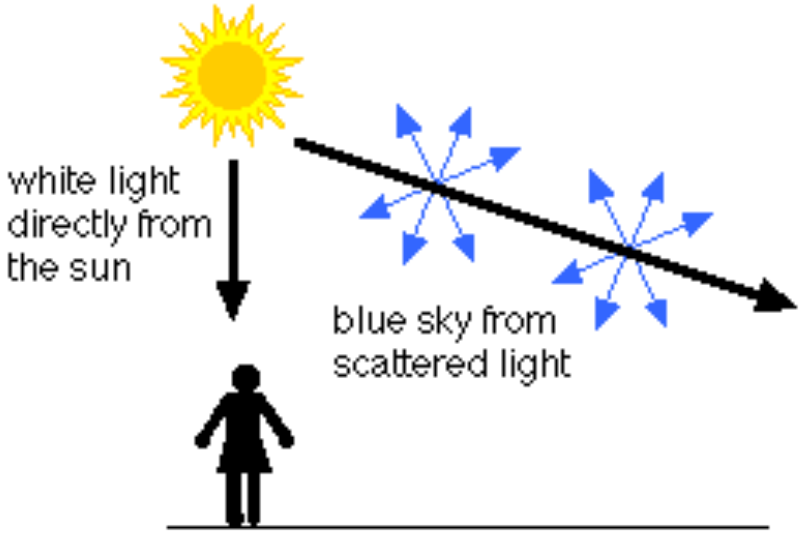
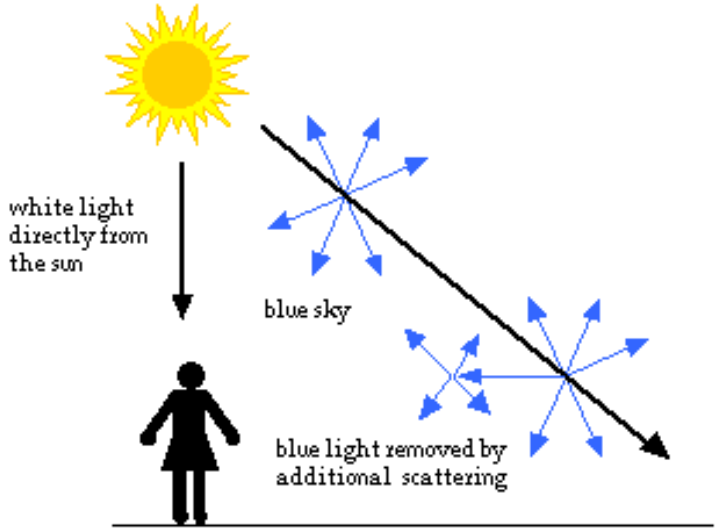
Announcements

- 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
  - part of Thursday's lecture will be a review
- Final Exam Tuesday Dec 11 7:45-9:45 AM

Why is the sky blue?

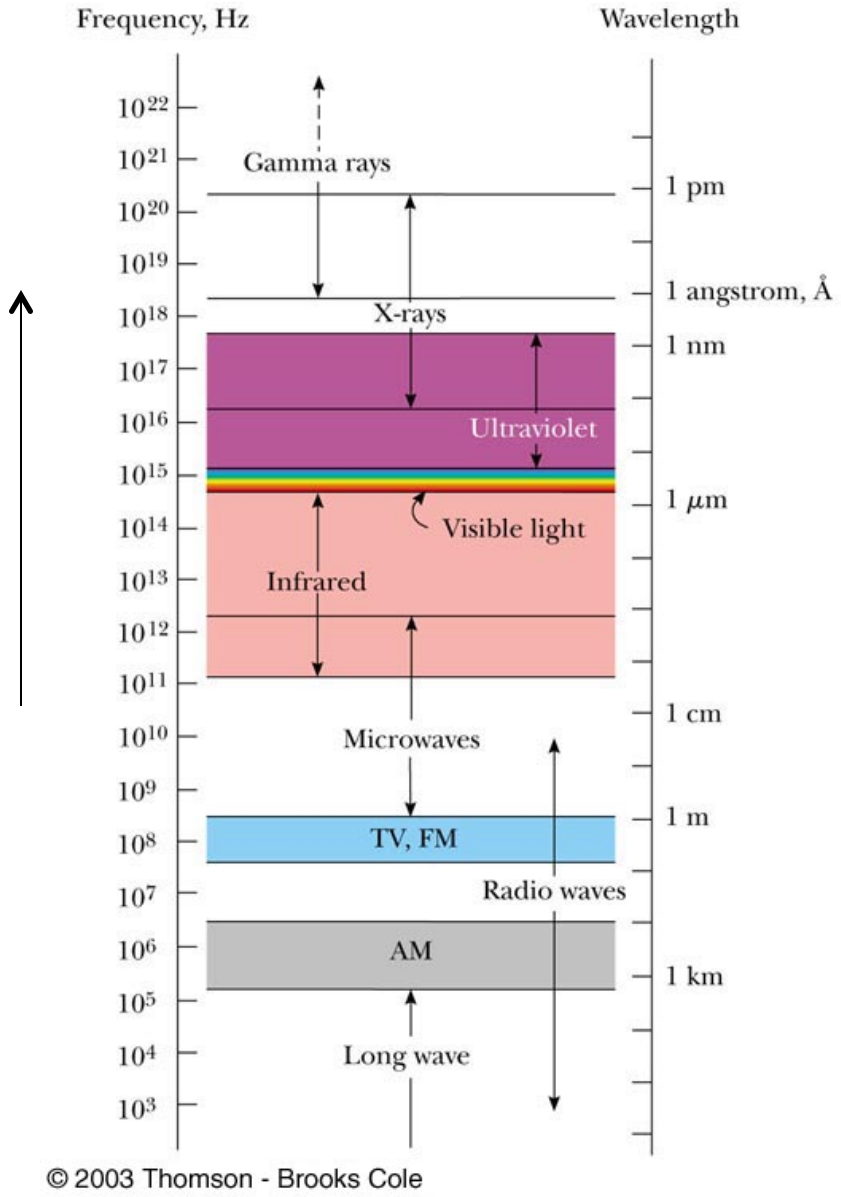
- Light from the Sun has all of the colors of the visible spectrum (but is peaked towards yellow)
- The cross section (probability) for scattering of light from air molecules goes as f^4 (frequency to the 4th power)
- So blue light is scattered preferentially and when you look away from the sun, all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





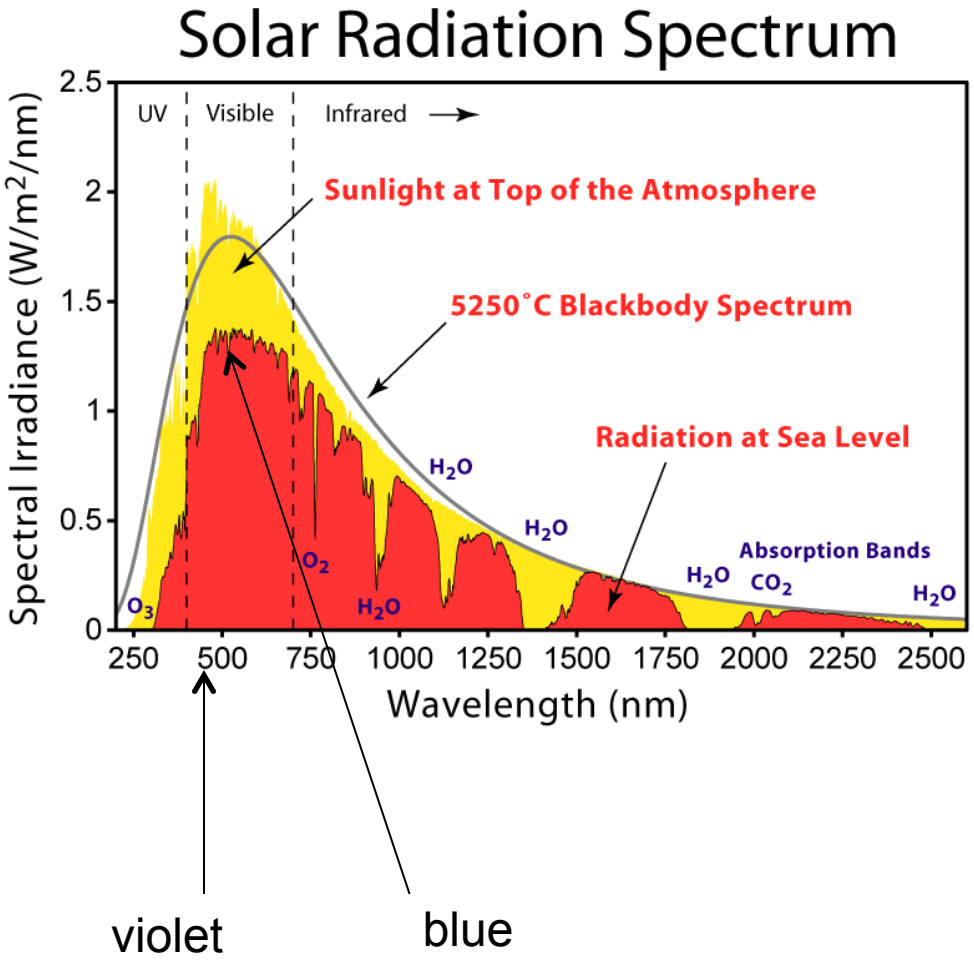
Question from last week

- Why is the sky not violet?
- Violet light has a higher frequency than blue light and so should be scattered even more than blue light



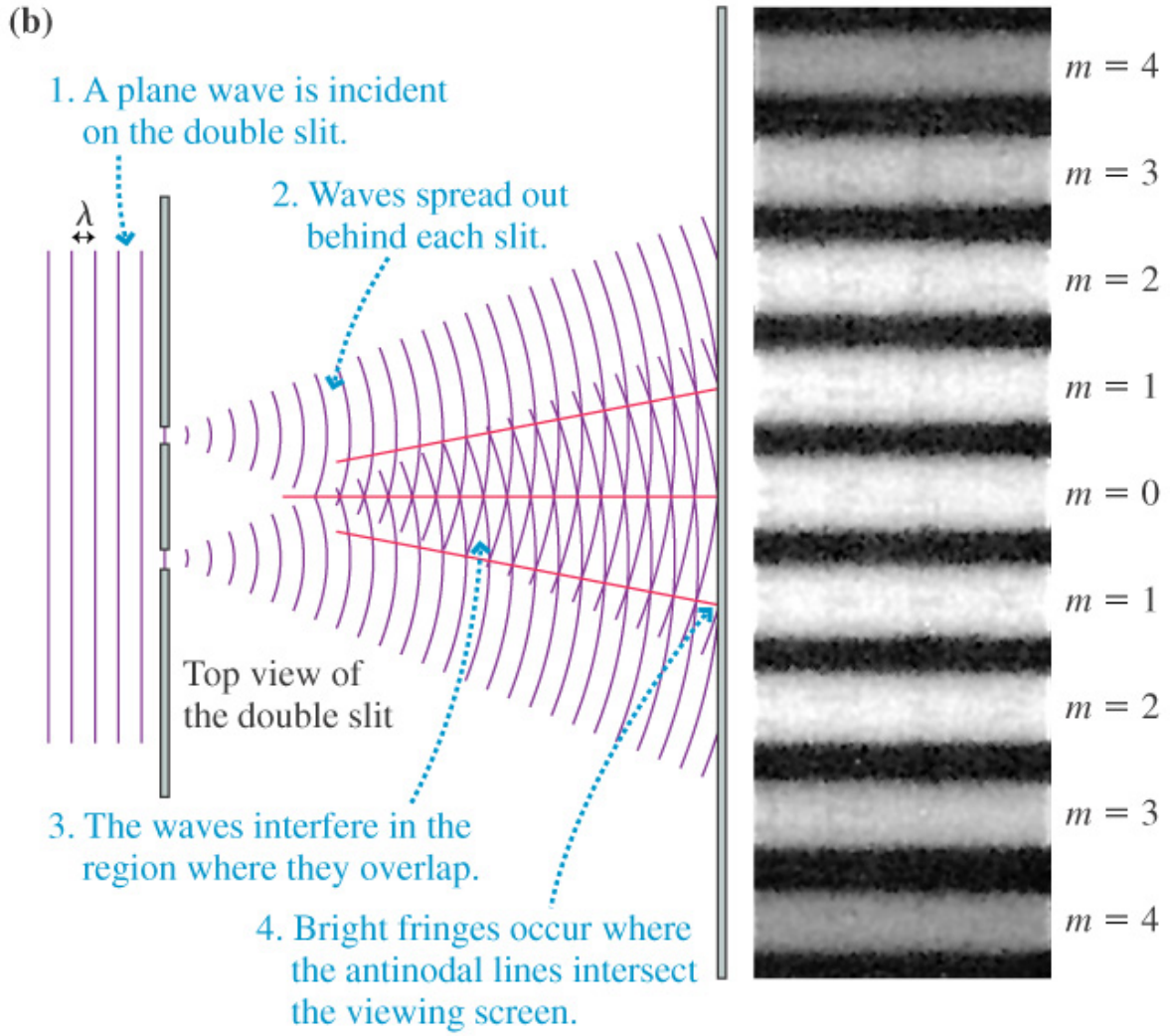
Answer

- The answer is somewhat involved
- First of all, there is less violet light in the output of the Sun than blue light
- Also, more of the violet light gets absorbed in the Earth's atmosphere
- And, our eyes are less sensitive to violet light than to blue light
- So the sky appears blue, and not violet, to us



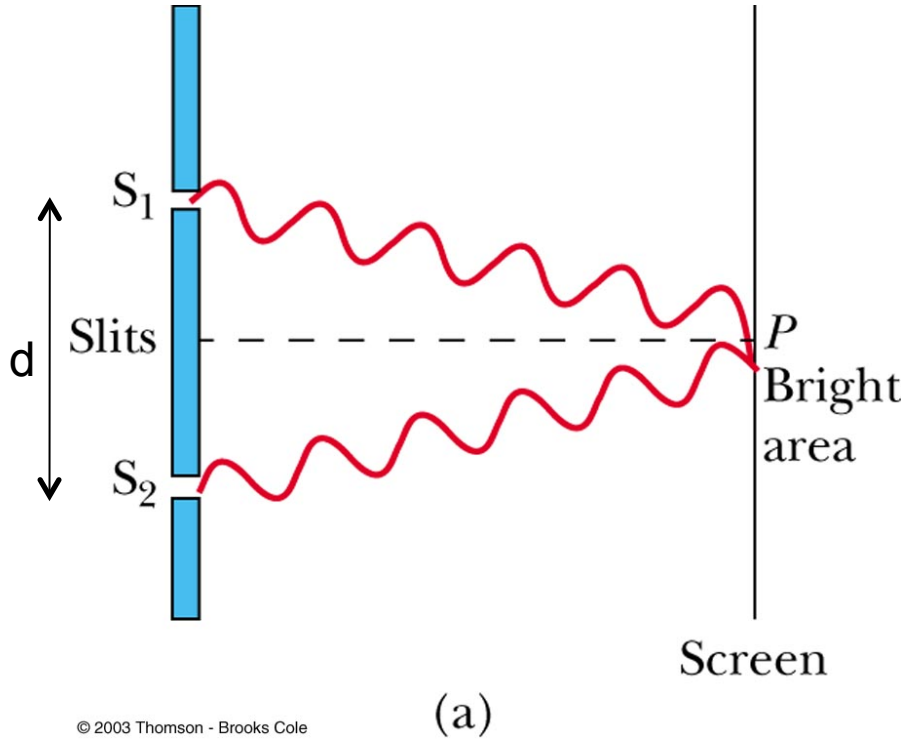
Inteference

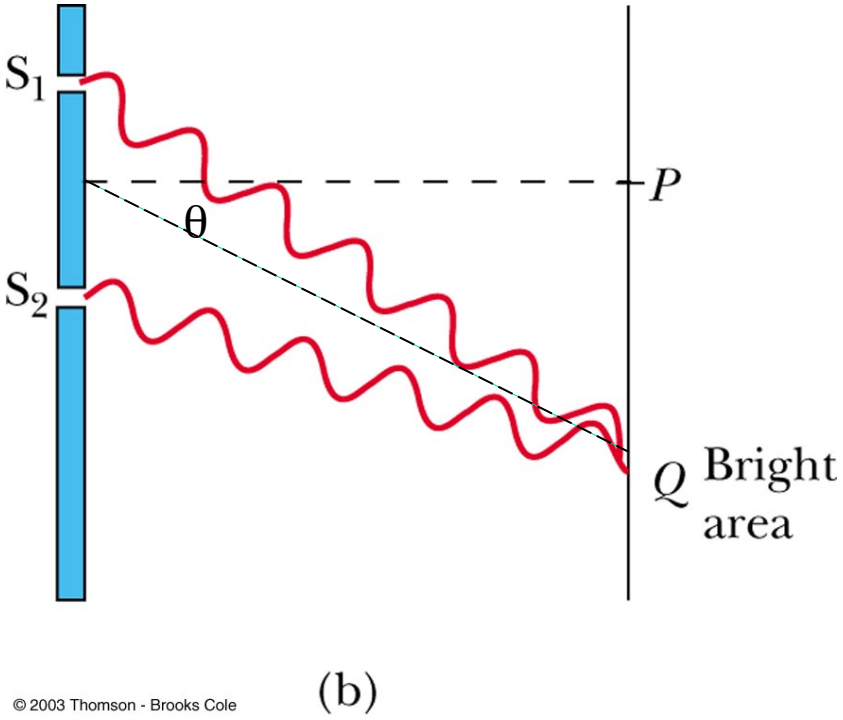
A series of bright and dark fringes appears on the screen. Bright for constructive interference and dark for destructive interference.



Constructive interference

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

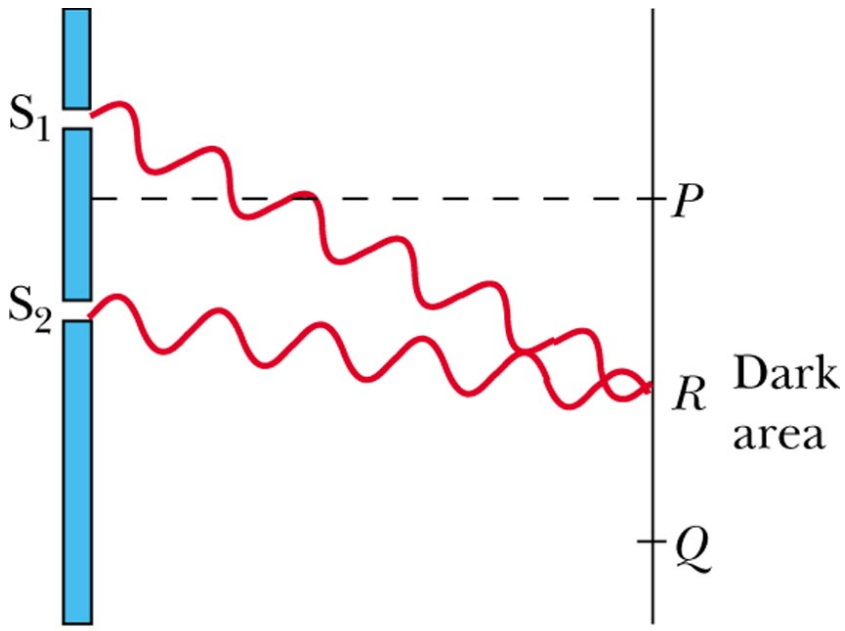




$d\sin\theta = m\lambda$, where m=0,+/-1,+/-2,…

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



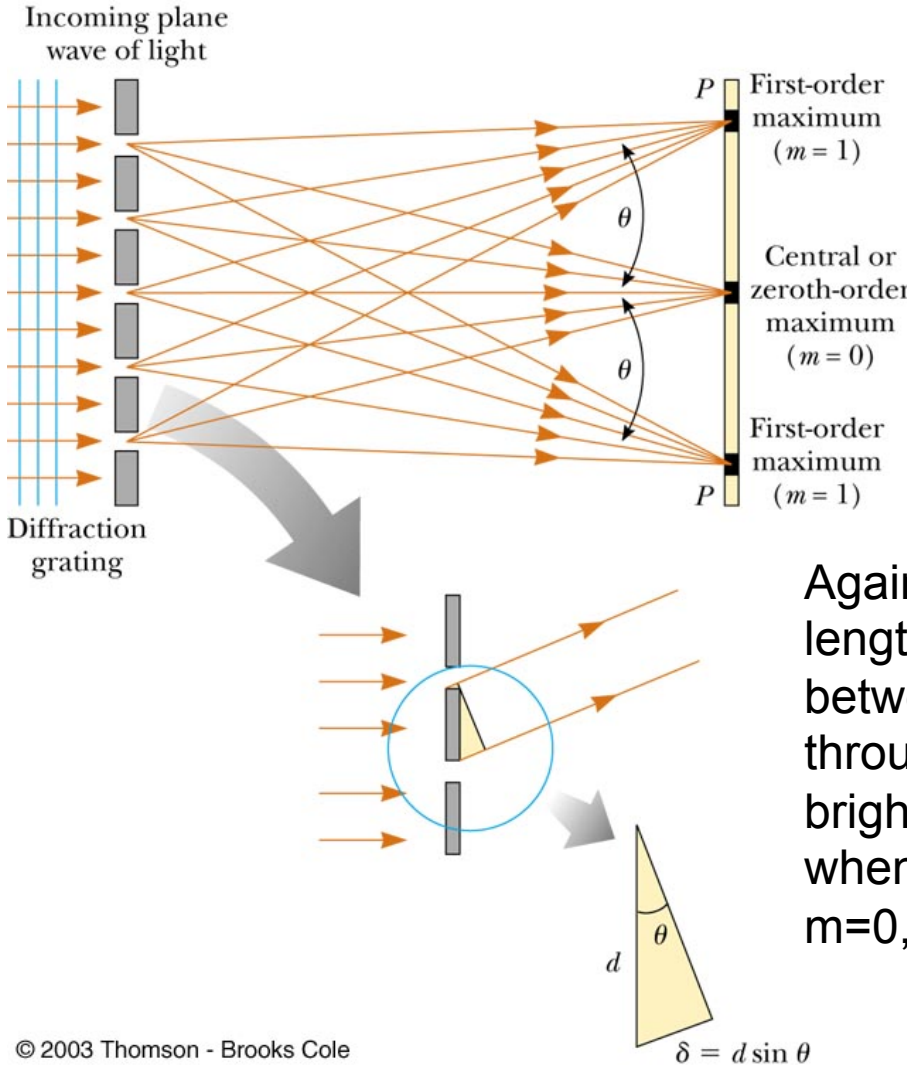
(c)

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

Diffraction grating: Let's go crazy and put in lots of slits

Light diffracts through each of the slits

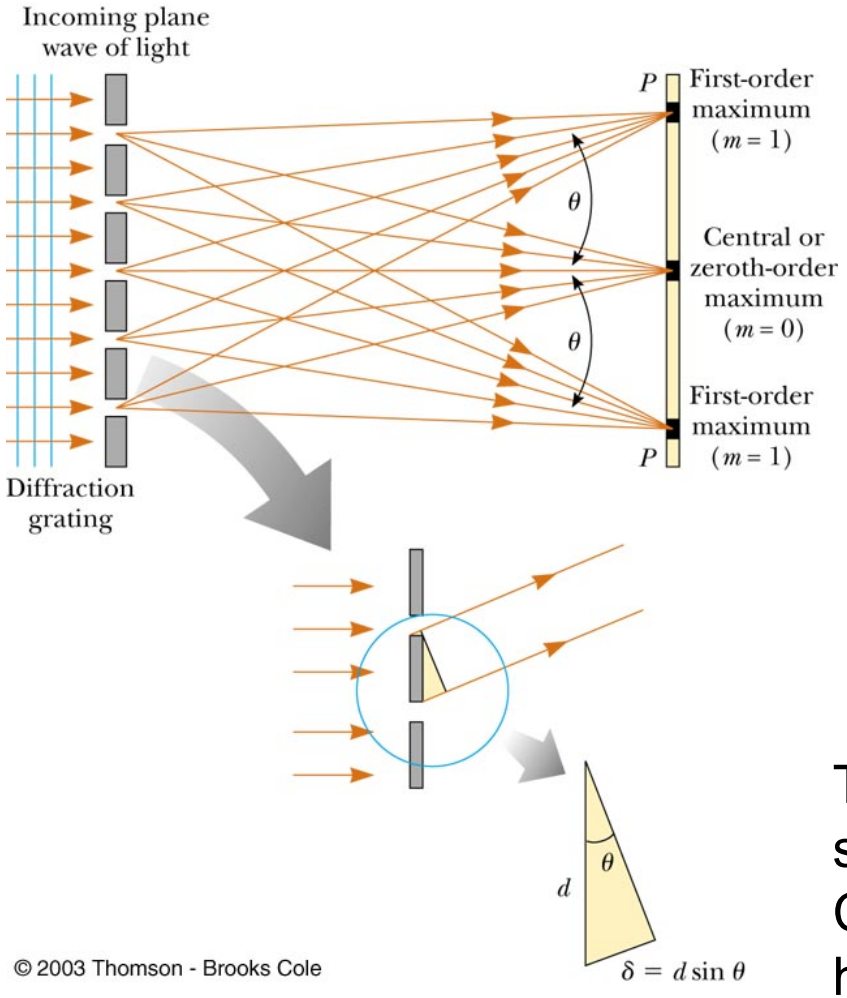
A device like this is called a diffraction grating but there's both diffraction and interference taking place

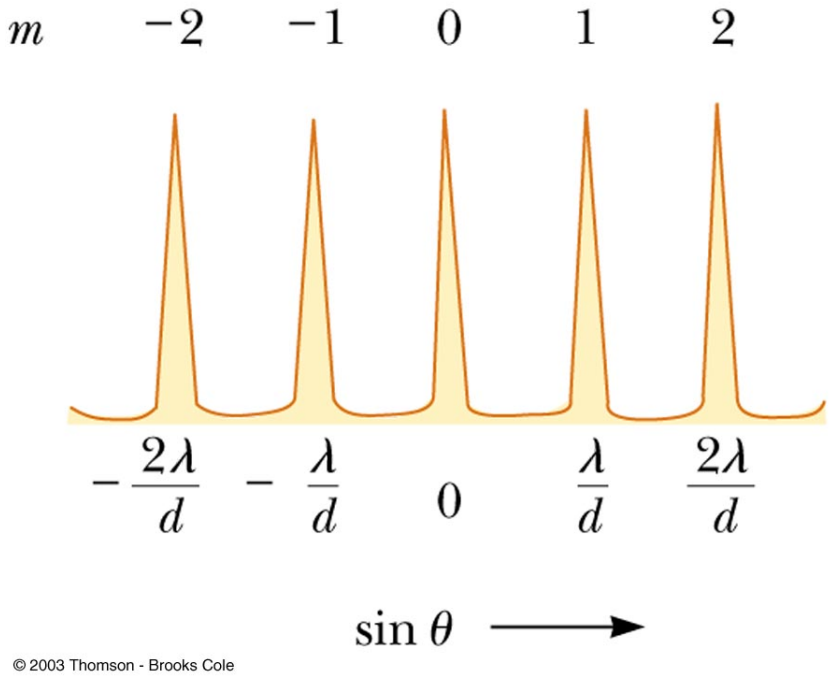


and we get interference between each of the diffracted waves

Again, there's a path length difference between light passing through different slits bright lines or spots when $d \sin\theta_{bright} = m\lambda$ m=0,1,2,…

Intensity pattern





The more slits in the grating the sharper are the interference peaks; Can also make a diffraction grating by having finely etched lines on a reflective surface

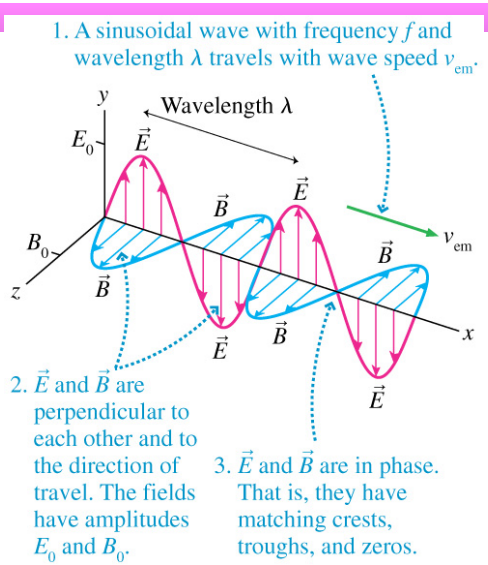
End of material on 2nd exam

Modern Physics

- Physics life near the end of the 19th century seemed pretty sedate
- Mechanics was very successful in describing phenomena both on earth and in the heavens
- Maxwell's equations described E&M
  - Heinrich Hertz confirmed Maxwell by discovering electromagnetic radiation
- A few flies in the ointment
  - for example, the discovery of radioactivity
    - who asked for atoms to be unstable?
- Another revolution took place in physics between 1900 and 1930: quantum mechanics
  - classical mechanics is highly successful in describing behavior for objects of macroscopic size
    - not so on the atomic level
  - classical mechanics is also very successful at describing the behavior of objects travelling at slow speeds
    - but not at high speeds

Prelude: ether and electromagnetic waves

- Maxwell realized that light was an electromagnetic wave
- By working with the 4 equations (Maxwell's equations), he was able to show that electromagnetic waves consisted of oscillating electric and magnetic fields
- The math is beyond us, but Maxwell was able to show that light (electromagnetic waves) does not need to travel through any medium
  - a changing electric field creates a magnetic field
  - that changing magnetic field then creates an electric field, whose changing then creates a magnetic field, and so on…
  - it keeps on propagating forever



- But physicists of the late 19th century were used to waves travelling in something
  - water, air,…
- So they hypothesized the existence of a mysterious substance known as the ether, which was colorless, massless, but absolutely rigid
- Light propagated through the ether…or so they thought

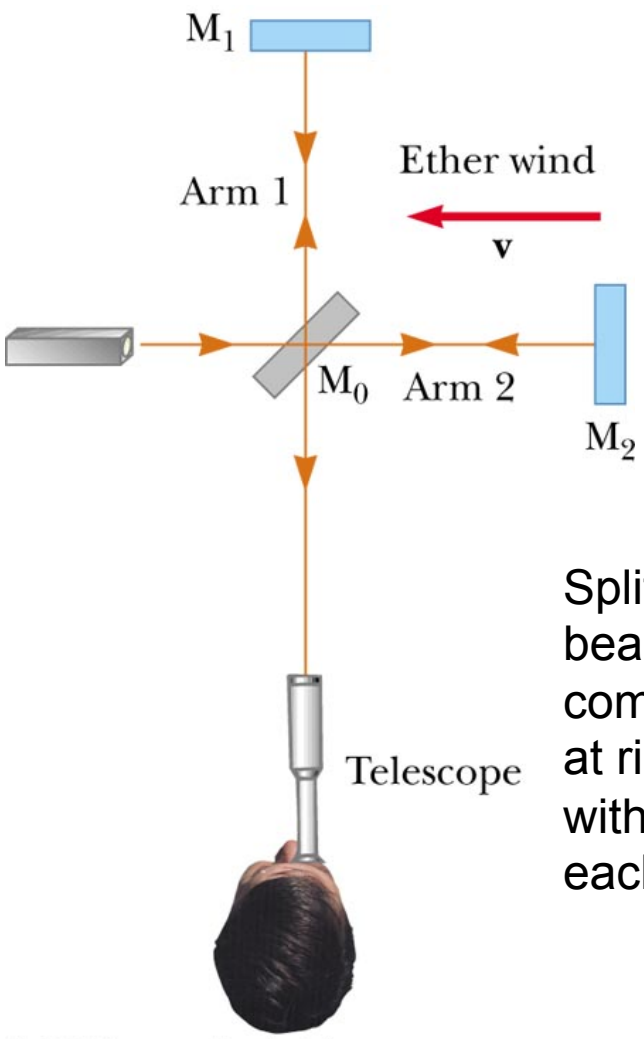
Ether

- Ether had the following properties
  - massless
  - provides no resistance to motion of objects through it
  - but, it has to have properties of a *stiff* elastic solid
  - had to be considered to be at rest with respect to *absolute space*
  - electromagnetic waves travel at a speed c with respect to the ether
  - strange stuff

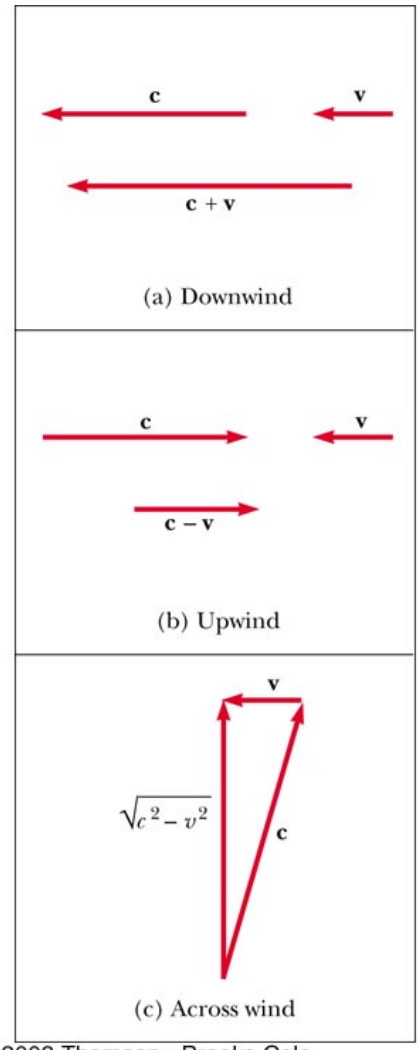
Starting in 1881, Albert Michelson, a young American, began a series of experiments intended to measure the motion of the Earth through the ether, the *ether drift*

All of his experiments were unsuccessful. Why?

Basic idea

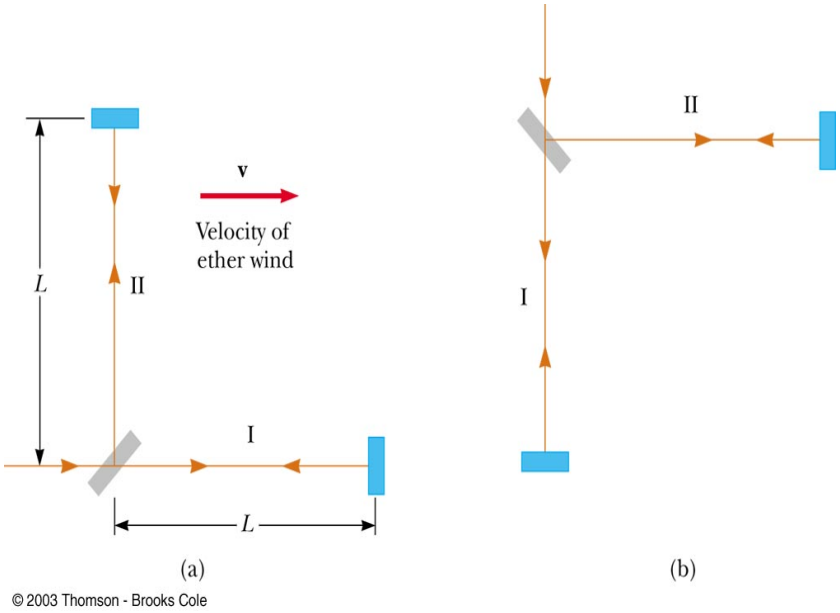


Split a light beam into 2 components at right angles with respect to each other



Ether drift

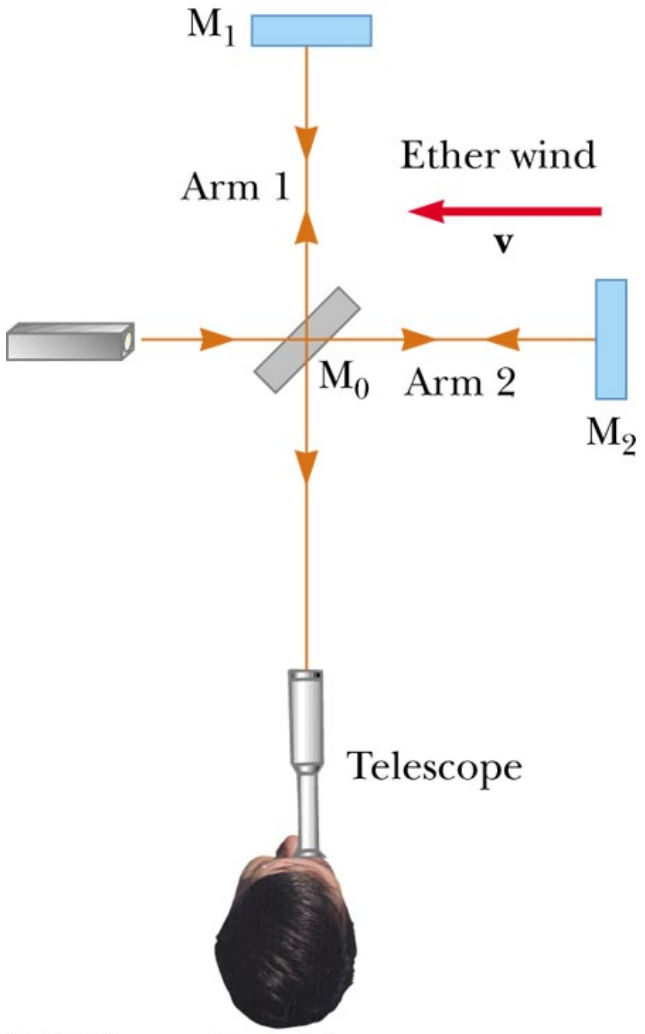
- If light travels at a constant speed with respect to the ether and if the earth is moving with respect to the ether, then light should travel at different speeds along paths I and II (which are arranged to be the same distance)
- The light starts out in phase but if it travels at different speeds, then it will be out of phase when it recombines
- …an interference pattern



Orbital speed of the earth is about $3X10^4$ m/s, about 10^{-4} of the speed of light

Ether drift

- Of course, we don't know which way the ether wind is blowing with respect to the earth's motion, but the apparatus was designed to be able to rotate
- There should be some difference in the interference patterns when the apparatus is set up at different angles
- Nope, they found no difference; and the sensitivity of their experiment was 40X as large as the effect they were trying to measure
- Sometimes you have to give up old ideas
- Sometimes a negative search is still a discovery

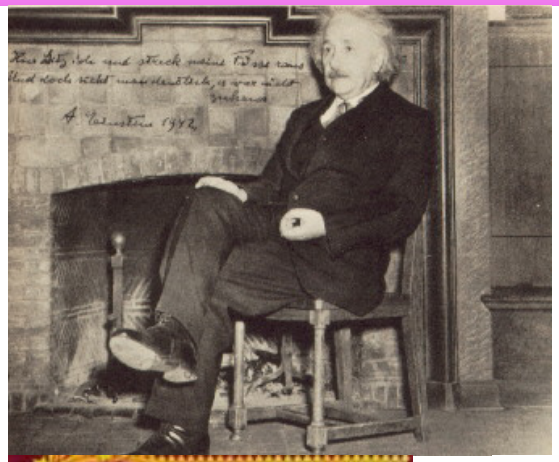


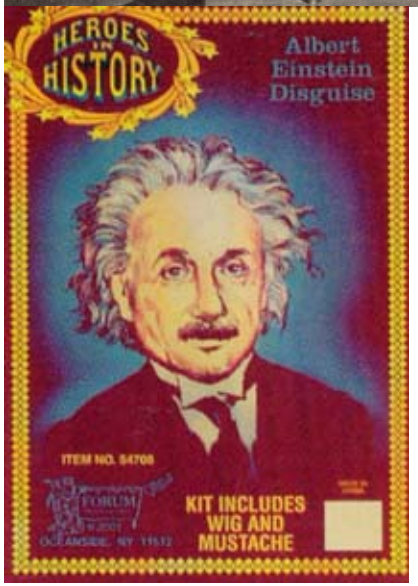
Enter Fitzgerald and Lorentz

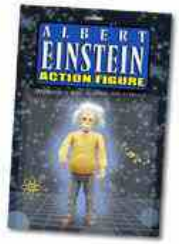
- In 1882, 2 physicists, G.F. Fitzgerald and H.A. Lorentz, suggested a solution to problem posed by Michelson-Morley experiment
- Fitzgerald: moving through ether generates a resisting force which compresses apparatus
  - 1/2 millionth of 1 percent
  - enough to explain lack of ether drift caused by Earths motion through the ether
- Lorentz was looking for transformation equations between inertial frames of reference that would leave electromagnetic forces invariant
- Same transformation as found by Fitzgerald; interesting consequences
  - moving objects would contract
  - time would slow down
- Poincare also pointed out that mass would increase with speed and that the maximum speed for any object would be the speed of light

Enter Einstein

- 1879-1955
- One of greatest physicists of all time
- Teacher once told him: "*You will never amount to anything Einstein*"
- Began speaking late, but gifts were evident from an early age
- In 1905, while working as a patent clerk, he published four papers that revolutionized physics
  - 1 on Brownian motion
  - 2 on special relativity
  - 1 on photoelectric effect
    - for which he received the Nobel prize in 1921
- Over 350 papers in career and a few patents
- And a Halloween costume as well as an action figure







Costume Kits Albert Enstein Costume Kit
costume kit includes: wig and moustache.

but he has no square dance song …or does he?

Einstein the genius

- 2005 was the centennial of Einstein's "Miracle Year" and there were celebrations around the world
- I tried to use this song in a worldwide broadcast, but was turned down because of the line "…along came relativity, ain't seen the damn thing since"

Albert Einstein

- All of the previous ideas are in Einstein's theory of special relativity
- Significance of Einstein's work is that he was able to show simply and directly that they were natural consequences of a profound and insightful reexamination of some basic assumptions about nature of physical measurements

- Circumstances at beginning of 20th century similar to those at time of Newton
- Several physicists were close to making a breakthrough but only one (Newton, Einstein) able to master the situation

- In 1905 paper, *On the Electrodynamics of Moving Bodies*, enumerated 2 special principles that should be applicable in all frames of reference
  - I: laws of physics are invariant (the same) in all inertial reference frames
  - II: It is a law of physics that the speed of light is the same in all inertial reference frames independent of speed of the source or detector
  - **Thus, ether can not be detected by experimental means; so should be discarded**
- Einstein realized that it was necessary to reconsider the meaning of space and time, and how they are measured. Space and time are not independent concepts but are intrinsically linked with each other.
  - no such thing as absolute length or absolute time
  - perhaps time is not the same in 2 inertial reference frames

Special relativity

- The special theory of relativity can be summarized with two precepts →
- Some of the consequences are not so intuitive
  - slowing down of clocks
  - lengths contracting
  - masses increasing

- The laws of physics are the same in all coordinate systems either at rest or moving at constant speed with respect to one another
- The speed of light in a vacuum has the same value regardless of the velocity of the observer or the velocity of the source emitting the light

Special theory of relativity

- Applies at all speeds, slow and fast
- What do we mean by fast?
  - approaching the speed of light
    - 186,000 miles per sec
    - 3 X 10^8 m/s
  - not your typical highway speeds
  - but ones approached for example by the particles at Fermilab, or at CERN
- Einstein came up with the special theory of relativity while thinking about light

video