Mark schemes

1 (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]

2 (a) electrons have a wave-like nature **(1)**
there is a (small) probability that an electron can cross the gap
[or an electron can tunnel across the gap] **(1)**
transfer is from - to + only **(1)**

3

(b) constant height mode:

gap width varies as tip scans across at constant height **(1)**
current due to electron transfer is measured **(1)**
current decreases as gap width increases (or vice versa) **(1)**
variation of current with time is used to map surface **(1)**

[or constant current mode:

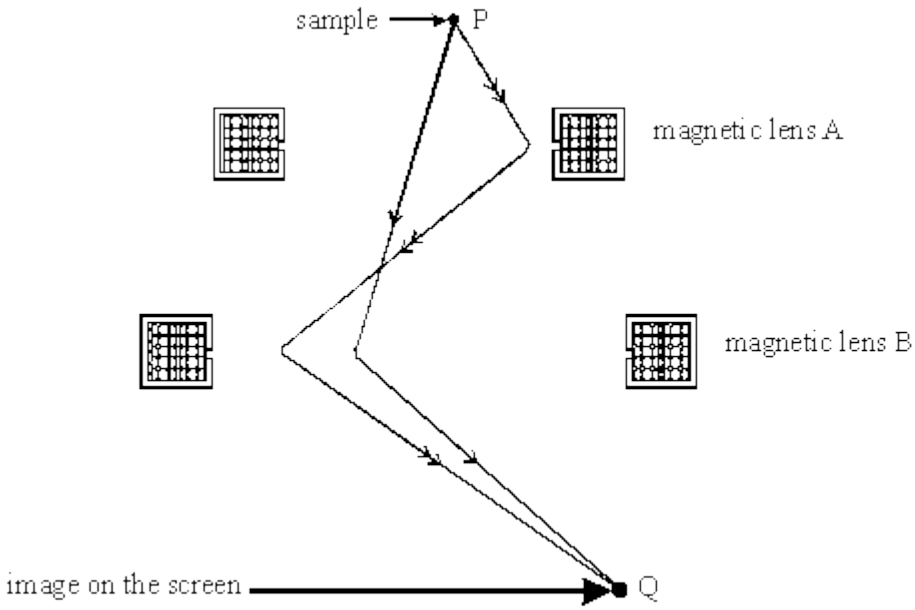
current due to electron transfer is measured **(1)**
feedback used to keep current constant
by changing height of probe tip **(1)**
height of probe tip changed to keep gap width constant **(1)**
variation of height of probe tip with time
used to map surface **(1)**]

3

[6]

3 (a) (i) straight paths outside the lenses **(1)**
correct direction of deflection on passing through A **(1)**
path through B correct for path drawn through A **(1)**

for examples
(only one required)



(ii) lens A: magnifies (or forms an intermediate image before B) **(1)**
lens B: magnifies and focuses (or forms an enlarged image on the screen) **(1)**

max 4

(b) increase of voltage causes increase of speed (of the electrons) **(1)**
hence a reduced de Broglie wavelength **(1)**
less diffraction for reduced wavelength **(1)**
better resolution if less diffraction **(1)**

max 3

[7]

4 (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)**

$v \left(= \frac{h}{m\lambda}\right) = \frac{6.6 \times 10^{-34}}{0.5 \times 10^{-9} \times 9.1 \times 10^{-11}}$ = 1.4×10^{6} (ms^{-1}) **(1)**

k.e. $\left(= \frac{1}{2}mv^2\right) = \frac{1}{2} \times 9.1 \times 10^{-31} \times (1.4 \times 10^{6})^2 = 9.4 \times 10^{-19}$ (J) **(1)**

$= \frac{9.4 \times 10^{-19}}{1.6 \times 10^{-19}}$ = 6eV (± 0.1eV) **(1)**

[6]

5 (a) (i) diffraction ✓ 1

(ii) the electrons in the beam must have the same wavelength ✓

otherwise electrons of different wavelengths (or speeds/velocities/energies/momenta) would diffract by different amounts (for the same order) [owtte] ✓ 2

(b) (i) (eV = ½ *m* **v**^{2} gives) **either v** = $\sqrt{\frac{2eV}{m}}$

or $1.6 \times 10^{-19} \times 25000 = ½ \times 9.1 \times 10^{-31} \times$ **v**^{2} ✓

$v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 25000}{9.1 \times 10^{-31}}} = 9.4 \times 10^{7}$ m s^{-1} ✓

p or *mv* (= $9.1 \times 10^{-31} \times 9.4 \times 10^{7}$) = 8.5×10^{-23} ✓

kg m s^{-1} (or N s) ✓

alternatives for first two marks

p or *mv* = $\sqrt{2meV}$ ✓ =

$\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 25000}$ ✓

4

(ii) **any two of the first three mark points**

increase of pd increases the speed (or velocity/energy/ momentum) of the electrons ✓

(so) the electron wavelength would be smaller ✓

(and) the electrons would diffract less (when they pass through the lenses) ✓

and

the image would show greater resolution (or be more detailed) ✓

max 3

[10]

6 (a) (i) wave-like nature allows an electron (to transfer) **(1)**
a wave can penetrate thin barriers (or gaps) **(1)**
(probability of) transfer of an electron (or tunnelling effect) negligible if gap is too wide **(1)**

(ii) with a p.d., electrons transfer from - to + only **(1)**
with zero p.d., equal transfer in either direction **(1)**
[or so a current can flow for **(1)** (only)]

4

(b) (use of $\lambda = \frac{h}{mv}$ gives) $v\ (= \frac{h}{mv}) = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.0 \times 10^{-9}} = 7.3 \times 10^{+5}\ \text{m s}^{-1}$

(1)

2

[6]

7 (a) (i) $E_k = eV = 1.6 \times 10^{-19} \times 20 \times 10^3 = 3.2 \times 10^{-15}$ (J) **(1)**

$v = \left(\frac{2E_k}{m}\right)^{1/2} = \left(\frac{2 \times 3.2 \times 10^{-15}}{9.11 \times 10^{-31}}\right)^{1/2}$ $= 8.4 \times 10^7\ \text{m s}^{-1}$ **(1)**

(ii) (use of $\lambda = \frac{h}{p}$ gives) $\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-11} \times 8.4 \times 10^7}$ **(1)**

$= 8.7 \times 10^{-12}$ m **(1)**

(allow C.E for value of v from (i))

[or $\lambda = \frac{h}{(2meV)}$ with **(1)** for correct substitution and **(1)** for correct answer]

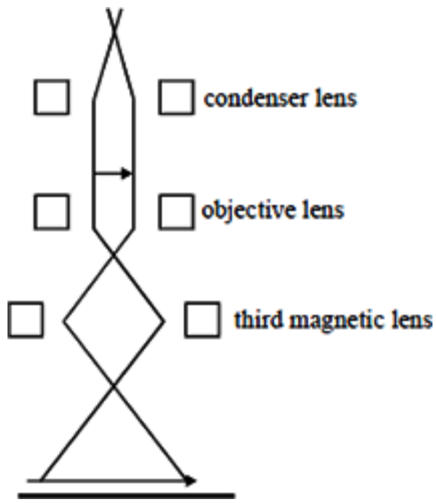
4

(b) image would be brighter because more electrons reach the screen per sec **(1)**
image would be more detailed because de Broglie wavelength
would be reduced **(1)**
and because speed of the electrons is increased **(1)**

max 2

[6]

8 (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]

Examiner reports

1 In part (a), many candidates were aware that electrons moving at different speeds would follow different paths, but few gave the reason for this, namely that the force on an electron moving in a magnetic field depends on the speed of the electron. Most candidates realised that different paths due to different speeds would produce a blurred image, but some candidates incorrectly thought that the blurred image was due to electrons having different speeds and arriving at the screen at different times.

Many candidates scored all three marks allocated to part (b), with an explanation that demonstrated not only a sound understanding of the physics principles involved, but also good awareness of the application of these principles. Some candidates lost marks as a result of not explaining why the de Broglie wavelength was reduced. A small number of candidates incorrectly considered the effect of the increased pd on the intensity of the image.

2 Most candidates were aware, in part (a), that electron transfer across the gap was due to the wave nature of the electron, and many candidates referred to tunnelling or to a non-zero probability of electrons crossing the gap. Few however, explained that a pd was necessary to ensure that electron transfer occurred in one direction only. A significant number of candidates considered incorrectly that electrostatic forces or secondary emission to be the cause of electron transfer.

In part (b) the majority of candidates were unable to give a coherent description of how an STM was used to obtain an image. Some failed to make it clear whether their description referred to 'constant height' or 'constant current' mode. Those who chose to describe the former frequently confused the constant height of the tip with the fixed gap between the tip and the surface needed for the latter mode. Those who described the 'constant current' mode failed to refer to the change of current over a gap or depression being used to raise or lower the tip in order to keep the gap width constant. Again, few candidates stated clearly what variable was used in their chosen mode to measure the surface height.

3 Most candidates scored at least two marks on the diagram in part (a)(i). They were clearly aware that the path changed direction at each lens and needed to end at Q. In part (ii), many candidates did not realise that the second lens focused the image on the screen as well as providing further magnification.

In part (b) most candidates knew that the speed of the electrons increased with anode voltage and therefore that the wavelength decreased. However, few candidates failed to mention that the reduced wavelength meant less diffraction and therefore better resolution.

4 In part (a) many candidates knew that the current decreased at the pit and some stated that it rose again after the pit. Few candidates gave an adequate explanation, other physical processes than the tunnelling effect often being mentioned

The calculation in part (b) was generally carried out adequately, although weaker candidates frequently earned no credit because they failed to realise that the de Broglie wavelength of a particle is not the same as the wavelength of electromagnetic radiation. A significant number of good candidates were unable to convert from joules to electronvolts or to recognise that eV is equal to the kinetic energy.

5 In part (a) most candidates named the process correctly in part (i) and demonstrated some knowledge of the process in the subsequent parts of the question. In (ii), many candidates knew that electrons with different speeds would not diffract in the same directions although some candidates did not mention that this is because they would have different wavelengths.

Many correct calculations were seen in part (b)(i) and most candidates scored the unit mark. Some candidates lost marks through careless numerical errors.

In (b)(ii), most candidates knew that the speed would increase and therefore the wavelength would be decrease. However, some candidates thought that this would cause more diffraction or that the resolution would be poorer. Candidates gained no marks if they gave an incorrect physical reason such as a greater number of electrons in the beam.

6 Most candidates knew in part (a) that the wave nature of the electron was the key property here, although few were able to relate this adequately to the STM. In part (a)(ii), most candidates failed to address the question asked, and usually provided a non-specific answer which could have been applied to almost any situation where there is an electric current.

A large majority of candidates scored full marks in part (b). However, some candidates failed to score at all because they attempted to use an expression relating the wavelength to the potential difference V, which they considered to be the speed of the electron.

7 In part (a)(i) many correct calculations for the speed of the electrons were seen, but some candidates omitted the unit of speed. Most of the candidates who used the value of the speed from part (i) to calculate the wavelength in part (ii) did so correctly, but those who chose to calculate the wavelength directly from the pd did so incorrectly. The reason for this was that the symbol for pd in the equation was thought to represent the speed, or else the charge of the electron was omitted from the calculation.

The majority of candidates correctly stated in part (b) that the resolution would be increased and then gave a correct explanation. However a significant number considered that the magnification, rather than the resolution, would be increased. Very few candidates realised that the image would be brighter.

8 Most candidates gained at least one mark in part (a)(i) and many scored both marks

A significant minority of candidates drew two parallel rays on to the screen. In part (b). Most candidates knew that a function of the first lens is to produce a parallel beam of electrons. Although many candidates realised that the second lens forms a magnified image, fewer appreciated that further magnification is produced by the third lens. However, many candidates did know that the third lens is used to focus the first image on the screen.

Although many candidates knew in part (c)(i) that the resolving power becomes greater when the p.d is raised, few gave a convincing explanation. Many candidates considered the increase of resolving power to be due to more electrons rather than faster electrons. Only a small minority of candidates provided a coherent explanation based on clear and correct physics principles. Few candidates scored both marks in part (c)(ii) although niany provided vague statements indicating that a non-uniform magnetic field limits the resolving power.