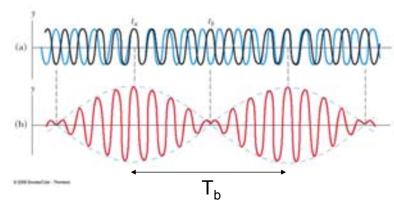
2.2 Beats, Doppler, Light

Beats
Doppler Effect.
Shock Waves
Electromagnetic Waves

Beats

Superposition of two waves with different frequencies produce oscillation in amplitude.



T_b

Beat Frequency $f_b = \frac{1}{T_b} = |f_2 - f_1|$

Tuning musical instruments

Beats are observed when two instruments have different frequencies

The beat frequency for two musical instruments is zero when the two are in tune.

Doppler Effect

Doppler effect- the shift in frequency of a wave where the source and observer are moving relative to one another.

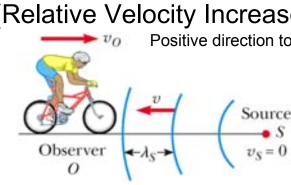
Doppler effect

Two different cases:
Observer moving – Relative velocity changes
Source moving- Wavelength changes

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

Observer moving toward a Stationary source (Relative Velocity Increases)

Positive direction toward source

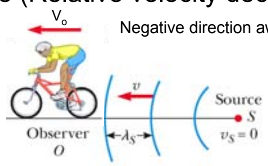


- Relative velocity of wave (v_o + v) increases.
- Frequency increases

$$f_o = \frac{v + v_o}{\lambda_s} \quad = \frac{v + v_o}{v} f_s = (1 + \frac{v_o}{v}) f_s$$

Observer moving away from a stationary source (Relative velocity decreases)

Negative direction away from source

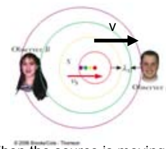


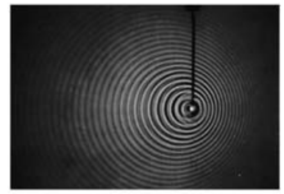
Relative velocity of wave ($v+v_o$) decreases.
Frequency decreases.

$$f_o = \frac{v + v_o}{v} f_s = (1 + \frac{v_o}{v}) f_s$$

v_o is negative

Source moving toward a stationary observer (wavelength in the medium decreases)

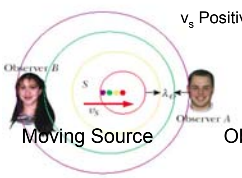




- When the source is moving the wavelength of the wave in the media is changed
  - source approaches observer A
    - Wavelength decreases and frequency heard by observer A increases
  - Source moves away from observer B.
    - Wavelength increases and frequency heard by observer B decreases.

Source Moving Toward observer A

v_s Positive direction toward observer



Observer

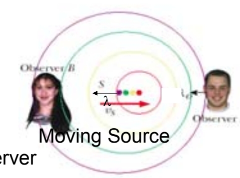
Distance traveled by source in one period

- Wavelength decreases $\lambda = \lambda_s - v_s T$
- Frequency increases $f_o = \frac{v}{\lambda_s - v_s T_s} = \frac{v}{v T_s - v_s T_s}$

$$f_o = \frac{v}{v - v_s} f_s$$

Source Moving Away from observer B

v_s negative direction for observer B

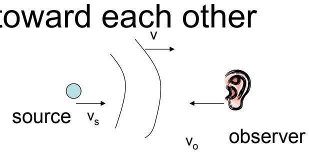


Observer

- Wavelength increases $\lambda = \lambda_s - v_s T$
- Frequency decreases $f_o = \frac{v}{v - v_s} f_s$

v_s is negative

Observer and source moving toward each other

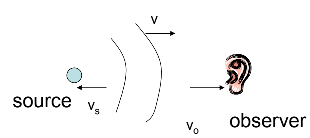


$$f_o = f_s \left(\frac{v + v_o}{v - v_s} \right)$$

v_s positive
v_o positive

- The frequency increases when the source and observer are moving toward each other.

Observer and source moving aw



$$f_o = f_s \left(\frac{v + v_o}{v - v_s} \right)$$

v_o negative
v_s negative

- The frequency decreases when the source and observer are moving away each other.

Example

A fire truck is approaching an observer with a speed of 30 m/s. The siren has a frequency of 700 Hz. What frequency does the observer hear as the truck approaches? What frequency is heard after the truck passes. speed of sound 340 m/s

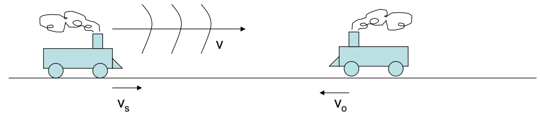
Approaching source v_s positive $v_o = 0$

$$f_o = f_s\left(\frac{v+v_o}{v-v_s}\right) = f_s\left(\frac{v}{v-v_s}\right) = 700\left(\frac{340}{340-30}\right) = 700(1.09) = 763\text{Hz}$$

Departing source v_s is negative

$$f_o = f_s\left(\frac{v+v_o}{v-v_s}\right) = f_s\left(\frac{v}{v-v_s}\right) = 700\left(\frac{340}{340+30}\right) = 700(0.92) = 643\text{Hz}$$

Two trains are approaching each other each moving at 34 m/s. One train sounds a whistle at a frequency of 1000 Hz. Find the frequency of sound heard by an observer on the other train.



v_o is positive v_s is positive

$$f_o = \frac{v+v_o}{v-v_s} f_s = \frac{340+34}{340-34} f_s = 1.22 f_s$$

$$f_o = 1.22\text{x}10^3\text{Hz}$$

Applications Doppler ultrasound

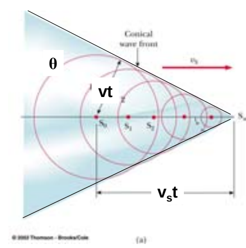
Ultrasonic waver 2-18 MHz.

Doppler shift used to measure blood flow speed.

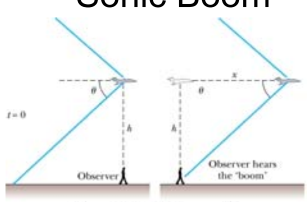
Shock Waves

When v_s > speed of sound, shock waves are formed.

$$\text{Sin}\theta = \frac{v}{v_s}$$



Sonic Boom



When a sonic boom is heard the observer sees the plane at an angle of $\theta = 45^0$ What is the speed of the plane relative to the speed of sound?

$$\sin\theta = \frac{v}{v_s} = \sin 45 = 0.707$$

$$v_s = \frac{v}{\sin\theta} = \frac{v}{0.707} = 1.41v$$

The plane travels at 1.41 time the speed of sound.

Doppler shift of Electromagnetic waves

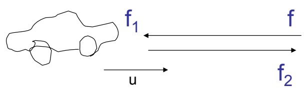
- Electromagnetic waves are also shifted by the Doppler effect.
- Since EM waves travel in a vacuum the equations governing the shift are different.
- The same shift is observed for moving source or moving observer.
- For motion with speeds less than the speed of light the relation is the same as for the approximate shift for sound waves when u<<v.

$$f = f_s(1 \pm \frac{u}{c})$$

u = relative velocity of source and observer.
c = speed of light =$3.00\text{x}10^8$ m/s
Positive sign when approaching
Negative sign when moving away.

Doppler Radar

Doppler radar is used to determine the speed of a car.



The beat frequency between the Doppler shifted frequency and the initial frequency is measured to determine the speed of the car.

$f_1 = f_s\,(1+u/c)$

$f_2 = f_1(1+u/c) = f_s\,(1+u/c)^2 = f_s\,(1+2u/c + (u/c)^2)$ ← negligible

beat frequency $= f_2 - f_s = 2\frac{u}{c}f_s$

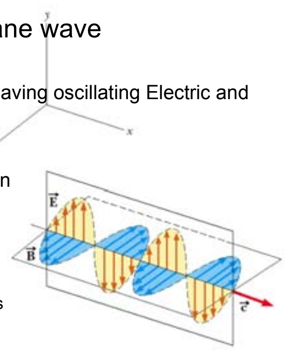
Electromagnetic Waves

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

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.



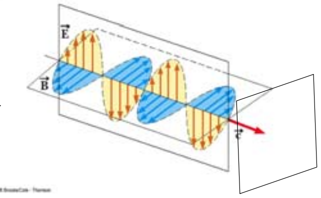
The speed of light in a vacuum is a universal constant

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

Intensity of EM wave

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

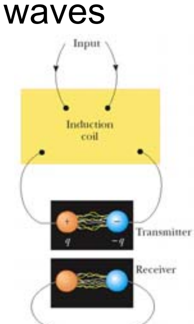
$$I = \frac{P}{A} = \frac{E_{max}^2}{2\mu_o c} = \frac{cB_{max}^2}{2\mu_o}$$



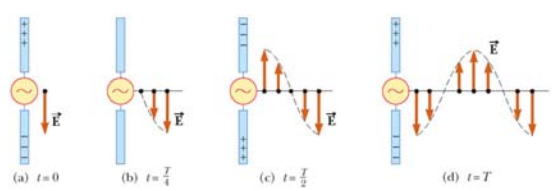
Production of EM waves

- 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.

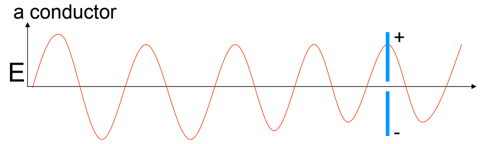


Generation of the E field by Oscillating Charges



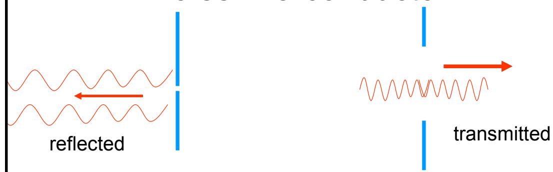
Interactions of EM radiation with an Antenna.

Oscillating Electric field drives the movement of charges in a conductor



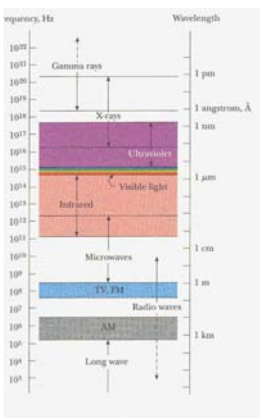
• An optimal antenna to capture energy from an EM wave has a size close λ.   (λ/2 for a dipole antenna)

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).

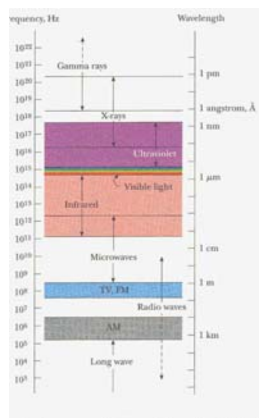


Radio Waves

Fm radio, TV

f ~ 100 MHz

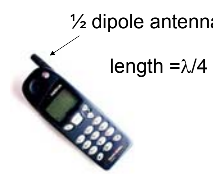
λ ~ 1 m



Microwaves

f~ 1-10 GHz

λ~ 1-10 cm

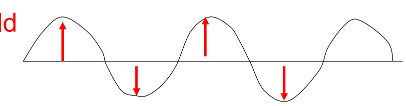


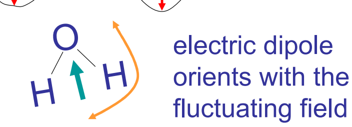
Microwave ovens and cell phones.

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.

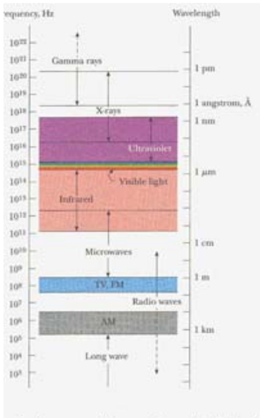
Microwaves are absorbed by water molecules reoriented by the E field





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

Infrared

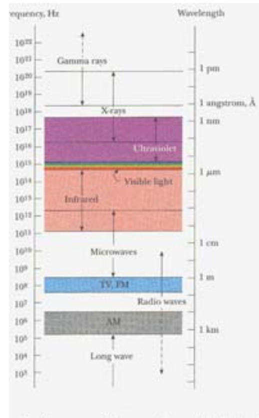


f~ 10^{11}-10^{14} Hz
λ~ 10^{-6}-10^{-3} m

Heat Lamp

excites molecular vibrations

Visible Light

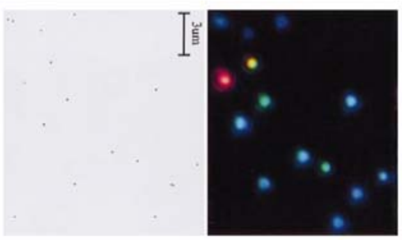


Excites electronic oscillations in pigment molecules.

f~10^{15} Hz
λ~ 400-700 nm

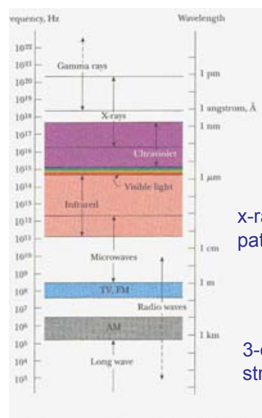
stained glass, gold particles with diameter ~100 nm scatter specific colors of light

Silver nano-particles



Electron micrograph light micrograph

X-rays



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

λ~ 10^{-8} -10^{-12} M

Atomic dimensions

x-ray diffraction pattern

3-dimensional structure