

1

Experiments on which of the following suggested the wave nature of electrons?

- | | | |
|----------|--|--------------------------|
| A | electron diffraction by a crystalline material | ☐ |
| B | β^- decay | ☐ |
| C | line spectra of atoms | ☐ |
| D | the photoelectric effect | ☐ |

(Total 1 mark)

2

- (a) What phenomenon can be used to demonstrate the wave properties of electrons?

(1)

- (b) Calculate the wavelength of electrons travelling at a speed of $2.5 \times 10^5 \text{ ms}^{-1}$.

Give your answer to an appropriate number of significant figures.

wavelength _____ m

(3)

- (c) Calculate the speed of muons with the same wavelength as these electrons.

mass of muon = $207 \times$ mass of electron

speed _____ ms^{-1}

(2)

(Total 6 marks)

3

Electrons exhibit *wave properties*.

- (a) What phenomenon can be used to demonstrate the wave properties of electrons? Details of any apparatus used are not required.

(1)

- (b) Calculate the de Broglie wavelength of electrons travelling at a speed of $4.50 \times 10^5 \text{ m s}^{-1}$.

answer = _____ m

(2)

- (c) The muon has a mass equal to 207 times the mass of an electron.
Calculate the speed of muons with the same de Broglie wavelength as the electrons in part (b).

answer = _____ m s^{-1}

(3)

(Total 6 marks)

4

- (a) State what is meant by the wave-particle duality of electrons.

(1)

- (b) Electrons of wavelength 1.2×10^{-10} m are required to investigate the spacing between planes of atoms in a crystal.

- (i) Calculate the momentum of an electron of this wavelength stating an appropriate unit.

momentum of electron = _____

(3)

- (ii) Calculate the speed of such an electron.

speed of electron = _____ m s^{-1}

(2)

- (iii) Calculate the kinetic energy of such an electron.

kinetic energy of electron = _____ J

(2)

(Total 8 marks)

5

- (a) Electrons and electromagnetic waves exhibit properties of both waves and particles. Suggest evidence which indicates that

- (i) electrons have wave properties,

- (ii) electromagnetic radiation has particle properties,

- (iii) electromagnetic radiation has wave properties.

(3)

- (b) Calculate the de Broglie wavelength of an electron travelling at $5.0 \times 10^6 \text{ m s}^{-1}$. You should ignore relativistic effects.

(3)

(Total 6 marks)

6

- (a) (i) State what is meant by the *wave-particle duality* of electromagnetic radiation.

- (ii) Which aspect of the dual nature of electromagnetic radiation is demonstrated by the photoelectric effect?

(2)

- (b) A metal plate is illuminated with ultra violet radiation of frequency $1.67 \times 10^{15} \text{ Hz}$. The maximum kinetic energy of the liberated electrons is $3.0 \times 10^{-19} \text{ J}$.

- (i) Calculate the work function of the metal.

- (ii) The radiation is maintained at the same frequency but the intensity is doubled. State what changes, if any, occur to the number of electrons released per second and to the maximum kinetic energy of these electrons.

number per second _____

maximum kinetic energy _____

- (iii) The metal plate is replaced by another metal plate of different material. When illuminated by radiation of the same frequency no electrons are liberated. Explain why this happens and what can be deduced about the work function of the new metal.

(8)

(Total 10 marks)

7

- (a) (i) Explain what is meant by *duality of electrons*.

- (ii) Give **one** example of each type of behaviour of electrons.

(3)

- (b) Electrons, of mass m and charge e , are accelerated from rest through a potential difference, V , and acquire a kinetic energy of $\frac{1}{2}mv^2$, where v is the final velocity of the electrons.

Show that

$$\lambda = \frac{h}{\sqrt{2meV}},$$

where h is the Planck constant and λ is the electron wavelength.

(3)

(Total 6 marks)

8

- (a) Calculate the de Broglie wavelength of an electron travelling at 2.00% of the speed of light.

- (b) Determine the frequency of the electromagnetic radiation that would have the same wavelength as this electron.

(Total 5 marks)

9

- (a) Calculate the speed of electrons which have a de Broglie wavelength of 1.5×10^{-10} m.

(2)

- (b) Would you expect the electrons in part (a) to be diffracted by crystals in which the atom spacing is 0.10 nm? Explain your answer.

(2)

(Total 4 marks)

10

- (a) (i) Explain what is meant by the *duality* of electrons.

- (ii) State the relation between the electron mass, electron velocity and the wavelength for a monoenergetic beam of electrons.

(3)

- (b) The spacing of atoms in a crystal is 1.0×10^{-10} m.

$$\begin{aligned}\text{mass of the electron} &= 9.1 \times 10^{-31} \text{ kg} \\ \text{the Planck constant} &= 6.6 \times 10^{-34} \text{ J s}\end{aligned}$$

Estimate the speed of electrons which would give detectable diffraction effects with such crystals.

(4)

- (c) Give **one** piece of evidence to demonstrate that electrons have particle properties.

(1)

(Total 8 marks)

[illegible]

(ii) $\nu = 5.5 \times 10^{-24} / 9.11 \times 10^{-31}$ (1)

$\nu = 6.1 \times 10^6 \text{ m s}^{-1}$ (1)

(iii) (use of $E = \frac{1}{2}mv^2$)

$E = \frac{1}{2} \times 9.11 \times 10^{-31} \times (6.1 \times 10^6)^2$ (1) (must see working or equation)

$E = 1.6(9) \times 10^{-17} \text{ J}$ (1) (no working max 1)

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[8]

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- (a) (i) (wave property) (electron) diffraction (1)
 (ii) (particle-property) photoelectric effect (1)
 (iii) (wave property) interference / diffraction / refraction (1)

(3)

(b) (momentum of electron =) $mv = 9.11 \times 10^{-31} \times 5.0 \times 10^6$ (1)

$(= 4.56 \times 10^{-24} \text{ (kg m s}^{-1}\text{)})$ (1)

$[(\lambda = h/mv \text{ gives}) \lambda = 6.6(3) \times 10^{-34} / 4.56 \times 10^{-24}]$ (1)

(allow e.c.f. for value of mv)

$= 1.5 \times 10^{-10} \text{ m}$ (1) $(1.45 \times 10^{-10} \text{ m})$

(3)

[6]

6

- (a) (i) electromagnetic radiation behaves either as a particle or as a wave (1)
 (ii) (electromagnetic radiation) behaves as a particle (1)

(2)

(b) (i) $hf = \phi + E_k$ (1)
 $\phi = (6.63 \times 10^{-34} \times 1.67 \times 10^{15}) - (3.0 \times 10^{-19})$ (1)
 $= 8.1 \times 10^{-19} \text{ J}$ (1) (8.07×10^{-19})

- (ii) (number per second) doubled (1)
 (maximum kinetic energy) remains constant (1)

- (iii) (all) electrons have insufficient energy to leave the (new) metal (1)
 the work function of the (new) metal is greater than hf
 [or the work function of the (new) metal is greater than that of the original metal] (1)

The Quality of Written Communication marks were awarded primarily for the quality of answers to this part.

(8)

1101

7

- (a) (i) electrons behave sometimes as particles, sometimes as waves (1)
- (ii) *particle example:* deflection in electric [or magnetic] field (1)
- wave example:* diffraction (1)

(3)

(b) (kinetic energy) $\frac{1}{2}mv^2 = eV$ (1)

$$p (= mv) = m \sqrt{\frac{2eV}{m}} \text{ (1) } (= \sqrt{2meV})$$

$$\lambda = \frac{h}{p}, \text{ gives result (1)}$$

(3)

[6]

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(a) speed of electron = $\frac{2.00 \times 3.00 \times 10^8}{100}$ (1) ($= 6.00 \times 10^6 \text{ (m s}^{-1}\text{)}$)

(use of $\lambda = \frac{h}{mv}$ gives) $\lambda = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 6.00 \times 10^6}$ (1)

$$= 1.21 \times 10^{-10} \text{ m (1)}$$

(b) (use of $c = f\lambda$ gives) $f = \frac{3.00 \times 10^8}{1.21 \times 10^{-10}}$ (1)

(allow C.E. for value of λ from (i))

$$= 2.48 \times 10^{18} \text{ Hz (1)}$$

5

[5]

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(a) $v = \frac{h}{m\lambda}$ (1) $\left(= \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.5 \times 10^{-10}} \right) = 4.86 \times 10^6 \text{ ms}^{-1}$ (1)

2

- (b) yes (1)
- same order as λ (1)

2

[4]

10

- (a) (i) electrons behave sometimes as particles (1)
- and sometimes as waves (1)
- (ii) $mv \propto 1 / \lambda$ (or $mv = h / \lambda$) (1)

(3)

- (b) For (crystal) diffraction, electron wavelength must be of order of atom spacing **(1)**
 hence $\lambda \approx 10^{-10} \text{ m}$ **(1)**

$$v = \frac{h}{m\lambda} \text{ (1)} = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 10^{-10}} = 7.2(5) \times 10^6 \text{ m s}^{-1} \text{ (1)}$$

4

- (c) deflection in E-field
 (or deflection in B-field, or any other correct evidence) **(1)**

(1)

[8]