Maxwell's Equations Predict Speed of EM Waves

$$\text{Wave speed } c = \omega/k = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

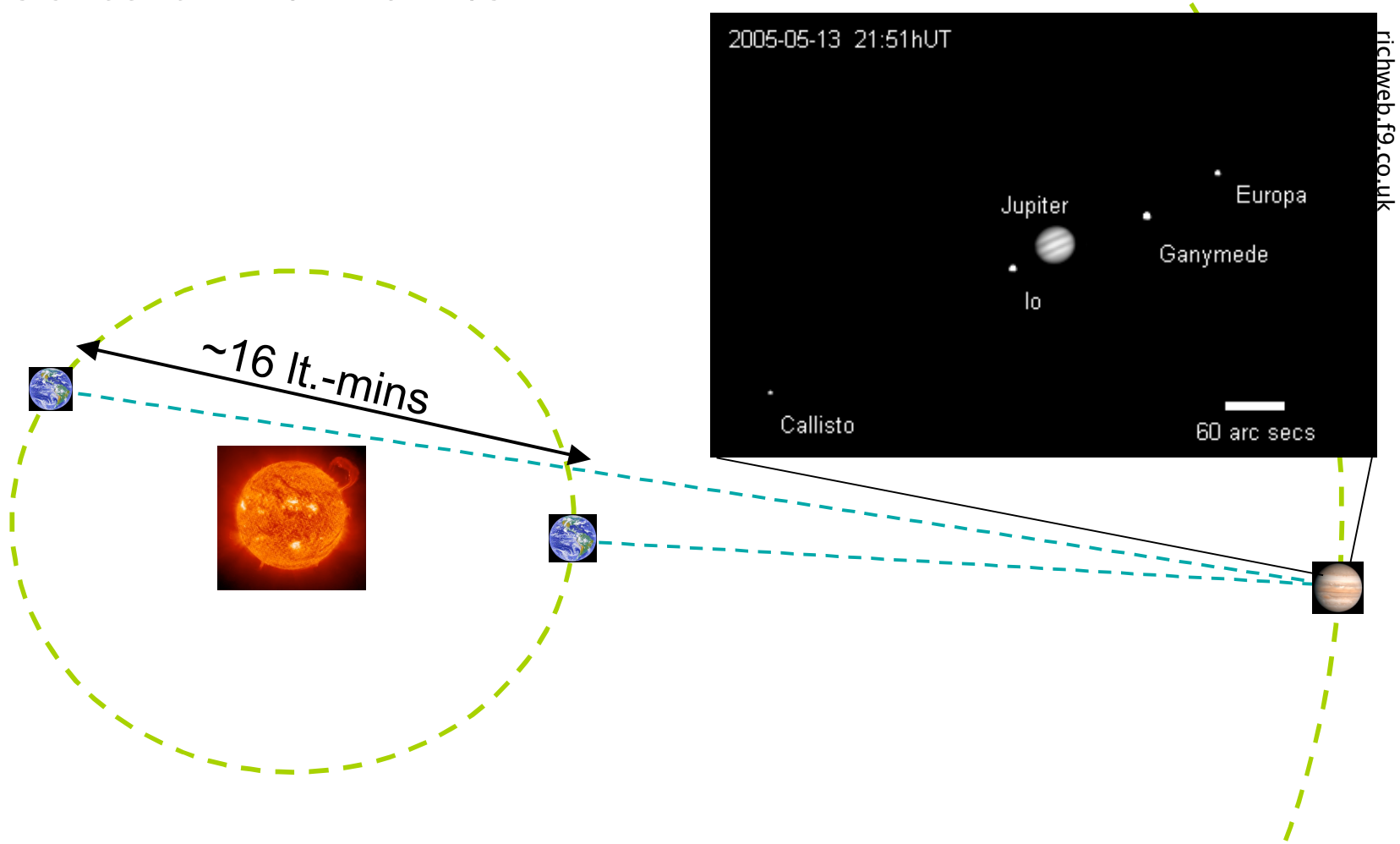
$$= \frac{1}{\sqrt{(8.85\times10^{-12} C^2 N^{-1} m^{-2})(4\pi\times10^{-7} N s^2 C^{-2})}}$$

$$= 2.998 \times 10^8 \text{ m s}^{-1}$$

Also, magnitudes of E- & B-fields are related: E/B = c

Measuring *c*

O. Roemer (1670s, Denmark): Times of observed eclipses of Jupiter's moons deviated from periodic; deviation varied with Earth–Jupiter distance. $c \sim 2.3 \times 10^8$ m/s



Measuring *c*

1728: J. Bradley: stellar aberration (changes in apparent position of stars) due to Earth's rotation: *c* ~ 295,000 km/s

1846: H.L. Fizeau: shining light between the teeth of a rapidly-rotating toothed wheel: *c* ~313,000 km/s

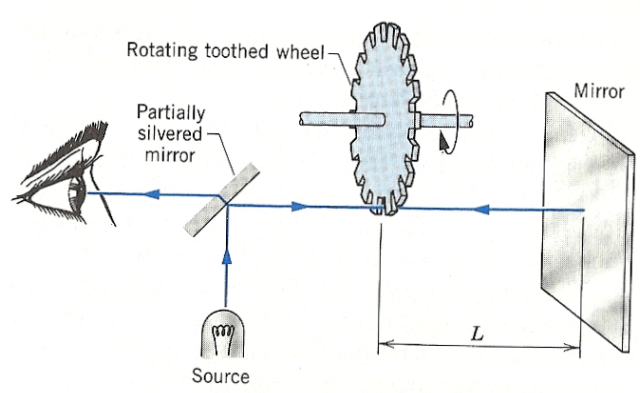
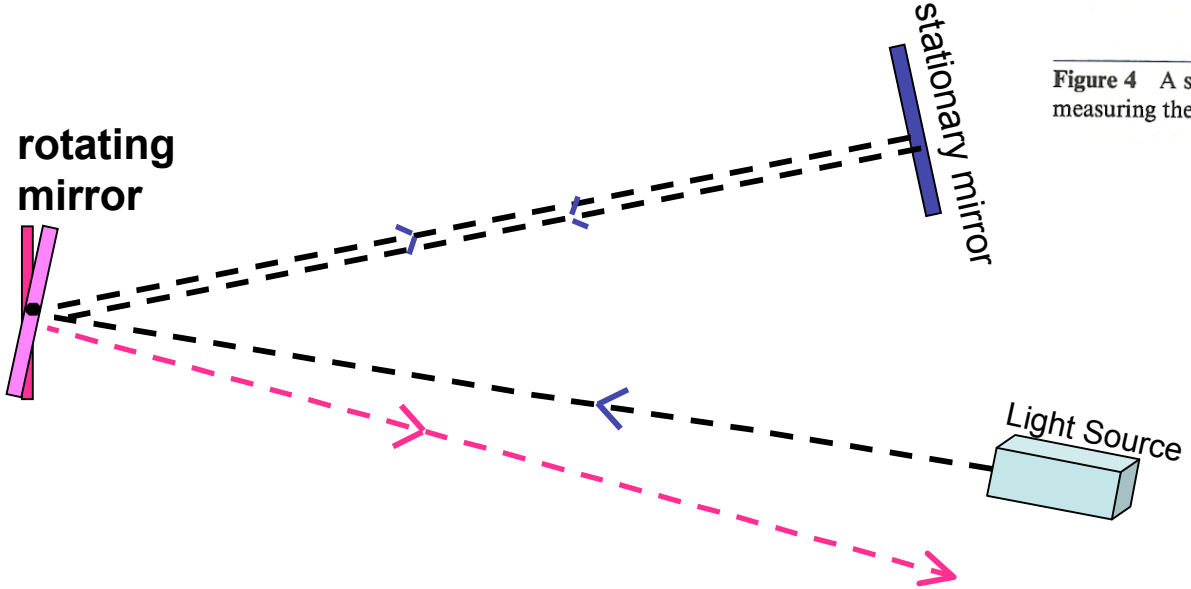
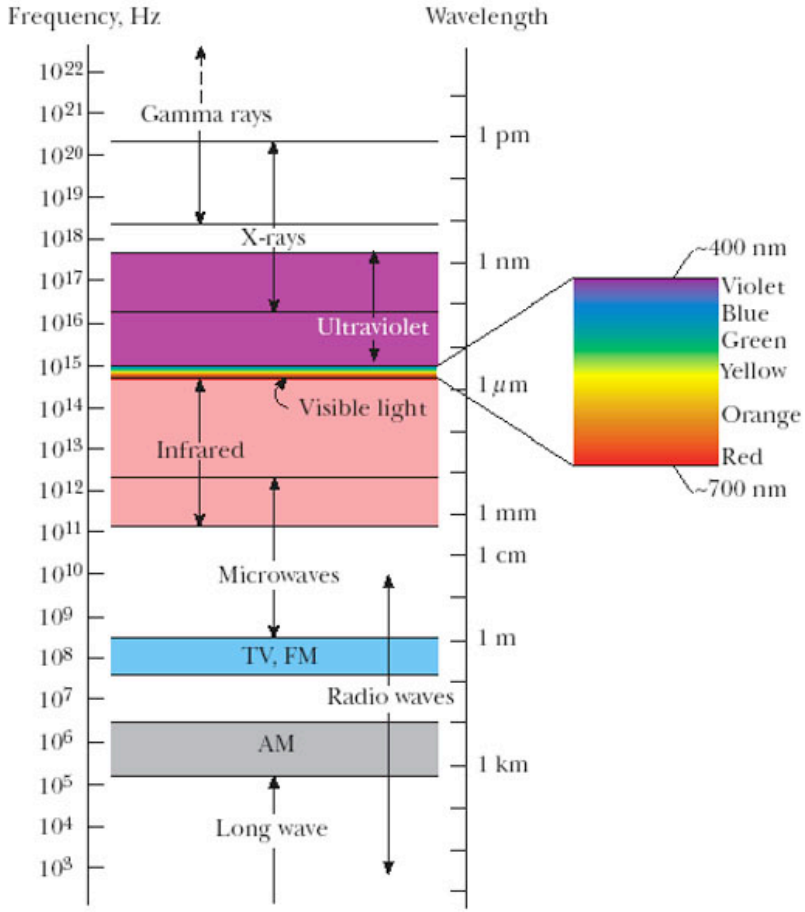


Figure 4 A schematic diagram of Fizeau's apparatus for measuring the speed of light.



Rotating mirrors: Foucault (1862), Michelson (1879): *c* ~ 300,000 km/s

The Electromagnetic Spectrum



1 micrometer (μm) = 10^{-6} m

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

1 angstrom (Å) = 10^{-10} m

ALL of these are forms of EM radiation, differing only in λ or f:

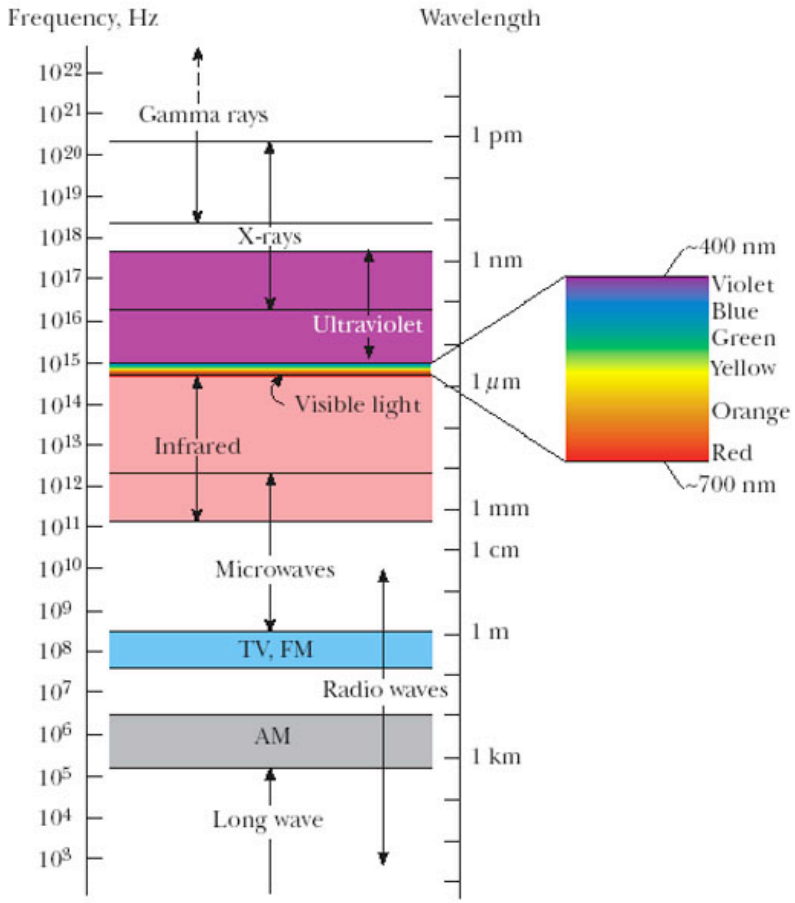
$$c = f\lambda$$

Visible light:

Blue/Violet light: λ ~ 400 nm, f ~ 7×10^{14} Hz

Red light: λ ~ 700nm, f ~ 4×10^{14} Hz

The Electromagnetic Spectrum



1 micrometer (μm) = 10^{-6} m

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Microwaves: cell phones, communication: λ ~ few cm

Broadcast TV, ch. 14-83: 440-884 MHz (UHF)

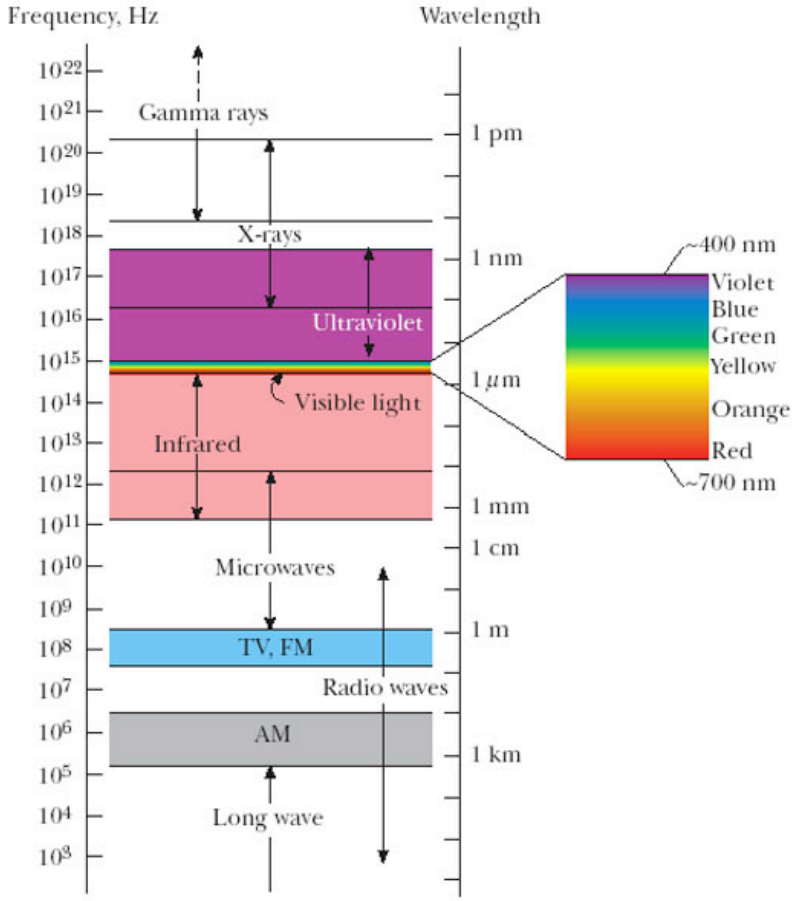
Broadcast TV, ch 8-13: 174-210 MHz (VHF-III)

FM Radio: 87.5-107.9 MHz (VHF-II)

Broadcast TV, ch. 2-7: 55-83 MHz (VHF-I)

AM Radio: 520-1700 kHz

The Electromagnetic Spectrum



1 micrometer (μm) = 10^{-6} m

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

1 angstrom (Å) = 10^{-10} m

Ultraviolet = UV

λ ~ 400 nm to ~ 10 nm

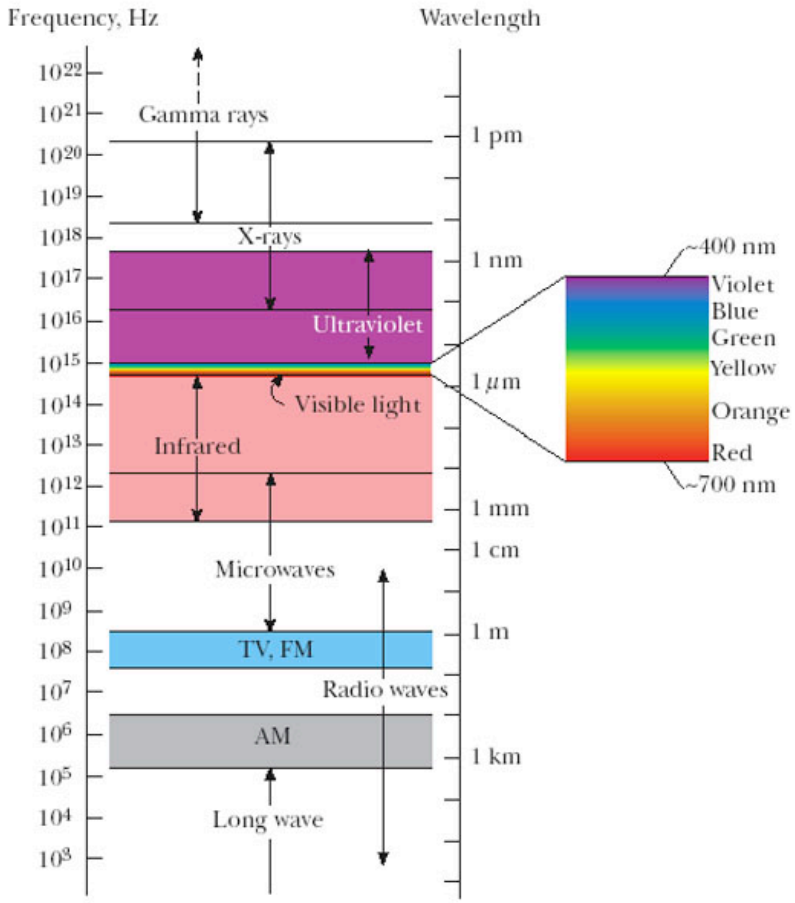
f ~ 8×10^{14} to 3×10^{16} Hz

Infrared=IR

λ~a few mm to ~700 nm

f ~ 10^{11} to 4×10^{14} Hz

The Electromagnetic Spectrum



1 micrometer (μm) = 10^{-6} m

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Gamma-rays: assoc. with nuclear decay

X-rays: highest-energy atomic transitions

Energy transport

As the EM wave propagates, it will transport energy

INTENSITY, I: rate at which energy is transported across a unit area (Power/Area = (Energy/Time) / Area)

Energy transport

Plane wave: I does not change

But if the origin is a point source, and emission is isotropic: wavefronts are expanding spheres.

intensity moving through a given point in space:

$I = \text{power/area} = P/(4\pi r^2)$

Energy transport

"Solar Constant": Intensity of sunlight at the radius of Earth's orbit (above atmosphere):

$I = 4x10^{26}W/(4\pi(1.5x10^{11}m)^2) = 1370\ W/m^2$

Sunlight at ground ~1000 W/m^2 (due to scattering, absn.)

At Saturn's orbit (d = 9.5 AU = 9.5x farther away from the Sun than the Earth is):

$I = 4x10^{26}W/(4\pi(1.4x10^{12}m)^2) = 15.6\ W/m^2$

Lasers: typ. MW/m^2 (which is why lasers can be very hazardous)

Doppler Effect for EM Waves

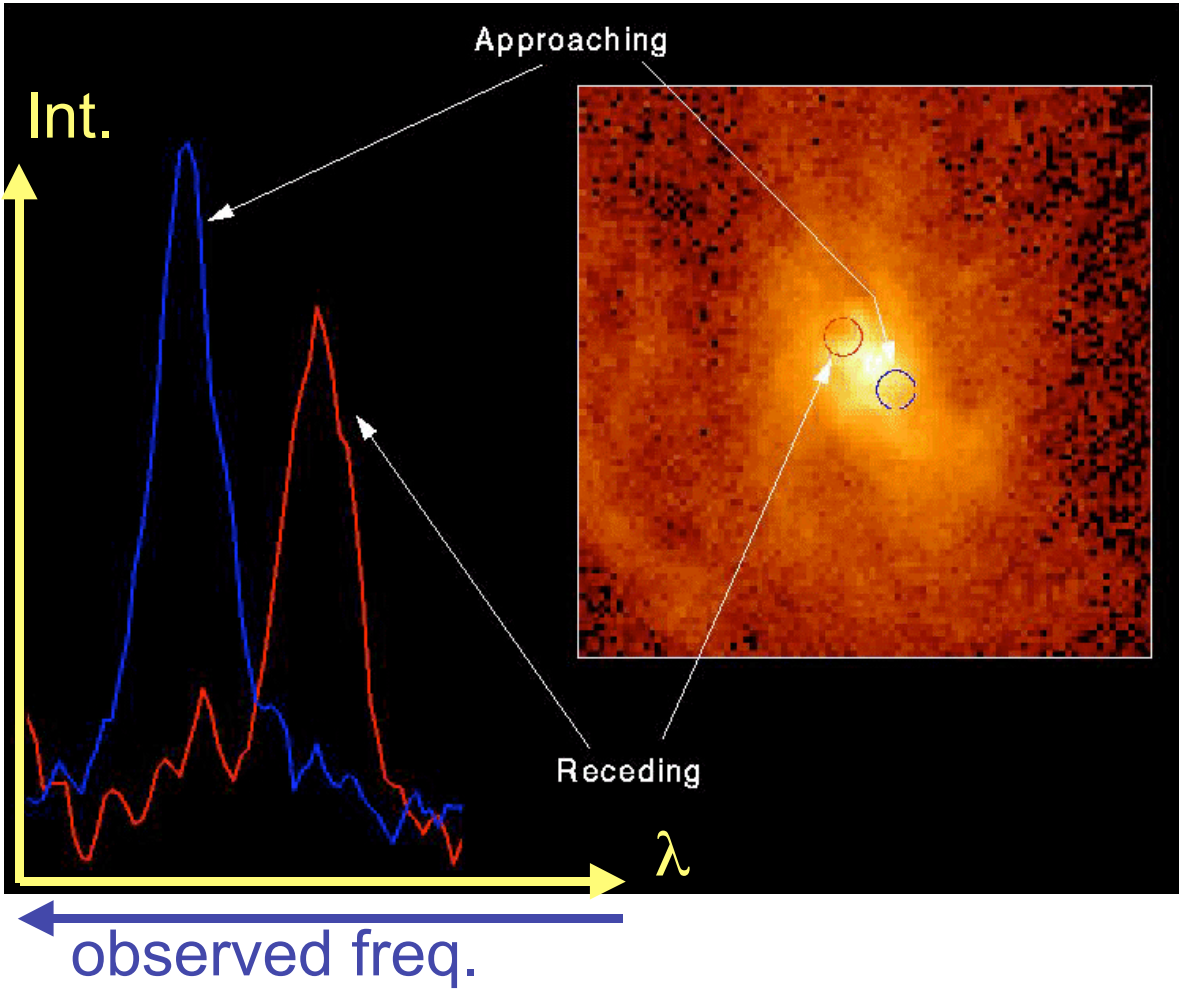
$$f_o \approx f_s \left(1 \pm \frac{u}{c}\right)$$

- f_o is the observed frequency
- f_s is the frequency emitted by the source
- u is the *relative speed* between the source and the observer
- The equation is valid only when u is much smaller than c
- Plus sign: src-observor distance decreasing
- Minus sign: src-observor distance increasing

Doppler Effect for EM Waves

Application: measuring rotation in galaxies

Optical emission lines from stars and gas in M87:



--- --- lab demos, then some final thoughts --- ---

i.e., material which is not covered on the final exam but is important nonetheless….

Capacitors & Inductors in AC circuits

Inductors dislike change (in current). When current varies rapidly (high frequency *f*), it becomes suppressed by the inductor.

L = low-pass filter: High freq.=suppressed
Low freq = okay

Capacitors: When *f* is high, there's less time available to charge a capacitor, so ΔV_C is low and opposition to current is low. When *f* is low (*f*=0 for DC), current can drop to 0.

C = high-pass filter: High freq.=okay
Low freq = suppressed

Application of Inductive and Capacitive Circuits

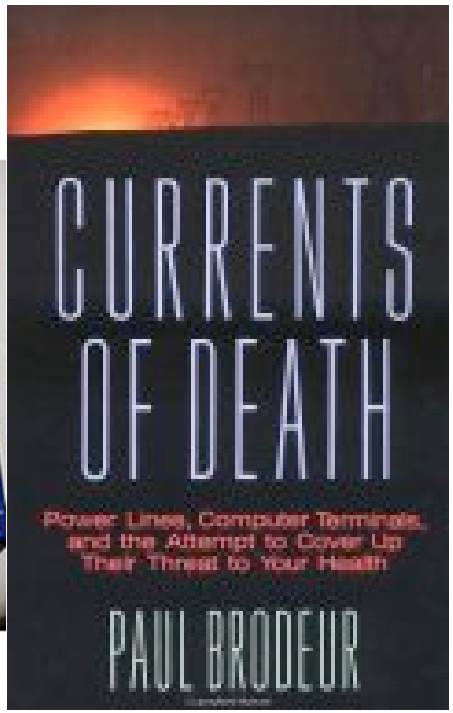
High-pass and low-pass filters in stereo systems; *f* = freq of digitized sound waves

Tweeters: Capacitive circuit: high-pass filter. Low-frequency variations suppressed

Woofers: Inductive circuit: low-pass filter. High-frequency variations are suppressed

Microwave Ovens, Power Lines, Cell Phones

… vs. Junk Science & Ignorance



Sources: "Voodoo Science" by Robert Park, quackwatch.org, skepdic.org, badscience.net

Magnetic Therapy?

Magnetic therapy bracelets, magnetic shoes, etc. are advertised to improve blood circulation, relieve pain, give you more free energy, etc. The main selling point is usually with regard to influencing/increasing blood circulation, because red blood cells contain hemoglobin, which contains Fe.

However, hemoglobin is not ferromagnetic; the Fe cannot participate in forming magnetic domains.

The iron represents 0.4 percent, by weight, of the molecule
The hemoglobin in the blood is not analogous to a tiny magnet

If hemoglobin contained large quantities of ferromagnetic iron it would be simple to separate red blood cells from other bloods cells with a magnet. But magnetic fields do not affect blood flow!

Multiple scientific studies: any effect from wearing a small static magnet is no better than placebo

* Researchers at the New York College of Podiatric Medicine have reported negative results in a study of patients with heel pain. Over a 4-week period, 19 patients wore a molded insole containing a magnetic foil, while 15 patients wore the same type of insole with no magnetic foil. In both groups, 60% reported improvement, which suggested that the magnetic foil conveyed no benefit [5]. (M. Caselli et al., 1997) Journal of the American Podiatric Medical Association

* Researchers at the VA Medical Center in Prescott, Arizona conducted a randomized, double-blind, placebo-controlled, crossover study involving 20 patients with chronic back pain. Each patient was exposed to real and sham bipolar permanent magnets during alternate weeks, for 6 hours per day, 3 days per week for a week, with a 1-week period between the treatment weeks. No difference in pain or mobility was found between the treatment and sham-treatment periods [6]. (EA Collacott et al, 2000, JAMA)

* Researchers at the Mayo Clinic compared the effects of wearing magnetic or sham-magnetic cushioned insoles over an 8-week period by 101 people with heel pain and found no difference between the treatment and control groups [7]. (NH Winemiller et al, 2000, JAMA)

Magnets have also been claimed to increase circulation. This claim is false. If it were true, placing a magnet on the skin would make the area under the magnet become red, which it does not. Moreover, a well-designed study that actually measured blood flow has found no increase. The study involved 12 healthy volunteers who were exposed to either a 1000-gauss magnetic disk or an identically appearing disk that was not magnetic. No change in the amount or speed of blood flow was observed when either disk was applied to their arm. [8]. The magnets were manufactured by Magnetherapy, Inc, of Riviera Beach, Florida, a company that has been subjected to two regulatory actions. (HN Mayrovitz et al 2002, Scient. Rev. of Altern. Med.)

(from quackwatch.org)

Magnetic Therapy?

For a single magnetic dipole, B(r) is prop. to $1/r^3$

So for a ~0.4-cm magnet with B=0.005 T at its surface (typical fridge magnet strength), B ~ B_{Earth} after only a couple cm.

Magnetic Therapy?

Numerous legal actions (e.g., from the FTC) in the late '90s and early '00s against companies making these false claims about these products.

see http://www.quackwatch.org/04ConsumerEducation/QA/magnet.html

BTW, Copper is not a ferromagnetic material.

Can electromagnetic radiation be harmful?

Energy of individual photons: $E = hf$

$h = 6.6 \times 10^{-34}$ J s (Planck's constant)

Energy of individual photons: E = h*f*

h = 6.6 x 10^{-34} J s (Planck's constant)

60Hz	f=60 Hz	E=4x10^{-32} J
Radio	f=10^{8} Hz	E=7x10^{-26} J = 4x10^{-7} eV
Microwave	f=10^{10} Hz	E=7x10^{-24} J = 4x10^{-5} eV
Optical	f=5x10^{14} Hz	E=3x10^{-19} J = 2 eV
UV	f=10^{16} Hz	E=7x10^{-18} J = 44 eV
X-ray	f=10^{18} Hz	E=7x10^{-16} J = 4.4x10^{3} eV

Only UV & higher-energy photons are adequate to break chemical bonds and cause problems in cells.

Microwave continuum EM radiation may cause tissue to heat lightly -- increasing vibrations of molecules, but not breaking chemical bonds