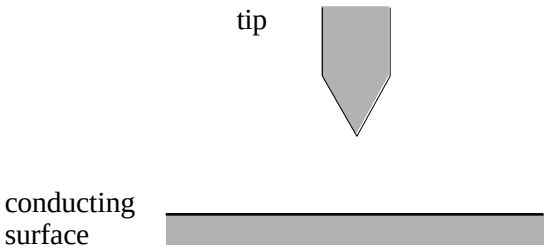
1. The diagram shows the tip of a scanning tunnelling microscope (STM) above a conducting surface. The tip is at a potential of –1.0 V relative to the surface. If the tip is sufficiently close to the surface, electrons transfer from the tip to the surface.



(i) 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.

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(ii) 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.

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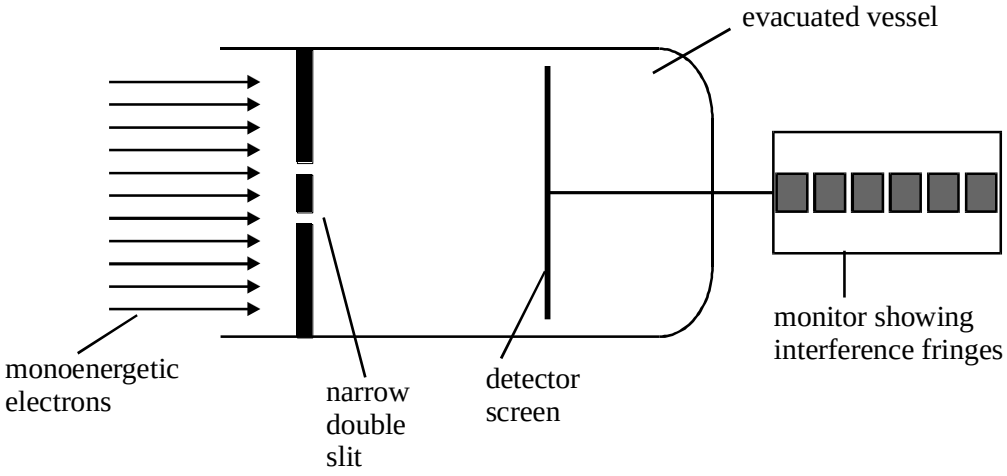
(Total 6 marks)

2. 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 ms.

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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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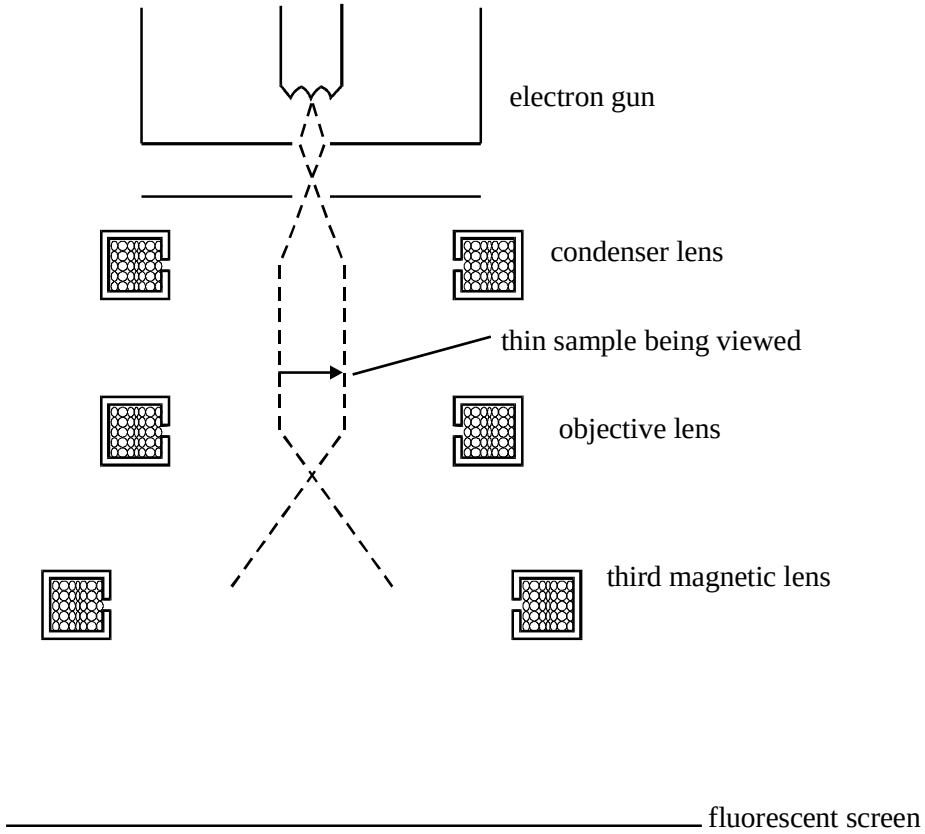
(2)
(Total 10 marks)

3. 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.



(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.

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

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(4)
(Total 9 marks)

4. (a) Describe, with the aid of a diagram, an electromagnetic wave propagating through free space.

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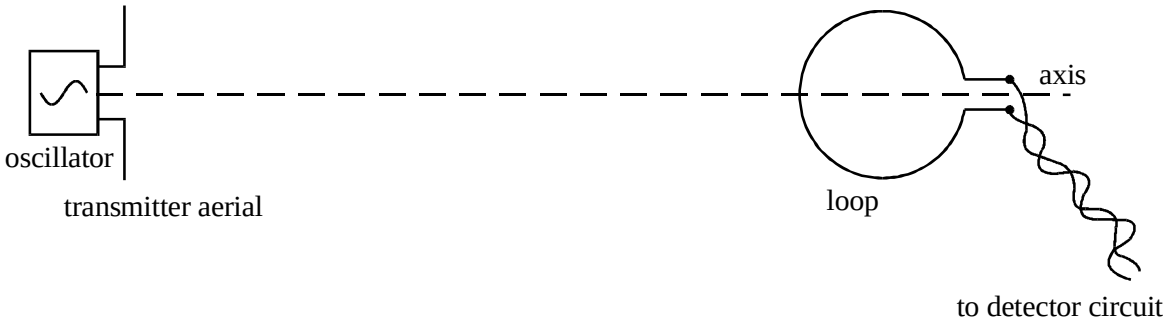
(3)

(b) When an alternating potential difference of a suitably high frequency is applied to a transmitter, an alternating emf of the same frequency is induced in a detector loop as shown. The loop and transmitter aerial are in the same vertical plane.



(i) Explain, in terms of electromagnetic waves, why an emf is induced in the loop when in this position.

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(ii) The alternating emf decreases to zero when the loop is rotated about the axis through 90 ° until it is horizontal. Explain why the emf is zero when the loop is horizontal.

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(4)
(Total 7 marks)

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

Calculate

(i) the speed of the accelerated electrons,

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(ii) the de Broglie wavelength of these electrons.

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(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)

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

(i) Explain what is meant by this statement.

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

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(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)

7. (a) In the Scanning Tunnelling Microscope (STM), electrons cross a gap between a sharp metal tip and a conducting surface when the gap is small and a potential difference exists across it.

(i) Explain, in terms of wave particle duality, why an electron can cross this small gap.

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(ii) Explain, why it is necessary for a potential difference to exist across the gap?

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(4)

(b) Calculate the speed of an electron which has a de Broglie wavelength of 1 nm.

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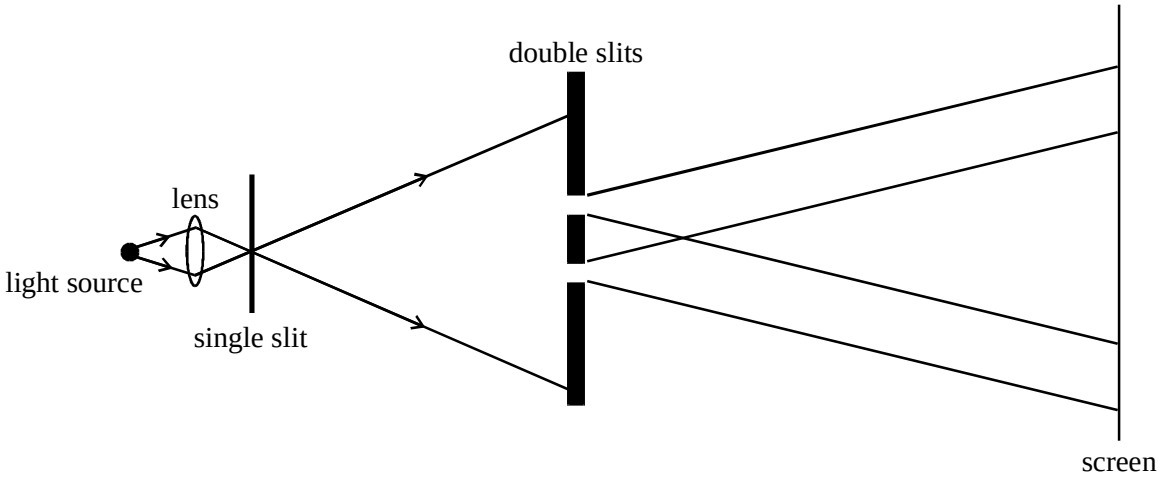
(2)
(Total 6 marks)

8. 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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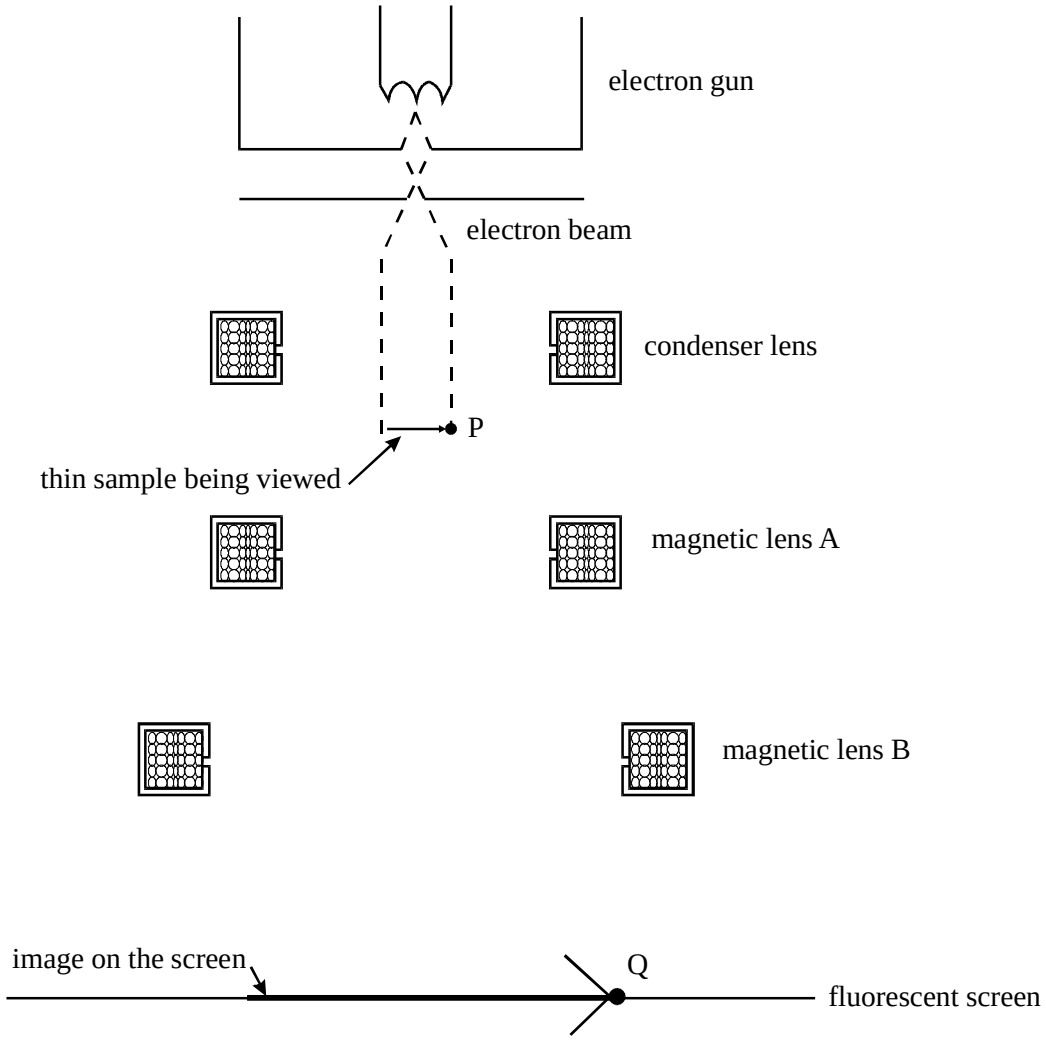
(3)
(Total 7 marks)

9. 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)

10. (a) Describe **one** piece of evidence that shows that matter has

(i) a wave-like nature,

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(ii) a particle-like nature.

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(3)

(b) For a proton of kinetic energy 5.0 MeV,

(i) show that its speed is 3.1×10^7 m s^{-1},

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(ii) calculate its de Broglie wavelength.

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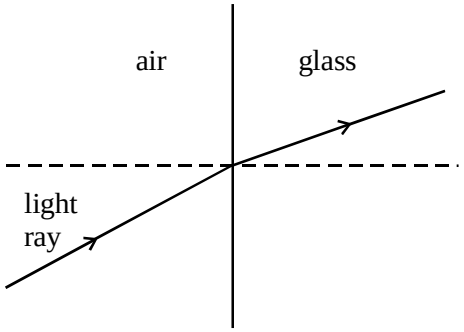
(4)
(Total 7 marks)

11. (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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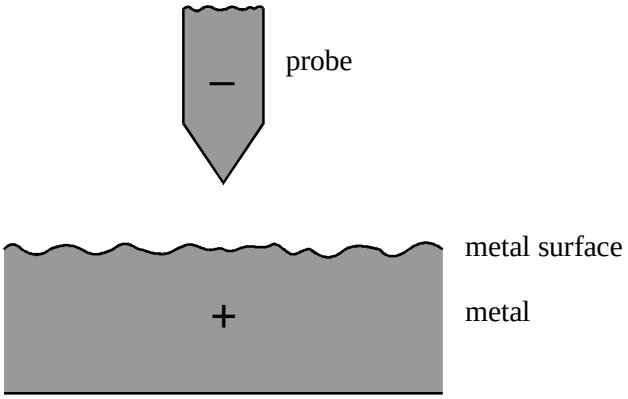
(3)
(Total 6 marks)

12. 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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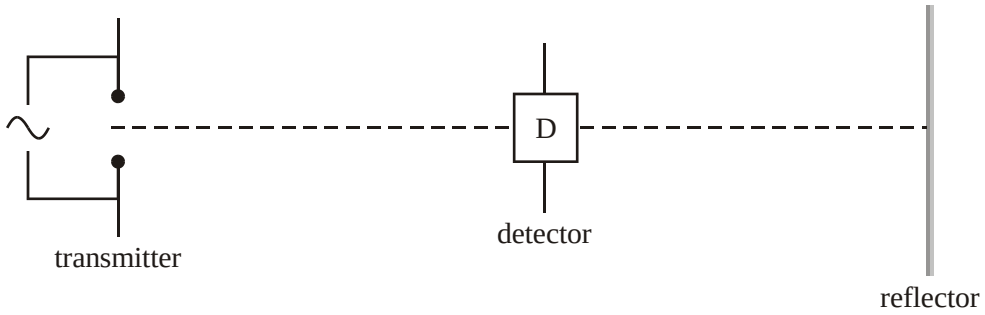
(3)
(Total 7 marks)

13. 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)

14. 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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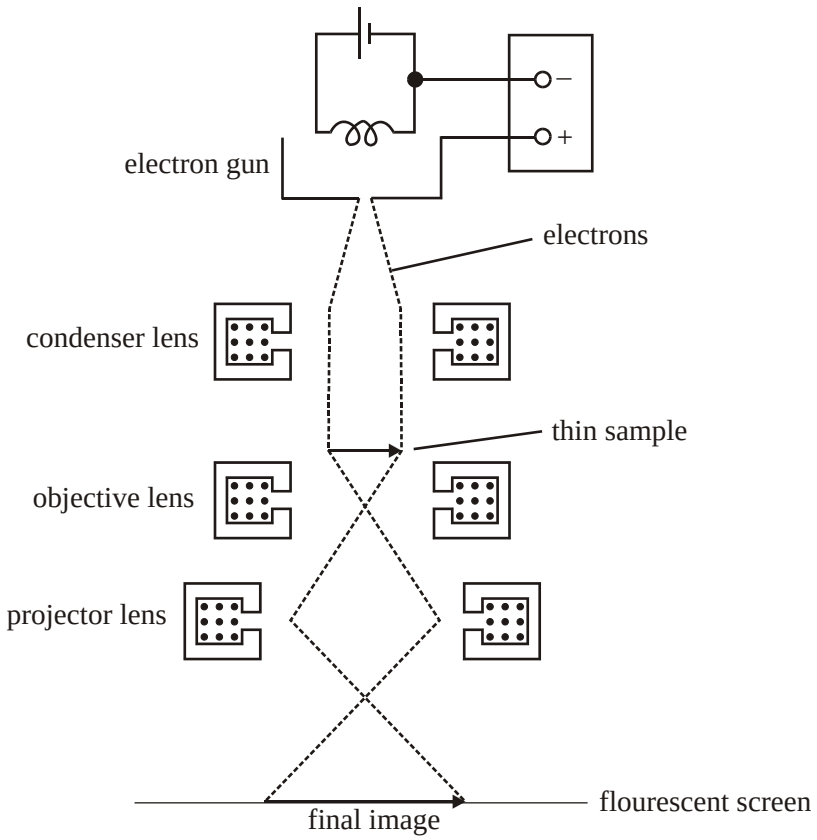
(2)
(Total 6 marks)

15. 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)

16. 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)

17. (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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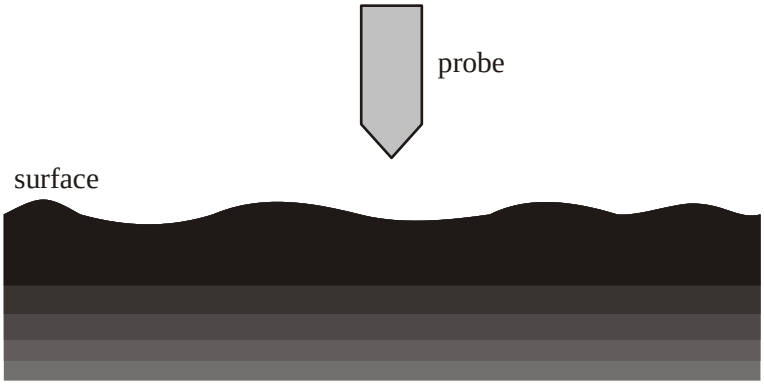
(4)
(Total 7 marks)

18. 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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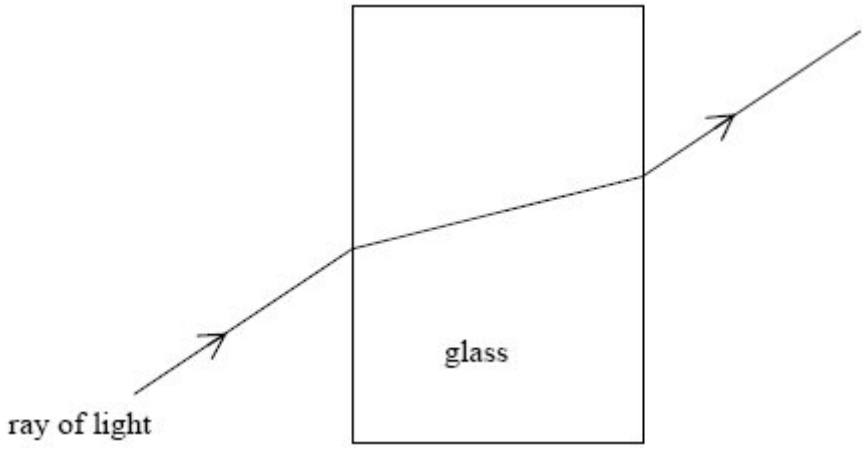
(3)
(Total 6 marks)

19. 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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(4)

(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)

20. (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)