Turning Points

Wave Particle Duality

Name:

Class:

Date:

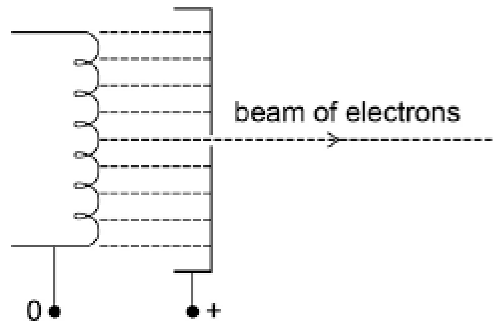
Time: **267 minutes**

Marks: **166 marks**

Comments:

1 **Figure 1** shows a narrow beam of electrons produced by attracting the electrons emitted from a filament wire, to a positively charged metal plate which has a small hole in it.

Figure 1



(a) Explain why an electric current through the filament wire causes the wire to emit electrons.

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(2)

(b) Explain why the filament wire and the metal plates must be in an evacuated tube.

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(1)

(c) The potential difference between the filament wire and the metal plate is 4800 V.

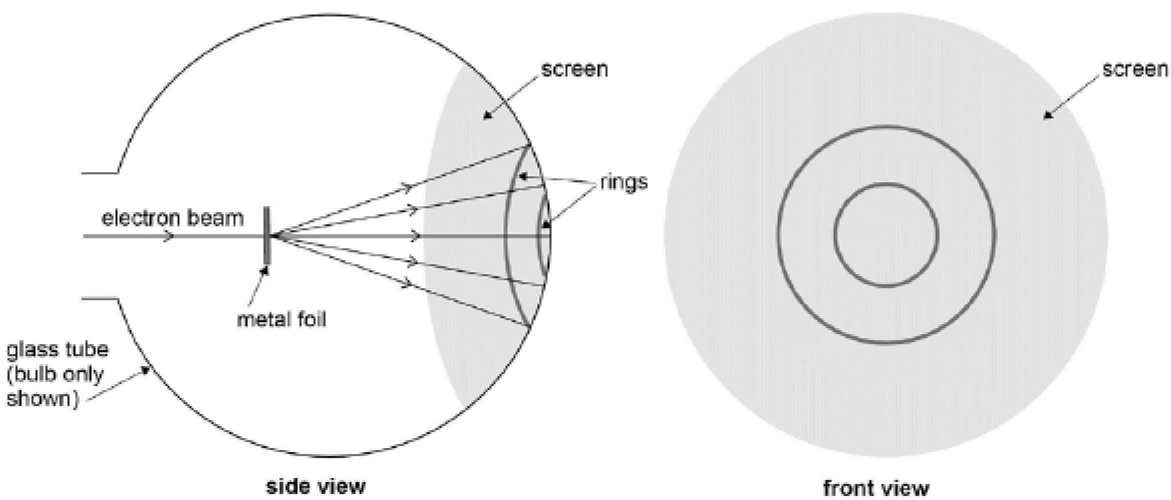
Calculate the de Broglie wavelength of the electrons in the beam.

wavelength = ____________________ m

(4)

The beam is directed at a thin metal foil between the metal plate and a fluorescent screen at the end of the tube, as shown in **Figure 2**.
The electrons that pass through the metal foil cause a pattern of concentric rings on the screen.

Figure 2



(d) The potential difference between the filament and the metal plate is increased. State and explain the effect this has on the diameter of the rings.

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(3)
(Total 10 marks)

2 Maxwell's theory suggested the existence of electromagnetic waves that travel at a speed of $\sqrt{\frac{1}{\varepsilon_0 \mu_0}}$

Hertz later discovered radio waves and performed experiments to investigate their properties.

The figure below shows a radio wave transmitter and a detector. The wave is transmitted by a dipole aerial. The detector consists of a metal loop connected to a meter.

(a) Explain how the detection of the wave by the loop demonstrates the magnetic nature of the radio waves.

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(2)

(b) Explain how the electric nature of the waves emitted by the dipole could be demonstrated.

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(1)

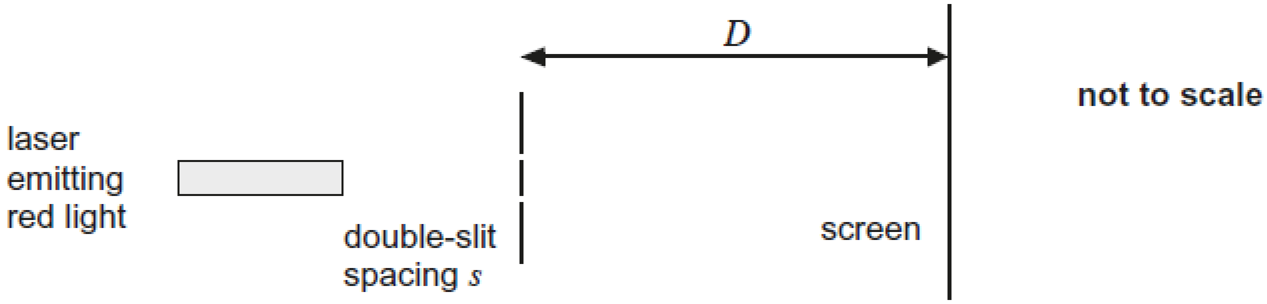
(c) Hertz used an arrangement like that shown in the figure above to determine the speed of radio waves.

Describe how the speed was determined. Go on to discuss how the experiments of Hertz confirmed Maxwell’s prediction and the experimental evidence that suggests that light is also an electromagnetic wave.

(6)

(Total 9 marks)

3 The diagram shows the arrangement of apparatus in an experiment to measure the wavelength of red light emitted by a laser. The light is incident on a double-slit so that an interference pattern is produced on the screen.



A student sets up the apparatus and measures the fringe width *w* of the interference pattern and the distance *D* between the double-slit and screen.

The student makes further measurements of *w* using the same laser but with different values of *D* and different slit spacing *s*.

The student's results are shown in the table below

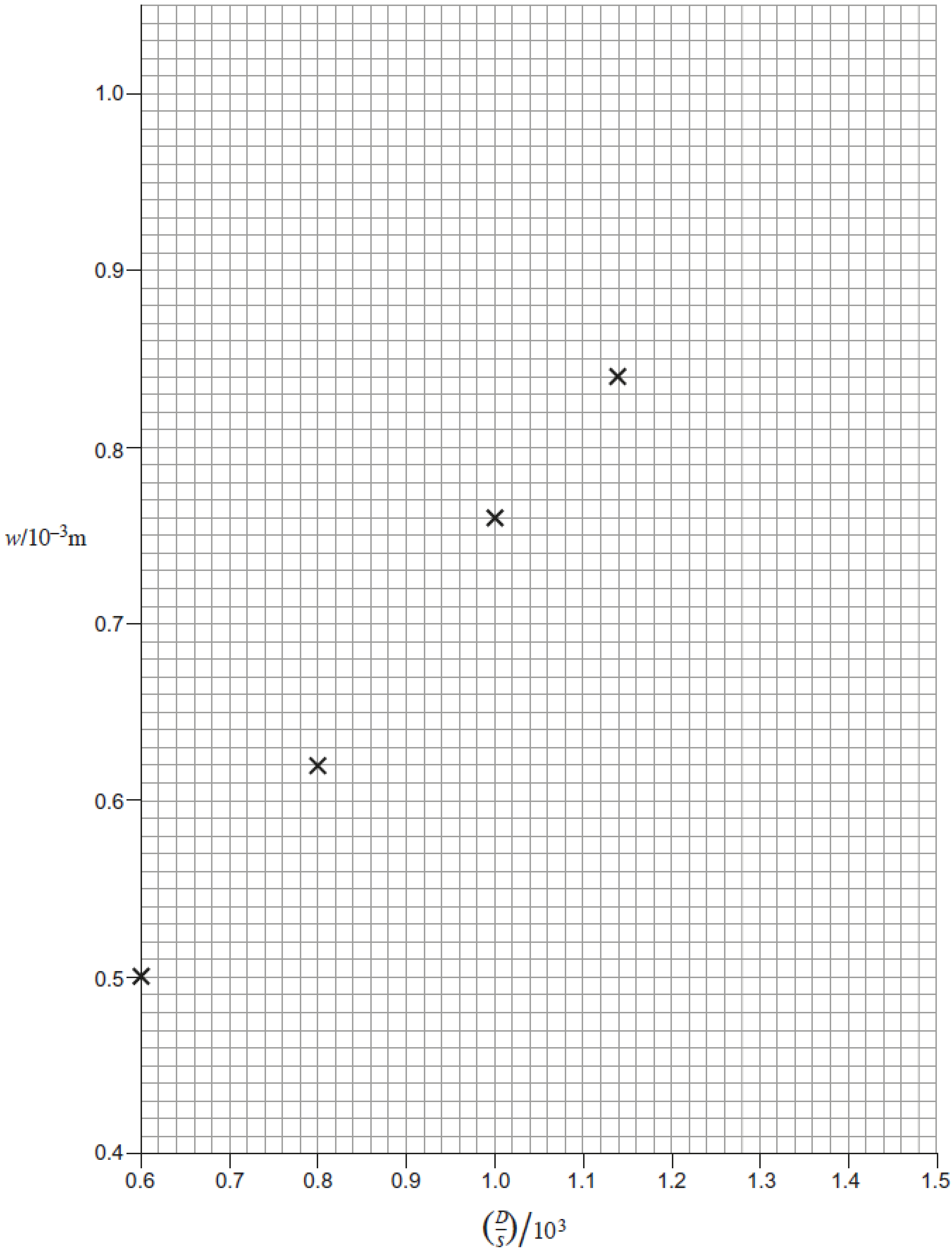
***D*/m**	$S/10^{-3}$ m	$\left(\frac{D}{S}\right)/10^{3}$	$w/10^{-3}$m
1.000	0.70		1.03
0.900	0.70		0.93
0.800	0.70	1.14	0.84
1.000	1.00	1.00	0.76
0.800	1.00	0.80	0.62
0.600	1.00	0.60	0.50

(a) Complete the table above.

(1)

(b) Complete the graph below by plotting the two remaining points and drawing a best fit straight line.

(2)



1.0
0.9
0.8
0.7
0.6
0.5
0.4
$w/10^{-3}$m
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
$\left(\frac{D}{s}\right)/10^3$

(c) (i) Determine the gradient of the graph above.

(3)

(ii) Determine the wavelength of the red laser light used in this experiment.

(1)

(d) (i) Theory suggests that the graph above should go through the origin.

State and explain what this suggests about the relationship between *w* and $\frac{D}{S}$.

(2)

(ii) The student discovers that the best fit line drawn in the graph does not go through the origin.

Determine, using information from the graph above, the value of *w* corresponding to $\left(\frac{D}{S}\right) = 0$.

(2)

(iii) The graph suggests a systematic error in a measurement.

Identify the measurement.

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(1)

(e) The interference pattern produced on the screen is much brighter in the centre of the screen than at the edges.

State what causes this effect.

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(1)

(Total 13 marks)

4 (a) (i) Describe how Newton used the corpuscular theory to explain the refraction of light as it passes from one substance into a substance of higher optical density.

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(3)

(ii) Huygens used a wave theory to explain refraction.

Explain why the corpuscular theory was rejected in favour of a wave theory to explain refraction.

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(2)

(iii) Describe and explain the difference in the appearance of the fringes in Young's double-slit experiment that are predicted by the corpuscular theory and by the wave theory for light.

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(2)

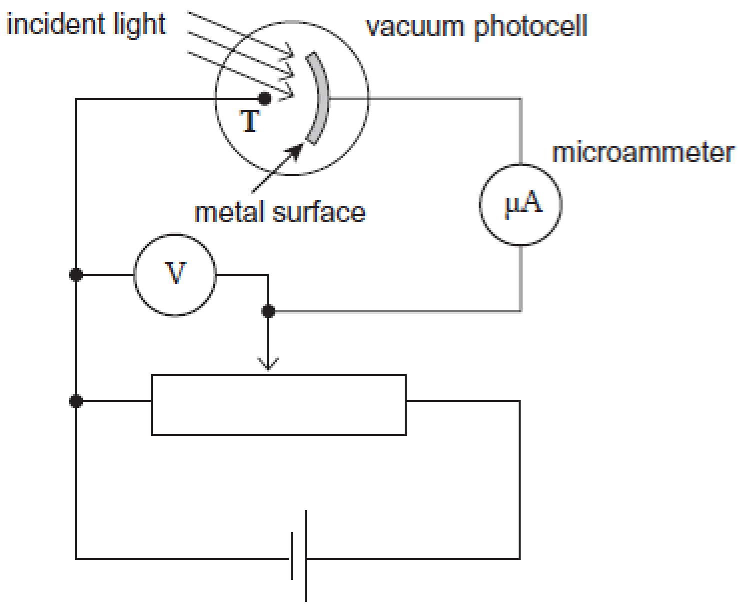
(b) Electromagnetic waves and matter are now known to exhibit both particle and wave behaviour. The photons for a particular X-ray wavelength have energy 5.0 keV.

Calculate the potential difference through which an electron has to be accelerated so that its de Broglie wavelength is the same as that of this X-ray.

(4)

(Total 11 marks)

5 The figure below shows a metal surface in a vacuum photocell illuminated by light of a certain frequency. Electrons emitted from the metal surface are collected by terminal **T** in the photocell.



(a) The potential of the metal surface may be changed by adjusting the potential divider. Explain why the microammeter reading decreases when the metal surface is made more positive relative to **T**.

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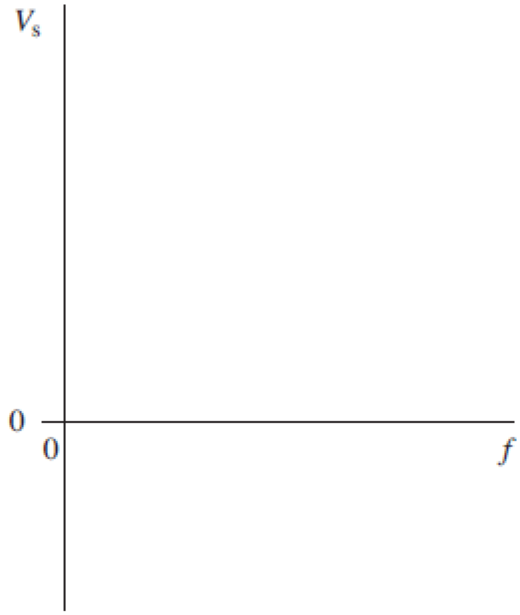
(3)

(b) The stopping potential V_s is the minimum potential that is applied to the metal surface to reduce the photoelectric current to zero when monochromatic light is incident on the surface. The circuit is used with light of different frequencies to measure the stopping potential V_s when the surface is illuminated at each frequency.

(i) Draw a graph on the axes below to show how V_s varies with the frequency f of the incident light.



(2)

(ii) Use the photoelectric equation $hf = \phi + E_k$ to explain your graph.

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(3)

(c) Using the circuit in the diagram above, the stopping potential was 1.92 V for light of wavelength 418 nm.

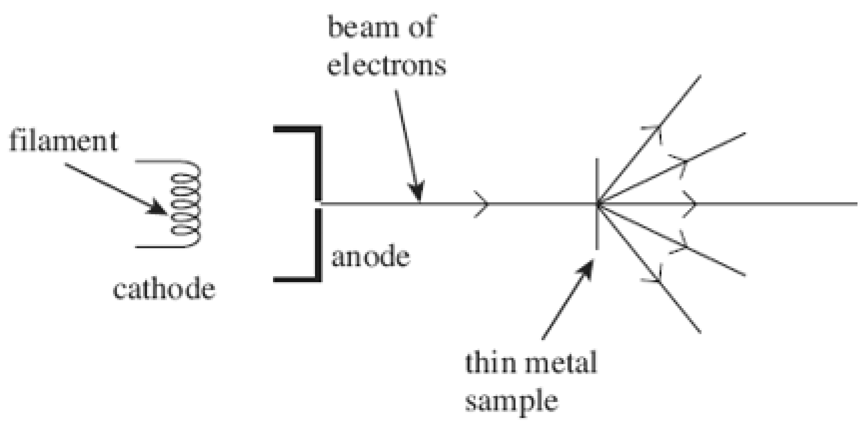
Use this information to calculate the work function of the metal surface.
Give an appropriate unit in your answer.

work function ____________________ unit __________

(4)

(Total 12 marks)

6 In the figure below, a beam of monoenergetic electrons is produced by thermionic emission from a wire filament in an evacuated tube. The beam is directed at a thin metal sample at normal incidence and it emerges from the sample in certain directions only, including its initial direction.



(a) (i) Name the physical process occurring at the thin metal sample in the figure above which shows the electrons behaving as waves.

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(1)

(ii) Explain why the electrons need to be monoenergetic in order for them to emerge in certain directions only.

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(2)

(b) A transmission electron microscope (TEM) operating at an anode potential of 25kV is used to observe an image of a thin sample.

(i) Calculate the momentum of the electrons emerging from the anode, stating an appropriate unit.

answer = ______________________

(4)

(ii) Describe and explain how the resolution of the image would change if the anode potential were increased.

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(3)

(Total 10 marks)

7 (a) Light has a dual wave-particle nature. State and outline a piece of evidence for the wave nature of light and a piece of evidence for its particle nature. For each piece of evidence, outline a characteristic feature that has been observed or measured and give a short explanation of its relevance to your answer. Details of experiments are not required.

The quality of your written communication will be assessed in your answer.

(6)

(b) An electron is travelling at a speed of 0.890 c where c is the speed of light in free space.

(i) Show that the electron has a de Broglie wavelength of 1.24×10^{-12} m.

(2)

(ii) Calculate the energy of a photon of wavelength 1.24×10^{-12} m.

answer = ____________________ J

(1)

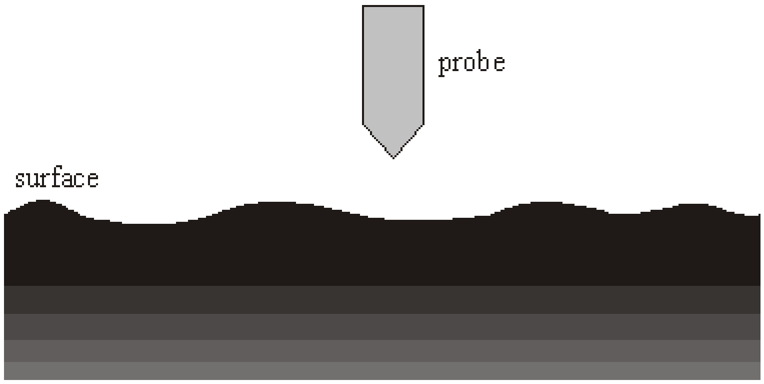
(iii) Calculate the kinetic energy of an electron with a de Broglie wavelength of 1.24×10^{-12} m.
Give your answer to an appropriate number of significant figures.

answer = ____________________ J

(2)

(Total 11 marks)

8 In a scanning tunnelling microscope (STM), a metal probe with a sharp tip is scanned across a surface, as shown in the figure below.



(a) Explain why electrons transfer between the tip of the probe and the surface when the gap between the tip and the surface is very narrow and a pd is applied across it.

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(3)

(b) Describe how an STM is used to obtain an image of a surface.

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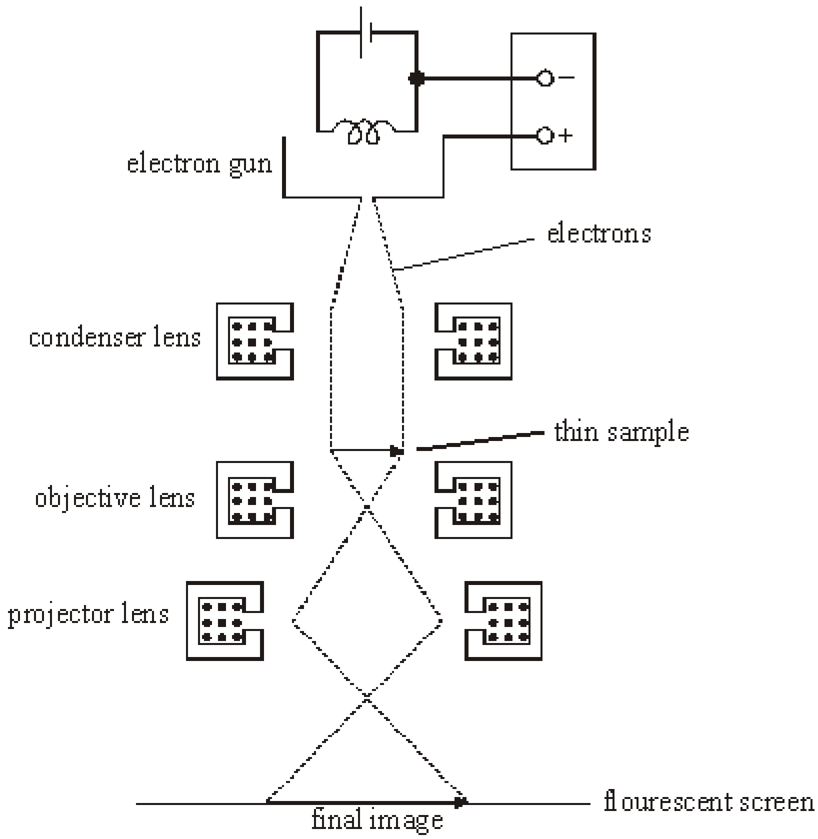
(3)

(Total 6 marks)

9 In a transmission electron microscope, electrons from a heated filament are accelerated through a certain potential difference and then directed in a beam through a thin sample. The electrons scattered by the sample are focused by magnetic lenses onto a fluorescent screen where an image of the sample is formed, as shown in the figure below.



(a) State and explain **one** reason why it is important that the electrons in the beam have the same speed.

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(2)

(b) When the potential difference is increased, a more detailed image is seen. Explain why this change happens.

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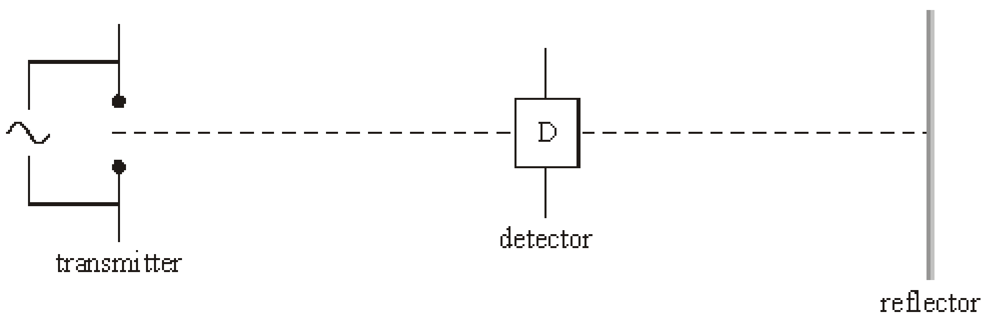
(3)

(Total 5 marks)

10 Hertz discovered how to produce and detect radio waves. He measured the wavelength of radio waves produced at a constant frequency using the arrangement shown in the diagram below.



(i) Explain why the strength of the detector signal varied repeatedly between a minimum and a maximum as the detector was moved slowly away from the transmitter along the dotted line.

You may be awarded marks for the quality of written communication in your answer.

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(ii) Hertz found that a minimum was detected each time the detector was moved a further 1.5 m away from the transmitter.
Calculate the frequency of the radio waves.

(Total 5 marks)

11 Photoelectric emission occurs from a certain metal plate when the plate is illuminated by blue light but not by red light.

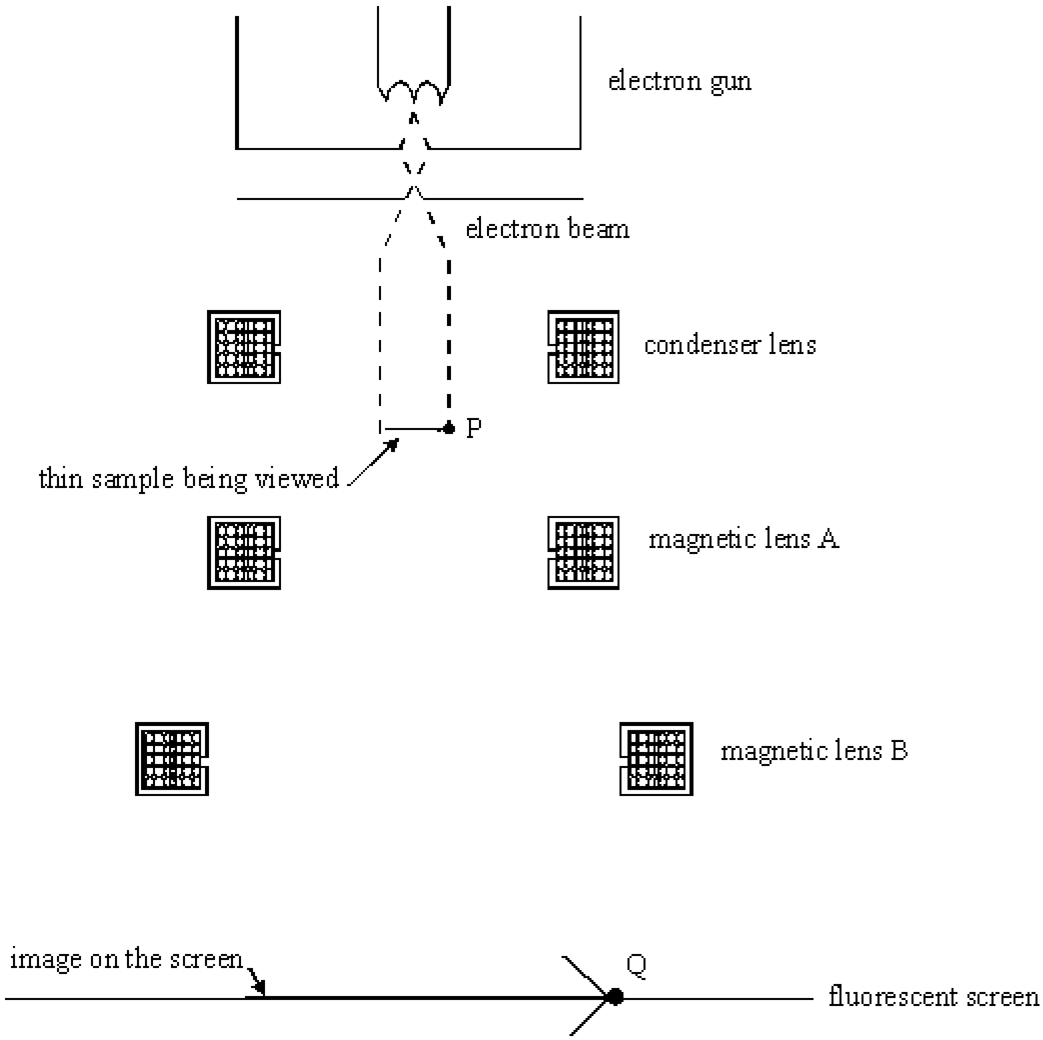
(a) Explain why photoelectric emission occurs from this plate using blue light but not using red light.

(4)

(b) Outline why Huygens' wave theory of light fails to explain the fact that blue light causes photoelectric emission from this plate but red light does not.

(2)
(Total 6 marks)

12 The diagram below shows a Transmission Electron Microscope. Electrons from the electron gun pass through a thin sample and then through two magnetic lenses A and B on to a fluorescent screen. An enlarged image of the sample is formed on the screen.



(a) (i) Sketch the path of an electron that reaches point Q on the screen after passing through the sample at point P and through the two magnetic lenses A and B.

(ii) State the function of magnetic lens A and the function of magnetic lens B.

magnetic lens A ____

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magnetic lens B ____

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(4)

(b) Explain why greater image detail is seen when the anode voltage is increased.

(3)

(Total 7 marks)

13 (a) A certain metal has a work function of 1.2 eV.

(i) Explain what is meant by this statement.

(ii) Calculate the threshold wavelength of light for this metal surface.

(3)

(b) When blue light is incident on a certain metal surface, electrons are emitted from the surface. No electrons are emitted when red light, instead of blue light, is incident on the same surface at the same potential.

(i) Use Einstein's theory of light to explain these observations.

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(ii) Outline the significance of Einstein's explanation.

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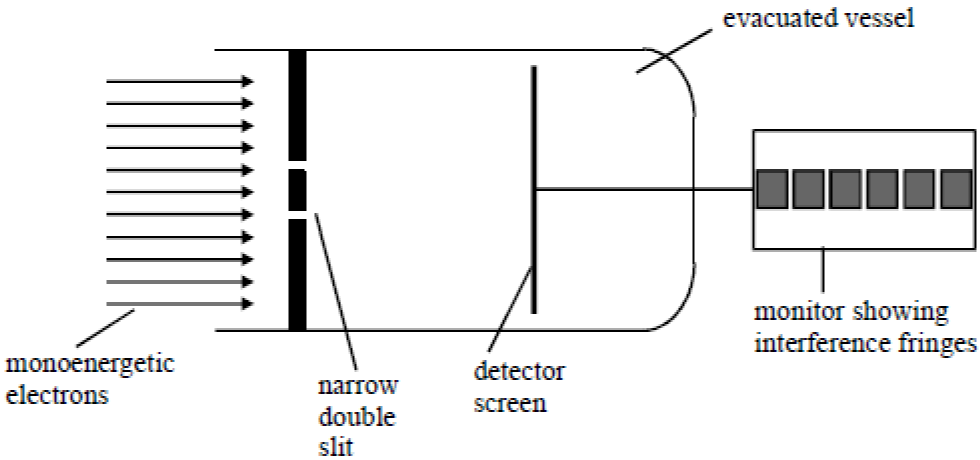
(5)
(Total 8 marks)

14 A beam of electrons travelling at 1.2×10^3 m s^{-1} inside an evacuated container is directed normally onto a double slit arrangement, as shown in the diagram. An array of detectors forms a screen which collects the electrons that pass through the slits for a selected period of time. The number of electrons collected by the detectors is displayed as a fringe pattern on a monitor.



(a) (i) Show that the de Broglie wavelength of the incident electrons is 6.1×10^{-7} m. Ignore relativistic effects.

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(ii) The monitor screen shows six bright fringes. Estimate the number of electrons that contribute to each bright fringe when the detector current is 4.8×10^{-13} A and the electrons are collected over a period of 1.0 m s.

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(4)

(b) (i) The intensity of the incident electron beam is reduced to a level where only one electron is travelling through the slits at a time. The collection time is increased to allow the original number of electrons to be collected. Compare the pattern observed on the monitor screen with that originally observed.

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(ii) The speed of the electrons in the beam is reduced to half by reducing the anode potential of the electron gun that produced the beam. Describe and explain how the pattern observed on the monitor screen would differ from that originally observed in part (a).

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(4)

(c) The electrons are replaced with a source of monochromatic light and the detector screen is replaced with a light-sensitive detecting screen. Determine the frequency of light that would produce fringes with the same fringe spacing as those originally observed using electrons.

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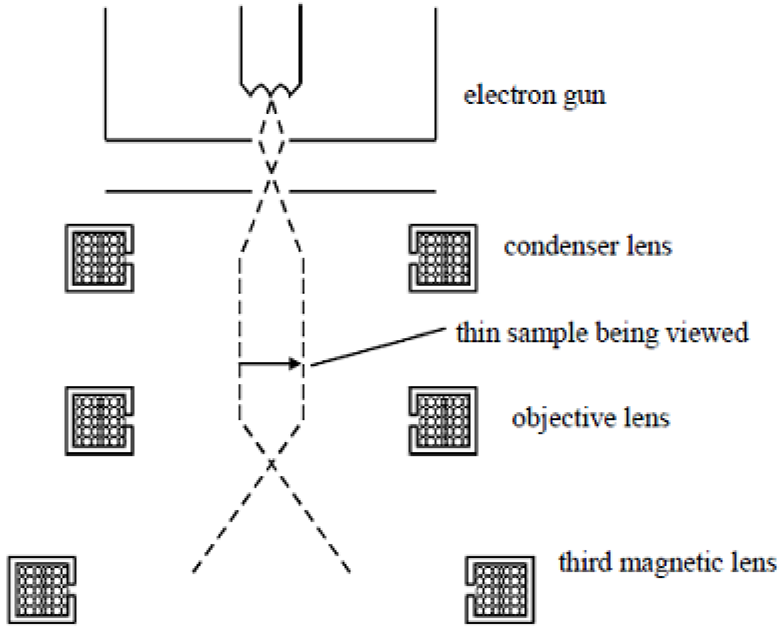
(2)
(Total 10 marks)

15 The diagram shows the lens arrangement of a transmission electron microscope (T.E.M.). The dashed lines show two of the many paths followed by electrons through the T.E.M.



______________________________________ fluorescent screen

(a) Complete the two electron paths on the diagram and draw an arrow to represent the final image

(2)

(b) What is the function of

(i) the condenser lens,

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(ii) the objective lens,

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(iii) the third magnetic lens?

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(3)

(c) (i) State and explain the effect on the resolving power of the T.E.M. if the anode voltage of the electron gun is increased.

(ii) In practice, the resolving power of a T.E.M. is limited. State and explain **one** factor that limits the resolving power.

(4)

(Total 9 marks)

16 (a) The anode voltage of a certain transmission electron microscope is 20 kV.

Calculate

(i) the speed of the accelerated electrons,

(ii) the de Broglie wavelength of these electrons.

(4)

(b) State and explain how the image of an object observed using this transmission electron microscope in part (a) would change when the anode voltage was increased.

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(2)

(Total 6 marks)

17 When a clean metal surface in a vacuum is irradiated with ultraviolet radiation, electrons are emitted from the metal. The following equation relates the frequency of the incident radiation to the kinetic energy of the emitted electrons.

$$hf = \phi + E_k$$

(a) Explain what each of the following terms represents in the above equation.

(i) hf ____

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(ii) ϕ ____

____

(iii) E_k ____

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(3)

(b) (i) State what would happen to the number of photoelectrons ejected per second if the ultraviolet source were replaced by a source of red light of the same intensity but of frequency less than ϕ/h.

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(ii) What would the wave theory of light predict about the effect of using the red light source instead of an ultraviolet source?

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(iii) Use the photon theory of light to explain the effect of using the red light source instead of an ultraviolet source.

(3)

(c) Monochromatic radiation of wavelength 3.00×10^{-7} m ejects photoelectrons at kinetic energies of up to 3.26×10^{-19} J when incident on a clean metal surface. Calculate the work function of the metal, in J.

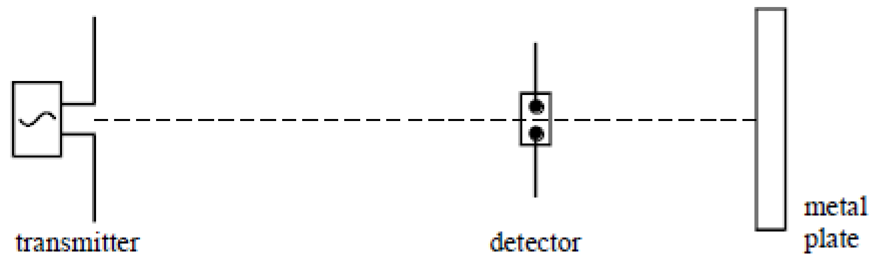
(2)

(Total 8 marks)

18 (a) With the aid of a diagram, explain what is meant by an electromagnetic wave.

(3)

(b) Hertz discovered how to produce and detect radio waves. He measured the wavelength of radio waves of frequency 4.5×10^8 Hz by reflecting the waves from a metal plate. When he moved the detector along the line between the transmitter and the metal plate, he found the detected signal fell to zero at intervals of 0.33 m.



(i) Explain how he deduced that the wavelength of the radio waves was 0.66 m.

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(ii) Calculate the speed of the radio waves.

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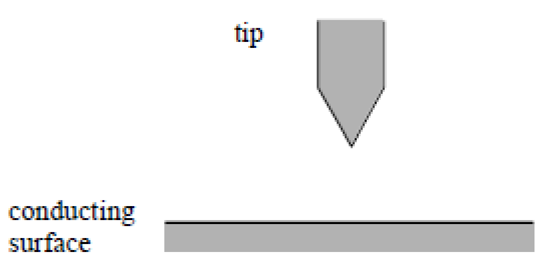
(5)

(Total 8 marks)

19 The diagram shows the tip of a scanning tunnelling microscope (STM) above a conducting surface. The tip is at a potential of –1.0 V relative to the surface. If the tip is sufficiently close to the surface, electrons transfer from the tip to the surface.

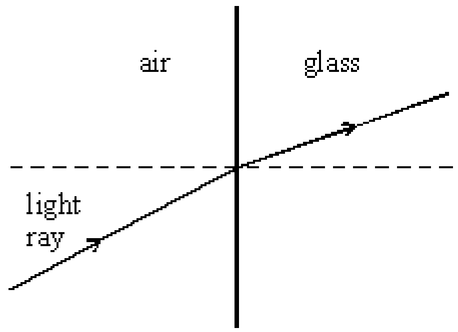


(a) The tip is made to scan the surface along a horizontal line. Describe and explain the effect on the current between the tip and the surface if the tip moves across a pit in the surface.

(b) An STM image can resolve individual atoms of diameter 0.5 nm on the surface. Estimate the kinetic energy, in eV, of an electron which has a de Broglie wavelength of 0.5 nm.

(Total 6 marks)

20 (a) The diagram below shows the path followed by a light ray travelling from air into glass.



Use Newton's theory of light to explain the refraction of the light ray at the air/glass boundary.

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(3)

(b) Newton's theory of light was eventually abandoned in favour of Huygens' wave theory which correctly predicted the speed of light in glass in comparison with the speed of light in air.

(i) What did each theory predict about the speed of light in glass in comparison with the speed of light in air?

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(ii) Describe **one** further piece of evidence that supports Huygens' wave theory.

(3)

(Total 6 marks)

Mark schemes

1 (a) current heats the wire ✓ 1

electrons (in filament) gain sufficient KE (to leave the filament) ✓ 1

(b) electrons would collide (or be absorbed or scattered) by gas atoms (or molecules) ✓ 1

(c) Rearrange ½ $m v^2 = eV$ to give $v = (2eV / m)^{1/2}$ 1

or correct substitution in equation. 1

$$v = \left(\frac{2 \times 1.6 \times 10^{-19} \times 4800}{9.1 \times 10^{-31}} \right)^{½} = 4.1 \times 10^{7}\ \text{m s}^{-1}$$ 1

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 4.1 \times 10^{7}} ✓ = 1.8 \times 10^{-11}\text{m} ✓$$ 1

(d) Increasing the pd increases the speed (or kinetic energy or momentum) of the electrons ✓ 1

which decreases their de Broglie wavelength ✓ 1

so they are diffracted less so the rings become smaller ✓ 1

[10]

2 (a) induced emf in the loop must be caused by changing magnetic flux through the loop✓ 1

magnetic flux change must be caused by the wave passing through the loop so the wave has a magnetic nature✓ 1

(b) Use another dipole aligned with the transmitter detects an electric field which changes✓ 1

(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>All three aspects covered:

A full description of Hertz's experiment including a clear description of how the wavelength was determined and how frequency and wavelength are combined to work out speed.
Analysis of Maxwell's prediction by stating link to em waves and calculation of speed from the formula.

Outline of Fizeau's experiment to calculate speed of light, and result in line with Maxwell's formula.</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>Two of the three aspects fully covered, with some detail missing from the third.</td></tr>
<tr><td>4</td><td>One aspect fully covered, with some detail missing from the other two

Or

Two aspects fully covered, with little or no relevant information about the third.</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>All three aspects partially covered, with some detail missing from each

Or

One aspect fully covered, with little or no relevant information about the other two</td></tr>
</table>

2	Two aspects partially covered, with little or no relevant information about the third.	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.
1	One aspect partially covered, with little or no relevant information about the other two.	
0	Little or no relevant information about any of the three aspects.	The student's presentation, spelling punctuation and grammar seriously obstruct understanding.

The following statements are likely to be present:

To measure the speed:

- diagram showing or clear description of transmitter, reflector and receiver between them.
- stationary waves set up between the transmitter and reflector
- interference between incident and reflected waves.
- determine wavelength by measuring distance between nodes / antinodes
- measured / known frequency of the radio wave
- Calculate speed using $v = f\lambda$

How it supports Maxwell's prediction:

- Maxwell result developed from a prediction of e-m waves
- Evidence of a substitution of data from the data booklet into the formula to give result for speed
- The speed of radio waves is the same as the speed of electromagnetic waves predicted by Maxwell

Experimental evidence that suggests light is an em wave:

- Fizeau determined speed of light waves
- outline detail of experiment
- agreement with value predicted by Maxwell suggests light waves are also electromagnetic waves

6

[9]

3 (a) 1.43, 1.29

1

(b) Both plotted points to nearest mm ✓

Best line of fit to points ✓

The line should be a straight line with approximately an equal number of points on either side of the line.

2

(c) (i) Large triangle drawn (at least 8 cm × 8 cm) ✓

Correct values read from graph ✓

Gradient value in range (0.618 to 0.652) × 10^{-6} to 2 or 3 sf ✓

Allow the 2nd mark for incorrect numerical values read <u>ignoring</u> incorrect power of 10.

Incorrect power of 10 <u>is</u> penalised in gradient value.

3

(ii) Same figure quoted for gradient but <u>with correct unit</u>

1

(d) (i) Straight line (through origin) ✓

(directly) proportional ✓

2

(ii) Evidence of substituting data from the table / graph into w = mD/s + c (from y = mx + c) ✓

Computation of correct value for c (i.e. value of w when D/s = 0) <u>with correct unit</u>.

Should be approximately 0.1 × 10^{-3} m, depending on the exact lobf drawn.

2

(iii) *w*

1

(e) Any reference to **either** width of slits **OR** single slit diffraction ✓

1

[13]

4 (a) (i) Appreciation that one component changes speed while the other component at right angles does not ✓

When entering a denser medium a corpuscle / light accelerates or its velocity / momentum increases <u>perpendicular to the interface</u> ✓

There is a (short range) attractive force between light <u>corpuscle</u> and the (denser) material ✓

Not allowed:

Attraction due to opposite charges

Force making them move faster is not enough

Accelerate in medium

Not gains energy

3

(ii) Light (was shown by experiment to) travel slower in (optically) denser medium OWTTE ✓

Condone 'waves..' instead of 'light'

OWTTE e.g. speed in vacuum higher than speed in other medium

Newton's theory required light to travel faster, wave theory suggested slower speed ✓
or
Newton's theory could not explain the slower speed
or
Huygens theory could explain the slower speed

Not allowed:

Reference to Young's two slit- question asks them about refraction

2

(iii) A corpuscular theory predicts only two (bright) lines / high intensity patches of light whereas a wave theory predicts many fringes ✓

Corpuscles can only travel in straight lines
or
waves can produce fringes because (diffract and) interfere / superpose / arrive in and out of phase / have different path differences ✓

Need to describe the patterns ie not just interference fringes are seen for the first mark

2

(b) Substitutes data in photon wavelength = hc / E ; Allow for substitution with no conversion to J ✓

2.48×10^{-10} m ✓

For electron: Substitution in $\lambda = \frac{h}{\sqrt{2mE}}$

2.48×10^{-10}(or their λ)

$= 6.6 \times 10^{-34} / (2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19}\ V)^{1/2}$ ✓

No conversion to J gives $\lambda \approx 4 \times 10^{-29}$ and $V \approx 9 \times 10^{38}$ V)

V = 24(.4) V ✓ $=1.49 \times 10^{-18} / (\text{their } \lambda)^2$ ✓

Allow small rounding errors in dp

May calculate v using $v = h / m\lambda$ then substitution in $V = ½\ mv^2 / e$ ✓ (for third mark)

4

[11]

5 (a) emitted electrons have a range of speeds ✓

(electrostatic) force acting on electrons emitted from surface increases OR pull / attraction on electrons from surface increases ✓

microammeter reading due to electrons reaching T (moving round circuit) ✓

(microammeter reading decreases because) electrons unable to reach T due to increasing force(or insufficient ke or too much work needed) ✓

Alternative for last point ; (microammeter reading decreases because) fewer electrons can reach T as pd increases,

3 max

(b) (i) Graph ; straight line with a positive gradient ✓
intercept on + x-axis (or on – y-axis if drawn) ✓

Need to see 1st point to get the 2nd point

2

(ii) $E_{K(max)} = eV_S$ (or $E_{K(max)}$ proportional to V_S) ✓

gives $eV_S = hf - \varphi$

where hf = photon energy
and φ = work function of metal ✓

Alt for 2nd mark; recognition that

$$V_S = \frac{hf}{e} - \frac{\varphi}{e}$$

where φ = work function of metal so this is equation for st line (or y = mx + c)

Graph of V_S against f is a straight line with gradient h / e ✓

and x-intercept = φ / h
(or y-intercept = $-\varphi / e$) ✓

Accept either of last 2 marks if shown on the graph clearly

3 max

(c) $hf = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{418\times10^{-9}} = 4.76 \times 10^{-19}$ J ✓

Accept sub or ans for marks1 and 2

$E_{K(max)} = eV_S = 1.6\times 10^{-19} \times 1.92 = 3.07 \times 10^{-19}$J ✓

(Ans in J; allow 1.7 or 1.66 or 1.70 in place of 1.69)*

$\varphi = hf - E_{K(max)}$ (or $4.76 \times 10^{-19} - 3.07 \times 10^{-19}$)
$= 1.69 \times 10^{-19}$ ✓ J ✓ (or 1.06 eV)

(Ans in eV ; allow 1.1 or 1.04)*
**arises from rounding 3.07 to 3.1)*

4

[12]

6 (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 $\mathbf{v}^2$ gives) **either** $\mathbf{v} = \sqrt{\frac{2eV}{m}}$

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

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

7 (a) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate provides a comprehensive and coherent answer that includes a stated property of light such as interference or diffraction that can only be explained in terms of the wave nature of light and a stated property such as photoelectricity that can only be explained in terms of the particle nature of light. In each case, a relevant specific observational feature should be referred to and should be accompanied by a coherent explanation of the observation. Both explanations should be relevant and logical.

For full marks, the candidate may show some appreciation as to why the specific feature of either the named wave property cannot be explained using the particle nature of light or the named particle property cannot be explained using the wave nature of light.

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate provides a logical and coherent explanation that includes a stated property of light such as interference or diffraction that can only be explained in terms of the wave nature of light ***and*** *a stated property such as photoelectricity that can only be explained in terms of the particle nature of light.*

For 4 marks, the candidate should be able to refer to a relevant specific observational feature of each property, at least one of which should be followed by an adequate explanation of the observation. Candidates who fail to refer to a relevant specific observational feature for one of the properties may be able to score 3 marks by providing an adequate explanation of the observational feature referred to.

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate provides some relevant information relating to two relevant stated properties for 1 mark. Their answer may lack coherence and may well introduce irrelevant or incorrect physics ideas in their explanation.

Points that can be used to support the explanation:

Wave-like nature property

- property is either interference **or** diffraction
- observational feature is either the bright and dark fringes of a double slit interference pattern or of the single slit diffraction pattern (or the spectra of a diffraction grating)
- explanation of bright or dark fringes (or explanation of diffraction grating spectra) in terms of path or phase difference
- particle/corpuscular theory predicts two bright fringes for double slits or a single bright fringe for single slit or no diffraction for a diffraction grating

Particle-like nature

- property is photoelectricity
- observational feature is the existence of the threshold frequency for the incident light **or** instant emission of electrons from the metal surface
- explanation of above using the photon theory including reference to photon energy *hf*, the work function of the metal and '1 photon being absorbed by 1 electron'
- wave theory predicts emission at all light frequencies **or** delayed emission for (very) low intensity

6

(b) (i) m (= $m_o (1 - v^2 / c^2)^{-0.5} = 9.11 \times 10^{-31} (1 - 0.890^2)^{-0.5}$)

(= 1.998×10^{-30} kg) = $2.0(00) \times 10^{-30}$ kg ✓

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{2.0(0) \times 10^{-30} \times 0.89(0) \times 3.0(0) \times 10^{8}}$$ ✓

(= $1.2(4) \times 10^{-12}$m)

2

(ii) $$E_{Ph} = \left(hf = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{1.24 \times 10^{-12}} \right) = 1.6(0) \times 10^{-13} \text{ J}$$ ✓

1

(iii) $E_K = (m - m_o) c^2$

$= (1.998 \times 10^{-30} - 9.11 \times 10^{-31}) \times (3.0 \times 10^8)^2$

$= 9.78 \times 10^{-14}$ J ✓ 3 sf only ✓

2

[11]

8 (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]

9 (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]

10 (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]

11 (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

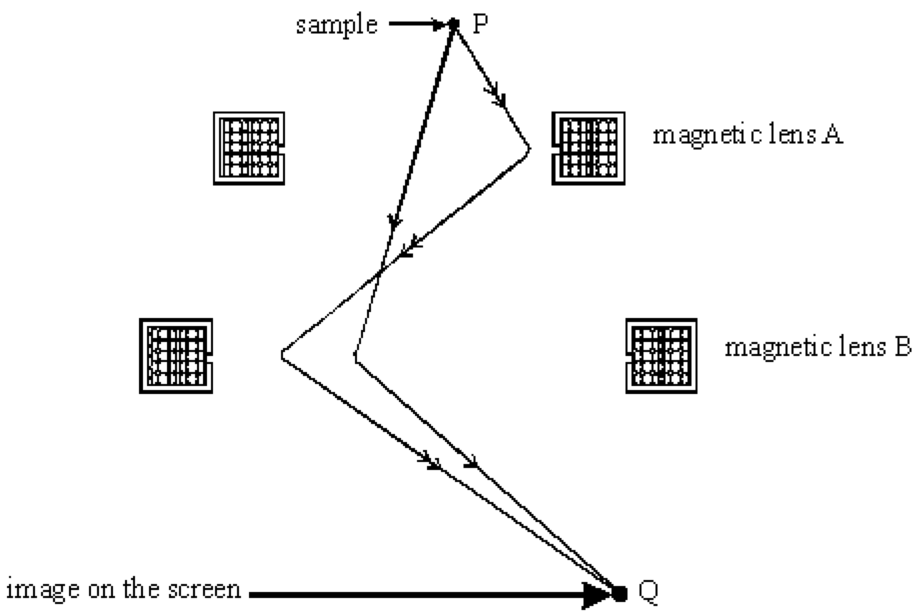
(b) every electron would gain sufficient energy from the waves in time **(1)**
no matter what the frequency/colour/wavelength of the light is **(1)**

2

[6]

12 (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]

13 (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)**

(= 2.9×10^{14} (Hz))

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

14 (a) (i) wavelength = $\frac{h}{mv}$ **(1)**

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

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

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

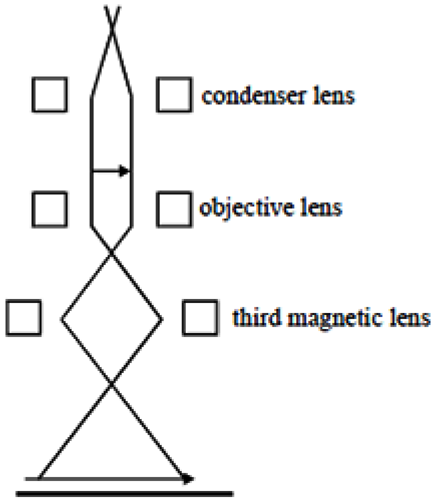
(c) $f\left(=\frac{c}{\lambda}\right) = \frac{300 \times 10^8}{6.1 \times 10^{-7}}$ **(1)**

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

(2)

[10]

15 (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]

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

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

17 (a) (i) hf = photon energy **(1)**

(ii) ϕ = **minimum** energy to eject electron from metal surface **(1)**

(iii) E_k = **maximum** kinetic energy of a photoelectron **(1)**

3

(b) (i) no photoelectrons are emitted **(1)**

(ii) wave theory predicts photoelectrons will be emitted with red light (or at any frequency) **(1)**

(iii) one photon absorbed by one electron **(1)**
electron emitted from metal if photon energy [or hf] > ϕ (or not if < ϕ) **(1)**
red light photon energy < ϕ **(1)**

max 3

(c) $\phi = \frac{hc}{\lambda}$ **(1)** k.e.$_{max}$ **(1)**

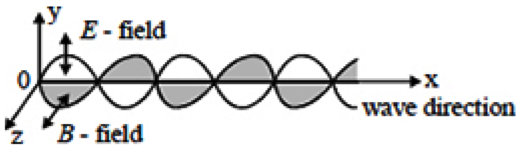
$$\phi = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{3.00 \times 10^{-7}} - 3.26 \times 10^{-19}$$ **(1)**

$\phi = 3.4 \times 10^{-19}$ J **(1)**

2

[8]

18 (a) diagram to show sinusoidal E and B fields at 90° to each other **(1)**
direction of propagation perpendicular to E and B **(1)**
E and B waves in phase **(1)**



(3)

(b) (i) stationary wave pattern is formed by incident and reflected waves **(1)**
detector reading is zero at nodes **(1)**
nodes are at spacing equal to one-half wavelength **(1)**

(ii) λ = 0.66 m, $c(= f\lambda)$ = 4.5 × 10^8 × 0.66 **(1)**
= 3.0 × 10^8 m s^{-1} **(1)**

(5)

[8]

19 (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 × 10^6 (ms^{-1}) **(1)**

k.e. $\left(=\frac{1}{2}mv^2\right) = \frac{1}{2}$ × 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)**

[6]

20 (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 $speed_{glass} > speed_{air}$
<u>and</u> Huygens predicted $speed_{glass} < speed_{air}$ **(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]