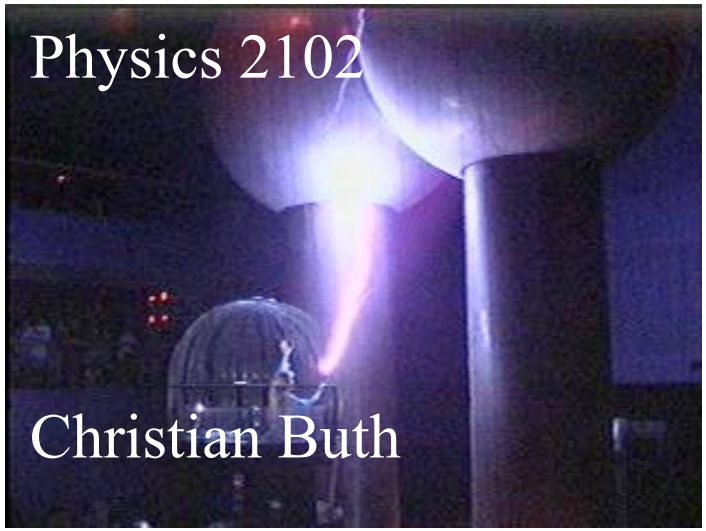
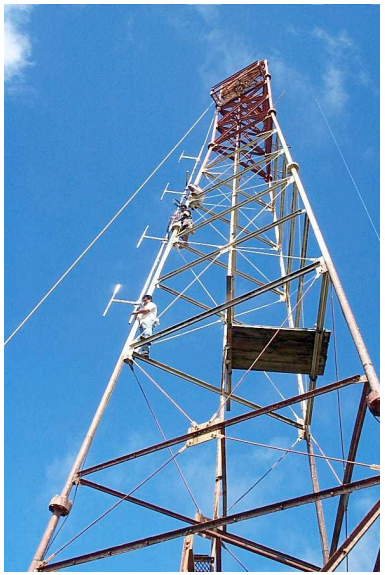
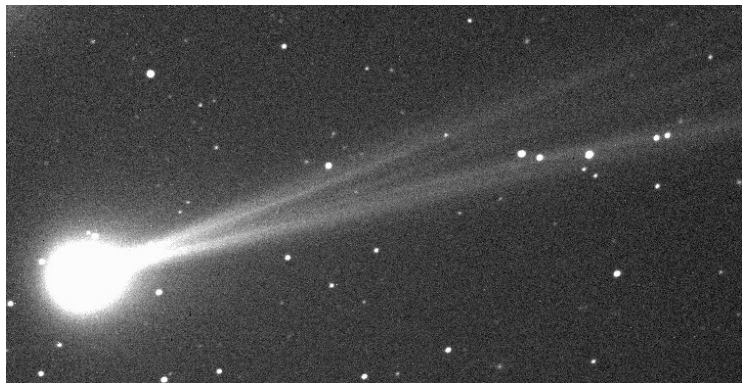




Lecture 33

Electromagnetic Waves 1

04/03/2009



Review

- Transformer equation

$$V_S = \frac{N_S}{N_P} V_P \qquad i_S = \frac{N_P}{N_S} i_P$$

- **Maxwell's equations** are:
  - Gauss law for electric fields
  - Gauss law for **magnetic** fields $\oint B \bullet dA = 0$
  - **Ampere-Maxwell** law

$$\oint_C \vec{B} \bullet d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{\text{enc}}$$

  - Faraday's law

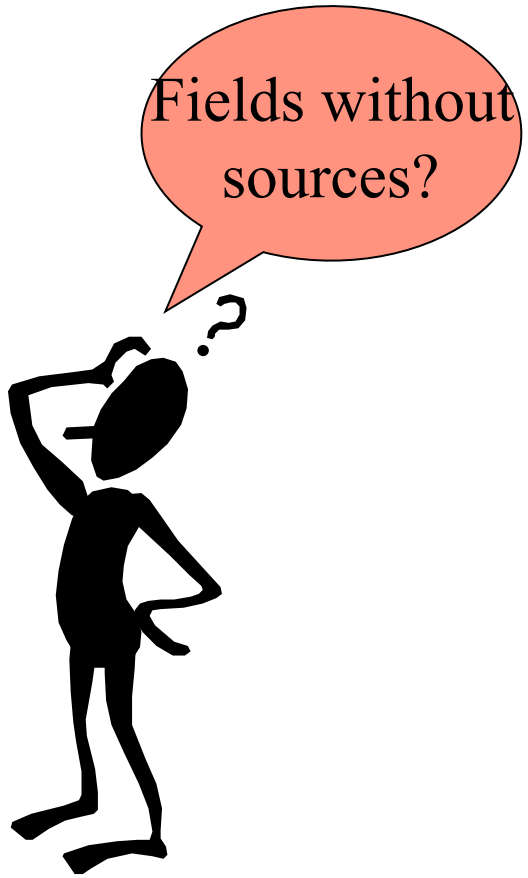
Maxwell equations in free space

$$\oint_S E \bullet dA = 0$$

$$\oint_S B \bullet dA = 0$$

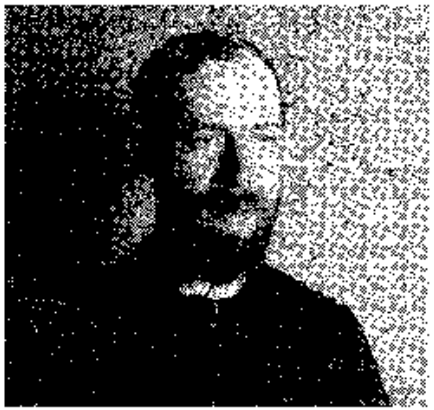
$$\oint_C B \bullet ds = \mu_0 \varepsilon_0 \frac{d}{dt} \int_S E \bullet dA$$

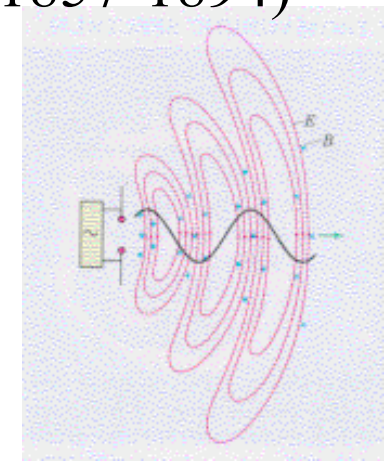
$$\oint_C E \bullet ds = -\frac{d}{dt} \int_S B \bullet dA$$



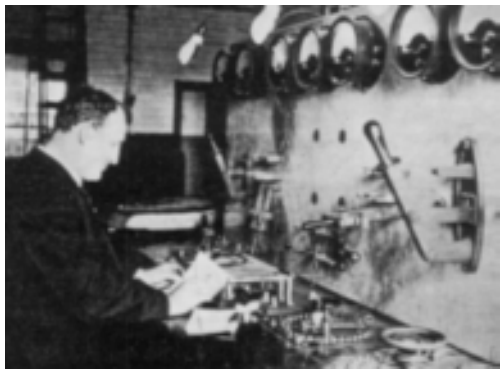
Electromagnetic waves

First person to prove that electromagnetic waves existed:
Heinrich Hertz (1857-1894)



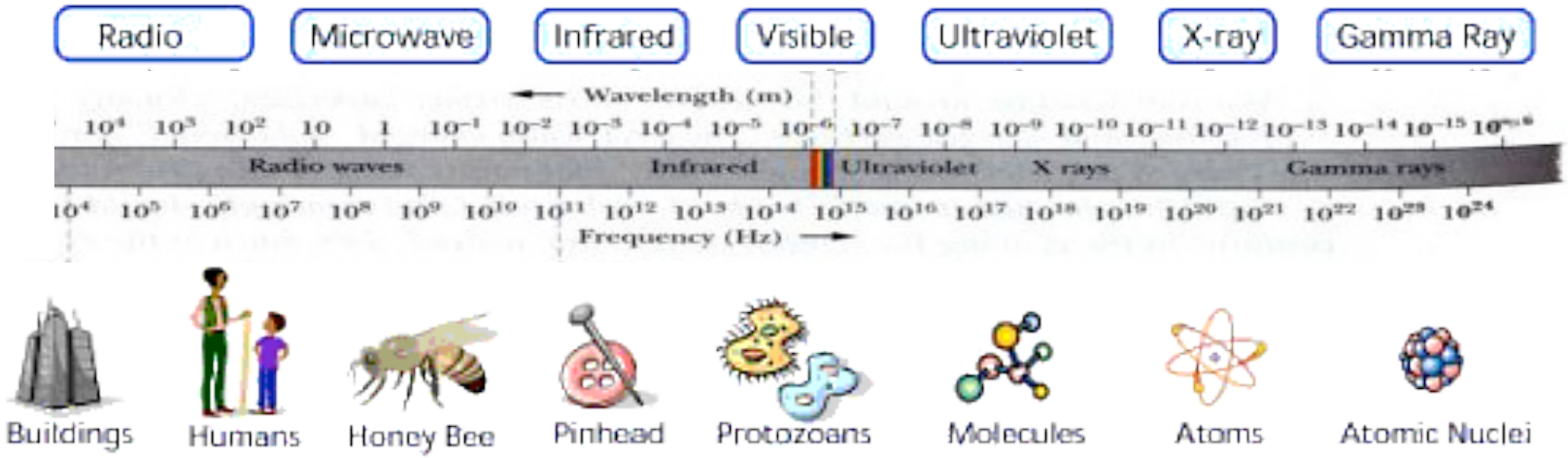


First person to use electromagnetic waves for communications:
Guglielmo Marconi (1874-1937), 1909 Nobel Prize



(first transatlantic commercial wireless service, Nova Scotia, 1909)

Electromagnetic waves: one velocity, many frequencies!



with frequencies measured in "Hertz" (cycles per second) and wavelength in meters.

http://imagers.gsfc.nasa.gov/ems/
http://www.astro.uiuc.edu/~kaler/sow/spectra.html

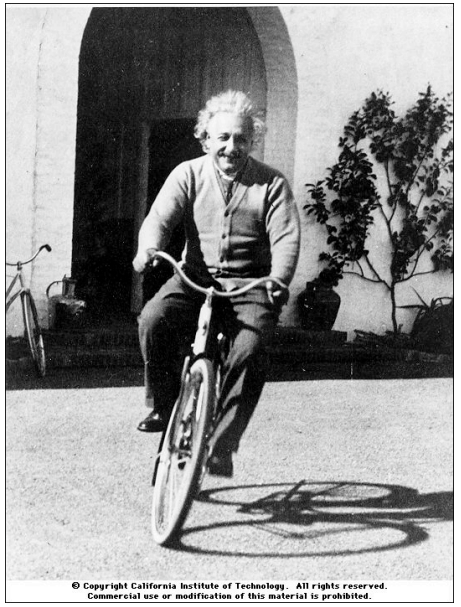
How do waves travel?

Is there an ether they ride on? Michelson and Morley looked and looked, and decided it wasn't there. How do waves travel???

Electricity and magnetism are "relative": Whether charges move or not depends on which frame we use…

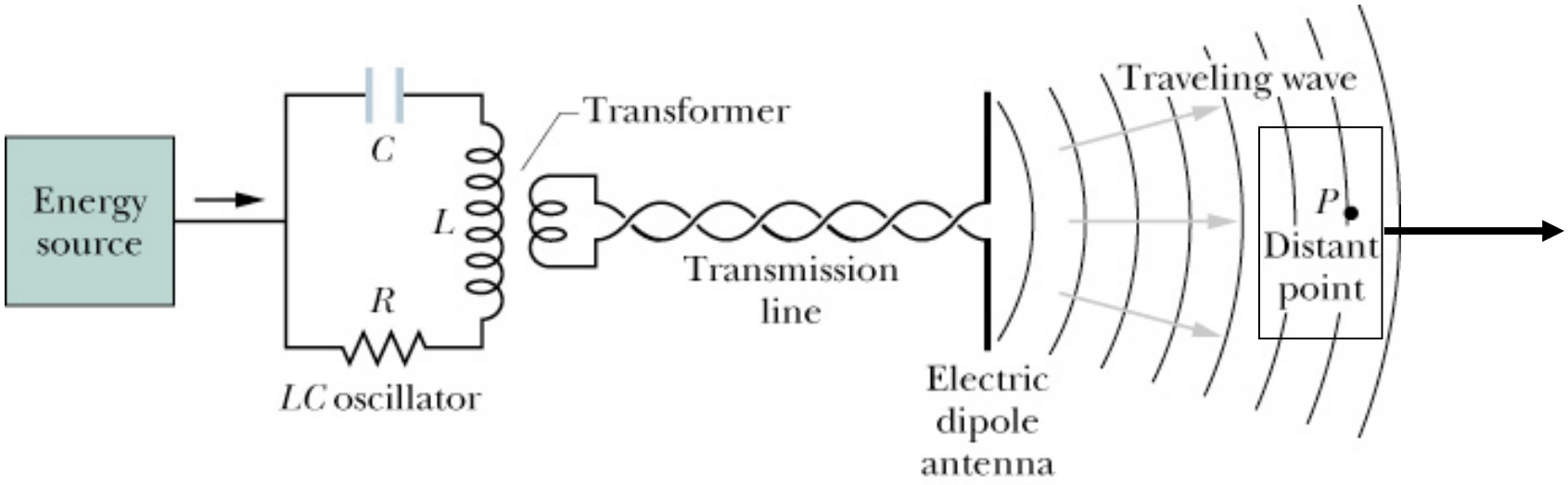
This was how Einstein began thinking about his "theory of special relativity"…

We'll leave that theory for later…



Traveling Electromagnetic (EM) Wave 1

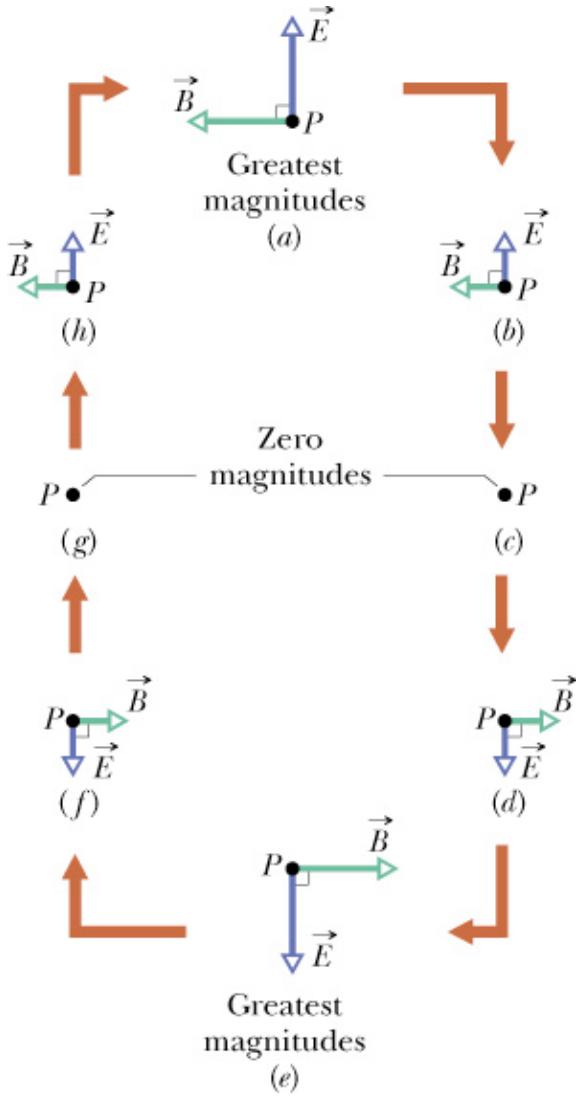
An **LC oscillator** causes currents to flow sinusoidally, which in turn produces oscillating electric and magnetic fields, which then **propagate** through space as **EM waves**



Oscillation Frequency:

$$\omega = \sqrt{\frac{1}{LC}}$$

Traveling Electromagnetic (EM) Wave 2



EM fields at P looking back toward LC oscillator

1. Electric $\vec{E}$ and magnetic $\vec{B}$ fields are always perpendicular to direction in which wave is traveling → transverse wave (Ch. 16).
2. $\vec{E}$ is always perpendicular to $\vec{B}$.
3. $\vec{E} \times \vec{B}$ always gives direction of wave travel.
4. $\vec{E}$ and $\vec{B}$ vary sinusoidally (in time and space) and are *in phase* (in step) with each other.

Electromagnetic Waves

A solution to Maxwell's equations in free space:

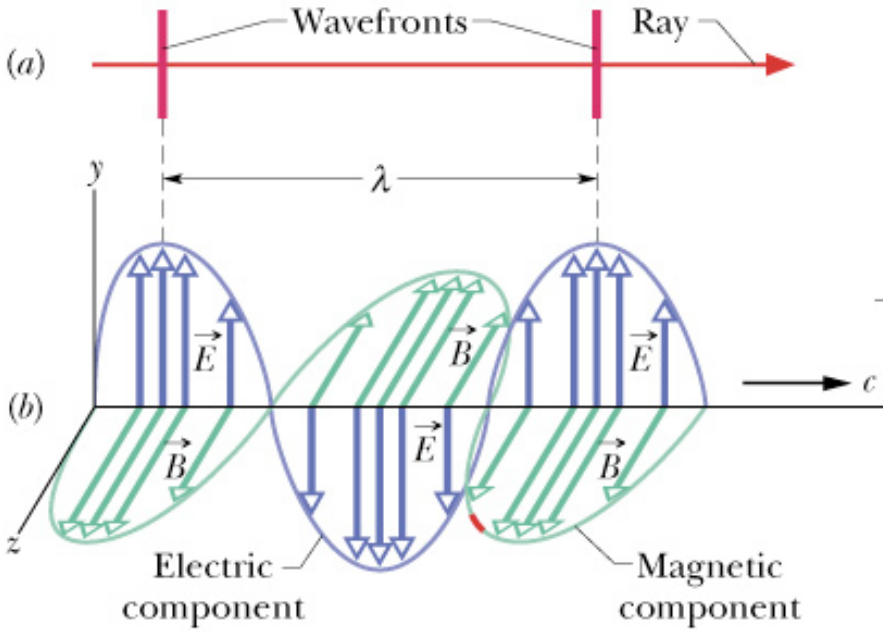
$$E = E_m \sin(kx - \omega t)$$

$$B = B_m \sin(kx - \omega t)$$

$$\frac{\omega}{k} = c, \quad \text{speed of propagation.}$$

$$c = \frac{E_m}{B_m} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

$$= 299{,}462{,}954 \frac{m}{s} = 187{,}163 mps$$



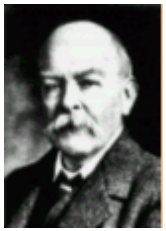
Visible light, infrared, ultraviolet, radio waves, X rays, Gamma rays are all electromagnetic waves.

186,000 MILES PER SECOND
IS NOT JUST A GOOD IDEA

IT'S THE LAW

The Poynting Vector

Electromagnetic waves transport energy from transmitter to receiver (example: from the Sun to skin)

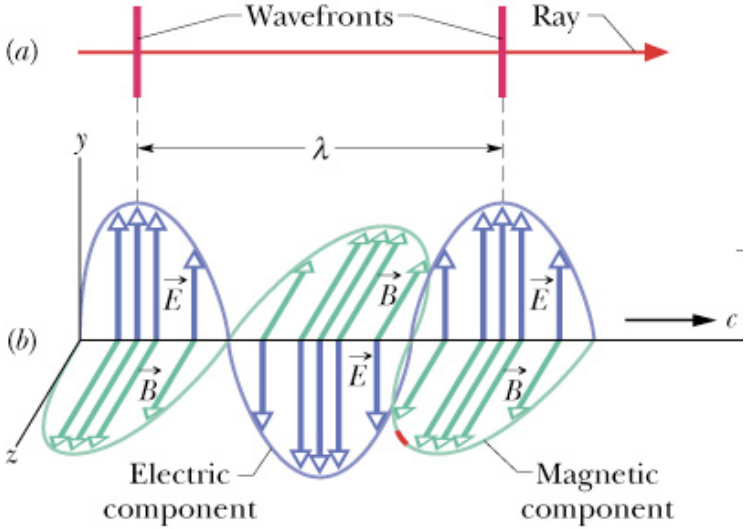


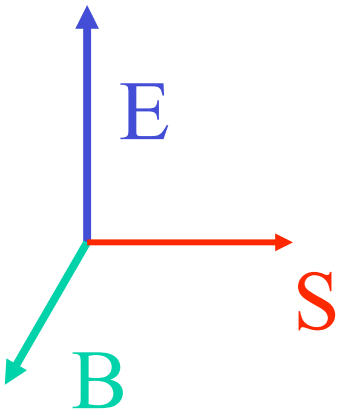
John Henry Poynting (1852-1914)

Power and direction from Poynting vector

$$\vec{S} = \frac{1}{\mu_0}\vec{E}\times\vec{B} \qquad S = \left(\frac{\text{energy/time}}{\text{area}}\right)_{\text{inst}} = \left(\frac{\text{power}}{\text{area}}\right)_{\text{inst}}$$

Units: Watt/m^2





E is perpendicular to B:

$$|S| = \frac{1}{\mu_0}EB = \frac{1}{c\mu_0}E^2$$

Poynting vector changes with time! The direction is constant

Summary

- Maxwell's laws: **electromagnetic (EM) waves** (in vacuum)
- EM waves travel at the **speed of light**, are transversal
- ***E***, ***B*** are **perpendicular**; form right-handed coordinate system with propagation direction and vary sinusoidally
- **Poynting Vector *S***: energy in propagation direction

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$$