Access Tuition

A-Level Physics

Thermionic Emissions of Electrons

Mark Scheme

Time available: 70 minutes
Marks available: 49 marks

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1. (a) **A** is filament ✓

B is the anode ✓

V_1 is the p.d. to supply energy/ drive current to heat **A**. ✓

V_2 is the p.d./produces accelerating electric field to accelerate electrons.

Allow heated cathode

4

(b) (Atom diameter about 0.1 nm)

Allow 0.05 nm to 0.1 nm for wavelength

So wavelength should be about 0.05 nm ✓

$\lambda = \frac{h}{\sqrt{2meV}}$ seen ✓

Ecf for wavelength for MP 2, 3, 4

Rearranged with substitutions of h, m, e to give

$V = \frac{h^2}{2me\lambda^2}$ ✓

= 600 V ✓

Allow 1 sf answer

4

(c) State inverse relationship between wavelength and momentum✓

De Broglie hypothesis suggests that λ will decrease/increase if the momentum increases/decreases

Identify link between V_2 and momentum of electrons. ✓

Allow qualitative statements.

Measure V_2 to determine (KE of electrons and therefore) momentum/speed of electrons

Identify how ring diameter is related to wavelength. ✓

Measure ring diameter as increased/decreased diameter indicates increased/decreased wavelength

State change in ring diameter due to change in V_2 (which is consistent with de Broglie hypothesis) ✓

(De Broglie hypothesis therefore supported by)

increasing/decreasing V_2 resulting in decreased/increased ring diameter.

4

(d)

STM	TEM	
Moving electrons can cross a potential barrier.	Moving electrons can be deflected by a magnetic field.	✓
Moving electrons can be deflected by a magnetic field.	Moving electrons can be deflected by a magnetic field.	
Moving electrons can be deflected by a magnetic field.	Moving electrons can cross a potential barrier.	
Moving electrons can cross a potential barrier.	Moving electrons can cross a potential barrier.	

Tick in first box ✓

Only answer

1

[13]

2. (a) 2 From ✓✓

(High) electric field pulls electrons from (gas) atoms/ ionises (gas) atoms

positive ions in tube are accelerated to C/cathode and strike surface/electrons in surface

Electrons (in cathode) emitted and accelerated towards A (and B) (to form cathode ray).

Do not award MP3 if there is a suggestion of a p.d. between A and B

2

(b) Y to X ✓

1

(c) Reference to v = E/B (when path straight) ✓

(Eg Electric force = magnetic force

Eq= Bqv

v = E/B)

(Therefore for greater v)

Either increase E ✓

Or decrease B. ✓

For MP2 and MP3 there must be some correct supporting theory e.g. $F_M = Bqv$

3

(d) (Magnitude of) specific charge much greater (approximately x 2000) specific charge of hydrogen (ion), (largest then known). ✓

(If charges similar) Cathode rays particles mass much smaller than hydrogen ion and therefore smaller than atom. ✓

Do not condone "he deduced they were electrons"

MP2 cannot be awarded if MP1 is incorrect.

If no other creditable answer given, one mark can be awarded for stating that the sign of the specific charge of cathode ray is opposite to that of hydrogen ion.

2

[8]

3. (a) Filament / metal is heated due to the current through it ✓

OR

Temperature of the filament rises due to the current through it

(Free / conduction) electrons gain sufficient/enough (kinetic) energy to leave (the metal surface)

OR

Work function (defines work function) ≤ energy supplied to an electron/electron energy ✓

Thermionic emission ✓

Not

Electrons are heated

Not heated due to the pd across it

Allow

By electrical power or electrically heated

Not allowed

Reference to electrons leaving atoms or ionisation

Allow

Energy supplied sufficient to overcome the work function

3

(b) Use one of $\frac{1}{2}mv^2 = eV$ and $r = \frac{mv}{Be}$ or $\frac{mv^2}{r} = Bev$

To arrive at

$\frac{Ber}{m} = v$ or $v = \sqrt{\frac{2eV}{m}}$ or $v^2 = \frac{2eV}{m}$

or $\frac{e}{m} = \frac{v}{Br}$ or $\frac{e}{m} = \frac{v^2}{2V}$ ✓

Substitution in the other equation and manipulates correctly and clearly to give $\frac{e}{m} = \frac{2V}{B^2r^2}$ ✓

Condone q for e

Substitution in other equation and correct manipulation

NB this is a show that so mark is not simply for stating the equation given

I presented such that v (velocity) and V (voltage) are indistinguishable in manipulation then award only first mark

2

(c) Correct substitution $\frac{e}{m} = \frac{2 \times 320}{(1.5 \times 10^{-3})^2 \times 0.040^2}$

And answer 1.8×10^{11} ✓

Answer to 2 sig figs ✓

Allow for incorrect answer following incorrect substitution in equation

As answer is on the data sheet must see correct substitution with all correct powers of ten

2

(d) The specific charge of the cathode rays/the particles was(much) larger/greater than the hydrogen ion/proton ✓

This provided evidence that cathode rays were composed of electrons/particles which have a (very) small mass / have a high (negative) charge

OR

Mass (much) smaller than the mass of a hydrogen (ion)/proton ✓

Not higher

If mark 1 not given then 0 for the question

Not lightest as substitute for mass

2

[9]

4. (a) Converts 6.2 eV, 0.5 eV or 6.7 eV to J

eg $6.2 \times 1.6 \times 10^{-19}$ J or $9.9(2) \times 10^{-19}$ seen

for 0.5 eV 8.0×10^{-20} seen

for 6.7eV 1.07×10^{-18} seen ✓

$\lambda = \frac{hc}{E}$ or substitution $E = \frac{6.63\times10^{-34}\times3\times10^{8}}{\lambda}$

With one of the above values included for energy✓

190 (185,186 or 187) nm ✓

NB use of λ=h/mv is a PE and scores 0

May use $f = \frac{E}{h}$ and then $\lambda = \frac{c}{f}$

Treat incorrect E in the same way

Guidance

Use of 0.5 eV gives 4.0×10^{-25}

6.2 eV 3.2×10^{-26}

6.7 eV 3.0×10^{-26}

These will score 1

8.0×10^{-20} gives 2500 nm

$9.9(2) \times 10^{-19}$ 200 nm

These will score 2

1 sf answers are not allowed so correct working with answer 186 nm rounded to 200 nm will also score 2

1
1
1

(b) **Classical Wave Model**

Wave model <u>predicts an increase</u> in the photocurrent
<u>Plus one from</u>

- As energy transferred into each electron increases (over time) /energy of the emitted electrons increases
- Electrons can gain sufficient KE <u>to reach T</u>
- Electrons can leave the surface with greater KE ✓

Photon Model

The photon model <u>predicts no change</u> in the photocurrent
Or photocurrent <u>remains at zero</u> ✓

<u>One from</u>

- The energy of a photon depends on the frequency not the intensity
- Energy of each incident photon remains the same
- KE of electrons leaving the surface does not change
- Electrons released <u>are still unable</u> to reach T✓

NB The response has to discuss the effect of each theory on the maximum KE of the electrons when they leave the surface

Discussions that relate to threshold frequency or delay before emission are not relevant

3

(c) Fewer electrons will have sufficient energy to move away from the surface/or to reach T/anode
Or
Electrons need more energy to cross the gap
Or
Some of the electrons released were more tightly bound to the surface
Or
Electrons have a range of energies(when emitted from surface)
or
Some electrons use more of the photon energy to escape from the surface (this is related to the energy of the photoelectrons). ✓

Fewer electrons <u>per second</u> have <u>sufficient kinetic energy to reach T</u> scores 2

1

Fewer electrons <u>per second/rate at which electrons reach T</u> will <u>reach terminal T/cross the gap</u>
(the per second part captures what is going on in terms of the current)✓

Do not allow

Fewer photoelectrons per second flowing through the circuit

1

(d) A > B > C ✓

1

[9]

5. (a)

	Tick (✓) if correct
Beta particle emission	
Electron diffraction	
Photoelectric effect	
Thermionic emission	✓

1

(b) Use of $\lambda = \frac{h}{\sqrt{(2mE)}}$ seen including correct substitution

1

$\lambda = 2.4 \times 10^{-11}$ (m)

1

Statement to the effect that this is similar to or less than 0.1 nm/atomic dimension/diameter of the atom (so individual atoms can be resolved).

1

Condone missing unit

Allow a correct conclusion that follows from an incorrect value of λ

3

(c) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer.**

Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

<table>
<tr><th>Mark</th><th>Criteria</th><th>QoWC</th></tr>
<tr><td>6</td><td>At least six of the likely statements will be covered to a good standard including at least three from image formation and at least three from quality and detail.</td><td rowspan="2">The student presents relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.</td></tr>
<tr><td>5</td><td>At least five of the likely statements will be covered to a good standard including at least two from image formation and at least one from quality and detail.</td></tr>
<tr><td>4</td><td>At least three of the likely statements will be covered to a good standard. The response must include one of both image formation and factors affecting quality and detail.</td><td rowspan="2">The student presents relevant information and in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.</td></tr>
<tr><td>3</td><td>At least two of the likely statements will be covered to a good standard. The response must include one of both image formation and factors affecting quality and detail.</td></tr>
<tr><td>2</td><td>At least two of the likely statements from image formation or quality and level of detail will be covered to a good standard. The other area (if covered) will have errors and omissions.</td><td rowspan="2">The student presents some relevant information in a simple form. The text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.</td></tr>
<tr><td>1</td><td>One of the likely statements will be covered to a good standard.</td></tr>
</table>

0	No relevant coverage of the likely statements.	The student's presentation, SP&G seriously obstruct understanding..

The following statements are likely to be present.

Process of Image formation

- Electrons through the middle of the lenses are undeviated
- Electrons on the edges are deflected by magnetic fields toward the axis of the TEM
- The condenser lens deflects the electrons into a wide parallel beam incident uniformly on the sample.
- The objective lens then forms an image of the sample.
- The projector lens then casts a second image onto the fluorescent screen.

Factors affecting the quality and level of detail

- Wavelength depends on speed of the electrons
- Lower the wavelength gives greater the detail.
- Emitted electrons come from a heated cathode and therefore have a speed distribution dependent on temperature.
- The speed of the electrons is not always the same which causes different pathways through the lens and so aberration.
- The sample thickness reduces the speed of the electrons increasing the wavelength and decreasing the detail.

[6]