1. (i) 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)**

(ii) $m\upsilon = \frac{h}{\lambda}$ **(1)**

$\upsilon\left(=\frac{h}{m\lambda}\right) = \frac{6.6\times10^{-34}}{0.5\times10^{-9}\times9.1\times10^{-31}}$ = 1.4 ×10^6 (ms^{-1}) **(1)**

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

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

[6]

2. (a) (i) wavelength = $\frac{h}{m\upsilon}$ **(1)**

= $\frac{6.63\times10^{-34}}{9.11\times10^{-31}\times1.2\times10^{3}}$ **(1)** (= 6.1 × 10^{-7}m)

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

number of electrons per fringe = $\frac{4.8\times10^{-16}}{(1.6\times10^{-19}\times6)}$ = 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)**

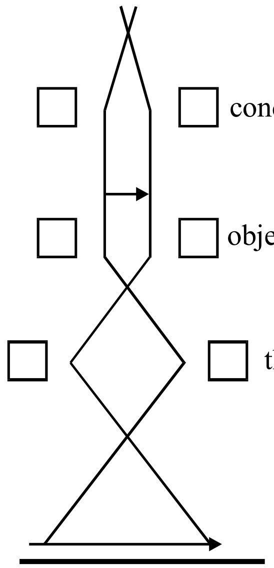
because $\lambda \propto \frac{1}{\text{speed}}\left[\text{or} \propto \frac{1}{\text{momentum}}\right]$ **(1)** max 4

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

= 4.9 × 10^{14} Hz **(1)** 2

[10]

3. (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]

4. (a) two waves in phase in planes perpendicular to each other **(1)**
waves labelled E and B (or similar) **(1)**
direction of propagation shown or stated **(1)** 3

(b) (i) magnetic wave causes alternating magnetic field (or flux) through loop **(1)**
induced emf in loop due to changing magnetic flux (in loop) **(1)**

(ii) radio wave is polarised **(1)**
no magnetic flux passes through the loop in new position **(1)** 4

[7]

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

$v = \left(\frac{2E_k}{m}\right)^{½} = \left(\frac{2 \times 3.2 \times 10^{-15}}{9.11 \times 10^{-31}}\right)^{1/2} = 8.4 \times 10^7 \text{ m s}^{-1}$ **(1)**

(ii) (use of $\lambda = \frac{h}{p}$ gives) $\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 8.4 \times 10^7}$ **(1)**

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

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

[or $\lambda = \frac{h}{(2meV)^{½}}$ 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]

6. (a) (i) an electron requires 1.2 eV of energy to escape from the metal (surface) **(1)**

(ii) (use of $\phi = hf_0$ gives) $f_0 \left(= \frac{\phi}{h}\right) = \frac{1.2 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}}$ **(1)**

$(= 2.9 \times 10^{14}$ (Hz))

(use of $c = f_0\lambda_0$ gives) $\lambda_0 \left(= \frac{c}{f_0}\right) = \frac{3.0 \times 10^8}{2.9 \times 10^{14}} = 1.0 \times 10^{-6}$ m **(1)**

(allow C.E. for value of f_0, if f_0 calculated) 3

(b) (i) energy of a (light) photon = hf **(1)**
a blue photon has more energy than a red photon **(1)**
[or has higher frequency if first mark awarded]
an electron (at the metal surface) absorbs a photon **(1)**
an electron needs a certain amount of energy to escape from the metal **(1)**
[or frequency > threshold frequency if 1st and 3rd marks awarded)
a blue photon gives an electron enough energy to escape, whereas a red photon does not **(1)**

(ii) classical wave theory predicted that all wavelengths/colours/ frequencies
of light should cause electrons to be emitted **(1)**
classical wave theory was rejected in favour of the photon theory **(1)** max 5

[8]

7. (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 (= $\frac{h}{m\lambda}$) = $\frac{6.6\times10^{-34}}{9.1\times10^{-31}\times1.0\times10^{-9}}$ **(1)**
$= 7.3 \times 10^{+5}$ m s^{-1} **(1)** 2

[6]

8. (a) waves/ wavelets are emitted by each slit **(1)**
each slit diffracts light **(1)**
the two slits are coherent emitters / sources of light waves **(1)**
bright fringes formed where light from one slit reinforces light from the other slit
[or dark fringes formed where light from one slit cancels light from the other slit] **(1)**
path difference to a bright fringe = whole number of wavelengths
[or path difference to a dark fringe = (whole number + half) wavelengths)] **(1)** max 4
QWC 2

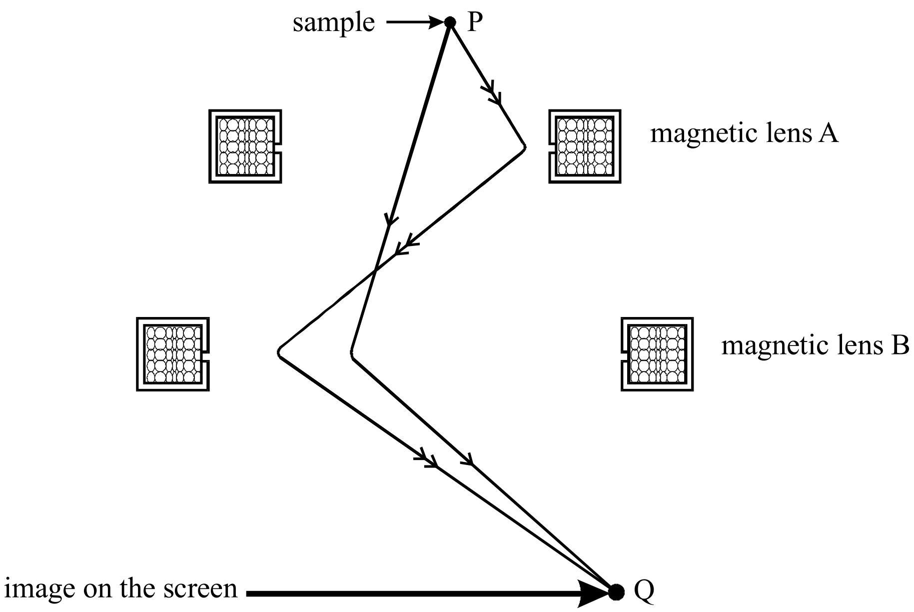
(b) (i) light consists of corpuscles/particles **(1)**
corpuscles would not be diffracted
[or pass straight through] **(1)**
only two bright fringes would be seen **(1)**

(ii) Newton's scientific pre-eminence
[or there was no evidence that light travelled slower in water as predicted by Huygens' theory]
[or Huygens' theory considered light waves as longitudinal and therefore could not explain polarisation] **(1)** max 3

[7]

9. (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]

10. (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) $v \left(= \left(\frac{2E_k}{m}\right)^{1/2} \right)$

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

($= 3.1 \times 10^{-7}$ 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]

11. (a) particles of light/corpuscles **(1)**
attracted towards glass surface (on entry into glass) **(1)**
velocity/momentum normal to surface increased **(1)**
velocity/momentum parallel to surface unchanged **(1)** max 3

(b) (i) Newton predicted $\text{speed}_{\text{glass}} > \text{speed}_{\text{air}}$
and Huygens predicted $\text{speed}_{\text{glass}} < \text{speed}_{\text{air}}$ **(1)**

(ii) named experiment **(1)**
relevance explained **(1)**
(e.g. Young's double slit **(1)** give rise to fringes/interference which is a wave property **(1)**
or diffraction of light **(1)** which is a wave property **(1)**) 3

[6]

12. (a) electrons can behave as waves 4
[or electrons can tunnel across gap] **(1)**
waves can cross narrow gaps
[or non-zero probability of crossing gap] **(1)**
electron waves would be attenuated too much by large gap
[or probability of transfer negligible if gap too wide]
[or the narrower the gap, the greater the probability] **(1)**
electron transfer is from – to + **(1)** QWC 2

(b) constant height mode: tip height constant **(1)** 3
current varies as gap width changes **(1)**
image built up as tip moves across surface
[or as tip moves across, a decrease (or increase)
of current means the gap widens (or narrows)] **(1)**

[or constant current mode: tip height altered **(1)**
to keep current constant **(1)**
image built up as above or as tip moves across, the tip
height rises (or falls) if the surface rises or falls **(1)**]

[7]

13. (i) reflected waves and incident waves form a stationary/standing wave pattern or interfere/reinforce/cancel **(1)**
nodes formed where signal is a minimum **(1)**

(ii) $\lambda/2 = 1.5$ (m) [or $\lambda = 3$ (m)]
[or nodes formed at half–wavelength separation] **(1)**

(use of $c = f\lambda$ gives) $f = \dfrac{3.0 \times 10^8}{2 \times 1.5}$ **(1)**
$= 100$ MHz **(1)** 5

[5]

14. (a) light, passing through each slit, is diffracted **(1)**
diffracted light from one slit overlaps with (diffracted) light from the other slit **(1)**
bright fringes formed where light waves from each slit reinforce
(or in phase)
(or interfere constructively) **(1)**
dark fringes formed where light waves (from the two slits) cancel **(1)**
(or out of phase by 180°) **(1)**
path difference = whole number of wavelengths for a bright fringe
[or whole number + ½ wavelength for a dark fringe] **(1)** max 4

QWC 1

(b) corpuscles passing through a slit form a bright fringe **(1)**
two slits produce only two bright fringes according to corpuscular theory **(1)**
more than two fringes are observed **(1)**
dark fringes (or cancellation) cannot happen with corpuscles **(1)** max 2

[6]

15. (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]

16. (a) light consists of photons **(1)**
an electron in the metal absorbs a photon **(1)**
an electron needs a minimum amount of energy to escape **(1)**
a blue photon has more energy than a red photon **(1)**
$hf > \phi$ for blue photon, $< \phi$ for red photon **(1)** Max 4

(b) every electron would gain sufficient energy from the waves in time **(1)**
no matter what the frequency/colour/wavelength of the light is **(1)** 2

[6]

17. (a) diagram/description of electric wave and magnetic wave in phase **(1)**
diagram/description/statement that electric wave is at 90° to the magnetic wave **(1)**
diagram/description/statement that direction of propagation/travel is perpendicular to both waves **(1)** 3

(b) (i) (conduction) electron (in the metal) absorbs a photon and gains energy hf **(1)**
work function of a metal is the minimum energy needed by an electron to escape from the metal (surface) **(1)**
an electron can only escape if $hf >$ work function **(1)**

any two (**(1)(1)**)

(ii) the photon is the quantum of em radiation/light **(1)**
classical wave theory could not explain threshold frequency **(1)**
classical wave theory was replaced by the photon theory **(1)**
[or photons can behave as waves or particles]
[or photons have a dual wave/particle nature]

any two (**(1)(1)**) 4

[7]

18. (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]

19. (a) particles of light (or corpuscles) **(1)**

attracted towards glass surface **(1)**
(*on entry to glass (or leaving glass)*)

velocity (or momentum) parallel to surface unchanged **(1)**

velocity (or momentum) perpendicular to surface increased (or decreased on leaving) **(1)**

direction (or velocity or momentum) same after leaving glass as before entry to glass **(1)** max 4

(b) named experiment **(1)** observational evidence **(1)** how it supports Huygens' theory **(1)**

(e.g. Young's double slits **(1)** shows interference **(1)** which is a wave property **(1)** or measurement of the speed of light **(1)** speed of light is less than in air **(1)** as predicted by wave theory **(1)**) max 3

[7]

20. (a) **one feature** (1 mark for one of the following)

- there is a threshold (minimum) frequency (of light) for photoelectric emission from a given metal
- photoelectric emission is instant

explanation

- light consists of photons (or wavepackets) **(1)**
- energy of a photon = hf where f is the light frequency **(1)**
- work function φ of metal is the minimum amount of energy it needs to escape **(1)**
- 1 electron absorbs 1 photon and gains energy hf **(1)**
- electron can escape if energy gained $hf > \phi$ **(1)** 6

(b) (i) an electron requires 2.2 eV of energy to escape from the metal surface **(1)**

(ii) photon frequency, f (= c/k = $\frac{3.0\times10^{8}}{5.2\times10^{-7}}$) = 5.77×10^{-19} J **(1)**

photon frequency (= hf) = $6.63 \times 10^{-34} \times 5.77 \times 10^{14} = 3.83 \times 10^{-19}$ J **(1)**

E_K max (= $hf - \phi$) = $3.83 \times 10^{-19} - (2.2 \times 1.6 \times 10^{-19})$ **(1)**
= 3.1×10^{-20} J **(1)** 5

[11]