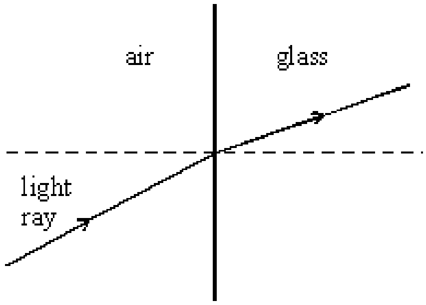
Q1. (a) The diagram below shows the path followed by a light ray travelling from air into glass.



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.

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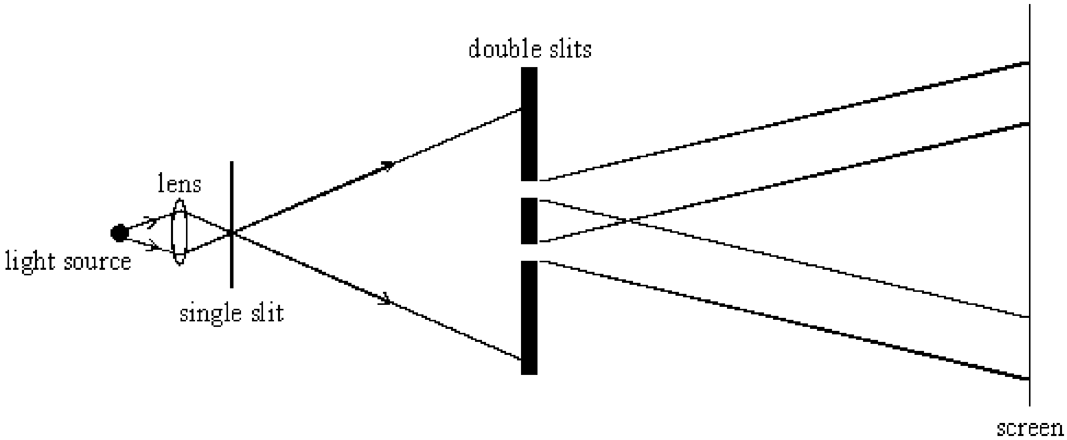
(3)
(Total 6 marks)

Q2. Light from a point source was passed through two closely spaced parallel slits, as shown in the diagram. A pattern of alternate bright and dark fringes was observed on the screen.



(a) Use Huygens' wave theory of light to explain the formation of these fringes by the double slits. You may be awarded marks for the quality of written communication provided in your answer.

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(4)

(b) (i) Explain what Newton's theory of light would predict for the same experimental arrangement.

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(ii) Give **one** reason why Huygens' wave theory of light did not replace Newton's theory of light when the fringe pattern due to the double slits was first observed.

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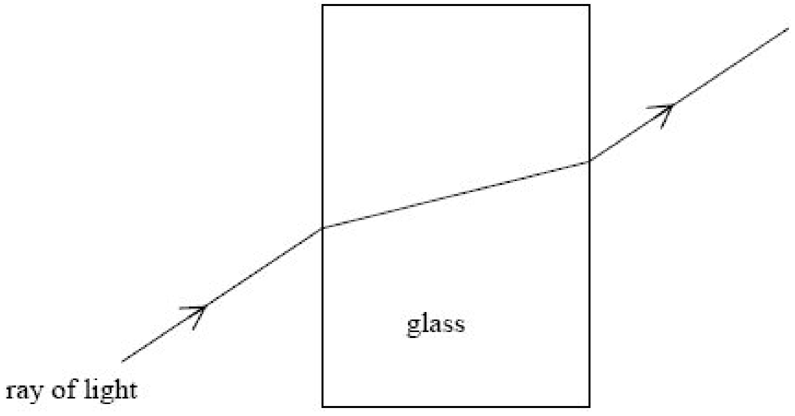
(3)
(Total 7 marks)

Q3. The diagram below shows the path followed by a ray light which is incident at non-normal incidence on a glass block in air.



(a) Use Newton's theory of light to explain the path of the light ray shown in the diagram above.

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(b) Newton's theory of light was eventually abandoned by the scientific community in favour of Huygen's theory of light. State one piece of evidence that supports Huygen's theory and explain why it supports Huygen's theory.

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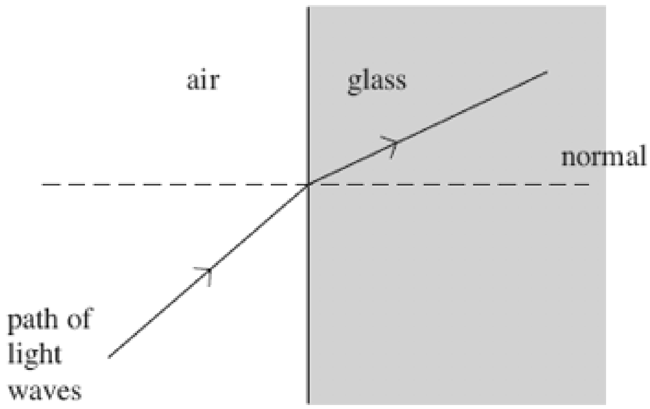
(3)
(Total 7 marks)

Q4. (a) Newton suggested a theory that light is composed of corpuscles. He used his theory to explain the refraction of a light ray travelling from air to glass, as shown in **Figure 1**. Huygens explained the refraction of light using his own theory that light consists of waves.

Figure 1



(i) State **one** reason why Huygens' theory of light was rejected for many years after it was first proposed, in favour of Newton's corpuscular theory of light.

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(1)

(ii) Explain why the eventual measurement of the speed of light in water led to the definite conclusion that light consists of waves and not corpuscles.

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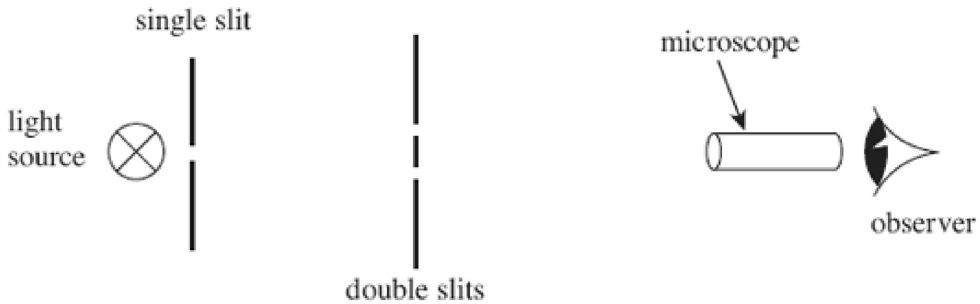
(2)

(b) Young demonstrated that a pattern of alternate bright and dark fringes was observed when light from a narrow single slit passed through double slits, as shown in **Figure 2**.

Figure 2



Newton's corpuscular theory predicted incorrectly that just two bright fringes would be formed in this pattern. Use Huygens' theory of light to explain why more than two bright fringes are formed in this pattern.

The quality of your written communication will be assessed in this question.

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(6)
(Total 9 marks)

Q5. (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.

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(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)

Q6. (a) Experiments based on the photoelectric effect support the particle nature of light. In such experiments light is directed at a metal surface.

(i) State what is meant by the threshold frequency of the incident light.

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(1)

(ii) Explain why the photoelectric effect is **not** observed below the threshold frequency.

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(2)

(b) Monochromatic light of wavelength 5.40×10^{-7} m is incident on a metal surface which has a work function of 1.40×10^{-19} J.

(i) Calculate the energy of a single photon of this light.

answer = ... J

(2)

(ii) Calculate the maximum kinetic energy of an electron emitted from the surface.

answer = ... J

(2)

(iii) Calculate the maximum speed of the emitted electron.

answer = ... m s^{-1}

(2)

(iv) Calculate the de Broglie wavelength of the fastest electrons.

answer = ... m

(2)

(Total 11 marks)

Q7. (a) The discovery of photoelectricity and subsequent investigations led to the wave theory of light being replaced by the photon theory. State one feature of photoelectricity that could not be explained using the wave theory of light and describe how it is explained using photon theory.
The quality of your written answer will be assessed in this question.

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(6)

(b) A certain metal has a work function of 2.2 eV.

(i) Explain what is meant by this statement.

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(ii) The surface of the metal is illuminated with light of wavelength 520 nm. Calculate the maximum kinetic energy of electrons emitted from the surface.

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(5)
(Total 11 marks)

Q8. 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.

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(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.

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(2)
(Total 6 marks)

Q9. (a) Describe, in terms of electric and magnetic fields, the nature of electromagnetic waves travelling in a vacuum. You may wish to draw a labelled diagram.

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(3)

(b) Electrons are emitted from a metal plate when monochromatic light is incident on it, provided that the frequency of the light is greater than or equal to a threshold value.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

(i) How did Einstein explain this effect?

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

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(4)
(Total 7 marks)

Q10. In an experiment to demonstrate the wave nature of light, a parallel beam of monochromatic light was directed at two closely spaced slits, as shown in **Figure 1**. A pattern of bright and dark fringes due to this light passing through the slits was seen on the screen.

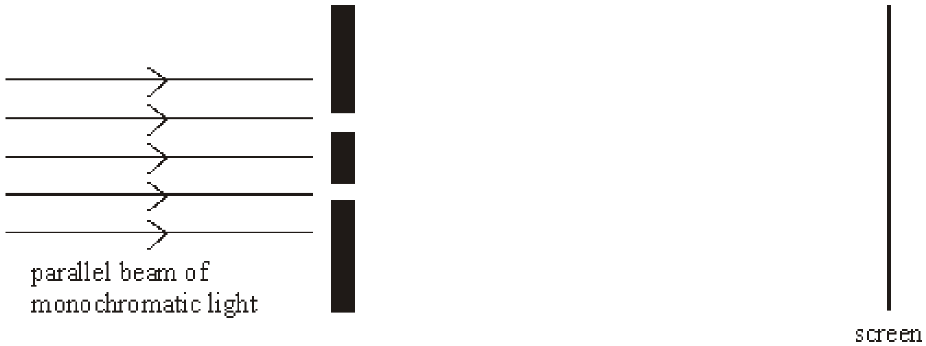

Figure 1

(a) Explain why this fringe pattern was formed.

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

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(4)

(b) Discuss why this fringe pattern cannot be explained using Newton's corpuscular theory of light.

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(2)
(Total 6 marks)

Q11. (a) Describe, in terms of electric and magnetic fields, a plane polarised electromagnetic wave travelling in a vacuum. You may wish to draw a labelled diagram.

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(3)

(b) In his theory of electromagnetic waves, Maxwell predicted that the speed of all electromagnetic waves travelling through free space is given by

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

where μ_o is the permeability of free space and ε_o is the permittivity of free space.

Explain why this prediction led to the conclusion that light waves are electromagnetic waves.

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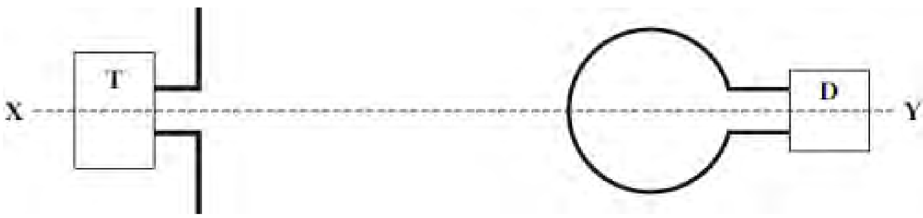
(2)

(c) Hertz discovered how to produce and detect radio waves. The figure below shows a transmitter of radio waves, **T**, and a detector **D**. The detector loop and the transmitter aerial are in the same vertical plane.



(i) Explain why an alternating emf is induced in the loop when it is in this position.

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(3)

(ii) Explain why an alternating emf **cannot** be detected if the detector loop is turned through 90° about the axis **XY**.

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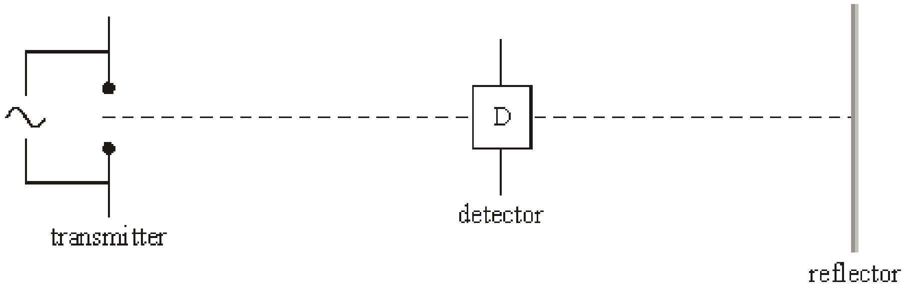
(1)
(Total 9 marks)

Q12. 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.

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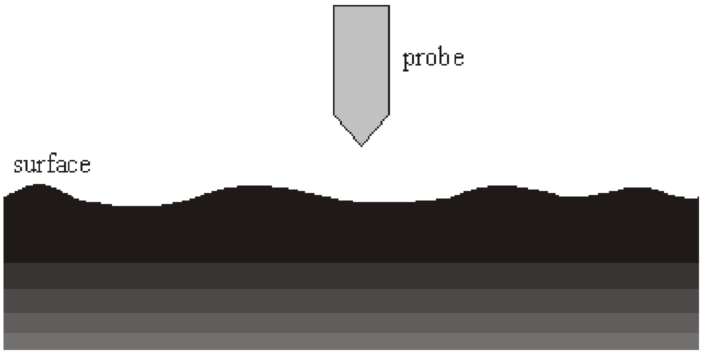
(Total 5 marks)

Q13. 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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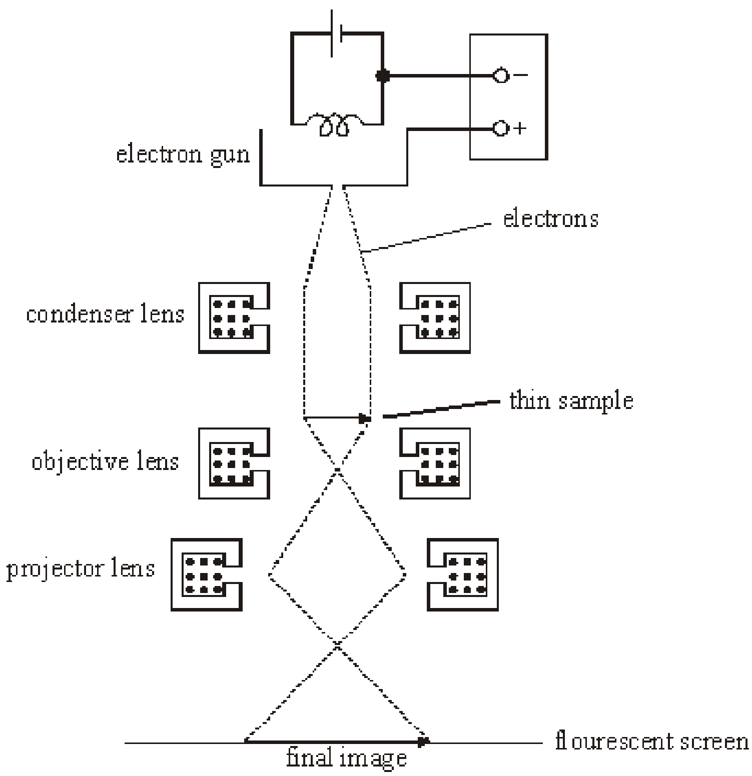
(3)
(Total 6 marks)

Q14. 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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(b) When the potential difference is increased, a more detailed image is seen. Explain why this change happens.

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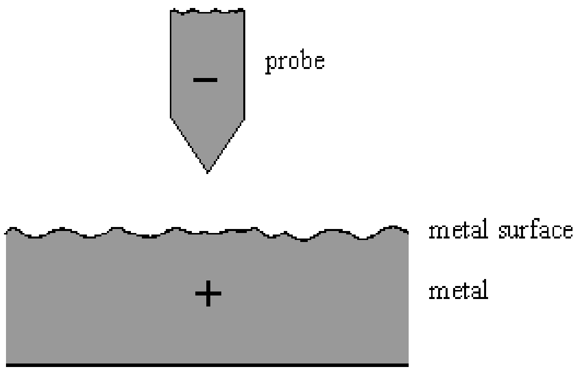
(3)
(Total 5 marks)

Q15. The diagram below shows the probe tip of a scanning tunnelling microscope (STM) above a metal surface. The probe tip is at a constant negative potential relative to the metal surface.



(a) Explain why electrons can cross the gap between the probe tip and the surface, provided the gap is sufficiently narrow.

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

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(4)

(b) Describe **one** way in which an STM is used to investigate a surface.

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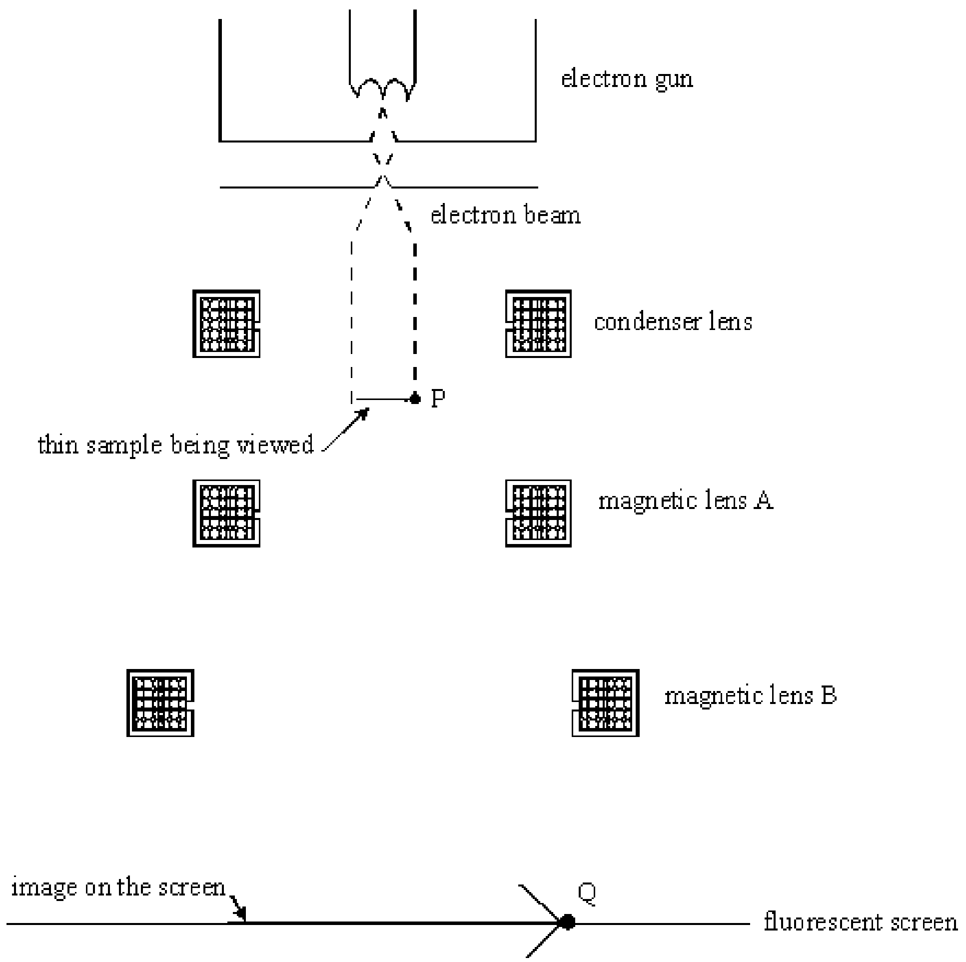
(3)
(Total 7 marks)

Q16. 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.

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(3)
(Total 7 marks)

M1. (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 $\text{speed}_{\text{glass}} > \text{speed}_{\text{air}}$
<u>and</u> 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]

M2. (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]

M3. (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]

M4. (a) (i) Newton's other theories were successful (or Newton was more eminent so Newton's view was accepted) ✓

alternatives, Huygens' theory was based on longitudinal waves which cannot explain polarisation **or**

Huygens' theory could not explain sharp shadows

1

(ii) **either**

Newton predicted that light travels faster in glass than in air, Huygens predicted the opposite ✓

or

there was no evidence (for many years) that light travels slower or faster in glass than in air ✓

the speed of light in water (or glass) was (eventually) found to be less than the speed of light in air ✓

diffraction/interference observations not conclusive ✓

max 2

(b) **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, coherent and logical explanation which recognises that the pattern is due to interference of light which is a wave property. They should know that at a bright fringe, the waves from the two slits are in phase and therefore reinforce each other and this can happen at positions where the path difference is zero or a whole number of wavelengths.
They may not refer to the need for the waves to be coherent.
Their answer should be well-presented in terms of spelling, punctuation and grammar.

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 i le appropriate

The candidate provides a logical explanation which recognises that interference of light is a wave property. They should know either a bright fringe is where the waves from the two slits are in phase or a dark fringe is where they are out of phase by 180° and be aware there are different positions where these conditions apply. They may know the general condition for the path difference for a bright fringe or a dark fringe although they may not recognise that this condition explains why there are more than two bright fringes.
Their answer should be adequately or well-presented in terms of spelling, punctuation and grammar.

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 recognises that interference of light is a wave property and that the waves from the two slits reinforce at a bright fringe or cancel at a dark fringe. They may confuse path difference and phase difference and their explanation of why there are more than two bright fringes may be vague or absent.
Their answer may lack coherence and may contain a significant number of errors in terms of spelling and punctuation.

Incorrect, inappropriate of no response: 0 marks

No answer or answer refers to unrelated, incorrect or inappropriate physics.

Statements expected in a competent answer should include some of the following marking points.

the pattern is due to interference of light from the two slits

interference is a wave property

light from the two slits is in phase at a bright fringe and therefore reinforces

the path difference (from the central bright fringe to the two slits) is zero

either bright fringes are formed away from the centre wherever the path difference is a whole number of wavelengths **or** dark fringes are formed away from the centre wherever the path difference is a whole number of wavelengths + a half wavelength

the path difference for the m^{th} bright fringe from the centre is *m* wavelengths where *m* is any whole number

since *m* is any whole number, more than two bright fringes are observed

max 6

[9]

M5. (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 <u>stated property</u> such as photoelectricity that can only be explained in terms of the particle nature of light. In each case, a relevant specific <u>observational feature</u> should be referred to and should be accompanied by a <u>coherent explanation</u> of the observation. Both explanations should be relevant and <u>logical</u>.

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

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

1

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

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

= 9.78×10^{-14} J ✓ 3 sf only ✓

2

[11]

M6. (a) (i) **below a certain** frequency (called the threshold frequency) no electrons emitted **(1)**

or minimum frequency for electrons to overcome work function

1

(ii) (light travels as photons) energy of a photon depends on frequency **(1)**

below threshold frequency (photon) does not have enough **energy** to liberate an electron **(1)**

or reference to work function eg a photon does not have enough **energy** (to allow the electron) to overcome the work function

2

(b) (i) (use of $E = hc/\lambda$)

$E = 6.63 \times 10^{-34} \times 3.00 \times 10^{8}/5.40 \times 10^{-7}$ **(1)**

$E = 3.68 \times 10^{-19}$ (J) **(1)**

2

(ii) (use of $hf = E_k + \phi$)

$3.68 \times 10^{-19} = E_k + 1.40 \times 10^{-19}$ **(1)**

$E_k = 2.28 \times 10^{-19}$ (J) **(1)**

2

(iii) (use of $E_k = mv^2/2$)

$2.28 \times 10^{-19} = 1/2 \times 9.11 \times 10^{-31} \times v^2$ **(1)**

$v^2 = 2 \times 2.28 \times 10^{-19}/9.11 \times 10^{-31} = 5.0 \times 10^{11}$

$v = 7.1 \times 10^5$ (m s^{-1}) **(1)**

2

(iv) (use of $\lambda = h/mv$)

$\lambda = 6.63 \times 10^{-34}(9.11 \times 10^{-31} \times 7.1 \times 10^5)$ **(1)**

$\lambda = 1.03 \times 10^{-9}$ (m) **(1)**

2

[11]

M7. (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/λ = $\frac{3.0 \times 10^8}{5.2 \times 10^{-7}}$) = 5.77 × 10^{-19} J **(1)**

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

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

5

[11]

M8. (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]

M9. (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) ab orb 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 $hf \geq$ 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]

M10. (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]

M11. (a) (vibrations of) the electric wave and magnetic wave;

perpendicular to each other ✓

perpendicular to direction of propagation ✓

in phase with each other ✓

3

(b) μ_o and ε_o determined experimentally (or μ_o and ε_o values were known) ✓

(substitution of values of μ_o and ε_o into) predicted equation gives $3(.0) \times 10^8$ m s^{-1}
(or the speed of light) ✓

which is the speed of light (or $3(.0) \times 10^8$ m s^{-1}) ✓

2

(c) (i) magnetic wave vibrations perpendicular to (plane of) loop ✓

(magnetic wave) causes alternating (or changing) magnetic flux (linkage or cutting) through the loop ✓

alternating magnetic flux (or field) induces an alternating (or changing) emf (or pd) in the loop ✓

[**or** equivalent E-field statements

E-wave (or field) vibrations parallel to loop ✓

E-wave (or field) induces emf (or pd) in wire of loop ✓

E-wave (or field) alternates so induced emf is alternating ✓]

3

(ii) no magnetic flux (linkage or cutting) through the loop (as loop is now parallel to magnetic wave vibrations) so no induced emf (or pd) ✓

(**or** electric field perpendicular to loop so no induced emf (or pd) ✓)

1

[9]

M12. (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]

M13. (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]

M14. (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]

M15. (a) electrons can behave as waves
[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)**

4
QWC 2

(b) constant height mode:

tip height constant **(1)**

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)**

3

[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

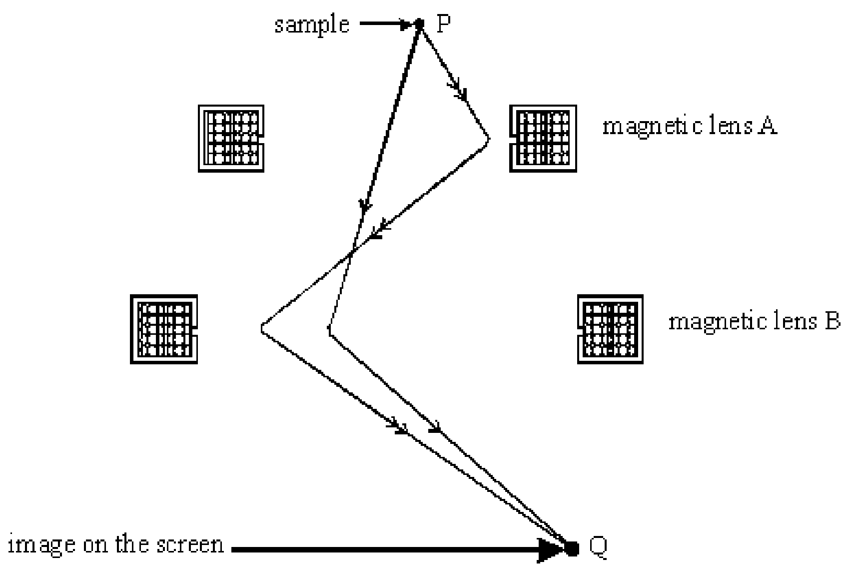
height rises (or falls) if the surface rises or

falls **(1)**]

[7]

M16. (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]