Chapter 29: Light Waves

Interference
- Light waves "interfere" with each other
- They can be said to be "in phase" or "out of phase" with each other
- In phase: amplitudes reinforce each other
- Out of phase: amplitudes cancel each other

Constructive Interference

Destructive Interference

Interference
Interference pattern of overlapping waves from two nearby sources

Diffraction
- Bending of light as it passes the edge of an object
- Demo: Hold your thumb and forefinger very close together: You can see diffraction around the edges!
Thin Films (Soap Bubbles)

Chapter 30: Light Emission

A Simple Atom

- Only 2 energy levels
  - Ground (E1)
  - Excited (E2)
- Right now electron is at E1

A Simple Atom

- Excitation
  - Electron absorbs a photon and jumps from E1 to E2
  - Photon only absorbed if it has energy = (E2-E1)
A Simple Atom

- **Ionization**
  - Electron absorbs a photon and leaves!
  - Only works if electron is in higher energy levels

- **De-excitation**
  - Electron emits a photon of energy (E2-E1)
  - Electrons like to be in the ground state

Continuous Spectrum

- All wavelengths, no breaks
- Rainbows!

Absorption Spectrum

- Rainbow with dark lines on top
- Also called dark-line spectrum
- Atoms in the cloud are absorbing photons, moving to higher energy levels

Emission Spectrum

- Bright, individual lines
- Also called bright-line spectrum
- Electrons are moving to lower energy levels, emitting photons of light

Kirchhoff’s Laws

I. A hot, dense substance will give off continuous spectrum
II. A hot, low-density gas will give off an emission spectrum
III. A cool, low-density gas in front of a continuous-spectrum source will give off an absorption spectrum
Chemical Fingerprints

- Downward transitions produce emission lines
- Upward transitions produce absorption lines

Chemical Fingerprints

- Each type of atom has a unique spectral fingerprint, due to spacing of energy levels

Lasers

- “Laser”: Light Amplification by Stimulated Emission of Radiation
- Lasers produce coherent light: all the waves are in phase
- Lasers also produce monochromatic light: all the same frequency (color)!
- NOT sources of energy: laser pointers run on batteries

Fin de Siécle Physics: A little history

Wave-Particle Duality

- Light behaves like a particle when emitted by an atom or absorbed by photographic film or other detectors
- Light behaves like a wave while traveling from a source to the place where it is detected.

Chapter 31: Light Quanta
What the heck is a quantum, anyway?

- Quantum = discrete, individual, point-like object
- Different from waves, as we typically think of them
- 1 quantum = 1 “piece”, or 1 step (think of increasing energy in small chunks, rather than continuously)

Other Quanta

- Matter is quantized: mass is contained in individual particles: protons, electrons, neutrons, etc.
- Electric charge is quantized: all charged particles have a multiple of the basic electric charge \( +e \) or \( -e \)
- You can’t have just any old charge that you want, it has to be some whole number times \( 1.602 \times 10^{-19} \) C!

The Photoelectric Effect

- When a light shines on a metal surface, electrons are ejected from the surface
- Explained by Einstein in 1905, in one of his three most famous papers (which would win him the Nobel Prize in 1921)

Why was the photoelectric effect surprising?

- Electrons weren’t initially ejected any faster with brighter or higher f light
- Easier effect with UV or violet light, hard with red light
- Rate of electrons ejected was \~ brightness
- Max. energy of electrons depended on f of light, but not brightness of the light!
- Most importantly, these observations couldn’t be explained by the wave theory of light!

Examples

Einstein’s Explanation

- Light is behaving like individual packets of energy (now called photons)
- Each photon carries a certain amount of energy that depends on the frequency of the light
  - Each photon gives ALL of its energy to the electrons, not part
  - Higher intensity just means more photons, NOT higher energy photons!
Quantized Light

- Light waves carry discrete amounts of energy
- Their energy depends on the frequency and Planck's constant:
  \[ E = h f \]
- Planck’s constant: \( h = 6.6 \times 10^{-34} \text{ J s} \)

De Broglie Wavelengths

- Matter can behave like a wave??!!?
- Yup! Wavelength = \( h/mv \)
  \[ \lambda = h/mv \]
- This wavelength is called the de Broglie wavelength, after a French physicist

De Broglie Wavelengths

Example: What is the de Broglie wavelength of a ping-pong ball of mass 2 grams after it has been slammed across the table at a speed of 5 m/s?

\[ \lambda = h/mv \]

Electron Diffraction

- The de Broglie hypothesis was unexpectedly experimentally confirmed in 1927 by two scientists firing electrons at a nickel crystal
- The regular spacing between atoms in the crystal acts like a diffraction grating
Images from Electron Microscopes

The Uncertainty Principle

- The act of taking a measurement itself introduces a little bit of uncertainty into the result
- When studying large objects, we don’t have to worry about this so much, but when we get down to the size of an atom or an electron we do!

Measuring the speed of a baseball vs. measuring the speed of an electron

Uncertainty Relations

\[ \Delta p \Delta x \geq \frac{h}{2\pi} \]
We can measure the speed, or where it is, but not both at once.

\[ \Delta E \Delta t \geq \frac{h}{2\pi} \]
We can measure the energy, or how long it had that energy, but not both at once.
Complementarity

- Both matter and light have both wave and particle properties
- The type of question that we ask (or the type of measurement that we seek to make) determines the properties that we will see!
- The wave and particle natures of matter and light are two complementary properties, like two sides to the same coin