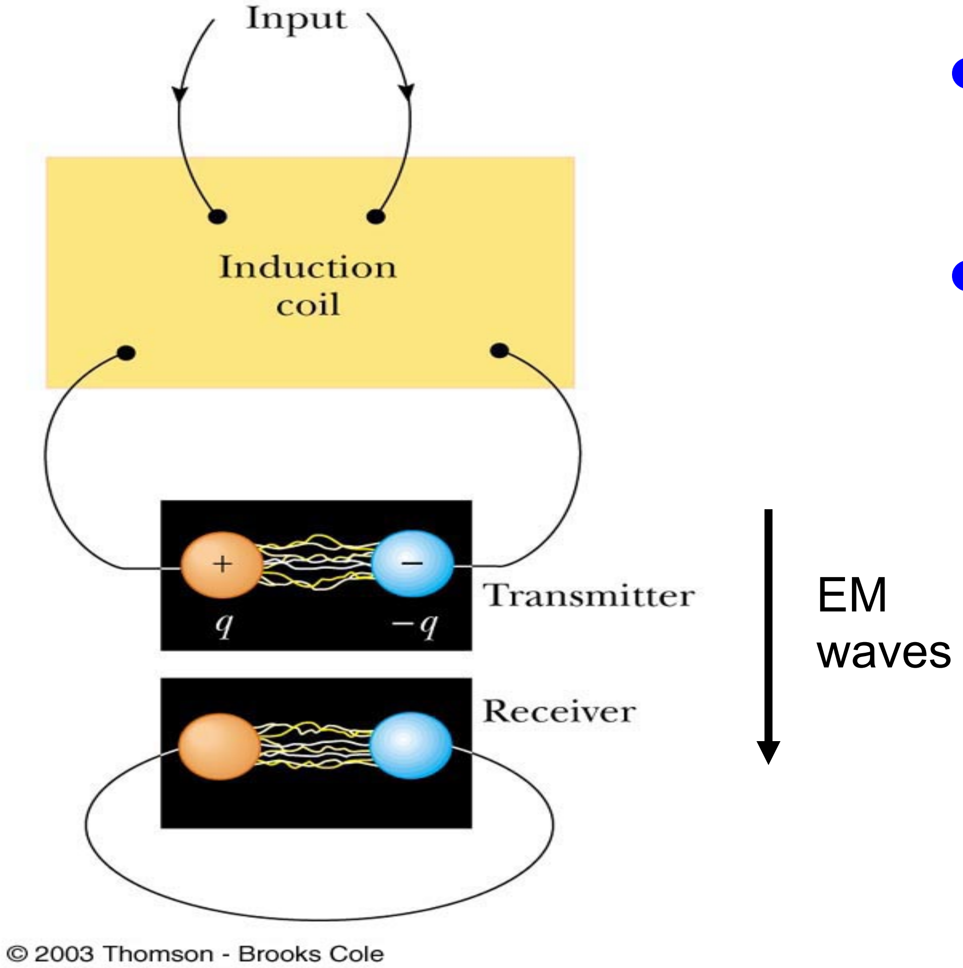
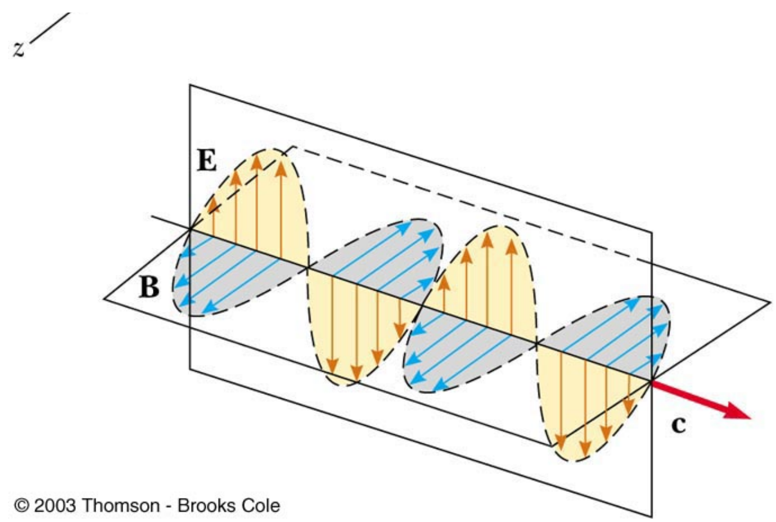
Announcements

- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM
  - Tues 12-3 PM
  - Wed 6-9 PM
  - Fri 10 AM-noon
- LON-CAPA #8 due Nov. 1
- 2nd hour exam on Tuesday Nov. 6
- Final Exam Tuesday Dec 11 7:45-9:45 AM

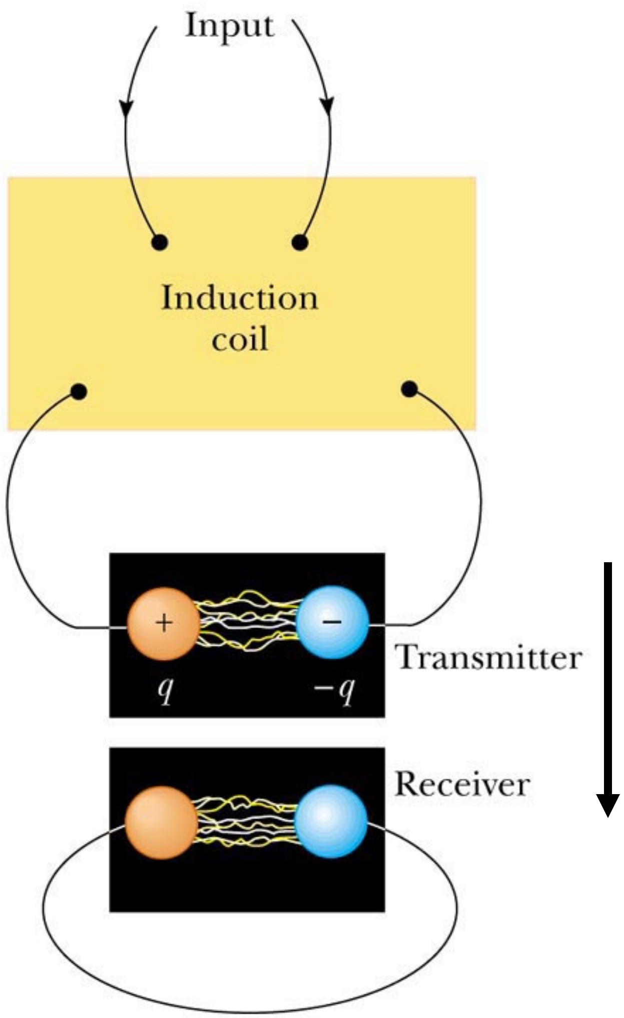
What we know



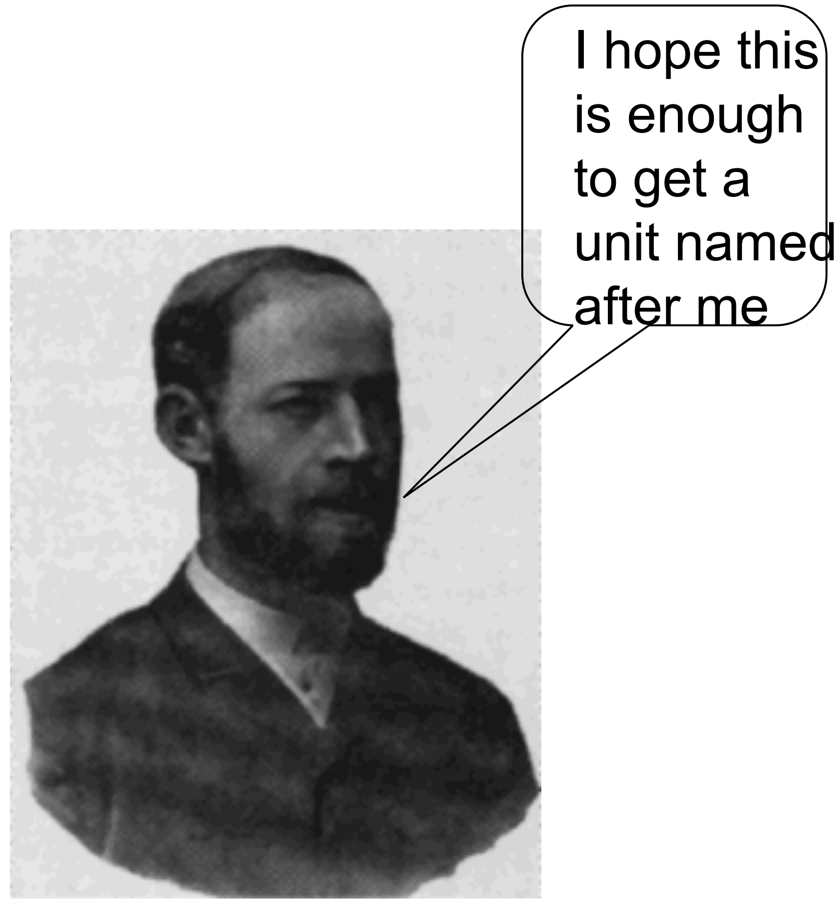
- Stationary electric charges produce electric fields
- Electric charges in uniform motion (currents) produce electric and magnetic fields
- Accelerated electric charges produce electric fields, magnetic fields, and electromagnetic waves



It was left to Heinrich Hertz to verify EM waves



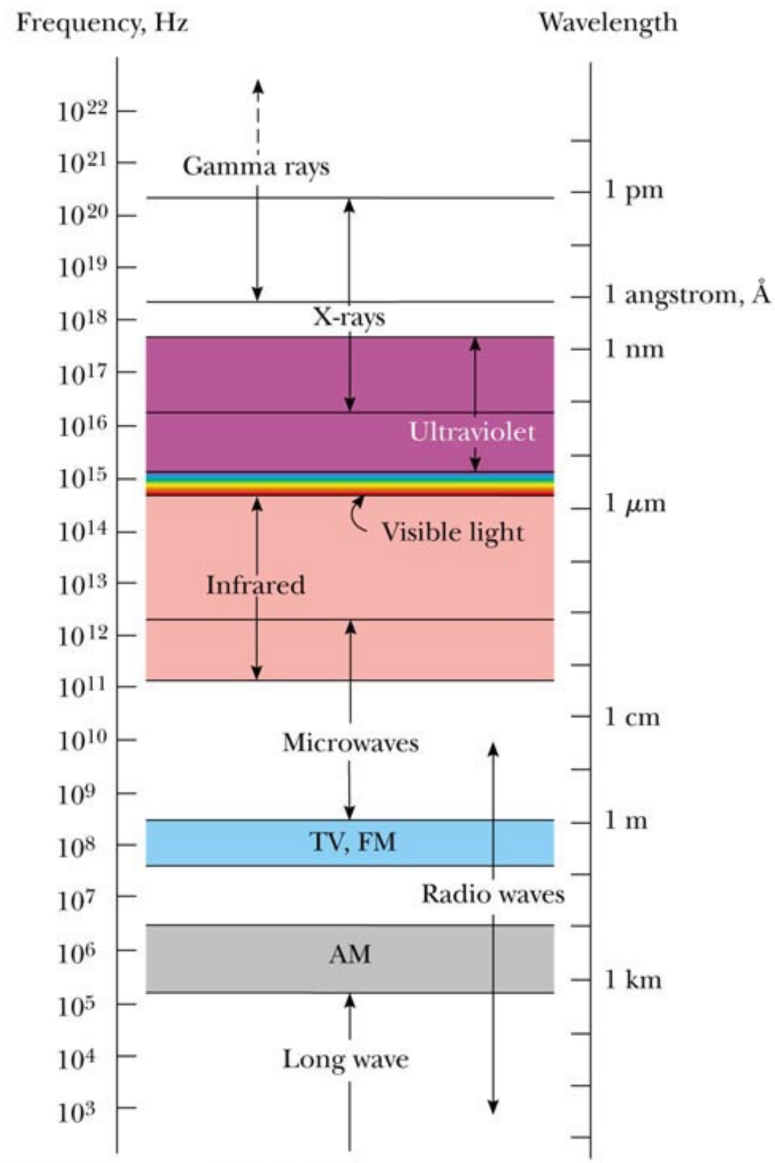
EM waves



…and of course the unit for frequency is Hertz

Electromagnetic spectrum

- All electromagnetic waves travel through vacuum with a speed c (3×10^8 m/s)
- For all EM waves, $c=\lambda f$ (true for any type of wave)
- $\lambda = c/f$
- The visible portion of the spectrum forms a tiny portion of the total EM spectrum



Clicker question

- In an electromagnetic wave, the electric and magnetic fields are oscillating

- A) perpendicular to each other and perpendicular to the direction of propagation of the wave
- B) perpendicular to each other and parallel to the direction of propagation of the wave
- C) parallel to each other and parallel to the direction of propagation of the wave
- D) parallel to each other and perpendicular to the direction of propagation of the wave

Clicker question

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- D) parallel to each other and perpendicular to the direction of propagation of the wave

Light has energy

- The sunlight incident on the Earth has an intensity of 1360 W/m^2
  - this energy is stored in the electric and magnetic fields of the electromagnetic waves
- Solar panels are an important way of capturing some of this energy
  - we remember from thermodynamics that no process for energy production can be 100% efficient
  - new solar panels are about 40% efficient
- Solar panels use something called the photoelectric effect to produce electricity
  - an explanation of this effect won Einstein his Nobel prize

which also explains why cell phones can not cause cancer

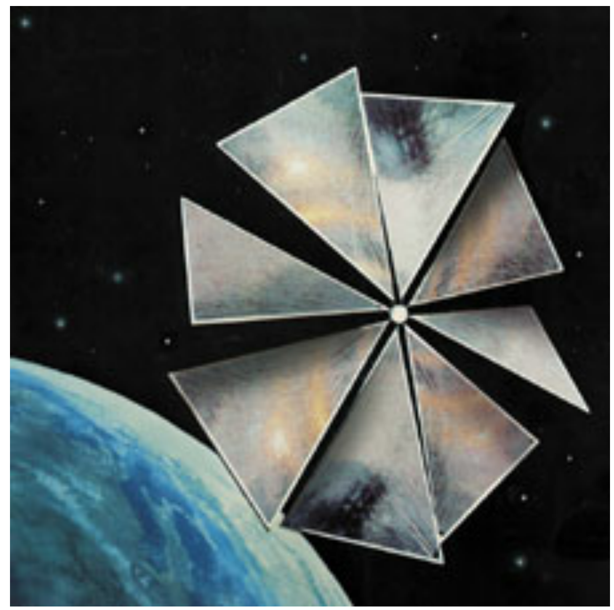
Light has momentum

- Tail(s) of a comet

from 'solar wind'

from light pressure

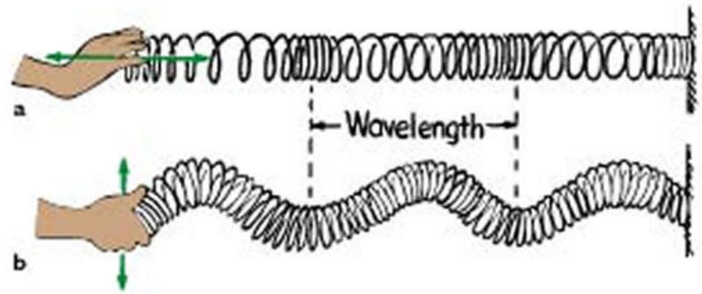
- solar sail



can use light pressure to sail around solar system

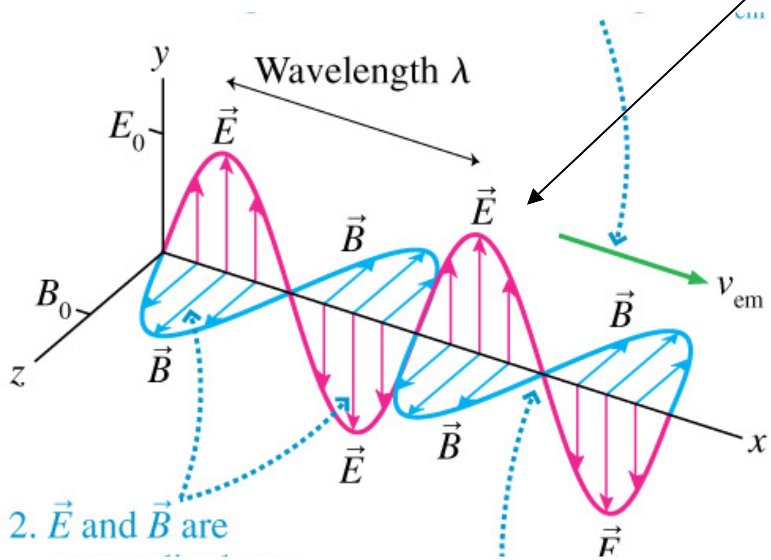
Polarization of a wave

- Consider a slinky
- I can send a wave down the slinky by
  - moving one end in and out
  - moving one end up and down
- The first type of wave is called a longitudinally polarized wave
- The second type is called a transversely polarized wave

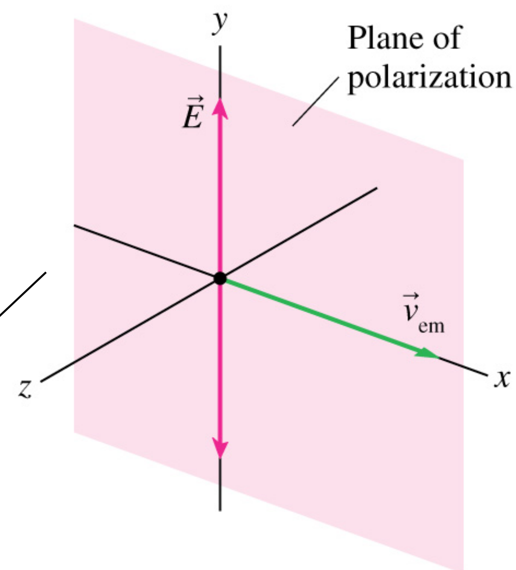


Polarization

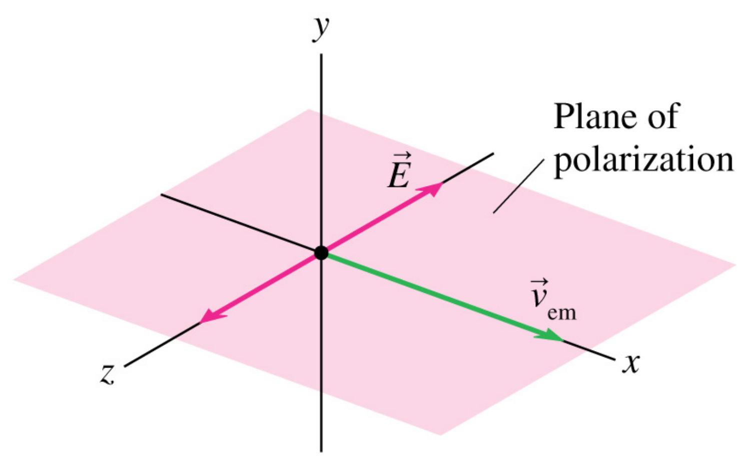
- An electromagnetic wave can also have a polarization
- Electromagnetic waves are always transversely polarized
- A particular electromagnetic wave may have its electric field oscillating in a certain orientation
- That is its plane of polarization



(a) Vertical polarization

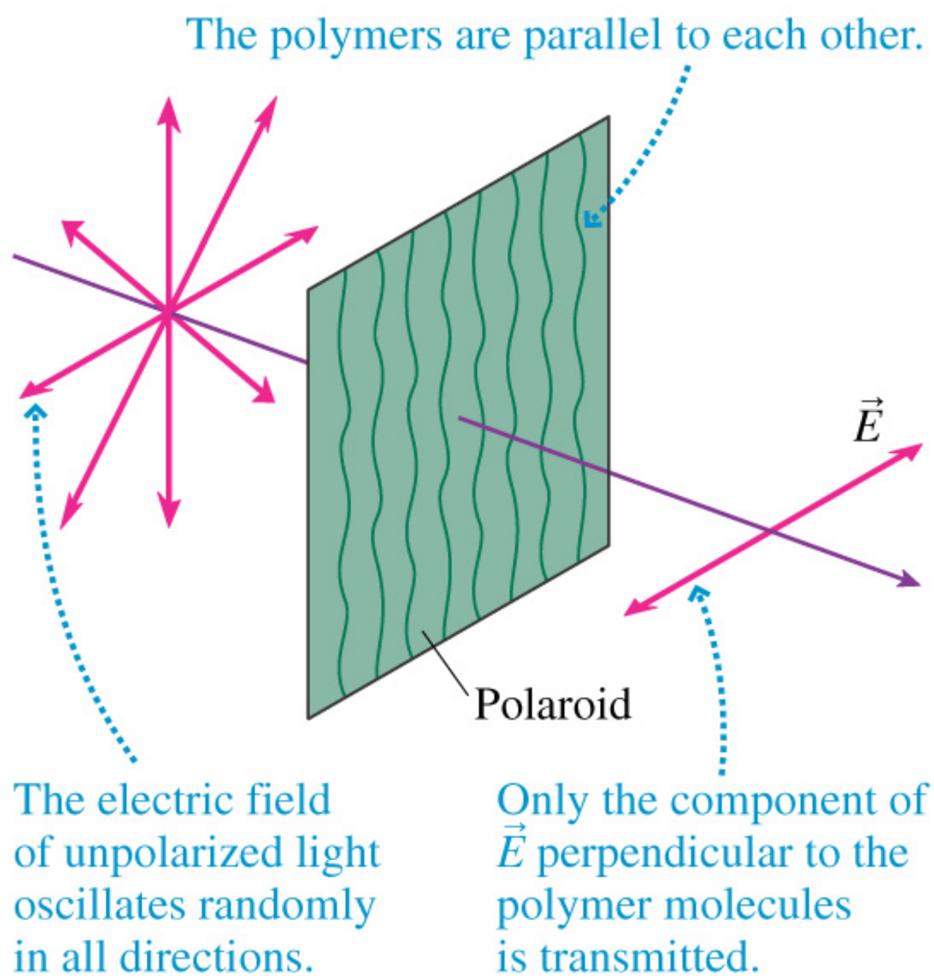


(b) Horizontal polarization



Polarizing filter

- Ordinary electromagnetic waves are unpolarized
  - the electric field vectors for each wave are in random (transverse) directions
- A polarizing filter lets in only those EM waves with a polarization in a particular direction
  - polymer chains are treated to make them conducting
  - electrons absorb energy from EM waves whose electric fields oscillate in the direction of the chains



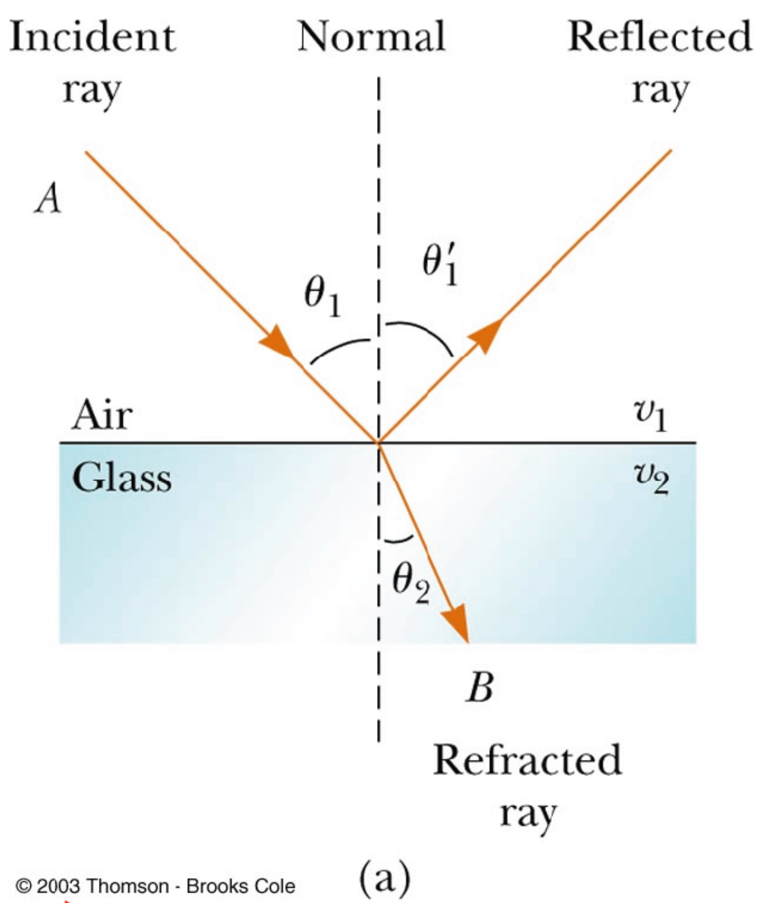
Two types of optics: geometric optics and wave optics

- There are two types of optics (or optical phenomena)
- Geometric optics
  - light moves in straight lines
  - can summarize everything by indicating direction of light using a ray
  - light behaves essentially the way a stream of particles (photons) would
- This works well for a number of phenomena
  - reflection
  - refraction
- …and allows us to understand the workings of
  - mirrors, thin lenses

- But our particle theory of light gives out when we try to understand phenomena like interference, diffraction and polarization
  - just doesn't work
- Have to resort to wave or physical optics
  - …and treat light like a wave
- For example, for study the diffraction and interference of light
  - not easy because of the short wavelengths of light involved ($4X10^{-7}$ m to $7X10^{-7}$ m)

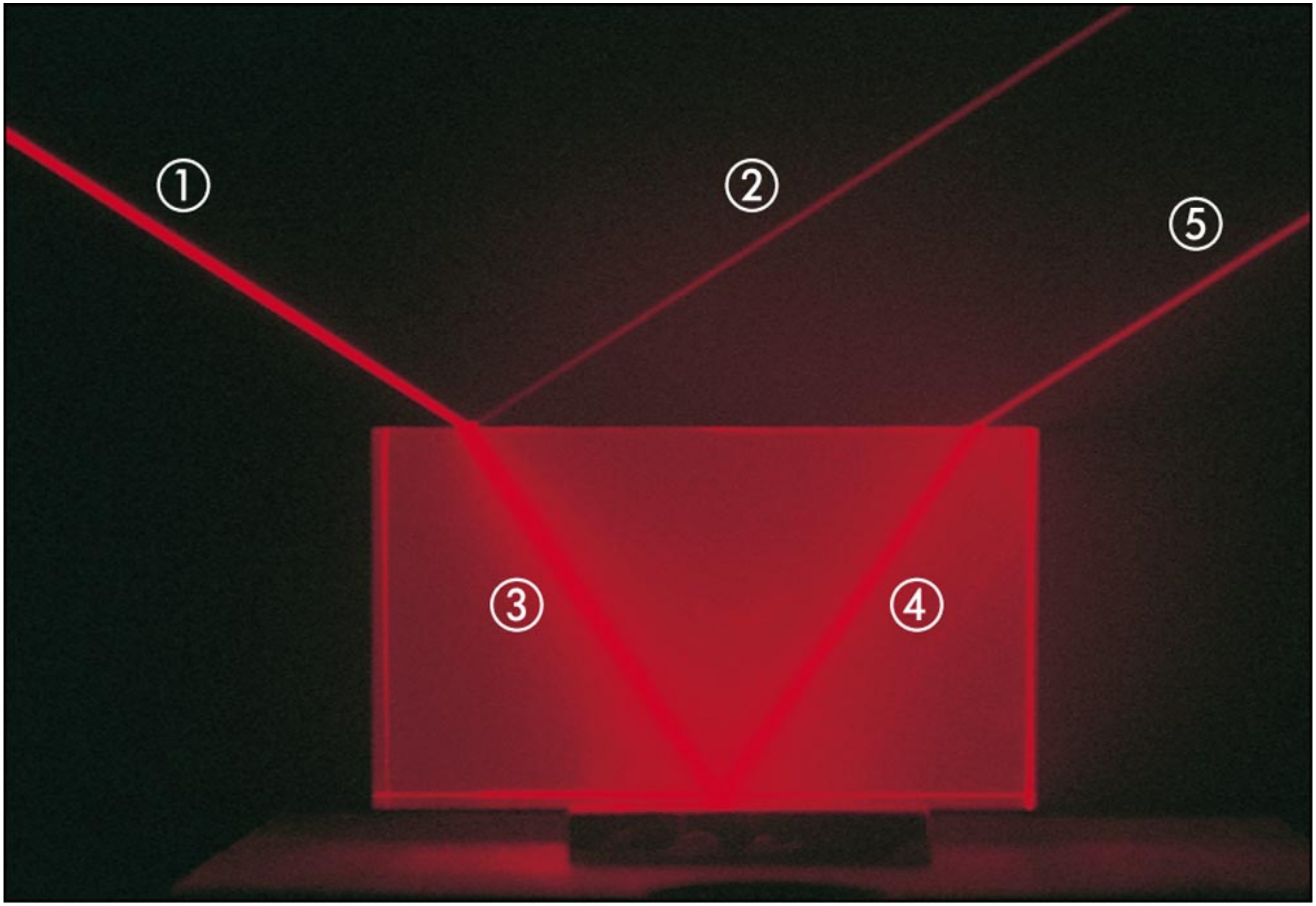
Geometric optics: Snell's law

- Light travels at a speed c in vacuum, but slower in other media
- Define n = c/v, where v is the speed that light travels in a given medium (glass, water, etc)
- So, as light travels from air to glass, its speed changes; its frequency does not, so its wavelength must
  - $\lambda_1 = \lambda_o/n$
- I can re-write the proportionality that we had before
  - $\sin \theta_1/\sin \theta_2 = v_2/v_1$
- as
  - $\sin \theta_1/\sin \theta_2 = n_2/n_1$
  - $n_1 \sin \theta_1 = n_2 \sin \theta_2$



Snell's law

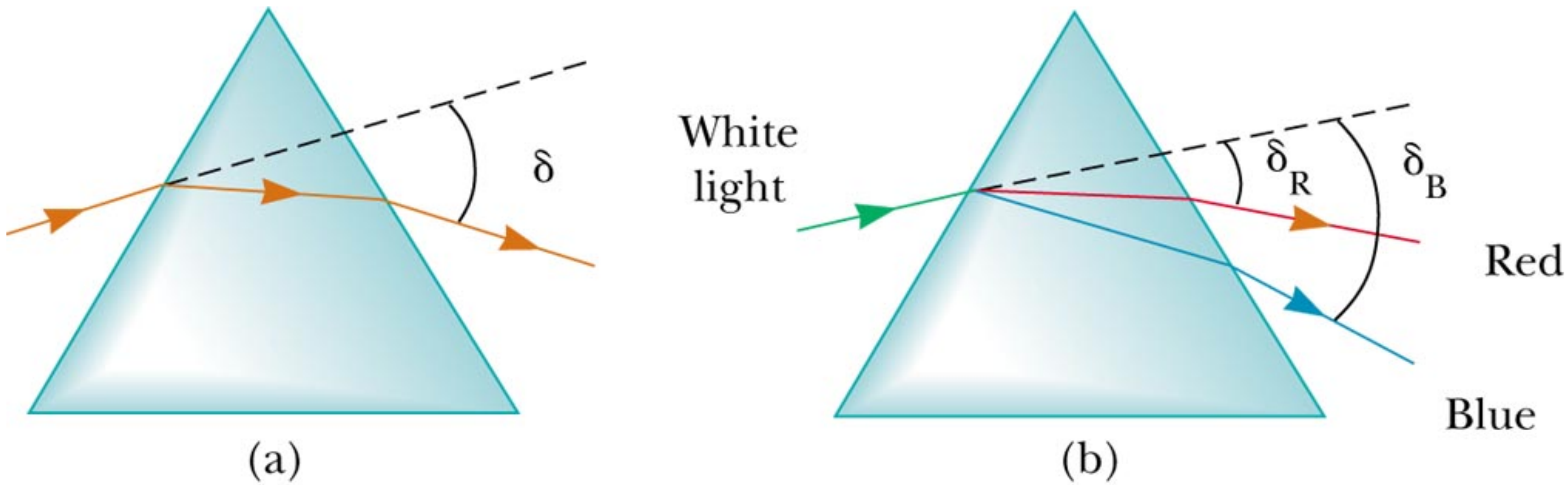
Example



Dispersion

red light passing through a prism

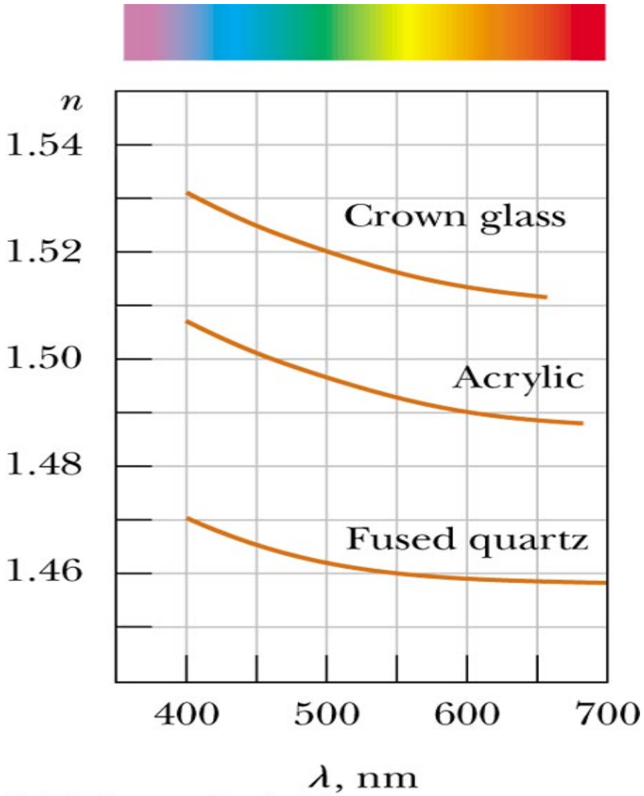
white light passing through a prism

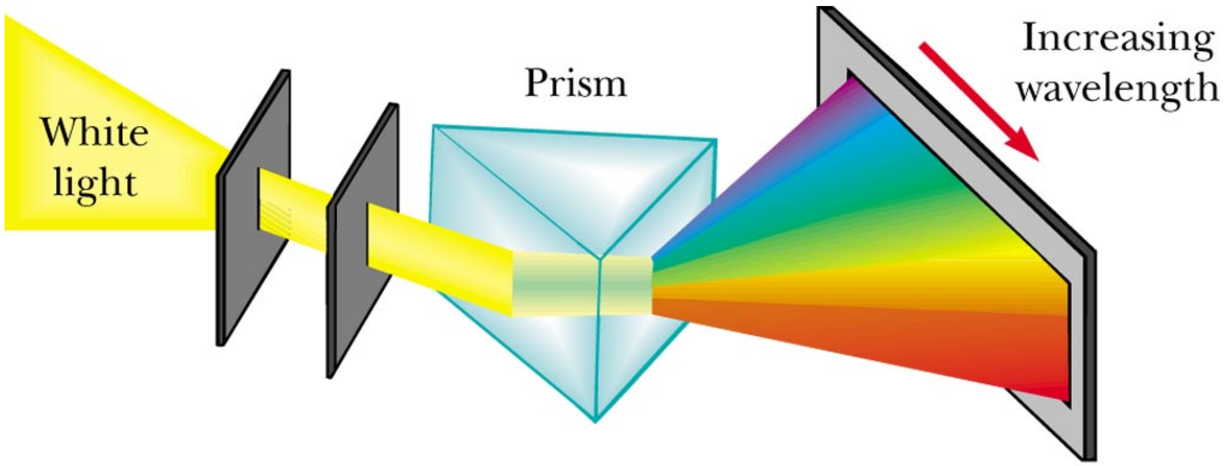


each wavelength has a different index of refraction and so refracts at a different angle

Dispersion

Index of refraction for blue light is larger than for red light,
so blue light bends more than red light

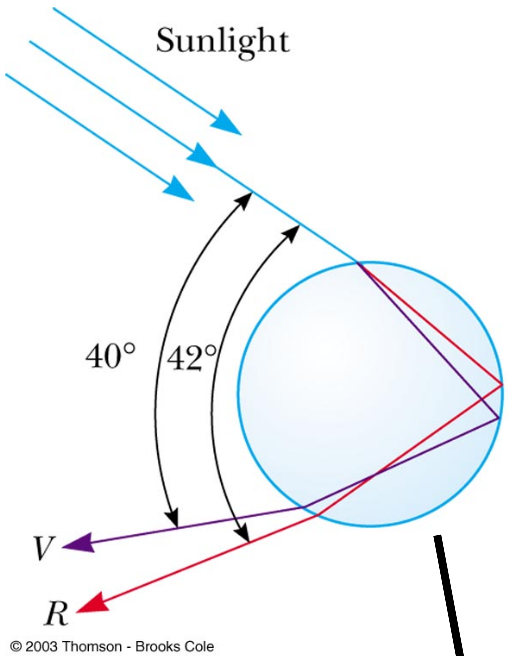




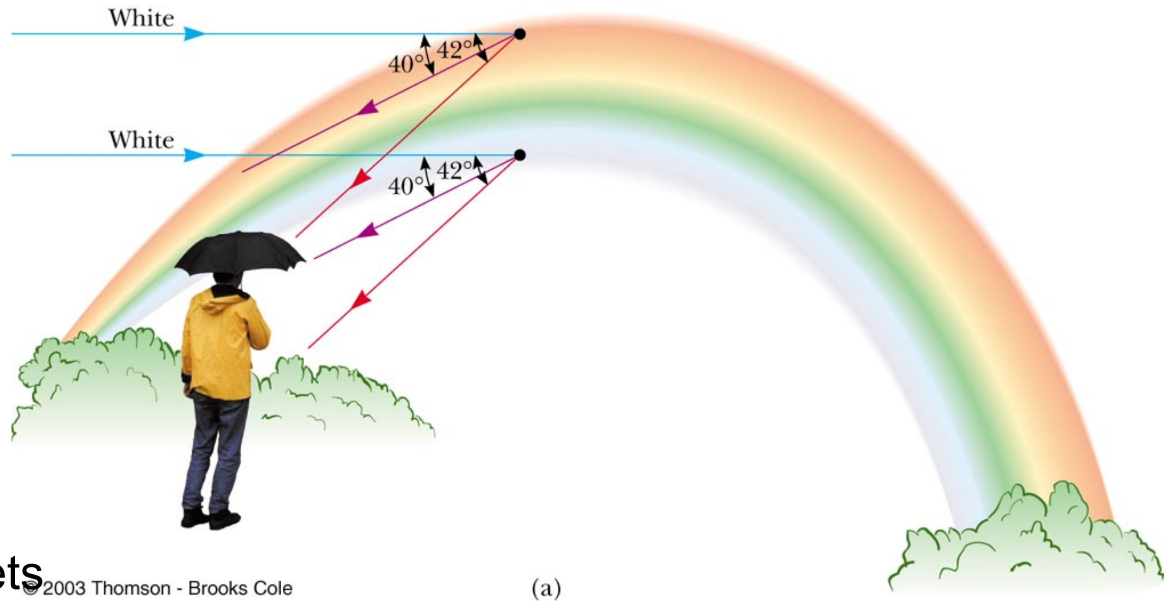
(a)

How rainbows form

red light from high in the sky reaches your eye; violet light from lower in the sky does the same



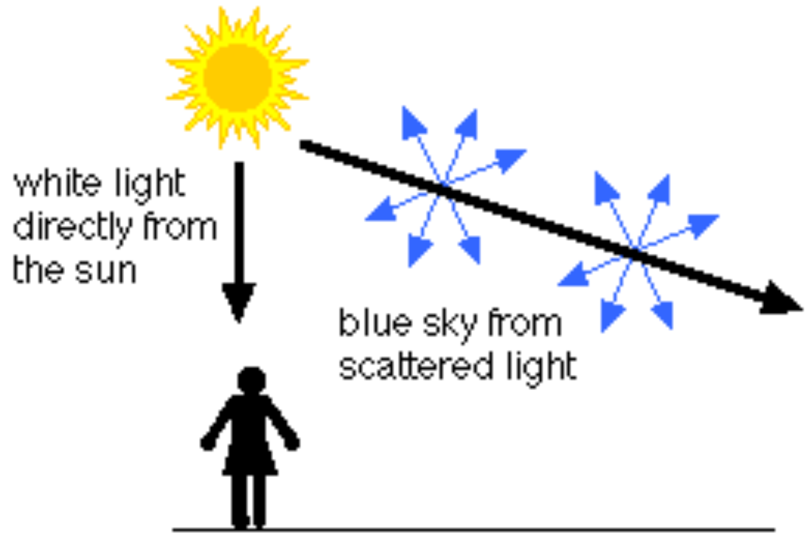
water droplets

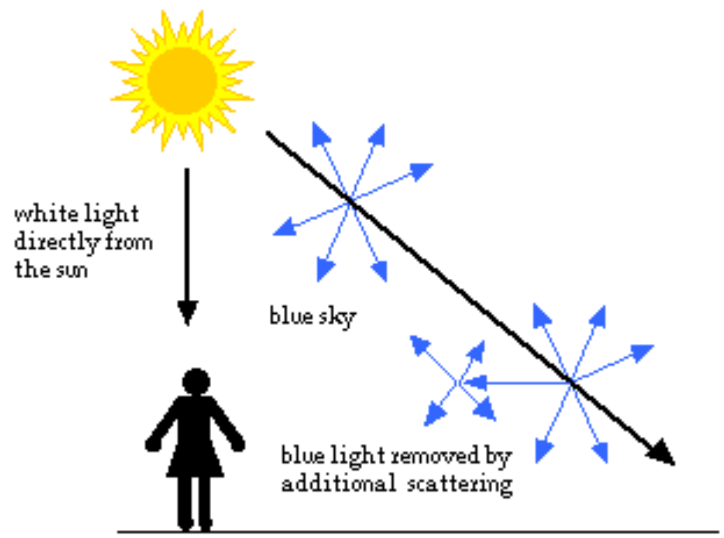


Sometimes there can be a double rainbow, when there are two internal reflections, but the order of colors will be reversed.

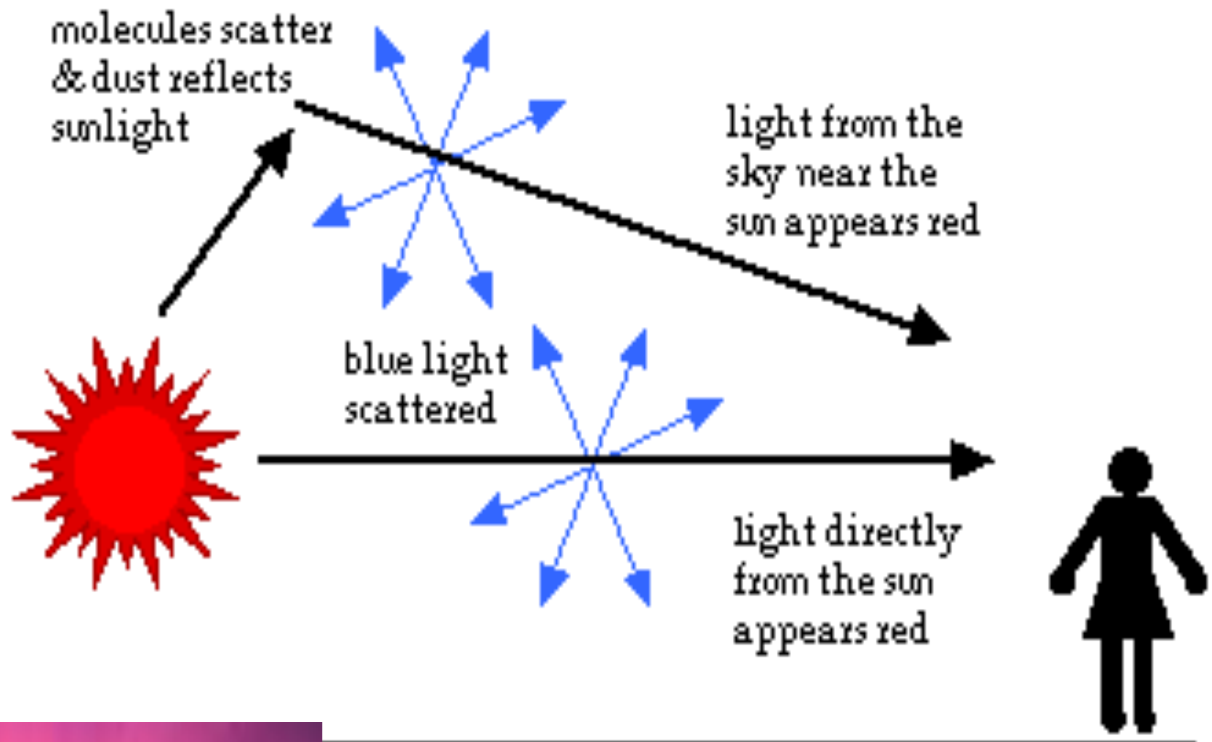
Why is the sky blue?

- Light from the Sun has all of the colors of the visible spectrum (but is peaked towards yellow)
- The cross section (probability) for scattering of light from air molecules goes as f^4 (frequency to the 4th power)
- So blue light is scattered preferentially and when you look away from the sun, all you see is the scattered blue component of sunlight
- The sky is paler towards the horizon



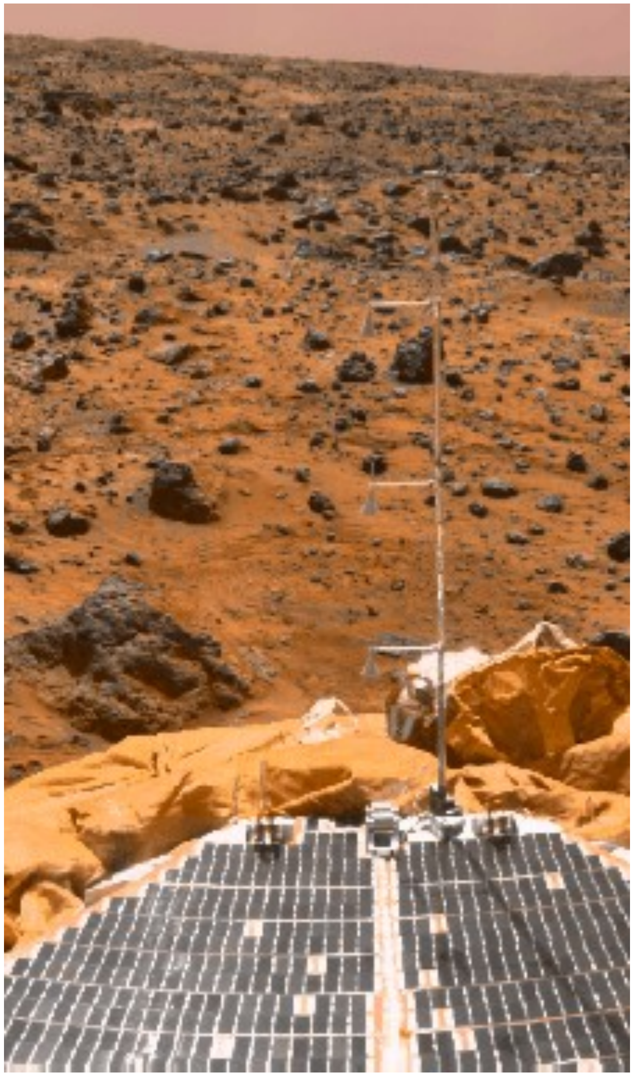


Why is the sunset red?

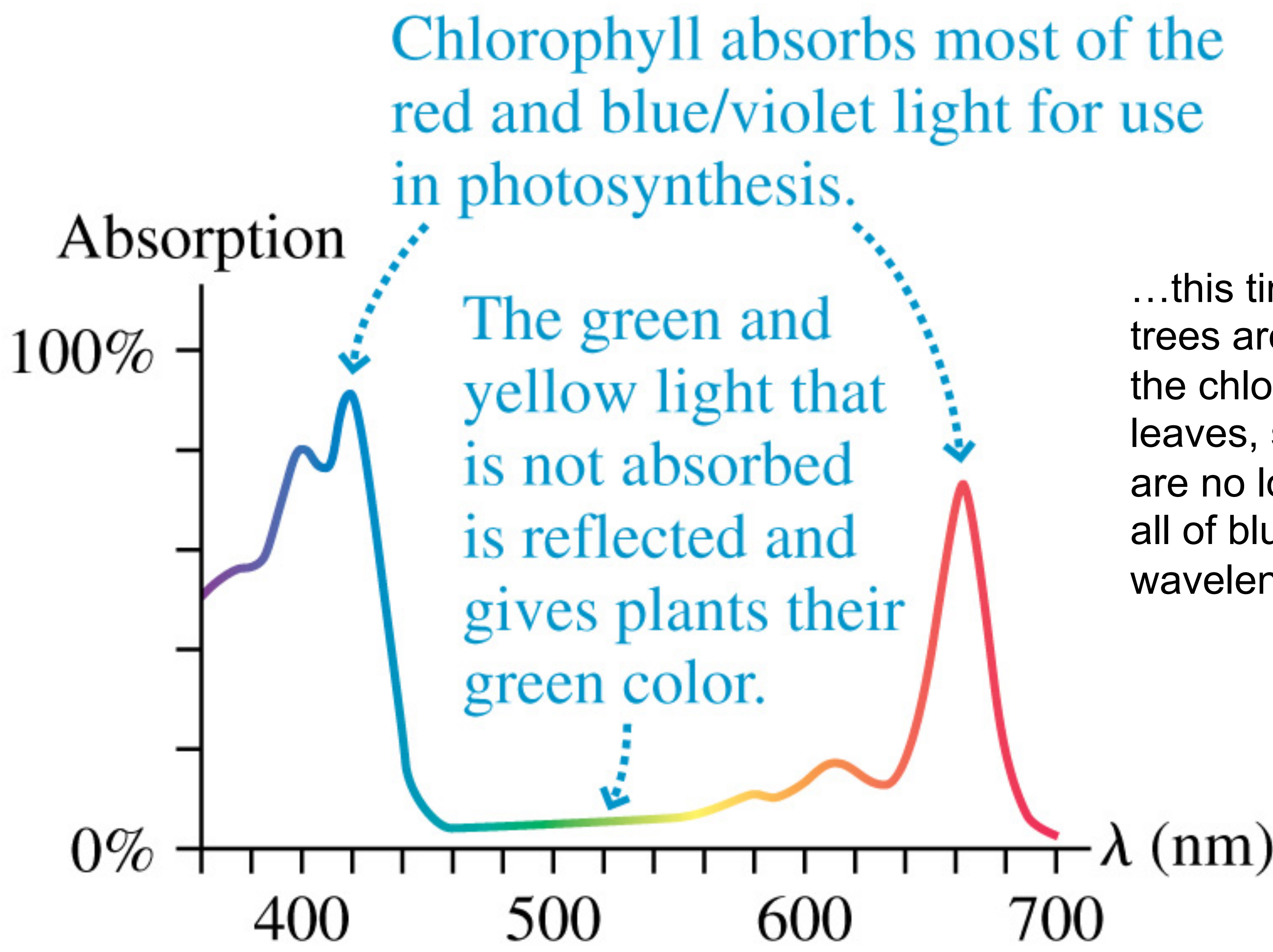


Sky on Mars

- Has a tan tint to it since there's usually a far amount of dust in the air, and the dust scatters the red light preferentially



Why are leaves green (sometimes)?



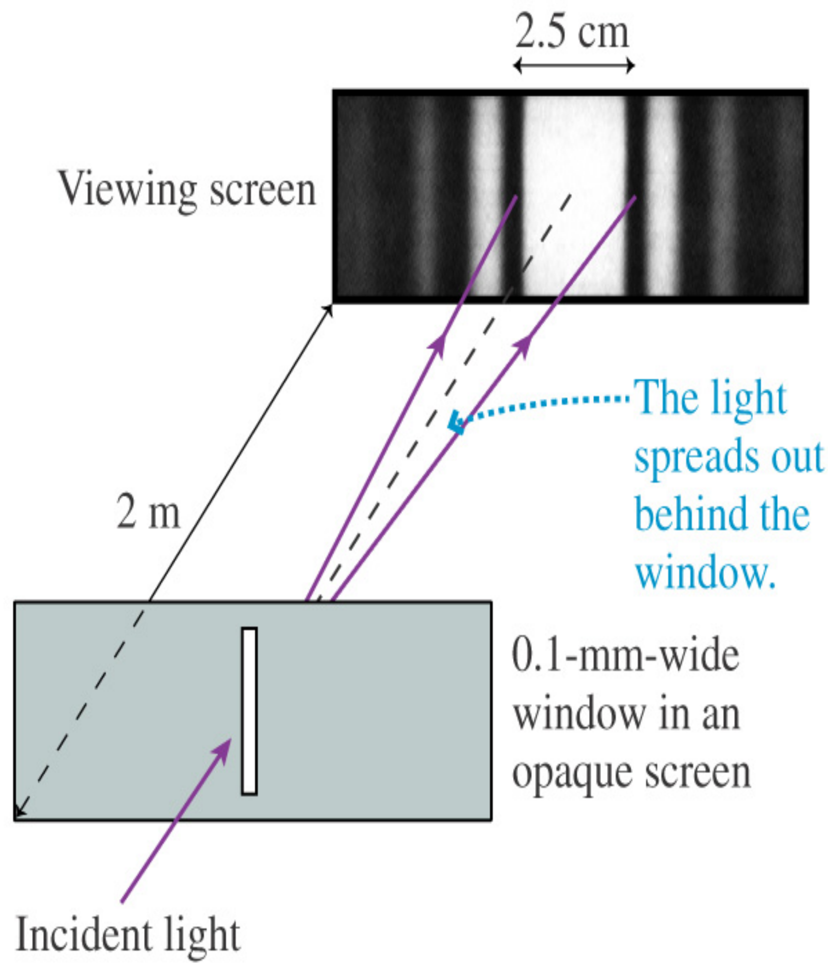
…this time of year, the trees are drawing back the chlorophyll from the leaves, so the leaves are no longer absorbing all of blue and red wavelengths

Why are clouds white?

- Clouds are made up of clusters of water droplets of a variety of sizes
- Tiniest clusters tend to reflect blue light, slightly larger clusters, green light…and so on
- The overall result is a white cloud
- Larger clusters of light absorb much of the light that falls on them
- Therefore clouds with a lot of large clusters (i.e. rainclouds) appears to be a dark gray

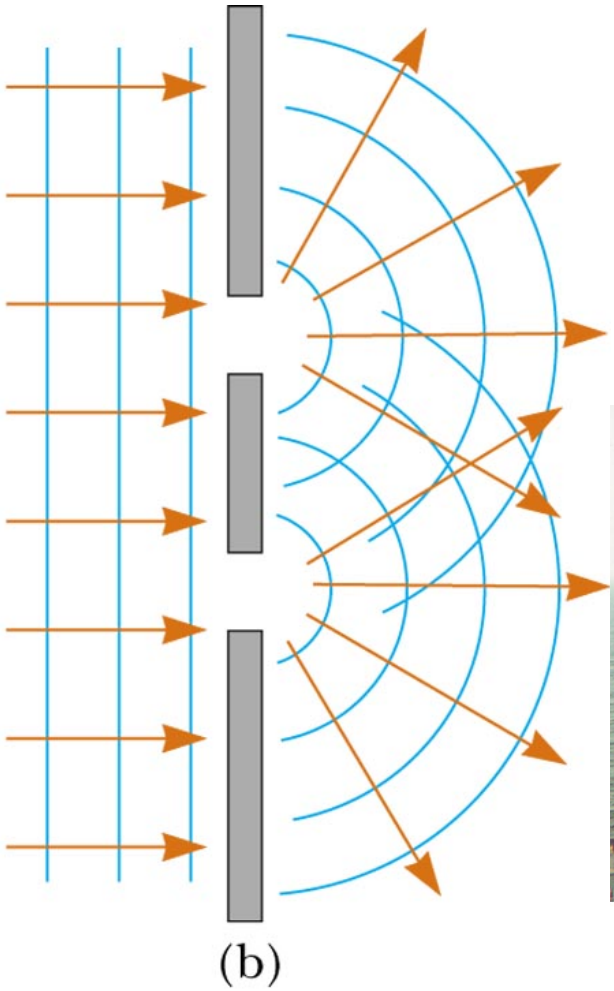
Wave optics: diffraction

- Like water waves passing through a breakwater, light waves spread out when passing through a narrow opening
- This is called diffraction
- We can say that the light waves spread out a great deal because they are passing through a very narrow opening
  - compared to the size of their wavelength



There is a broad central maximum, where the light spreads out, of width~$2\lambda L/a$, where λ is the wavelength of the light, L is the distance to the screen and a the width of the opening

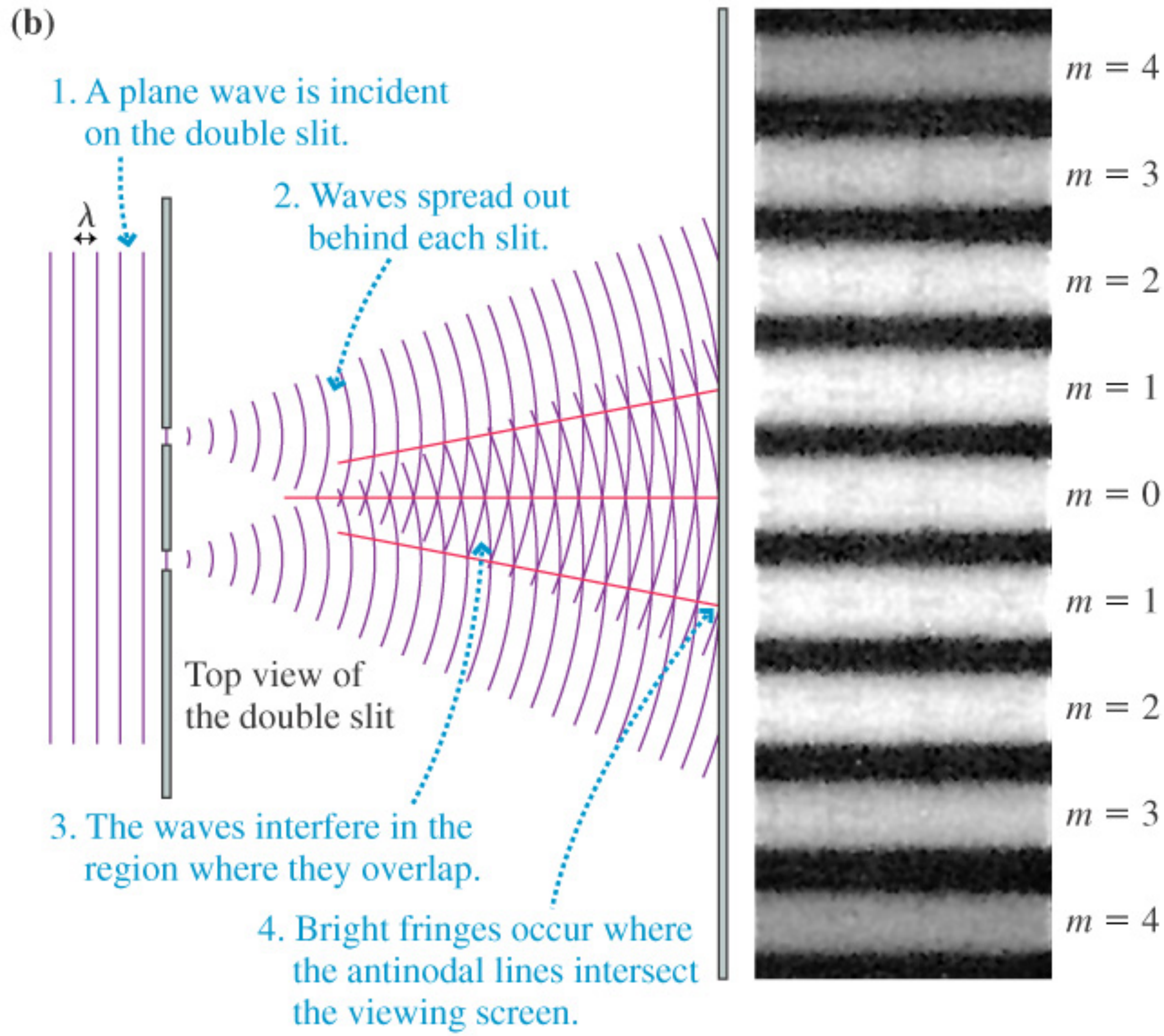
Interference



What happens if I have two waves passing through parallel small openings?
The wave diffracts through both openings and the diffracted waves interfere with each other.

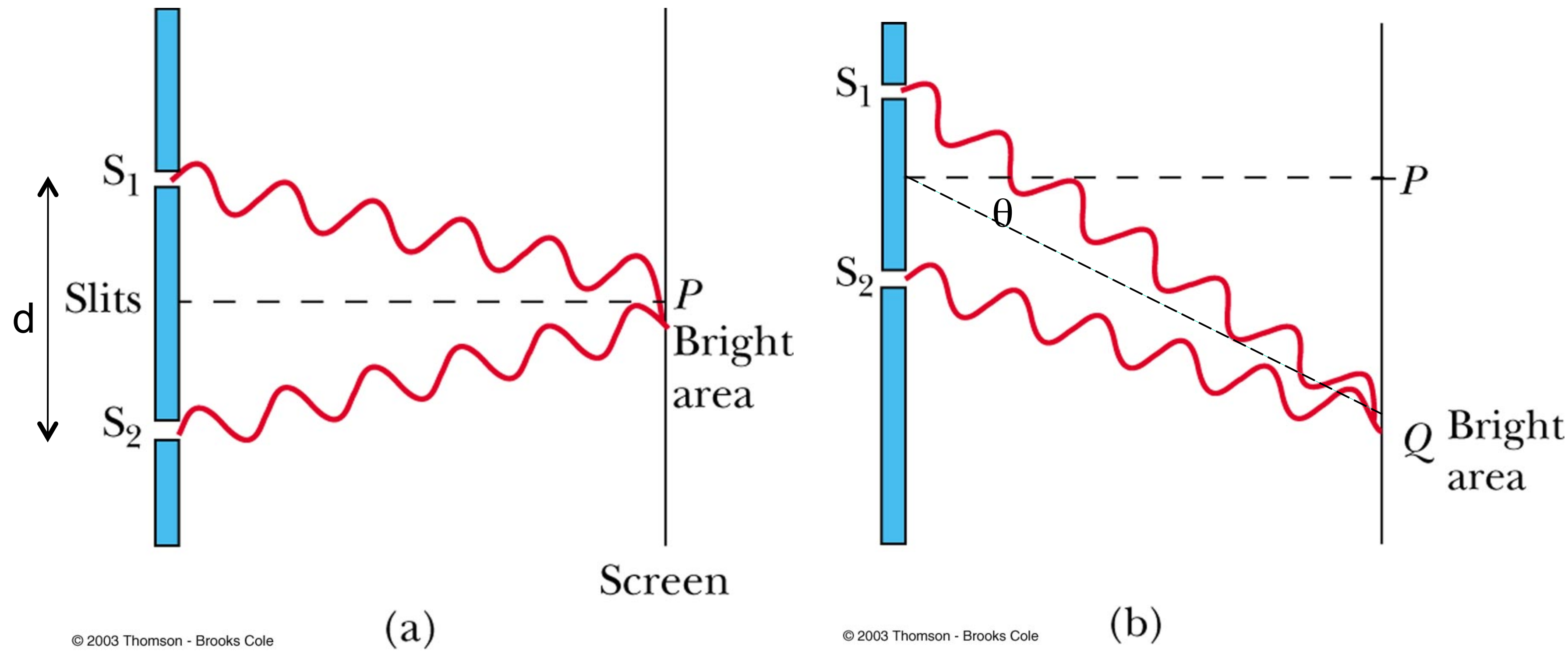
Inteference

A series of bright and dark fringes appears on the screen. Bright for constructive interference and dark for destructive interference.



Constructive interference

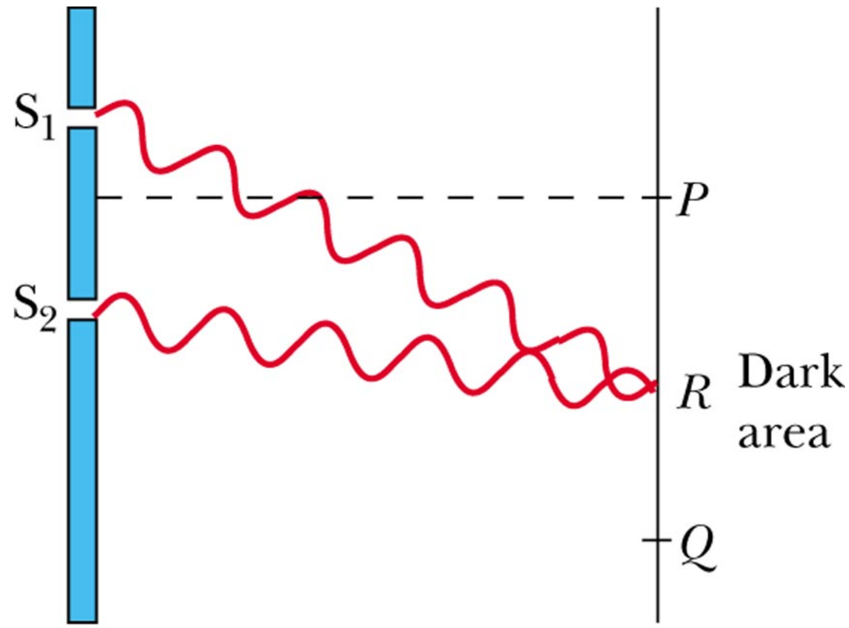
When light arrives from S_1 and S_2 so that constructive interference takes place, a bright fringe results



$d\sin\theta = m\lambda$, where $m = 0, +/-1, +/-2, \ldots$

Destructive interference

- If the light arrives from S_1 and S_2 at a point on the screen and there is destructive interference, then there is a dark spot



(c)

$d\sin\theta=(m+1/2)\lambda$, where m=0,+/-1,+/-2,…