Exam II in two weeks!

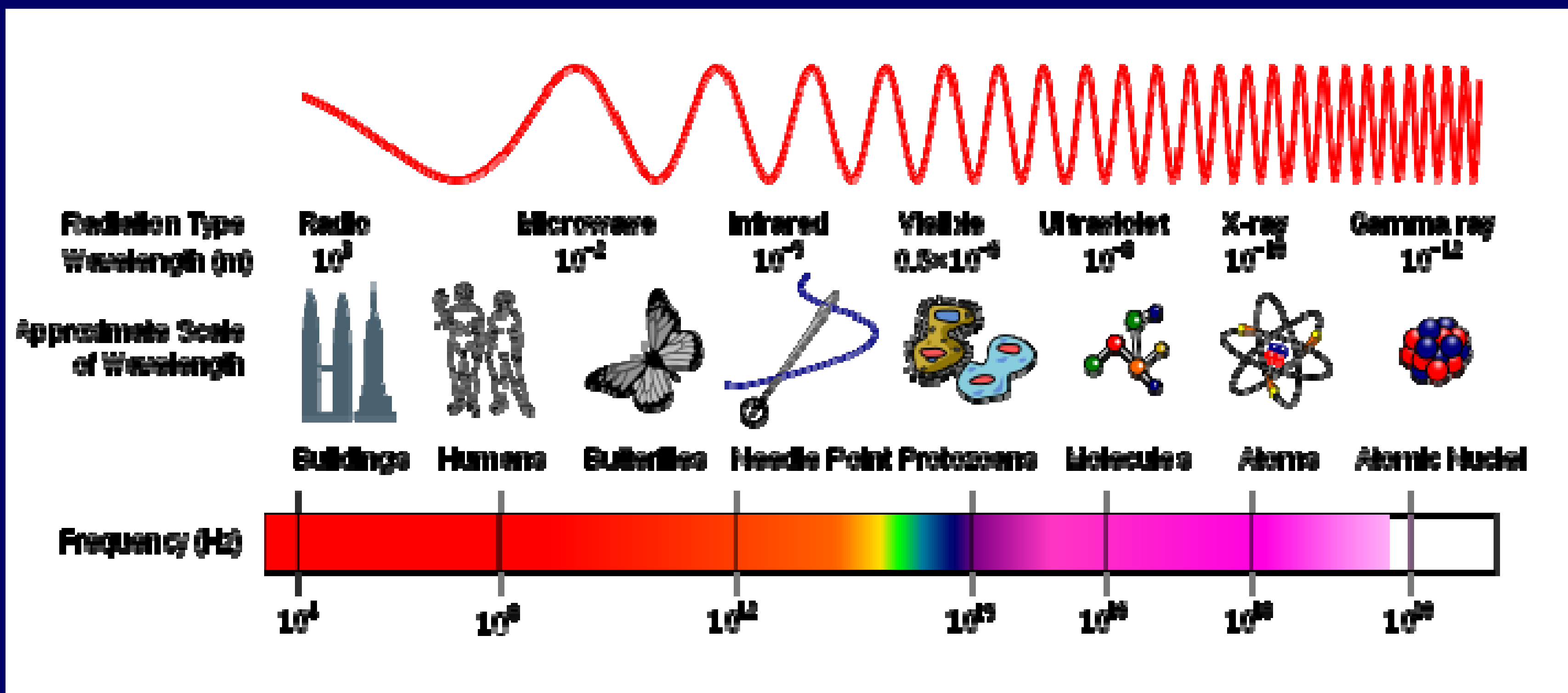
- What will exam cover?
  - Lectures 8 – 15 (Magnetic fields – Polarization)
- What do you need to bring?
  - All you need is a #2 pencil, calculator, and your ID
  - Go to correct room (sign-up for conflict)
- Review, Sunday, Oct. 27, 2 PM, 141 Loomis
  - I will go over a past midterm (TBA)

Exam II in two weeks

- How do you study for a Phys 102 exam?
  - Emphasize understanding concepts & problem solving, NOT memorization
  - Review lecture notes, problem solver summary
  - Understand formula sheet (i.e. when to use and when NOT to use an equation) & know what each symbol means
  - Do practice exam problems (time yourself!)
  - Go to office hours (there are extra office hours)
  - Go to the review session

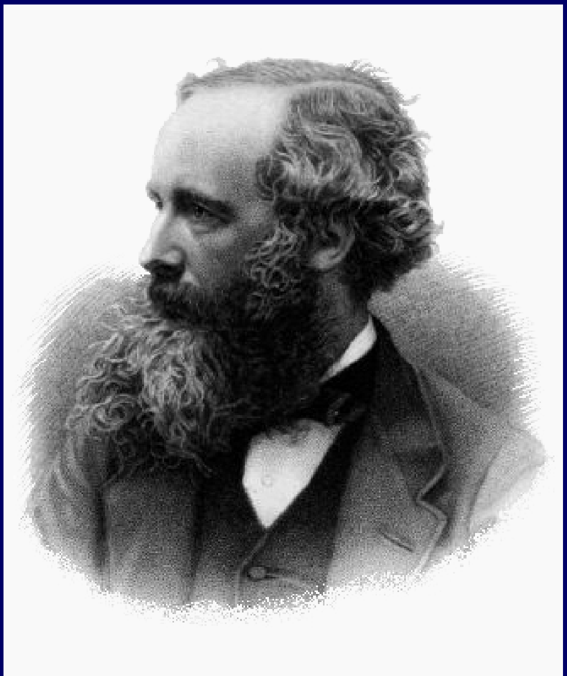
Physics 102: Lecture 14

Electromagnetic Waves



James Clerk Maxwell

(1831-1879)



4 laws unify electricity & magnetism:

1. E-field generated by electric charge

   (Gauss' Law – Lecture 2)

2. No magnetic charges

   (Lecture 8)

3. E-field generated by changing magnetic flux

   (Faraday's Law – Lecture 10)

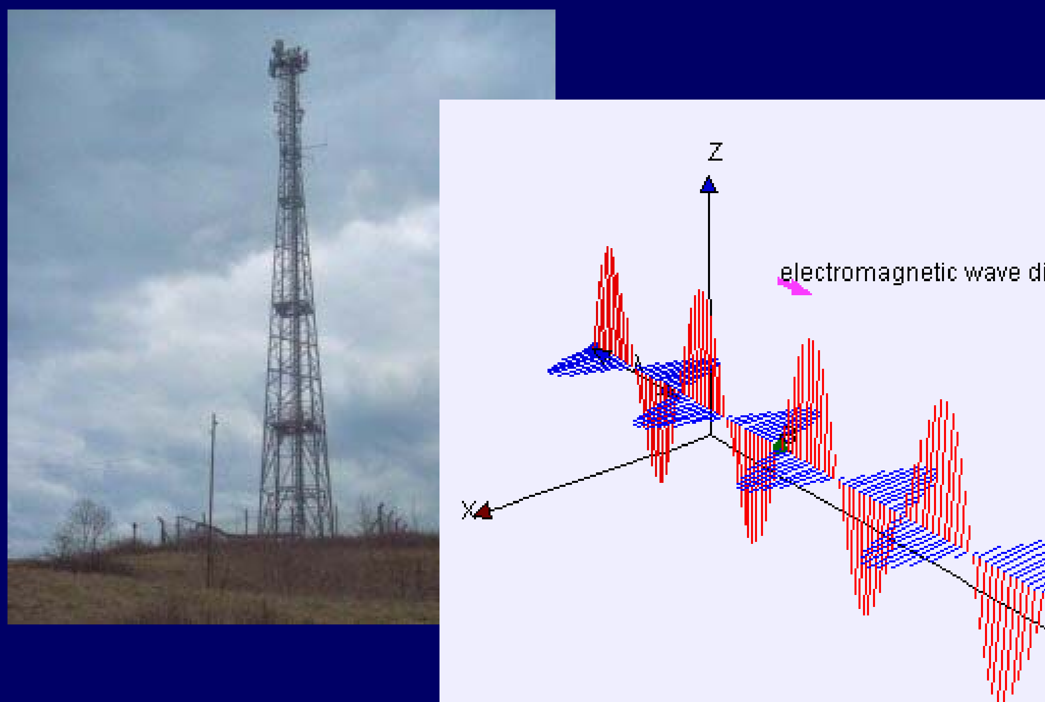
4. B-field generated by moving electric charge & changing electric flux!

   (Ampere's Law – Lecture 9)

Electromagnetic waves!

Electromagnetic waves are light!

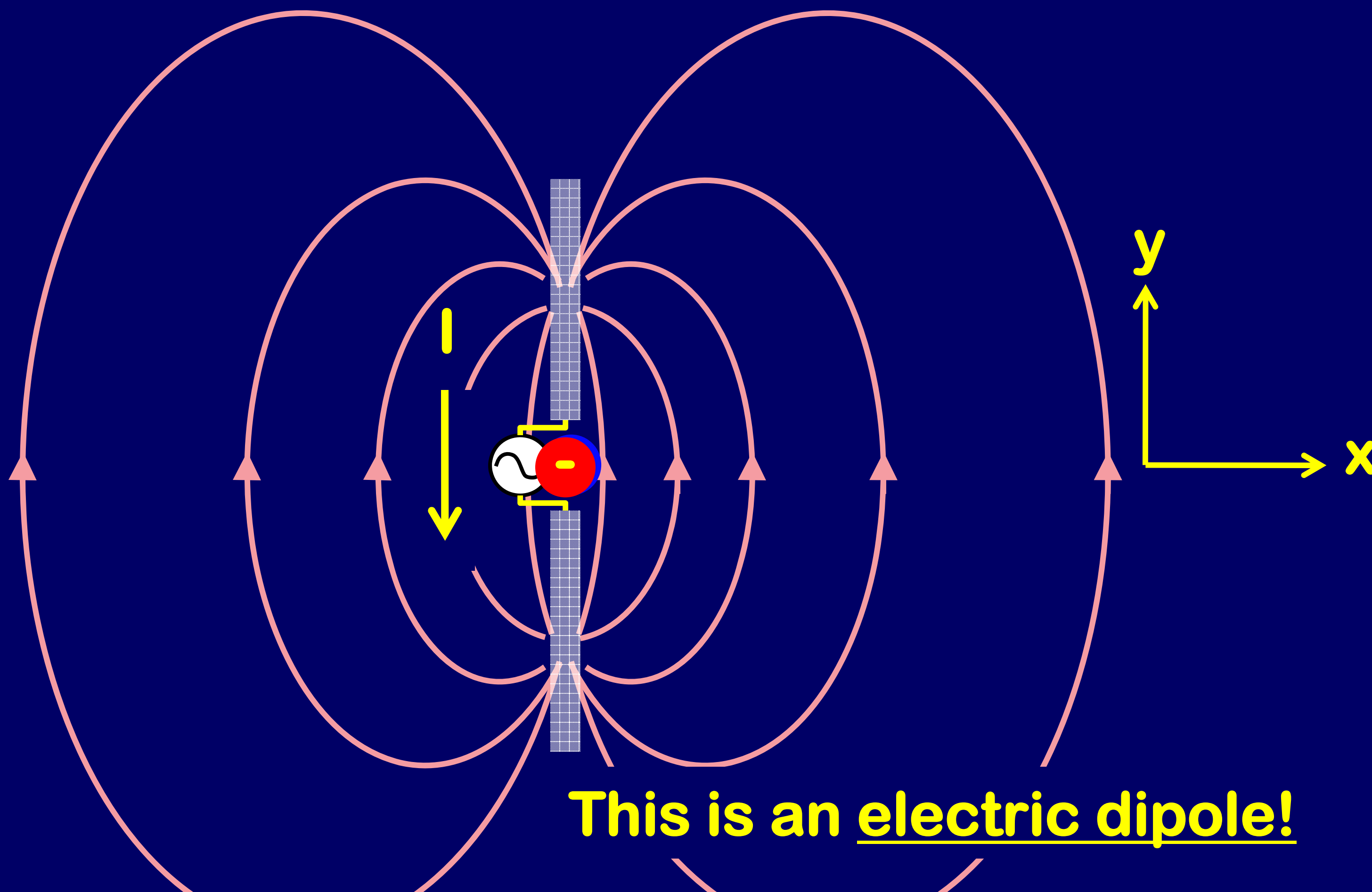
Electric and magnetic fields propagating and oscillating in space and time



Created by oscillating charges…

Radio antenna

Generator creates oscillating current up and down metal rods



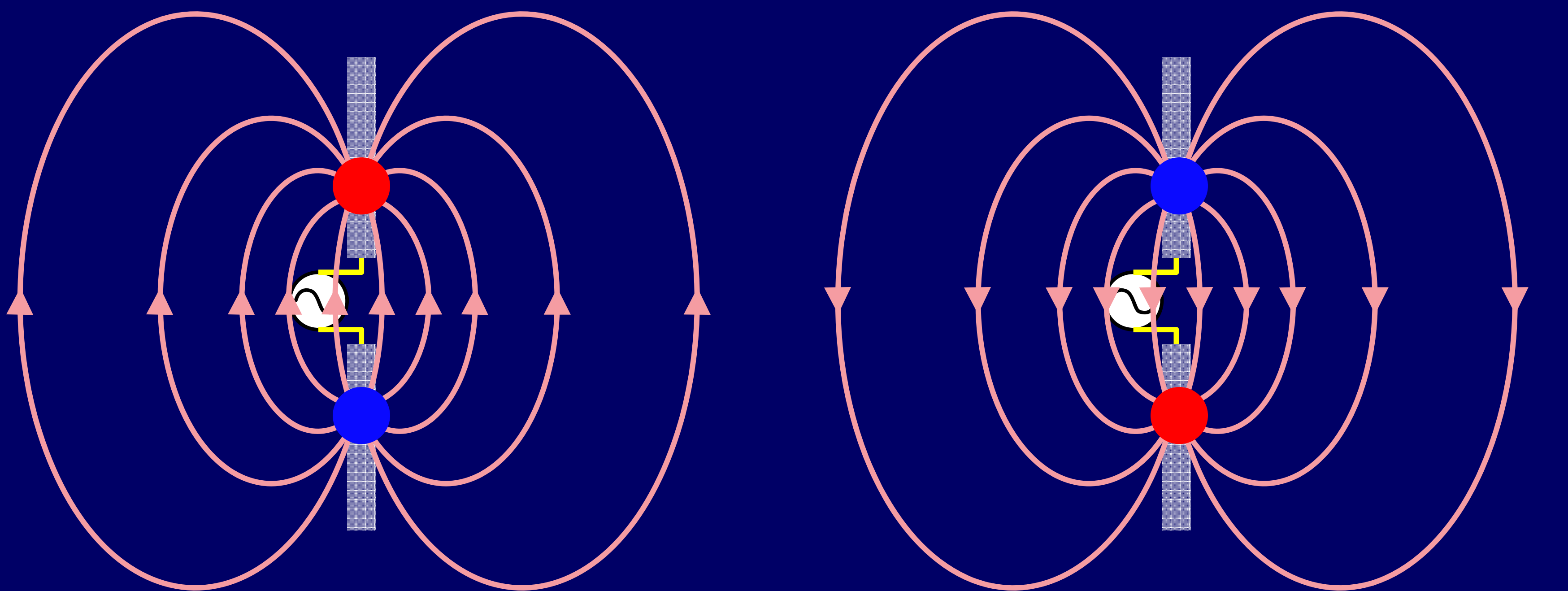
This is an <u>electric dipole!</u>

This is called an <u>electric dipole antenna</u>

Oscillating E field

Electric dipole antenna creates an oscillating electric field

In which direction does the E-field point at this time? ... and now?

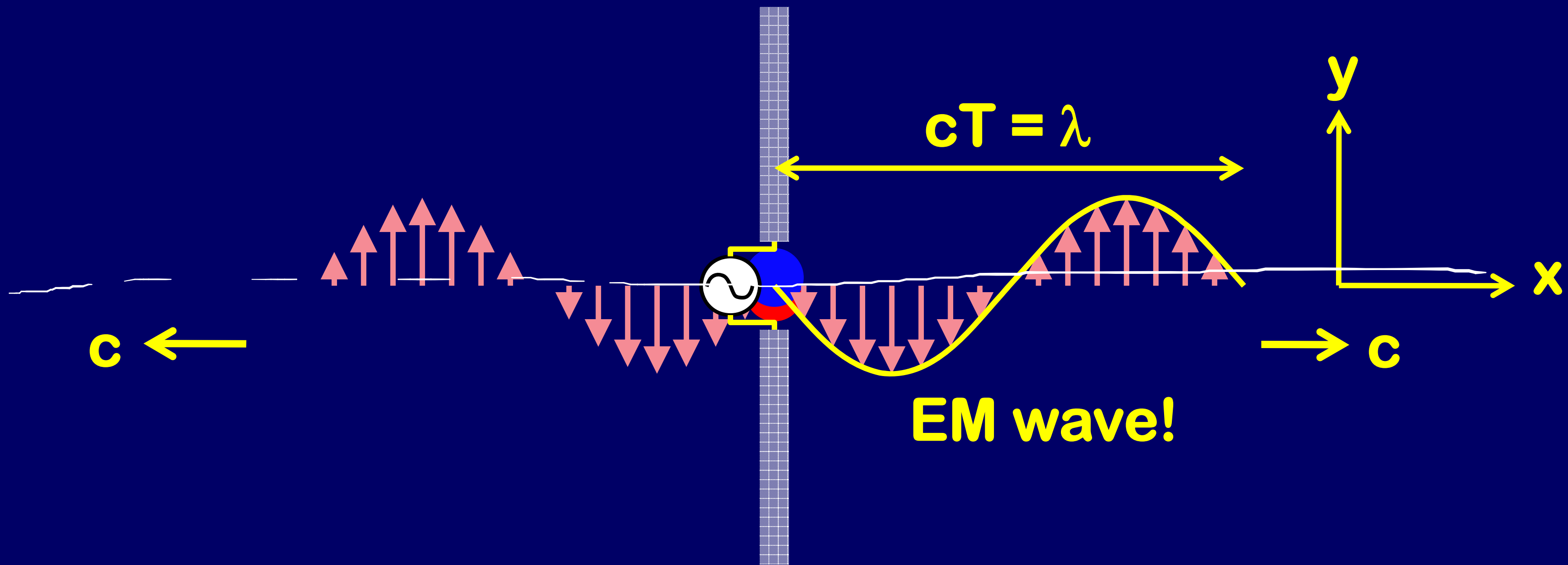


NOT QUITE! E-fields do NOT appear everywhere in space instantaneously, they travel at a finite speed **c**

PhET

Electromagnetic radiation

• E-fields do NOT appear everywhere in space instantaneously, they travel at a finite speed **c**



t=T (one full period) = 1/f

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

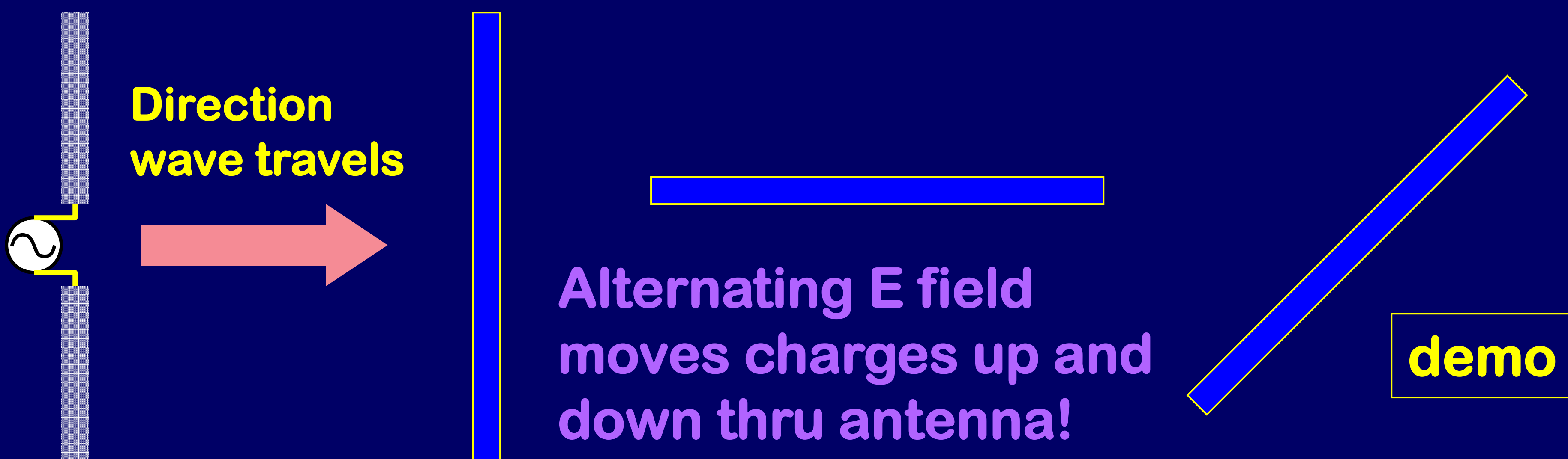
ACT: EM Waves

Which direction should I orient my antenna to best receive a signal from a vertical transmission tower?

1) Vertical

2) Horizontal

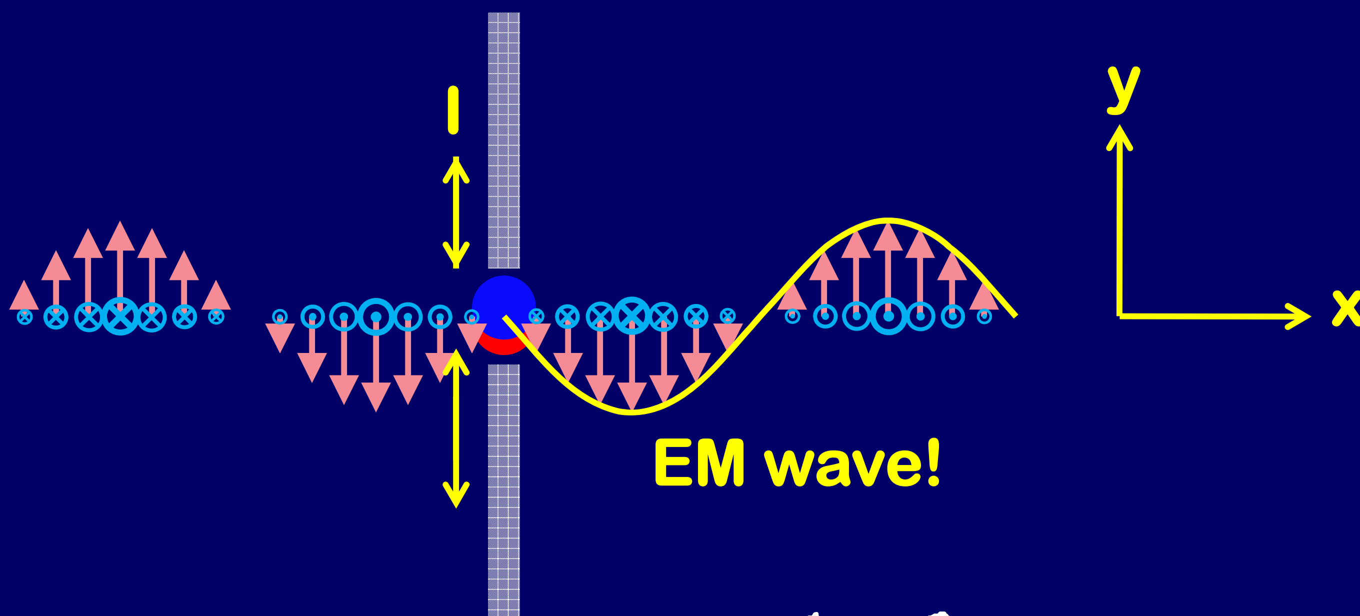
3) 45 Degrees



Electromagnetic radiation

- Current in antenna also creates oscillating B-field
- B-fields do NOT appear in space everywhere

instantaneously they travel at a finite speed **c**



$E \perp B$

E and B fields propagate together as EM waves

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

Speed of EM wave in vacuum

Recall fundamental constants of electricity and magnetism:

$$\varepsilon_0 = 8.85 \times 10^{-12} C^2/Nm^2$$

"Permittivity of free space" (electricity)

$$\mu_0 = 4\pi \times 10^{-7} Tm/A$$

"Permeability of free space" (magnetism)

Now multiply them:

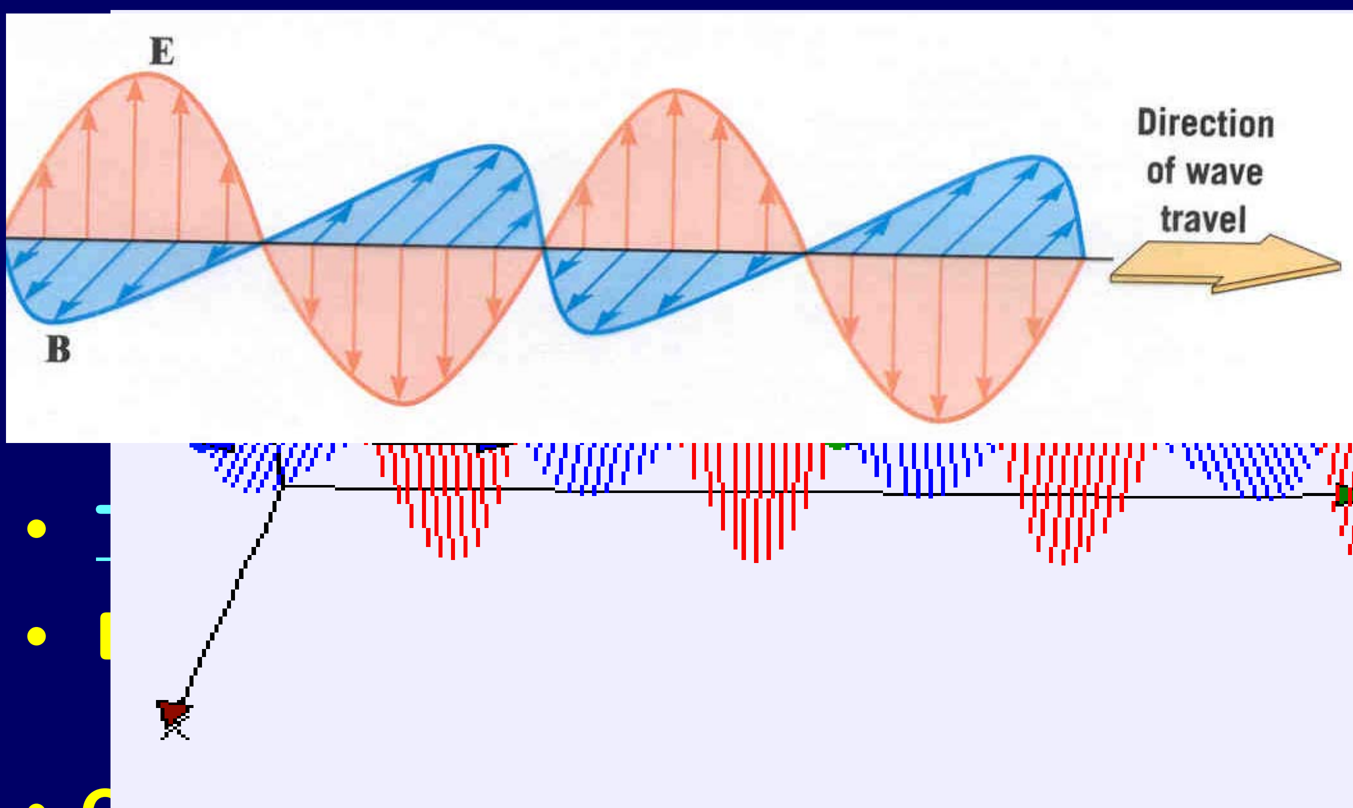
$$\varepsilon_0\mu_0 = 8.85 \times 10^{-12}\,\frac{\cancel{C}^2}{\cancel{N}m^2} \times 4\pi \times 10^{-7}\,\frac{\cancel{N}\cancel{m}}{\cancel{C}\cancel{m}/s\ \cancel{C}/s}$$

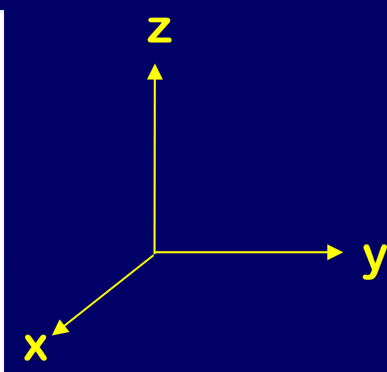
$$= 1.11 \times 10^{-17}\,\frac{s^2}{m^2}$$

Note:
1T = 1 N/Cm/s (from F = qvBsin(θ))
1A = 1 C/s (from I = ΔQ/Δt)

$$\boxed{\mathrm{c} = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = 3.0 \times 10^8 m/s}$$

Electromagnetic Waves





- al)
- times
- Can travel in empty space (sound waves can't!)
- **Speed of light in vacuum:** $v = c = 3 \times 10^8$ m/s
  (186,000 miles/second!)
- **Frequency:** $f = v/\lambda = c/\lambda$ **Period:** $T = 1/f$

CheckPoint 2.1-2.7

Which of the following are transverse waves?

- sound
- light
- radio
- X-ray
- microwave
- water waves
- “The Wave” (i.e. at football games)

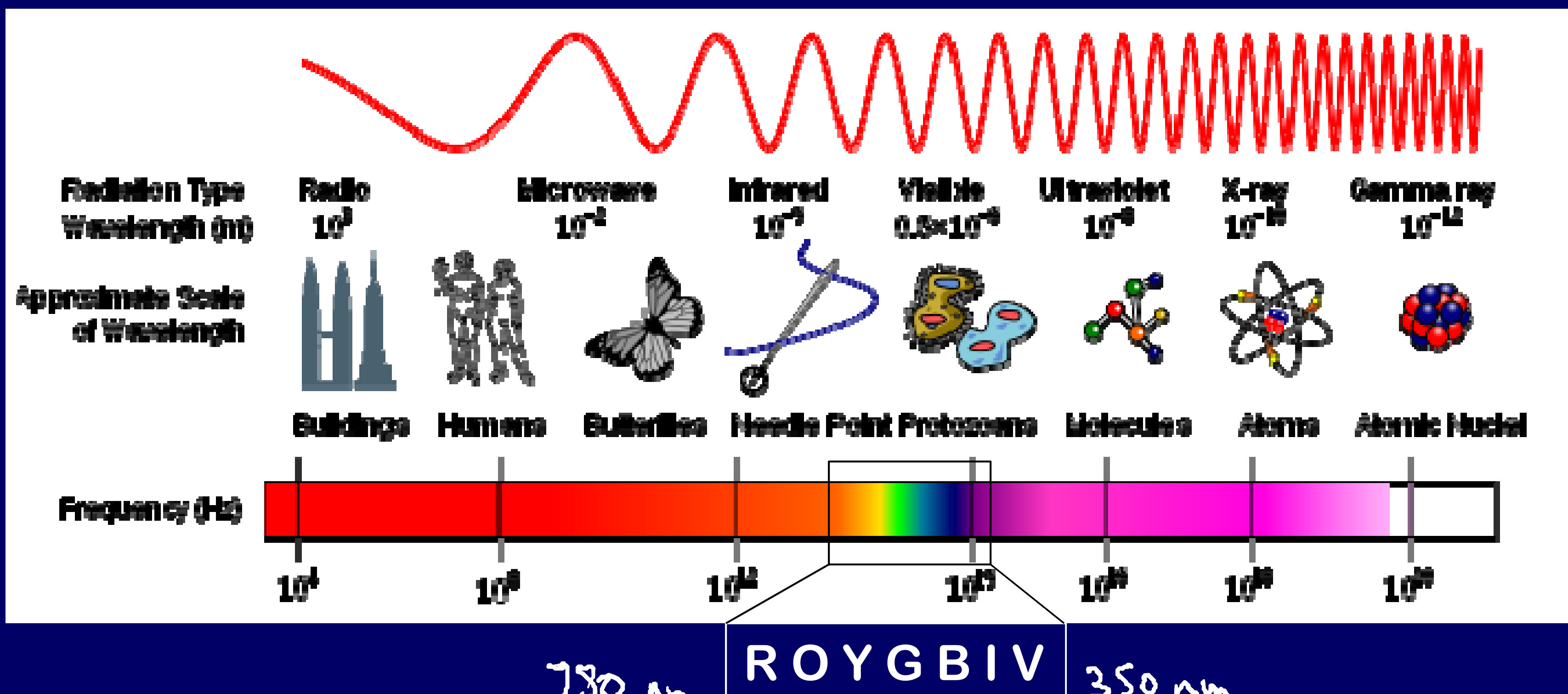
EM waves

All but sound!

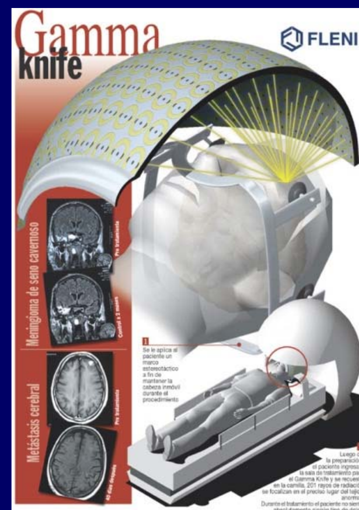
Electromagnetic Spectrum

- Light, Radio, TV, Microwaves, X-Rays are all electromagnetic waves!

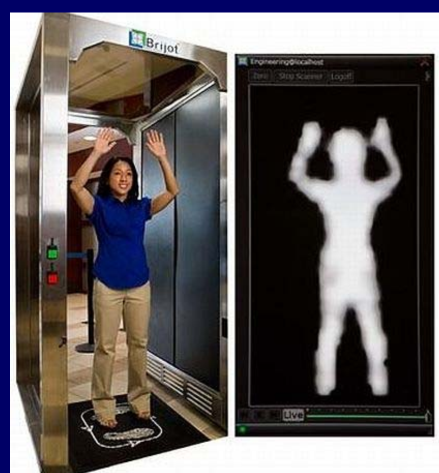
$$\boxed{c = \lambda f}$$



Regardless of wavelength, all EM waves have the same properties

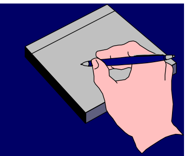


Carry energy (next lecture)



Can be used for imaging (lectures 16-19)

Example



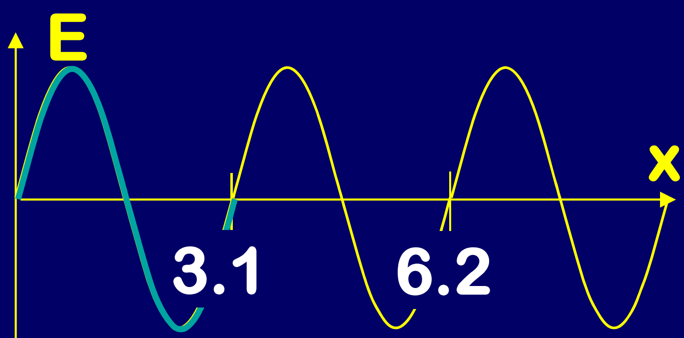
EM Waves Practice

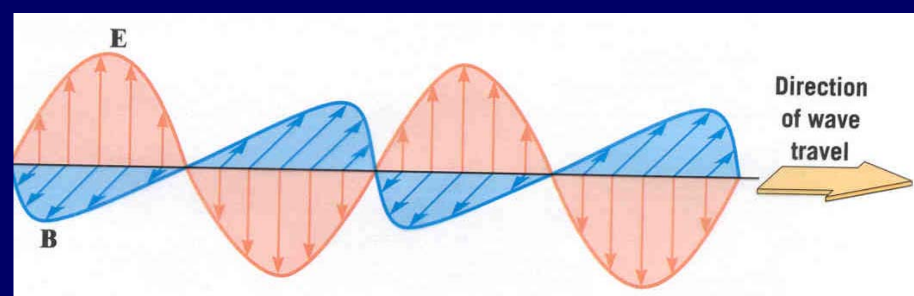
Shown below is the E field of an EM wave broadcast at 96.1 MHz and traveling to the right.

(1) What is the direction of the magnetic field?

Perpendicular to E, v: Into/out of the page

(2) Label the two tic marks on the x axis (in meters).

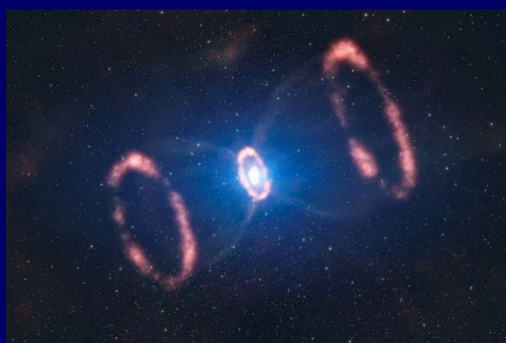




$$\lambda = \frac{v}{f} = \frac{3\times10^{8} m/s}{96.1\times10^{6}/s} = 3.1\text{m}$$

ACT

A distant star goes supernova and emits in the x-ray ($\lambda = 10$ nm) and infra-red ($\lambda = 3000$ nm) regions of the spectrum. Which light reaches the earth first?



$\lambda = 10\, nm$

$\lambda = 3000\, nm$

(A) x-ray

(B) infra-red

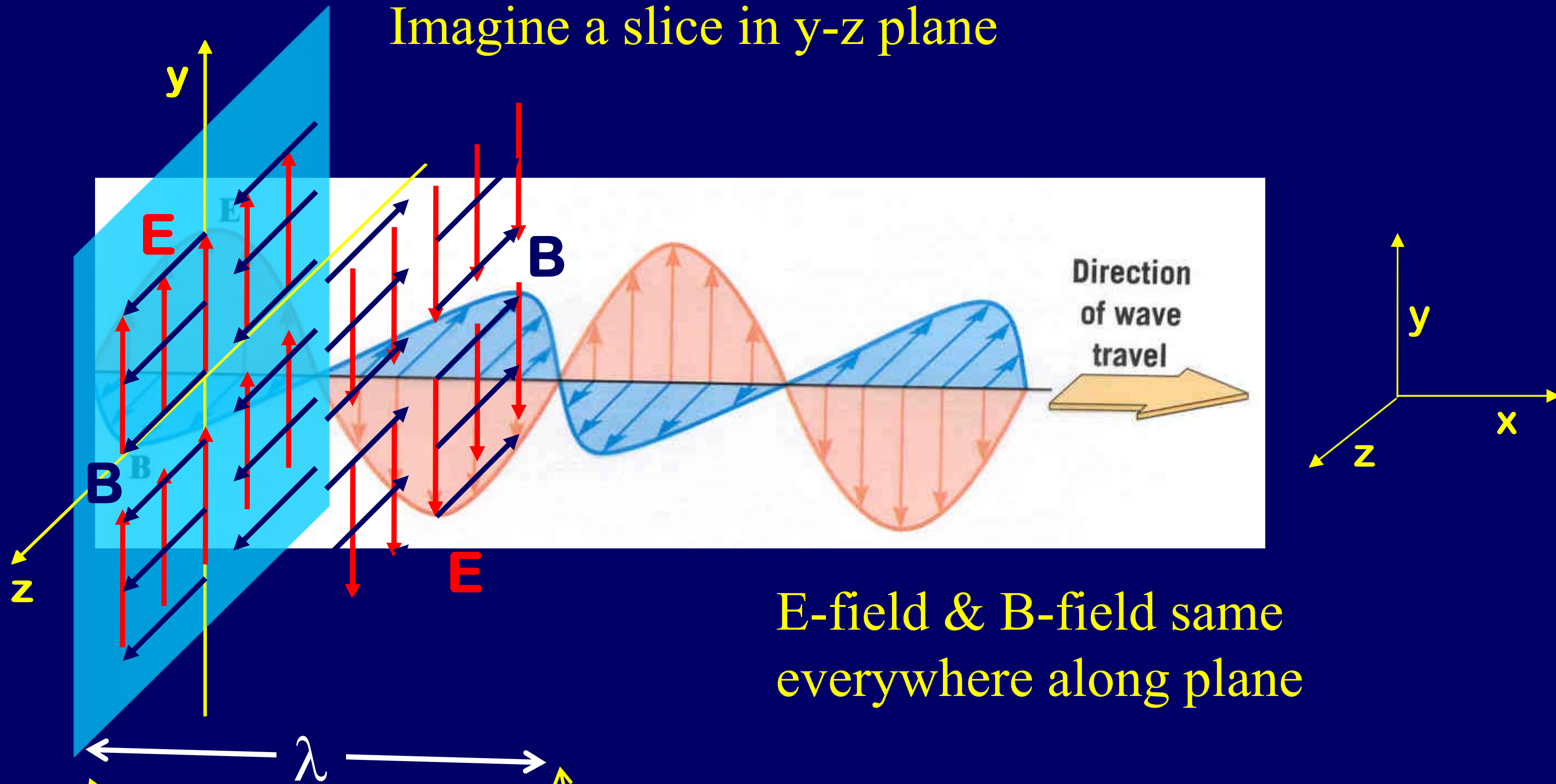
(C) Both arrive at the same time.

All travel at speed c

Representing EM wave: Wavefronts

This picture only represents EM wave along one line (x-axis)

Imagine a slice in y-z plane



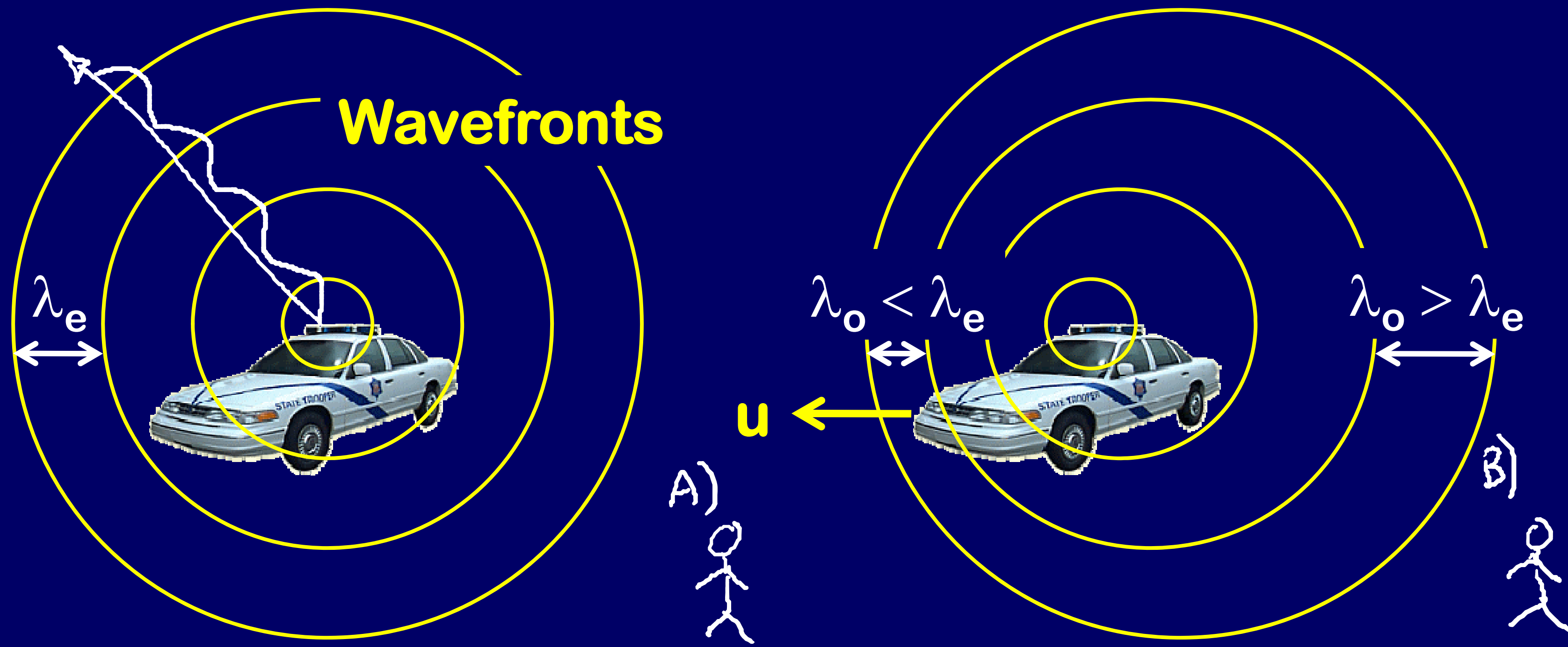
E-field & B-field same everywhere along plane

Wavefronts – surfaces at crests of EM wave

Doppler Effect

A police car emits light of wavelength λ_e

Now the car is moving to the left. Observed wavelength λ_o different!



A) Moving toward observer: $f_o = f_e(1 + u/c) > f_e$

B) Moving away from observer: $f_o = f_e(1 - u/c) < f_e$

$$\lambda = c/f$$

Only relative velocity matters:

$u = v_1 + v_2$ moving in opposite directions

$u = v_1 - v_2$ moving in same direction

ACT: Doppler Practice

V = 32 m/s **V = 50 m/s**

In the jeep, the frequency of the light from the troopers car will appear:

(A) Higher (more blue) (B) Lower (more red)

Cars are getting closer together: $f_o = f_e (1 + u/c)$

What value should you use for u in the equation?

(A) 32 (B) 50 (C) 50+32 (D) 50-32

Cars are moving in same directions: $u = v_1 - v_2$

Doppler velocimetry

Wavelength of light reflected from moving object shifted because of Doppler effect

Used to study bio-acousto-mechanics, exhaust from rockets, blood flow, fuel injection …

See you Wednesday!