4. The potentiometer is adjusted to give the minimum voltage at which there is zero reading on the microammeter. State and explain what change, if any, will occur in the microammeter when

   a) the intensity of the incident light is increased but the frequency remains unchanged.

      No change – stopping potential depends on energy of each electron – no change in frequency so no change in photon energy so no change in electron energy

   b) the frequency of the light is increased at a constant intensity.

      Reading increases from zero – photon energy increases so electron energy increases.

Matter Waves

Louis de Broglie (French physicist, 1892 – 1987) postulated in his doctoral dissertation that because light can have both wave and particle characteristics, perhaps all forms of matter have both characteristics.

De Broglie Hypothesis (1924):

All particles can behave like waves whose wavelength is given by **λ = h/p** where h = Planck's constant and **p** = the momentum of the particle

Matter wave:

All moving particles have a "matter wave" associated with them whose wavelength is the de Broglie wavelength.

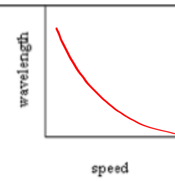
Wave-Particle Duality:

Both matter and radiation have a "dual nature". They exhibit both particle and wave properties.

De Broglie wavelength

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

Sketch the relationship between speed and the de Broglie wavelength of a moving object



1. Determine the de Broglie wavelength for an electron moving at 6.0×10^6 m/s and a baseball (mass = 0.15 kg) moving at 13 m/s.

$$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}\,J\cdot s}{9.11\times10^{-31}\,kg \cdot 6\cdot10^{6}\,m/s} \approx 1.2\times10^{-10}\,m$$

$$\frac{6.6\times10^{-34}\,J/s^{-1}}{.15\,kg\cdot 13\,m/s} \sim 10^{-34}\,m$$

2. Why don't we notice the wavelike nature of matter in everyday life? Wavelengths are too small

3. Compare the momentum of photons and particles. Which has more momentum – a red photon or a blue photon?

Photon Momentum

$$P = h/\lambda$$

$$E^2 = p^2c^2 + m_0^2c^4$$

Particle Momentum

$$P = h/\lambda = mv$$

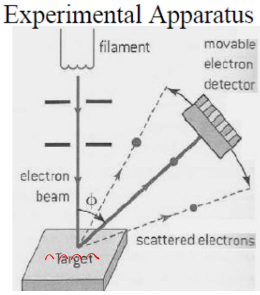
$$E_k = \tfrac{1}{2}mv^2 = qV$$

Experimental Confirmation:

I. Electron diffraction by scattering (reflection):

Method: "Boil" electrons off a hot filament and accelerate them through a potential difference to a high speed. Then direct this beam of electrons onto a crystal of nickel and measured number of electrons scattered (reflected) at various angles, Φ, by using a movable electron detector.

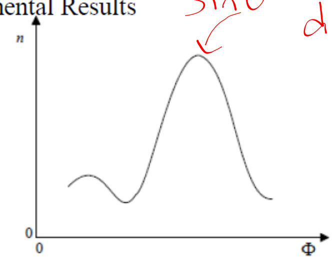
Experimental Apparatus



Experimental Results

$$\sin\theta = \frac{\lambda}{d}$$

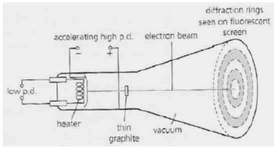
The number n of electrons scattered per second through an angle Φ is measured and graphed.



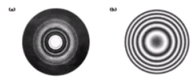
II. Electron diffraction by transmission IB 12

Method: "Boil" electrons off a hot filament and accelerate them through a potential difference to a high speed. Then direct this beam of electrons onto a thin target of graphite. After passing through the graphite, the electrons hit a fluorescent screen which glows when struck.

Experimental Apparatus



Experimental Results



Diffraction pattern for light Diffraction pattern for electrons

Importance: experimental confirmation of de Broglie hypothesis (matter waves)

Why are the wave-like properties of matter evident in these experiments but not in everyday life?

De Broglie wavelength of electrons is comparable to the size of the spacing between atoms so noticeable diffraction and interference occurs

4. Compare the energy of photons and particles.

$E^2 = p^2c^2 + m_0^2c^4$

Photon Energy

$P = h/\lambda$

$E = hf$ ← only for photons

Particle Energy

$P = h/\lambda$

$E_k = \frac{1}{2}mv^2$

$E_k = \frac{p^2}{2m}$

5. Compare the kinetic energy of a particle and its de Broglie wavelength

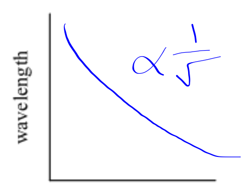
$E_k = \frac{p^2}{2m} = \frac{h^2/\lambda^2}{2m}$

$E_k = \frac{h^2}{2m} \cdot \frac{1}{\lambda^2}$

qV (↑ E_k)

$\lambda \propto \frac{1}{\sqrt{E_k}}$

$E_k \propto \frac{1}{\lambda^2}$



Kinetic energy

7. An electron is accelerated through a potential difference of 1.00 kV. What is its resulting de Broglie wavelength?

$E_k = qV = 1.6\times10^{-19}\,C \cdot 1000\,J/C = 1.6\times10^{-16}\,J = \frac{1}{2}mv^2$

$v \approx 2\times10^7\,m/s$

$P = mv$ $\lambda = \frac{h}{mv} = 3.9\times10^{-11}\,m$