A-Level Physics

Electron Microscopes

Mark Scheme

Time available: 65 minutes
Marks available: 45 marks

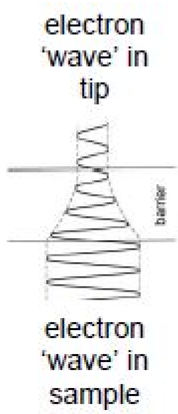
Mark schemes

1. (a) Electrons (in surface) have to overcome the potential/coulomb barrier ✓

Electrons have insufficient energy so (due to wave properties of electrons) there is a probability of electrons crossing from sample to tip
OR
a fraction of electrons will move from sample to tip. ✓

Credit diagram of high amplitude wave, barrier and lower amplitude transmitted wave for second mark

Eg



2

(b) Tip of probe maintained a certain distance (about 1nm) above surface. ✓

(Current from surface into probe due to tunnelling)

When probe moves over higher layer of electrons, current increases ✓

(Through a feedback process) Tip is moved higher to reduce current to original value.
(Distance moved by tip = distance new surface above/below original surface)✓

(Hence surface mapped by position of tip.)

Allow reverse argument

3

(c) Attempt to apply ½ mv^2 = eV
½ x 9.11 x 10^{-31} x v^2 = 2.4 x 10^{-19} ✓
If correct v = 7.26 x 10^5 (m s^{-1})

Allow if no or incorrect conversion of eV to J

Attempt to apply $\lambda = h/mv$
= 6.63 x 10^{-34}/(9.11 x 10^{-31} x 7.26 x 10^5) ✓

Allow for use of their v in substitution

1.0 x 10^{-9} m (cao) with conclusion ✓

Condone 1sf answer, but must have unit

Alternative one step route:
Attempt to put data in $\lambda = \frac{h}{\sqrt{2mE}}$ with no conversion to J ✓
Substitution of data with conversion to J ✓
Answer correct with conclusion ✓

Example conclusion

No - less energy (electron) would have longer wavelength and would be too long to map atom/wavelength should be smaller than 1nm

3

[8]

2. (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

λ = 2.4 × 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]

3. (a) $\lambda \propto \frac{1}{\sqrt{V}}$

1

(b) The resolution is improved for shorter wavelengths or shorter wavelengths enable more detailed images.✓

0.1 nm is the same order of magnitude as the diameter of an atom.✓

2

(c) Image not accurately focused / blurred✓

Due to electrons not all having the same speeds so focused to different points by the magnetic lenses.✓

Electrons slowed down passing through the sample.✓

Wavelength changes by different amounts as they pass through the sample so each wavelength diffracted differently.✓

4

[7]

4. (a) force on an electron in a magnetic field depends on speed **(1)**
electrons at different speeds would be focussed differently so image would be blurred **(1)**
[or electrons at different speeds would have different (de Broglie) wavelengths
therefore resolution would be reduced]

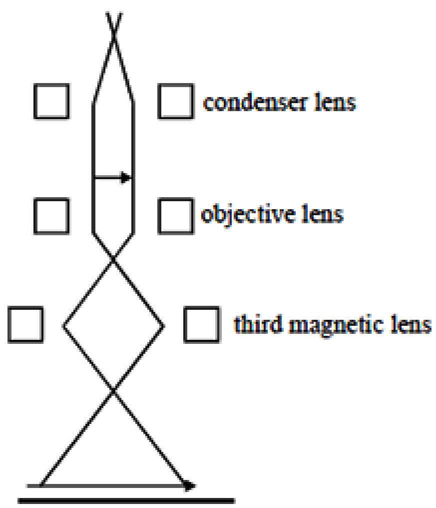
2

(b) increase in pd increases speed **(1)**
increase in speed/momentum/E_k causes reduction of (de Broglie) wavelength **(1)**
reduced (de Broglie) wavelength gives better resolution **(1)**

3

[5]

5. (a) (i)



crossed rays after third lens **(1)**
image arrow same way round as sample **(1)**

(2)

(b) (i) to make a (wide) parallel beam of electrons
[or to direct electrons straight at the sample] **(1)**
to ensure the beam is uniform across its width [or across the sample] **(1)**

(ii) to form a magnified image (of the sample) **(1)**

(iii) to magnify the image further **(1)**
to form the image on a screen **(1)**

(max 3)

(c) (i) resolving power increases with [proportional to]
increase of the accelerating p.d. **(1)**
electron wavelength becomes smaller the greater the p.d. **(1)**
resolving power is greater the smaller the wavelength **(1)**

(ii) lens aberrations [or defects] **(1)**
caused by electrons having a range of speeds [repelling each other] **(1)**
[or sample thickness **(1)**
which causes loss of electron speed **(1)**]

(max 4)

[9]

6. (a) current would fall **(1)**
then rise again **(1)**
probability of transfer decreases with increased gap width **(1)**
gap width widens then reduces as tip moves across pit **(1)**

(b) $mv = \frac{hc}{\lambda}$ **(1)**

$v\left(=\frac{h}{m\lambda}\right) = \frac{6.6\times10^{-34}}{0.5\times10^{-9}\times9.1\times10^{-11}} = 1.4\times10^{6}\ (\text{ms}^{-1})$ **(1)**

k.e. $\left(=\frac{1}{2}mv^2\right) = \frac{1}{2}\times9.1\times10^{-31}\times(1.4\times10^{6})^2 = 9.4\times10^{-19}\ (\text{J})$ **(1)**

$= \frac{9.4\times10^{-19}}{1.6\times10^{-19}} = 6\text{eV}\ (\pm\ 0.1\text{eV})$ **(1)**

[6]