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 marks)

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

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

(2 marks)

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

answer = ... J

(1 mark)

(b) (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.

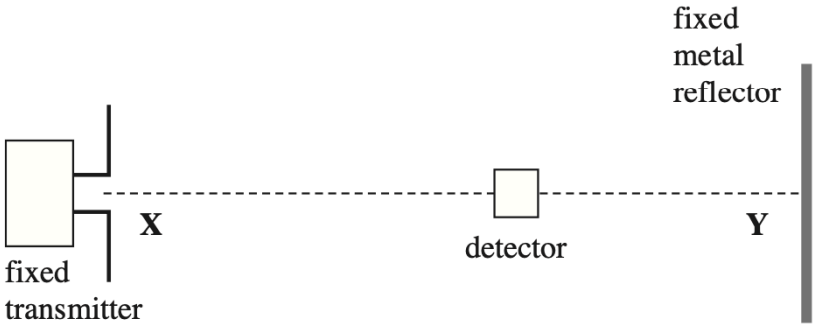
answer = ... J

(2 marks)

2)

In his investigation of radio waves, Hertz created stationary waves by using a large flat metal sheet to reflect radio waves as shown in **Figure 2**.

Figure 2



(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 marks)

(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 marks)

3)

(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.

[3 marks]

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(a) (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.

[2 marks]

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(a) (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.

[2 marks]

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(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 marks]

4)

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

$$c = \frac{1}{\sqrt{\mu_o \varepsilon_o}}$$

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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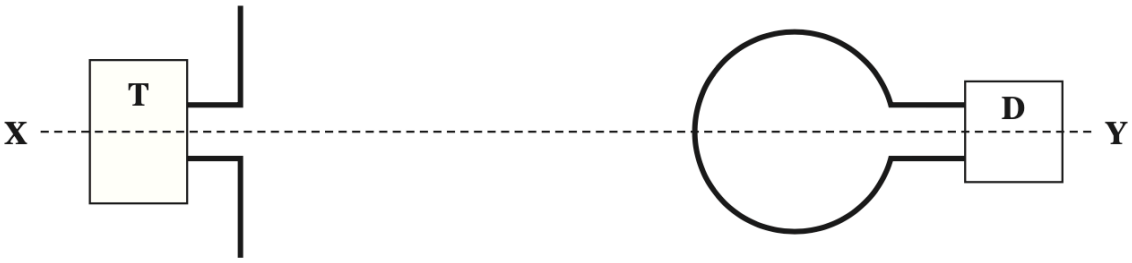
(2 marks)

b Hertz discovered how to produce and detect radio waves. **Figure 2** shows a transmitter of radio waves, **T**, and a detector **D**. The detector loop and the transmitter aerial are in the same vertical plane.

Figure 2



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

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(3 marks)

(c) (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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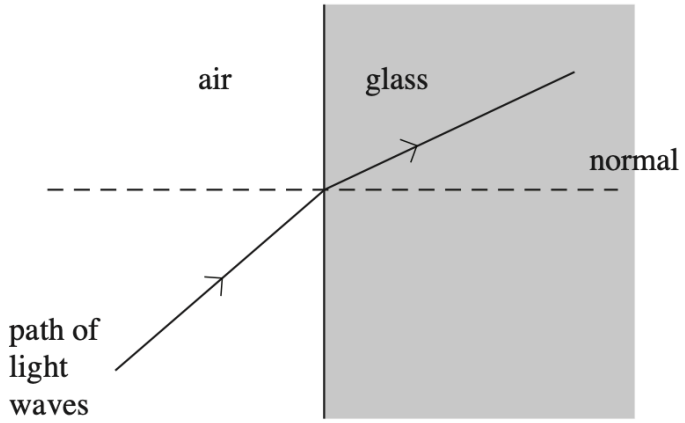
(1 mark)

5)

(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 3**. Huygens explained the refraction of light using his own theory that light consists of waves.

Figure 3



(a) (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 mark)

(a) (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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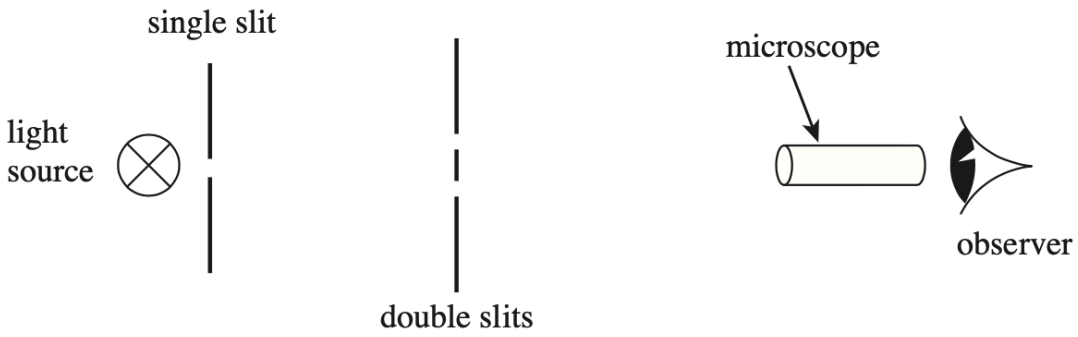
(2 marks)

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 4**.

Figure 4



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 marks)

6)

(a) Maxwell predicted the existence of electromagnetic waves that travelled in free space.

Identify the **two** quantities that vary in an electromagnetic wave and state the phase relationship between them.

[2 marks]

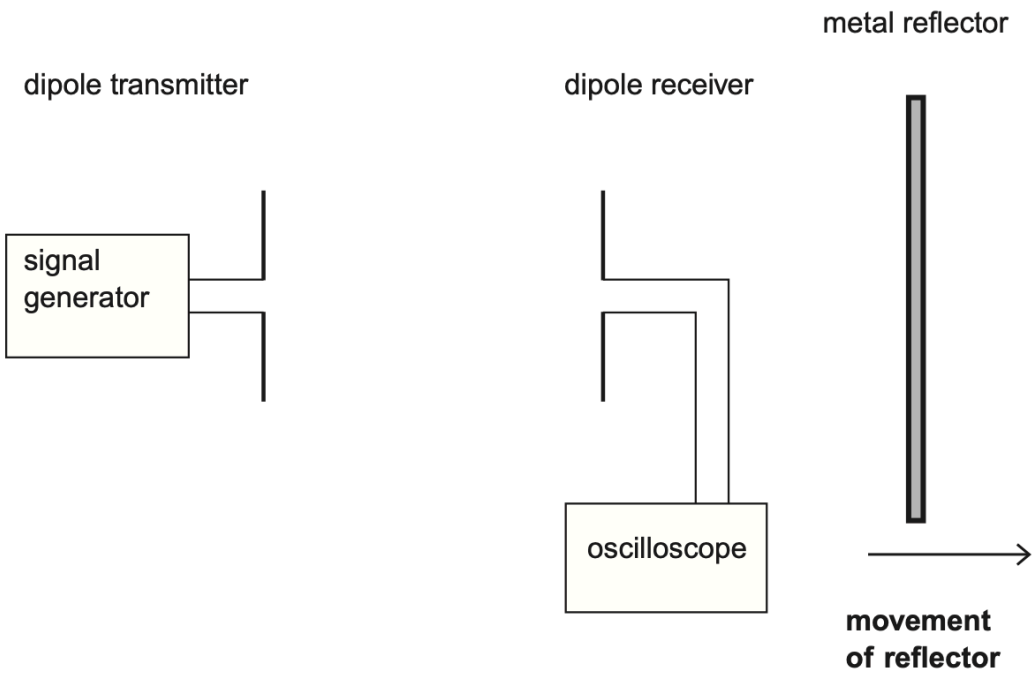
Quantity 1 _____

Quantity 2 _____

Phase relationship _____

(b) Hertz determined the speed of electromagnetic waves and found that they travelled at 3.0×10^8 m s^{-1}. **Figure 3** shows an arrangement using radio waves that is similar to that used by Hertz in his determination.

Figure 3



The dipole transmitter radiates an electromagnetic wave of frequency 2.2 GHz.
A signal is detected by the dipole receiver.
When the metal reflector is moved in the direction shown in **Figure 3**, the detected signal strength alternates between maximum and minimum intensities.

(b) (i) Explain why the detected signal strength changes from a maximum to a minimum as the metal reflector is moved.

[3 marks]

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(b) (ii) Determine the least distance the reflector has to move for the detected signal strength to change from a maximum to a minimum to confirm Hertz's value for the speed of electromagnetic radiation.

[2 marks]

least distance = _____ m

(c) Which **one** of the following observations originally led to the conclusion that light is an electromagnetic wave?

Place a tick (✓) in the right-hand column to show the correct answer.

[1 mark]

	✓ if correct
Light is diffracted when it falls on a narrow slit.	
Light travels at 3×10^8 m s^{-1} in free space.	
Light changes speed when it enters a medium of different optical density.	
Light can be polarised when it passes through Polaroid.	