

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)  $m\nu = \frac{h}{\lambda}$  (1)

$$\nu \left( = \frac{h}{m\lambda} \right) = \frac{6.6 \times 10^{-34}}{0.5 \times 10^{-9} \times 9.1 \times 10^{-31}} = 1.4 \times 10^6 \text{ (ms}^{-1}\text{)} \text{ (1)}$$

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

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

max 6

**[6]**

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

$$= \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.2 \times 10^3} \text{ (1)} (= 6.1 \times 10^{-7} \text{ m})$$

(ii) charge (=current  $\times$  time =  $4.8 \times 10^{-13} \times 1.0 \times 10^{-3}$ ) =  $4.8 \times 10^{-16}$  C (1)

$$\text{number of electrons per fringe} = \frac{4.8 \times 10^{-16}}{(1.6 \times 10^{-19} \times 6)} = 500 \text{ (1)}$$

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)

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

max 4

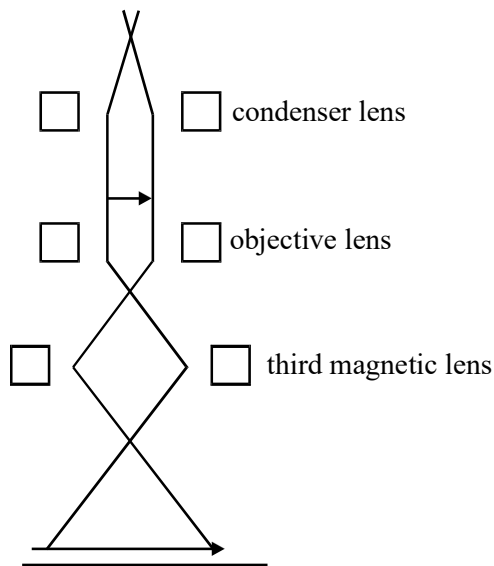
(c)  $f \left( = \frac{c}{\lambda} \right) = \frac{300 \times 10^8}{6.1 \times 10^{-7}}$  (1)

$$= 4.9 \times 10^{14} \text{ Hz (1)}$$

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)

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

(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)

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

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

[or  $\lambda = \frac{h}{(2meV)^{1/2}}$  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)  $f_0 (= \frac{\phi}{h}) = \frac{1.2 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}}$  (1)
- $$= 2.9 \times 10^{14} \text{ (Hz)}$$
- (use of  $c = f_0 \lambda_0$  gives)  $\lambda_0 (= \frac{c}{f_0}) = \frac{3.0 \times 10^8}{2.9 \times 10^{14}} = 1.0 \times 10^{-6} \text{ m (1)}$
- (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)  $v (= \frac{h}{m\lambda}) = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.0 \times 10^{-9}}$  (1)  
 $= 7.3 \times 10^{+5} \text{ m s}^{-1}$  (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)

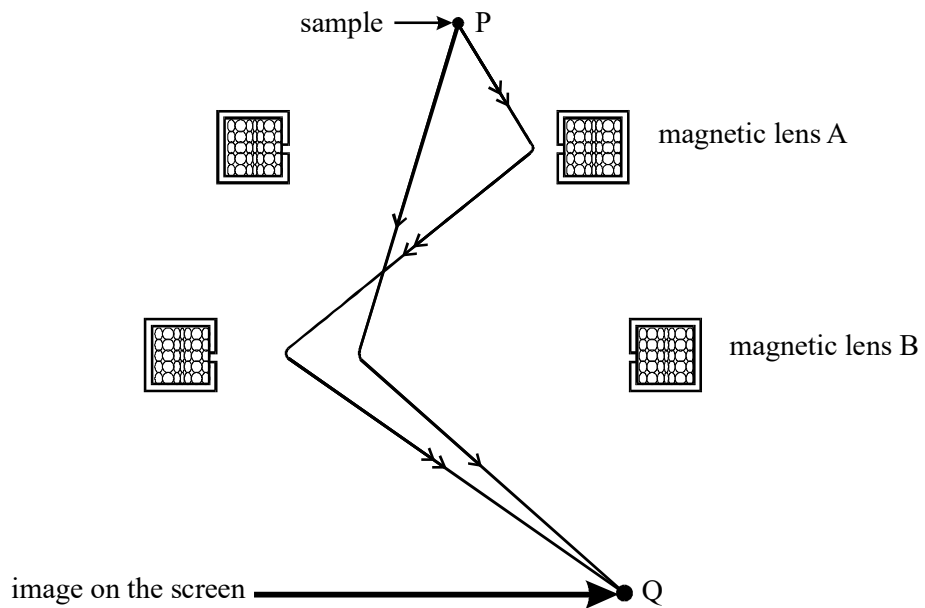
max 4  
QWC 2

- (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  $E_k = \frac{1}{2}mv^2$  gives)  $v = \left(\frac{2E_k}{m}\right)^{1/2}$

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

(=  $3.1 \times 10^{-7} \text{ ms}^{-1}$ )

(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)

$= 1.3 \times 10^{-14} \text{ m}$

[or alternatively  $\lambda \left( = \frac{h}{\sqrt{2meV}} \right) = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 1.6 \times 10^{-19} \times 5 \times 10^6}}$

$= 1.3 \times 10^{-14} \text{ m}$ ] (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)  $f = \frac{3.0 \times 10^8}{2 \times 1.5}$  (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  $180^\circ$ ) (1)  
 path difference = whole number of wavelengths for a bright fringe  
 [or whole number +  $\frac{1}{2}$  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  $90^\circ$  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  $\phi$  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,  $f (= c/\lambda = \frac{3.0 \times 10^8}{5.2 \times 10^{-7}}) = 5.77 \times 10^{14} \text{ J (1)}$

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

$E_{K \text{ max}} (= hf - \phi) = 3.83 \times 10^{-19} - (2.2 \times 1.6 \times 10^{-19}) \text{ (1)}$   
 $= 3.1 \times 10^{-20} \text{ J (1)}$

5

[11]