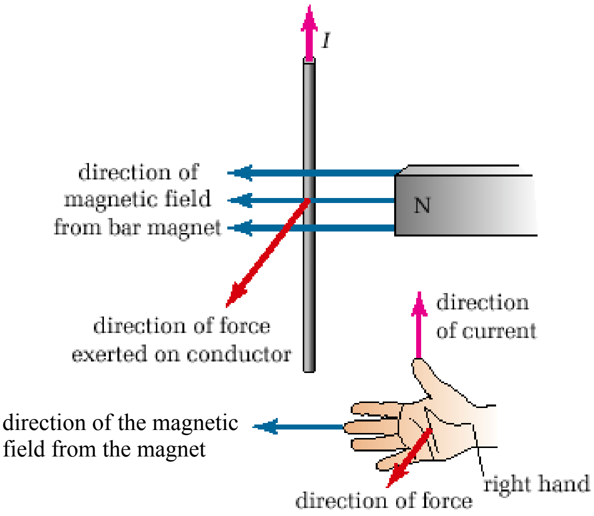

Figure 16.17 A conductor that carries a current at right angles to a magnetic field experiences a force at right angles to both the current and the direction of the field. This direction can be predicted by using right-hand rule #3.

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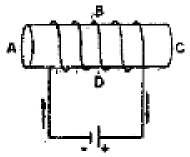
Intro and Hand Rules

Name ______________________________ Date ______________

Instructions: Circle the letter of the best answer.

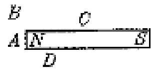
1. The north pole of the coil of wire shown in the diagram is directed toward

[✓ a)] *A* b) *B* c) *C* d) *D*



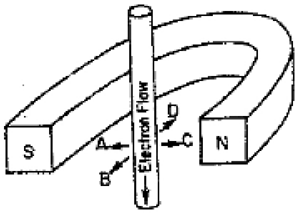
2. In the diagram shown, at which point is the magnetic field strongest?

[✓ a)] *A* b) *B* c) *C* d) *D*



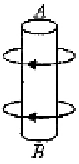
3. In the diagram shown, a wire is suspended in the presence of a magnetic field. As electrons begin to flow through the wire as indicated, in which direction will the wire tend to move?

a) *A* [✓ b)] *B* c) *C* d) *D*

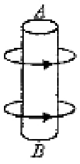


4. The electrons in a straight conductor move from *A* to *B*. Which diagram best represents the direction of the magnetic field around the conductor?

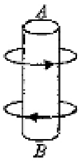
a)



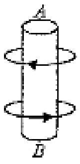
[✓ b)]



c)

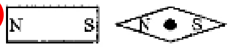


d)

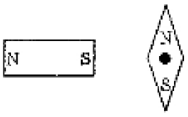


5. If a small compass is placed near a bar magnet, which diagram correctly shows the position of the compass needle?

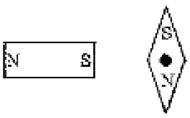
[✓ a)]



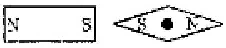
b)



c)



d)



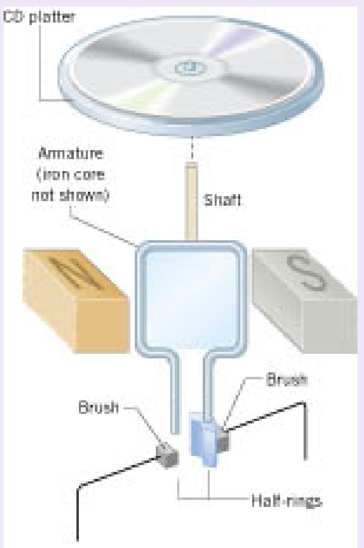
Science 122

Electric Motors

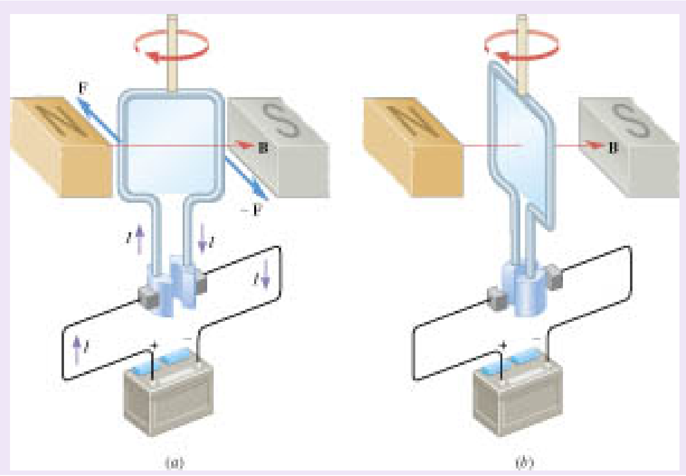
We have seen that a current-carrying wire can experience a force when placed in a magnetic field. If a loop of wire is suspended properly in a magnetic field, the magnetic force produces a torque that tends to rotate the loop. This torque is responsible for the operation of a widely used type of electric motor.

The electric motor is found in many devices, such as CD players, tape decks, automobiles, washing machines and air conditioners.

A direct-current (dc) motor consists of a coil of wire placed in a magnetic field that is free to rotate about a shaft. The coil of wire contains many turns and is wrapped around an iron cylinder that rotates with the coil. The coil and iron cylinder assembly is known as the **rotor** or **armature.** Each end of the wire coil is attached to a metallic half-ring (copper or brass). Rubbing against each of the half-rings is a carbon or metal contact called a brush. While the half-rings rotate with the coil, the brushes remain stationary. The two half-rings and the associated brushes are referred to as a **split-ring commutator**.



In diagram (a) below, the current from the battery enters the coil through the left brush and half-ring, goes around the coil, and then leaves through the right half-ring and brush. The two forces shown, **F** and **-F**, produce the torque that turns the coil. Eventually the coil reaches the position shown in (b). In this position, the half-rings momentarily lose electrical contact with the brushes so that there is no current in the coil and no applied torque. The moving coil does not stop rotating immediately because its inertia carries it onward. When the half-rings re-establish contact with the brushes, there is current in the coil again and a magnetic torque again rotates the coil in the same direction. The split-ring commutator ensures that the current is always in the proper direction to yield a torque that produces a continuous rotation of the coil.



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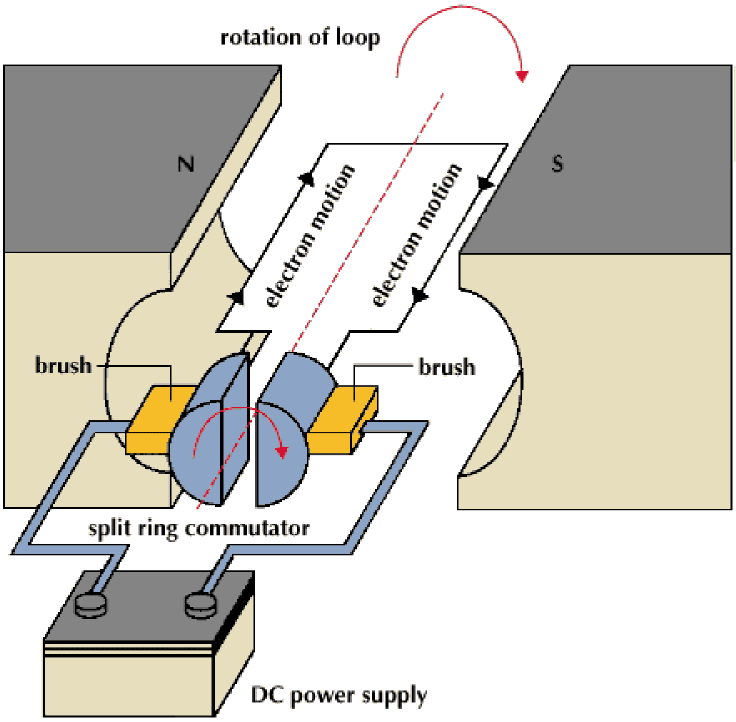
Chapter 21
Chapter 21: Magnetic Forces and Magnetic Fields

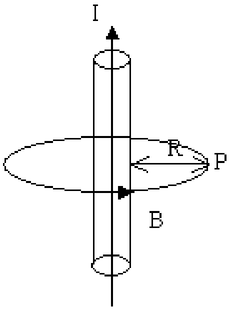
Science 122

Electric Motor



Science 122
The Magnitude of Magnetic Fields (Calculations)

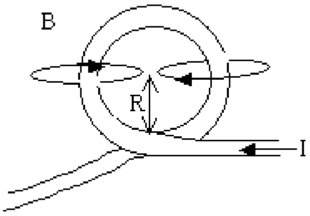
I. Long Straight Current-Carrying Wire



$$B = \frac{\mu_o I}{2\pi R}$$

B -> magnitude of the magnetic field at point P (T, tesla*)
μ_o -> permeability of free space** ($4\pi \times 10^{-7}$ Tm/A)
I -> current flowing through the wire (A)
R -> distance from P to the conductor (m)

II. Circular Loops



$$B = \frac{\mu_o I N}{2R}$$

B -> magnetic field at the center of the loop (T)
μ_o -> permeability of free space
I -> current through the coil (A)
N -> number of loops or turns
R -> radius of the loop (m)

III. Solenoid or Electromagnet

If the length of the solenoid is long compared to its diameter, the magnetic field inside the solenoid is found using:

$$B = \mu_o I n$$

B -> magnitude of the uniform magnetic field inside the solenoid (T)
μ_o -> permeability of free space
I -> current flowing through the solenoid (A)
n-> number of loops/length (m^{-1})

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* $T = \frac{N}{Am} = \frac{Ns}{Cm}$

** indication of the extent that a magnetic field can extend into a vacuum

Science 122

Magnetic Field Produced by a Wire

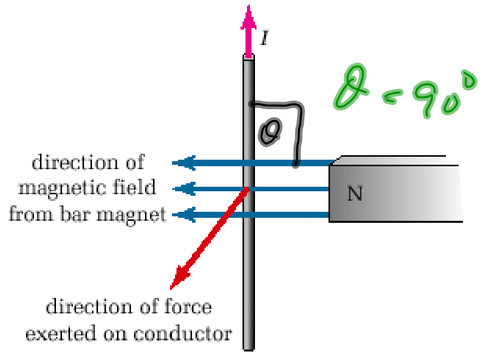
Problems

1. Calculate the magnitude of the magnetic field 9.0 cm from a long straight conductor carrying a current of 3.0 A. (6.7 x 10^{-6} T)
2. Calculate the current in a long straight conductor if it produces a magnetic field of 2.6 x 10^{-5} T at a distance of 25 cm from the conductor. (33 A)
3. A circular coil has a diameter of 9.0 cm and 12 loops. If the current flowing through the coil is 15 A, what is the magnetic field strength at the center of the coil? (2.5 x 10^{-3} T)
4. A 25.0 cm solenoid has 1800 loops and a diameter of 3.00 cm. Calculate the magnetic field in the air core of the solenoid when a current of 1.25 A is flowing. (1.13 x 10^{-2} T)
5. A circular coil has 9 loops and a current of 8.0 A flowing through it. If the magnetic field at the center of the coil is 1.1 x 10^{-3} T, what is its diameter? (0.082 m)
6. A circular coil with 18 loops of wire has a diameter of 12 cm. If the magnetic field at the center of this coil is 6.2 x 10^{-4} T, what is the current flowing through the coil? (3.3 A)
7. An air core solenoid is 25 cm long and carries a current of 0.72 A. If the magnetic field in the core is 2.1 x 10^{-3} T, how many turns does this solenoid have? (580)
8. An air core solenoid is 30.0 cm long and has 775 turns. If the magnetic field in the core is 0.100 T, what is the current flowing through this solenoid? (~~31 A~~)
   30.8A

The Force On A Wire Due To Magnetic Field

Experiments show that the magnitude of the force, F, on a wire in a magnetic field is proportional to three factors:

1. the strength, B, of the magnetic field
2. the current, I, in the wire
3. the length, L, of the wire that lies in the magnetic field



$$\boxed{F = ILB\sin\theta}$$

quantity	variable	unit
magnitude of force	F	N
current	I	A
length	L	m
magnitude of magnetic field	B	T

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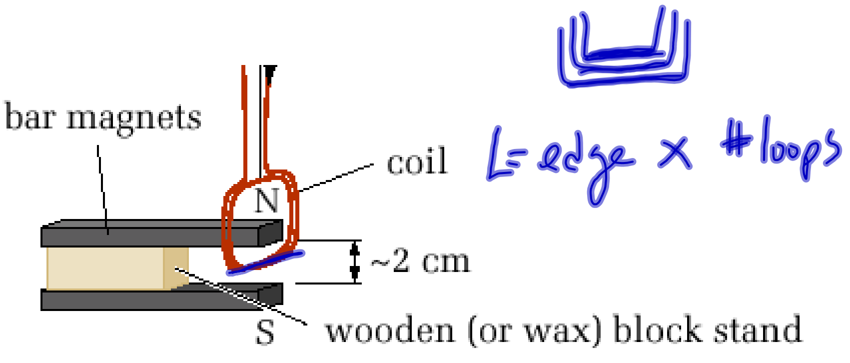
NOTE: The angle, θ, is the angle between the wire and the magnetic field.

Magnetic force is a maximum when the wire is perpendicular to the field (θ = 90°) and vanishes when the current is parallel to the field (θ = 0° or 180°).

NOTE: When a coil of wire is placed inside a magnetic field, the edge of the coil inside the field must be multiplied by the number of turns or loops of the wire to obtain the length of wire, L, in the magnetic field.



L = edge × # loops

Chapter 16 Magnets, Motors, and Generators • MHR 771

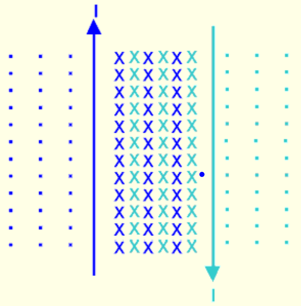
Science 122

The Force on a Wire in a Magnetic Field

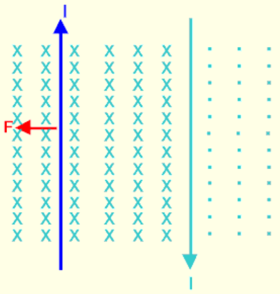
Problems

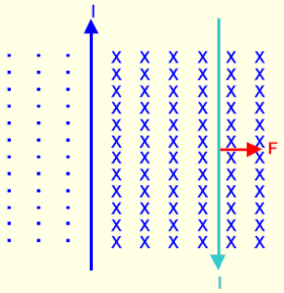
1. A wire 0.10 m long carries a current of 5.0 A. The wire is at right angles to a uniform magnetic field. The force on the wire is 0.20 N. What is the magnitude of the magnetic field? (0.40 T)
2. A 45 m length of wire is stretched horizontally between two vertical posts. The wire carries a current of 75 A and experiences a magnetic force of 0.15 N. Find the magnitude of the earth's magnetic field at the location of the wire, assuming the field makes an angle of 60.0° with respect to the wire. (5.1×10^{-5} T)
3. A magnetic field has an intensity of 1.2 T into the page. A current of 7.5 A flows vertically upward through a conductor that has 0.080 m inside the field. Find the magnitude and direction of the force that the field exerts on the conductor. (0.72 N, left)
4. An electric power line carries a current of 1400 A in a location where the earth's magnetic field is 5.0×10^{-5} T. The line makes an angle of 75° with respect to the field. Determine the magnitude of the magnetic force on a 120 m length of line. (8.1 N)
5. A wire 115 m long is at right angles to a uniform magnetic field. The field has a magnetic field strength of 5.0×10^{-5} T. The current through the wire is 400 A. Find the magnitude of the force. (2.3 N)
6. A coil that consists of 250 turns of wire has an edge 12 cm long that carries a current of 1.6 A to the right. If the edge of the coil is inside a magnetic field of 0.16 T pointing out of the page, what is the magnitude and direction of the force that the field exerts on the coil? (7.7 N, down)
7. A wire carries a current of 0.66 A. This wire makes an angle of 58° with respect to a magnetic field of magnitude 4.7×10^{-5} T. The wire experiences a magnetic force of magnitude 7.1×10^{-5} N. What is the length of the wire? (2.7 m)
8. A copper wire 40 cm long carries a current of 6.0 A and weighs 0.35 N. A certain magnetic field is strong enough to balance the force of gravity on the wire. What is the strength of the magnetic field? (0.15 T)
9. A wire of length 0.655 m carries a current of 21.0 A. In the presence of a 0.470 T magnetic field, the wire experiences a force of 5.46 N. What is the angle (less than 90°) between the wire and the magnetic field? (57.6°)

Two Current-Carrying Wires

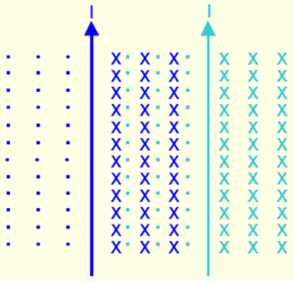


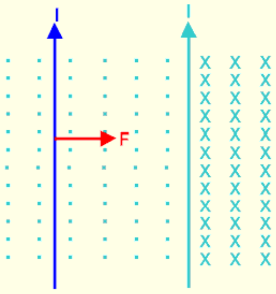
As you can see in the diagram above, if two parallel wires have currents traveling in opposite directions, the magnetic fields generated by those currents between the wires will both point in the same direction, in this case, into the plane of the page.

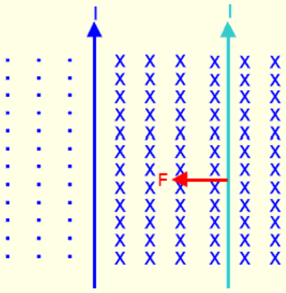


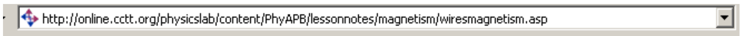


However, if two parallel wires have currents traveling in the same direction, the magnetic fields generated by those currents between the wires will both point in opposite directions.

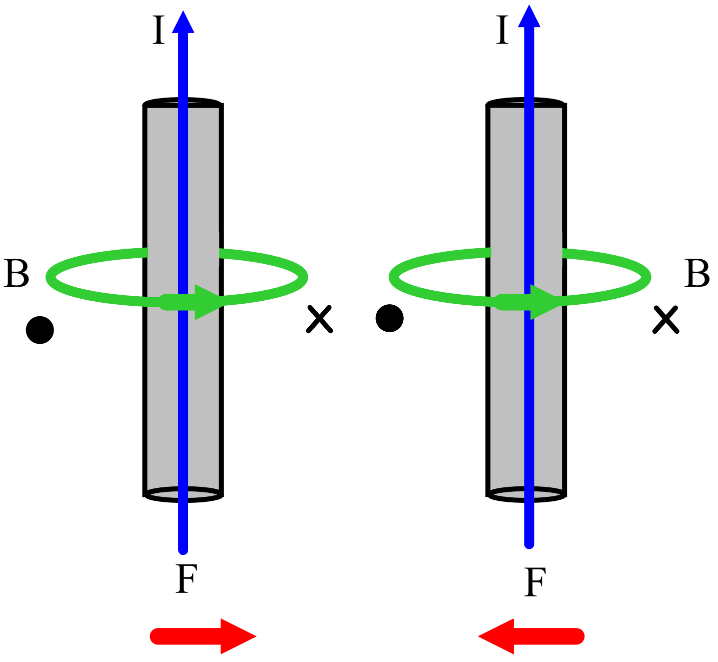






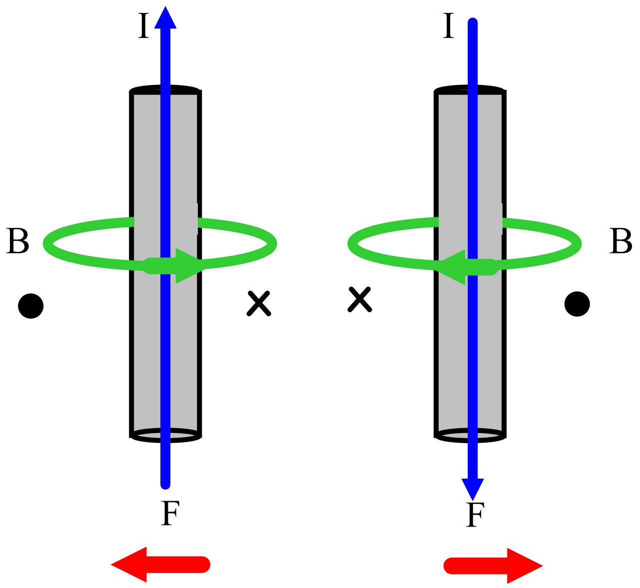

http://online.cctt.org/physicslab/content/PhyAPB/lessonnotes/magnetism/wiresmagnetism.asp

Current in the Same Direction



Current-carrying wires attract in this case.

Current in the Opposite Directions



Current-carrying wires repel in this case.

Force on a Single Charged Particle

A magnetic field exerts a magnetic force on a charged particle if that particle is moving.

The force produced by a magnetic field on a single charged particle depends upon:

1. the charge on the particle
2. the velocity of the charged particle
3. the strength of the magnetic field
4. the angle between the direction of the velocity of the particle and the direction of the magnetic field

Remember:

$$\boxed{F = ILB\sin\theta}$$

and

$$\boxed{I = \frac{q}{t}}$$

Combining the two equations:

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

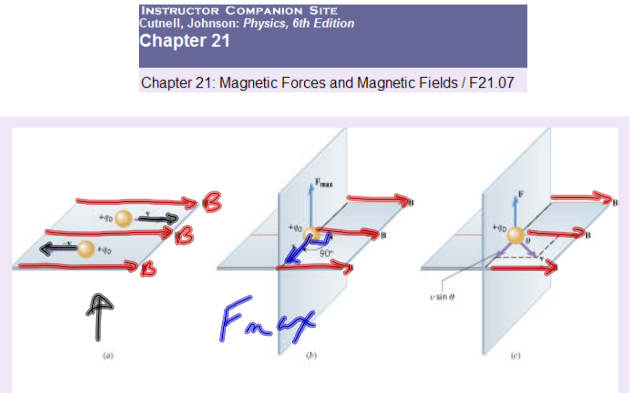
With a little rearranging:

$$F = q\frac{L}{t}B\sin\theta$$

$$\boxed{F = qvB\sin\theta}$$

F -> magnitude of magnetic force (N)
q -> magnitude of charge (C)
v -> magnitude of velocity (m/s)
B -> magnitude of magnetic field (T)
θ -> angle between the velocity vector and the direction of the magnetic field

The velocity of the moving charge must have a component that is perpendicular to the direction of the magnetic field.



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Chapter 21

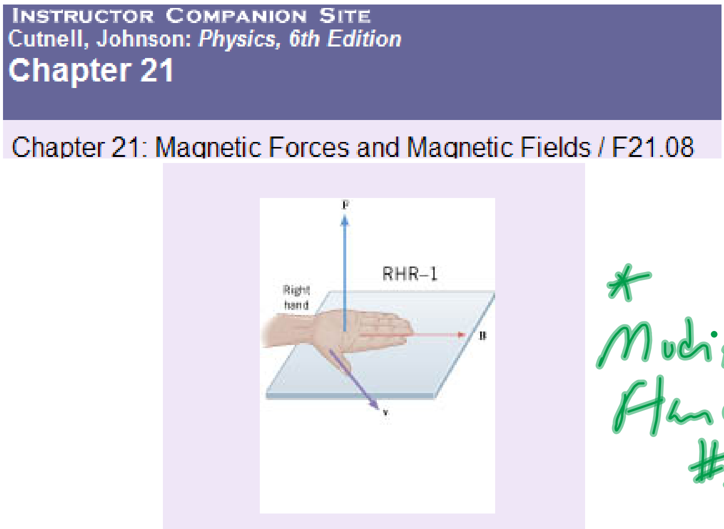
Chapter 21: Magnetic Forces and Magnetic Fields / F21.07

(a) No magnetic force acts on a charge moving with a velocity **v** that is parallel to a magnetic field **B**. θ = 0°, 180°

(b) The charge experiences a maximum force when the charge moves perpendicular to the field.

(c) If the charge travels at an angle θ with respect to **B**, only the velocity component perpendicular to **B** gives rise to a magnetic force (the component is vsinθ).

☆



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Chapter 21

Chapter 21: Magnetic Forces and Magnetic Fields / F21.08

* Modified Hand Rule #3

RH → positively charge particle

The right hand is oriented so the fingers point along the magnetic field **B** and the thumb points along the velocity **v** of a positively charged particle, the palm faces in the direction of the magnetic force **F** applied to the particle.

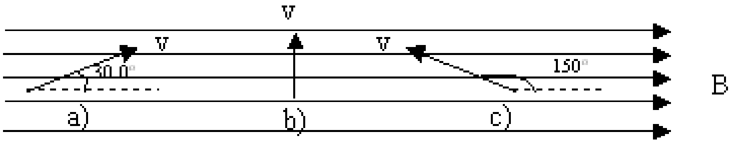
If the moving charge is negative instead of positive, the direction of the magnetic force is opposite that predicted when using the right hand.

Handout

<u>NOTE</u>: You may need formulas from Physics 122 for some of the problems on the handout.

Science 122
Magnetic Force on a Single Charged Particle
Problems

1. A particle with a charge of +8.4 μC and a speed of 45 m/s enters a uniform magnetic field whose magnitude is 0.30 T. For each of the cases in the drawing, find the magnitude and direction of the magnetic force on the particle. (5.7×10^{-5} N into the page, 1.1×10^{-4} N into the page, 5.7×10^{-5} N into the page)



2. Due to friction with the air, an airplane has acquired a net charge of 1.70×10^{-5} C. The plane moves with a speed of 2.80×10^{2} m/s at an angle Θ with respect to the earth's magnetic field, the magnitude of which is 5.00×10^{-5} T. The magnetic force on the airplane has a magnitude of 2.30×10^{-7} N. Find the angle Θ that is between 0° and 90°. (75.1°)

3. At a certain location, the earth's magnetic field is 2.5×10^{-5} T, due north. A proton moves due east with just the right speed, so the magnetic force on it balances its weight. Find the speed of the proton. (4.1×10^{-3} m/s)

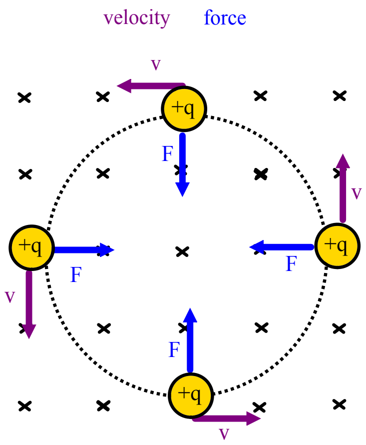
4. In New England, the horizontal component of earth's magnetic field has a magnitude of 1.6×10^{-5} T. An electron is shot vertically straight up from the ground with a speed of 2.1×10^{6} m/s. What is the magnitude of the acceleration caused by the magnetic force? Ignore the gravitational force acting on the electron. (5.9×10^{12} m/s^2)

5. An electron is moving through a magnetic field whose magnitude is 8.70×10^{-4} T. The electron experiences only a magnetic force and has an acceleration of magnitude 3.50×10^{14} m/s^2. At a certain instant, it has a speed of 6.80×10^{6} m/s. Determine the angle Θ (less than 90°) between the electron's velocity and the magnetic field. (19.7°)

6. The electrons in the beam of a television tube have a kinetic energy of 2.40×10^{-15} J. Initially the electrons move horizontally from west to east. The vertical component of the earth's magnetic field points down toward the earth's surface, and has a magnitude of 2.00×10^{-5} T. What is the acceleration of an electron under these circumstances? (2.55×10^{14} m/s^2)

Trajectory of A Single Charged Particle in a Uniform Magnetic Field

When the velocity of a charged particle is perpendicular to a **uniform** magnetic field, a special case exists. Study the diagram below.



The magnetic force always remains perpendicular to the velocity and is directed toward the center of the circular path.

To find the radius of the path, the concept of centripetal force is used. The centripetal force is the net force directed toward the center of the circle that is needed to keep a particle moving along a circular path.

$$F_c = \frac{mv^2}{r}$$

In the special case, the **magnetic force is the centripetal force** and $\theta = 90^\circ$ so:

$$F = qvB$$

Combining formulas:

$$qvB = \frac{mv^2}{r}$$

$$r = \frac{mv^2}{qvB}$$

$$\boxed{r = \frac{mv}{qB}}$$

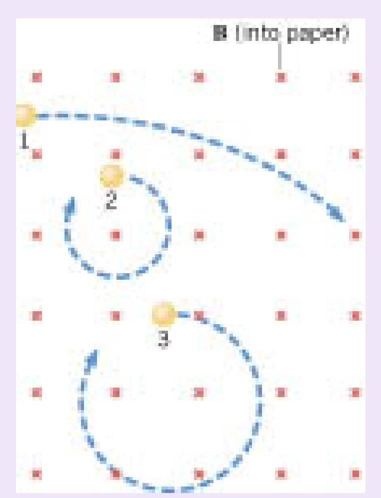
Michael Vick
quarterback

r -> radius of the circular path (m)
m -> mass of the particle (kg)
v -> speed of the particle (m/s)
q -> magnitude of charge (C)
B -> magnitude of magnetic field intensity (T)

★

Try:

Three particles have identical charges and masses. They enter a constant magnetic field and follow the paths shown in the drawing. Rank the speeds of the particles, largest to smallest.



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Chapter 21: Magnetic Forces and Magnetic Fields / Insert-2102

Rank: Largest -> Smallest

What happens as the magnetic field increases?

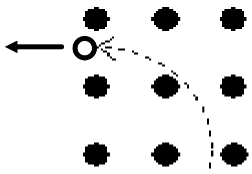
☆

Science 122

Magnetic Fields and Circular Paths

1. An electron moves at a speed of 6.0×10^{6} m/s perpendicular to a constant magnetic field. The path is a circle of radius 1.3×10^{-3} m.
   a) What is the magnitude of the magnetic field? (2.6×10^{-2} T)
   b) Find the magnitude of the electron's acceleration. (2.7×10^{16} m/s^{2})

2. A charged particle enters a uniform magnetic field and follows the circular path shown in the drawing.
   a) Is the particle positively or negatively charged?
   b) The particle's speed is140 m/s, the magnitude of the field is 0.48 T and the radius of the path is 960 m. Determine the mass of the particle given that its charge is 8.2×10^{-4} C. (2.7×10^{-3} kg)



3. A beam of protons moves in a circle of radius 0.25 m. The protons move perpendicular to a 0.30 T magnetic field.
   a) What is the speed of each proton? (7.2×10^{6} m/s)
   b) What is the magnitude of the centripetal force that acts on each proton? (3.5×10^{-13} N)

http://www.coolschool.ca/lor/PH12/unit7/U07L05.htm

What are some devices which use the laws of electromagnetism and how do they work?

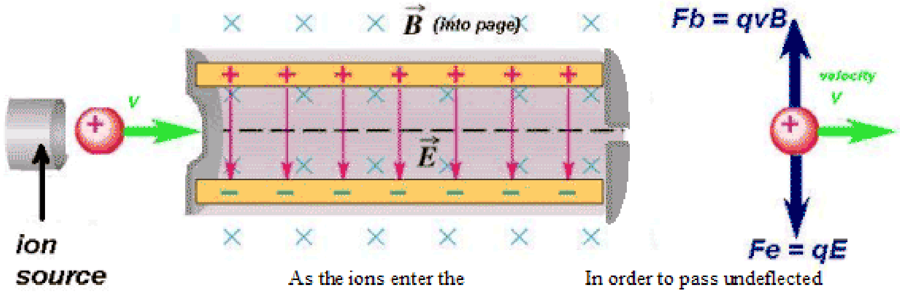
Many devices make use of electromagnetic interactions for various reasons. Two of these are the velocity selector and mass spectrometer.

Velocity Selector

A velocity selector, uses electric fields at right angles to magnetic fields to allow charged particles of only a particular velocity to pass through, hence its name. These two crossed fields provide opposing forces on a charged particle as it moves through them. This is shown in the following link.

Cross-section of a velocity selector

While in the magnetic field an electromagnetic force is felt as $F_B = QvB$. The right hand rule gives us the direction, with fingers into the page (B), thumb to the right (I), gives force in direction of the palm being UP.



The source provides positively charged particles entering the selector at this end.

As the ions enter the electric field a force Fe = QE is created based on the charge of the ion and field strength. This force is directed downward as the positive plate repels the positive particle.

In order to pass undeflected through the crossed fields $F_B = Fe$ or $QvB = QE$. Factoring the charge gives us $vB = E$ or solving for v gives $v = E / B$. Thus by controlling E and B we allow particles of only a specific velocity to pass through.

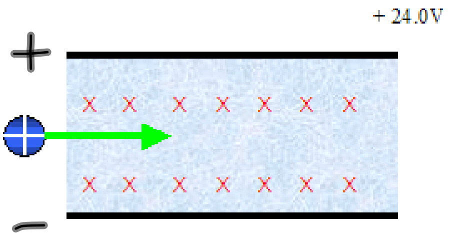
$$\boxed{\begin{gathered} F_{electric} = F_{magnetic} \\ v = \frac{E}{B} \end{gathered}}$$

If the velocity of the particle is too high, then Fb > Fe and the particle curves up hitting the plate at the end of the selector. If the velocity is to low, Fb < Fe and the particle curves down hitting the lower portion of the same plate.

In a velocity selector the fields are said to be crossed as they are a right angles to one another. It is worthwhile to note that the mass and charge of the particle are not relevant to the velocity selection process. Only the velocity, magnetic field and electric field affect the path of the charged ions. Examples follow below.

Example 1) A proton enters a region of crossed magnetic and electric fields. The parallel plates creating the field are 5.0 cm apart with the top plate having a + 24.0 V potential difference relative to the bottom plate. A magnetic field of 0.12 T is directed into the page in the same region. What speed proton will be allowed to pass through the selector?

$$\boxed{E = \frac{V}{d}}$$



$E = V/d$
$E = \frac{24}{0.05}$
$E = 480\text{V/m}$

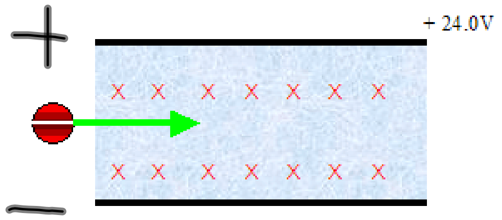
We first determine the magnitude and direction of the E-field using the formula E = V/d as seen in blue.
The force on the proton from this field is set equal to the force on the proton by the magnetic field this is shown in green.
The equation is solved for v as seen in yellow.

B = 0.12 T into page

$Fe = Fb$
$QE = QvB$

$E = vB$
$v = E/B \quad v = 480 / 0.12 = 4000\ \text{m/s}$

An electron of velocity 4000 m/s enters the same velocity selector as in the previous problem. Will it pass through?



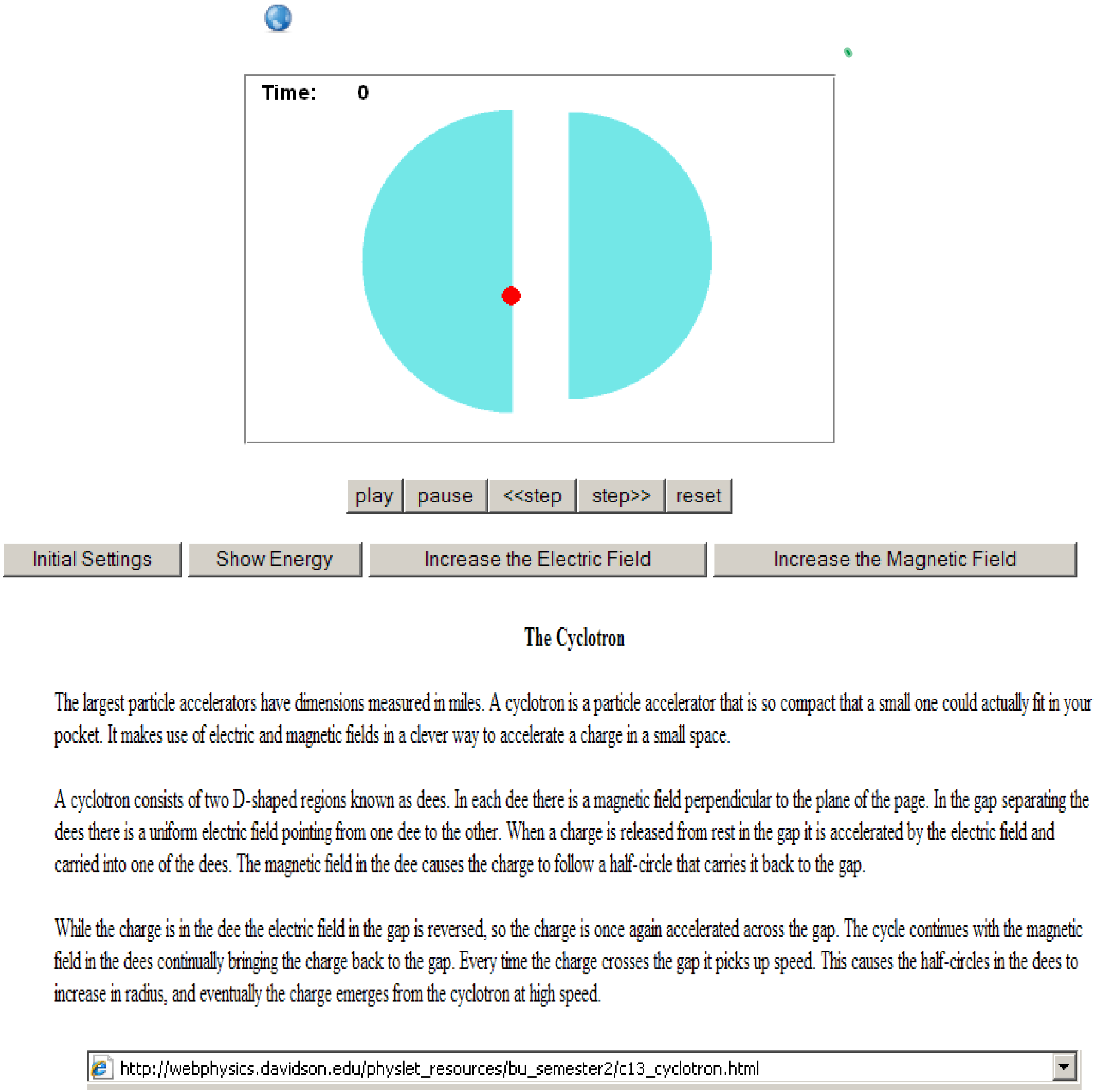
B = 0.12 T into page

In order to determine the passage of the electron we must consider the direction of the electro-static force Fe. As the electron enters the electric field it will be drawn upward toward the positive plate. Note this is the opposite direction as the proton in the previous example!

The effect of the magnetic field on the electron is given using the right hand rule. Fingers (B) still remain into page, however as the electron is negatively charged, and current direction is the direction a positive charge move, our thumb is directed toward the left. This leaves our palm to give Fb as being downward. This too is opposite that of the proton!

The result of the reversals of Fe and Fb factor one another out, and the mathematics of the velocity are the same so the electron makes it through!

Particle Accelerators
The Cyclotron



The Cyclotron

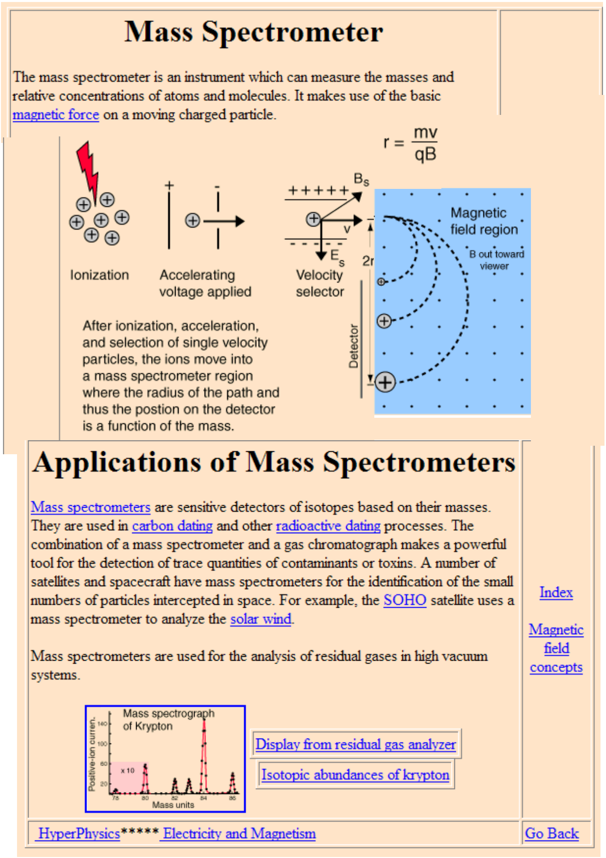
The largest particle accelerators have dimensions measured in miles. A cyclotron is a particle accelerator that is so compact that a small one could actually fit in your pocket. It makes use of electric and magnetic fields in a clever way to accelerate a charge in a small space.

A cyclotron consists of two D-shaped regions known as dees. In each dee there is a magnetic field perpendicular to the plane of the page. In the gap separating the dees there is a uniform electric field pointing from one dee to the other. When a charge is released from rest in the gap it is accelerated by the electric field and carried into one of the dees. The magnetic field in the dee causes the charge to follow a half-circle that carries it back to the gap.

While the charge is in the dee the electric field in the gap is reversed, so the charge is once again accelerated across the gap. The cycle continues with the magnetic field in the dees continually bringing the charge back to the gap. Every time the charge crosses the gap it picks up speed. This causes the half-circles in the dees to increase in radius, and eventually the charge emerges from the cyclotron at high speed.

http://webphysics.davidson.edu/physlet_resources/bu_semester2/c13_cyclotron.html

Mass Spectrometer



Mass Spectrometer

The mass spectrometer is an instrument which can measure the masses and relative concentrations of atoms and molecules. It makes use of the basic magnetic force on a moving charged particle.

After ionization, acceleration, and selection of single velocity particles, the ions move into a mass spectrometer region where the radius of the path and thus the postion on the detector is a function of the mass.

Applications of Mass Spectrometers

Mass spectrometers are sensitive detectors of isotopes based on their masses. They are used in carbon dating and other radioactive dating processes. The combination of a mass spectrometer and a gas chromatograph makes a powerful tool for the detection of trace quantities of contaminants or toxins. A number of satellites and spacecraft have mass spectrometers for the identification of the small numbers of particles intercepted in space. For example, the SOHO satellite uses a mass spectrometer to analyze the solar wind.

Mass spectrometers are used for the analysis of residual gases in high vacuum systems.

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/maspec.html

$E_k = \frac{1}{2}mv^2$ $V = \frac{W}{q}$ and $W = qV$

$$\frac{1}{2}mv^2 = qV$$

$$v^2 = \frac{2qV}{m}$$

$$v = \sqrt{\frac{2qV}{m}}$$

Remember: $r = \frac{mv}{qB}$

$$r = \frac{m}{qB}\sqrt{\frac{2qV}{m}}$$

charge to mass ratio of ion $\boxed{\frac{q}{m} = \frac{2V}{B^2r^2}}$

potential diff or voltage

☆

Examples

1. A stream of singly-ionized lithium atoms is not deflected as it passes through a 1.5 x 10^{-3} T magnetic field perpendicular to a 6.0 x 10^{2} V/m electric field.

a) What is the speed of the lithium atoms as they pass through the crossed fields? (4.0 x 10^{5} m/s)

b) The lithium atoms move into a 0.18 T magnetic field. They follow a circular path of radius 0.165 m. What is the mass of a lithium atom? (1.2 x 10^{-26} kg)

2. A mass spectrometer gives data for a beam of doubly-ionized argon atoms, the values are B = 5.0 x 10^{-2} T, q = 2(1.60 x 10^{-19} C), r = 0.106 m and V = 66.0 V. Find the mass of an argon atom. (6.8 x 10^{-26} kg)

[Handout: #2, 4, 8, 9, 10, 11, 12, 13]

☆

Electromagnetic Induction

In the same year (1832), Michael Faraday, an English chemist and physicist, and American high school teacher, Joseph Henry, showed that a changing magnetic field could produce an electric current.

To generate a current, either the conductor can move through a magnetic field or the magnetic field can move past the conductor. It is the relative motion between the wire and the magnetic field that produces the current. The process of generating a current through a circuit in this way is called electromagnetic induction and the current is called an induced current.

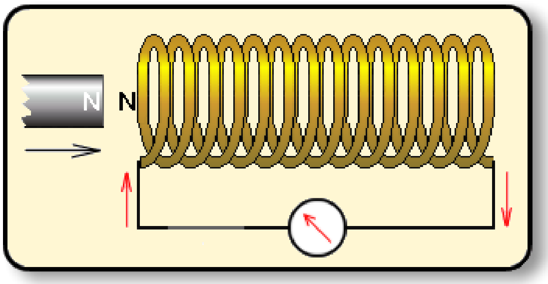
Red Text - Page 516, Figure 25-1

To find the direction of the current, use your right hand. Hold your hand so that your thumb points in the direction in which the wire is moving and your fingers point in the direction of the magnetic field. The palm of your hand will point in the direction of the conventional current.

Electromagnetic Induction - Continued

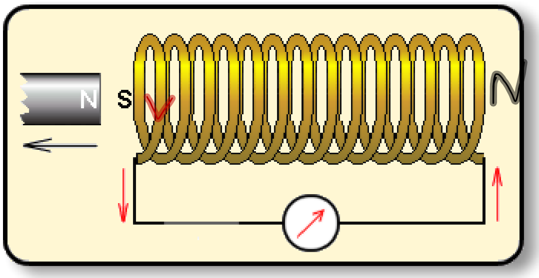
An electric current can be induced in a loop of wire or solenoid by moving a magnet into or out of the loop or solenoid. The direction of the induced current can be found using Lenz's Law.

<u>Lenz's Law</u>: The induced current will always flow in a direction such that its magnetic field opposes the <u>change</u> in magnetic field that induced the current.



The above diagram shows the north pole of a bar magnet approaching a solenoid. According to Lenz's law, the current which is thereby generated in the coil must cause an effect which opposes the approaching magnetic field. This is achieved if the direction of the induced current creates a north pole at the end of the solenoid closest to the approaching magnet, as the induced north pole tends to repel the approaching north pole.

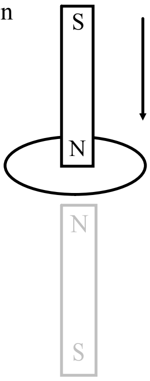

http://www.physchem.co.za/Current10/Magnetic3.htm



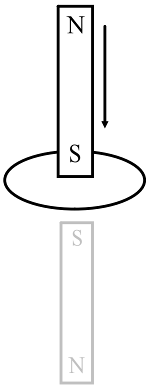
The above diagram shows the north pole of a bar magnet withdrawing from a solenoid. According to Lenz's law, the current which is thereby generated in the coil must cause an effect which opposes the departing magnetic field. This is achieved if the direction of the induced current creates a south pole at the end of the solenoid closest to the departing magnet, as the induced south pole tends to attract the departing north pole.

Simulation

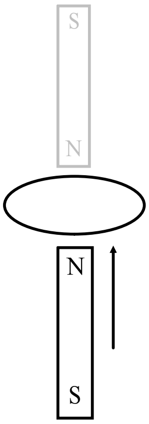
Example: The figure to the right shows a bar magnet moving down through a circular loop of wire. What will be the direction of the induced current?



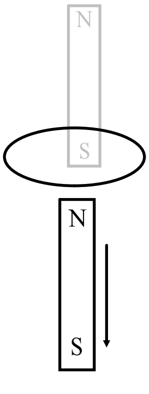
Example: What will be the direction of the induced current?



Example: What will be the direction of the induced current?



Example: What will be the direction of the induced current?



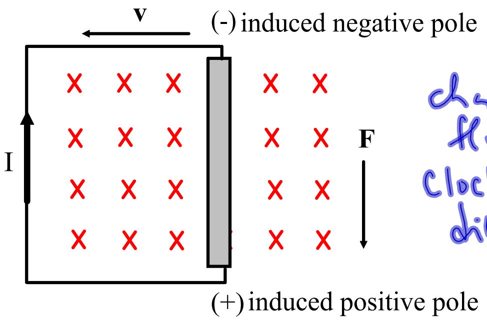
Induced Electromotive Force (EMF)

Inside a battery, chemical reactions create a potential difference, called the $\underbrace{\text{electromotive force}}_{\text{voltage}}$ or EMF (represented in equations by ξ*).

*Greek Letter Ξ ξ **XI** (KS-EYE)

The potential difference or voltage created by a changing magnetic field that causes a current to flow in a wire is called induced EMF.

If a conducting rod is moved through a constant uniform magnetic field, an EMF is induced in the rod. The induced EMF is called motional EMF because it originates from the motion of charged particles through a magnetic field. If the rod stops, the EMF disappears.



charges flow Clockwise direction

thumb - direction of moving conductor
fingers - direction of magnetic field
palm - direction of force acting on positive particles

Motional EMF depends upon:

- magnitude of magnetic field strength, B (T)
- the length of the conductor in the magnetic field, L (m)
- the speed of the conductor, v (m/s)

If **B** and **v** are perpendicular,

$$\boxed{\begin{array}{c}\text{EMF} = BLv \\ \xi = BLv\end{array}}$$

Once the induced EMF is found, the induced current can be calculated using Ohm's Law, V = IR, where V = EMF and R represents the resistance of a resistor placed in the circuit.

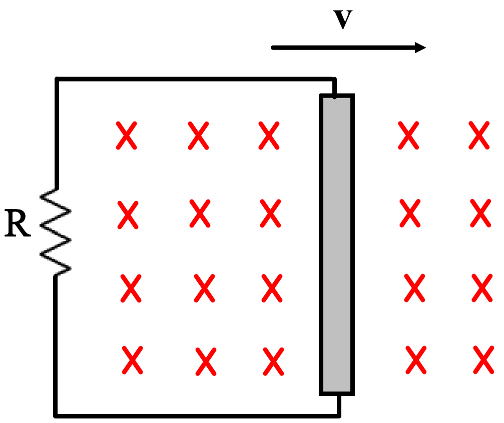
Applies to moving wires or conducting rods.

NOTE: To find magnetic force, use:

$$\boxed{F = ILB}$$

F -> magnetic force (N)
B -> magnetic field (T)
I -> current (A)
L -> length of wire or rod (m)

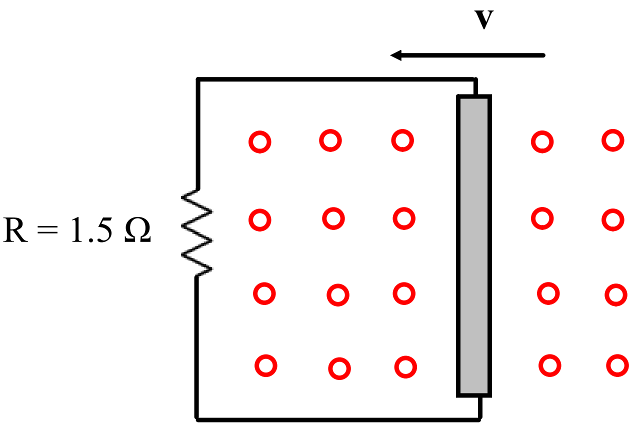
Example: The conducting rod in the diagram below is 22.0 cm long and is moving at a speed of 1.25 m/s perpendicular to a 0.150 T magnetic field. If R = 2.25 Ω, what is the magnitude and direction of **electron flow** through the circuit? (1.83×10^{-2} A, C)



Example: The conducting rod in the diagram below is 15.0 cm long and is moving at a speed of 0.95 m/s perpendicular to a magnetic field. If a current of 5.6×10^{-2} A is induced in the circuit

a) what is the magnitude of the magnetic field? (0.59 T)

b) what is the direction of the induced **electron flow**? (C)

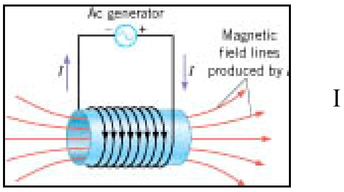


Red Text: Page 518, Practice Problems #1 (4 V, 0.7 A), #2 (0.16 V), #3 (bottom pole)
Page 531, Applying Concepts #1, 2, 8, 10
Page 532, Problems #3 (0.89 V)
#5 (17 mA)
#8 (5.0×10^{-3} T)
#9 (20 m/s)

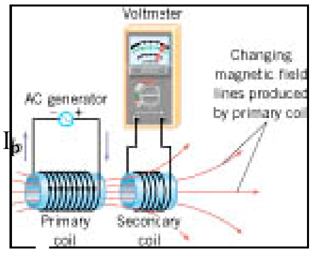
Handout - Conducting Rods and Lenz's Law

Self-Inductance

The effect in which a changing current in a circuit induces an EMF in the same circuit is referred to as self-inductance.



Mutual Inductance



The effect in which a changing current in one circuit induces an EMF in another circuit is called mutual inductance.

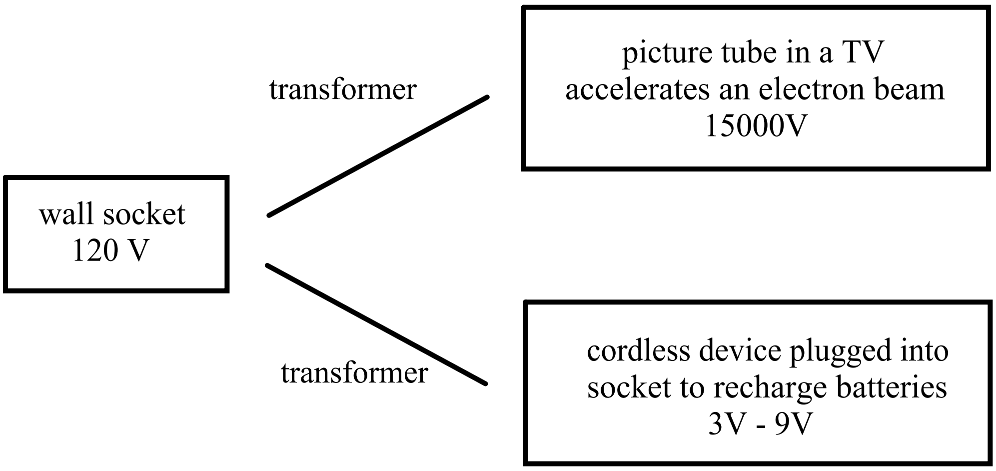
Two coils of wire are placed close to each other. The primary coil is attached to an AC generator which sends alternating current, I_p, through it. The secondary coil is not attached to a generator. A voltmeter can be connected across the secondary coil to register any induced EMF.

The current-carrying primary coil is an electromagnet and creates a magnetic field in the surrounding region. An EMF is induced in the secondary coil.

⇧

Transformers

Inductance between coils is the basis for the operation of a transformer. A transformer is a device used to increase or decrease AC voltage. They are widely used because they change voltages with essentially no loss of energy.



wall socket
120 V

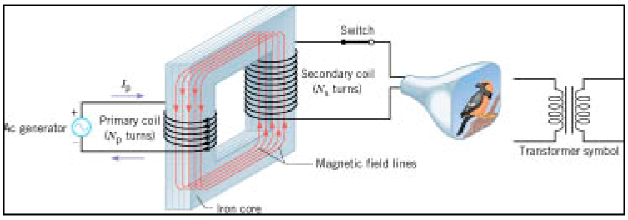
transformer

picture tube in a TV
accelerates an electron beam
15000V

transformer

cordless device plugged into
socket to recharge batteries
3V - 9V

A transformer has two coils, electrically insulated from each other, but wound around the same iron core. One coil is called the primary coil and the other is called the secondary coil. When the primary coil is connected to an AC generator, the changing current creates a varying magnetic field. The iron core is easily magnetized and guides field lines to the secondary coil. An EMF is induced in both coils. The EMF induced in the primary coil is due to self-inductance and the EMF induced in the secondary coil is due to mutual inductance.



P S

The EMF induced in the second coil, called the secondary voltage, is proportional to the primary voltage. The secondary voltage also depends on the ratio of turns on the secondary coil to turns on the primary coil.

turns ratio $\frac{N_s}{N_p}$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

V_s -> secondary voltage (V)
V_p -> primary voltage (V)
N_s -> number of turns on secondary coil
N_p -> number of turns on primary coil

If the secondary voltage is larger than the primary voltage, the transformer is called a step-up transformer. If the voltage out of the transformer is smaller than the voltage put in, the transformer is called a step-down transformer.

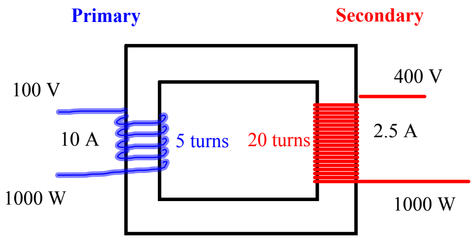
In an ideal transformer, the electric power delivered to the secondary circuit equals the power supplied to the primary circuit. An ideal transformer dissipates no power itself. Since P = VI,

$$V_p I_p = V_s I_s$$

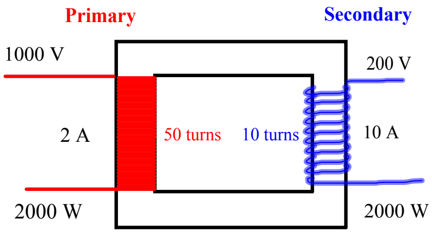
The current that flows in the primary circuit depends on how much current is required by the secondary circuit.

$$\boxed{\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}}$$

A transformer that steps up the voltage simultaneously steps down the current and a transformer that steps down the voltage, steps up the current.



Step-Up Transformer



Step-Down Transformer

Example

A certain step-up transformer has 2.00×10^2 turns on its primary coil and 3.00×10^3 turns on its secondary coil.

a) The primary coil is supplied with an alternating current at an effective voltage of 90.0 V. What is the voltage in the secondary circuit? (1.35×10^3 V)
b) The current flowing in the secondary circuit is 2.00 A. What current flows in the primary circuit? (30.0 A)
c) What is the power in the primary circuit? in the secondary circuit? (2.70×10^3 W)

Attachments

Science 122 - Problems Magnetic Field Produced by A Wire.doc

Science 122 - The Force on a Wire in a Magnetic Field.doc

Science 122 - Quiz - Magnets (Start to Motors).doc

Science 122 - Force on a Charged Particle.doc

Science 122 - Magnetic Fields and Circular Paths.doc