The de Broglie Wavelength

Lesson 11

Review

- Remember that it has been proven that waves can occasionally act as particles. (ie: photons are ***particles*** of light that can interfere with other photons but can also collide and have momentum)
- This is called the wave-particle duality of nature.

de Broglie

- In 1923, Louis de Broglie proposed a new idea…
  - Could things believed to be particles (like electrons and baseballs) sometimes act as waves?
- Nobody really took de Broglie seriously until Einstein read his paper and agreed with his ideas

Formula

- de Broglie suggested combining a couple of formulas, one of them a particle type, the other a wave type:

$$p = mv \qquad p = \frac{h}{\lambda}$$

$$mv = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{mv}$$

Formula, con't

- This formula allows us to calculate the de Broglie wavelength of a moving particle
  - For an object to have a wavelength, it must be moving
  - Day to day objects that are around us have wavelengths so small that we can never hope to measure them

Warning!
Many people make the mistake of calculating the energy of the moving particle using kinetic energy, then using $E = hc / \lambda$ to find the wavelength. You can NOT do this, as it assumes the mass stops, changing all its energy into a pulse of EMR.

Example

Example 1: **Determine** the de Broglie wavelength of a 0.20kg ball moving at 15m/s.

$$\lambda = \frac{h}{mv}$$

$$\lambda = \frac{6.63\text{e-}34}{0.20(15)}$$

$$\lambda = 2.2\text{e-}34\,m$$

Problems: Evidence

- Now the hard part: finding experimental data to support the theory
  - The problem was that no one had ever seen a particle diffract or interfere with another particle (proof it was acting like a wave)
  - With wavelengths as small as the one we found in Example 1, it’s impossible observe the wave properties

The Solution

- Remember Young’s double slit experiment? In order to be able to see the effects of diffraction (and measure wavelength), you need slits or objects which are not much bigger than the wavelength being studied
- It is impossible to create a diffraction grating as small as 10^{-34} m – that’s smaller than the orbits of electrons around the nucleus!!
- However…with a really small mass (note the position of mass in the formula), like an electron, the wavelength gets bigger and might be measureable.

Example

Example 2: **Determine** the wavelength of an electron accelerated by a 100V potential difference. First calculate the velocity of the electron using formulas you used in the electricity unit…

$$E_k = \frac{1}{2} m v^2 \qquad E = q\,V$$

$$qV = \frac{1}{2} m v^2$$

$$v = \sqrt{\frac{2qV}{m}}$$

$$v = \sqrt{\frac{2(1.60\text{e-}19)(100)}{9.11\text{e-}31}}$$

$$v = 5.93\text{e}6\, m/s$$

Example, con't

- Now use that velocity to calculate the wavelength…

$$\lambda = \frac{h}{mv}$$

$$\lambda = \frac{6.63e\text{-}34}{9.11e\text{-}31(5.93e6)}$$

$$\lambda = 1.23e\text{-}10\,m$$

Experimental Evidence

- Although the wavelength in the previous example is small, the spaces in an atom of a crystal are about this size

- Davisson and Germer shot electrons at a crystal sample of nickel in a vacuum tube and observed a diffraction pattern.
  - The spaces between the atoms of nickel are about the same size as the wavelength of the moving electrons, so they acted like the openings in a diffraction grating.
  - On the other side of the nickel the electrons (acting as waves interfering with each other) hit the phosphorescent coating on the tube and formed the glowing pattern as shown in *Illustration 2*.
  - Just like measuring values in Young's Double Slit experiment, we can make similar measurements here to find the wavelength.
- The value de Broglie predicted and Davisson-Germer's values were exactly the same.
- The conclusion: particles have wave properties!

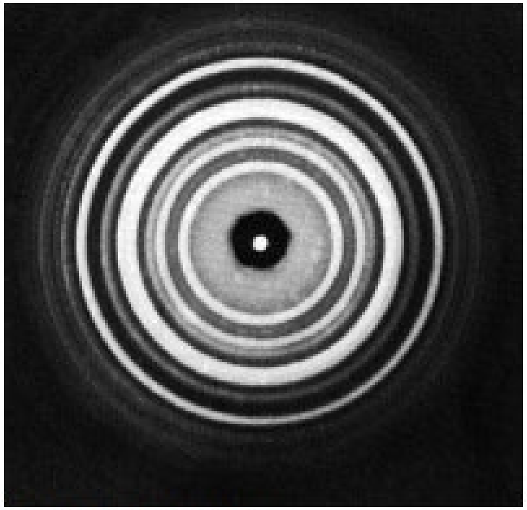

Illustration 2: Interference pattern seen for electron diffraction.

Standing Waves

- According to de Broglie, an electron travelling the circumference of a circle such that

$$2\pi R = n\lambda$$

  will create a matter wave that will constructively interfere with itself
- There are as many standing waves in an energy level as there are quantum states.
- This explains why energy levels must be exact or the wave collapses.
- This also explains why electrons cannot sit between energy levels.

Technology

- As a result of de Broglie's discovery, we now have the Scanning Electron Microscope (SEM).
- It uses interference patterns to help determine the composition of different objects