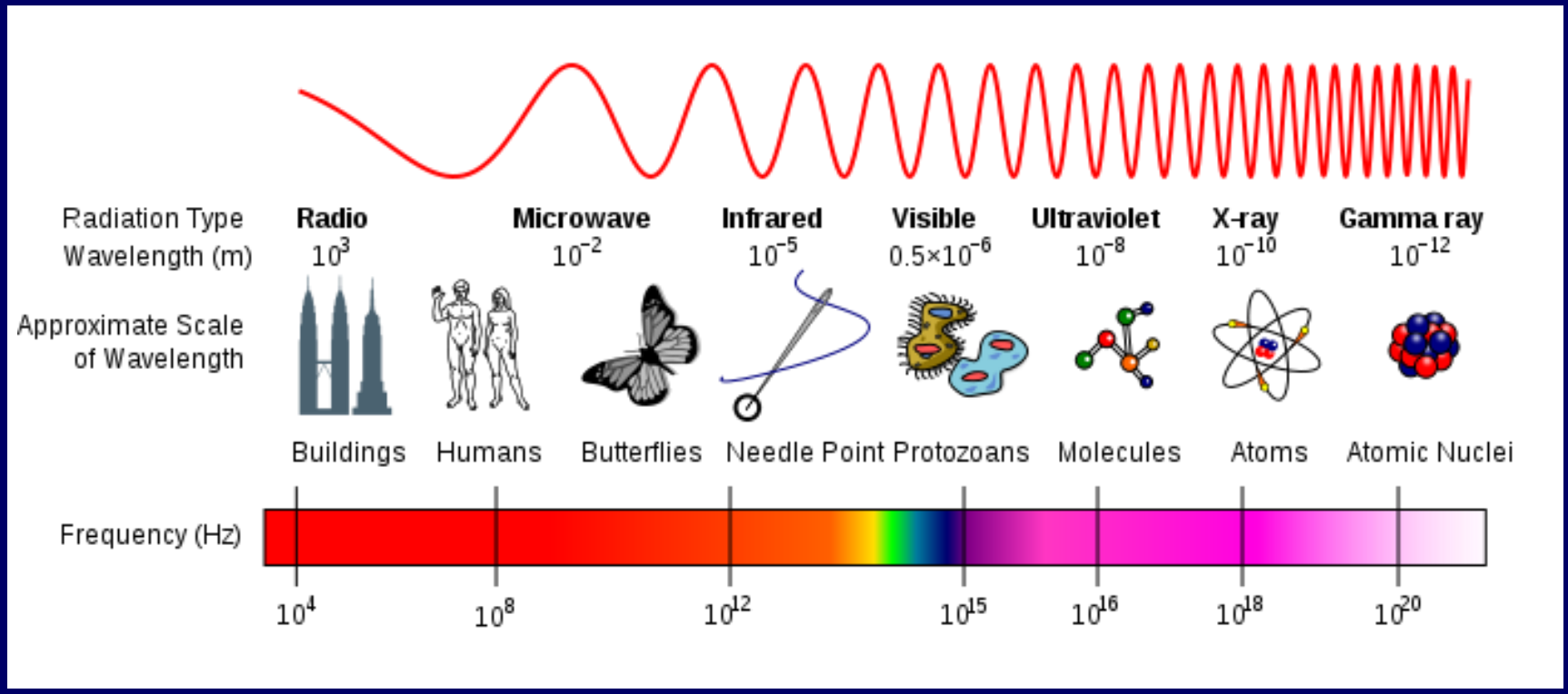
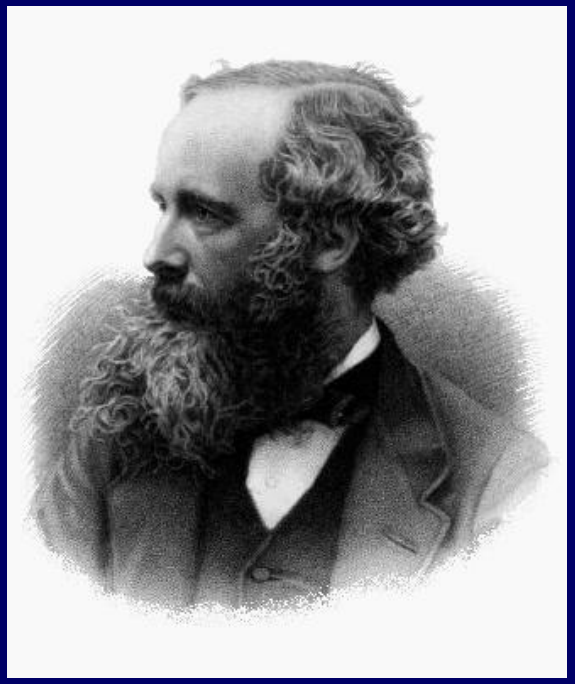
Physics 102: Lecture 14

Electromagnetic Waves



James Clerk Maxwell

(1831-1879)



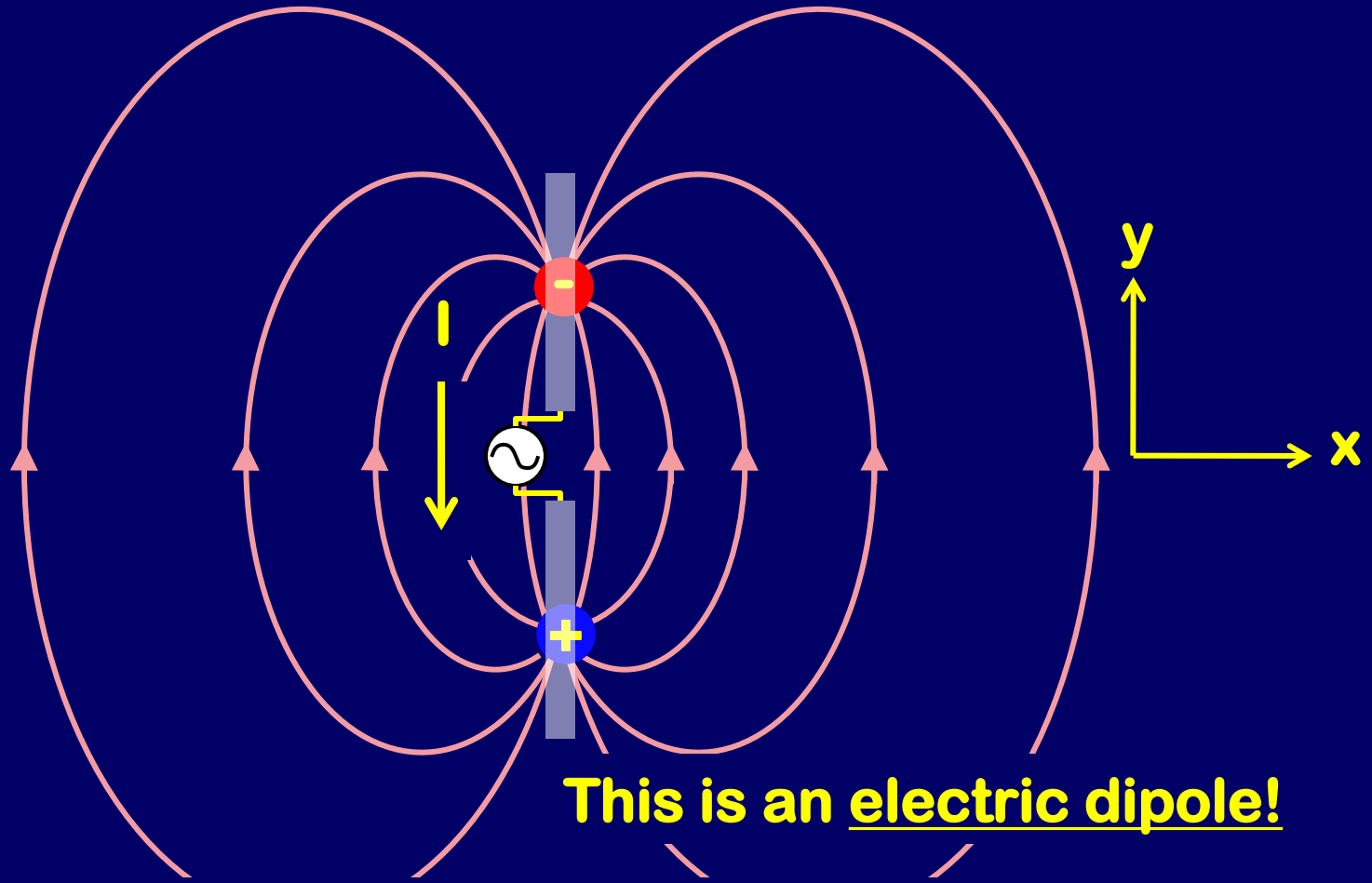
4 laws unify electricity & magnetism:

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!

Radio antenna

Generator creates oscillating current up and down metal rods



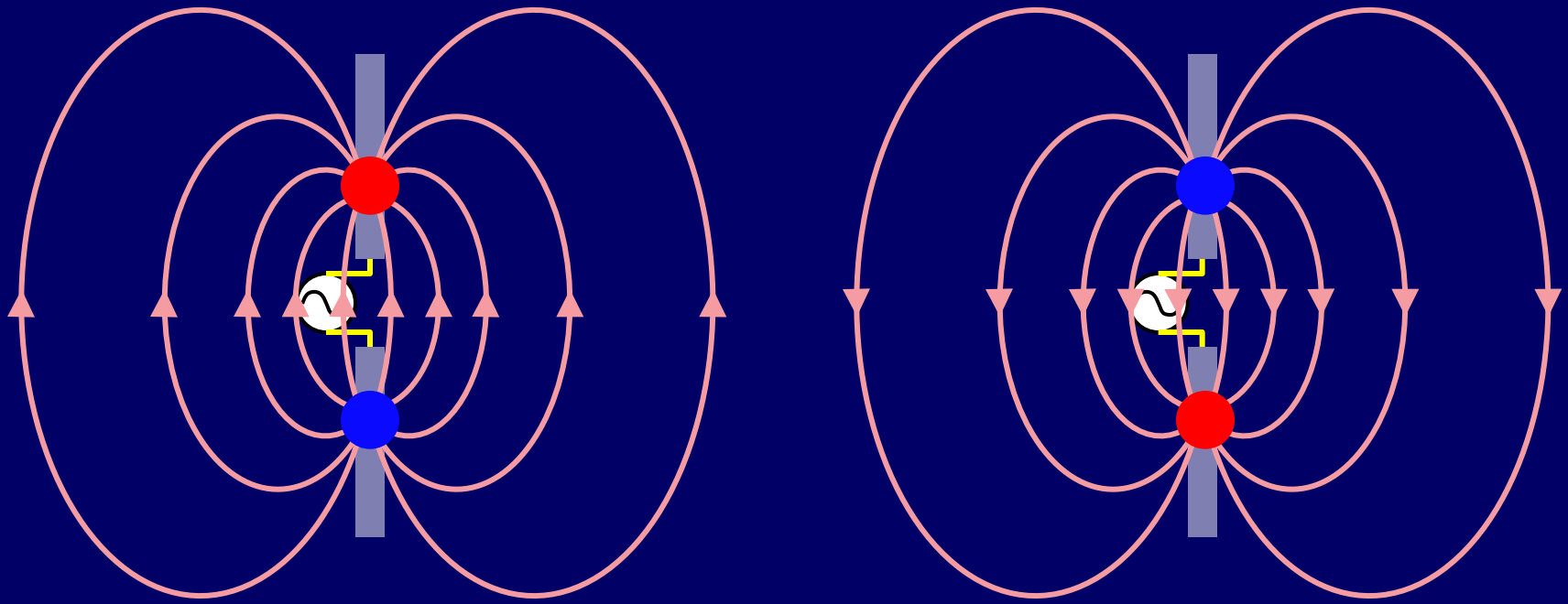
This is an electric dipole!

This is called an electric dipole antenna

Oscillating E field

Electric dipole antenna creates an oscillating electric field

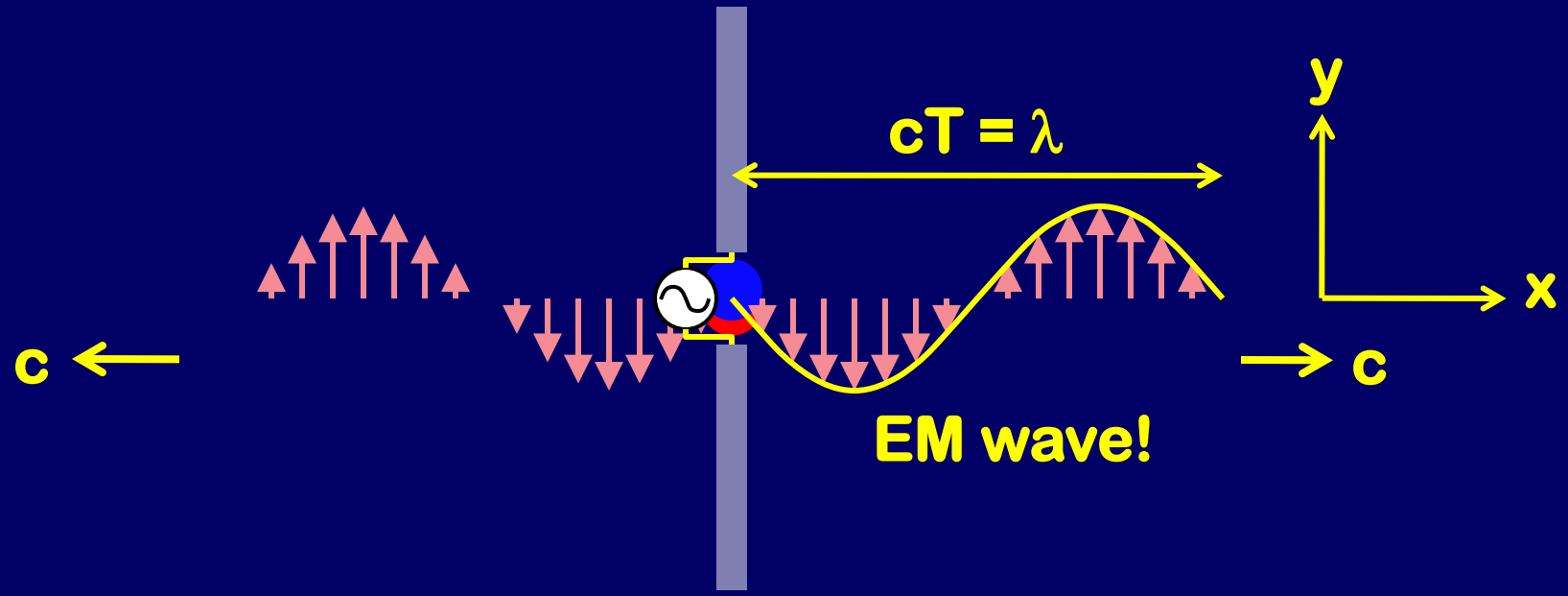
In which direction does the E-field point at this time? ... and now?



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

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

$$c = \lambda f$$

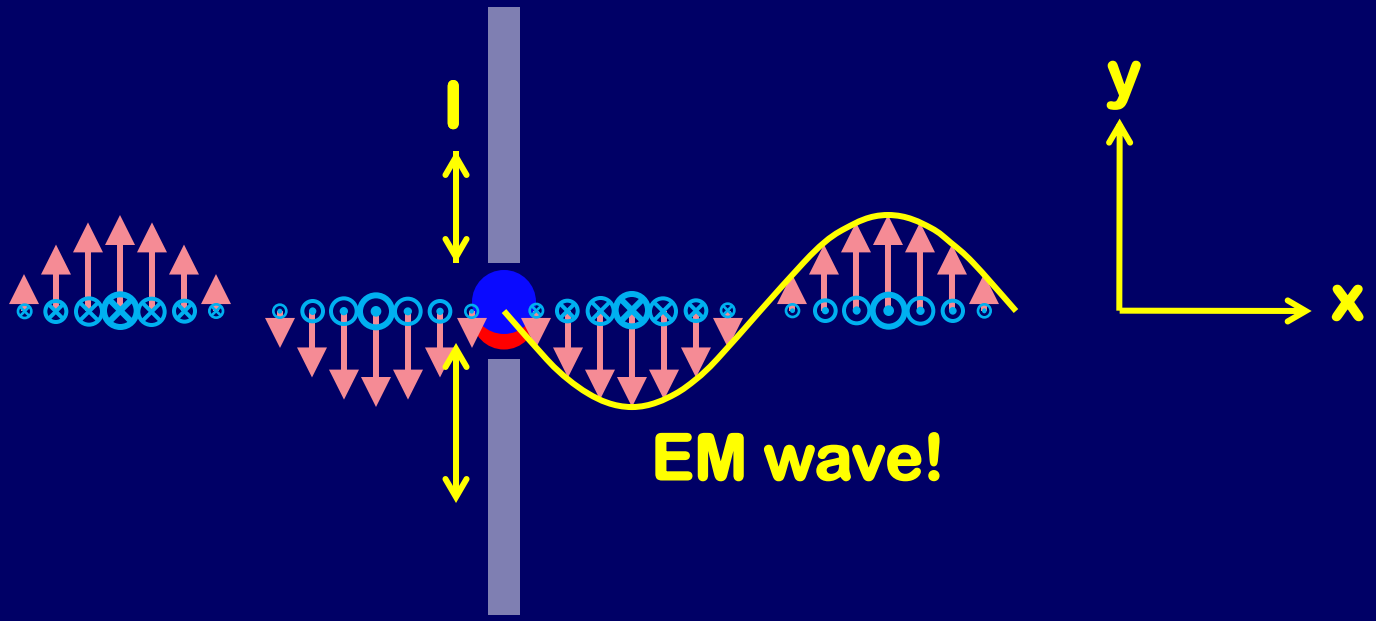
ACT: EM Waves

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 and B fields propagate together as EM waves

$$c = \lambda f$$

Speed of EM wave in vacuum

Recall fundamental constants of electricity and magnetism:

$$\varepsilon_0 = 8.85 \times 10^{-12} C^2/Nm^2 \qquad \mu_0 = 4\pi \times 10^{-7} Tm/A$$

"Permittivity of free space" (electricity)

"Permeability of free space" (magnetism)

Now multiply them:

$$\varepsilon_0\mu_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2} \times 4\pi \times 10^{-7} \frac{Nm}{Cm/s\ C/s}$$

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

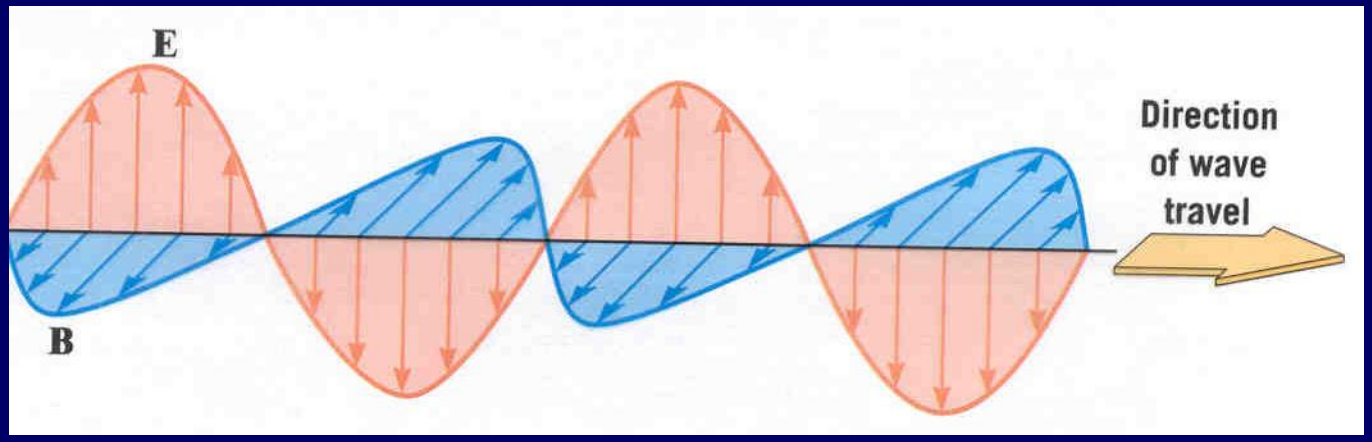
Note:

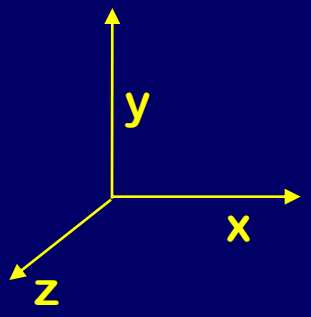
1T = 1 N/Cm/s (from F = qvBsin(θ))

1A = 1 C/s (from I = ΔQ/Δt)

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

Electromagnetic Waves





- **Transverse** (vs. sound waves – longitudinal)
- **E perpendicular to B and always in phase**
  E & B increase and decrease at same 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

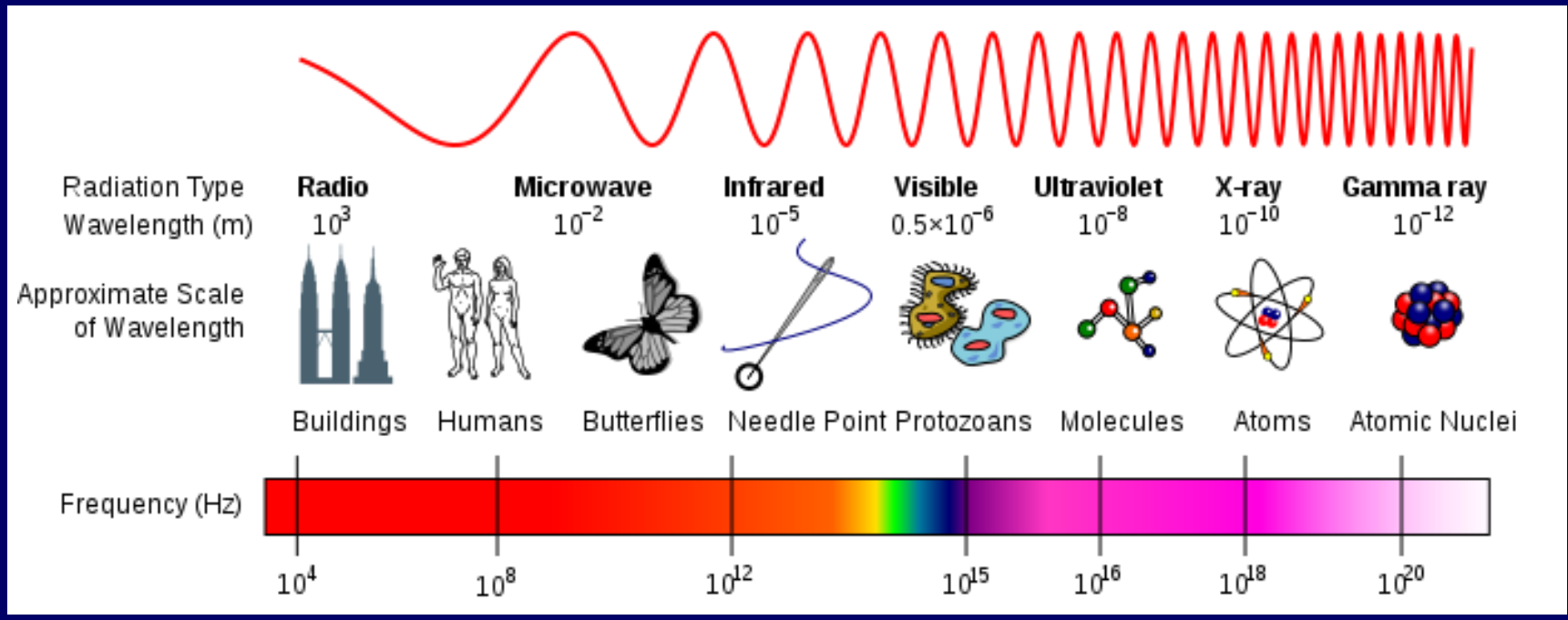
Which of the following are transverse waves?

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

Electromagnetic Spectrum

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

$$c = \lambda f$$



ROYGBIV

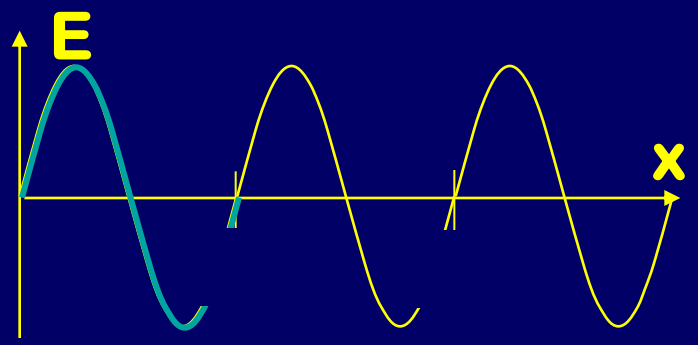
EM Waves Practice

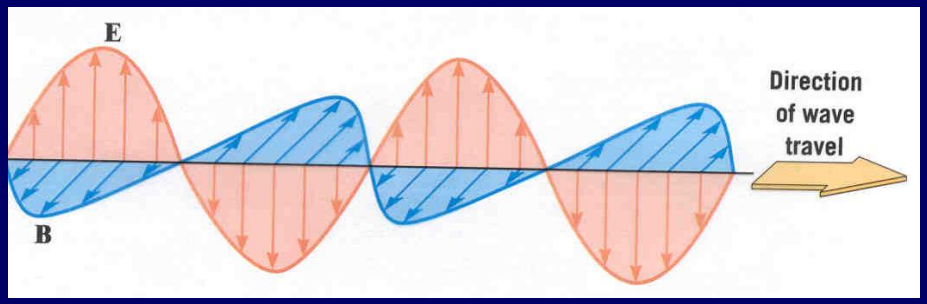
Shown below is the E field of an EM wave broadcast at 96.1 MHz and traveling to the right.

(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).



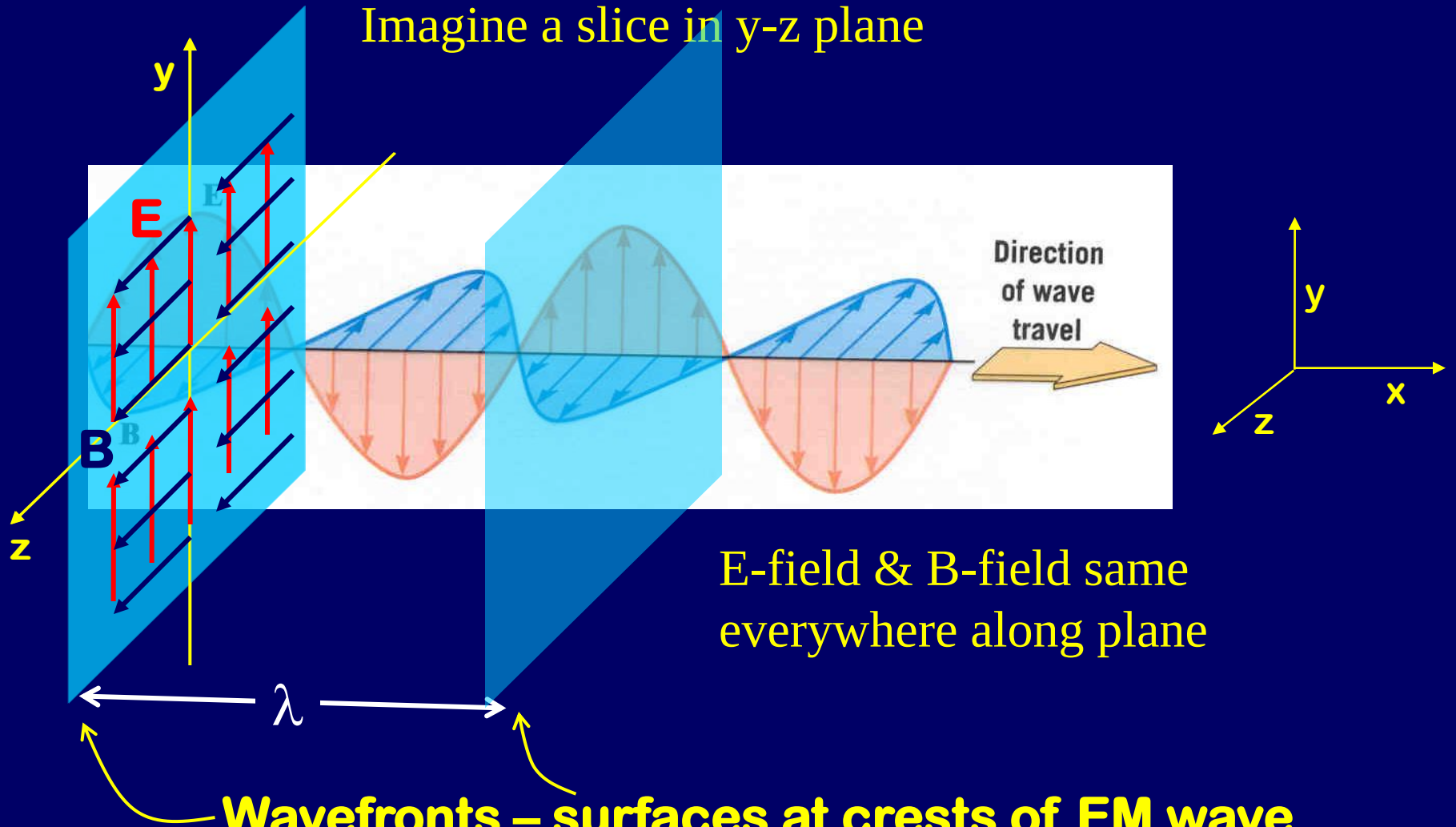


$$\lambda = \frac{v}{f} = \frac{3 \times 10^8\, m/s}{96.1 \times 10^6/s} = 3.1\boldsymbol{m}$$

Representing EM wave: Wavefronts

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

Imagine a slice in y-z plane

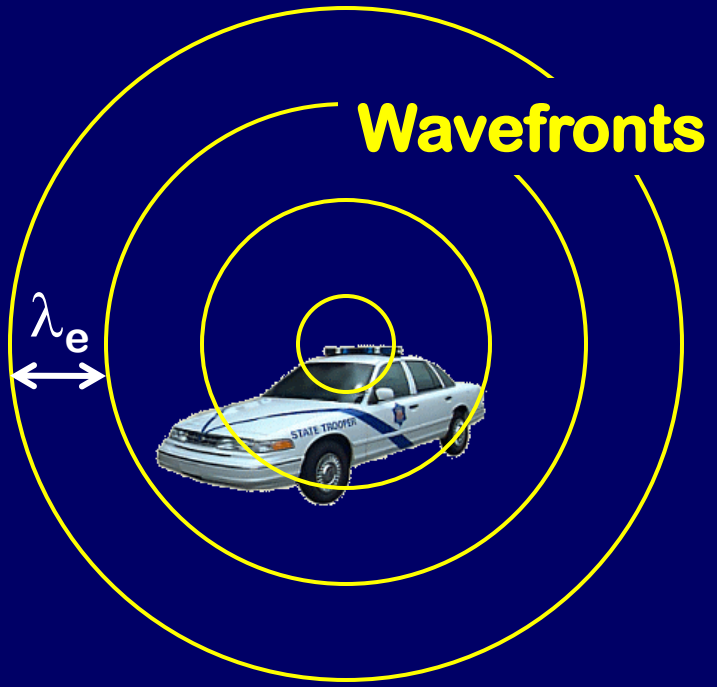


E-field & B-field same everywhere along plane

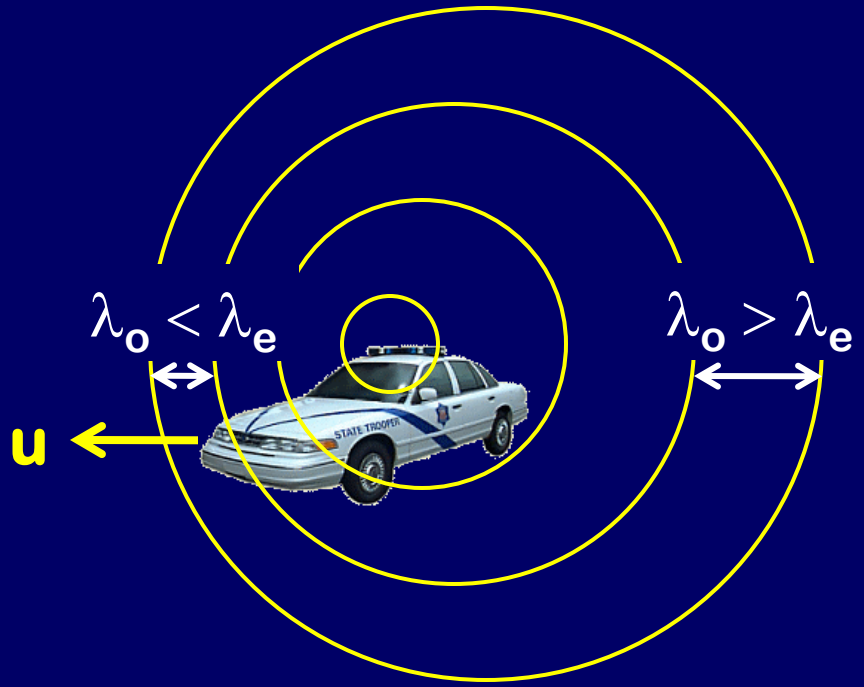
Wavefronts – surfaces at crests of EM wave

Doppler Effect

A police car emits light of wavelength λ_e



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



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

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

$\lambda = c/f$

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)

What value should you use for u in the Doppler equation?

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