A-Level Physics

Waves Particle Duality

Mark Scheme

Time available: 62 minutes
Marks available: 51 marks

1.

(a) **Q**

because the pattern indicates diffraction ✓

the electrons are behaving like waves as they pass though the gaps in the graphite ✓

*No mark for stating **Q**, but must identify as **Q** to obtain both marks.*

*Allow one mark for demonstrating particle behaviour at **P and R** with one reason given:*

- acceleration is a particle phenomenon

- fluorescence is due to a collision with atomic electron which is particle phenomenon.

*Do not accept interference at **R**.*

2

(b) **MAX 3**

Increased speed decreases wavelength OR quotes $\lambda = \frac{h}{mv}$ ✓

Increased momentum of electrons ✓

Shorter associated wavelength (relative to the gaps in the graphite) ✓

less diffraction ✓

3

[5]

2.

(a) Clear indication of correct process

two correct values for λv from working plus conclusion

(7.35; 7.25; 7.35) ✓

three correct values plus conclusion ✓

Condone no or misuse of powers of 10

Allow use of value of h as the constant to show that v values in table are consistent with the λ values

1

.....

ratio approach $v_1/v_2 = \lambda_2/\lambda_1$ shown for 2 sets of data ✓

shown for two other sets of data + conclusion ✓

May predict one of the values assuming inverse proportionality and compare with table value

(once for 1 mark; twice for 2 marks)

1

(b) $h = \lambda mv$ or substitution of correct data in any form ✓

May determine average value using mean constant from 2.1 or average 3 calculations in this part

1

$6.7(0) \times 10^{-34}$ from first and third data set; $6.6(0) \times 10^{-34}$ from second ✓

1

(c) Particle behaviour would only produce a patch/circle of light /small spot of light or Particles would scatter randomly ✓

Wave property shown by diffraction/ interference ✓

Graphite causes (electron)waves/beam to spread out /electrons to travel in particular directions ✓

Bright rings/maximum intensity occurs where waves

interfere constructively/ are in phase ✓

for a diffraction grating maxima when $\sin\theta = n\lambda/d$ ✓

Marks are essentially for

1. Explaining appearance of screen if particle

2. Identifying explicitly a wave property

3. Explaining what happens when diffraction occurs

4. Explaining cause of bright rings

5. Similar to diffraction grating formula (although not same)

NB Not expected: For graphite target maxima occur when $\sin\theta = \lambda/2d$ *(d =spacing of atomic layers in crystal)*

1
1
1

(d) Electrons must provide enough (kinetic) energy

'instantly' to cause the excitation

OR

the atom or energy transfer in 1 to 1 interaction

OR

electron can provide the energy in discrete amounts

OR

energy cannot be provided over time as it would be in a wave

Description of Photoelectric effect = 0

Not allowed: any idea that wave cannot pass on energy, e.g. waves pass through the screen

1

Any 2 from

Idea of light emission due to excitation and de-excitation of electrons/atoms ✓

Idea of collisions by incident electrons moving electrons in atoms between energy levels/shells/orbits ✓

Light/photon emitted when atoms de-excite or electrons move to lower energy levels ✓

1
1

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3.

(a) (electron) diffraction / interference / superposition ✓

Accept derfraction

1

(b) (*use of* $\lambda = h / mv$)

$\lambda = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 2.5 \times 10^{5})$ ✓

$\lambda = 2.9 \times 10^{-9}$m ✓ ✓ (2 sig figs.)

3

(c) $v = 2.5 \times 10^{5} / 207$ ✓

$v = 1200$ m s^{-1} ✓

OR use $v = h / m\lambda$ with CE from part (b)

Answer alone gets 2 marks

2

[6]

4.

(a) (i) <u>minimum energy</u> required ✓

to remove electron from metal (surface) OR cadmium OR the material ✓

2

(ii) photons have energy dependent on frequency OR energy of photons constant ✓

one to one interaction between photon and electron ✓

Max KE = photon energy – work function in words or symbols ✓

more energy required to remove deeper electrons ✓

4

(iii) *(use of* $hf = \varnothing + E_{k(max)}$*)*

$6.63 \times 10^{-34} \times f = 4.07 \times 1.60 \times 10^{-19}$ ✓ $+ 3.51 \times 10^{-20}$ ✓

$f = 1.04 \times 10^{15}$ (Hz) OR 1.03×10^{15} (Hz) ✓ ✓ (3 sig figs)

4

(b) theory makes predictions tested ✓ by repeatable/checked by other scientists/peer reviewed (experiments) OR new evidence that is repeatable/ checked by other scientists/peer reviewed✓

2

[12]

5.

(a) electrons can have wavelike properties and particle like properties **(1)**

1

(b) (i) (use of $\lambda = h/mv$)

$mv = 6.63 \times 10^{-34}/1.2 \times 10^{-10}$ **(1)**

$mv = 5.5 \times 10^{-24}$ **(1)** kg m s^{-1} **(1)** (or Ns)

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

$v = 6.1 \times 10^{6}$ 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)

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

7

[8]

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) $hf = \varphi + E_k$ **(1)**
$\varphi = (6.63 \times 10^{-34} \times 1.67 \times 10^{15}) - (3.0 \times 10^{-19})$ **(1)**
$= 8.1 \times 10^{-19}$ **(1)** 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)

[10]