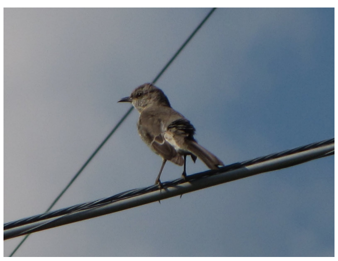
MAgnetism and Electromagnetic induction

Dr. Coman

Guess what today's topic will be !



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CREDITS

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Objectives I

- Recognize basic magnetic properties of matter
- Analyze the concept of electromagnetic induction and use it to explain everyday physical phenomena.
- Recognize and explain magnetic fields
- Differentiate between different methods of producing electricity
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Objectives II

- Analyze the concept of electromagnetic induction
- Use the concept of electromagnetic induction to explain everyday physical phenomena.
- Describe and use Maxwell's equations to solve problems in electricity and magnetism.
-

Outline I

- Magnetic properties
- Electricity Magnetism relationship
- Electromagnetic Induction and Waves

  - Inductive charging pad for asmartphone, using the Qi system, $\rightarrow$ near-field wireless transfer.

- Electric Generators and Back emf
- Transformers and Power Transmission
- Maxwell's equations
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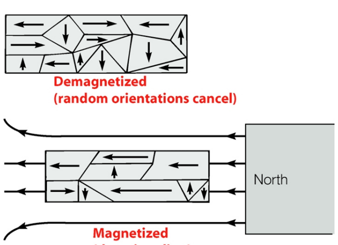
Magnetism

- Magnets derive their name from Magnesia in Western Turkey, an ancient Greek colony, where many naturally magnetic ores (the iron oxide magnetite) were mined about 2500 years ago.



- In an unmagnetized piece of iron, the magnetic domains have random arrangement that cancels any overall magnetic properties.
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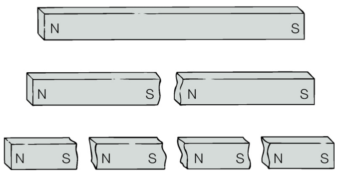
Magnetism

- Magnets attract iron and certain other metals.

- They have two poles, usually called North, N and South, S.

- 

Magnetism

- Magnets have magnetic field lines similar to electric field lines.
  - They run from the North pole to the South pole.
  - Every north pole has an accompanying south pole of equal magnitude.

  - Magnetic monopoles (equivalent to an isolated charge q) have been postulated, but they have not been found so far.
- like poles repel each other, and opposite poles attract each other.
  - $N-N$ and $S-S$ are repulsive, but $N-S$ and $S-N$ are attractive.
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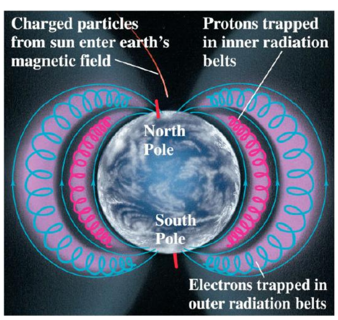
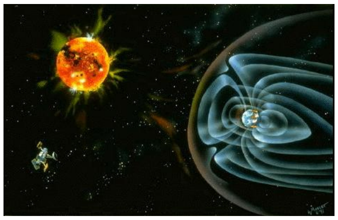
Earth's magnetic field



- The magnetic north pole acts as if the south pole of a huge bar magnet were inside the earth.



- You know that is must be a magnetic south pole since the north end of a magnetic compass is attracted to it and opposite poles attract
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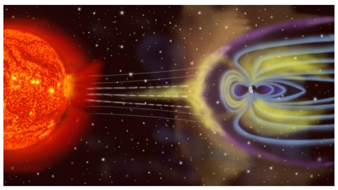
The magnetosphere



- The magnetosphere shields the surface of the Earth from the charged particles of the solar wind.
- It is compressed on the day (Sun) side due to the force of the arriving particles, and extended on the night side. (Image not to scale.)
- The strength of the Earth's magnetic field:
  c
  $25,000$ to $65,000 nano\ \ Tesla$, or 0.25 to $0.65 gauss$
- 1Gauss is about 6.5 magnetic field lines per square inch;
-

Aurora borealis

- The auroral electrons are thus guided to the high latitude atmosphere.

  - they penetrate into the upper atmosphere,
  - they collide with an atom or molecule
  - the atom or molecule takes some of the energy of the energetic particle and stores it as internal energy -excitation

- An excited atom or molecule can return to the non-excited state (ground state) by sending off a photon, i.e. by making light.
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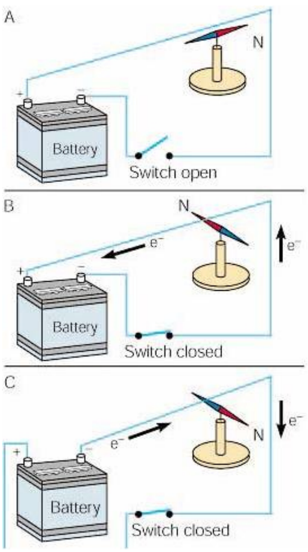
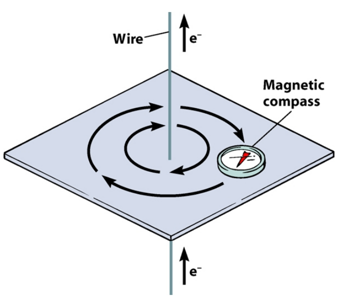
Electricity magnetism relationship

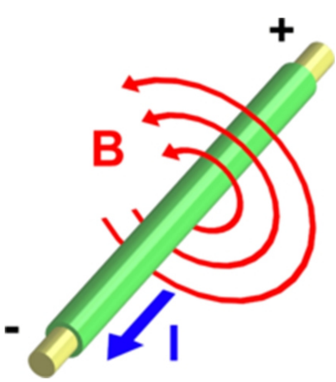
- Oersted discovered that a compass needle below a wire pointed north when there was not a current,



  - moved at right angles when a current flowed one way,



  - moved at right angles in the opposite direction when the current was reversed



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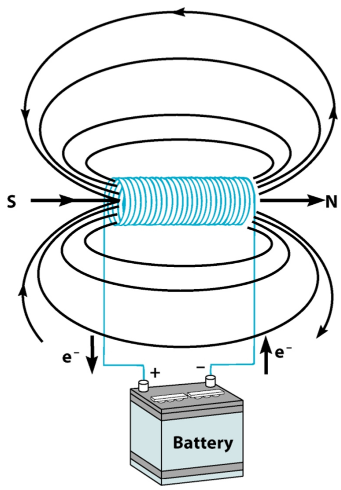
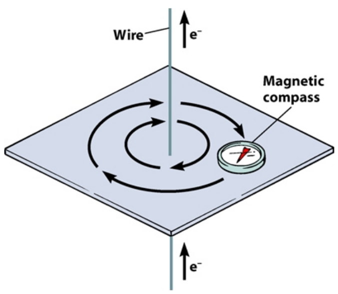
Electricity magnetism relationship II

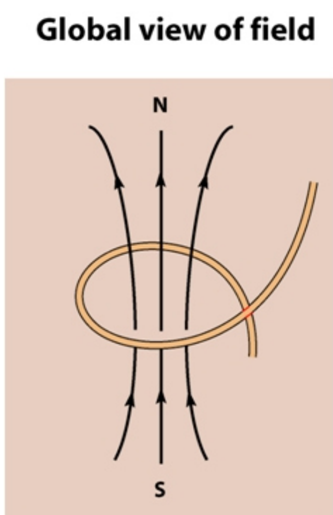
- Moving charges (currents) produce magnetic fields



- Shape of field determined by geometry of current:
    - Straight wire



- Current loops
- Solenoid



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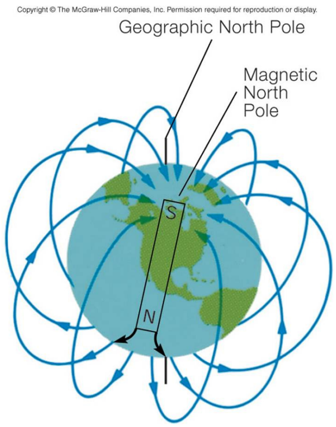
Classroom task

- 1. What happens if you move a magnet in and out of a solenoid ?
- 2. What happens if you stop the magnet midway through the loop ?
- 3. What happens if you move the loop of wire "in" and out of the magnet (Around the magnet)
- 4. Could you use the Earth's magnetic field to produce electricity ?



  - What else do you need ?

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Magnetic Field definition

- We can define the magnetic field, $\vec{B}$, based on the force the field exerts upon a charged particle, q entering the field:
- The magnetic field, $\vec{B}$ is a vector and points along the magnetic field lines.
  $\vec{F}_{\text{magnetic}} = q\vec{v}\vec{B}\sin\theta \rightarrow$

  $\vec{B} = \dfrac{\vec{F}_{\text{magnetic}}}{q\vec{v}\sin\theta} \rightarrow$
- The units of B can be deduced from Lorentz force:
  $\dfrac{1N \cdot s}{C \cdot m} = 1T1\text{Tesla}$

  $1T = 1\dfrac{N}{A \cdot m}$
- The force is perpendicular to both the velocity and to the field.
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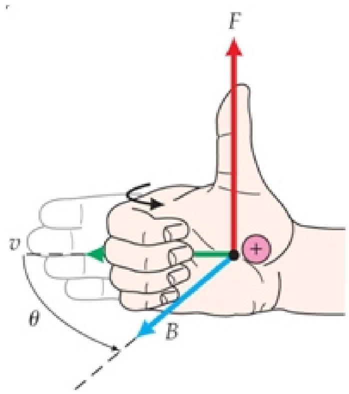
Lorentz Force direction:

- The force is perpendicular to both the velocity and to the field.
- You can find the direction of the Lorentz force using the right-hand rule.



- If points in the direction of the thumb, and points in the direction of the index finger, then the force is outward in the direction of the middle finger, as shown to the right.

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Sample problem Lorentz Force

- Determine the magnitude and direction of the force exerted on a moving charge if $q = 120mC$, the speed of the charge $v_q = 12\frac{m}{s}$ and the charge moves in a magnetic field $B = 0.04T$ if the angle $\theta_{\text{between vec v and vec B}} = 20^o$.?
  $F = \left(120 \cdot 10^{-3}C \cdot 12\frac{m}{s} \cdot 0.004T\right.$
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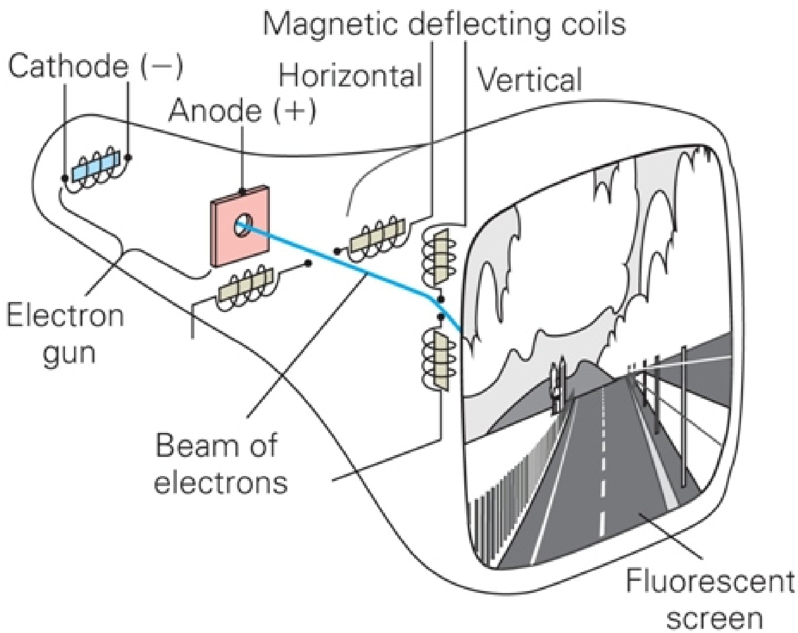
Applications: Charged Particles in Magnetic Fields

- In a TV magnetic fields are used to direct a beam of electrons to different regions on the screen thus creating an image.



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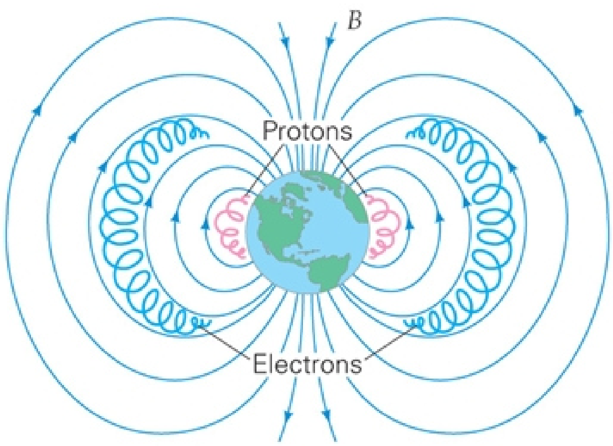
Applications: Charged Particles in Magnetic Fields

- Charged particles can become trapped around magnetic field lines.



- Such trapping of solar wind particles has resulted in bands of charged particles around the Earth called Van Allen belts.
-

Applications: Velocity selector

- Charged particles can be distinguished/selected based on their velocity
- A velocity selector consists of an electric and magnetic field at right angles to each other.
- Charges/Ions entering the selector will be subject to both an electric force:

$$\vec{F}_{\text{electric}} = q \cdot \vec{E}$$

- and a magnetic force:

$$\vec{F}_{\text{magnetic}} = q\vec{v}\vec{B}\,\sin\theta$$
$$\vec{F}_{\text{magnetic}} \perp \vec{E}$$
$$\vec{F}_{\text{total}} = F_{\text{magnetic}} + \vec{F}_{\text{electric}}$$
$$\vec{F}_{\text{total}} = q \cdot \vec{E} + q\left|\vec{v}\right|\left|\vec{B}\right|\,\sin\theta$$

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Applications: Charged Particles in Magnetic Fields

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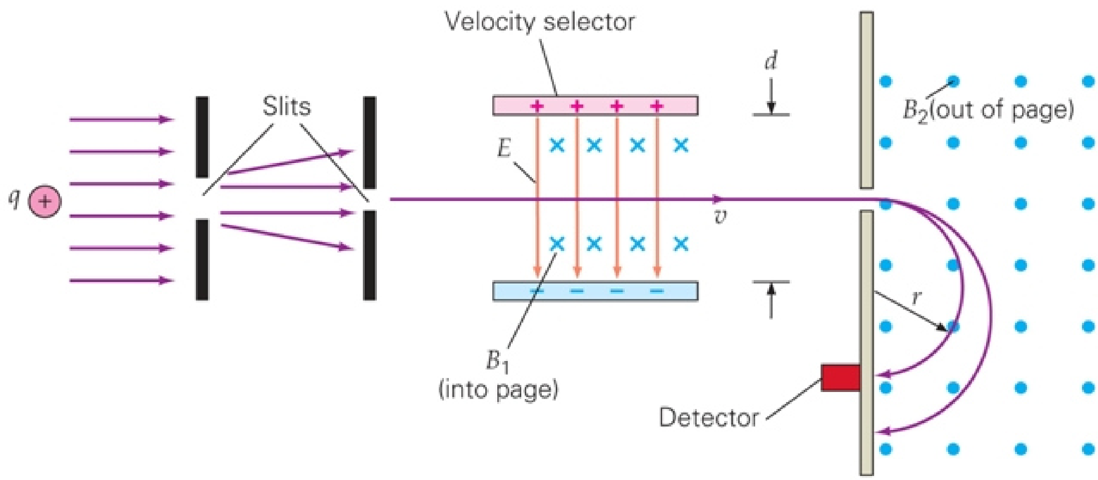

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Applications : mass spectrometers

- Measure the masses of ions with equal charges and velocities.
- After passing through a velocity selector, ions enter a magnetic field. They will move in a circle of radius:
  $F_{\text{centripetal}} = F_{\text{magnetic}} \rightarrow$
  $m \cdot \frac{v^2}{R} = q \cdot v \cdot B \cdot \sin\theta \rightarrow$
  $R = \frac{m \cdot v}{q \cdot B}$
- if $\sin\theta = 1 \rightarrow \vec{v} \perp \vec{B}$
-
-

Magnetic Forces on Current-Carrying Wires

- THe Force exerted upon a straight wire whose length is L when a current I goes through the wire:
  $\vec{F}_{\text{magnetic}} = ILB \sin\theta$
  where $\sin\theta$ is the angle between the direction of the electric current and $\vec{B}$
- The right hand rule applies for the direction of the force.
  - The current I points along the thumb, $\vec{B}$ points along the index fingers, then $\vec{F}_{\text{magnetic}}$ points along the middle finger.
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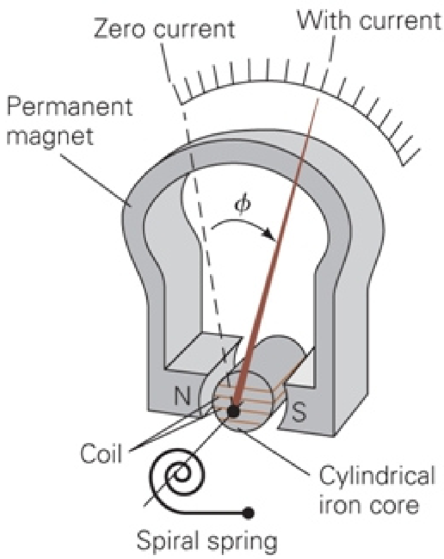
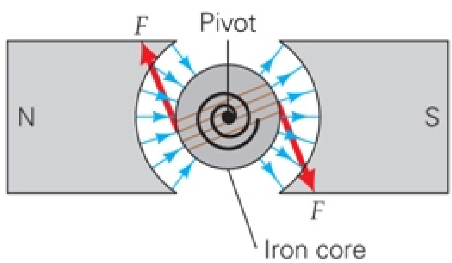
Applications: Current-Carrying Wires in Magnetic Fields



(a)



(b)

- A galvanometer has a coil in a magnetic field. When current flows in the coil, the deflection is proportional to the current.
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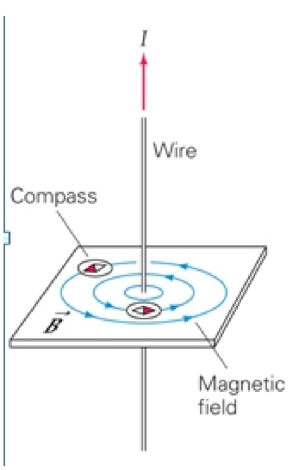
Electromagnetism: The Source of Magnetic Fields

- Experimentally, we observe that a current-carrying wire creates a magnetic field.



- The magnitude of the magnetic field, B at a distance d away from the wire is:

$B = \frac{\mu_0 \cdot I}{2 \cdot \pi \cdot d}$

- where

$(\mu_0 = 4 \cdot \pi \cdot 10^{-7} \frac{T \cdot m}{A}$

- is the permeabiity of vacuum
-

The magnetic field at the center of a loop of wire traversed by current:

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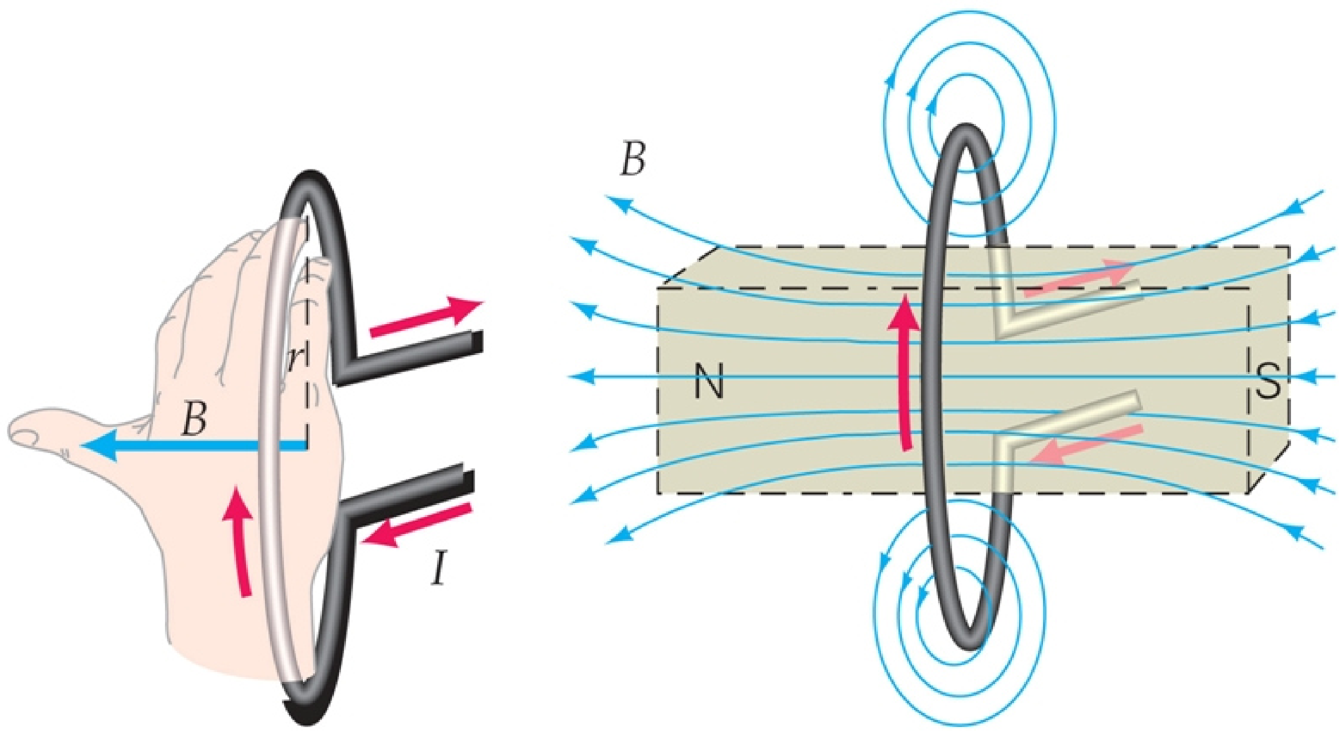

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MAgnetic moments

- Atomic electrons have a property called â€œspinâ€ that gives them a small magnetic moment.
- In multielectron atoms, the electrons are usually paired with an electron of the opposite spin, leaving no net magnetic moment.
- some atoms do have a permanent magnetic moment.
- They will experience a torque in a magnetic field, and will tend to align with it.
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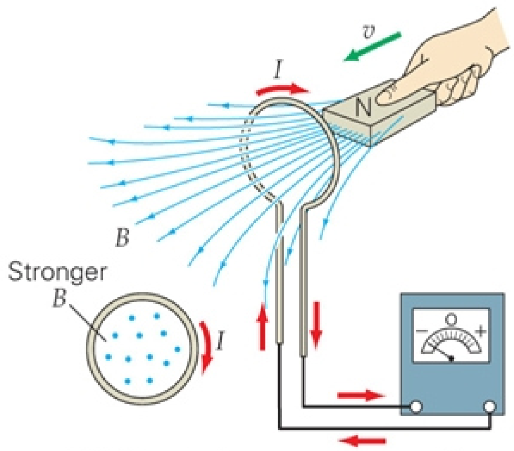
Electromagnetic induction

- when a magnet is moved near a conducting loop, a current is induced.



(b) Magnet is moved toward loop

- A measure of the current induced is the magnetic flux:
  $\Phi = B \cdot A \cdot \cos\theta$
- where B is the magnetic field, A the surface area of the circular loop and θ is the angle that a normal to the surface of the loop makes with B
- SI unit of magnetic flux: the weber, Wb
-

Induced emf: Faraday's Law and Lenz's Law

- Whenever a magnet is moved in or out of a loop of wire a current is induced, emf:
  $$\varepsilon = -\frac{\Delta\ \Phi}{\Delta\ t}$$
  $$\varepsilon = -\frac{\Delta\ (B \cdot A \cdot \cos\theta)}{\Delta\ t}$$
- The minus sign indicates the direction of the induced emf, which is given by Lenz's law.
- Lenz's law:
- An induced emf in a wire loop or coil has a direction such that the current it creates produces its own magnetic field that opposes the change in magnetic flux through that loop or coil.
- Lenzâ€™s law is a consequence of the conservation of energy
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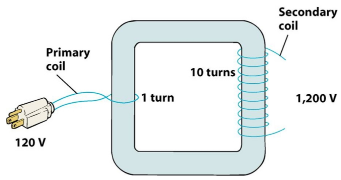
Transformers

- A transformer has two basic parts.



  - A primary coil, which is connected to a source of alternating current
  - A secondary coil, which is close by.
  - A growing and collapsing magnetic field in the primary coil induces a voltage in the secondary coil.

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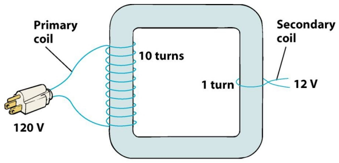
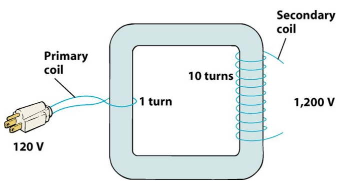
Step up and step down Transformers

- A step up or step down transformer steps up or steps down the voltage of an alternating current ;



- Done according to the ratio of wire loops in the primary and secondary coils.
- The power input on the primary coil equals the power output on the secondary coil.
- Energy losses in transmission are reduced by stepping *up* the voltage.



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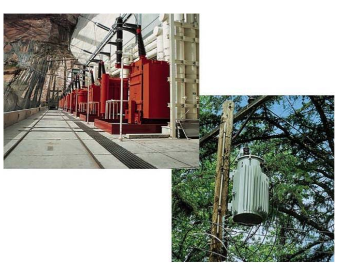
Taser guns: applications of transformers

- Electroshock weapon is an incapacitant weapon used for subduing a person by administering electric shock aimed at disrupting superficial muscle functions ;

- Energy losses in transmission are reduced by increasing the voltage, so the voltage of generated power is stepped up at the power plant



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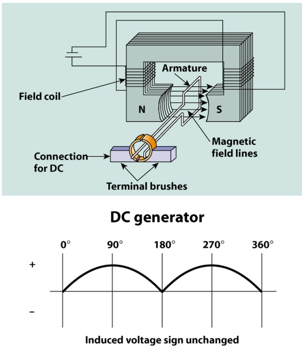
Electric generators

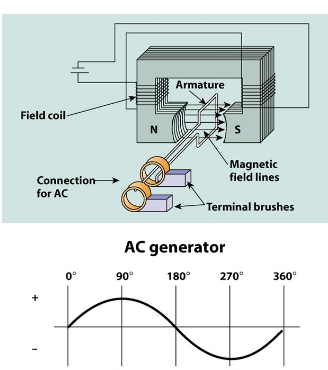
- An axle with many wire loops that rotates in a magnetic field;



- The axle is turned by some form of mechanical energy
- a water turbine
- a steam engine.

Simple alternators, AC generator

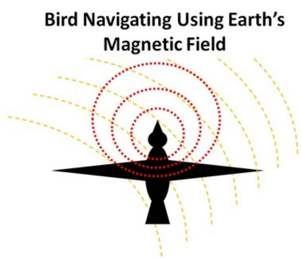
- A loop turns in a constant magnetic field, which alternates the induced current each half cycle;



- The split ring (commutator) reverses the sign of the output when the voltage starts to reverse;
- the induced current has half-cycle voltages of a constant sign, which is the definition of direct current.

Applications of Electromagnets

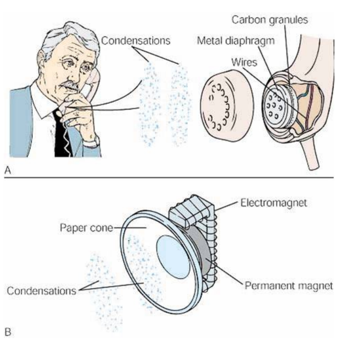
- NMR
- Birds navigation
- Birds fly as if they had a compass in their heads.



- Birds sense magnetic N
- The weak magnetism radiated from the US Navy's test facility in Wisconsin has changed the birds' flight pattern
- Attaching tiny magnets to the sides of the birds' heads $\rightarrow$:
  - poor navigators
-

Applications of Electromagnets II

- Sound waves are converted into a changing electrical current in a telephone.



- Changing electrical current can be changed to sound waves in a speaker by the action of an electromagnet pushing and pulling on a permanent magnet.
- The permanent magnet is attached to a stiff paper cone or some other material that makes sound waves as it moves in and out
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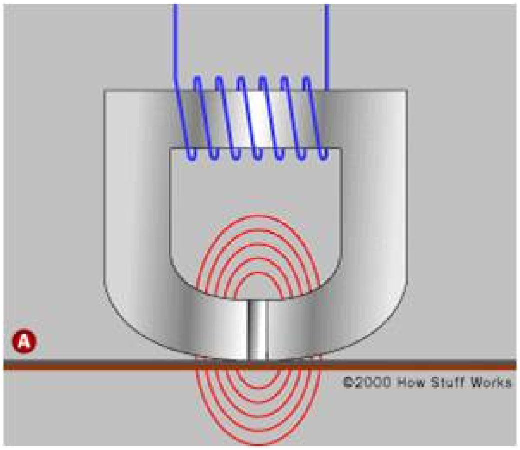
Electro-Magnetic induction applications: Tape recorder

- A tape recorder's record head is a very small, circular electromagnet with a small gap in it;
- An electromagnet applies a magnetic flux to the oxide on the tape.

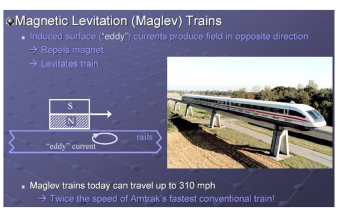


- the magnetic flux magnetizes the oxide on the tape.
- The oxide permanently "remembers" the flux it sees.

- During recording, the audio signal is sent through the coil of wire to create a magnetic field in the core.
- During playback, the motion of the tape pulls a varying magnetic field across the gap.
  - This creates a varying magnetic field in the core and therefore a signal in the coil.
-

Electro-Magnetic induction applications

- Maglev trains



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Sample problem magnetic flux

- What should be the diameter of a circular wire loop if it is to have a magnetic field of $1.5T$ oriented perpendicular to its area which produces a magnetic flux of $1.2 \cdot 10^{-2} T$?
- Solution:

$$\Phi = BA \cos\theta = B\pi r^2 \cos\theta = B\pi\left(\frac{d^2}{2}\right)\cos\theta \rightarrow d$$

-
-
-

Sample problem emf

- The plane of a conductive loop with an area of $0.02m^2$ is perpendicular to a uniform $B = 0.3T$. If the field drops to zero in $0.0045s$ what is the average emf induced in the loop?
  $\varepsilon = -N\frac{\Delta\ \Phi}{\Delta\ t} = -N\frac{A\ \Delta\ B}{\Delta\ t}$
-

Sample problem electromotive force calculation

-
- A uniform B is at right angles to the plane of a wire loop. If the field decreases by $0.2T$ in $10^{-3}s$ and the average inducd emf is $80V$ what is the area of the loop ? What would be the emf if the field change was the same but took twice as long to decrease ?
  $\varepsilon = -N\frac{\Delta\ \Phi}{\Delta\ t} = -N\frac{A\ \Delta\ B}{\Delta\ t} \rightarrow A = ?$
-
-
-

Sample problem transformers

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

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Sample problem Transformers

-
  $\frac{I_p}{I_s} = \frac{V_s}{V_p} = \frac{N_s}{N_p} \rightarrow N_p = ?$
  $I_p = ?$
-