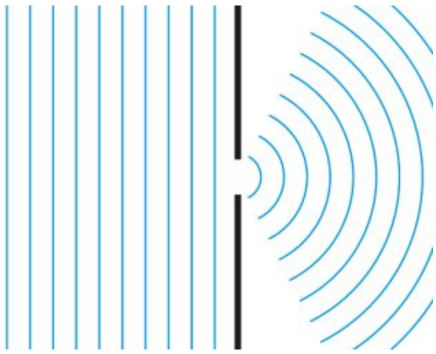
2.11 Wave particle duality

We have seen, from the photoelectric effect, that light can have particle-like properties. Could particles have wave-like properties? The answer is yes!

videos

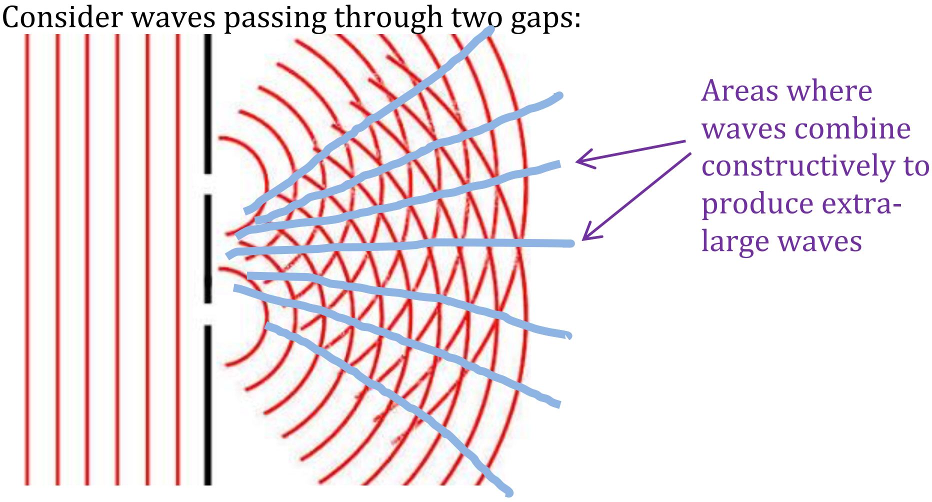
When we think about waves, we know that they can refract, diffract, and interfere. To show that particles (such as electrons) have wave-like properties, we need to show that in certain circumstances they can do these things.

Consider waves passing through gap in a barrier:



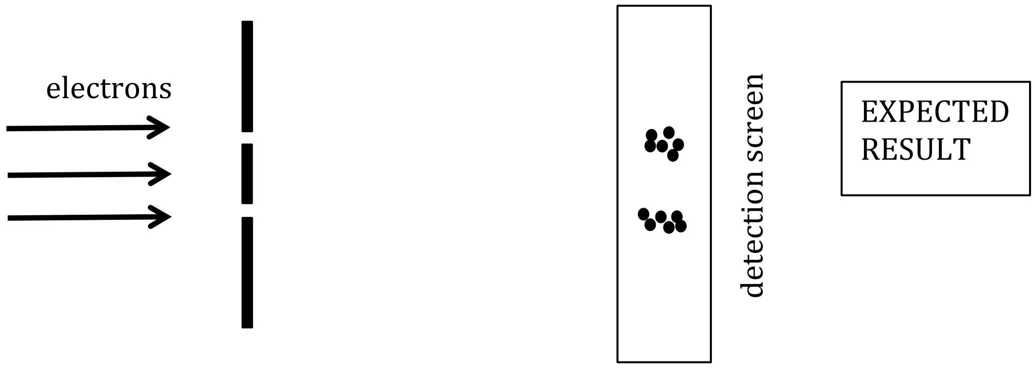
Provided the size of the gap is similar in size to the wavelength, we will see the waves bending around behind the barrier. This is called diffraction.

Consider waves passing through two gaps:

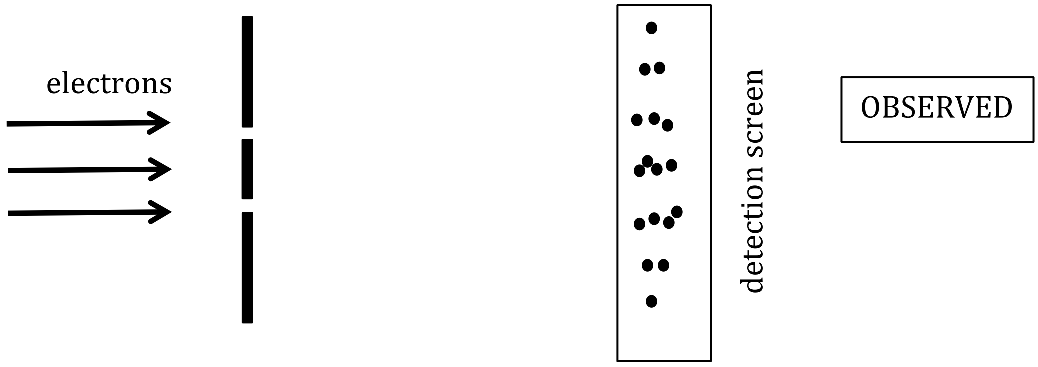


The waves diffract on passing through the two gaps and overlap in such a way as to produce areas where the waves reinforce (constructive interference) and areas where waves cancel (destructive interference).

Now imagine firing particles (such as electrons) at two gaps, as above. We would expect that the electrons would pass through one gap or the other and we would detect them in two locations, as shown in the diagram below:



What in actually observed is the following:



This shows that electrons are clustered in bands, with gaps between. The bands correspond with the wave picture above where waves combine constructively. The gaps in between correspond to the wave picture where wave combine destructively. So, it appears that the electrons are behaving like waves. The electron (or the electron 'wave function') is passing through both slits and interfering with itself. The electron is detected on the screen in a statistical pattern determined by this interference.

The spacing of the bands seen on the screen is found to depend on the velocity of the electrons. The faster they travel the closer the bands are together. It can be shown that the wavelength of a particle is given by the formula:

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

where h = Planck Constant and p = momentum (mass x velocity) of the particle

Substituting $p = mv$, where m is the mass and v is the velocity:

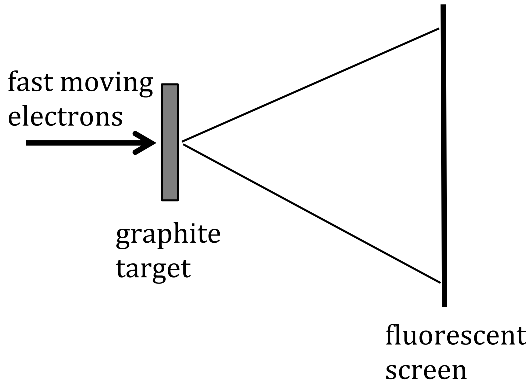
$$\lambda = \frac{h}{mv}$$

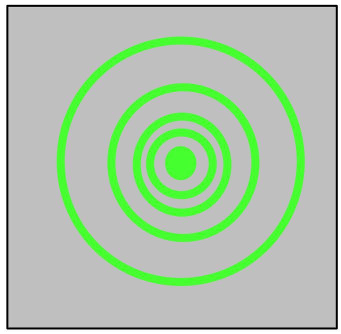
This is called the de Broglie wavelength.

(1)✐What is the de Broglie wavelength of an electron (mass = 9.1×10^{-31}kg) moving with a velocity of 3×10^{6}ms^{-1}? The Planck constant = 6.63×10^{-34}m^{2}kgs^{-1}.

Practical method for demonstrating the de Broglie effect

We can create an interference pattern for electrons using the following equipment:





observed on screen

Electrons are accelerated through a potential difference and fired at a graphite target. The screen is coated with a material which fluoresces when hit by an electron. The crystals of graphite consist of densely packed sheets of carbon atoms. They act as small 'gaps' through which the electron waves diffract.

(2)✐Why do you think graphite crystals are used?

If we look close up at the graphite crystals, we find that they are arranged randomly.

(3)✐Explain why a circular interference pattern is observed.