

Physics Notes Ch. 21 – Magnetism

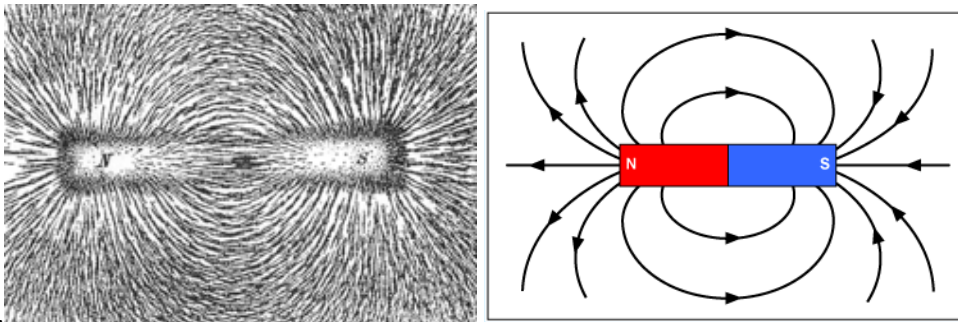
I. Magnetism is a Force Field that is formed because of moving electric charges. These moving charges can be in a beam of charged particles like an electron beam in a cathode ray, a beam of alpha particles from nuclear reactions, or they can be the spinning of the electrons in any neutral atom.

- Magnetism can be *induced* in ferromagnetic materials. **Ferromagnetic** materials are substances such as iron, cobalt, and nickel that exhibit magnetic properties when exposed to an external magnetic field. Magnetism in a substance is a result of the alignment of the magnetic domains. **Magnetic domains** are groups of atoms that have the same magnetic dipole orientation. In unmagnetized ferromagnetic substances the domains are randomly arranged. Alignment of the domains produces the magnetic properties of the substance. This alignment can be permanent or just temporary like in electromagnets.

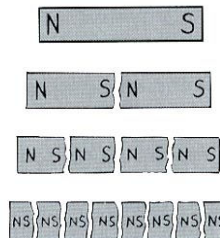


II. Properties of permanent magnets

- Objects are most strongly attracted to the ends of bar magnets (N and S pole); highest concentration of magnetic field lines at the poles so the field is strongest there.



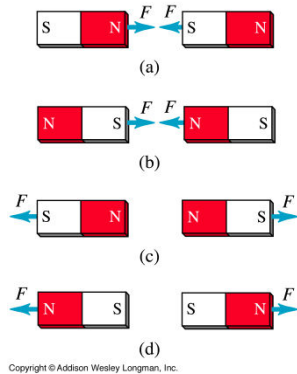
- Magnetic poles *always* occur in pairs (*dipoles*). No matter how many times a bar magnet is cut in half, there is always a north and a south pole, even in the smallest piece. In fact, if we break the magnet down into subatomic parts, we find that even the electrons, protons, and neutrons within atoms behave



as magnetic dipoles (that is, very little bar magnets).

As it turns out, the magnetic effect of a bar magnet arises from the combination of the effects of the little bar magnets in the electrons in iron, nickel, or cobalt. Each electron's magnet is small, but when you turn them in the same direction and add them all up, the total effect is strong.

- *Like poles repel, unlike attract.*



Question: An electric charge is either + or -, so are magnets always either N or S?

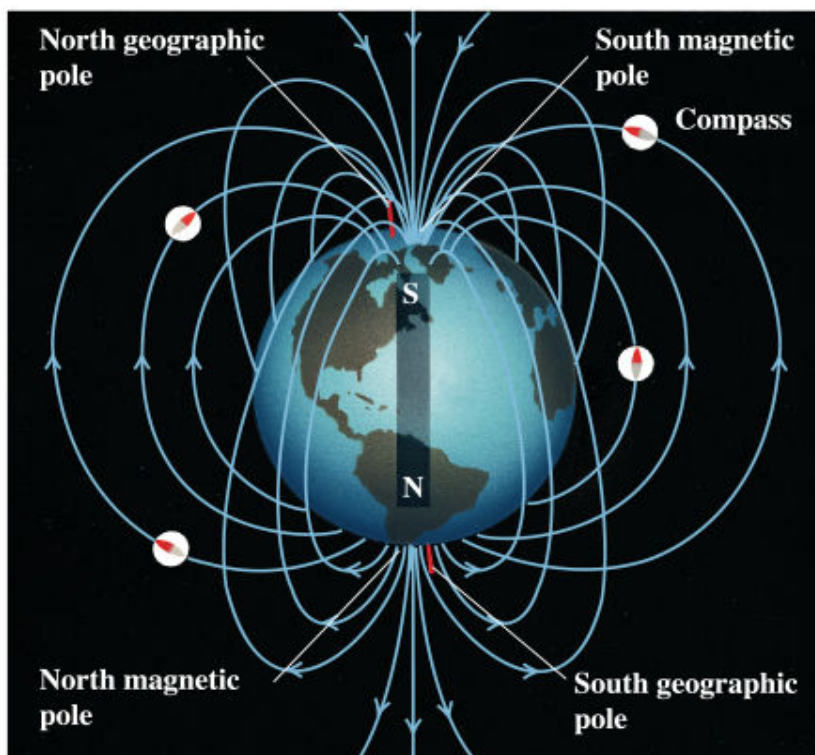
III. Comparing Electricity (E fields) and Magnetism (B fields)

Electric Fields and forces	Magnetic Fields and forces
1. Almost <u>any</u> substance can become electrically charged by friction or conduction, but the excess charge usually bleeds off quickly and it is discharged.	a few substances can be magnetized, but to be a powerful permanent magnet, it must be made from a ferromagnetic material -- Most commonly, Iron, Nickel or Cobalt
2. charges can exist by themselves as either a + or - charge.	a magnet cannot exist as a single pole...NO Monopoles!
3. Force field is just a straight line vector outward or away from a "+" charge and can end at infinity...and inward from infinity toward a "-" charge	The force field exists in complete loops always starting outside the magnet from the North Pole and looping to the South Pole and then back through (inside) the magnet to the North Pole again.
4. electric fields exert forces on charges whether they are moving or not and the force is parallel to the field and directly away from or toward the charge producing the field.	Magnets exert a force on moving charges, but the force is always perpendicular to BOTH the force field lines and to the velocity of the charges!! Doubly Perpendicular!! That is why we need the right hand rule to determine the effects.
5. An electric field can accelerate a charged particle or particle beam in every way...speed it up, slow it down, or make it change direction.	a magnetic field can accelerate a moving charged particle or beam of charged particles... BUT it CANNOT speed it up or slow it down...it can only accelerate it by changing its direction of motion. Charged objects are NOT attracted to a magnet, but when charges are moving their path is deflected at right angles by a magnetic field.

IV. Magnetic field of the Earth

Question: If a compass needles' North pole points to the North, what kind of magnetic pole must be at the North end of Earth?

- The Earth's magnetic field is probably due the movement of charges in convection currents beneath the earth's crust. As you can see in picture below, the north pole of a compass needle will point towards a point on the globe just north of Hudson Bay. Since unlike poles attract, this must mean that the earth's south magnetic pole is near the earth's geographic North Pole. Also, since the magnetic pole does not line up with the geographic pole, the difference between the two must be taken into account when using a compass for navigation. **Magnetic declination** is the difference between true north and the magnetic South Pole.



Copyright © Addison Wesley Longman, Inc.

V. Calculating with Magnetic fields

- A permanent magnet or a moving charge will produce a magnetic field. To describe any type of field (electric, gravitational, or magnetic), we must define both the magnitude and the direction of the field. For magnetic fields, the following two conventions are used:
 - **Direction of the magnetic field, B , at any location is the direction in which the N pole of a compass needle points at that location. For a permanent magnet, arrows originate on the N pole and terminate on S pole.**
 - **Magnitude of magnetic field is determined by the force the field exerts on a moving charge.**

$$B = \frac{F}{qv \sin \theta} \quad \text{or} \quad F = qvB \sin \theta. \quad \text{You will not use the } \sin \theta \text{ part in this course...so the formula}$$

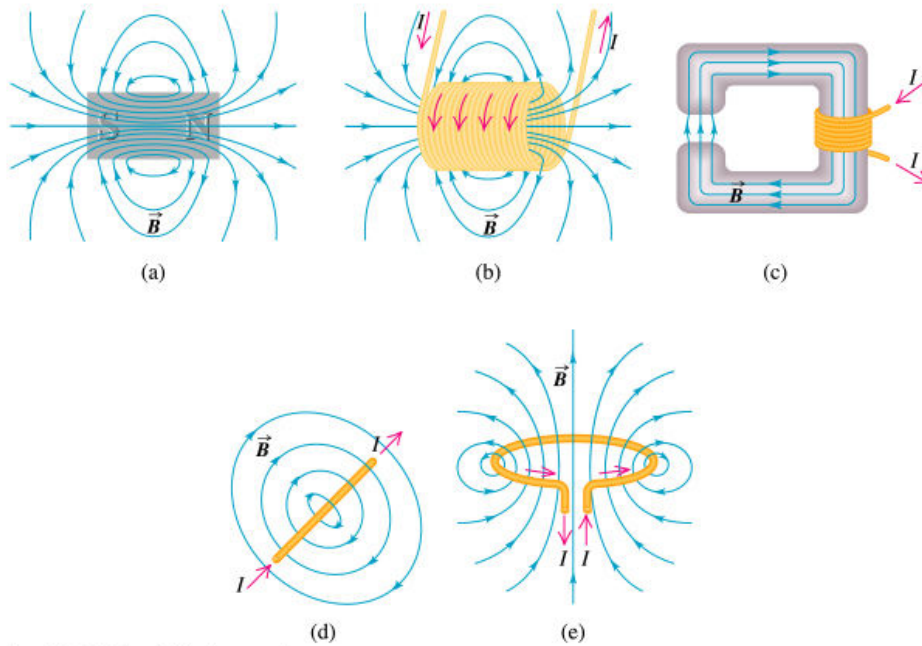
$$\text{becomes } B = \frac{F}{qv} \quad F = qvB$$

For calculating...First, if the charge isn't moving at all OR If the charge is moving parallel to the direction of the field, there would be...NO FORCE or interaction between the magnetic field and the charged particle.

AND keep in mind that the force will be maximum if the charge moves into the field at a 90 degree angle ... if it is at some angle other than perpendicular to the field, the force would be reduced until, if parallel, zero force.

VI. Representations of magnetic fields:

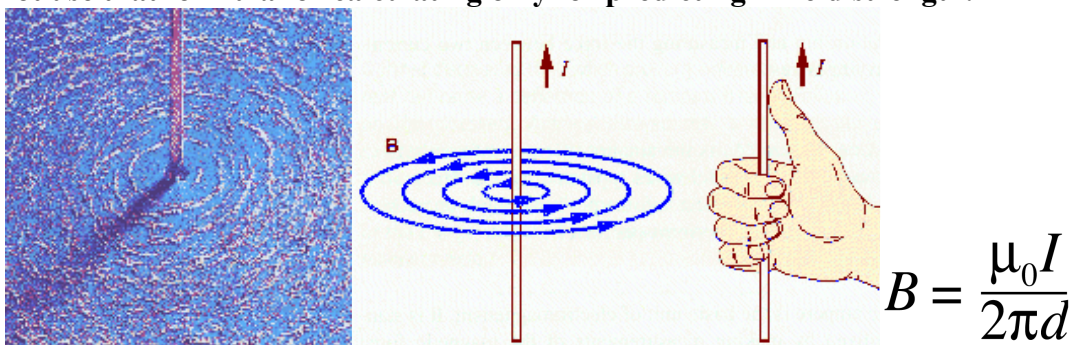
- a. Permanent Magnet b. Solenoid without a core c. Electromagnet – Solenoid with a core
- d. B field around a conducting wire e. B field inside a loop of conducting wire

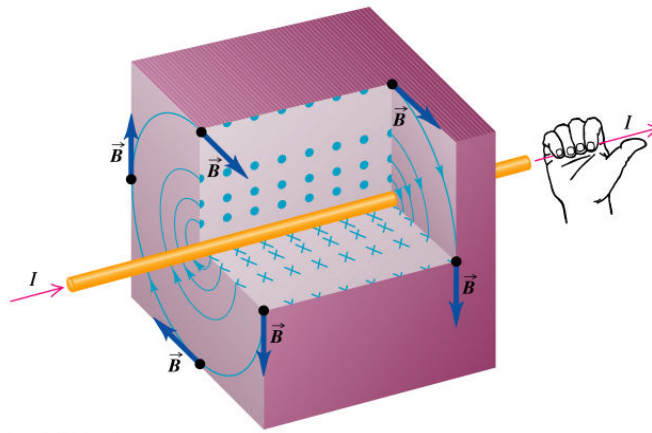


Copyright © Addison Wesley Longman, Inc.

Magnetic field of a long, straight current carrying wire - Like “d” above

- Moving charges produce magnetic fields. The direction of the field is always perpendicular to the direction of the moving charge (circular around the motion of the charge). The direction of the magnetic field produced by a moving charge can be found by using **Right Hand Rule #1**. **Point your thumb in the direction of the current (flow of positive charge) and your fingers coil in the direction of the field.**
- By varying current and distance from the wire, one finds that **B is proportional to the current and inversely proportional to the distance from the wire...as depicted in the formula below...you will not use that formula for calculating only for predicting B field strength.**

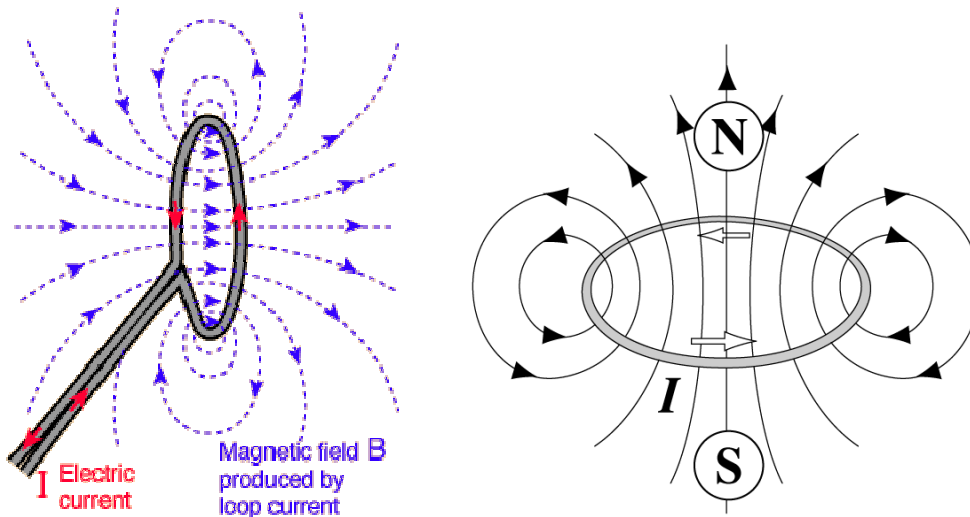




Copyright © Addison Wesley Longman, Inc.

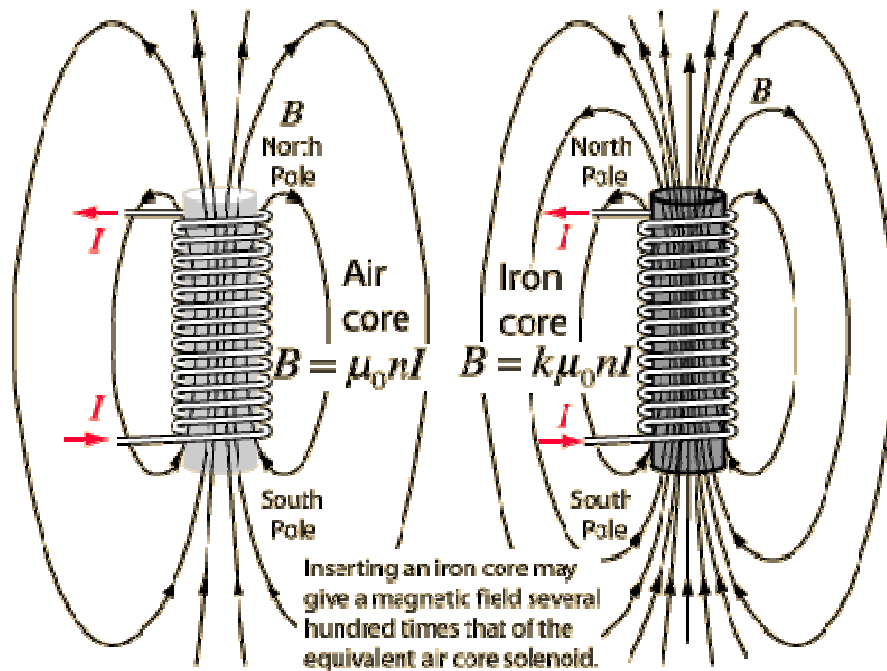
Magnetic field of a current loop – see “e” above

- Magnetic field set up by a current loop is similar to that of a bar magnet. The polarity of the loop of wire can be found using your right hand. **Right Hand Rule #2 (RHR #2):** Coil your fingers in the direction of the current and your thumb will point to the North of the B field.



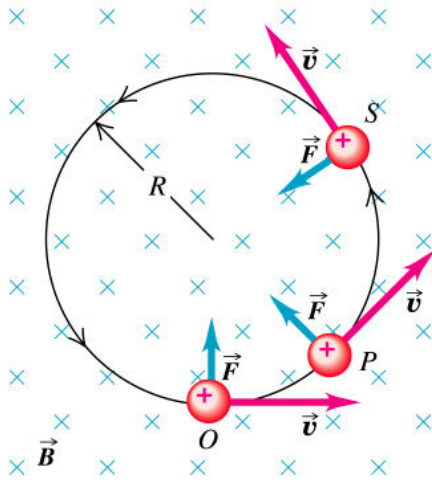
Magnetic field of a solenoid - see “b and c” above

- A **solenoid or electromagnet** is a device consisting of a wire bent into a coil of several closely spaced loops that is magnetic when a current passes through the coil. The magnetic field inside the solenoid is nearly uniform and strong, but the magnetic field outside is relatively weak. Solenoids have many useful applications since they are magnetic only when they carry a current.
- **Right Hand Rule #2: RHR #2**
- **The polarity of a solenoid can be found the same way you found the polarity of a current carrying loop. Coil your fingers in the direction of the current and your thumb will point north.** The strength of the magnetic field depends upon the magnitude of the current, the number of coils per unit length, and whether or not an iron (ferromagnetic) core is inserted.



VII. Charged particles in a magnetic field

- A charged particle will experience a force due to an external magnetic field only if the charged particle is **moving perpendicular** (or has a component of the velocity that is perpendicular) to the magnetic field. The magnitude of the force depends upon the strength of the field, the magnitude of the charge, and the component of the velocity that is perpendicular to the field ($F=qvB\sin\theta$). *If the velocity given is already perpendicular to the field the equation simplifies to $F=qvB$.*
 - The direction of the force on a positive charge can be found by using the **right hand rule** (if the charge is negative, use your left hand or just remember the force is oppositely directed) **RHR #3**. (probably the most useful of the RHRules). **Point your fingers in the direction of the B field, thumb in the direction of the velocity that is perpendicular to the field, and your palm will point in the direction of the magnetic force.**
- >>RHR #3 - Remember: Thumb – points to the direction of the current or velocity of moving charge
 Fingers – point in the direction of the B field
 Then the palm of your hand shows the direction of the force on the charged particle
- *A charged particle moving perpendicular through a magnetic field follows a circular or semi-circular path.* The path will be spiral if only a component of the velocity is perpendicular to the field. Application of the right hand rule at any point along the path shows that the **magnetic force is always toward the center of a circular path.**
 - Magnetic force is effectively a centripetal force that **changes only the direction of the v and not the magnitude of the v.** Since the magnetic force is a centripetal force, the magnetic force can do NO work on a charged particle. That is, **the magnetic force CANNOT change the speed or the kinetic energy of a particle.**



(a)

Copyright © Addison Wesley Longman, Inc.

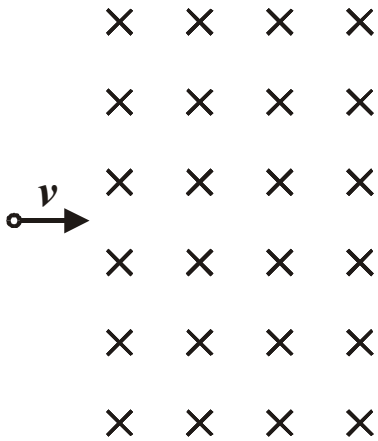
A charged particle moving in a plane perpendicular to a magnetic field will move in a circular orbit with the magnetic force playing the role of centripetal force. The direction of the force is given by the right-hand rule.

Equating the centripetal force with the magnetic force and solving for R the radius of the circular path we get

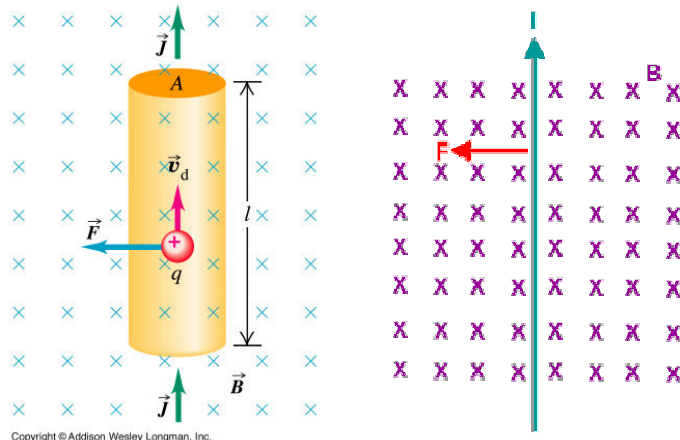
$$qvB = mv^2/R$$

$$R = mv/(qB)$$

- Example 1:** An electron is traveling horizontally at 1.50×10^6 m/s when it enters a magnetic field of magnitude 750 T directed into the page, as shown in the diagram below. Gravity is negligible. (a) On the diagram below, sketch a **possible** path for the electron while it is in the magnetic field. (b) Calculate the magnitude of the magnetic force acting on the electron in the field. (c) Determine the radius of the electron's path in the magnetic field. (d) Determine the speed of the electron when it leaves the field.

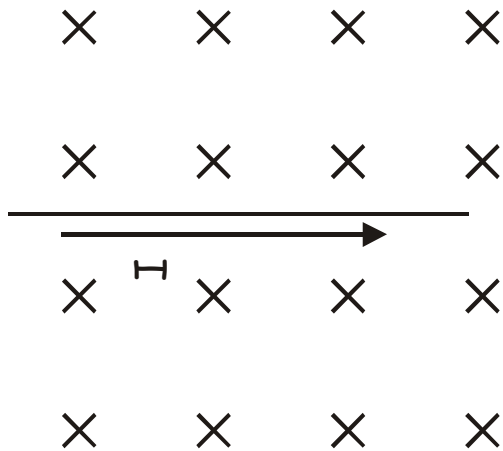


- Since a charged particle moving perpendicular to a magnetic field experiences a force due to the field, a **current carrying conductor perpendicular to a magnetic field will experience a force since a current is moving charge**. The magnitude of the force depends upon the strength of the field, the current, and the length of the conductor in the field ($F=BIL$). [or as in your text ($F=BI\ell$)]. The direction of the force can be found using the right hand rule. Point fingers in the direction of the magnetic field, thumb in the direction of the conventional current (flow of positive charge), and your palm will point in the direction of the force.



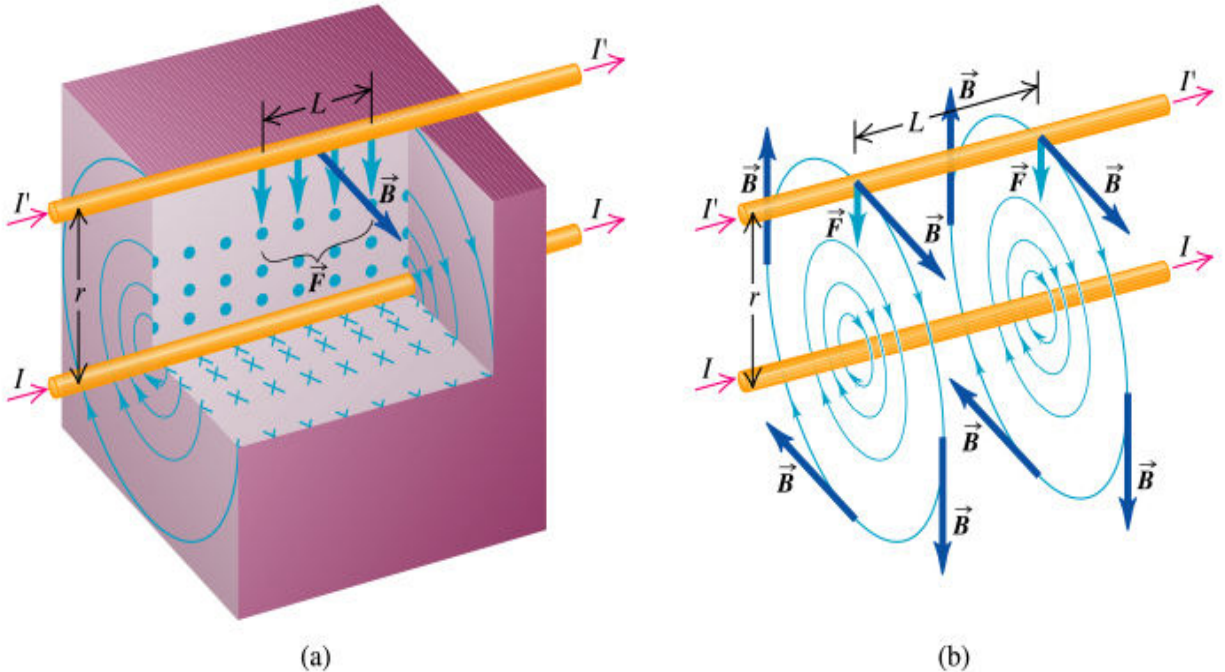
$$F = BIL \sin \theta$$

- Example 2:** As shown below, a thin 2.00 m long copper rod oriented perpendicular to a uniform magnetic field has a mass of 75.0 g. When the rod carries a current of 1.00 A, it floats in the magnetic field. What is the strength of the magnetic field?



VIII. Magnetic force between two parallel conductors

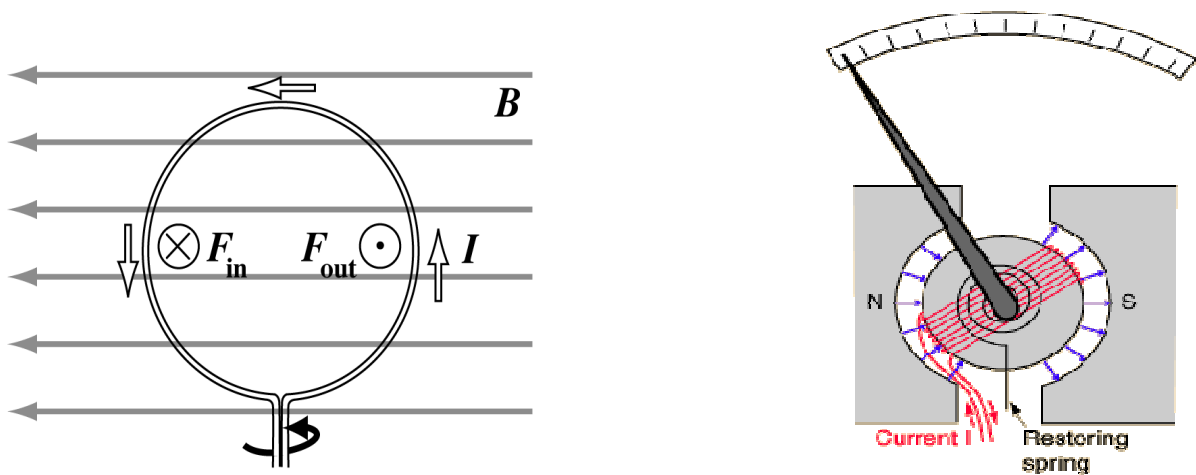
- Two parallel wires, each carrying a steady current, exert forces on each other. This is due to the fact that current carrying wires produce their own magnetic field and therefore experience a force due to external magnetic fields (see previous section). Application of the right hand rules will show that the **forces are attractive if the currents are in the same direction and repulsive if the currents are in opposite directions.**



Copyright © Addison Wesley Longman, Inc.

Galvanometer

- A galvanometer is a device used in the construction of both ammeters and voltmeters. In its simplest form, a **galvanometer consists of a wire coil situated in a magnetic field.** When current passes through the coil, torque due to the magnetic force on a current carrying wire causes the coil to twist. The angle to which the coil rotates depends upon the magnitude of the current.

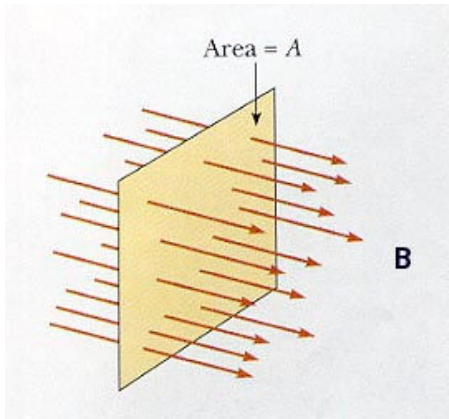


Regular Physics problems Ch 21 p. 781 #'s 2,3,9,11,13,22,24,26,and 34-36.

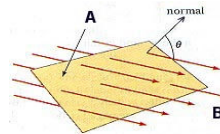
Notes - Regular Physics - Ch 22
Electromagnetic Induction and Alternating Current

Electromagnetic induction

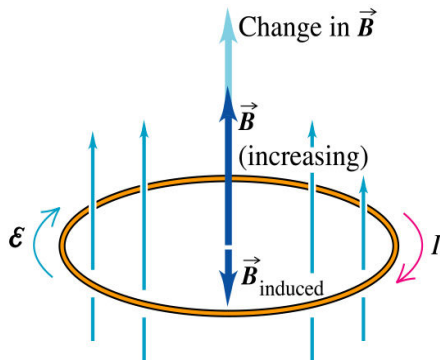
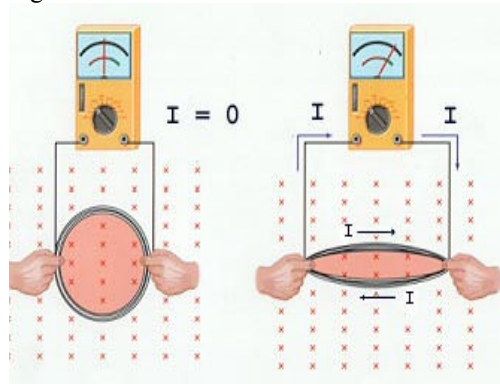
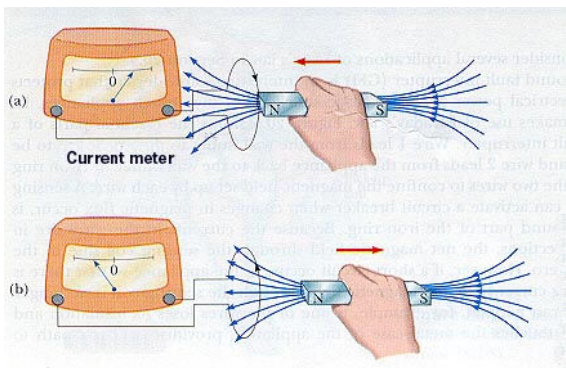
- Electromagnetic induction is the principle behind the operation of *electric generators and transformers*. The electrical energy that powers our cities is produced by this process. **Electromagnetic induction** is the process of inducing an emf (*voltage*) and consequently a current in a circuit by a *change* in magnetic flux. **Magnetic flux**, as shown below, is the product of the magnetic field and the area through which the magnetic field lines pass ($\phi_m = AB \cos\theta$). The angle is measured to the normal of the plane of the coil, so maximum flux would be when the normal is parallel to the B field (as in the picture on the left below).



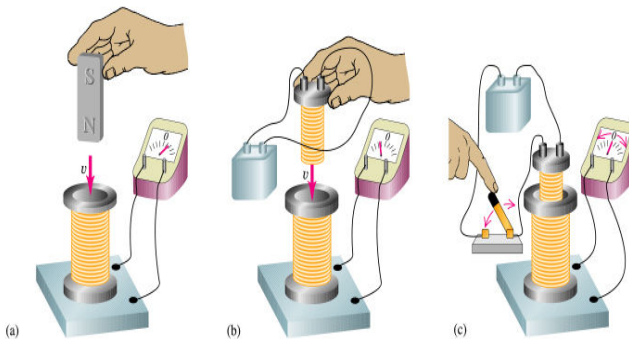
Magnetic flux is proportional to the strength of the magnetic field passing through a specific cross-sectional area and is calculated by the equation $\phi_m = AB \cos\theta$. In order to have an emf and current induced in a circuit there must be a *change* in magnetic flux. [Flux is maximum when the plane of the loop is perpendicular to the B field direction which makes the “normal” parallel to the B field (the angle θ would be zero degrees and $\cos 0^\circ = 1$)] .



- As shown in the diagrams below, an emf and current will be induced in a circuit if there is a *change* in magnetic flux. In order to change magnetic flux, there must be a change in the strength, position, and/or orientation of the external magnetic field relative to the conductor. There are three primary ways of changing magnetic flux.
 - Relative motion between magnet and conductor
 - Changing the area of a coil in a constant magnetic field
 - Increasing or decreasing magnetic field strength



Copyright © Addison Wesley Longman, Inc.

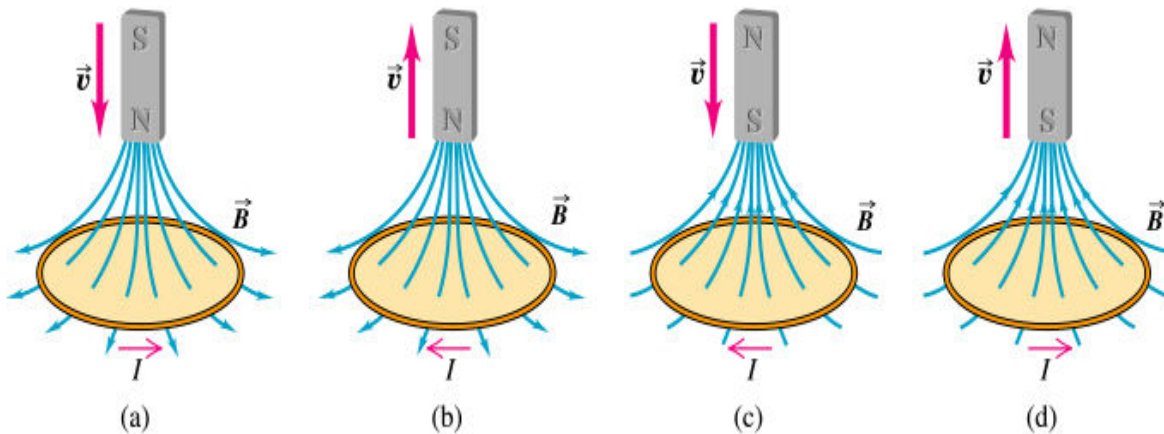


Copyright © Addison Wesley Longman, Inc.

- **Faraday's law of induction** states that the instantaneous emf induced in a circuit equals *the rate of change of magnetic flux* in the circuit. That is, the greater the rate of change in magnetic flux, the larger the magnitude of the induced emf and the induced current in the circuit.

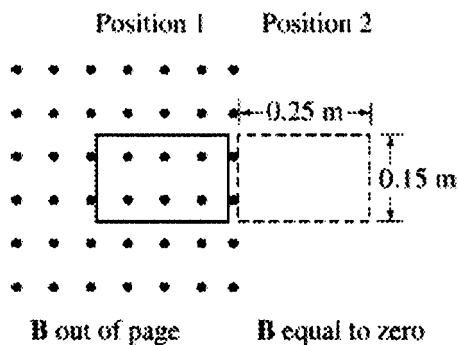
$$\epsilon = -N \Delta \phi_m / t$$

- ϵ is the induced emf in the circuit (units are **volts**); to find the magnitude of the current induced in the circuit use ohm's law ($V=IR$ or $\epsilon=IR$)
- N = number of tightly wound loops
- $\Delta \phi_m / t$ = the rate of change in magnetic flux
- The negative sign indicates that the direction (polarity) of the induced emf opposes the change in magnetic flux. Lenz's law is used to determine the direction of the induced current and therefore the polarity of the induced emf. **Lenz's law** states that the polarity of the induced emf is such that it produces a **current whose magnetic field opposes the change in magnetic flux**. If the north pole of a magnet is moving towards a loop (diagram (a) below), the loop will produce a current which has a north magnetic pole pointing towards the magnet. If the north pole of a magnet is moving away from a loop (diagram (b) below), the loop will produce a current which has a south magnetic pole pointing towards the magnet.



Copyright © Addison Wesley Longman, Inc.

- **Example 1:** A 20-turn wire coil in the shape of a rectangle, 0.25 m by 0.15 m, has a resistance of 5.0 Ω . In position 1 shown below, the loop is in a uniform magnetic field \mathbf{B} of 0.20 T. The field is directed out of the page, perpendicular to the plane of the loop. The loop is pulled to the right at a constant velocity, reaching position 2 in 0.50 s, where \mathbf{B} is equal to zero. (a) Calculate the average emf induced in the 20-turn coil during this period. (b) Calculate the magnitude of the current induced in the 20-turn coil and state its direction.

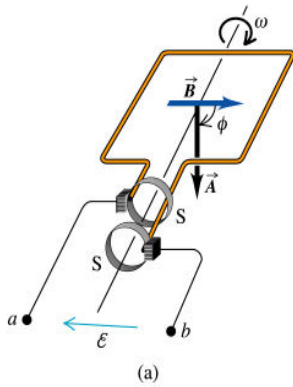


Do worksheets – Part 3.

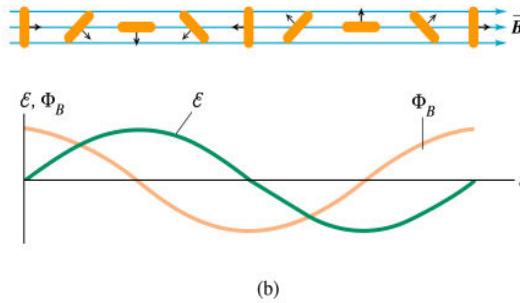
Generators

- A **generator** is a device that converts mechanical energy to electrical energy. In its simplest form, a generator consists of a wire loop (connected to a circuit) that is rotated in a magnetic field by some external means. As the wire loop rotates in the magnetic field there is a change in magnetic flux through the loop and consequently an emf and current induced in the loop. The diagrams below show the basic forms for both an **AC (alternating current) generator** and a **DC (direct current) generator**. Note that the AC generator has two solid rings (called slip rings) and the DC generator has a split ring (called a commutator). Since the AC generator has solid rings connecting the loop to the external circuit, the current will change

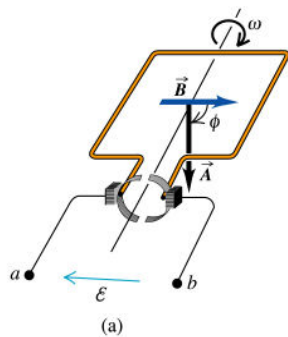
directions each time the loop makes $\frac{1}{2}$ a revolution. Since the DC generator has a split ring, each brush will touch the opposite ring after each $\frac{1}{2}$ revolution, thereby keeping the current flowing in one direction. If only a single loop were used in the construction of a DC generator, a pulsating one directional current would be produced. To produce a steady DC current, many loops and commutators are used.



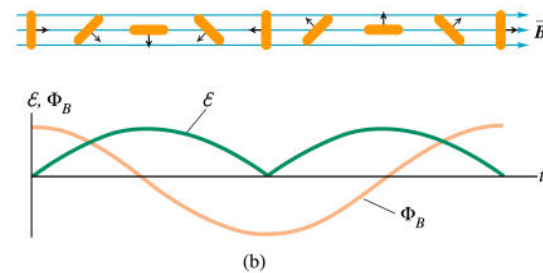
Copyright © Addison Wesley Longman, Inc.



AC generator has two solid rings. The emf changes directions as it rotates (varies sinusoidally with time).



Copyright © Addison Wesley Longman, Inc.



DC generator has a split ring commutator. For a single loop the emf will change in magnitude but not direction as the loop rotates.

- Maximum emf for a generator can be calculated by the equation:

Maximum emf = $NAB\omega = NAB(2\pi f)$. **N = number of turns in the coil, A is area of the coil in the magnetic field, B is the magnetic field strength, and ω is the rotational speed which is equal to 2π times the frequency of rotation. Once you know the emf (Voltage), you use $V=IR$ to get the current that would be produced.**

<http://www.wvic.com/how-gen-works.htm>

Example 2: Calculate the magnetic field strength in a generator that produces 480V maximum with a 5.0 turn coil (area of $.10\text{m}^2$) rotating at a frequency of 60 Hertz.

Example 3: Calculate the maximum emf and the current produced by a generator with a coil that is 1.2m^2 with 200-turns rotating at 60 Hz in a magnetic field of 18 Tesla.

Motors

- Motors are essentially generators run in reverse. **Motors convert electrical energy to mechanical energy.** A current is supplied to the loop by an external source and the magnetic force on the current carrying loop causes it to rotate.

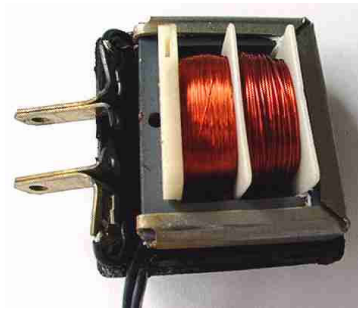
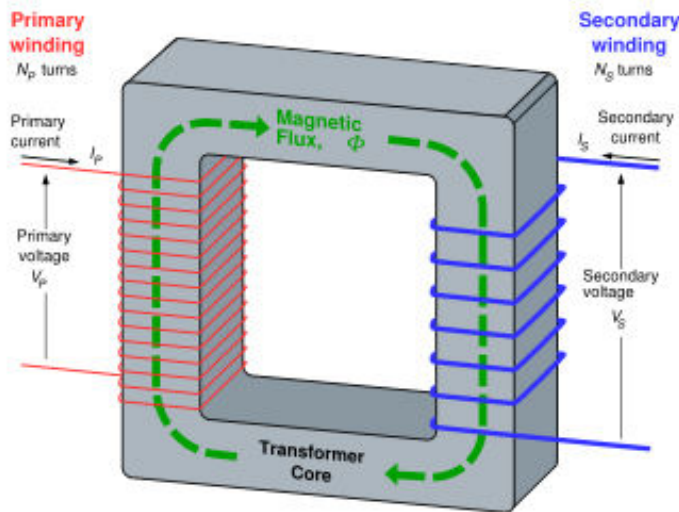
AC circuits

In an AC circuit, the emf and current are continually changing in magnitude and direction. The direction of current has no effect on the behavior of many resistors. For example, an incandescent light bulb has a filament of large resistance that converts electrical energy into heat and light energy. The direction of the current through the filament does not matter. Electric energy will be converted to heat and light energy whichever way the current flows

Transformers

- A **transformer** is a device used to increase or decrease **AC voltage**. Transformers operate by mutual induction. **Mutual induction** is the effect in which a changing current in one circuit induces an emf in another circuit. Transformers consist of two coils electrically insulated from each other but wrapped around the same iron core. The **primary coil** is attached to a source of AC. The varying magnetic flux is carried through the iron core to the **secondary coil** which has an emf and current induced in it. The voltage in the secondary coil is controlled by the ratio of the turns in the two windings. A **step-up transformer** increases the voltage in the secondary coil by having more windings than the primary coil. A **step-down transformer** decreases the voltage in secondary coil by having fewer windings than the primary coil. Also, the power input in the primary coil must equal the power output at the secondary coil (small amount is lost as heat due to the resistance in the wires). For the power ($P=IV$) to be the same, an increase in voltage must accompany a decrease in current. That is, step-up transformers step-down current and step-down transformers step-up current.

$$V_2/V_1 = N_2/N_1 = I_1/I_2$$



- **Example 4:** A transformer is used on a 120 V line to provide a potential difference of 2400 V. Is this a step-up or step-down transformer? If the primary has 75 turns, how many turns must the secondary have? What will be the current produced by the secondary if the current in the primary was 5.0A?