Towards quantum mechanics...

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Lesson Objectives

1. Know what particle diffraction is, and how it changes our view of particles.
2. Check understanding of the photoelectic effect (waves as photon particles).
3. Be able to calculate the de Broglie wavelength.

Textbook pp. 41–42

Specification Requirement

Candidates should know that electron diffraction suggests the wave nature of particles and the photoelectric effect suggests the particle nature of electromagnetic waves; details or particular methods of particle diffraction are not expected.

de Broglie wavelength $\lambda = \frac{h}{mv}$,

where mv *is the momentum.*

[AQA GCE AS and A Level Specification Physics A, 2009/10 onwards]

Photoelectric effect AGAIN!

A source emitting light of all wavelengths is covered with a red filter so that light of essentially one wavelength is transmitted. When the light strikes a metal surface, a stream of electrons emerges from the metal. If the red filter in front of the source is replaced with a blue one, then

1. more electrons are emitted.
2. emitted electrons more energetic.
3. Both (1) and (2) are true.
4. Both (1) and (2) may be true.
5. Both (1) and (2) are false.

Photoelectric effect AGAIN!

A beam of ultraviolet light is incident on the metal ball of an electroscope. Which statement(s) is/are true?

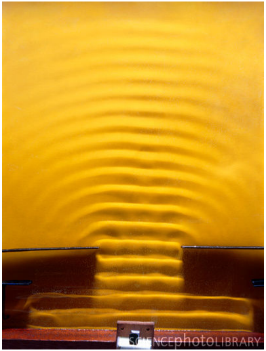
1. If the electroscope was initially positively charged, it discharges.
2. If the electroscope was initially negatively charged, it discharges.
3. Both of the above.
4. Neither of the above.

Photoelectric effect AGAIN!

A beam of ultraviolet light is incident on the metal ball of an electroscope that is initially uncharged. Does the electroscope acquire a charge?

1. Yes, it acquires a positive charge.
2. Yes, it acquires a negative charge.
3. No, it does not acquire a charge.

Diffraction means the spreading out of waves.



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Everyday examples:

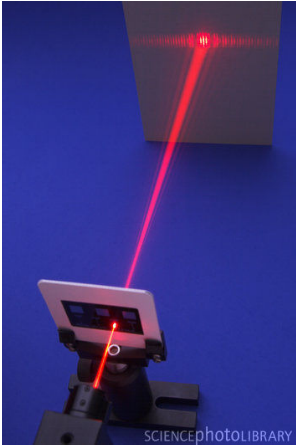
- Water waves (harbour wall)
- Sound through a building (around corners)
- Light around edges of objects (sometimes, e.g. look through your thumbs!)
- Radio waves around a hill / building

Diffraction of light

For light, the wavelength is much smaller ($\approx 10^{-7}$ m for visible) than water waves, so the aperture has to be much smaller.

Examples:

- Very fine specially-made grating
- CD / DVD lines
- Wire gauze / silk
- Girls' hair
- Your thumbs



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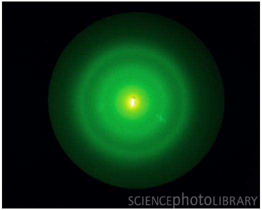
The images below show a diffraction pattern from electrons (!) An electron gun has been fired at a thin sheet of graphite. The electrons passed through and hit a phosphor screen, producing the patterns of rings associated with diffraction.



Diffraction through Carbon

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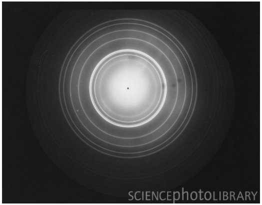

Diffraction through Beryllium

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But electrons are particles, so shouldn't diffract. What's going on?

Wave–particle duality

Electrons are behaving like waves here. This is an example of the so-called 'wave–particle duality'.

De Broglie (1892–1987) correctly proposed in 1924 that this was the case and that particles have wavelengths inversely proportional to their momentum. This was before the electron diffraction had been observed!

De Broglie's formula was confirmed three years later when electron diffraction was observed by two separate teams of scientists:

1. University of Aberdeen: George Paget Thomson (beam of electrons through a thin metal film)
2. Bell Labs (US): Clinton Davisson and Lester Germer (electron beam through a crystalline grid)

de Broglie wavelength

de Broglie was awarded the Nobel Prize for Physics in 1929 for his hypothesis. Thomson and Davisson shared the Nobel Prize for Physics in 1937 for their experimental work.

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

λ is the de Broglie wavelength
h is the Planck constant, 6.64×10^{-34} J s
mv is the momentum

A couple of examples

1. Calculating the de Broglie wavelength for a cricket ball, $m = 0.16\,\mathrm{kg}$, bowled at $38\,\mathrm{m\,s^{-1}}$.
2. What speed does an electron need to go to have a de Broglie wavelength of $10 \times 10^{-10}\,\mathrm{m}$?