22. Quantum Physics

22.3 Wave-particle duality

Paper 4

Question Paper

1 Electrons in a vacuum are accelerated from rest through a potential difference (p.d.) V to form a beam. The electrons each have mass m and charge q.

The beam is incident on a graphite crystal that acts as a diffraction grating. After passing through the crystal, the beam reaches a fluorescent screen. An interference pattern is observed on this screen.

(a) Explain what this observation shows about the nature of electrons.

.....

.....

..... [1]

(b) Determine an expression, in terms of m, q and V, for the momentum p of an electron in the beam.

$p =$ ..... [3]

(c) The p.d. through which the electrons are accelerated is now increased to a greater value.

Describe and explain the effect of this change on the interference pattern observed.

.....

.....

..... [2]

(d) The electrons are now accelerated through different values of V, resulting in pairs of corresponding values for p and the de Broglie wavelength λ.

(i) On Fig. 9.1, sketch the variation of p with $\frac{1}{\lambda}$.

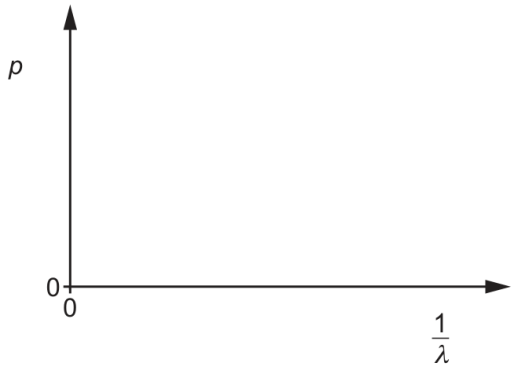


Fig. 9.1

[2]

(ii) State the name of the quantity represented by the gradient of the line in Fig. 9.1.

..... [1]

2 **(a)** State what is meant by the de Broglie wavelength.

.....

..... [1]

(b) Fig. 7.1 shows a glass tube in which electrons are accelerated through a high p.d. to form a beam that is incident on a thin graphite crystal.

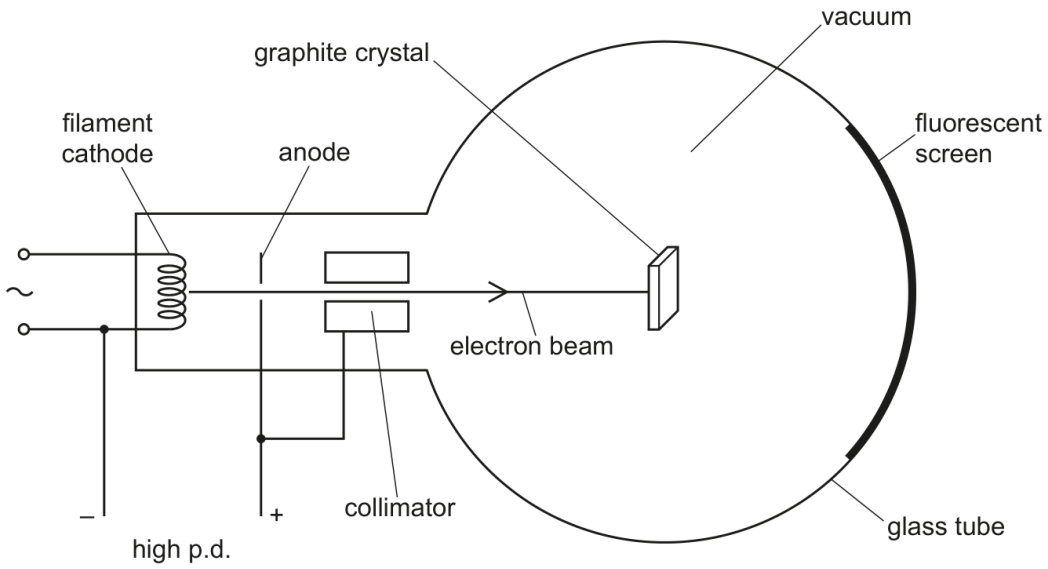


Fig. 7.1 (not to scale)

After passing through the graphite crystal, the electrons reach the fluorescent screen. The screen glows where the electrons strike it.

Fig. 7.2 shows the fluorescent screen viewed end-on, from the right-hand side of Fig. 7.1.

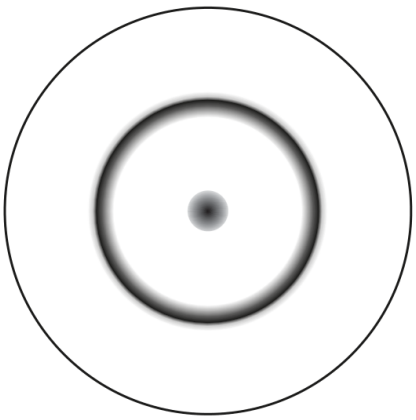


Fig. 7.2

(i) State the name of the phenomenon demonstrated by the pattern shown in Fig. 7.2.

..... [1]

(ii) Explain what can be concluded from the pattern in Fig. 7.2 about the nature of electrons.

.....

.....

..... [2]

(c) The electrons in **(b)** are now accelerated through a greater potential difference between the cathode and the anode.

(i) On Fig. 7.3, sketch the pattern that is now seen on the fluorescent screen in Fig. 7.1.

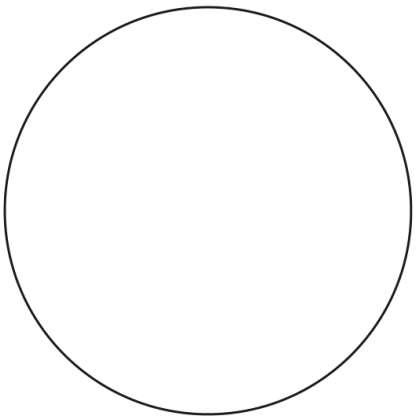


Fig. 7.3

[2]

(ii) Explain, with reference to de Broglie wavelength, the change in the pattern on the fluorescent screen.

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..... [3]

3 **(a)** State **one** piece of experimental evidence for:

(i) the particulate nature of electromagnetic radiation

..... [1]

(ii) the wave nature of matter.

..... [1]

(b) **(i)** Calculate the de Broglie wavelength λ of an alpha-particle moving at a speed of $6.2 \times 10^7\,\text{m s}^{-1}$.

λ = ... m [3]

(ii) The speed v of the alpha-particle in **(b)(i)** is gradually reduced to zero.

On Fig. 8.1, sketch the variation with v of λ.

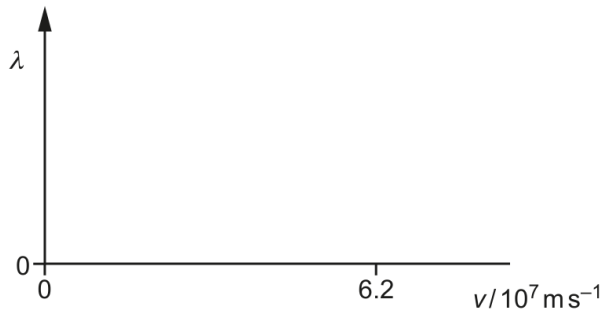


Fig. 8.1

[2]

(c) Suggest an explanation for why people are not observed to diffract when they walk through a doorway.

.....

.....

..... [1]

4 **(b)** The de Broglie wavelength of a particle is λ_0 when its momentum is p_0.

On Fig. 6.2, sketch the variation with momentum p of the de Broglie wavelength λ of the particle for values of momentum from $\frac{p_0}{2}$ to p_0.

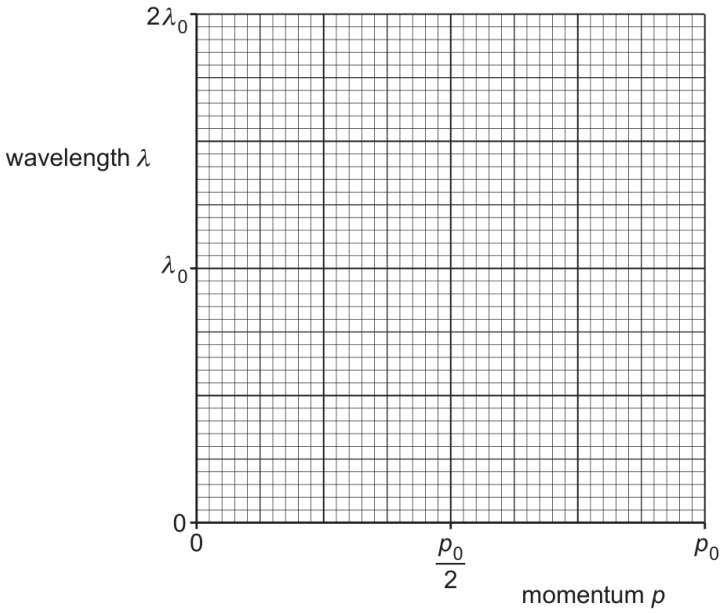


Fig. 6.2

[2]

5 **(a)** State an experimental phenomenon that provides evidence for:

(i) the particulate nature of electromagnetic radiation

..... [1]

(ii) the wave nature of matter.

..... [1]

(b) A particle of matter moves with momentum p.

(i) State the equation that gives the effective wavelength λ of the particle. State the name of any other symbols used.

[2]

(ii) State the name given to the wavelength of the moving particle.

..... [1]

(c) Electrons are accelerated from rest through a potential difference (p.d.) of 4.8 kV.

(ii) Calculate the effective wavelength of a beam of electrons moving at the speed in **(c)(i)**.

wavelength = ... m [2]

6 **(b)** The structure of a copper crystal is to be examined using electron diffraction.

Electrons, having been accelerated from rest through a potential difference V, are incident on the crystal.

The de Broglie wavelength λ of the electrons is 2.6×10^{-11} m.

Calculate the accelerating potential difference V.

V = ... V [4]