

Note on Posted Slides

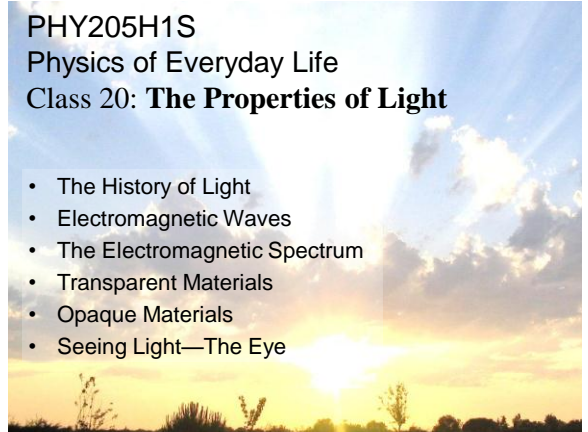
- These are the slides that I intended to show in class on Wed. Mar. 27, 2013.
- They contain important ideas and questions from your reading.
- Due to time constraints, I was probably not able to show all the slides during class.
- They are all posted here for completeness.

PHY205H1S

Physics of Everyday Life

Class 20: The Properties of Light

- The History of Light
- Electromagnetic Waves
- The Electromagnetic Spectrum
- Transparent Materials
- Opaque Materials
- Seeing Light—The Eye



History of Light

- 300 B.C. – **Euclid** of Alexandria noted that light travels in straight lines, and wrote down the Law of Reflection for plane mirrors.

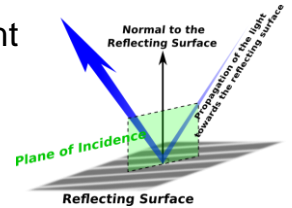
$$\theta_i = \theta_r$$

- Unfortunately, Euclid believed that vision was due to our eyes **emitting** rays of light.



History of Light

- 1000 A.D. – **Alhazen** of Basra considered the law of reflection in 3-D, noting that the angles of incidence and reflection are in the same plane normal to the interface.



- Alhazen proved experimentally that vision is due to light proceeding from objects into our eyes.



[Image from <http://www.ck12.com/ck12p:optics/planes-of-incidence.html>]

History of Light

- 1665 – **Isaac Newton** used a glass prism to disperse light and create a rainbow. He concluded that white light was composed of a mixture of a whole range of colours.



- Unfortunately, Newton advocated the idea that light was a stream of particles, not a wave phenomenon.



History of Light

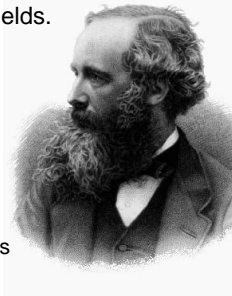
- 1814 – **Jean Fresnel** promoted a wave theory of light, to explain fuzzy shadows, and interference.

- Fresnel modelled light as a transverse wave (in something called the "aether") and successfully predicted amplitudes of reflected and transmitted light from glass interfaces.
- These successes convinced the scientific community that light was definitely a wave phenomenon.



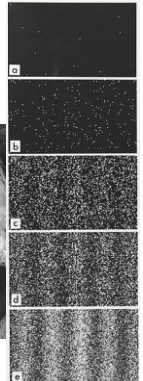
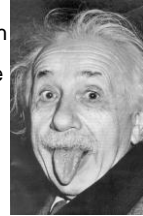
History of Light

- 1864 – **James Clerk Maxwell** published his equations describing the dynamic relations of the electric and magnetic fields.
- Maxwell showed that disturbances in the electric and magnetic fields could propagate as a transverse wave, and he solved for the theoretical speed of this wave.
- This speed was very close to the current experimental value, justifying his theory that light was an electromagnetic wave.



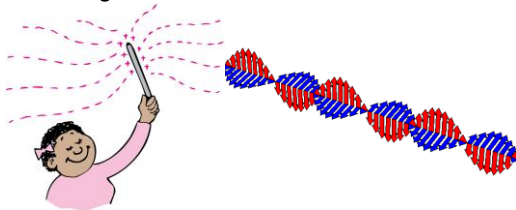
History of Light

- 1905 – **Albert Einstein** explained the photoelectric effect by proposing that light could only be delivered in globs or “particles” of energy (photons).
- This led to the theory of Quantum Mechanics, which states that every particle moves according to a wave equation which gives the probability density of its future location.
- Thus, light is correctly understood as a stream of particles! But tiny particles move like waves.



Electromagnetic Waves

Any time you shake an electrically charged object back and forth, you produce an electromagnetic wave.



Electromagnetic Waves CHECK YOUR NEIGHBOUR

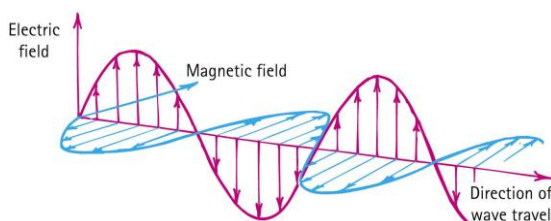
Consider the following three directions associated with a particular electromagnetic wave:

- \vec{E} is the direction of electric field oscillations
- \vec{M} is the direction of magnetic field oscillations
- \vec{v} is the direction of wave motion

- All 3 of \vec{E} , \vec{M} and \vec{v} are parallel
- All 3 of \vec{E} , \vec{M} and \vec{v} are perpendicular
- \vec{E} and \vec{v} are parallel to each other, but both are perpendicular to \vec{M}
- \vec{E} and \vec{M} are parallel to each other, but both are perpendicular to \vec{v}
- \vec{E} and \vec{v} are parallel to each other, but both are perpendicular to \vec{M}

Electromagnetic Waves

The electric and magnetic fields of an electromagnetic wave are perpendicular to each other and to the direction of motion of the wave.



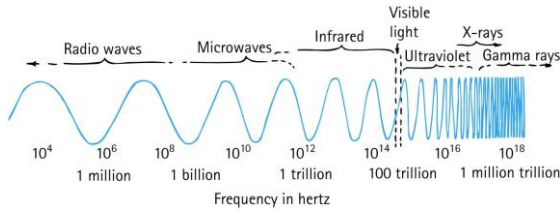
Electromagnetic Waves CHECK YOUR NEIGHBOUR

If an electron vibrates up and down 1000 times each second, it generates an electromagnetic wave with a

- period of 1000 s.
- speed of 1000 m/s.
- wavelength of 1000 m.
- None of the above.

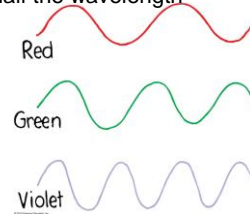
Electromagnetic Spectrum

- In a vacuum, all electromagnetic waves move at the same speed
- We classify electromagnetic waves according to their frequency (or wavelength)
- Light is one kind of electromagnetic wave



Electromagnetic Spectrum

- The lowest frequency (and longest wavelength) light our eyes can see appears red
- As the frequency increases, the light goes through the colors: orange, yellow, green, blue, violet
- Violet light has nearly twice the frequency of red light, and half the wavelength



Electromagnetic Waves CHECK YOUR NEIGHBOUR

If a certain material is “transparent” (ie, not opaque), what does this mean?

- Electromagnetic waves of all frequencies can pass straight through it
- Electromagnetic waves of all frequencies are reflected from its surface
- Electromagnetic waves of all frequencies are absorbed throughout its volume
- Electromagnetic waves of a certain frequency can pass straight through it

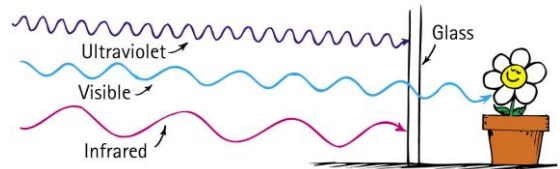
Refraction of Light CHECK YOUR NEIGHBOUR

- When light passes from water into air or vice-versa, it can bend its direction (making the spoon look broken below).
- What causes this bending of the light rays?
 - Absorption due to resonance
 - Change in wave speed
 - Reflection
 - Scattering from small particles
 - Selective transmission



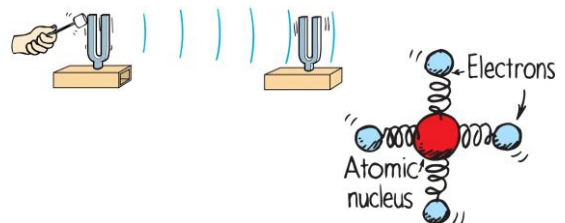
Transparent Materials

Glass blocks both infrared and ultraviolet, but it is transparent to visible light.

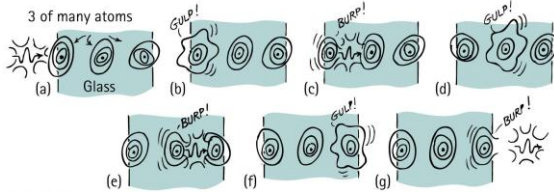


Light is transmitted similarly to sound.

- Both are vibrations due to a vibrating source.



- Photons can only travel at exactly the speed of light.
- Each photon is absorbed and re-emitted each time it encounters an atom in a transparent material.
- Averaged over many molecules, light travels more slowly through a transparent material than through a vacuum.



Transparent Materials

Average speed of light through different materials

- Vacuum: $c = 300,000,000$ m/s
- Atmosphere: slightly less than c (but rounded off to c)
- Water: $0.75 c$
- Glass: $0.67 c$, depending on material
- Diamond: $0.41 c$



Transparent Materials CHECK YOUR NEIGHBOUR

Compared with the frequency of illuminating light on a piece of clear glass, the frequency of light that is transmitted into the glass

- is less.
- is the same.
- is higher.

Opaque Materials

- Most things around us are **opaque**—they absorb light without re-emitting it.
- Vibrations given by light to their atoms and molecules are turned into random kinetic energy—into internal energy.
- These materials become slightly warmer.



Opaque Materials

Metals

- Light shining on metal forces free electrons in the metal into vibrations that emit their own light as reflection.



Reflection CHECK YOUR NEIGHBOUR

Which reflects more light, a white piece of paper or a black piece of paper?

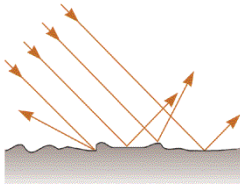
- Black
- White
- About the same

Reflection
CHECK YOUR NEIGHBOUR

Which reflects more light, a white piece of paper or a mirror?

- A. White Paper
- B. Mirror
- C. About the same

Mirror versus White Paper

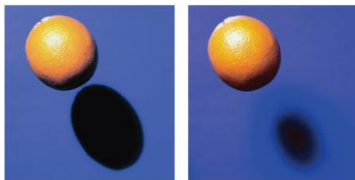


White Paper

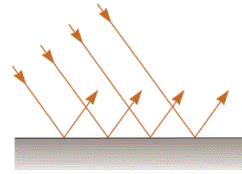
- The surface is *rough* at distance scales near or above the wavelength of light
- Almost **all** surfaces reflect in this way!

Rays and Shadows

- A very distant or small light source will produce a sharp shadow.
- A larger or more nearby light source produces a blurry shadow.



Mirror versus White Paper

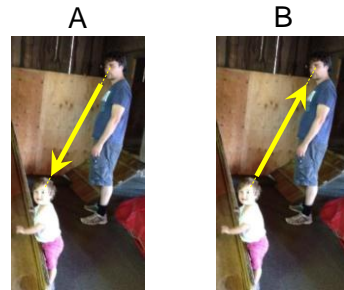


Mirrors

- The surface is *flat* at distance scales near or above the wavelength of light
- It looks “shiny”, and you can see images in it.

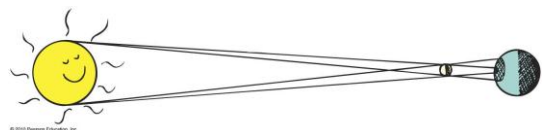
Reflection
CHECK YOUR NEIGHBOUR

Harlow is looking at his daughter, Zainab. In terms of what physically allows him to see her, which arrow is best?



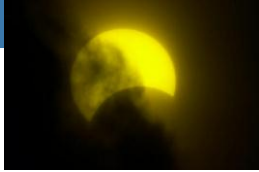
Shadows

The dark part inside a shadow where the light is totally blocked is called an **umbra**.
The **penumbra** is a lighter part around the edges of a shadow, where light from a broad source is only partially blocked.



Reflection
CHECK YOUR NEIGHBOUR

The photo shows a heavily filtered image of the sun during a partial solar eclipse. What is physically happening to cause this eclipse?



- A. Only the penumbra of the Earth's shadow is falling on the moon.
- B. Part of the umbra of the Earth's shadow is falling on the moon.
- C. The photographer is standing in the penumbra of the shadow of the moon which is falling on the Earth.
- D. The photographer is standing in the umbra of the shadow of the moon which is falling on the Earth.

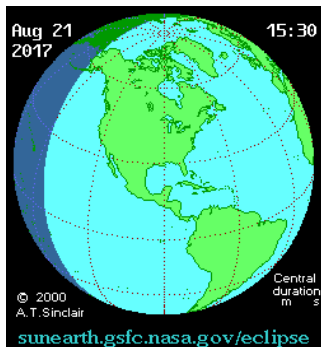
Reflection
CHECK YOUR NEIGHBOUR

The photo shows an image of the moon during a partial lunar eclipse. What is physically happening to cause this eclipse?



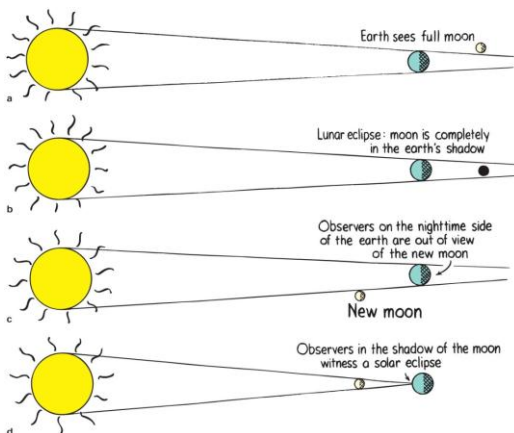
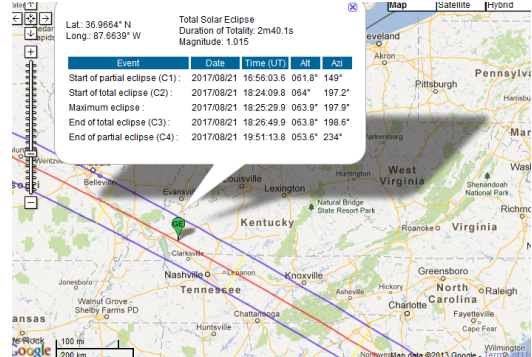
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- C. The photographer is standing in the penumbra of the shadow of the moon which is falling on the Earth.
- D. The photographer is standing in the umbra of the shadow of the moon which is falling on the Earth.

Total Solar Eclipse of August 21, 2017.
Do NOT miss it!



...where will I be in 4 years from this summer? Driving to Nashville, Tennessee!

Total Solar Eclipse of August 21, 2017.
Do NOT miss it!



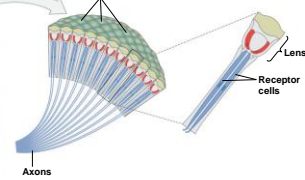
Insect eyes are compound!

Each ommatidium sends separate information to their brain.

(a) Ommatidia are the functional units of insect eyes.

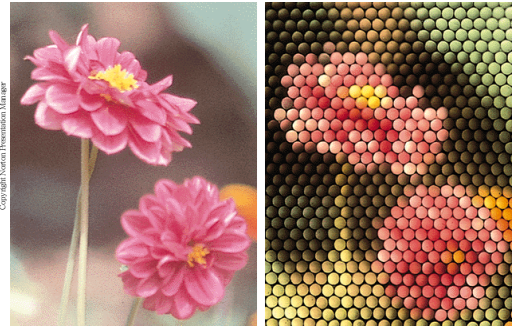
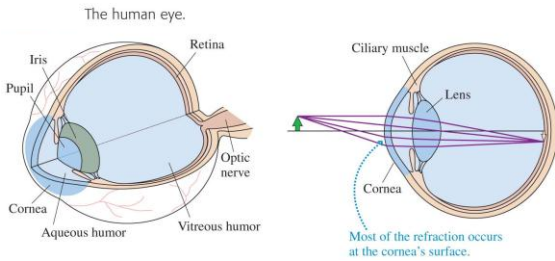


(b) Ommatidia contain receptor cells that send axons to the insect's brain.



Slide courtesy of Ross Koning, Biology Department, Eastern Connecticut State University <http://plantphys.info/sciencematters/vison.ppt>

Human vs Insect Vision

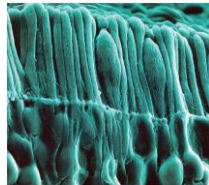


Slide courtesy of Ross Koning, Biology Department, Eastern Connecticut State Univ
<http://plantphys.info/sciencematters/vision.ppt>

Seeing Light – The Eye

The retina is composed of tiny antennae that resonate to the incoming light.

- Rods handle vision in low light.
 - They predominate toward the periphery of the retina.
- Cones handle color vision and detail.
 - They are denser toward the fovea.
 - There are three types of cones, stimulated by low, intermediate and high frequencies of light.



Retina

- The retina is filled with rods and cones
- The spot where the optic nerve exits contains no receptors and is insensitive to light: **blind spot** (we don't notice it because our brain fills in the gap with what it expects)
- At the centre of the retina is the **macula**, which contains twice as many cones as rods
- At the centre of the macula is the **fovea centralis**. It contains no rods, and the cones are very densely packed.
- We constantly move our eyeballs to cause the light coming from the object of primary interest to fall on the fovea centralis.

Use right eye only (close left eye) ...focus only on the target for this test!
 Lock head in position...hold one finger up at arm's length to cover view of target
 Move arm slowly to the right, away from the target
 Find your blind spot for that eye



Slide courtesy of Ross Koning, Biology Department, Eastern Connecticut State Univ
<http://plantphys.info/sciencematters/vision.ppt>

Use right eye only (close left eye)...our target is a row of numbers

1 2 3 4 5 6 7 8 9



Focus on each number in turn, until the break in the blue lines is in your blind spot. What is different when the blind spot holds a blank area?

Slide courtesy of Ross Koning, Biology Department, Eastern Connecticut State Univ
<http://plantphys.info/sciencematters/vision.ppt>

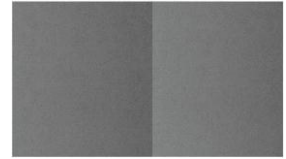
Seeing Light – The Eye

- Although our vision is poor from the corner of our eye, we are sensitive to anything moving there.



Optical Illusions CHECK YOUR NEIGHBOUR

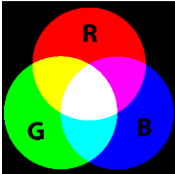
Which half of this box is a lighter shade of gray?



- A. The left half
- B. The right half
- C. Both halves are exactly the same shade of gray
- D. I cannot tell!

Before class on Monday

- Please read Chapter 27, or at least watch the 10-minute pre-class video for class 20.



- Something to think about:
- Why are there exactly 3 “primary colours”? What physical property of the universe causes this?