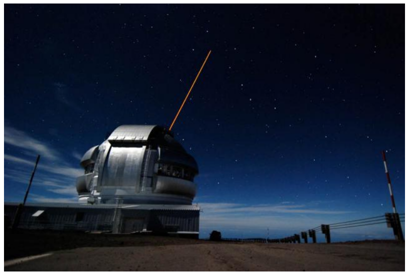
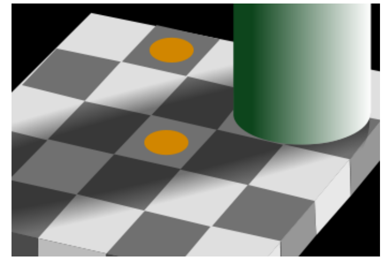
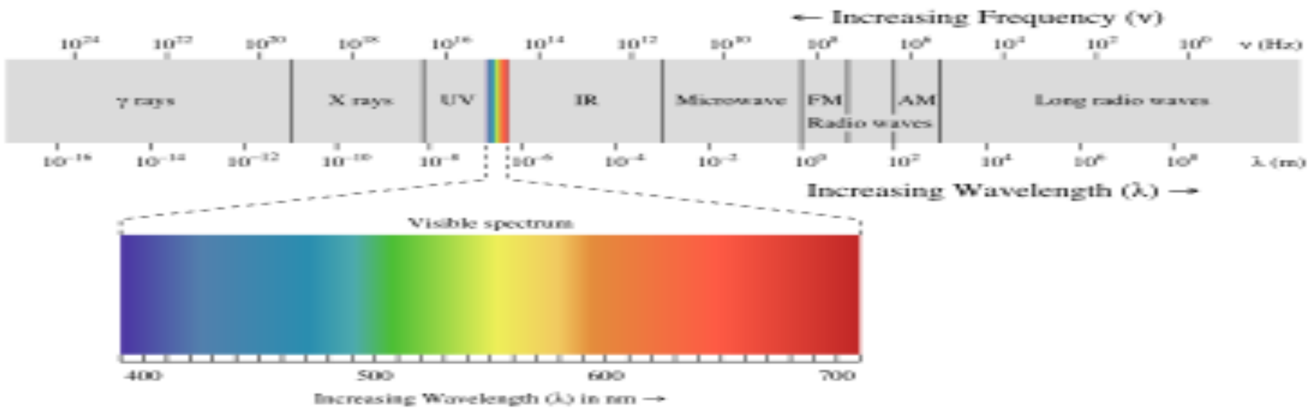
Physics 1230: Light and Color



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http://www.colorado.edu/physics/phys1230/

What is light?

Announcements:

- lecture 1 is posted on the class website
- homework 1 is posted on D2L
  - due Tuesday, Jan 21 in class
  - solutions will be posted on D2L

- reading for this week is:
  - Ch 1 and 2 in SL
  - course syllabus details

- remember to bring your clicker to every class
  - register it (once)
  - set it to frequency BA

Fire up the iClickers

- swap clicker code to BA
- hold down on/off switch for 4 seconds
- flashing blue light: hit BA
- should see GREEN light and you're ready to go

clicker question

Speed of light

Q: *How long does it take light to go once around the equator? (equator is approximately 40,000 km)*

a) 1 minute
b) 1 millionth of a second
c) 0.13 seconds
d) instantaneously
e) no idea

A: *c) time = 40,000km / 300,000 km/sec = 0.13 seconds, i.e., 7.5 times around in 1 second!*

Last Time

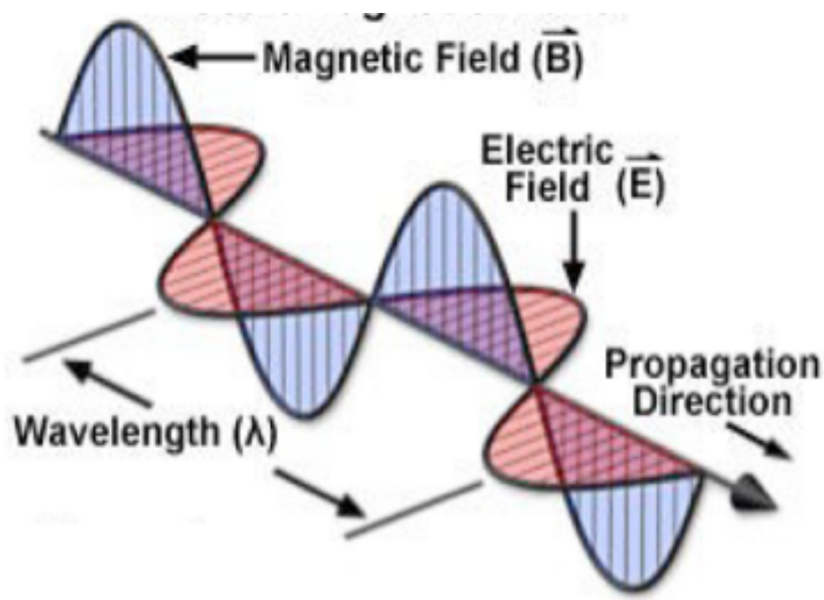
recall lecture 1:

- course logistics: http://www.colorado.edu/physics/phys1230
- course overview:
  - fundamentals of light:
    - . EM waves
    - . photons
    - . ray optics
  - applications:
    - . lenses and mirrors
    - . photography
    - . the eye
    - . optical instruments
  - perception
- introduction: “what is light?”

Today

What is light?

- charges -> electric and magnetic fields
- force on a charge due to E and B fields
- electromagnetic waves
- spectrum
- generating different types of EM radiation

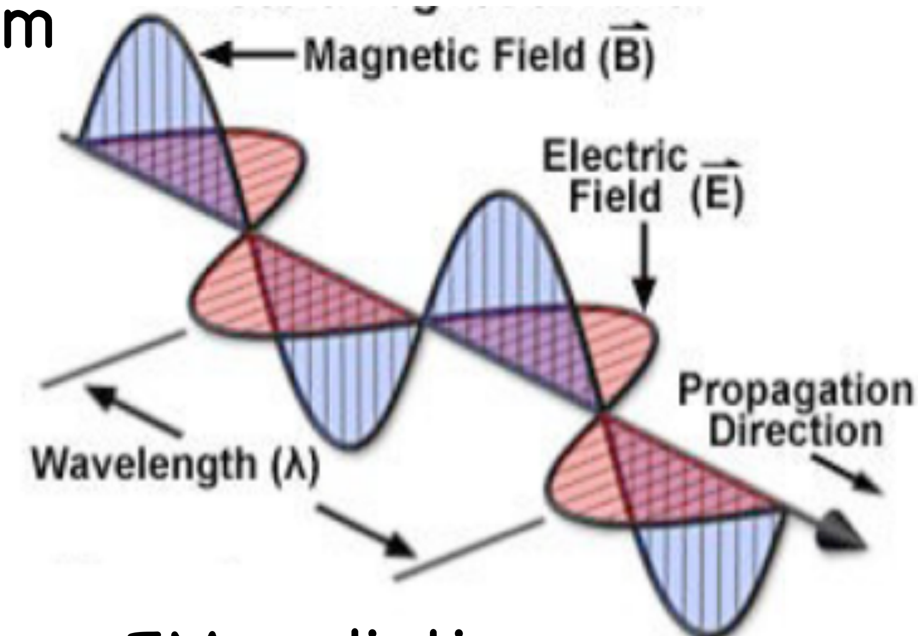


Recall

What is light?

Electromagnetic (EM) wave or field:

- a wave of oscillating electric (E) and magnetic (B) fields, traveling with speed c = 300,000 km/sec, carrying energy and momentum



- part of more general phenomena: EM radiation

Recall

Scientific notation and metric system

Powers of 10 give a shorthand notation for very large numbers:

- $10^0 = 1$
- $10^1 = 10$
- $10^2 = 100$
- $10^3 = 1000$
- …
- $10^n = 1000…000$ (n zeros)

or very small numbers:

- $10^{-1} = 0.1$
- $10^{-2} = 0.01$
- $10^{-3} = 0.001$
- …

Scientists don't use feet or miles to indicate distances.

They use metric system (SI units):

meters (m)
1 meter = 39.4 inches

kilometers (km)
1 km = 1000 m = 0.625 mi

centimeters (cm)
1 cm = 10^{-2} m = 0.394 inches

millimeters (mm)
1 mm = 10^{-3} m

nanometers (nm)
1 nm = 10^{-9} m

Angstrom (A)
1 A = 10^{-10} m

light oscillates approx. 10^{15} times/sec = 1,000,000,000,000,000 Hertz

Electric charge and Coulomb's law

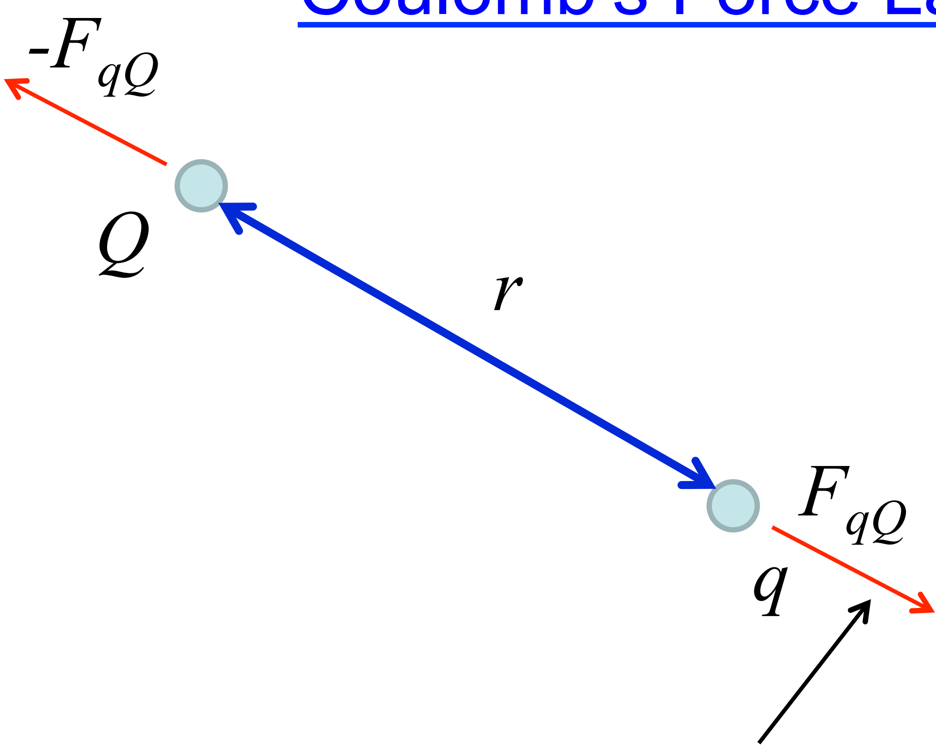
- electrical charges (units = Coulomb)
  - positive (e.g., proton) and negative (e.g., electron)
  - like repel, opposite attract

Coulomb's Force Law:

$$F_{qQ} = k\frac{qQ}{r^2}$$

constant of nature

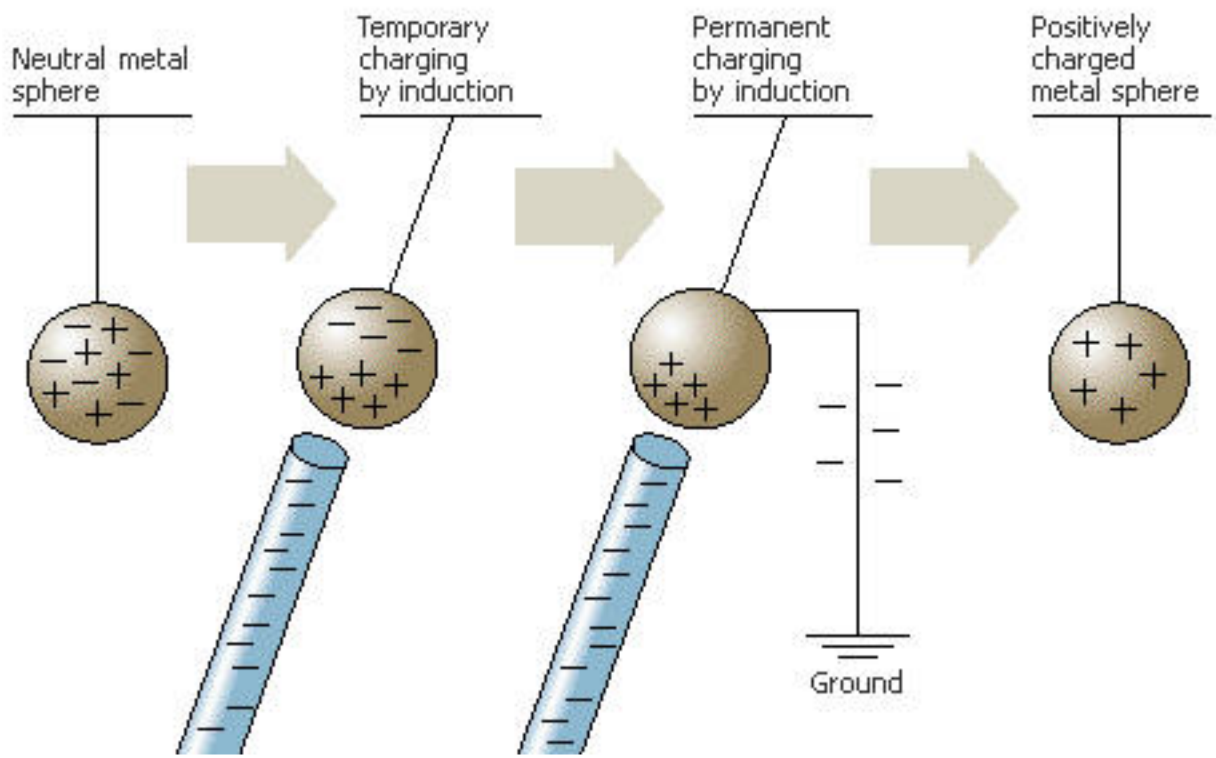
Q - q separation



force that q feels from Q

Electric charge and Coulomb's law

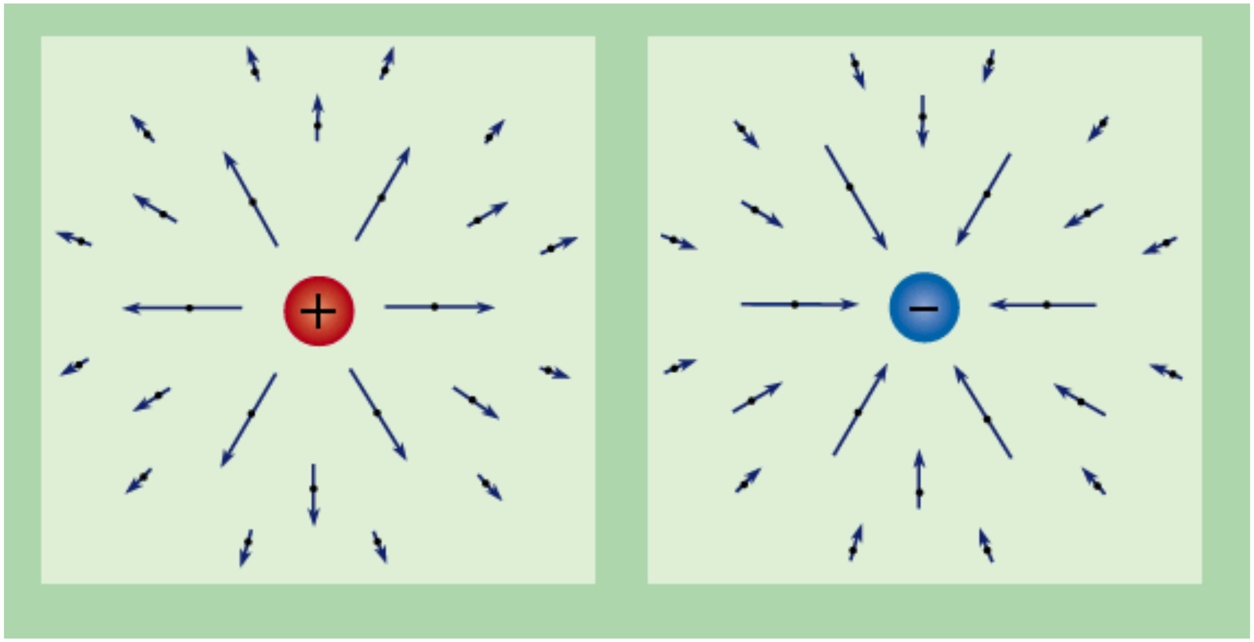
- electrical charges (units = Coulomb, e = 1.6 x 10^{-19} Coulombs)
  - positive (e.g., proton, e) and negative (e.g., electron, -e)
  - like repel, opposite attract $F_{qQ} = k\dfrac{qQ}{r^2}$



Electric field

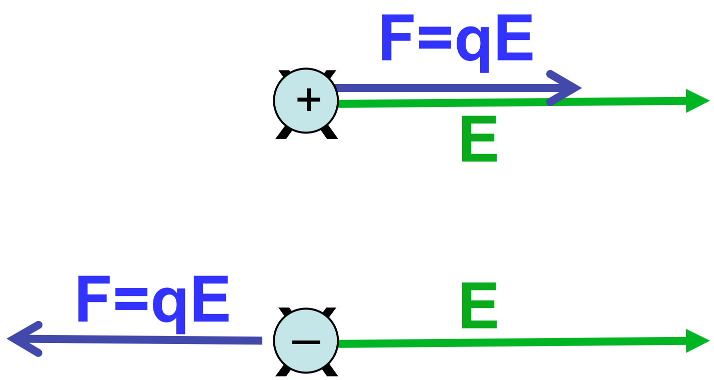
- electric charge Q -> electric field, $E_Q(r)$ (Newton/Coulomb)

  gets weaker further away as $1/r^2$, points along force on a positive test charge



- another charge q feels a force F_{qQ} due to E_Q :

$$F_{qQ} = k\frac{qQ}{r^2} = qE_Q$$

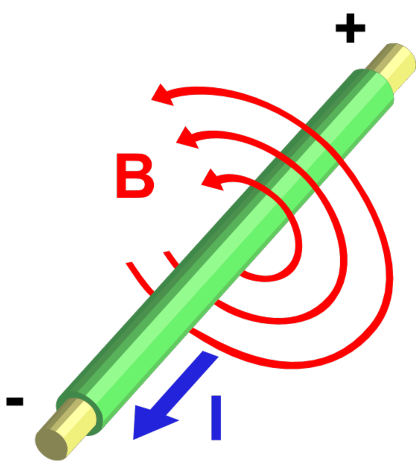


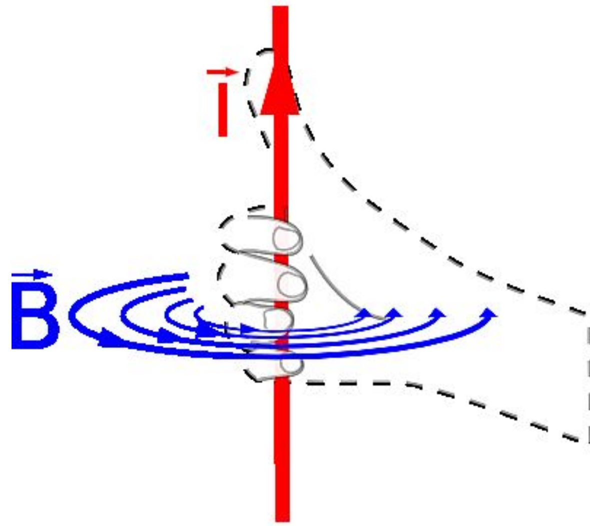
Force = charge x electric field E

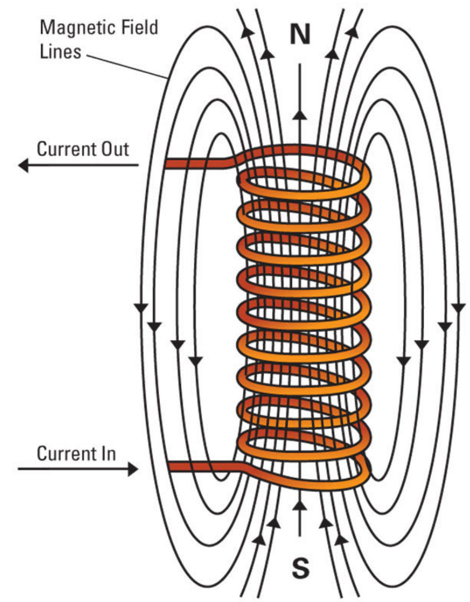
F= qE

Magnetic field

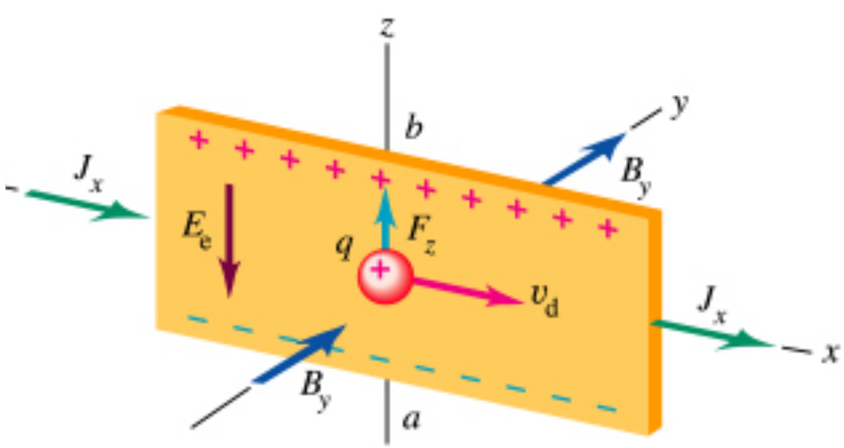
- moving electric charge, i.e., current I -> magnetic field, $B_I(r)$
  gets weaker further away as 1/r

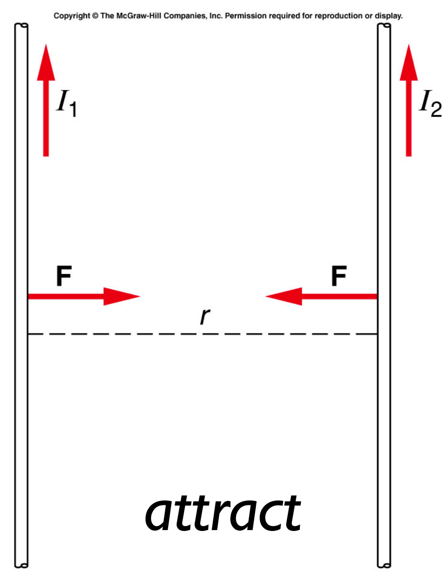






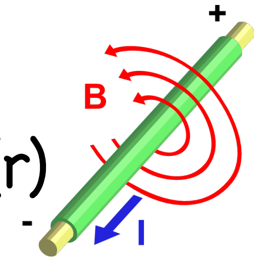
- moving charge (current carrying wire) feels force from B field:
  Lorentz force: $F = qE + q\, v \times B$

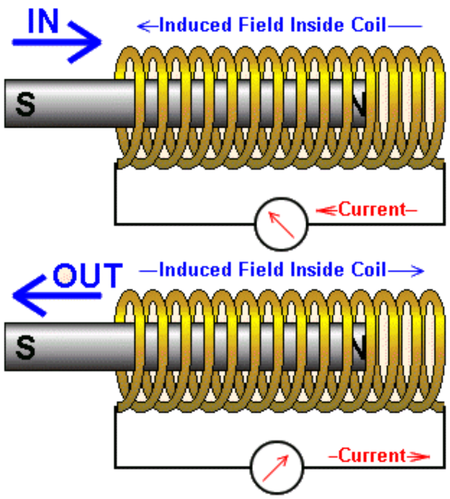


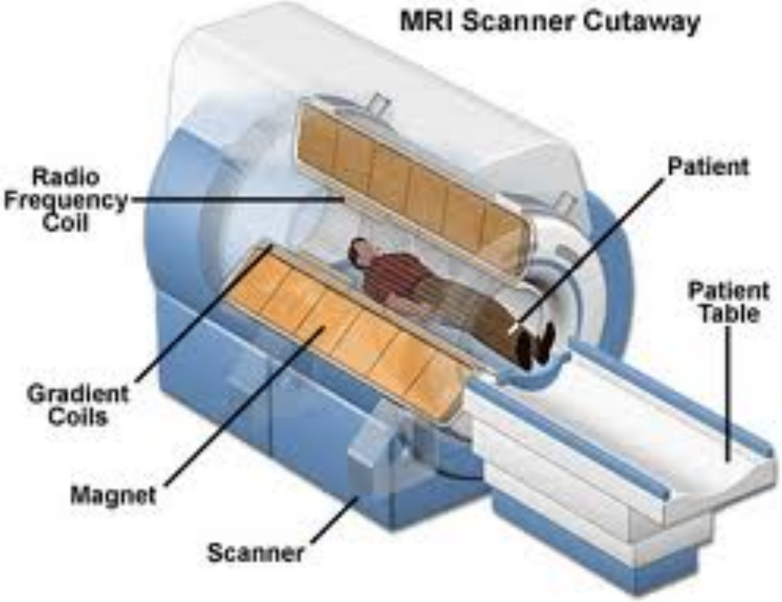


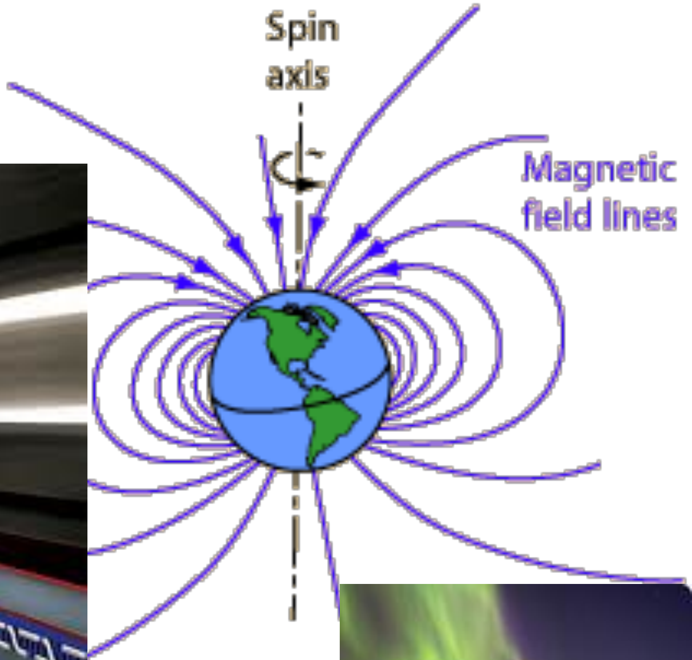
Electro-magnet

- moving electric charge, i.e., current I -> magnetic field, $B_I(r)$
  gets weaker further away from straight wire as 1/r









Monumental discovery

James Clerk Maxwell
(1831–1879)

- Maxwell (1861) discovered that changing E field creates B field and changing B field creates E field -> Electromagnetic waves -> light!

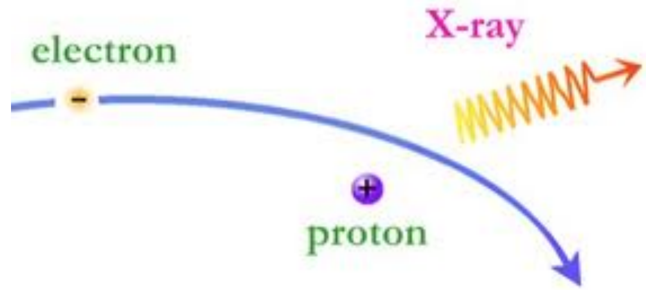
- developed a detailed theory of EM waves, building on work of Isaac Newton, Robert Hooke, Michael Faraday, Ampere,...

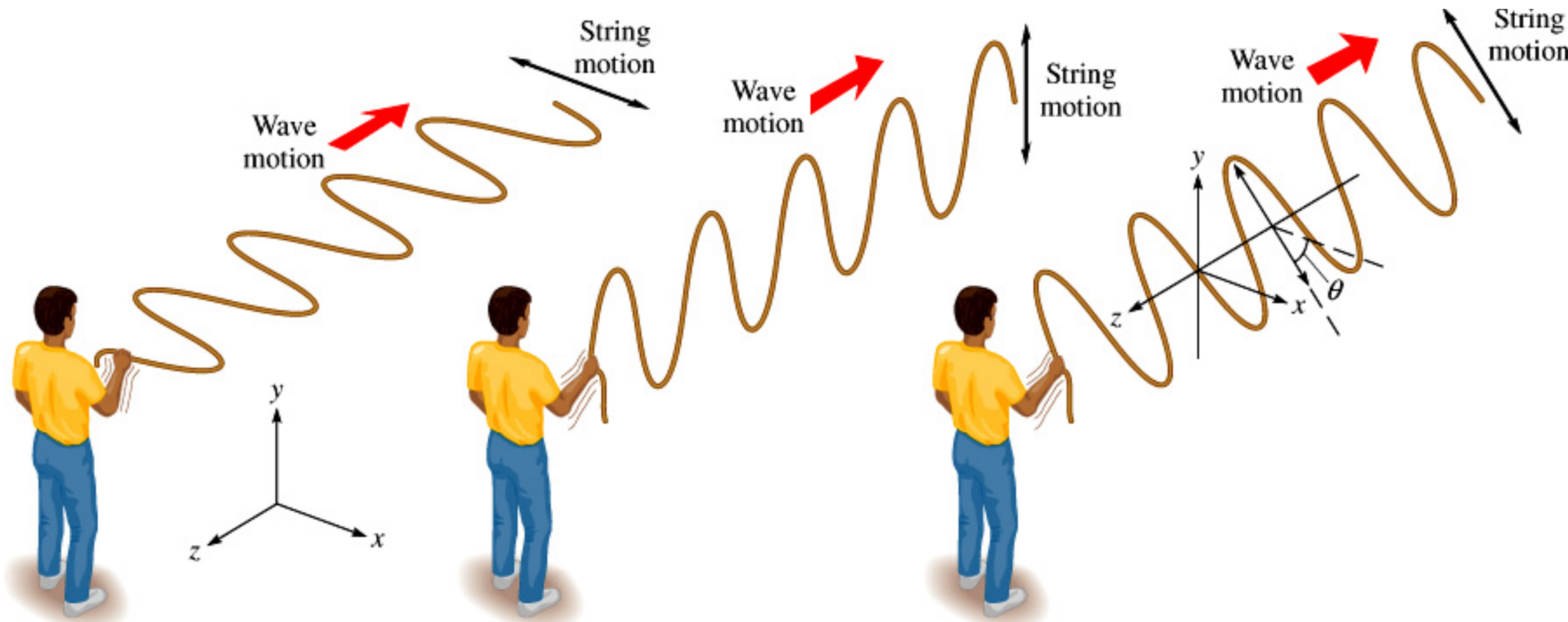
- "*most profound and the most fruitful that physics has experienced since the time of Newton.*" --- Albert Einstein

- "*From the long view of the history of mankind – seen from, say, ten thousand years from now – there can be little doubt that the most significant event of the 19th century will be judged as Maxwell's discovery of the laws of electrodynamics. The American Civil War will pale into provincial insignificance in comparison with this important scientific event of the same decade.*" --- Richard P. Feynman

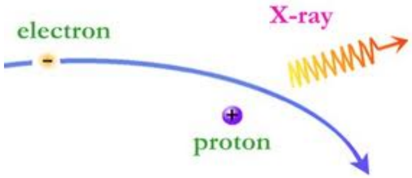
Electromagnetic radiation generation

- accelerating electric charge -> time varying E and B fields -> electromagnetic radiation





polarization of EM wave



Electromagnetic radiation generation

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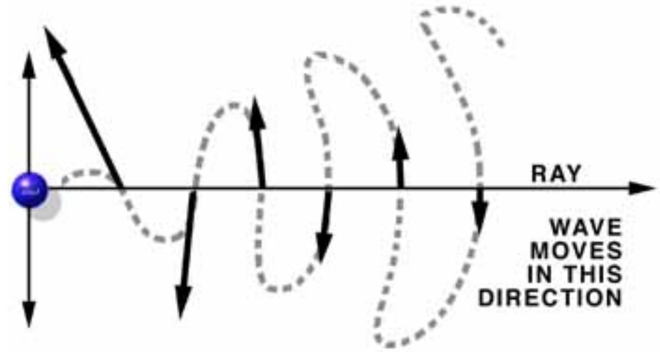
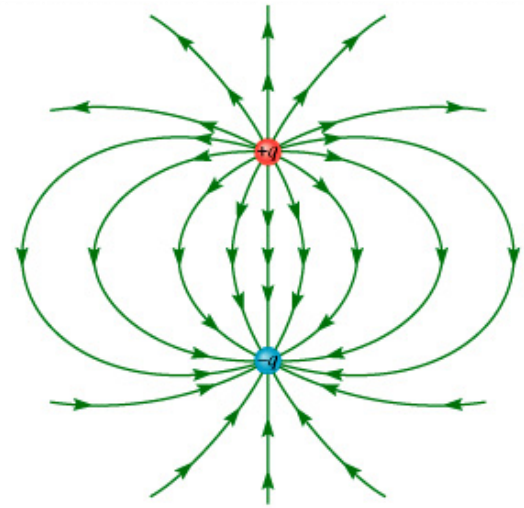
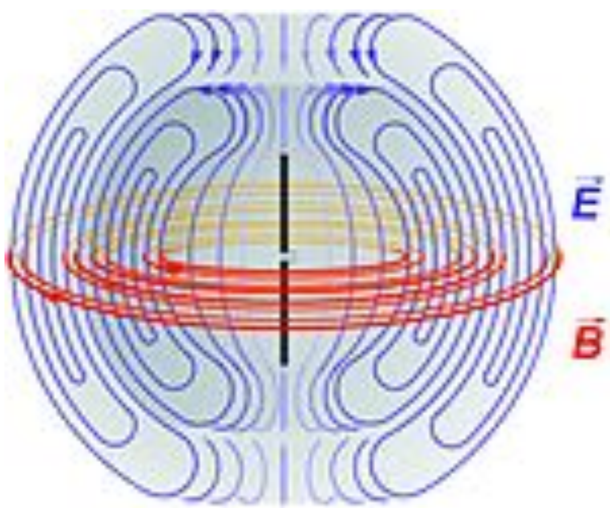
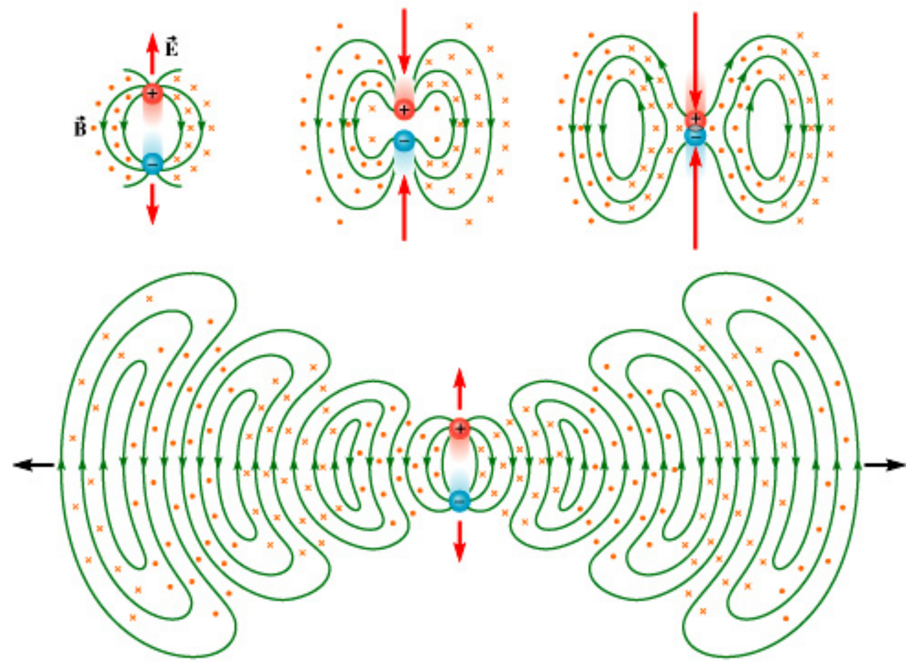




(a)

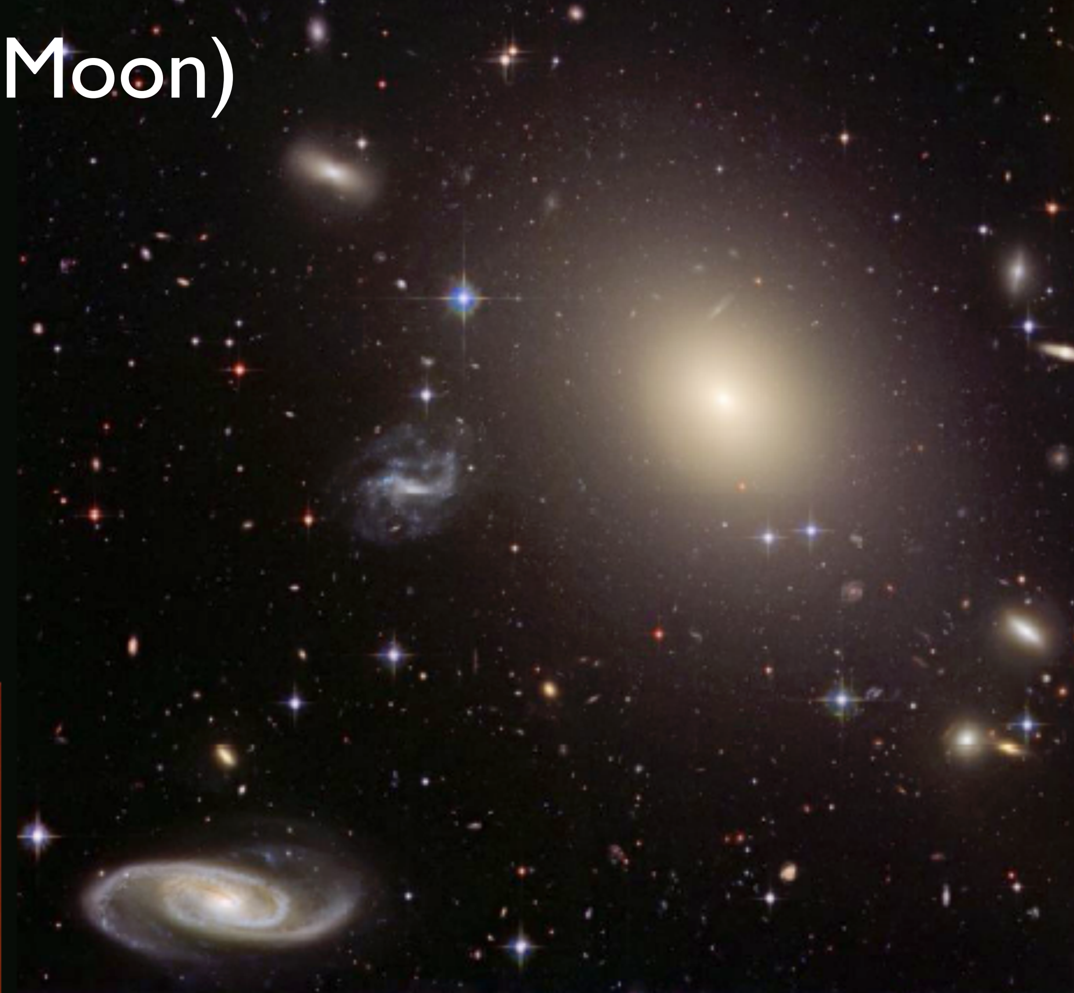
antenna (ac current)





(b)

Not self-luminous (e.g., Moon)



Sources of Light in Nature

luminous (e.g., Sun)

Sources of Light
in Nature

clicker question

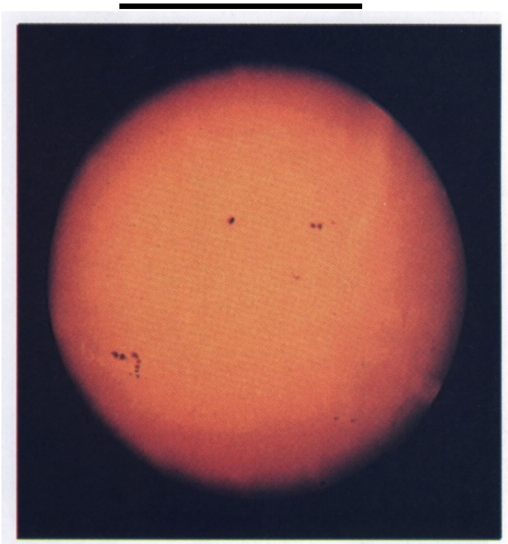
Heat generates light

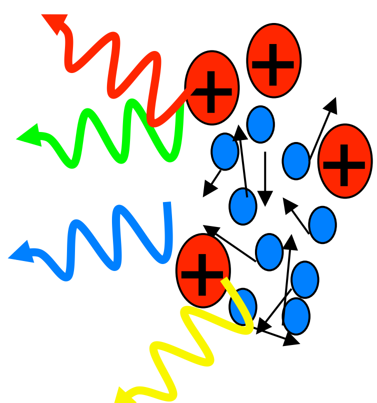
Q: **How does Sun generate light (EM radiation)?**

a. Stationary charges
b. Charges moving at a constant velocity
c. Accelerating charges
d. b and c
e. a, b, and c

A: **c. *Accelerating* charges create EM radiation.**

The Sun



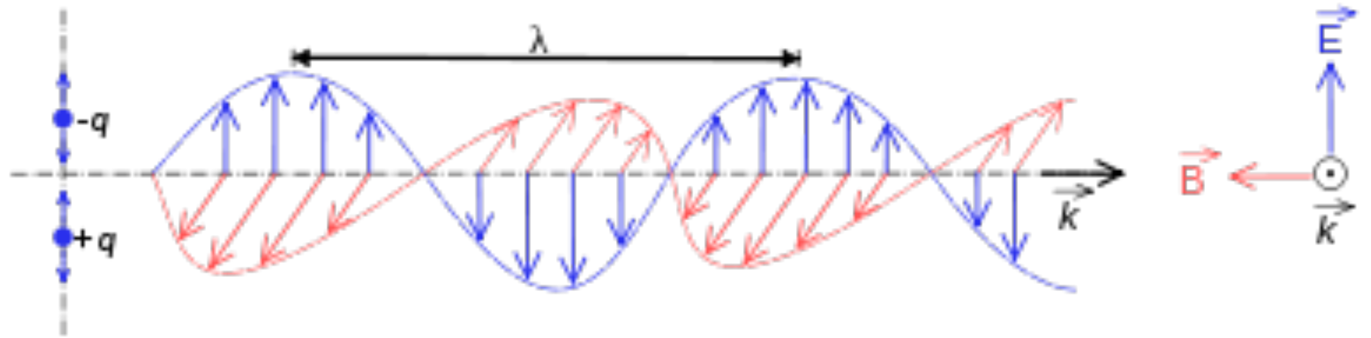


Surface of sun is very hot! 6000K Whole bunch of free electrons whizzing around like crazy and equal number of protons (but heavier so moving slower), generating EM waves --- Sun light

Go to radiowave sim

Electromagnetic radiation generators

- EM wave generated by oscillating electrical currents -> send signal (radio antenna, garage door opener, remote control, ...)

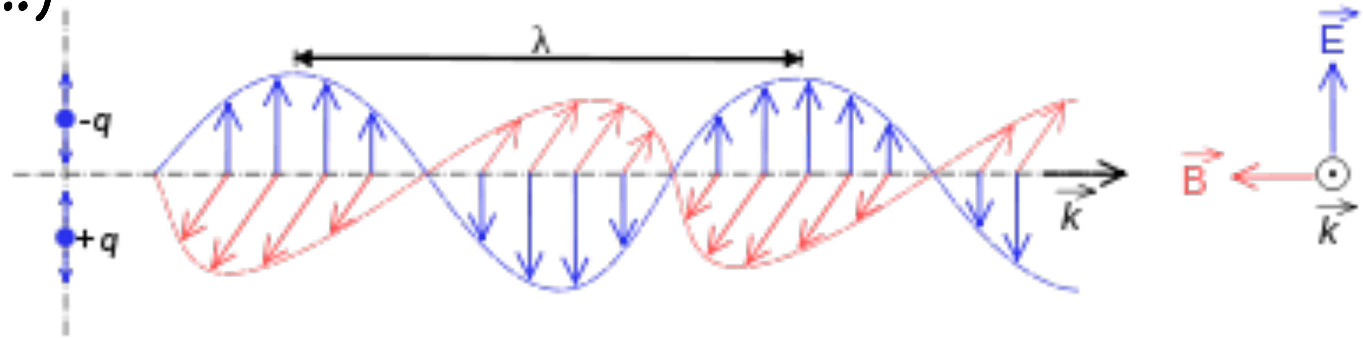


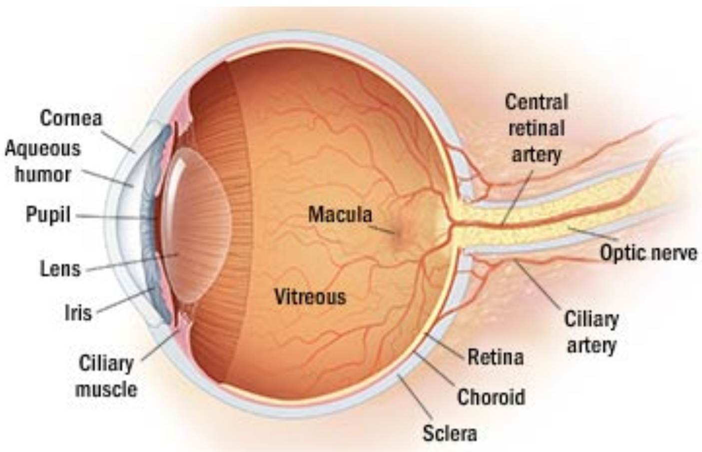
tv, radio antennas

Atacama Large Millimeter Array

Electromagnetic radiation sensors

- EM wave exerts oscillating force on charges (electrons) in matter (radio antenna, your eyes, ...) -> ac current -> image (speaker sound, brain, tv, lcd,...)



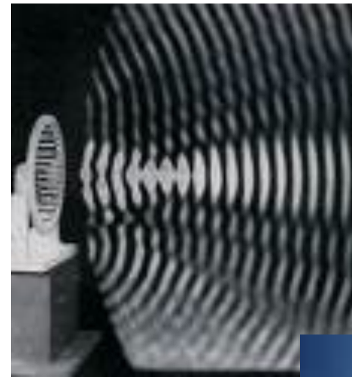


Atacama Large Millimeter Array

tv, radio antennas

EM-waves in what?

- *Sound wave* propagates through air, with velocity (330 m/sec) relative to *air*



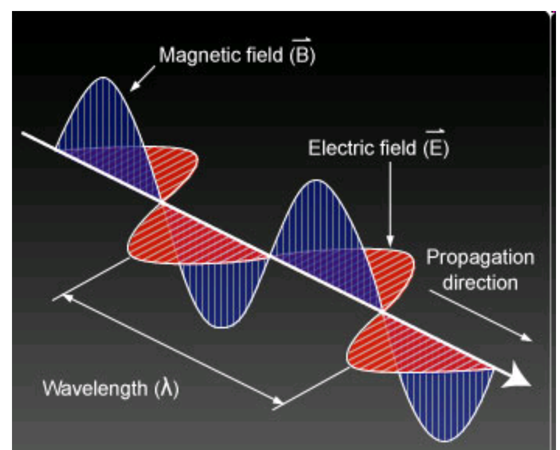
- *Water waves* propagates through water, with velocity relative to *water*

- *"The wave"* propagates through a crowd in a stadium, with velocity relative to the *crowd*

- *Electromagnetic wave* propagates through what??? What is "moving"/oscillating?

~~*Ether*~~...so it was (incorrectly) thought in 19th century before Einstein

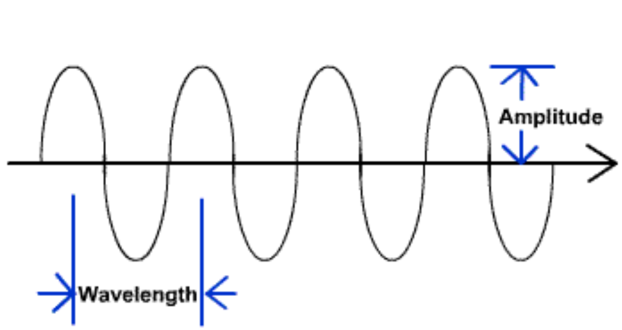
Michelson & Morley (1887): there is no Ether!

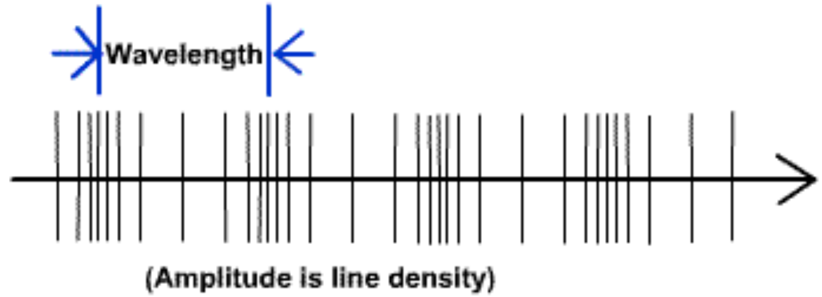


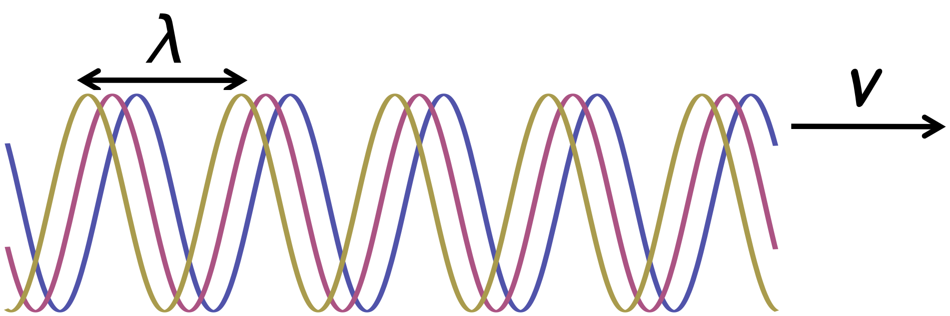
Waves primer: basics

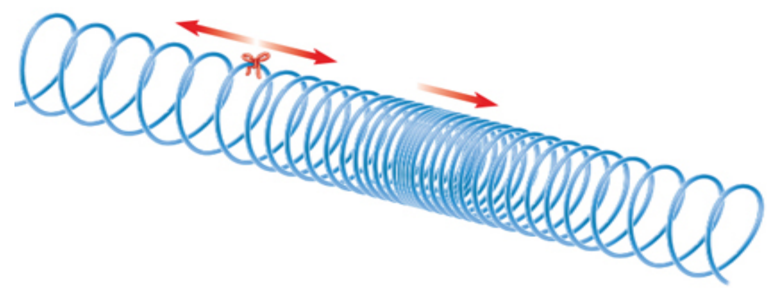
- periodic *(spatially-temporally extended)* disturbance

  e.g., sound, water, stadium, EM waves (in gas, liquid, solid, people, vacuum)









$$\mathcal{E} = \mathcal{E}_0 \cos(kx - \omega t) = \mathcal{E}_0 \cos[k(x - vt)]$$

- *frequency:* $\omega = 2\pi\nu$
- *wavevector:* $k = 2\pi/\lambda$
- *phase velocity:* $\omega = v_p\, k$

Interference

- key wave property: *interference*

- constructive
  destructive