From Last Time…

- Electric and magnetic fields
- Light, Doppler effect, interference

Today…

Interference, the speed of light

Relativity

HW#5: Chapter 10: Conceptual: # 6, 11, 17, 22
Problems: # 4, 6, 8

Due: Oct 18th

The electric and magnetic force and fields

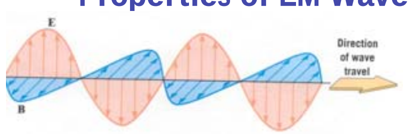
$$F = \frac{kq_1q_2}{r^2} \qquad E = \frac{kQ}{r^2}$$

$$F = qE$$

$$F = qvB$$

- Changing electric or magnetic fields can cause magnetic or electric fields
- Electric field is from a charge and exerts a force on other charges
- Magnetic field is from a moving charge and exerts a force on other moving charges!

Properties of EM Waves



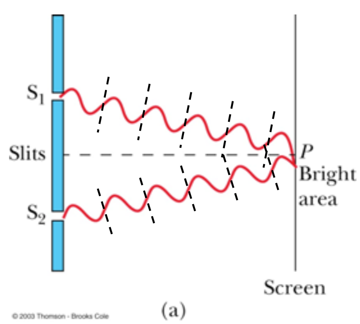
- Light is a set of electric and magnetic fields where the changing electric field creates the magnetic field and the changing magnetic field creates the electric field
- Only works when the fields change from up to down and back again at the speed of light
- The speed of light is a special value - we'll see this again in Einstein's relativity.
- Has all properties of a wave: $c = v = \lambda f$

Wave effects in EM radiation

- Same properties as sound waves: common to all waves.
- **Doppler shift**: change in light frequency due to motion of source or observer
- **Interference**: superposition of light waves can result in either increase or decrease in brightness.

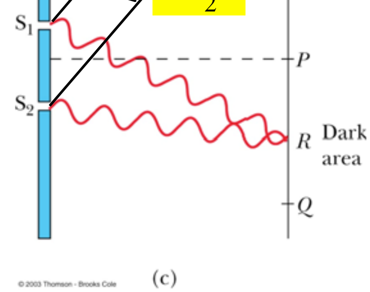
Interference of light waves

- Coherent beams from two slits
- *Constructive interference:* waves in phase at screen

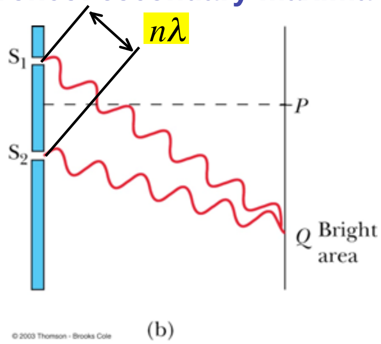


Destructive interference

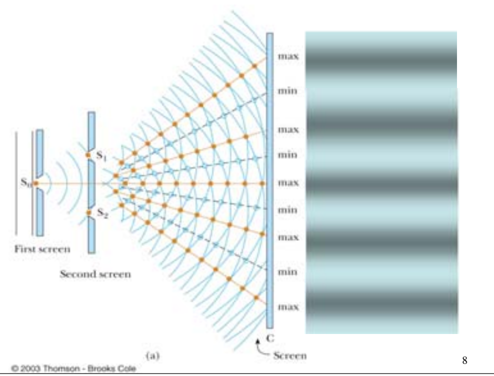
$$(n + \frac{1}{2})\lambda$$



Interference: secondary maxima



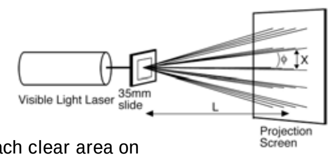
Resulting diffraction pattern



Hertz's measurement: the speed of electromagnetic waves

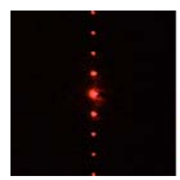
- Hertz measured the speed of the waves from the transmitter
  - He used the waves to form an interference pattern and calculated the wavelength
  - From v = f λ, v was found
  - v was very close to 3 x 10^8 m/s, the known speed of light
- This provided evidence in support of Maxwell's theory
- This idea still used today measure wavelengths when studying stars

Laser pointer interference



Each clear area on the slide acts as a light source.

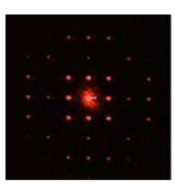
Interference with many light sources is sometimes called diffraction.

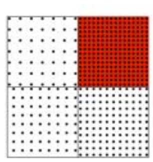


Complex interference patterns

White spaces act as array of sources.

The 'diffraction pattern' contains information about the original pattern.



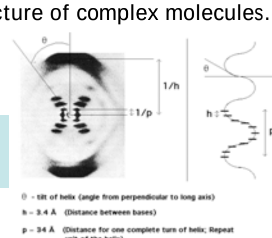


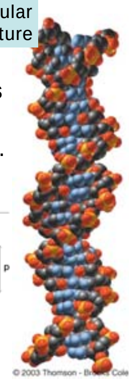
X-ray diffraction

DNA molecular structure

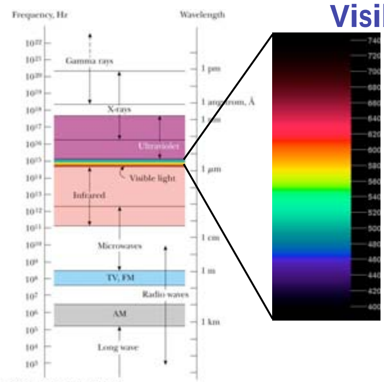
- X-rays are short-wavelength EM wave. Short wavelengths probe small spacings
- Diffraction pattern used to determine atomic structure of complex molecules.
  - e.g. DNA

DNA X-ray diffraction pattern





Visible Light

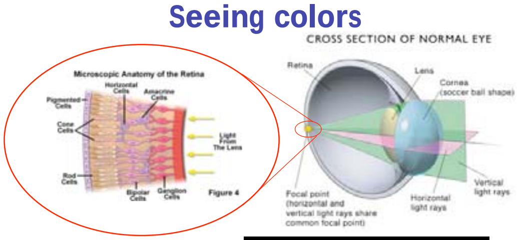


- We see only a narrow range of the EM spectrum
- 400-700nm
- To someone who could see the entire spectrum, our limitation to this narrow range might seem odd.

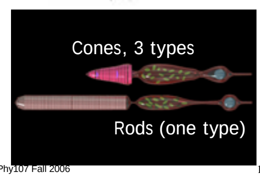
White light is a superposition

- Prism can separate the superposition into it's constituents.
- For example, 'white' light is an almost equal superposition of all visible wavelengths (as well a invisible ones!)
- This is a simple analyzer to 'deconstruct' a superposition of light waves (how much of each wavelength is present in the light).

Seeing colors

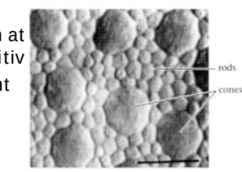


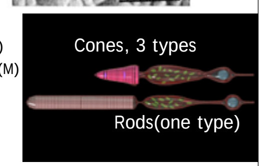
- Rods and cones send impulses to brain when they absorb light.
- Brain processes into color information.



Rods and cones

- Rods are responsible for vision at low light levels. No color sensitiv
- Cones are active at higher light levels
- The central fovea is populated only by cones.
- 3 types of cones
  - short-wavelength sensitive cones(S)
  - middle-wavelength sensitive cones(M)
  - long-wavelength sensitive cones(L)



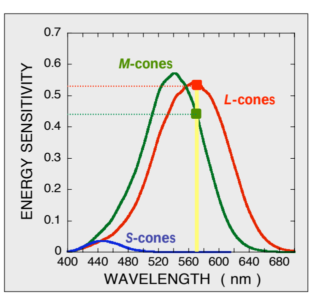


Eye sensitivity

- Eye's wavelength sensitivity by cone type.
- Sensitivities overlap.

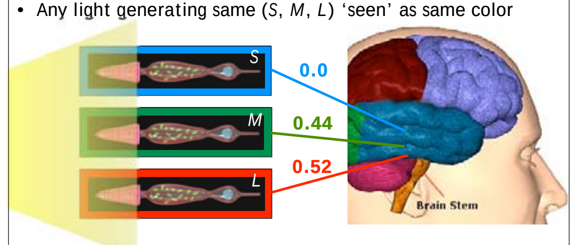
For instance, pure yellow (single wavelength of 570 nm) stimulates both *M* and *L* cones.

***M*-cone: 0.44**
***L*-cone: 0.52**
***S*-cone: 0**



Interpreting colors

- Each cone sends a signal in relation to its degree of stimulation
- A triplet of information (*S*, *M*, *L*) is conveyed.
- Brain uses only this information to assign a color
- Any light generating same (*S*, *M*, *L*) 'seen' as same color



Red + Green = ?

- Combined Green + Red

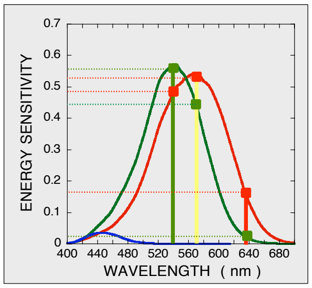
Total *M*-cone stimulus
= 0.55+0.02 = 0.57

Total *L*-cone stimulus
= 0.49+0.17=0.66

Reducing the intensity slightly (by 1.25) gives

(*S, M, L*)=(0,0.45,0.52)

Compare to spectrally pure yellow
(*S, M, L*)=(0,0.44,0.52)



Question

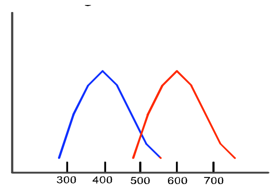
Suppose an eye has only two cones with spectral sensitivities shown here. It is stimulated by equal intensities of 300 and 700 nm pure spectral light. Which single wavelength might produce a similar color perception?

A. 330 nm

B. 430 nm

C. 500 nm

D. 530 nm



Relativity and Modern Physics

- Physics changed drastically in the early 1900's
- New discoveries —
  Relativity and *Quantum Mechanics*

- **Relativity**
  - Changed the way we think about space and time

- **Quantum mechanics**
  - Changed our conceptions of matter.

Special Relativity

- From 1905 to 1908, Einstein developed the special theory of relativity.
- Came up completely different idea of time and space.
- Everything is relative.
  No absolute lengths, times, energies.

Showed that our usual conceptions of space and time are misguided.

Frames of reference

- Frame of reference:
  - The coordinate system in which you observe events.
  - *e.g.* The room around you.
  - You judge how fast a thrown ball goes by its velocity relative to some stationary object in the room.
  - You judge how high a thrown ball goes by distance from the floor, ceiling, etc.
  - You judge how fast you are moving by looking at objects around you

Suzi prefers to carry her own frame of reference.

Which reference frame

Suppose you are on the bus to Chicago driving at 60 mph, and throw a ball forwards at 40 mph.

From your seat on the bus, the speed of ball is the same as in this classroom.

To the major league scout on the side of the road, your 40 mph throw has become a 100 mph fastball.

Who is correct?

You wouldn't last long in the majors.

The important velocity in a baseball game is the relative velocity of ball with respect to pitcher or the batter.

But what exactly is the absolute velocity of the ball?

- Earth spins on its axis
  - One rotation in (24 hrs)(60 min/hr)(60 sec/min)=86400 sec
  - Point on surface moves $2\pi R_E$ in one rotation.
  - Surface velocity = $2\pi(6.4\text{x}10^6$ m)/86400 sec = 465 m/s
- Earth revolves around sun
  - One revolution in (365 days)(86400 sec/day)=$3.15\text{x}10^7$ sec
  - Earth velocity = $2\pi(1.5\text{x}10^{11}$ m)/ $3.15\text{x}10^7$ sec=$3\text{x}10^4$ m/s
- Sun moves w/ respect to center of our galaxy
  - Sun velocity = $2.3\text{x}10^5$ m/s

Galilean relativity

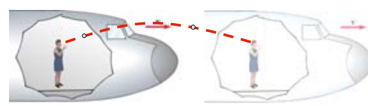
- Absolute velocity not clear, but we can seemingly agree on relative velocities.
  - In all cases the ball moves 40 mph faster than I do.
- Examples of two different reference frames
  - *On the bus*
  - *Off the bus*
- *In both cases we could talk about*
  - *the forces I put on the ball,*
  - *the acceleration of the ball, etc*

Newton's laws in moving frames

- In both cases,
  the acceleration of the ball is the same.
- This is because the two reference frames move at a constant relative velocity.
- Newton's laws hold for each observer.
- Which is good, because we apparently can't determine our absolute velocity,
  or even if we are moving at all!

This is an example of *Galilean Relativity*

Example of Galilean relativity



- Observer on ground

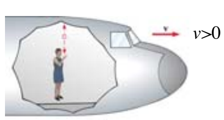
- *Experiment may look different to different observers, but both agree that Newton's laws hold*
  - Can make observations agree by incorporating relative velocities of frames.

- Observer in plane

Galilean relativity: example

- *Experiment performed…*
  - in laboratory at rest with respect to earth's surface
  - in airplane moving at constant velocity

  …*must give the same result.*



- In both cases, ball is observed to rise up and return to thrower's hand
  - Process measured to take same time in both experiments
  - Newton's laws can be used to calculate motion in both.

Some other examples

- On an airplane:
  - Pouring your tomato juice.
  - Throwing ~~peanuts~~ pretzel sticks into your mouth.
  - But when the ride gets bumpy…

- In a car:
  - Drinking coffee on a straight, smooth road
  - But accelerating from a light, or going around a curve

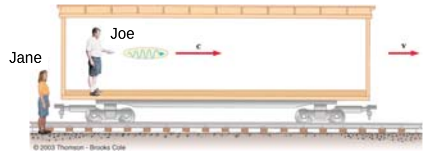
Turning this around…

- No experiment using the laws of mechanics can determine if a frame of reference is moving at zero velocity or at a constant velocity.
- Concept of *absolute motion* is not meaningful.
  - *There is no 'preferred' reference frame*

Inertial Frame:
reference frame moving in straight line with constant speed.

What about electromagnetism?

- Maxwell equations say that
  - Light moves at constant speed c=3x10^8 m/sec in vacuum
- Seems at odds with Galilean relativity:



- Jane would expect to see light pulse propagate at c+v
- But Maxwell says it should propagate at c, if physics is same in all inertial reference frames.
- If it is different for *Joe* and *Jane*, then in which frame is it c?