Chapter 7: Light

Light is electromagnetic radiation—energy—that interacts with matter. Light can only be studied indirectly in terms of how it behaves. Once you understand its behavior, you know everything there is to know about light.

Section 7.1: Sources of Light

Luminosity

- The sun shines, a candle glows, a lightbulb burns: it's all the same thing!
- Oscillate an electron! Seriously!
- Time-varying electromagnetic field!

The Electromagnetic Spectrum

- Accelerate an electron: greater acceleration, greater frequency of oscillation
- Visible light = obvious to us, but it's only a tiny part of a greater spectrum
- Radio waves and x-rays are exactly the same thing as visible light– just at a different frequency
- All e·m waves travel at the same speed! c = 3x108m/s

Blackbody Radiation

- Everything radiates: It's creepy, but it's true
- Everything that is a thing is made of matter containing moving electrons
- Higher temperature, higher frequency: You are radiating in the infrared (about 300K), but the sun radiates in the visible (about 6000K)

Section 7.2: Properties of Light

Rays of Light

- Straight-line propagation: Light follows a straight path
- Light can travel through either vacuum or material medium

Light Interacts With Matter

- What happened when light runs into an obstruction? Or a change in medium?
- Three possibilities: Reflection, absorption, transmission
- Sometimes all three at once!

The Material Makes a Difference

- Transparent: Material permits light to pass through (glass, water)
- Not all materials permit all frequencies to pass through!
- Opaque: Material either reflects or absorbs (or both!)

Reflection

- Specular reflection: Smooth surface, crisp, well-focused reflected image
- Diffuse reflection: Rough surface, fuzzy, poorly-focused image
- Some materials may reflect only certain frequencies

Law of Reflection

- One rule only: angle in = angle out
- This holds for any kind of wave (not just light)
- This holds for any shape of surface (not just smooth flat planes)

Image Formation

- Virtual image: Upright (right side up, might be magnified or "minified"
- Real Image: Inverted (upside down), might be magnified or "minified"
- Plane mirror: Virtual image is the same size as real object
- Concave mirror: Can form either real or virtual images!
- Convex mirror: Virtual images only (objects in mirror are closer than they appear!)

Refraction

- Change in medium means change in speed
- Change in speed means change in direction
- Light ray bends towards the slower medium

The Medium Makes a Difference

- Anything that is not vacuum is slower! Vacuum is the fastest
- Glass: speed is about ⅔c
- Water: speed is about ¾c

The Angle Makes a Difference

- Always measure angle with respect to the normal!
- Light incoming along normal: no refraction
- Greater angle of incidence, greater amount of refraction

Total Internal Reflection

- Only happens when light travels from slower to faster medium (water to air, for example)
- As angle of incidence increases, more and more light reflects instead of transmits
- Critical angle: All of the light is reflected back, none is transmitted

Snell's Law

- $n_1 \sin\theta_1 = n_2 \sin\theta_2$
- n = index of refraction
- Index of refraction = ratio of speeds: $n = \frac{c}{v}$
- $n = 1$ for vacuum, anything else (slower), $n > 1$

Lenses

- Curve a piece of glass (or plastic) to control the refraction
- Convex lens: Curved outward
- Concave Lens: Curved inward

Convex Lenses

- Can form either real (magnified or "mini-fied") or virtual ("minified") images
- Type of lens in the human eye
- Corrects far-sightedness (hyperopia)

Concave Lenses

- Can only form virtual images that are "mini-fied"
- Corrects near-sightedness (myopia)

Dispersion and Color

- Wavelength is related to frequency
- All frequencies have same speed, so higher frequency = shorter wavelength
- Shorter wavelengths are dispersed (bent) more than longer wavelengths

ROYGBIV

- White light can be separated into colors according to wavelength (frequency)
- The spectrum of colors is always ROYGBIV, never VIBGORY (or any other combination)
- Red = low frequency, long wavelength
- Violet = high frequency, short wavelength

Color Vision

- Human eye sensitive only to the visible part of the e·m spectrum, about 400nm–700nm (ish)
- Difference in wavelength (frequency) perceived as difference in color
- Human eye is most sensitive to the wavelength which matches the sun's peak output

Rainbows!

- The geometry is very particular: That's why you don't see them all the time!
- Spherical droplets: Refract, reflect, refract
- Double rainbow: Refract, reflect, reflect, refract

Section 7.3: Evidence for Waves

Particle or Wave?

- In the late 1600s, Newton was convinced light was a particle
- At the same time, Christaan Huygens was convinced it was a wave
- Who was right? Turns out they both were

Interference

- Same as we saw with sound waves! Interference is a wave phenomenon!
- Easy to do an experiment that shows light waves interfering
- By measuring the pattern, you can calculate the wavelength

Polarization

- Demonstrates that light is a transverse (not longitudinal) wave
- Sunlight, light bulb: Unpolarized light (oscillations in many random directions)
- Polarized sunglasses: Allow only one direction of vibration to pass through

Section 7.4: Evidence for Particles

Why Would Light Be a Particle?

- Wave theory explains things that particles simply can't do
- Doesn't actually explain why light slows down in glass or water

Photoelectric Effect

- You can use light to bounce electrons off a surface
- Specific material requires a specific wavelength (frequency); other colors don't work
- Lower intensity light, fewer e^- ejected (higher intensity, more ejected)
- Ejected e^- have the same KE no matter the intensity of the light

Quantization of Energy

- Photon = particle of light (massless), or packet of energy
- Just like charge is quantized, photons are as well
- Each photon with the same frequency has the same energy: $E = hf$

Section 7.5: The Present Theory

Wave-Particle Duality

- Light exhibits both traits, but never at the same time
- If it's behaving like a wave, no particle properties
- If it's behaving like a particle, no wave traits