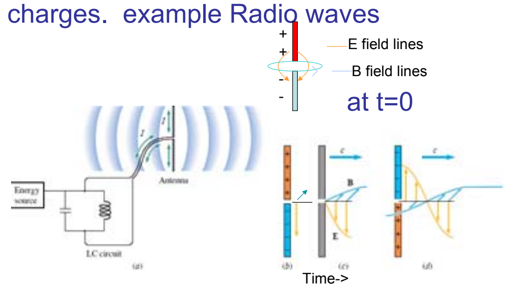
EM waves
3.2

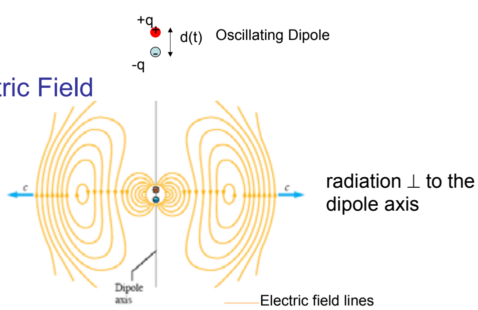
- Producing EM waves
- Electromagnetic Spectrum
- Energy in EM waves

EM radiation is produced by accelerating charges. example Radio waves



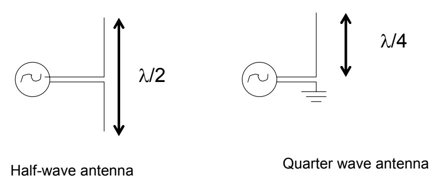
Evolution of the E and B fields

Dipole Antenna



No radiation || to the dipole axis (Why?)

Dipole antenna



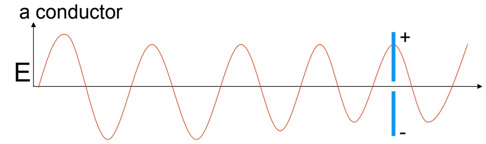
Question

A cell phone uses a frequency of 2.0 GHz. Find the length of the quarter wave antenna.

1) 3.8mm
2) 0.38 cm
3) 3.8 cm
4) 38 cm

Interactions of EM radiation with an Antenna.

Oscillating Electric field drives the movement of charges in a conductor



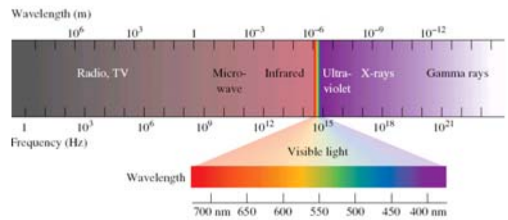
- An optimal antenna to capture energy from an EM wave has a size close λ. (λ/2 for a dipole antenna)

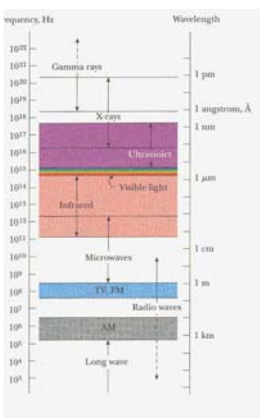
Passage of EM radiation through holes in a conductor

• 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).

Spectrum of EM waves

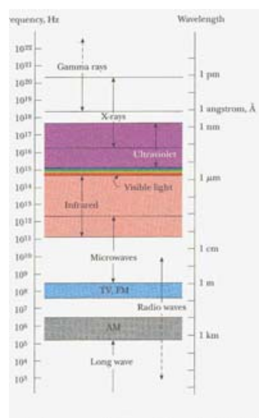




Radio Waves

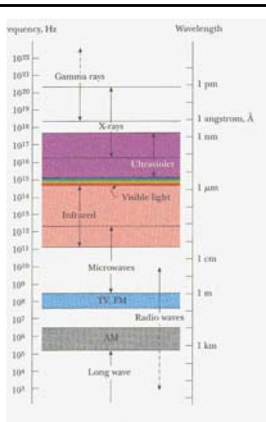
Fm radio, TV

f~ 100 MHz
λ ~ 1 m



Microwaves

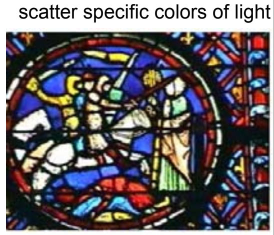
f~ 1-10 GHz
λ~ 1-10 cm



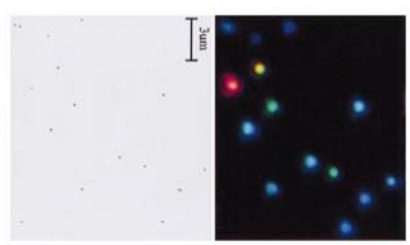
Visible Light

f~10^{15} Hz
λ~ 400-700 nm

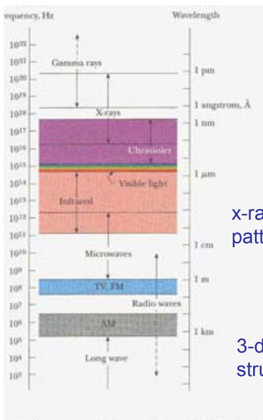
stained glass, gold particles with diameter ~100 nm scatter specific colors of light



Silver nano-particles



Electron micrograph light micrograph



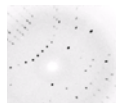
X-rays

$f \sim 10^{16}$-10^{20} Hz

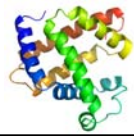
$\lambda \sim 10^{-8}$ -10^{-12} M

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.

Energy carried by an EM wave

Energy density of E and B fields (from capacitor and inductor)

$$\mu_E = \frac{1}{2}\varepsilon_o E^2$$

$$\mu_B = \frac{B^2}{2\mu_o}$$

Joules/m^3

Average energy density (average of $\sin^2\theta = 1/2$)

E_o and B_o are the peak fields

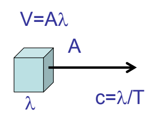
$$\overline{\mu_E} = \frac{1}{4}\varepsilon_o E_o^2 = \frac{1}{4}\varepsilon_o c^2 B_o^2 = \frac{1}{4}\frac{B_o^2}{\mu_o}$$

Use $E_o^2 = c^2 B_o^2$

$$\overline{\mu_B} = \frac{B_o^2}{4\mu_o}$$

The average energy density for E and B are the same

Intensity



Average power $\overline{P} = \frac{\mu_{total} A\lambda}{T}$

Average Intensity $\overline{S} = \frac{\overline{P}}{A} = \overline{\mu_{total}}c = 2\overline{\mu_E}c = 2\overline{\mu_B}c$

Use

$\overline{\mu_E} = \frac{1}{4}\varepsilon_o E_o^2$ => $\overline{S} = \frac{1}{2}\varepsilon_o E_o^2 c$

$\overline{\mu_B} = \frac{B_o^2}{4\mu_o}$ => $\overline{S} = \frac{1}{2}\frac{B_o^2}{\mu_o}c$

$E_o = cB_o$ => $\overline{S} = \frac{1}{2}\frac{B_o E_o}{\mu_o}$

Poynting Vector

In general expression for the intensity of EM radiation

$$\vec{S} = \frac{\vec{E} x \vec{B}}{\mu_o}$$

Units W/m^2

The average intensity

$$\vec{S}_{average} = \frac{\vec{E}_{rms} x \vec{B}_{rms}}{\mu_o}$$

$$\vec{S}_{average} = \frac{\vec{E}_o x \vec{B}_o}{2\mu_o}$$

34.4 Light intensity

The light intensity at noon on a sunny day is about 1kW/m^2. What is the peak E field due to the light? What is peak B field?

Electric Field

$$\overline{S} = \frac{1}{2}\varepsilon_o E_o^2 c$$

$$E_o = \sqrt{\frac{2\overline{S}}{\varepsilon_o c}} = \sqrt{\frac{2(1000)}{8.85x10^{-12}(3x10^8)}} = 8.7x10^2\,V/m$$

Magnetic Field

$$B_o = \frac{E_o}{c} = \frac{8.7x10^2}{3x10^8} = 3x10^{-6}\,T$$

In terms of normal laboratory fields the E field is more significant than the B field. (i.e. for interactions with matter.

Cell phone

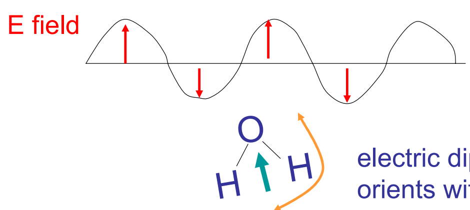
If a cell phone antenna can detect a peak electric field of 10^{-3} V/m how much power must a transmitter that is 10 km away have if it transmits waves in all directions.

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



electric dipole orients with the fluctuating field