Class 32: Outline

Hour 1:

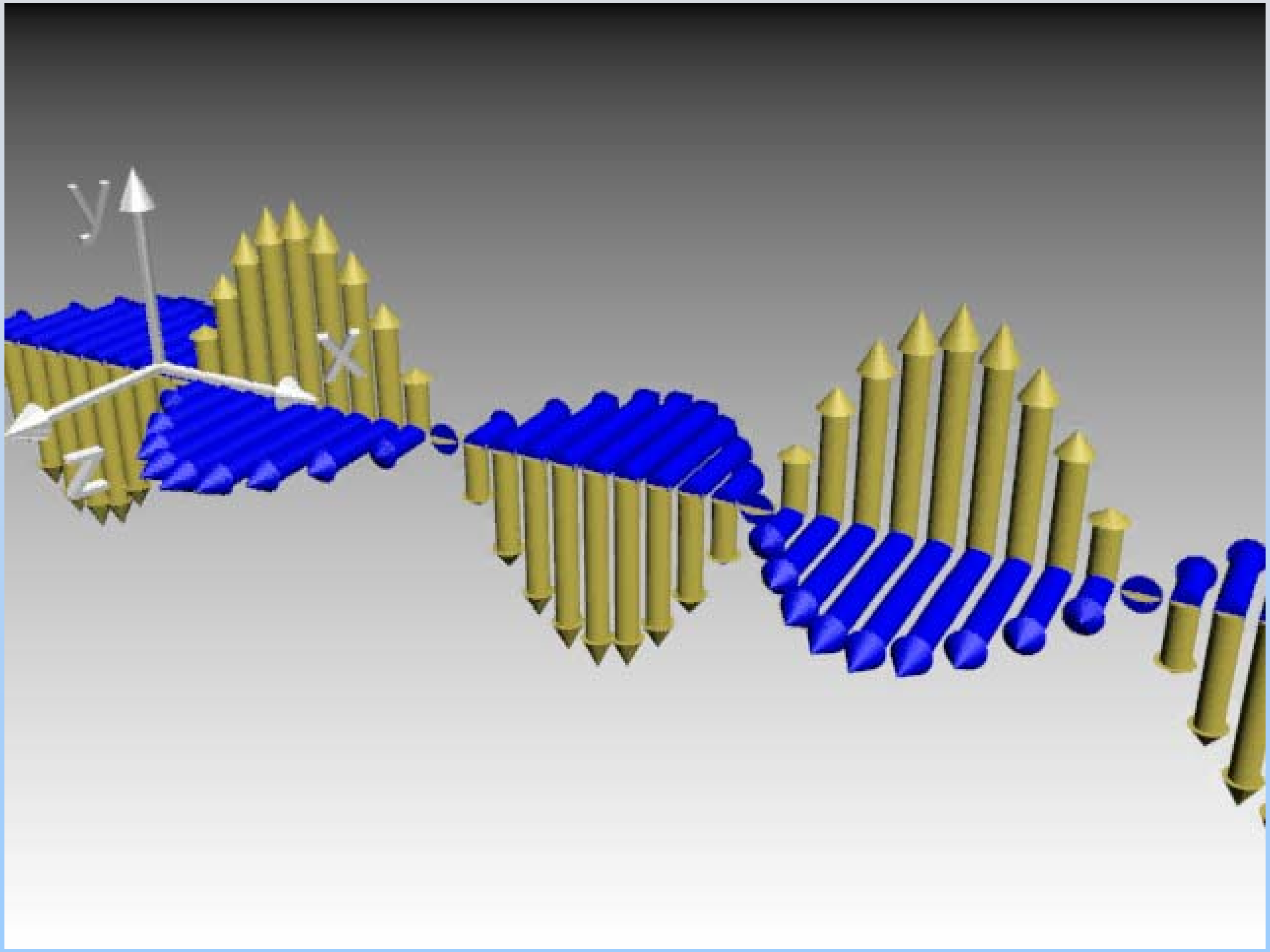
- Generating Electromagnetic Waves
  - Plane EM Waves
  - Electric Dipole EM Waves

Hour 2:

- Experiment 12: Microwaves
- Review Exam 3 Results

Recall:
Electromagnetic Radiation

Recall Electromagnetic Radiation: Plane Waves

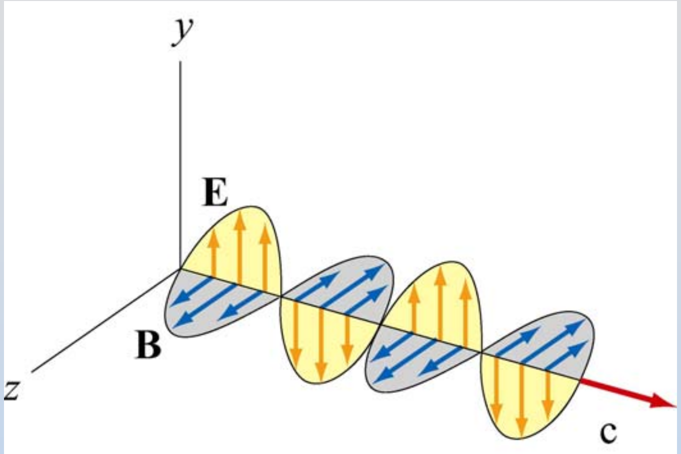


http://ocw.mit.edu/ans7870/8/8.02T/f04/visualizations/light/07-EBlight/07-EB_Light_320.html

Properties of EM Waves

Travel (through vacuum) with speed of light

$$v = c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3\times10^8 \frac{m}{s}$$



At every point in the wave and any instant of time, E and B are in phase with one another, with

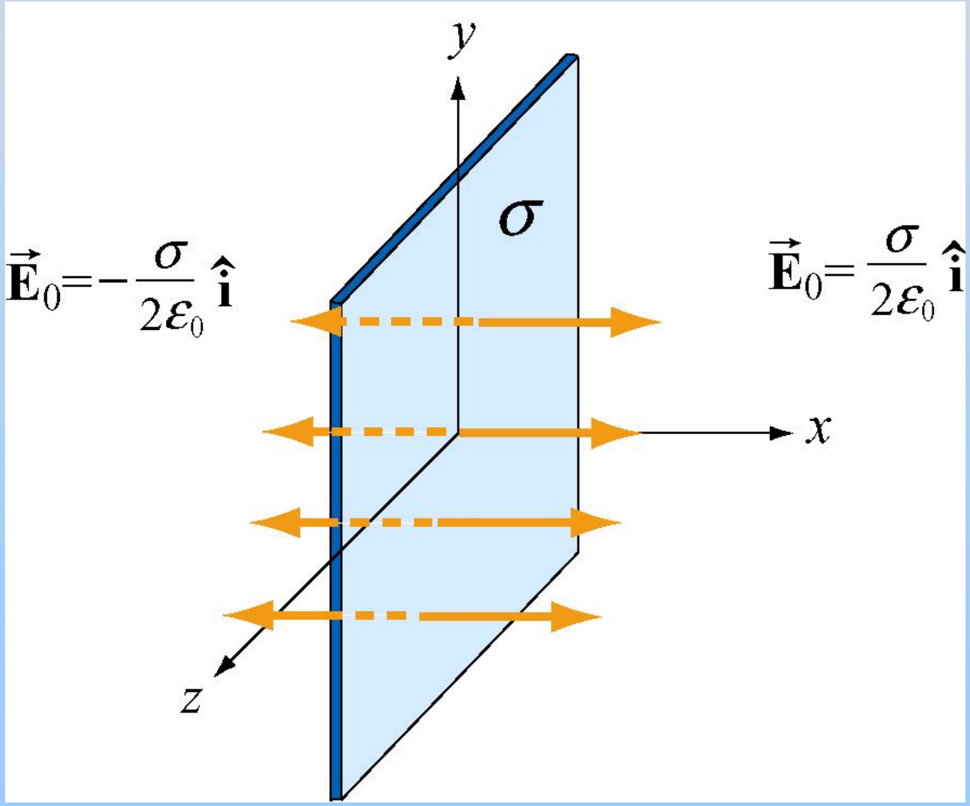
$$\frac{E}{B} = \frac{E_0}{B_0} = c$$

E and B fields perpendicular to one another, and to the direction of propagation (they are **transverse**):

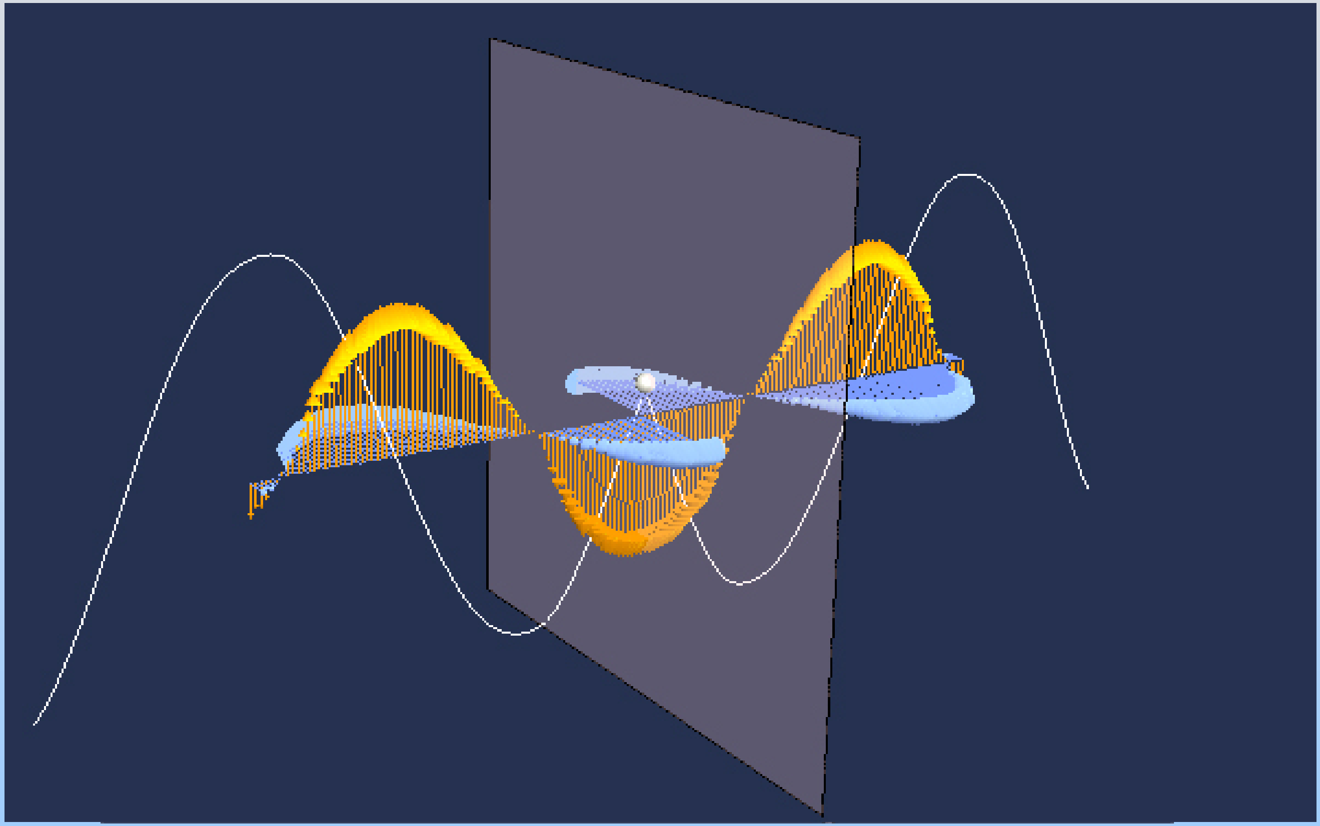
$$\text{Direction of propagation} = \text{Direction of } \vec{\mathbf{E}} \times \vec{\mathbf{B}}$$

Generating Plane Electromagnetic Radiation

Shake A Sheet of Charge Up and Down



Java Applet for Generation of Plane Waves



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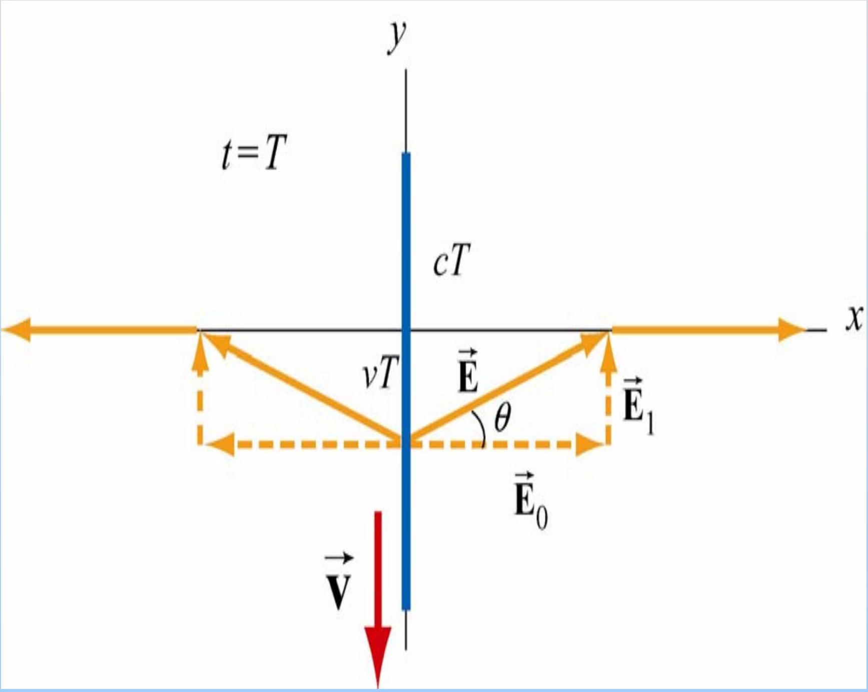
First Pull The Sheet of Charge Down At Speed v



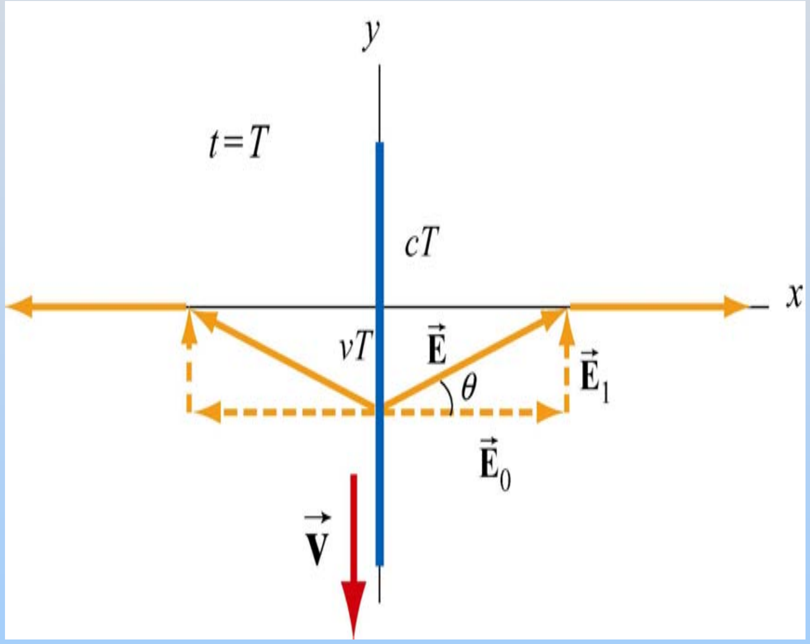
$$\tan\theta = \frac{E_1}{E_0} = \frac{vT}{cT} = \frac{v}{c}$$

$$\vec{\mathbf{E}}_1 = \left(\frac{v}{c}E_0\right)\hat{\mathbf{j}} = \left(\frac{v\sigma}{2\varepsilon_0 c}\right)\hat{\mathbf{j}}$$

When you pull down, there is a back force up!

Rate of Work Done?

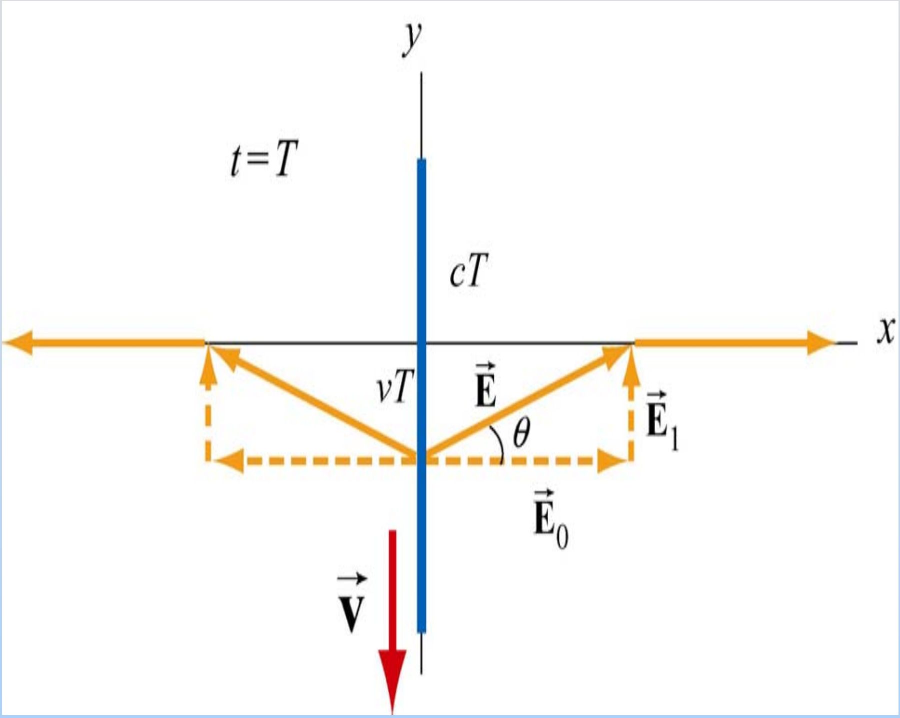
$$d\vec{\mathbf{F}}_e = dq\vec{\mathbf{E}}_1 = (\sigma dA)\left(\frac{v\sigma}{2\varepsilon_0 c}\right)\hat{\mathbf{j}} = \left(\frac{v\sigma^2 dA}{2\varepsilon_0 c}\right)\hat{\mathbf{j}}$$

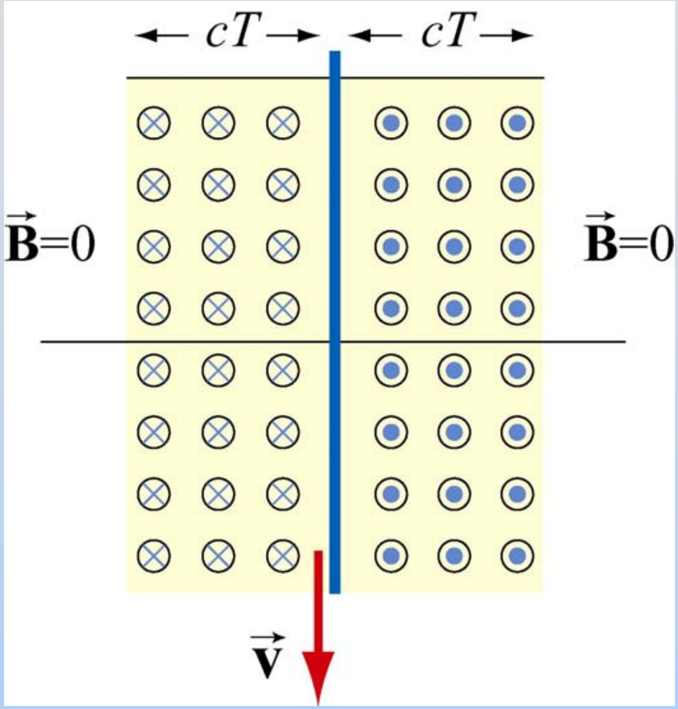


$$d\vec{\mathbf{F}}_{\text{ext}} = -d\vec{\mathbf{F}}_e = -\left(\frac{v\sigma^2 dA}{2\varepsilon_0 c}\right)\hat{\mathbf{j}}$$

$$\frac{d^2W_{\text{ext}}}{dA\,dt} = \frac{d\vec{\mathbf{F}}_{\text{ext}}}{dA}\cdot\frac{d\vec{\mathbf{s}}}{dt} = \left(-\frac{v\sigma^2}{2\varepsilon_0 c}\hat{\mathbf{j}}\right)\cdot\left(-v\,\hat{\mathbf{j}}\right) = \frac{v^2\sigma^2}{2\varepsilon_0 c}$$

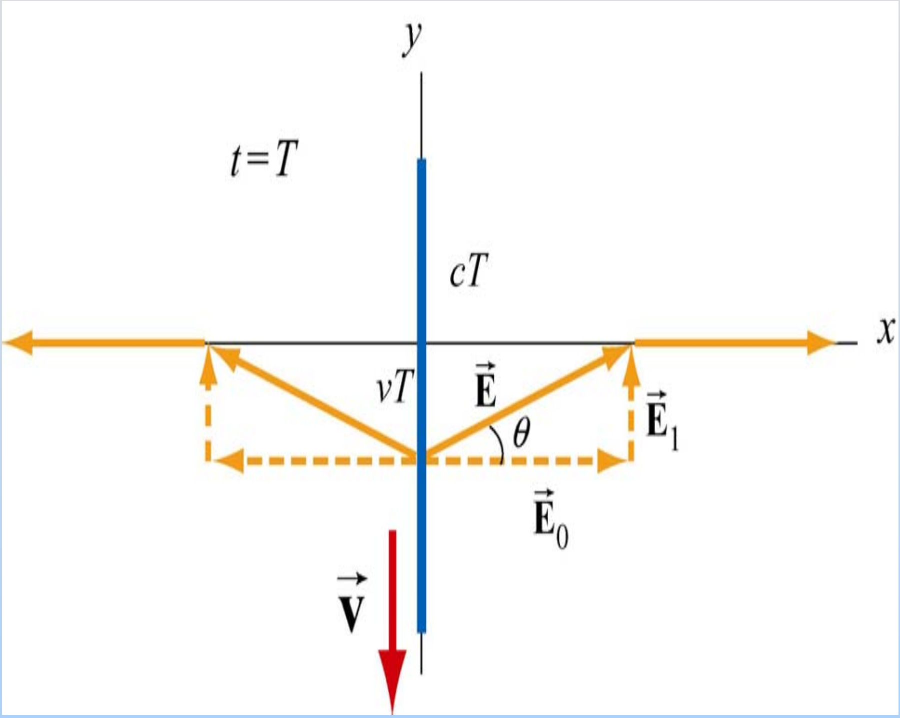
What About B Field?

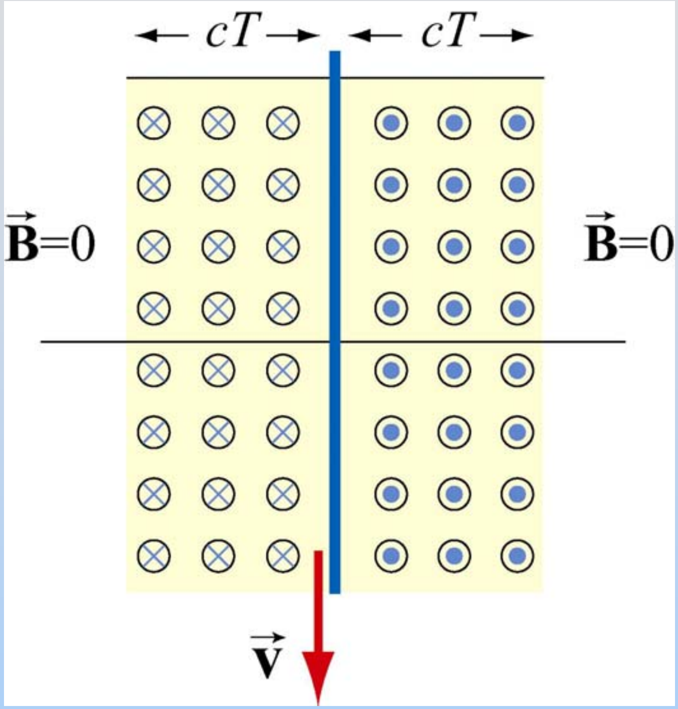




$$\vec{\mathbf{E}}_1 = \left(\frac{v}{c}E_0\right)\hat{\mathbf{j}} = \left(\frac{v\sigma}{2\varepsilon_0 c}\right)\hat{\mathbf{j}} \qquad \vec{\mathbf{B}}_1 = \begin{cases} +(\mu_0\sigma v/2)\hat{\mathbf{k}}, & x > 0 \\ -(\mu_0\sigma v/2)\hat{\mathbf{k}}, & x < 0 \end{cases}$$

Rate Energy Carried Away?

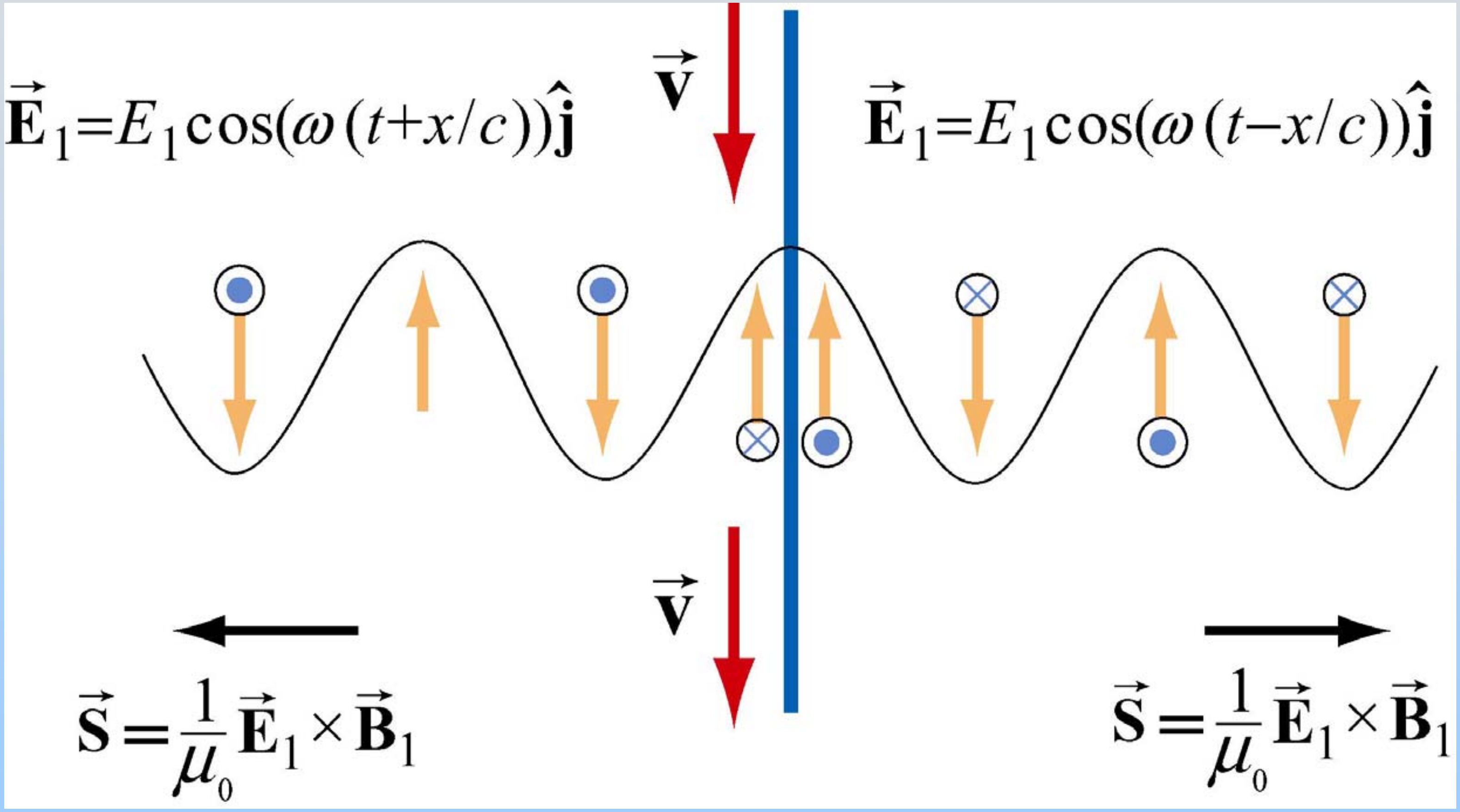




$$\vec{S} = \frac{1}{\mu_0}\vec{E}_1 \times \vec{B}_1 = \frac{1}{\mu_0}\left(\frac{v\sigma}{2\varepsilon_0 c}\hat{j}\right)\times\left(\frac{\mu_0 \sigma v}{2}\hat{k}\right) = \left(\frac{v^2\sigma^2}{4\varepsilon_0 c}\right)\hat{i}$$

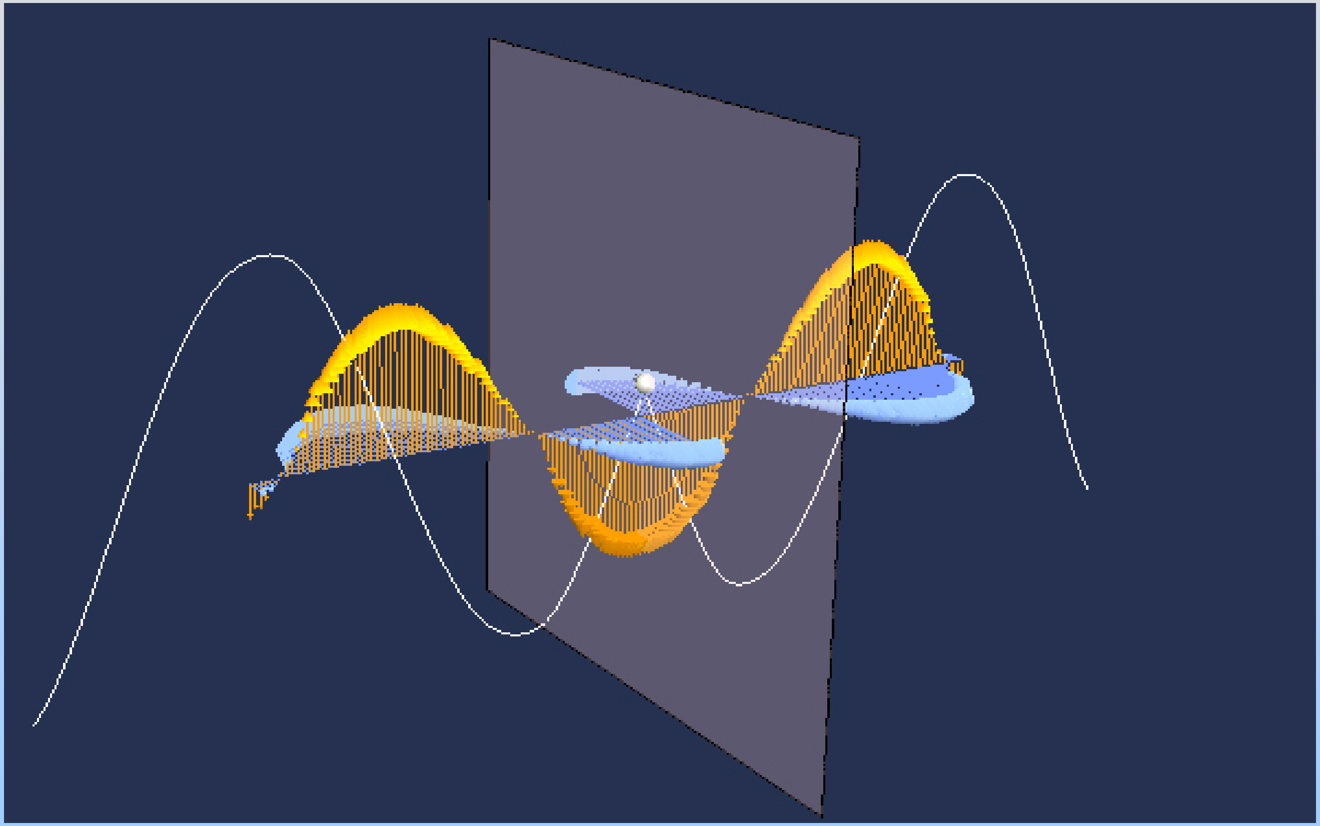
Energy radiated to left and right is exactly equal to the rate of work required to move sheet down

To generate plane wave, move sheet up and down sinusoidally



The work you do in moving the sheet is carried away as electromagnetic radiation, with 100% efficiency.

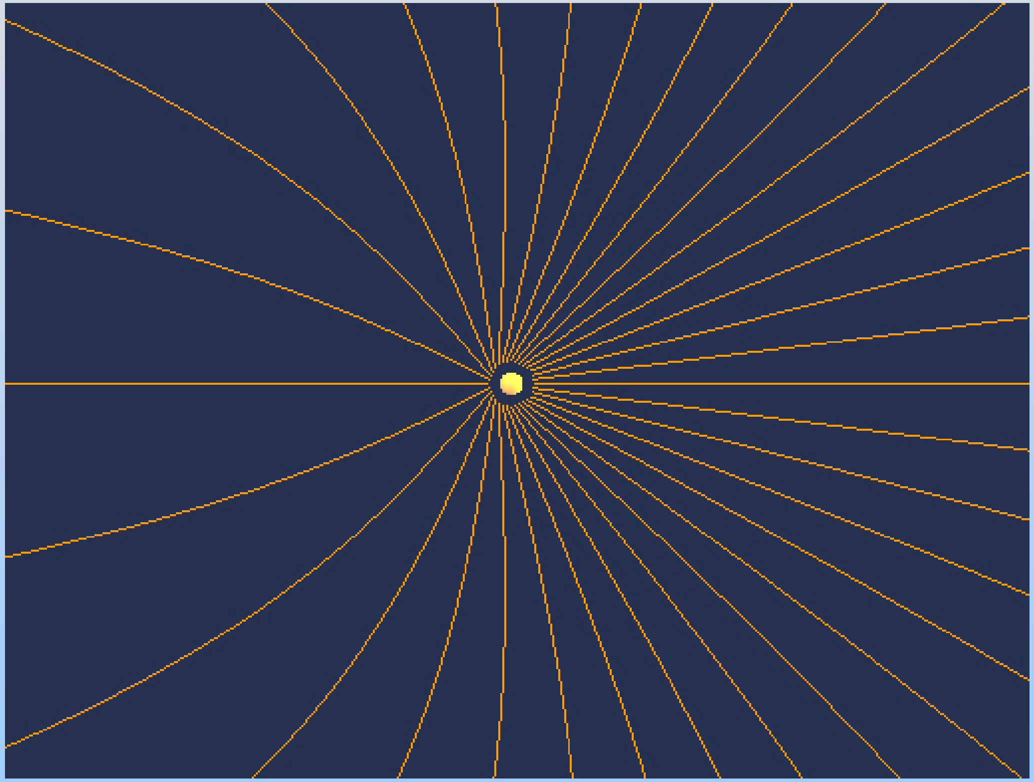
Generating Plane Wave Applet



PRS Question:
Generating A Plane Wave

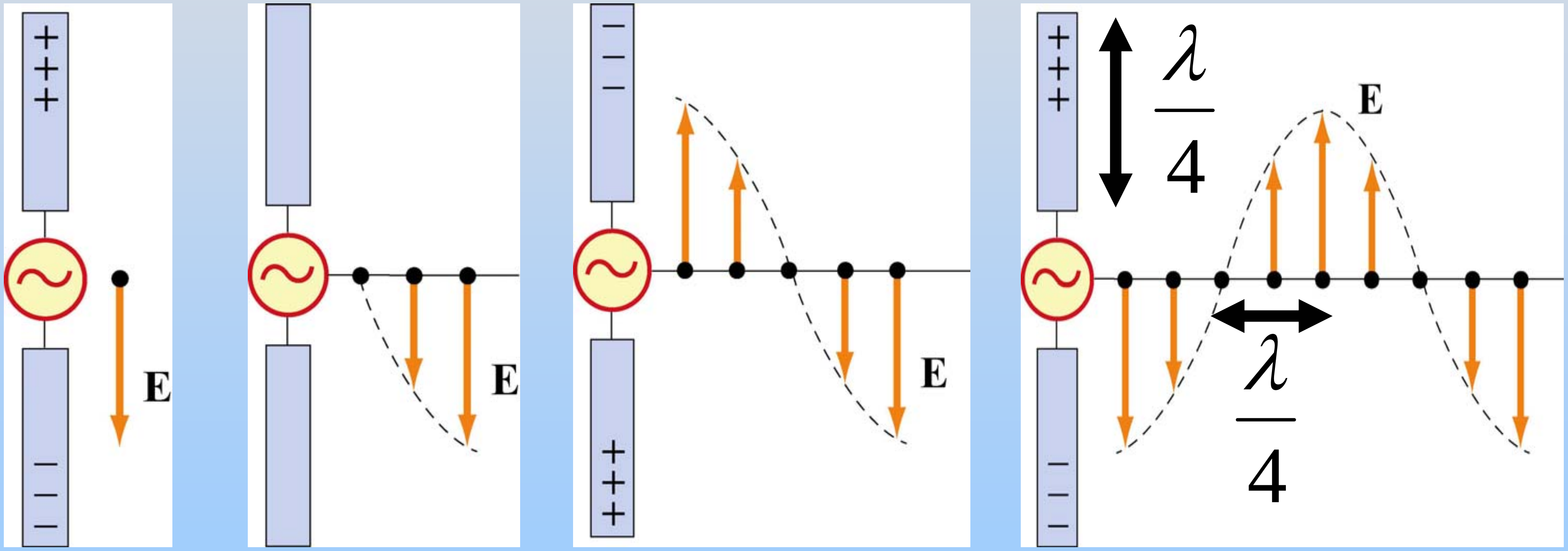
Generating Electric Dipole Electromagnetic Waves

Generating Electric Dipole Radiation Applet



Quarter-Wavelength Antenna

Accelerated charges are the source of EM waves.
Most common example: Electric Dipole Radiation.



t = 0 t = T/4 t = T/2 t = T

Why are Radio Towers Tall?

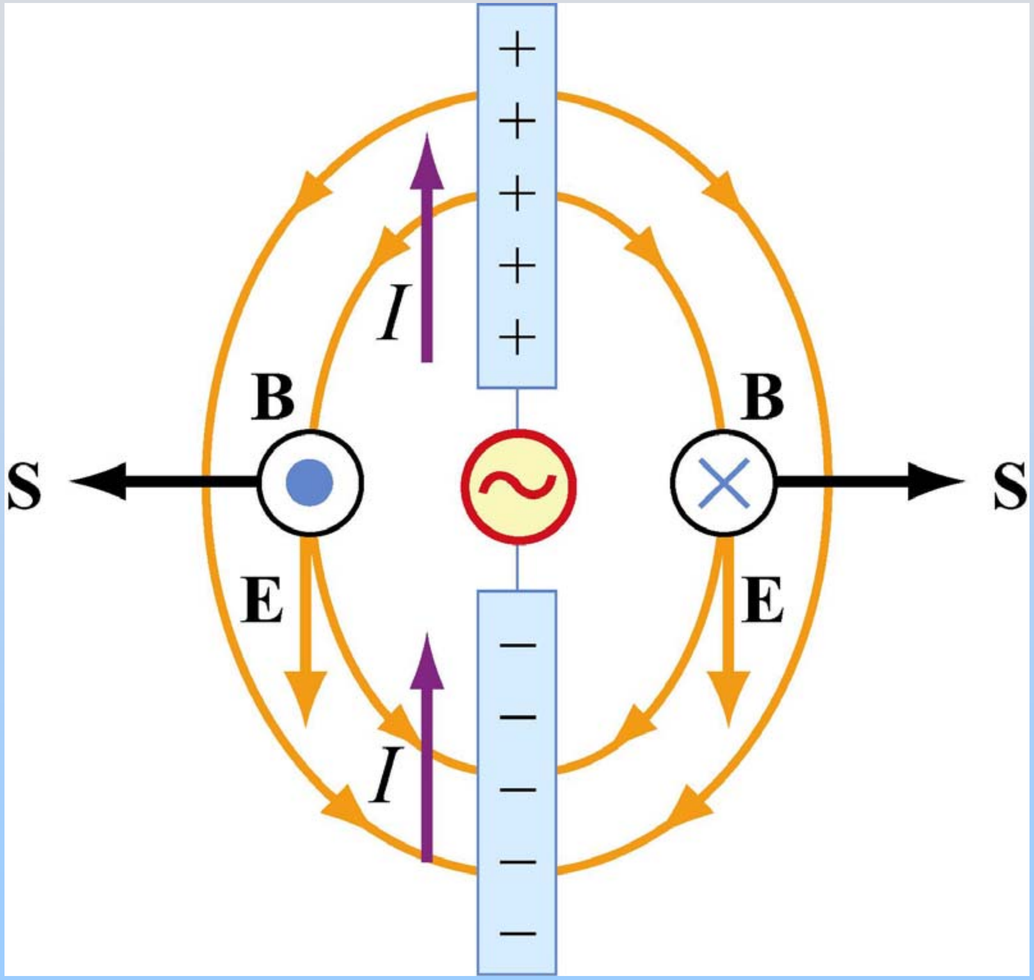
AM Radio stations have frequencies 535 – 1605 kHz. WLW 700 Cincinnati is at 700 kHz.

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}\,\text{m/s}}{700\times10^{3}\,\text{Hz}} = 429\,\text{m}$$

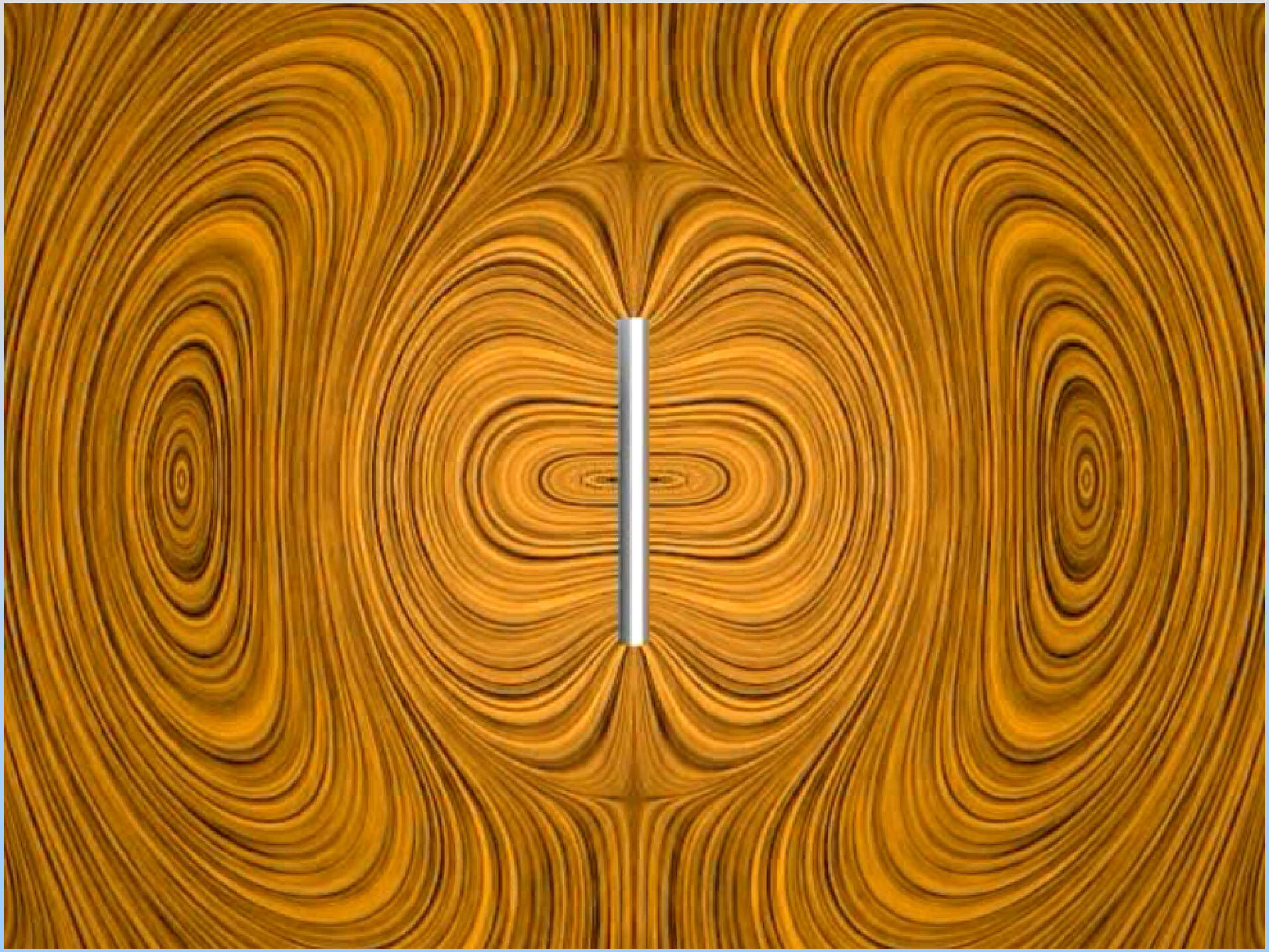
$$\lambda / 4 \approx 107\,\text{m} \approx 350\,\text{ft}$$

The WLW 700 Cincinnati Tower is 747 ft tall

Quarter-Wavelength Antenna

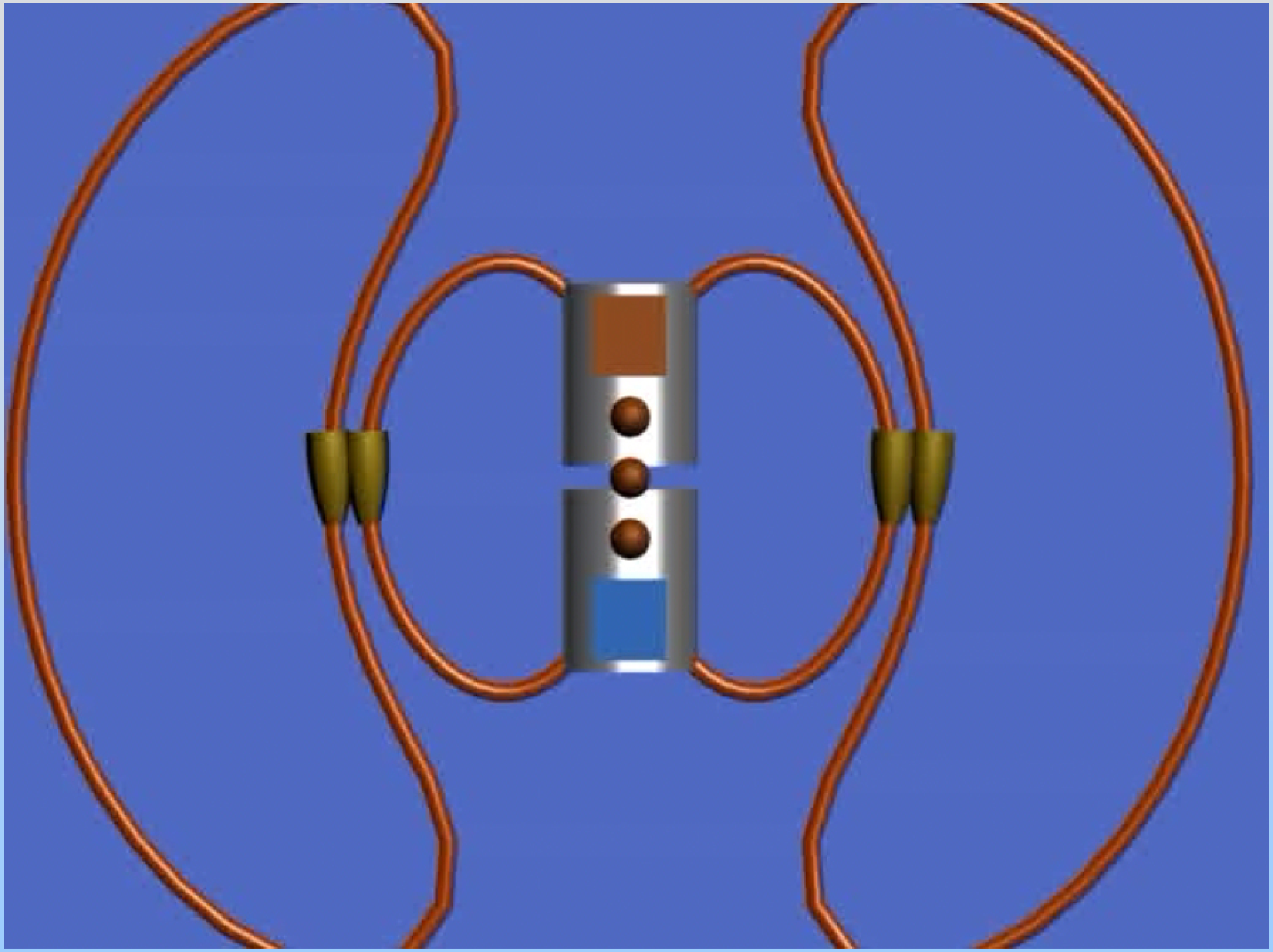


Quarter-Wavelength Antenna



http://ocw.mit.edu/ans7870/8/8.02T/f04/visualizations/light/04-QuarterWaveAntenna/04-MicrowaveDLICS_320.html

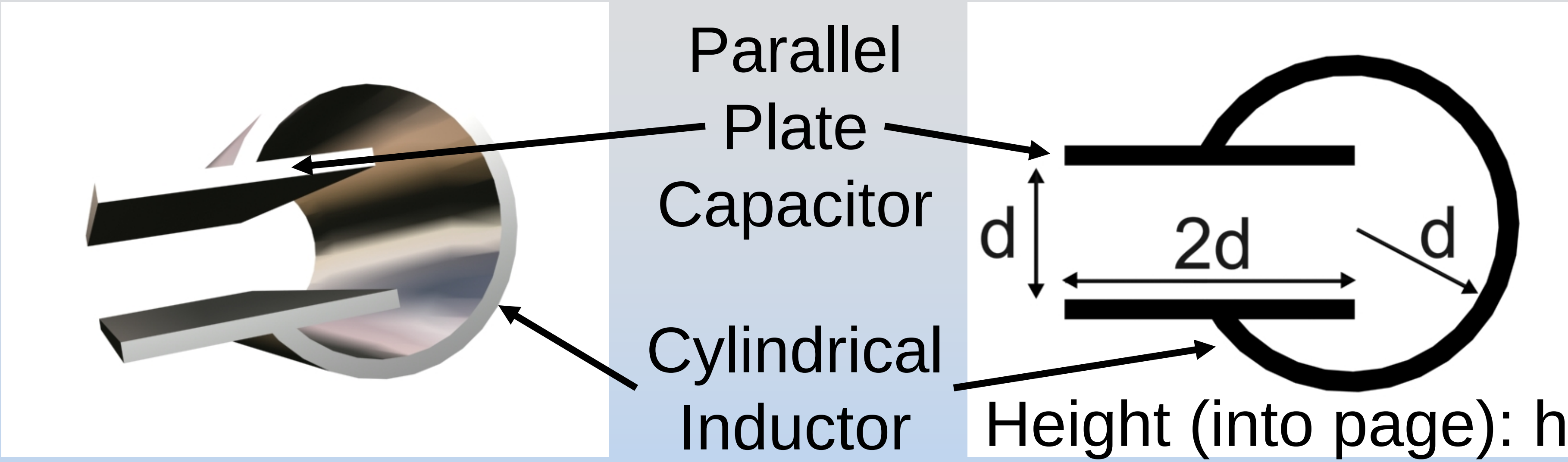
Spark Gap Transmitter



Spark Gap Generator: An LC Oscillator

First: Example of “lumped” LC Oscillator (Capacitor & Inductor together as one)

Group Problem: Lumped LC Circuit



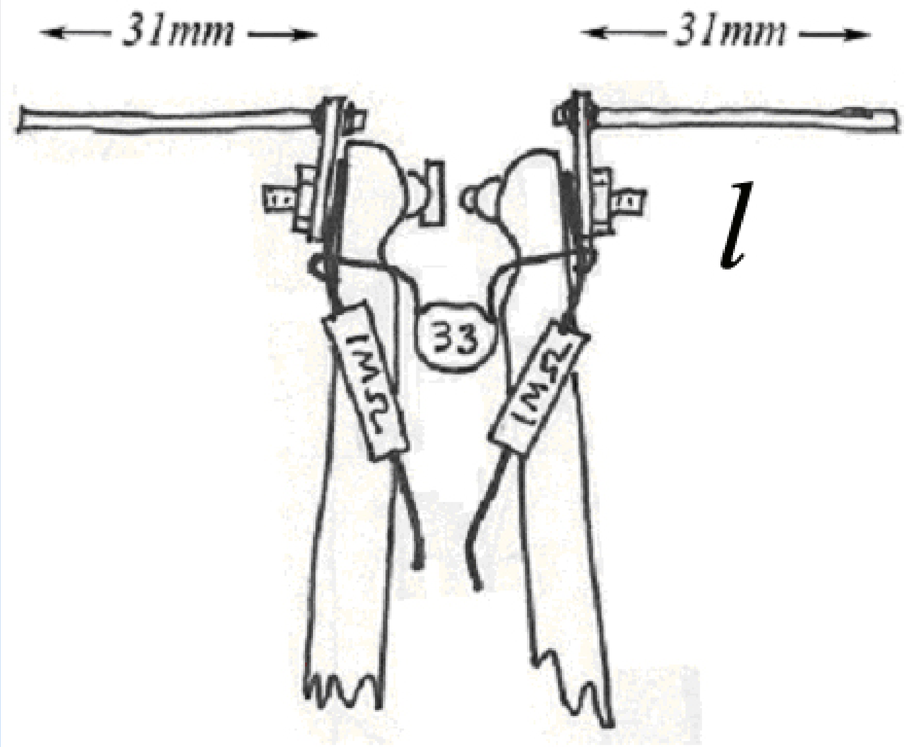
Question: What is the resonance frequency?

Recall:

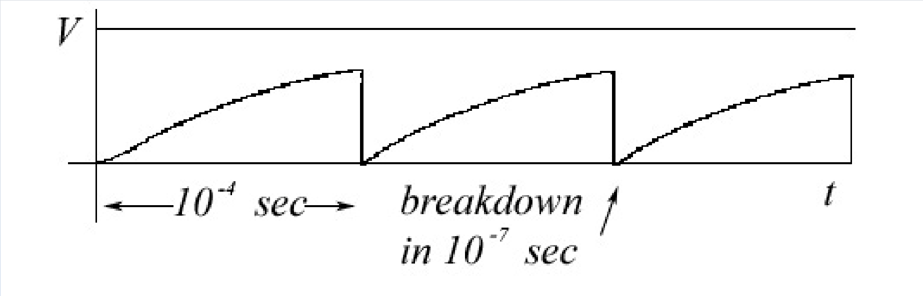
$$C = \frac{\varepsilon_0 A}{d} \quad L = \frac{\Phi}{I} \qquad \omega_0 = \frac{1}{\sqrt{LC}}$$

$$B_{\text{solenoid}} = \mu_o \left[\text{current per unit length} \right]$$

Our spark gap antenna

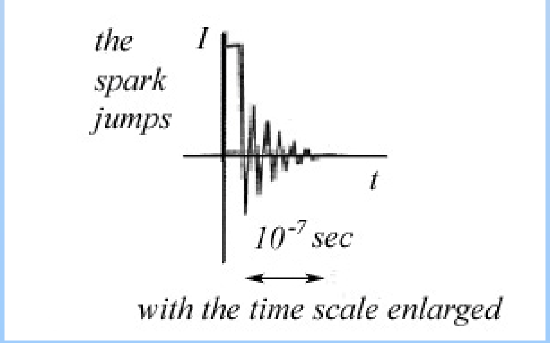


1) Charge gap (RC)



$$\tau = RC = (4.5\times10^{6}\,\Omega)(33\times10^{-12}\,\mathrm{F}) = 1.5\times10^{-4}\,\mathrm{s}$$

2) Breakdown! (LC)

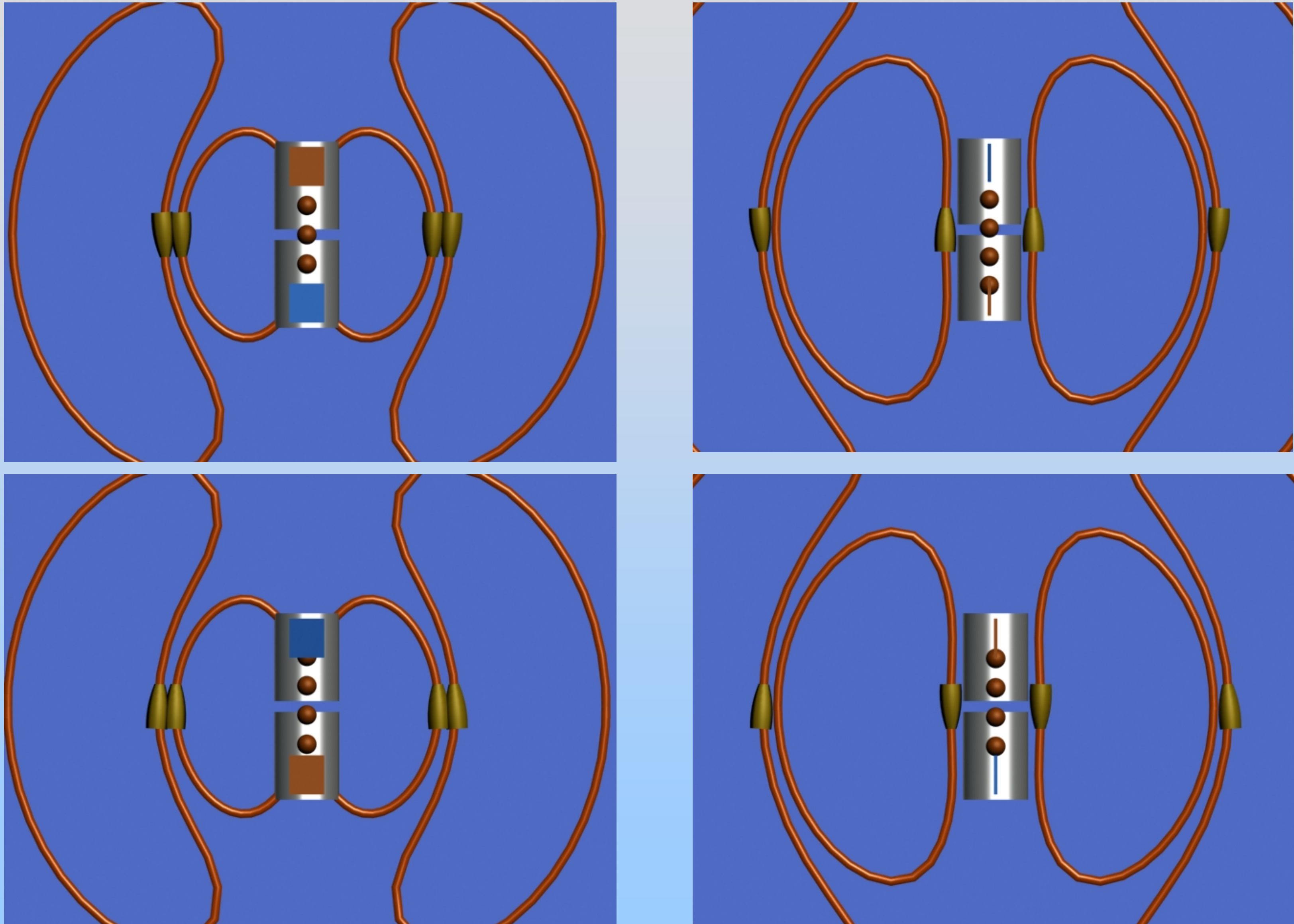


$$f_{\mathrm{rad}} = \frac{1}{T} = \frac{c}{4l} = \frac{3\times10^{10}\,\mathrm{cm/s}}{12.4\,\mathrm{cm}}$$

$$= 2.4\times10^{9}\,\mathrm{Hz} = 2.4\,\mathrm{GHz}$$

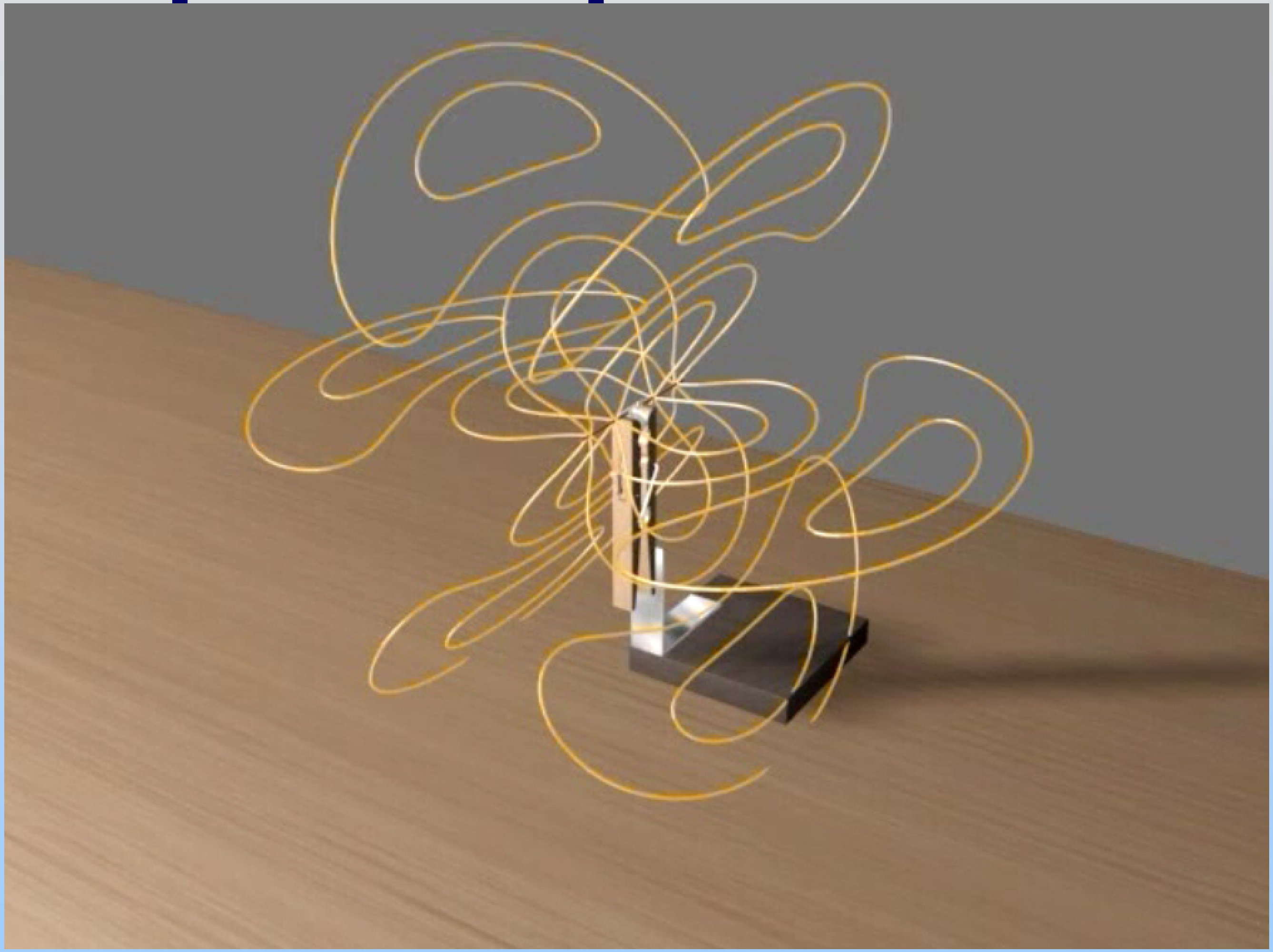
3) Repeat

Spark Gap Transmitter



PRS Question:
Spark Gap Antenna

Spark Gap Antenna



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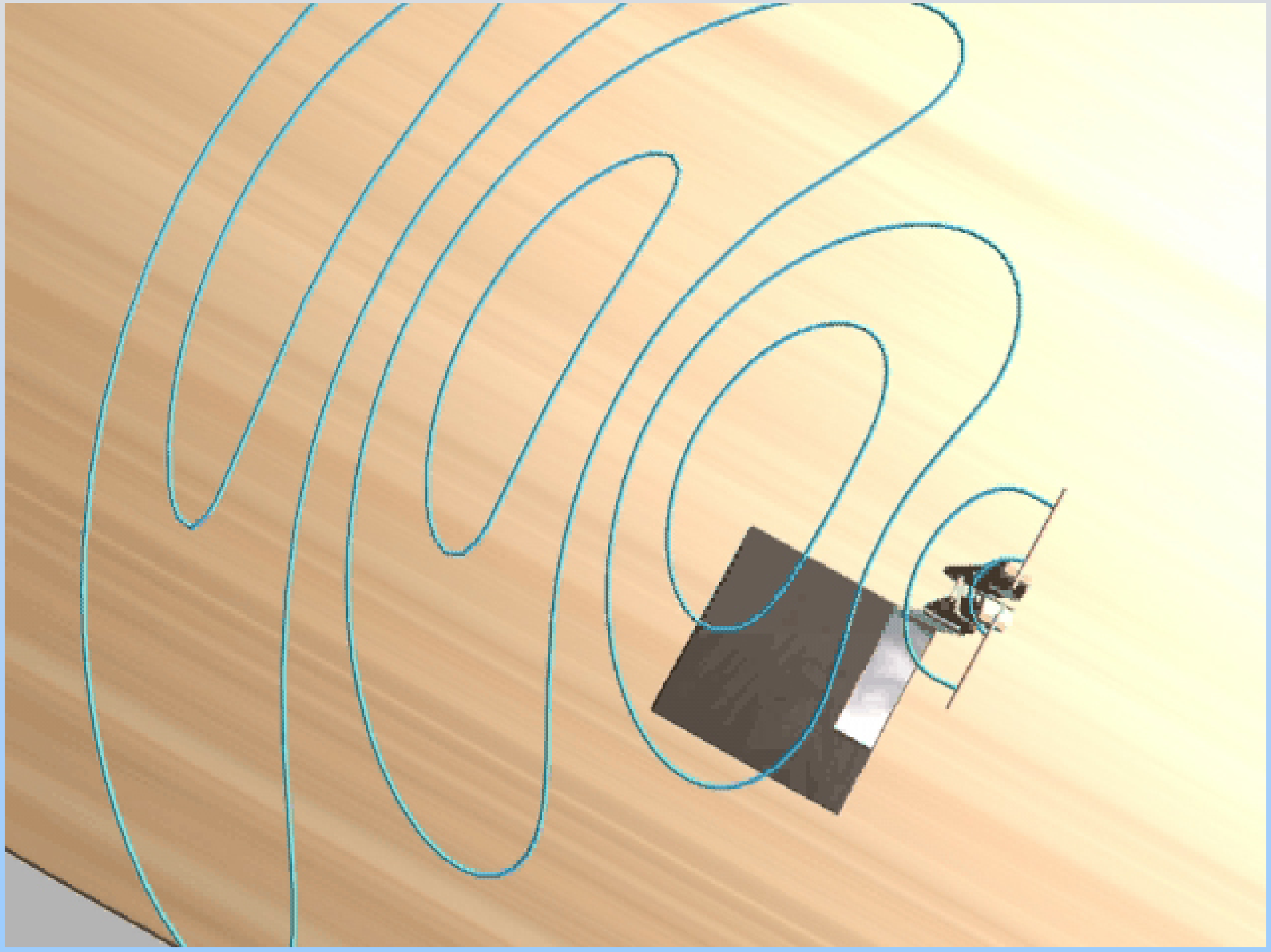
Spark Gap Antenna

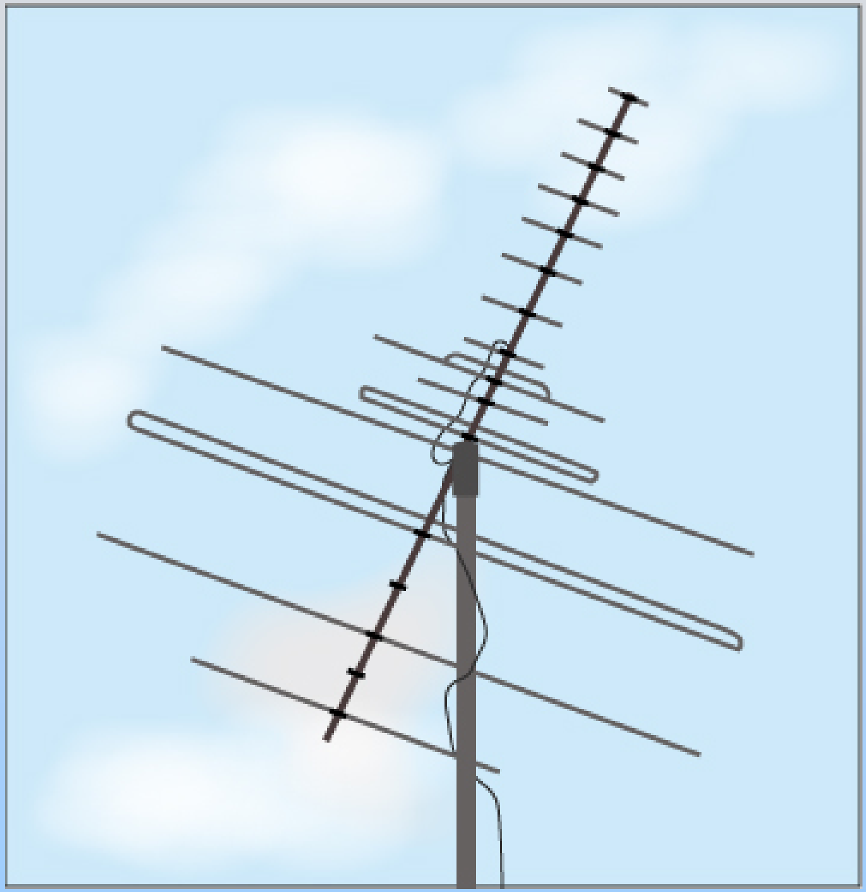


PRS Questions:
Angular Distribution &
Polarization of Radiation

Demonstration: Antenna

Polarization

Polarization of TV EM Waves

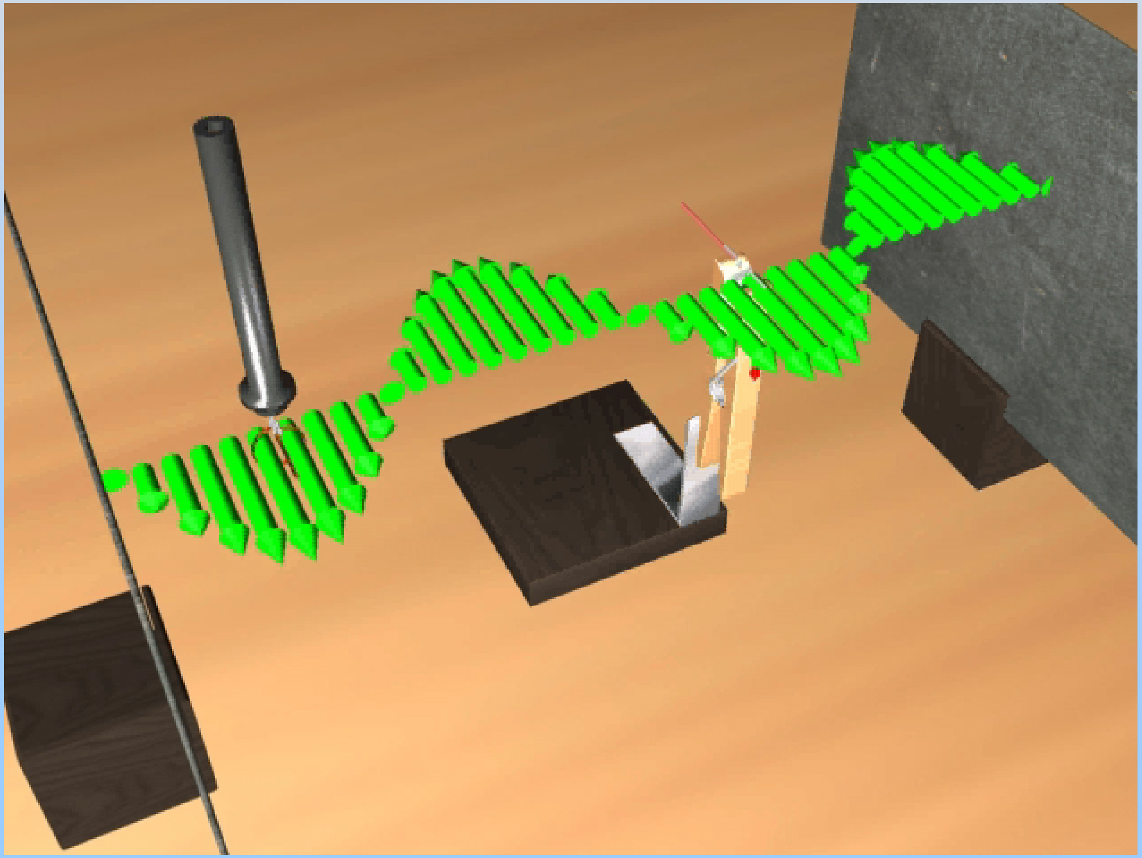


Why oriented as shown?

Why different lengths?

Demonstration:
Microwave Polarization

Experiment 12: Measure Wavelength by Setting Up Standing Wave



Experiment 12: Microwaves

Exam 3 Results