Access Tuition

A-Level Physics

Wave Particle Duality

Mark Scheme

Time available: 44 minutes
Marks available: 36 marks

Mark schemes

1. (a) (Matter) particles have wave-like properties (owtte) ✓

Accept mv or mass x velocity in place of p

and an associated wavelength = *h / p where p* is the momentum of the particles ✓.

Accept 'inversely proportional to momentum (or mv)' after 'wavelength'

2

(b) E_K (= 0.021 eV) = 0.021 × 1.60 × 10^{-19} or 3.36 × 10^{-21} J ✓

(Using $E_K = ½ m v^2$ gives)

For 2nd mark, allow individual values of e and V in place of E_K value in data substitution

$mv = (2 m E_K)^{1/2} = (2 \times 1.67(5)\times10^{-27} \times 3.36 \times 10^{-21})^{1/2}$

(= 3.35 × 10^{-24} kg m s^{-1}) ✓

For 3rd mark, allow individual values of m and v in denominator

[OR

$v = (2 E_K/ m)^{1/2} = (2 \times 3.36 \times 10^{-21}/ \times 1.67(5)\times10^{-27})^{1/2}$

(= 2.0 × 10^3 m s^{-1})

mv = (1.67(5)×10^{-27} × 2.0 × 10^3 (= 3.35 × 10^{-24} kg m s^{-1})]

$$\lambda = \frac{h}{mv} (= \frac{6.63\times10^{-34}}{3.35\times10^{-24}}) = 1.88\times 10^{-10} \text{ m}$$ ✓

= 2.0 × 10^{-10} m to 2 sf ✓

Alternative;

Correct use of 0.021 eV in $\lambda = h / (2meV)^{1/2}$ ✓

$$= \frac{6.63\times10^{-34}}{(2\times1.67(5)\times10^{-27}\times0.021\times1.6\times10^{-19})^{0.5}}$$ ✓

= 1.88 × 10^{-10} m ✓ *= 2.0 × 10^{-10} m to 2 sf* ✓

Final sf mark - need to see some valid working

4

(c) electron's momentum (p) is the same (as that of the neutron) and its mass is (much) smaller than neutron mass ✓

kinetic energy = $p^2 / 2m$ so kinetic energy of electron is (much) greater ✓

Alternative for 2nd mark;- (so) electron's speed is (much) greater and as kinetic energy = ½ mv^2, the electron's kinetic energy is (much) greater as v^2 is more significant than m (here) (owtte)

2nd alternative for 2nd mark using $\lambda = h / (2 mE_K)^{1/2}$

$\lambda = h / (2 mE_K)^{1/2}$ so (same λ means) mE_K (in equation) is the same for electron as for the neutron). So E_K is (much) greater as electron mass is (much) smaller than neutron mass (owtte)

Note; allow use of eV in place of E_K if eV is identified as E_K.

2

[8]

2. (a) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate provides a comprehensive and coherent answer that includes a stated property of light such as interference or diffraction that can only be explained in terms of the wave nature of light and a stated property such as photoelectricity that can only be explained in terms of the particle nature of light. In each case, a relevant specific observational feature should be referred to and should be accompanied by a coherent explanation of the observation. Both explanations should be relevant and logical.

For full marks, the candidate may show some appreciation as to why the specific feature of either the named wave property cannot be explained using the particle nature of light or the named particle property cannot be explained using the wave nature of light.

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate provides a logical and coherent explanation that includes a stated property of light such as interference or diffraction that can only be explained in terms of the wave nature of light ***and*** *a stated property such as photoelectricity that can only be explained in terms of the particle nature of light.*

For 4 marks, the candidate should be able to refer to a relevant specific observational feature of each property, at least one of which should be followed by an adequate explanation of the observation. Candidates who fail to refer to a relevant specific observational feature for one of the properties may be able to score 3 marks by providing an adequate explanation of the observational feature referred to.

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate provides some relevant information relating to two relevant stated properties for 1 mark. Their answer may lack coherence and may well introduce irrelevant or incorrect physics ideas in their explanation.

Points that can be used to support the explanation:

Wave-like nature property

- property is either interference **or** diffraction
- observational feature is either the bright and dark fringes of a double slit interference pattern or of the single slit diffraction pattern (or the spectra of a diffraction grating)
- explanation of bright or dark fringes (or explanation of diffraction grating spectra) in terms of path or phase difference
- particle/corpuscular theory predicts two bright fringes for double slits or a single bright fringe for single slit or no diffraction for a diffraction grating

Particle-like nature

- property is photoelectricity
- observational feature is the existence of the threshold frequency for the incident light **or** instant emission of electrons from the metal surface
- explanation of above using the photon theory including reference to photon energy *hf*, the work function of the metal and '1 photon being absorbed by 1 electron'
- wave theory predicts emission at all light frequencies **or** delayed emission for (very) low intensity

6

(b) (i) $m\ (= m_o\ (1 - v^2 / c^2)^{-0.5} = 9.11 \times 10^{-31}\ (1 - 0.890^2)^{-0.5})$

$(= 1.998 \times 10^{-30}$ kg$) = 2.0(00) \times 10^{-30}$ kg ✓

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{2.0(0) \times 10^{-30} \times 0.89(0) \times 3.0(0) \times 10^{8}}$$ ✓

$(= 1.2(4) \times 10^{-12}m)$

2

(ii) $E_{Ph} = \left(hf = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{1.24 \times 10^{-12}} \right) = 1.6(0) \times 10^{-13}$ J ✓

1

(iii) $E_K = (m - m_o)\ c^2$

$= (1.998 \times 10^{-30} - 9.11 \times 10^{-31}) \times (3.0 \times 10^8)^2$

$= 9.78 \times 10^{-14}$ J ✓ 3 sf only ✓

2

[11]

3. (a) (i) suitable description and outline detail **(1)**
for an appropriate named particle **(1)**
(e.g. electron diffraction of a beam of electrons by a thin metal sample or tunnelling in the STM across a gap by electrons)

(ii) suitable description and outline detail **(1)**
for an appropriate named particle **(1)**
(e.g. a beam of electrons deflected by an electric or magnetic field or collision/impact on a screen of electrons/ions)

max 3

(b) (i) $E_k = 5.0 \times 10^6 \times 1.6 \times 10^{-19}$ (J) **(1)**

(use of $E_k = ½mv^2$ gives) $v\ (= \left(\frac{2E_k}{m}\right)^{1/2})$

$= \frac{(2 \times 5.0 \times 1.6 \times 10^{-13})^{1/2}}{1.67 \times 10^{-27}}$ **(1)**

(= 3.1×10^{-7} ms^{-1})

(ii) (use of $\lambda = \frac{h}{mv}$ gives) $\lambda = \frac{6.63 \times 10^{-34}}{1.67 \times 10^{-27} \times 3.1 \times 10^7}$ **(1)**

$= 1.3 \times 10^{-14}$ m

[or alternatively $\lambda \left(= \frac{h}{\sqrt{2meV}}\right) = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 1.6 \times 10^{-19} \times 5 \times 10^6}}$

$= 1.3 \times 10^{-14}$ m] **(1)**

4

[7]

4.

(a) (i) wavelength $= \frac{h}{mv}$ **(1)**

$= \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.2 \times 10^3}$ **(1)** (= 6.1×10^{-7} m)

(ii) charge (= current × time = $4.8 \times 10^{-13} \times 1.0 \times 10^{-3}$) = 4.8×10^{-16} C **(1)**

number of electrons per fringe $= \frac{4.8 \times 10^{-16}}{(1.6 \times 10^{-19} \times 6)} = 500$ **(1)**

(4)

(b) (i) same **(1)**

(ii) interference fringes would be further apart **(1)**

at twice the spacing **(1)**

as the wavelength would be doubled **(1)**

because $\lambda \propto \frac{1}{\text{speed}}$ $\left[\text{or} \propto \frac{1}{\text{momentum}}\right]$ **(1)**

(max 4)

(c) $f\left(=\frac{c}{\lambda}\right)=\frac{300\times10^{8}}{6.1\times10^{-7}}$ **(1)**

$= 4.9 \times 10^{14}$ Hz **(1)**

(2)

[10]