Let's work through an example:

Assume an electron beam with kinetic energy of 100 eV. What is the de Broglie wavelength of the electron?

Use: mass of electron $= 9.11 \times 10^{-31}$ kg

energy of electron $= 100 \text{ eV} = 1.602 \times 10^{-17}$ J

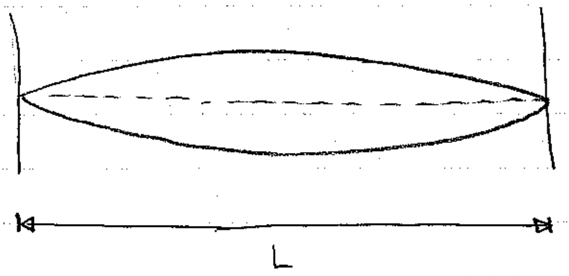
↑ convert to Joules, since you have mass in kg

$$\Rightarrow \lambda = \frac{6.626 \times 10^{-34} \text{ Js}}{\sqrt{2 \times 9.11 \times 10^{-31} \text{ kg} \times 1.602 \times 10^{-17} \text{ J}}}$$

$$= 1.227 \times 10^{-10} \text{ m}$$

Before we continue by showing that any massive particle has indeed wave character, we briefly discuss how de Broglie was able to relate his proposal to Bohr's quantization of the angular momentum.

Think about a standing wave in a box



In a box of length L the longest wavelength

of a standing wave is $\lambda = 2L$
More general, any standing wave in the box must fulfill the relation

$$\lambda = \frac{2L}{n} \qquad \text{with} \quad n = 1, 2, 3, \ldots$$

between wavelength λ and box length L.
In other words: The wavelength or multiples of the wavelength must be equal to the length of a complete path of the wave (from start, say at the left end of the box, all the way to the other end and back $= 2L$)

To relate this the circular orbits in Bohr's hydrogen model, we must extend this concept of a standing wave to a circle. The path is then the circumference of the circle of radius r and we get as condition for a standing wave on a ring

$$2\pi r = n\lambda$$

Now deBroglie used his postulate of the wave-particle duality and assumed that the stationary orbitals are related to standing waves. This gives for the angular momentum of the particle

$$\underline{L} = mvr = pr = \frac{h}{\lambda} r = \underbrace{\frac{2\pi r}{\lambda}}_{\substack{= n \\ \text{for standing} \\ \text{wave}}} \underbrace{\frac{h}{2\pi}}_{= \hbar} = \underline{n\hbar}$$

This is exactly Bohr's quantization condition for angular momentum. Although this gives a justification for $L = n\hbar$, we still have all the other problems with Bohr's model.

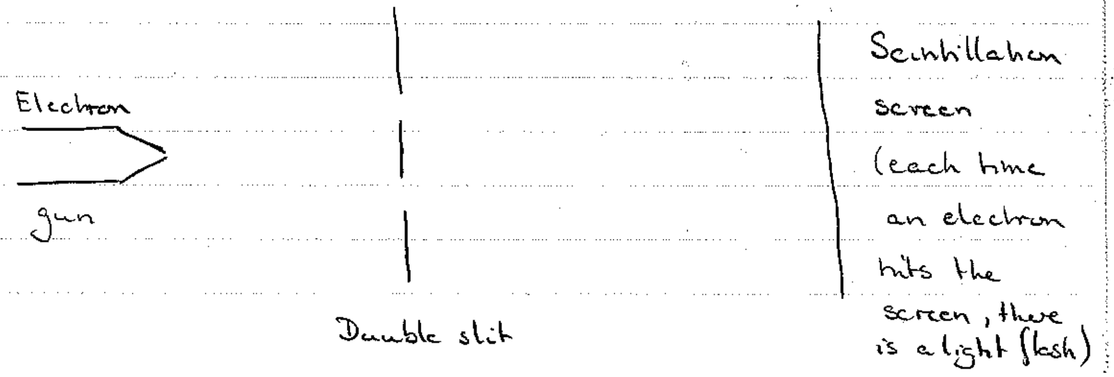
We really need a <u>new</u> theory / description of the microscopic world and the experimental observation that particles such as electrons have a dual wave-particle behavior will path the way to this quan<u>tum</u> <u>theory</u>.

4.3. Double slit experiments

We know from experiments with light that interference phenomena are characteristic for waves. And, the double slit experiment is a prototype experiment for interference phenomena.

The <u>first</u> experiment of this kind with electrons was done in 1927 by Davisson and Germer who used the layers of a crystalline solid for the interference. Later, typical double slit experiments with a beam of single electrons were performed:

Scheme of set up



Summary of observations

- There are always individual light flashes, each electron accounts for one flash. There are never two light flashes at the same time, i.e. the electrons do not split

→ particle feature

- After many events there is a regular pattern, namely the typical two-slit interference pattern

→ wave feature

- Light flashes appear randomly. One cannot determine where the next light flash will occur. However, there are regions (maxima of interference pattern) where it is more likely to find the electron and others (minima of interference pattern) where it is less likely to find the electron

→ probabilistic aspect

Thus, we can clearly see that this experiment cannot be described with means of classical physics:

- Concepts of particles and waves are not anymore mutually different. They must be related.
- There are (many) aspects that are probabilistic and not deterministic.