2.3 Light and Electromagnetic Radiation

- Maxwell's discovery
- Properties of EM radiation
- Production of EM radiation
- Spectrum of EM radiation

James Clerk Maxwell

Electromagnetic Waves

- Radio waves- radio, television
- Microwaves – cell phones, microwave oven
- Light waves – infrared, visible, ultraviolet light
- x-rays – x-ray diffraction, medical x-ray

Wave properties of light

- Maxwell discovered that light is a form of electromagnetic radiation.
- Electromagnetic waves are produced that propagate through a vacuum at the speed of light.
- The speed of light is a fundamental constant. $c=2.99792 \times 10^8$ m/s

Speed of Light

Measured values

permeability of free space $\mu_o = 4\pi \times 10^{-7}$ T·m/A

permittivity of free space $\varepsilon_o = 8.85419 \times 10^{-12}$ C²/N·m²

speed of light $c = 2.99792458 \times 10^8$ m/s

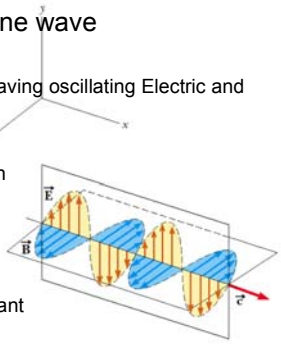
Predicted value $c = \sqrt{\frac{1}{\varepsilon_o \mu_o}} = 2.997924 \times 10^8 \text{ m/s}$

Perfect agreement !!!!

Electromagnetic plane wave

Light is a Transverse wave having oscillating Electric and Magnetic fields.

Electric field perpendicular to the direction of propagation
Magnetic field perpendicular to direction of propagation and to the Electric field.



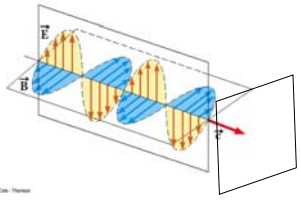
The ratio of E and B is constant

$$\frac{E}{B} = c$$

Intensity of EM wave

The average power/ area in an EM wave is related to the square of the field (E or B)

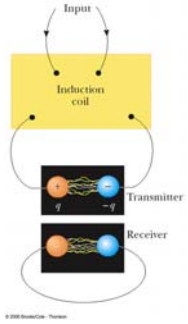
$$I = \frac{P}{A} = \frac{E_{max}^2}{2\mu_o c} = \frac{cB_{max}^2}{2\mu_o}$$



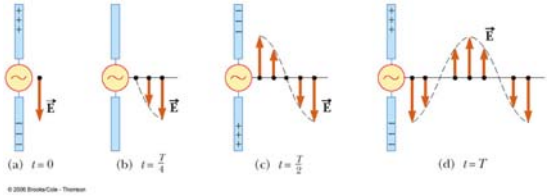
Production of EM waves

- EM waves are produced by oscillations of Electric and Magnetic fields.

Heinrich Hertz
Showed that electrical oscillation in transmitter produce electromagnetic waves that propagate to the receiver.

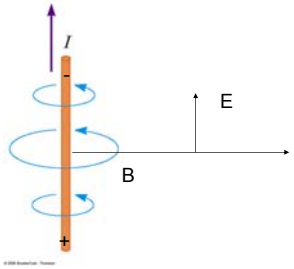


Generation of the E field by an oscillating dipole antenna



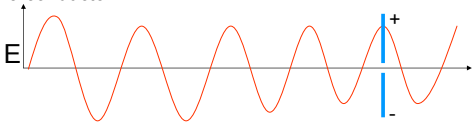
The magnetic field associated with the E field

A B field is generated perpendicular to the E field.



Interactions of EM radiation with an Antenna.

Oscillating Electric field drives the movement of charges in a conductor

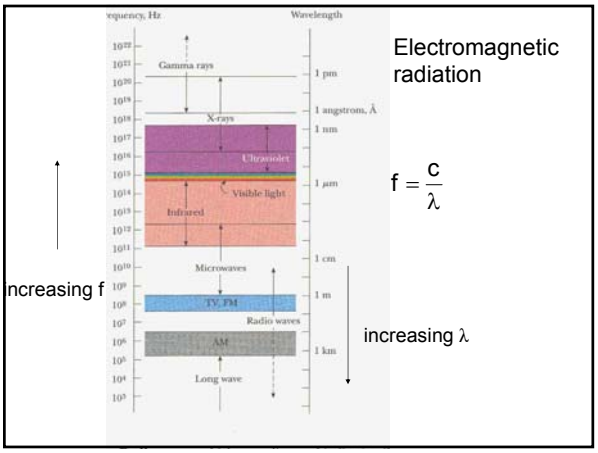


• An optimal antenna to capture energy from an EM wave has a size close λ. (λ/2 for a dipole antenna)

Passage of EM radiation through holes in a conductor

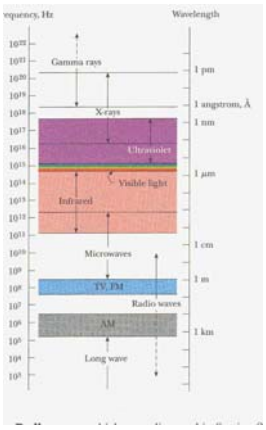
• EM waves pass easily through holes in a conductor that are larger than λ but are blocked by holes smaller than λ.

• When the size of the hole is close to the λ, interference and diffraction effects are observed (discussed later).



Electromagnetic radiation

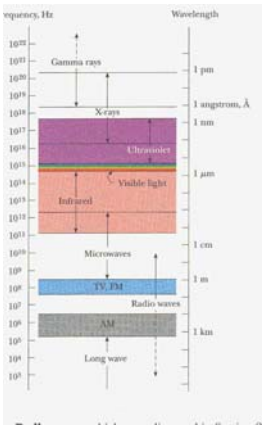
$f = \frac{c}{\lambda}$



Radio Waves

Fm radio, TV

f ~ 100 MHz
λ ~ 1 m



Microwaves

f~ 1-10 GHz
λ~ 1-10 cm

½ dipole antenna

length =λ/4

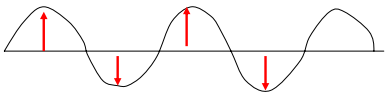
Microwave ovens and cell phones.

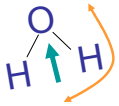
Frequency =2.45GHz
Power ~ 1kW
compare to cell phone power ~1W.

- Microwaves are reflected from the walls of the cooking chamber and the energy is confined to cook the food.
- Microwaves form standing waves in the chamber.

Microwaves are absorbed by water molecules reoriented by the E field

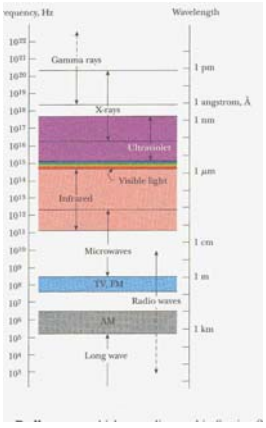
E field





electric dipole orients with the fluctuating field

The reorientation time for water rotation is matched to the microwave frequency

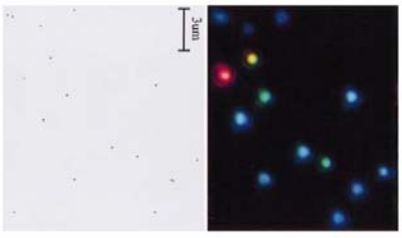


Visible Light

f~10^{15} Hz
λ~ 400-700 nm

stained glass, gold particles with diameter ~100 nm scatter specific colors of light

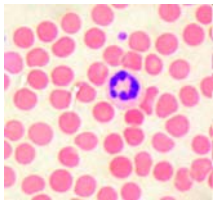
Silver nano-particles



Electron micrograph

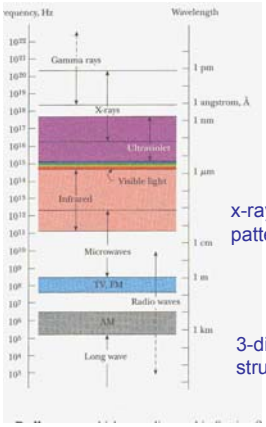
light micrograph

The wavelength of light limits the resolution of the microscope to $\lambda \sim 1\mu m$



~ 10 μm

Red Blood cels



X-rays

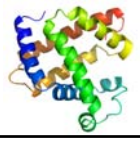
f ~ 10^{16}-10^{20} Hz

λ~ 10^{-8} -10^{-12} M

Atomic dimensions

x-ray diffraction pattern

3-dimensional structure



X-rays

X-rays penetrate soft tissue but are absorbed by heavy atoms, such as Calcium in bones.