

Please pick up second midterm from the front of the class if you have not already...

Today:

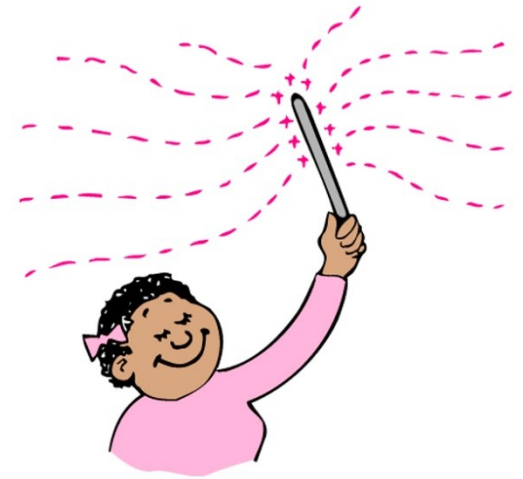
**Chapter 26 (Properties of
Light)**

Light: preliminaries

- Light is the only thing we actually see – e.g. When I “see” you, I am actually seeing light reflected off you.
- Light is a transverse wave (recall earlier), whose origin is *accelerating electrons*, e.g. in the sun
- Accelerating electrons not only can produce light, but also radio waves, microwaves, x-rays.... Grouped together as *electromagnetic waves*.
- Different types of electromagnetic waves differ in their frequency (and wavelength): light is just a small part of the electromagnetic spectrum with certain frequency range

Electromagnetic Waves

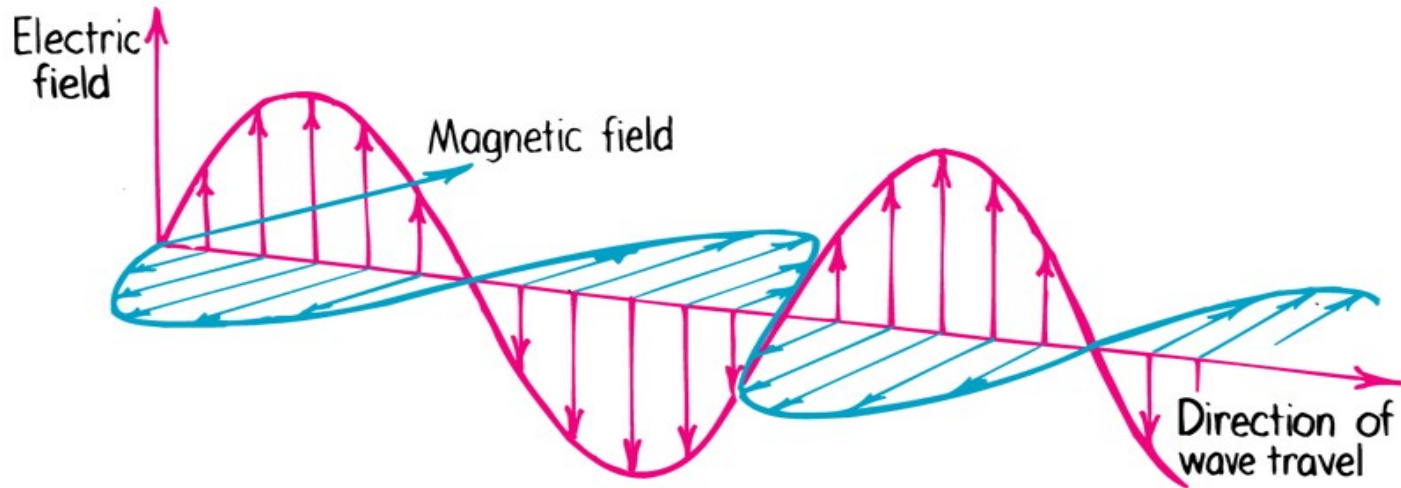
- Origin is accelerating electron: how?
- Consider shaking a charged rod back and forth in space
i.e. You create a current (= moving charges) that varies in time, i.e. a changing electric field in space.



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- Recall from last chapter: a changing electric field creates a changing magnetic field, that in turn creates a changing electric field, that in turn...
i.e. a propagating disturbance
- The vibrating (oscillating) electric and magnetic fields regenerate each other - this is the electromagnetic (EM) wave.

Electromagnetic Waves cont.



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- The EM wave moves outwards (*emanates*) from the vibrating charge.

Electromagnetic Wave Velocity

- An electromagnetic wave travels at ***one constant speed*** through space. Why?

Inherently due to wave nature (e.g. objects like spacecrafts can change speed, and go at different constant speeds); specifically, induction and energy conservation:

- Recall (last chap): the strength of the induced fields depends on the *rate of change* of the field that created it.

So, if light traveled slower, then its electric field would change slower, so would generate a weaker magnetic field, that in turn generates a weaker electric field, etc* wave dies out.

Similarly, if light sped up, would get stronger fields, with ever-increasing energy.

- Both cases violate energy conservation.

Electromagnetic Wave Velocity cont.

- Then what is the critical speed at which mutual induction sustains itself? Maxwell calculated this:

$$\underline{300\,000\text{ km/s}} = c$$

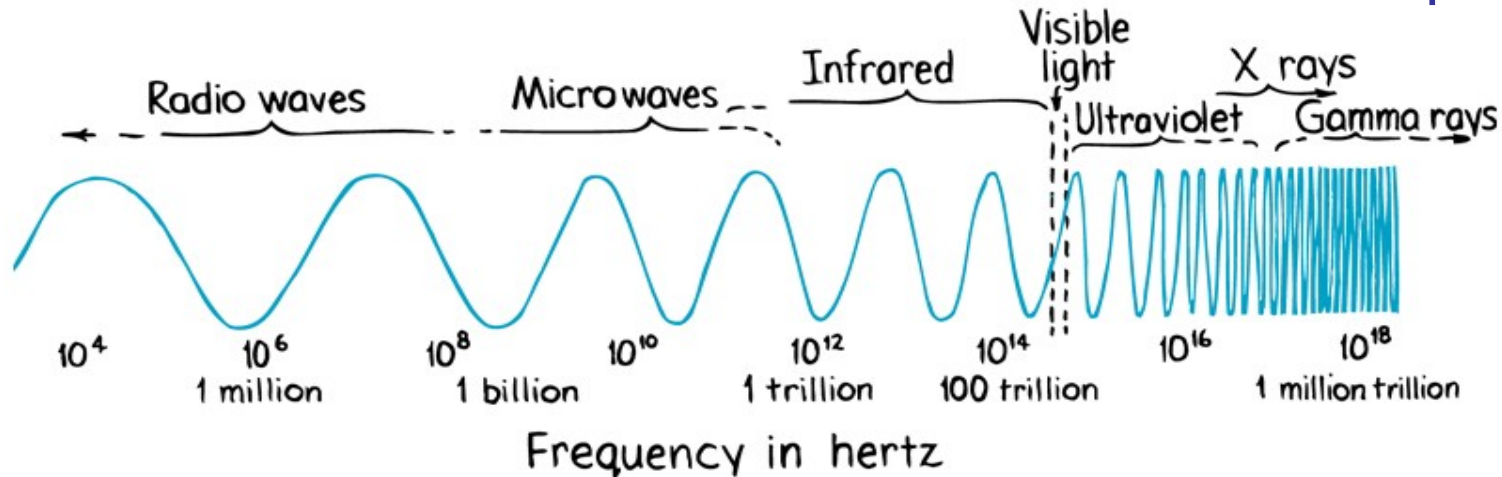
$$\text{i.e. } 3 \times 10^8 \text{ m/s}$$

- This is the speed in vacuum, and about the same in air. Slower in different media (see later)

The Electromagnetic Spectrum

- In vacuum, all electromagnetic waves move at the same speed c , but differ in their frequency (and wavelength).

recall speed $c = f \lambda$



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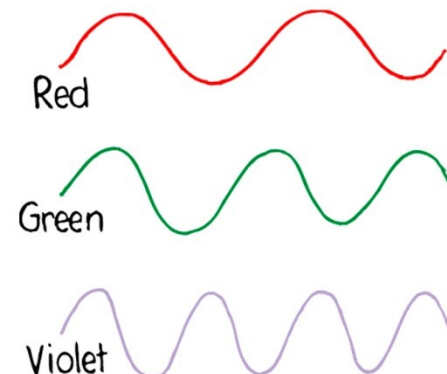
Visible light: **4.3×10^{14} Hz** to **7×10^{14} Hz**

i.e. red is at the low-freq end of light (next lowest is infrared)

and long-wavelength

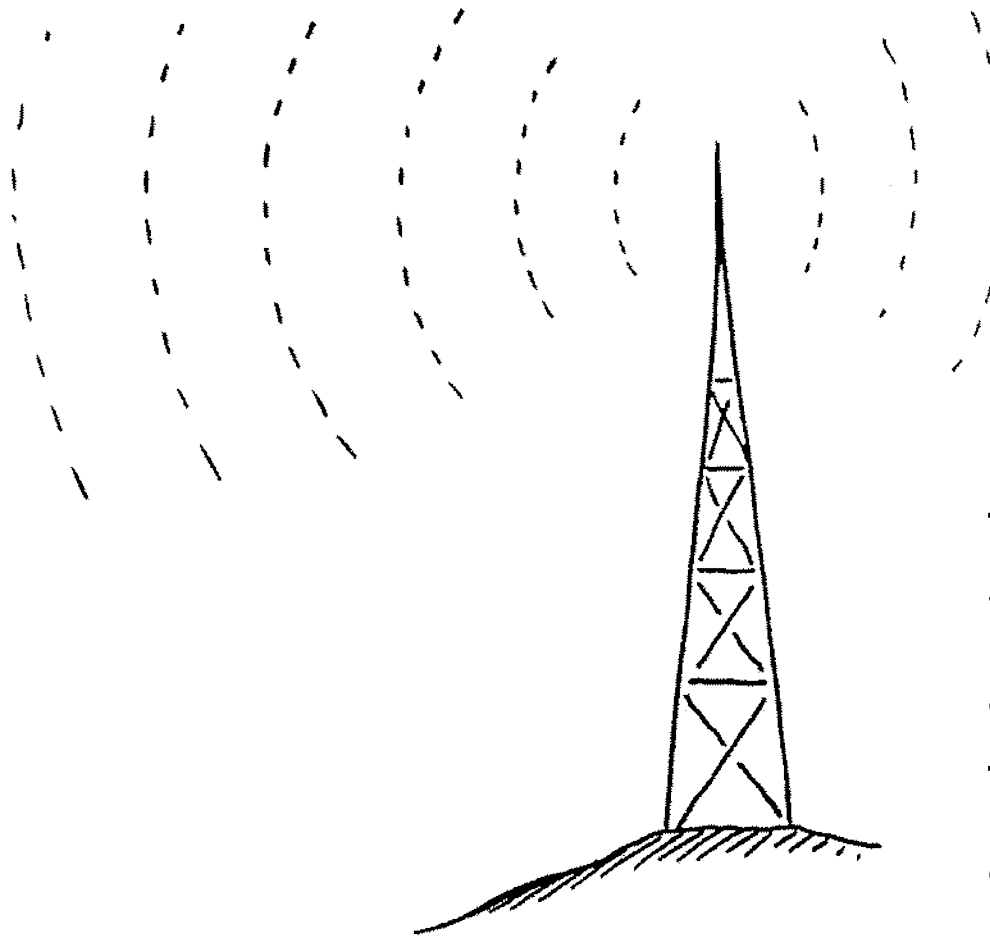
violet is the high-freq end (next highest is ultraviolet)

short wavelength



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Clicker Question



Is it correct to say that in every case, without exception, any radio wave travels faster than any sound wave?

1. Yes
2. No

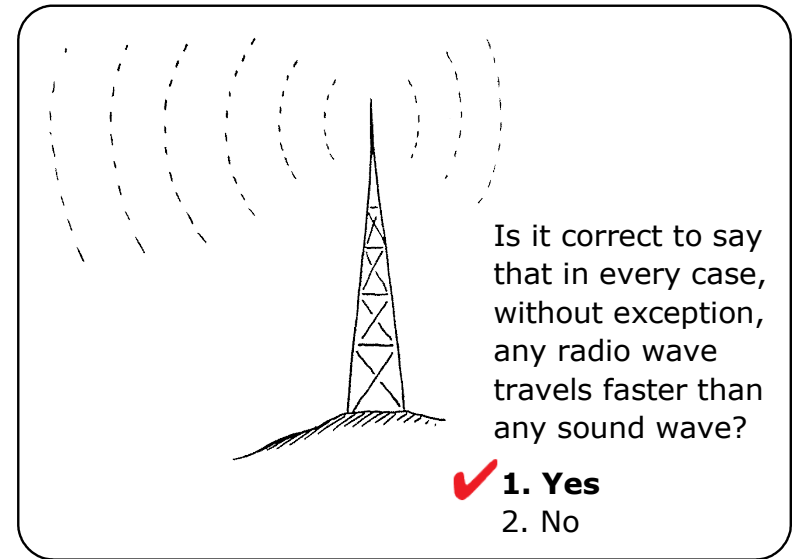
Answer: 1,

At least until very recently*:

Any radio wave travels at the speed of light. A radio wave is an electromagnetic wave, like a low-frequency light wave.

A sound wave, on the other hand, is fundamentally different. A sound wave is a mechanical disturbance propagated through a material medium by material particles that vibrate against one another. Sound is not part of the EM spectrum!

In air, the speed of sound is about 340 m/s, about one millionth the speed of a radio wave. Sound travels faster in other media, and light is slower in other media, but, these factors are usually more like factor of 2 or 3, at most, not a million...



** In 1999, however, researchers in carefully controlled expts managed to slow light down to 17m/s!*

The electromagnetic spectrum cont.

- Recall Ch 18 on waves: frequency of wave = freq of vibrating source.
Applies to EM waves too, where source is oscillating electrons
- Note that EM waves are everywhere! Not just in air, but in interplanetary “empty space” - actually a dense sea of radiation. Vibrating electrons in sun put out EM waves of frequencies across the whole spectrum.
- *Any* body at any temperature other than absolute zero, have electrons that vibrate and (re-)emit in response to the EM radiation that permeates us, even if very low frequency.

Question

A helium-neon laser emits light of wavelength 633 nanometers (nm). What frequency is this? What color ?

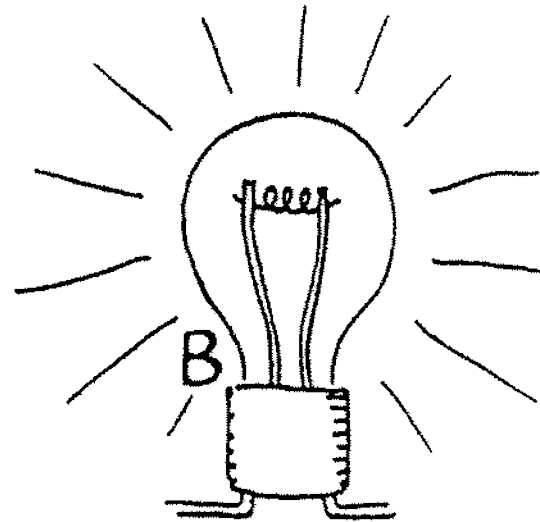
$$\begin{aligned} \text{Use } c &= f \lambda, \text{ so } f = c/\lambda \\ &= (3 \times 10^8 \text{ m/s}) / (633 \times 10^{-9} \text{ m}) \\ &= \underline{4.74 \times 10^{14} \text{ Hz}} \end{aligned}$$

i.e. red

Clicker Question

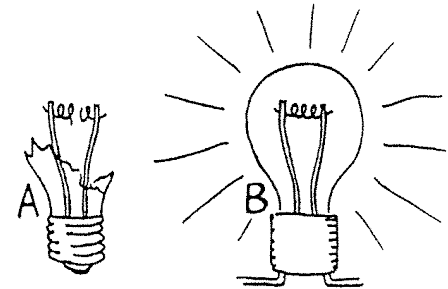
Which of these lamps is emitting electromagnetic radiation?

1. Lamp A
2. Lamp B
3. Both
4. Neither



Which of these lamps is emitting electromagnetic radiation?

1. Lamp A
2. Lamp B
3. Both
4. Neither



Answer: 3

All bodies with any temperature at all continually emit electromagnetic waves. The frequency of these waves varies with temperature. Lamp B is hot enough to emit visible light. Lamp A is cooler, and the radiation it emits is too low in frequency to be visible—it emits infrared waves, which aren't seen with the eye. You emit waves as well. Even in a completely dark room your waves are there. Your friends may not be able to see you, but a rattlesnake can!

Transparent materials

- When light goes through matter, electrons in the matter are forced to vibrate along with the light.
- Recall Ch 20 on sound – response of material depends on how close the forced vibration is to the natural frequency of the material. Same is true here with light.
- First note that visible light has very high freq ($\sim 10^{14}$ Hz), so if charged object is to respond to this freq, it has to have very little inertia i.e. mass. An electron *does* have tiny mass!
- **Transparent materials – allow light to pass in straight lines**

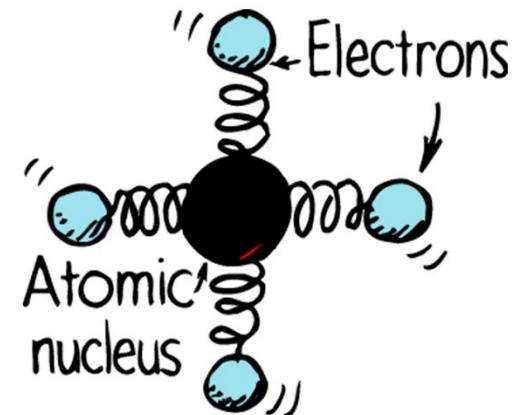
Transparent materials

Simple model of atom: think of electrons attached to nucleus with springs. Light makes these springs oscillate.

- Different atoms/molecules have different “spring strengths” - so different natural frequencies.

- ***If this natural freq = that of impinging light, resonance occurs*** (recall ch 20) i.e. vibrations of electrons build up to high amplitudes, electrons hold on to the energy for “long” times, while passing it to other atoms via collisions, finally transferred to heat. ***Not transparent, i.e opaque***

- So materials that are *opaque* to visible light, have natural frequencies in the range of visible light.



Transparent materials cont.

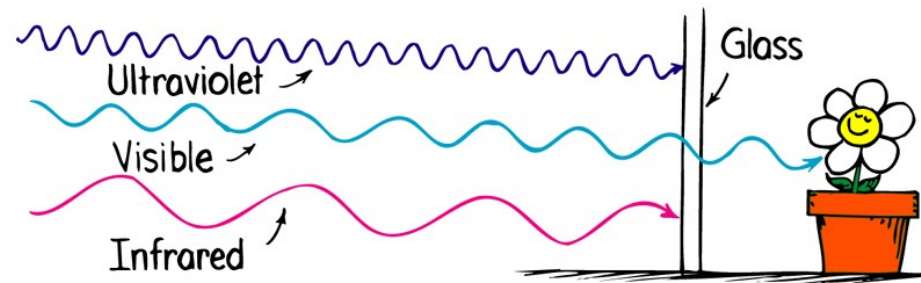
- Glass is transparent: its natural freqs are higher, in the ultraviolet range. So glass is not transparent to ultraviolet. But *is* transparent to lower freqs i.e. visible spectrum.
- **What happens in this off-resonance case?**
 - Atoms are forced into vibration but at less amplitude, so don't hold on to the energy long enough to transfer much to other atoms through collisions. Less is transferred to heat; instead vibrating electrons *re-emit* it as light at same frequency of the impinging light. (see more next slides)
- Infrared waves – frequencies lower than visible – can force vibrations of atoms/molecules as well as electrons in glass. Increases internal energy and temperature of glass. Often called *heat waves*.

Clicker Question

Given that electrons in the atoms in glass have natural frequencies in the ultraviolet (UV), and that the atoms/molecules in glass have natural frequencies in the infrared (IR), which of the following is true?

- A) Glass is transparent to UV and IR, but not to visible
- B) Glass is transparent to UV, but not to visible or IR
- C) Glass is transparent to IR and visible, but not to infrared
- D) Glass is transparent to visible, but not to UV or IR
- E) None of the above is true

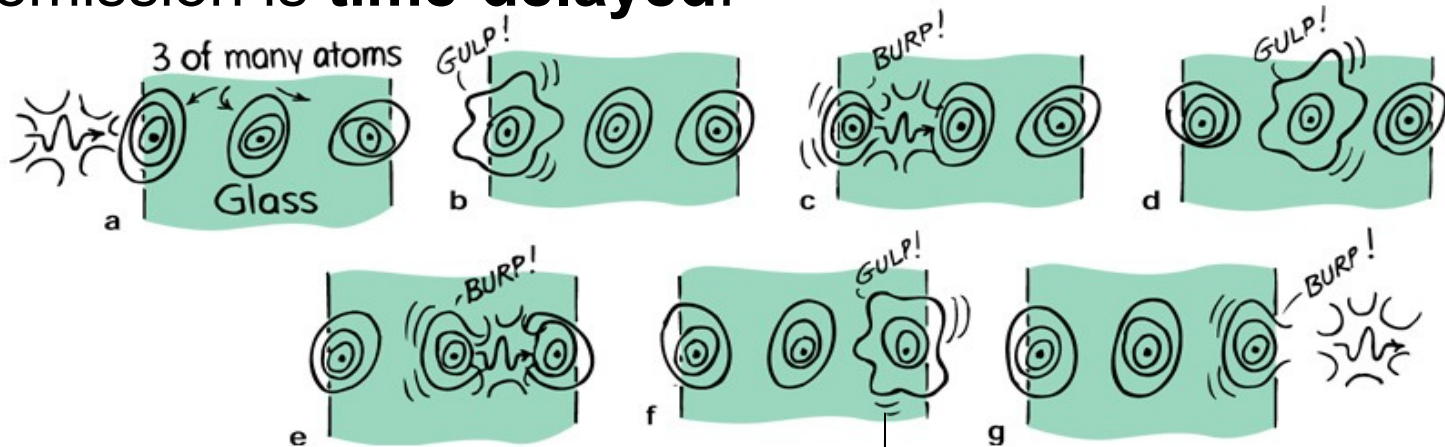
Answer: D



Transparent materials cont.

- So: Light-transparent materials (like glass) have natural frequencies that don't coincide with those of light. The atoms re-emit after absorbing.

This re-emission is **time-delayed**:



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- This leads to speed of light being different in different media:

In vacuum, it's c

In air, only slightly less than c

In water, it's $0.75c$

In glass, $0.67c$ (but depends on type of glass)

When light emerges back into air, it travels again at original c

Questions

- (1) Why in the sunlight is a black tar road hotter to the touch than a pane of window glass?

Sunlight is absorbed and turned to internal energy in the road surface, but transmitted through the glass to somewhere else.

- (3) Can you get sunburned through a glass window?

Glass is opaque to ultraviolet light, so won't transmit it, so you won't get sunburned (although you might get hot! as light in the visible-range is transmitted and then you absorb it).

Opaque materials

- Have natural frequencies in the visible range, E.g. books, you, tables, metals...
- So, they absorb light without re-emitting it.
- Light energy goes into random kinetic energy, i.e. heat.
- Usually, not all the frequencies in the visible light spectrum are resonant - those that aren't, get reflected: this gives the object color (*see much more next chapter*)

Some cases of interest:

- **Earth's atmosphere** – transparent to some UV, all visible, some infrared. But is (thankfully) opaque to high UV.
 - the small amount of UV that does get through causes dangerous sunburn.
 - clouds are semi-transparent to UV, so can still get sunburned on a cloudy day.
- **Water** – transparent in the visible. This explains why objects look darker when wet:

Light is absorbed and re-emitted, bouncing around inside wet region; each bounce loses some energy to material. So less light enters your eye – looks darker.

Shadows

- A thin beam of light is called a *ray*.
- *Shadow* = region where light rays cannot reach e.g. caused by an obstacle in the path of the light.
- Sharp shadows are from large far-away light source, or from a small nearby one.
- Blurry shadows – from large nearby source. If too big, no shadow.

E.g. Move a pen from near the LCD projector (or a light bulb) to further away – shadow on screen (or wall) gets sharper.

Shadows cont.

- Question: Why is there no definite shadow of your hand when you hold it high above your desk?

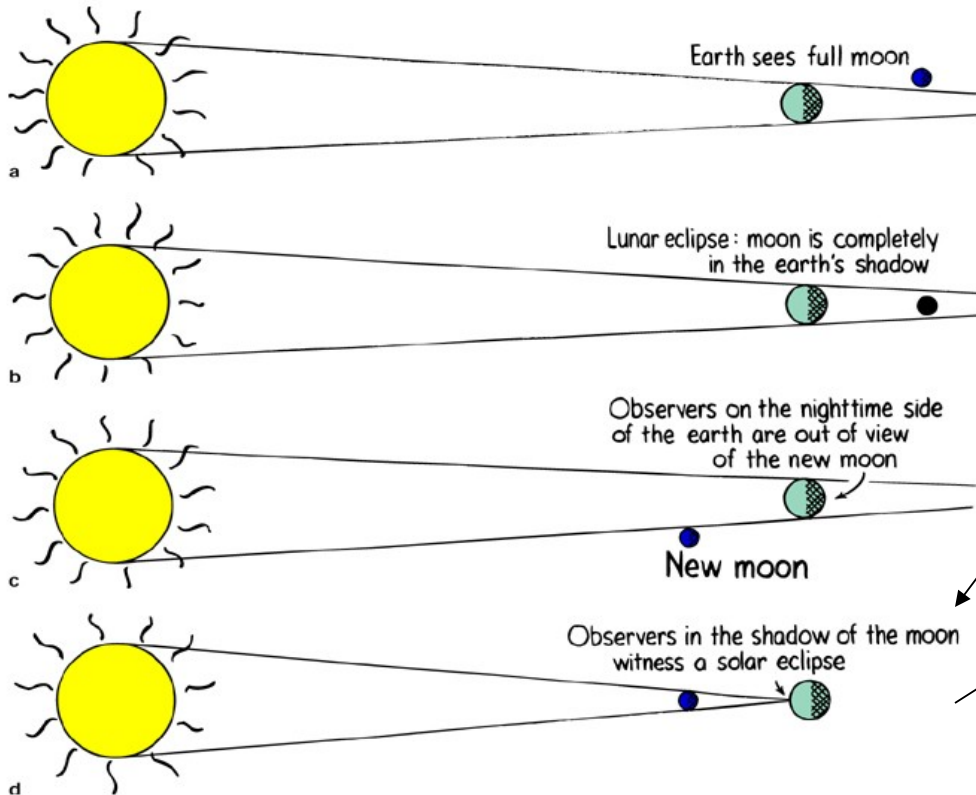
Because of the many different light sources in the room - the shadow cast by one source is illuminated by another light source.

- *Umbra* = total shadow; *penumbra* = partial shadow – how do we get penumbras?

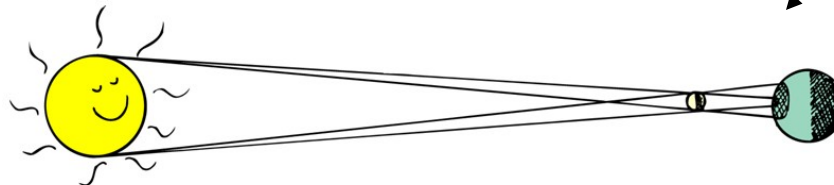
e.g. where some of the light is blocked and light from another source fills it in. Or when light from a large source is only partly blocked.

Shadows of the earth and moon

- Both earth and moon cast shadows when sunlight incident
- When one passes into the shadow of the other – *eclipse*:



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Demonstrates umbra vs penumbra:

Sun is so big that some parts of earth are in the umbra - see complete darkness - whereas others are in penumbra – see partial eclipse (crescent)

Questions

- (1) Why do you not cast a shadow on the ground on an overcast day?

A relatively small light and distant source such as the sun casts a relatively sharp shadow. On an overcast day, the primary sun is blocked and the whole sky (the “secondary” light source), illuminates you. The source is now so big that no shadow is seen.

- (3) Lunar eclipses are always eclipses of a full moon. i.e moon is full just before and after the earth’s shadow passes over it. Why? Can we have a lunar eclipse when we have a half-moon?

Lunar eclipse is perfect alignment of Sun-Earth-Moon. Not-quite-perfect alignment gives Earth observers a full view of the moon since the sunny-side of the moon is facing the night-side of the Earth.

We cannot have a half-moon eclipse, since at halfmoon, the lines from Earth to moon and from Earth to sun are at right angles, so shadow of the Earth does not fall on the moon.

The Eye

is what we detect light with:

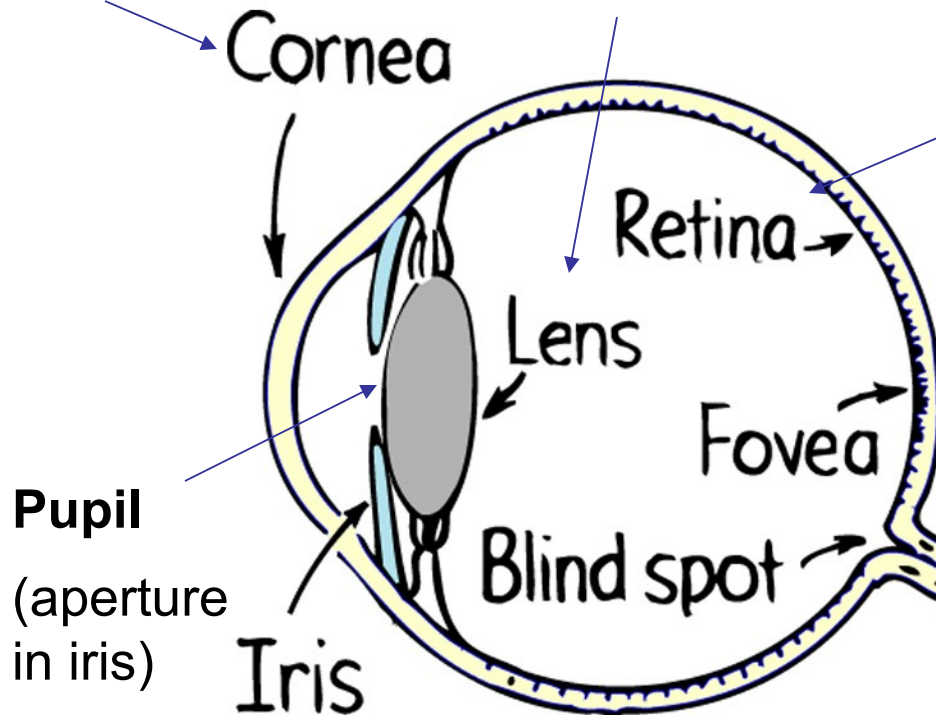
Cornea -transparent cover, through which light enters and bends to enter pupil...

Lens does most of the bending to focus images onto the retina.

Retina is very sensitive to light, made of “antennae” called **rods** and **cones** (see next slide). Not uniform.

Fovea is most concentrated – so images most distinct here.

Blind spot – no rods and cones - optic nerve exits here. Try the fun expt (26.15) in your book !!
Image disappears if focused on blind spot.



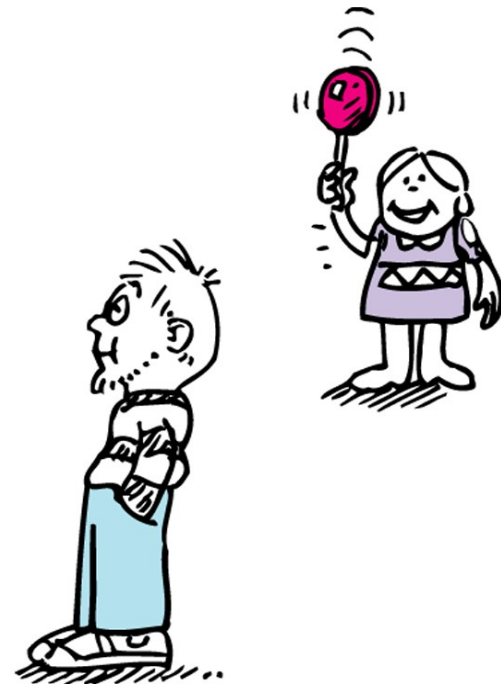
More on the eye

- **Rods** - mostly towards periphery of retina
 - sensitive to light or dark but not color.
- **Cones** - 3 types, depending on whether they detect high-freq, intermediate-freq, or low-freq.
 - denser towards the fovea, and most dense there.
 - detect color
 - need more energy than rods before they “fire” an impulse
- So, cones don't detect low intensities, e.g. at night, it's your rods that do the seeing.
- If want to see detail and color of object, focus it on the fovea.
- In contrast, at periphery of vision, can't tell what color objects are (...next slide)

More on the eye

Eg. DEMO for homework! Get a friend to jiggle colored objects at side, where you can only just see them – you see them moving, but can't tell what color they are!

- Periphery of eye is very sensitive to motion – makes sense from evolutionary point of view.



- There's some more about the eye in your book, that makes for interesting reading, but won't be covered or examinable in this course.

E.g. How pupil dilates when we sense something that pleases us, and contracts if we find something repugnant!

E.g. “Lateral Inhibition” effect – which tends to make us notice boundaries....

E.g. Optical illusions – consider the illusions in Fig. 26.21 in your book!

Clicker Question

Given that cones don't work at low intensity, why do stars always look white to us, even though time-exposure with camera shows them to be brightly colored (red for cooler stars, blue for hotter)?

- A) Because the color only arises through interaction with the camera – actually starlight is white
- B) Because starlight too weak to trigger the cones in our retina
- C) Because starlight is too weak to trigger the rods
- D) None of the above

Answer: B Cones have a higher threshold intensity before they fire, c.f. rods. So we see the stars with our rods which cannot detect color; hence perceived as white.