L 29 Electricity and Magnetism [6]

- Review- magnetism- what is a magnet?
- Faraday's Law of Electromagnetic Induction
  - induced currents
  - electric generator
  - eddy currents
- Electromagnetic Waves (Maxwell & Hertz)

Laws of Magnetism

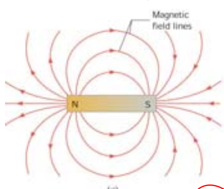
- If you pass current through a loop of wire. you get a magnet ➔ Oersted's discovery
- Basic laws of magnetism

➔electric currents produce magnetic fields (Ampere)

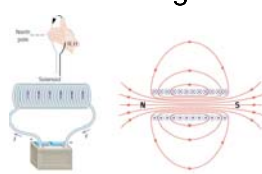
➔magnetic field lines are always closed loops – no isolated magnetic poles

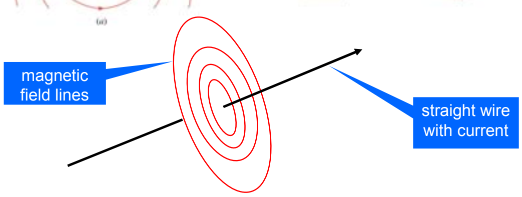
- permanent magnets: the currents are *atomic currents* – due to electrons spinning in atoms- these currents are always there
- electromagnets: the currents flow through wires and require a power source, e.g. a battery

Bar Magnet

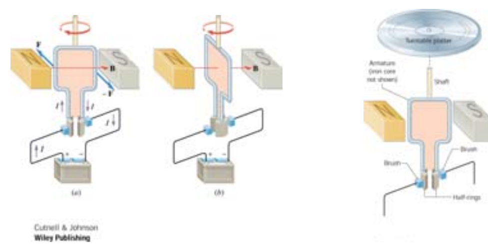


Electromagnet





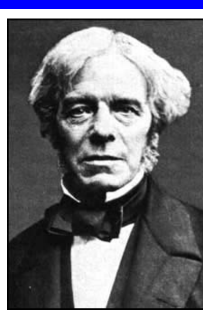
The electric motor



When a current is present in a coil, it experiences a torque and rotates.

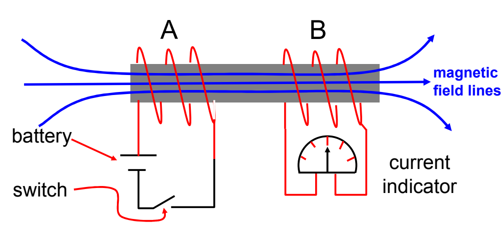
Faraday's Law of Electromagnetic induction

- Faraday thought that if currents could produce magnetic fields, (Oersted) magnetic fields should be able to produce currents
- He was correct with one important requirement ➔ *the magnetic field must be* *__changing__* *in some way to produce a current*
- the phenomenon that a changing magnetic field can produce a current is called **electromagnetic induction**



Michael Faraday (1791-1867)

Induced currents (a)



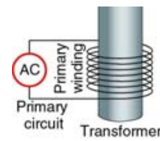
→ When a current is turned on or off in coil A, a current **briefly** appears in coil B

→The current in coil B is called an **induced current.** The current in B is only present when the current in A is changing.

Induced currents (b)

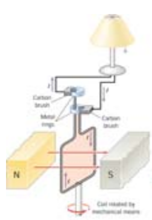
a) No current is induced if the magnet is stationary.
b) When the magnet is pushed toward the coil or pulled away from it an induced current appears in the coil.
c) The induced current only appears when the magnet is being moved

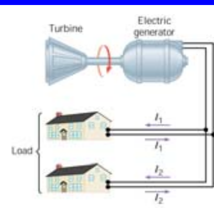
Induced currents (c)



- If an AC (time varying) current is used in the primary circuit, a current is induced in the secondary windings.
- If the current in the primary windings were DC, there would be NO induced current in the secondary circuit.

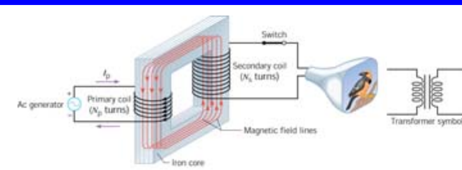
electric generators





When a coil is rotated in a magnetic field, an induced current appears in it. This is how electricity is generated. Some external source of energy is needed to rotate the turbine which turns the coil.

The transformer

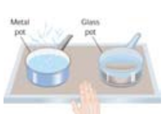


The voltage on the secondary depends on the number of turns on the primary and secondary.

Step-up→ the secondary has more turns than the primary
Step-down→ the secondary has less turns than the primary

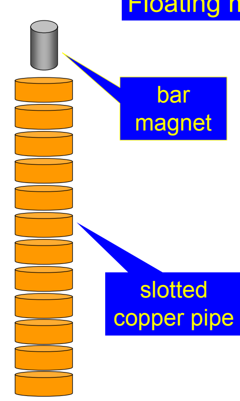
Eddy currents

- When time varying magnetic fields are around, currents can appear in nearby conductors --- these are eddy currents
- an induction stove uses eddy currents to cook food



Only the metal pot gets hot, not the glass pot or the stove.

Floating magnet – induced currents



As the magnet falls, it induces currents in the copper pipe known as eddy currents. These currents produce a magnetic field that opposes that of the falling magnet, so the magnet does not accelerate but descends slowly

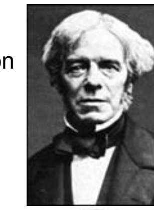
The laws of electricity and magnetism

- Law of electricity.— electric charges produce *electric "fields"*
- Laws of magnetism.—
  - currents produce magnetic fields
  - magnetic field lines are closed loops
  - Faraday's law of electromagnetic induction.— a changing magnetic field can produce a current (*induced currents*)

ELECTROMAGNETIC WAVES

- Faraday laid the groundwork with his discovery of electromagnetic induction
- Maxwell added the last piece of the puzzle

James Clerk Maxwell
(1831-1879)



Heinrich Hertz made the experimental discovery in 1886

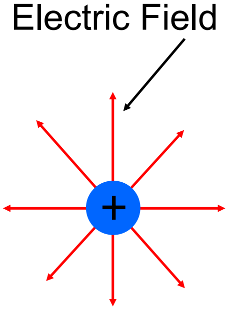
Electromagnetic (EM) waves

- A wave is a disturbance that propagates in a *medium*
  - transverse waves on a string
  - longitudinal sound waves in air
- *an electromagnetic wave is an electric and magnetic disturbance that propagates through space (even vacuum) at the speed of light 299,792,458 m/s or 186,000 miles/s. No medium is required!*
- EM waves include radio, microwaves, x-rays, light waves, gamma rays . . . . . .

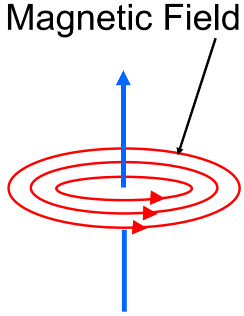
Electric and Magnetic Fields

- electric charges produce electric fields (Coulomb's Law)
- electric currents (moving charges) produce magnetic fields (Ampere's Law)
- *an electromagnetic wave is a combination of electric and magnetic fields that vibrate together in space and time in a synchronous fashion*

Electric Field Magnetic Field

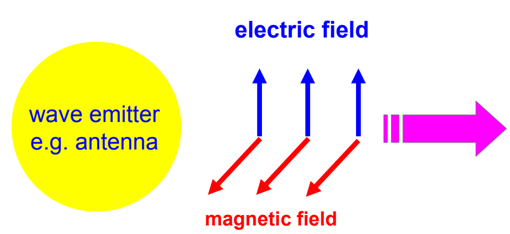


electric field of a positive charge



magnetic field of a current in a wire

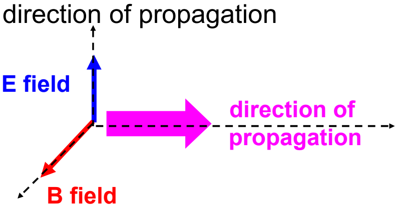
the generation of an electromagnetic wave



The time varying electric field generated the time varying magnetic field which generates the time varying electric field and so on and so on . . . .

EM waves: transverse

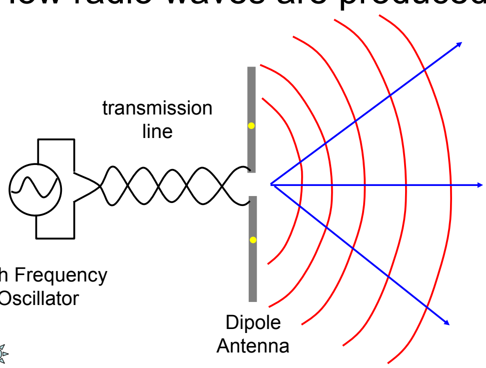
- the electromagnetic wave is a *transverse wave*, the electric and magnetic fields oscillate in the direction perpendicular to the direction of propagation



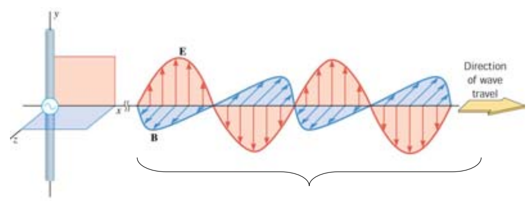
Electromagnetic waves

- the EM wave propagates because the electric field recreates the magnetic field and the magnetic field recreates the electric field
- an oscillating voltage applied to the antenna makes the charges in the antenna vibrate up and down sending out a synchronized pattern of electric and magnetic fields
- *an* ***electromagnetic*** *wave must have both an electric and magnetic field component*

How radio waves are produced



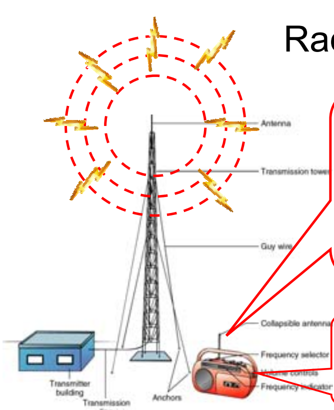
Electromagnetic Waves



Antenna: emits waves

EM WAVE: electric and magnetic fields moving through space at the speed of light 186,000 miles/sec

Radio antenna

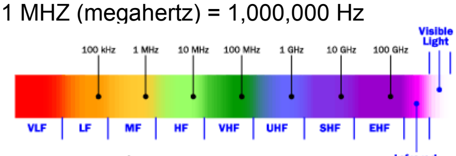


the oscillating electric field of the EM wave causes the electrons in the receiving antenna to oscillate at the same frequency

the amplifier converts the electrical signal to sound waves

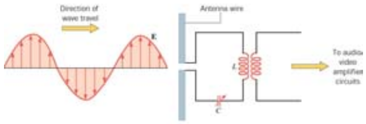
Common frequency bands

1 Hertz (Hz) = 1 vibration per second
1 KHZ (kilohertz) = 1000 Hz
1 MHZ (megahertz) = 1,000,000 Hz



- **AM radio** - 535 KHZ to 1.7 MHZ
- **FM radio**: 88:108 MHZ
- GPS: 1,227 and 1,575 MHZ
- **Citizens band (CB) radio** - 26.96 to 27.41 MHZ
- **Cell phones**: 824 to 1900 MHZ

Detecting (receiving) the Wave



The golden rule applies to electromagnetic waves

- the golden rule: **$c = \lambda f$**
  speed = wavelength × frequency
  applies to electromagnetic waves.
- the speed **c** is roughly 300,000,000 m/s
- for example, the wavelength of a 1 MHZ radio wave is:
  wavelength = speed/frequency

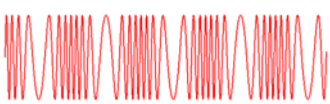
  = 300,~~000,000~~/1,~~000,000~~ = 300 meters

Amplitude Modulation (AM)

AM ➔ the information is coded into the way that the amplitude is modulated

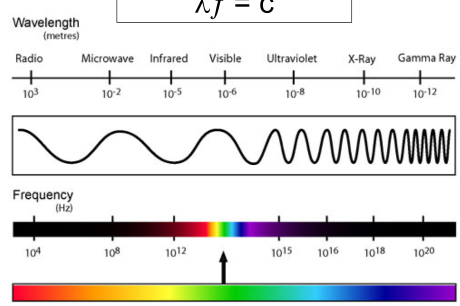
Frequency modulation (FM)

FM ➔ information is coded into the way that the modulation frequency is varied



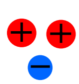
Electromagnetic spectrum

$\lambda f = c$



Microwaves

- are in the frequency range of a few billion Hz or wavelengths of about several cm (about the same range as radar → the "Radarange"
- How do microwaves heat water?
- Remember that the water molecule has a positive end and a negative end.



- The electric field of the microwave grabs onto these charges and shakes them violently a few billion times each second
- all this shaking energizes the molecules making the water hotter and hotter.