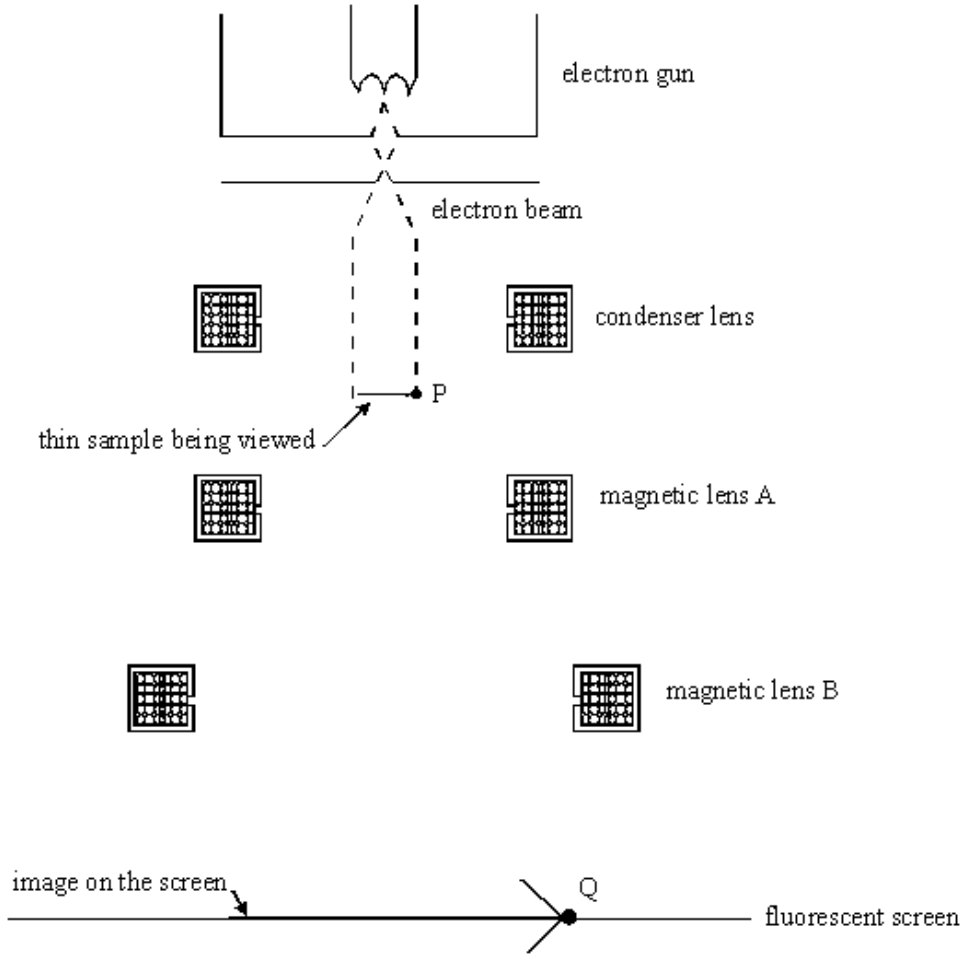
Q1. The diagram below shows a Transmission Electron Microscope. Electrons from the electron gun pass through a thin sample and then through two magnetic lenses A and B on to a fluorescent screen. An enlarged image of the sample is formed on the screen.



(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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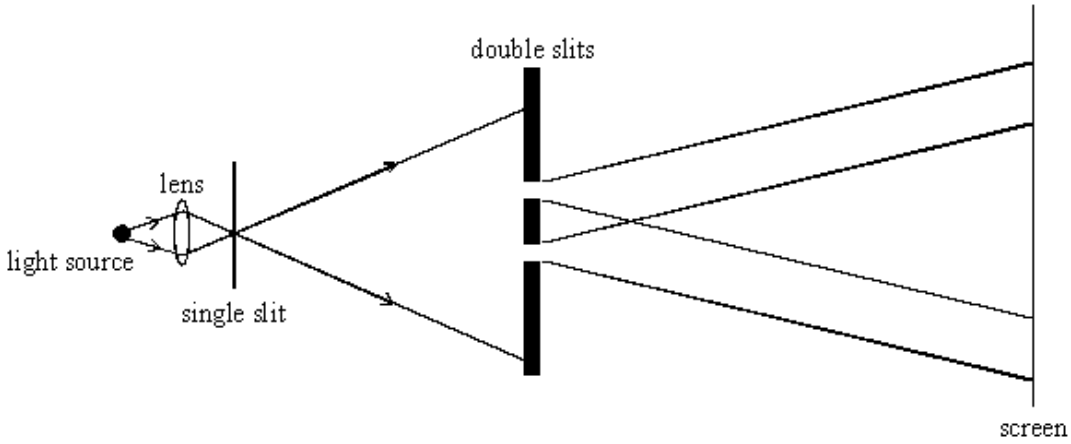
(3)
(Total 7 marks)

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. (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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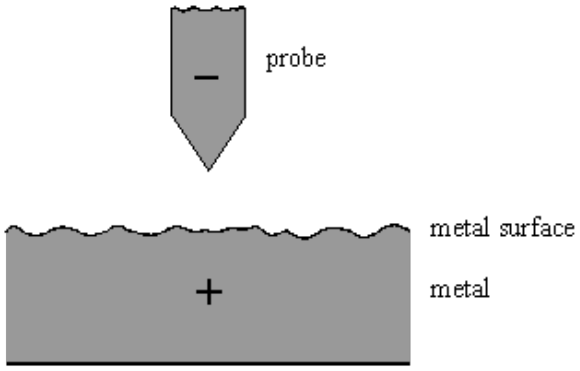
(4)
(Total 7 marks)

Q4. 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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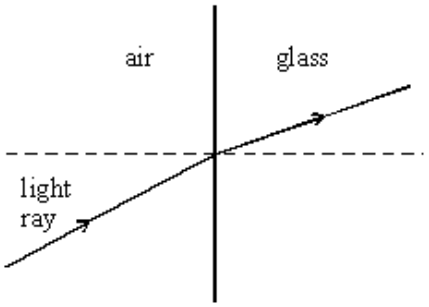
(3)
(Total 7 marks)

Q5. (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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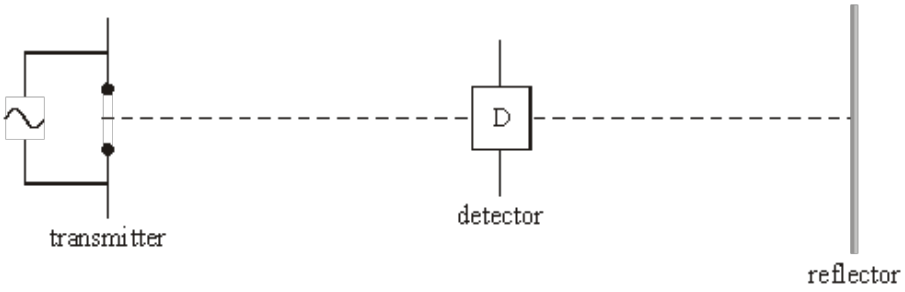
(3)
(Total 6 marks)

Q6. 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)

Q7. 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)

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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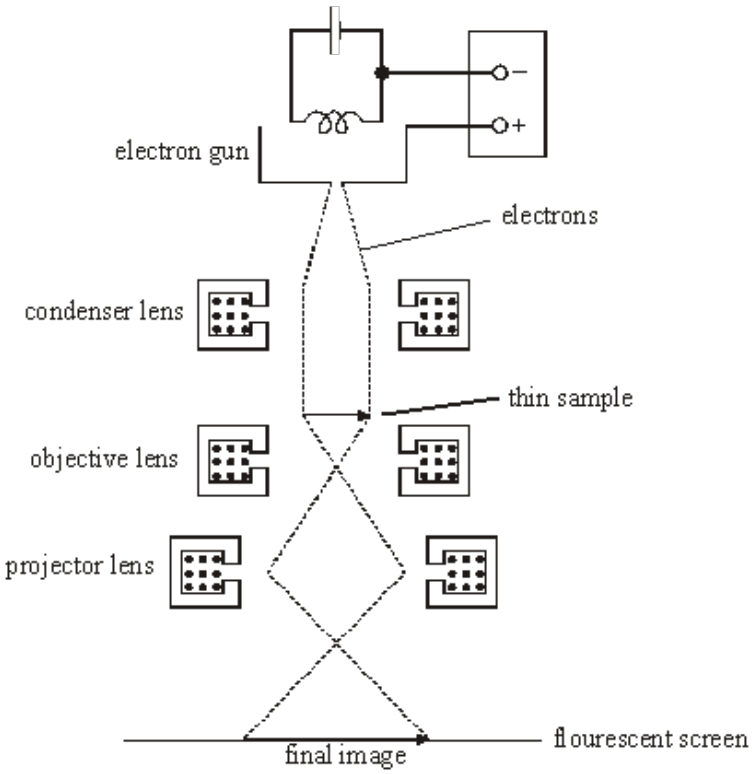
(2)
(Total 6 marks)

Q9. 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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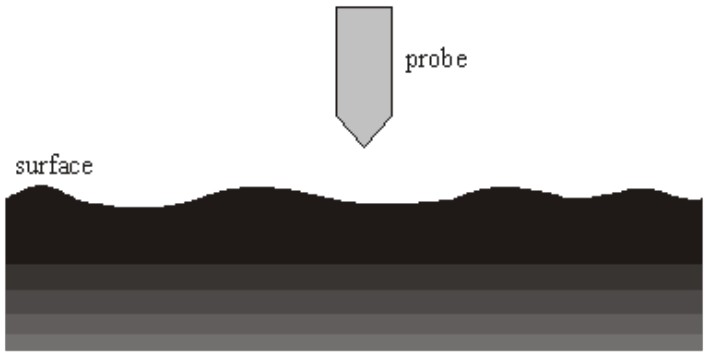
(3)
(Total 5 marks)

Q10. 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)

Q11. (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)

Q12. (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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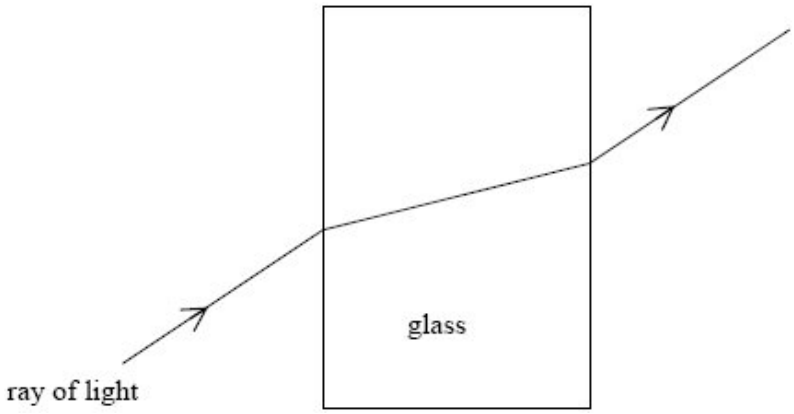
(5)
(Total 11 marks)

Q13. 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)

Q14. When light of wavelength 590 nm is directed at an uncharged surface of a certain metal X, electrons are emitted from the metal surface causing a photoelectric current.

(a) When the metal surface is charged positively, the photoelectric current decreases and becomes zero when the potential of the surface is +0.35 V.

(i) Calculate the maximum kinetic energy of a photoelectron emitted from the surface when the metal surface is uncharged.

answer = ... J

(2)

(ii) Calculate the work function of the metal surface, in J.

answer = ... J

(3)

(b) When the experiment was repeated using a different metal, Y, illuminated by light of the same wavelength, there was no photoelectric emission when the metal surface was uncharged.

(i) Explain this observation.

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(2)

(ii) How did this observation contribute to the failure of the wave theory of light?

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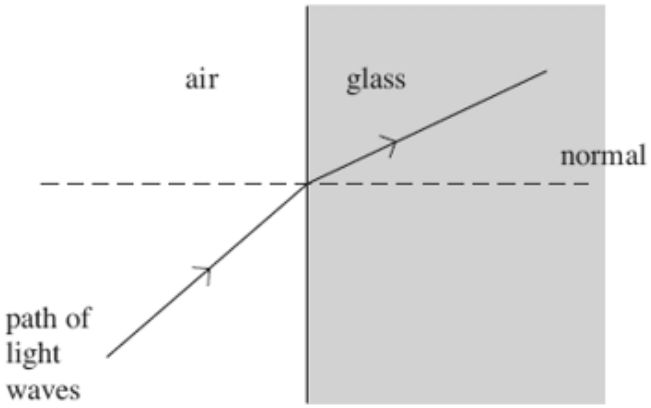
(2)
(Total 9 marks)

Q15. (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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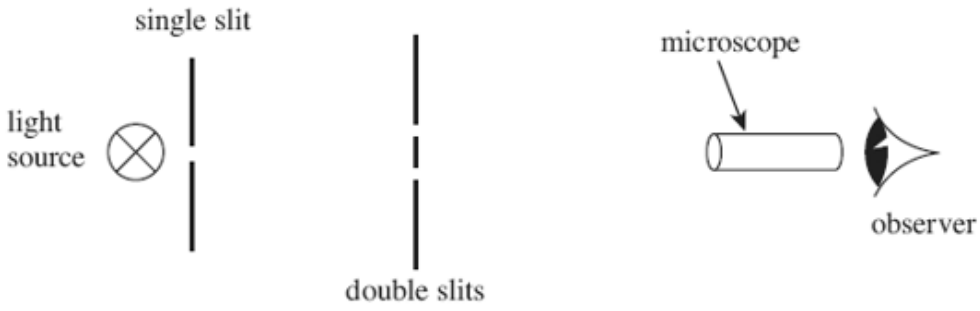
(2)

(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)

Q16. (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)

Q17. (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_0 is the permeability of free space and ε_0 is the permittivity of free space.

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

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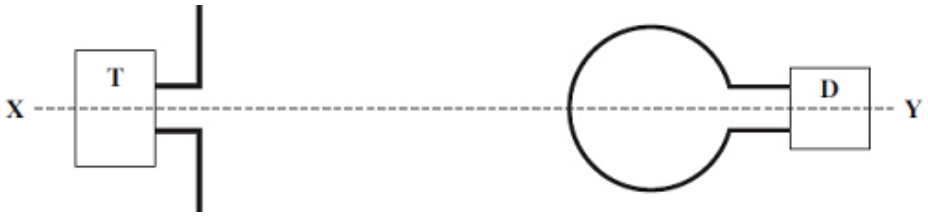
(2)

(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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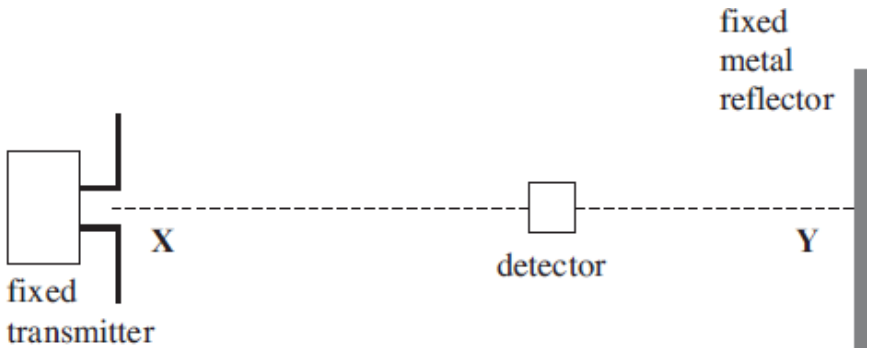
(1)
(Total 9 marks)

Q18. In his investigation of radio waves, Hertz created stationary waves by using a large flat metal sheet to reflect radio waves as shown in the diagram below.



(a) Explain why stationary waves are formed in this arrangement and describe how the wavelength of the radio waves can be determined by moving a suitable detector along **XY**.

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

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(6)

(b) Hertz knew the frequency of the radio waves from the electrical characteristics of the transmitter. He found the wavelength from the investigation described in part (a) and was then able to calculate the speed of the radio waves. Explain the significance of the result of this calculation.

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(2)
(Total 8 marks)

Q19. (a) State de Broglie's hypothesis.

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(2)

(b) Neutrons in a narrow beam can be diffracted by crystals thereby exhibiting wave behaviour. Calculate the de Broglie wavelength of a neutron of kinetic energy 0.021 eV. Give your answer to an appropriate number of significant figures.

de Broglie wavelength ..... m

(4)

(c) Explain why an electron of the same de Broglie wavelength as the neutron in part (b) has much more kinetic energy than 0.021 eV. Assume relativistic effects are negligible.

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(2)
(Total 8 marks)