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PHYSICS
STANDARD LEVEL
PAPER 3

Candidate session number

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Thursday 7 November 2013 (afternoon)

1 hour

Examination code

8	8	1	3	–	6	5	0	6

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the ***Physics*** *Data Booklet* is required for this paper.
- The maximum mark for this examination paper is *[40 marks]*.

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Option A — Sight and wave phenomena

1. This question is about the accommodation of the eye.

(a) State, with reference to the term accommodation, what is meant by the near point and the far point of the eye. *[3]*

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(b) Explain how the eye accommodates objects placed at the

(i) near point. *[2]*

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(ii) far point. *[1]*

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(Option A continues on the following page)

(Option A continued)

2. This question is about the Doppler effect.

(a) Describe what is meant by the Doppler effect as it relates to sound. *[2]*

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(b) An ambulance is travelling at a speed of $28.0\,m\,s^{-1}$ along a straight road. Its siren emits a continuous sound of frequency 520 Hz. The ambulance is approaching a stationary observer. The observer measures the frequency of the note to be 566 Hz. Determine the speed of sound. *[3]*

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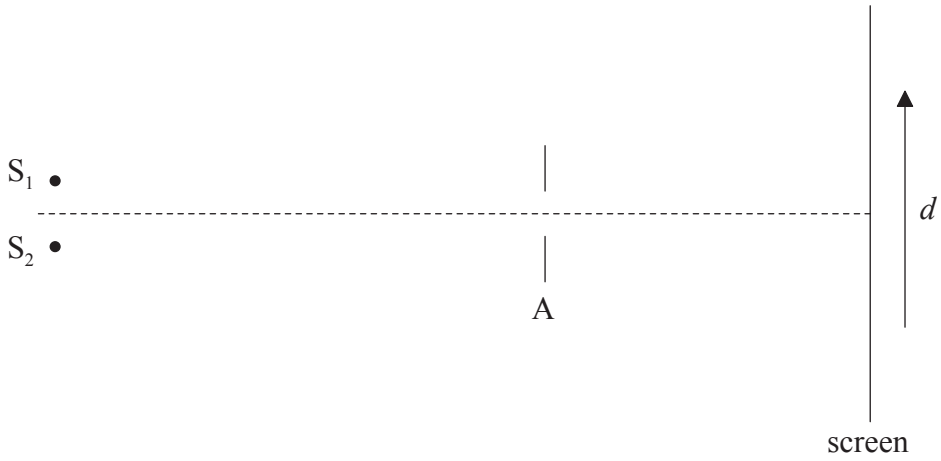
(Option A continues on the following page)

(Option A continued)

3. This question is about resolution.

(a) Two point sources S_1 and S_2 emit monochromatic light of the same wavelength. The light is incident on a small aperture A and is then brought to focus on a screen.



The images of the two sources on the screen are just resolved according to the Rayleigh criterion. Sketch, using the axes below, how the relative intensity *I* of light on the screen varies with distance along the screen *d*. *[3]*

(Option A continues on the following page)

(Option A, question 3 continued)

(b) A car is travelling at night along a straight road. Diane is walking towards the car. She sees the headlights of the car as one single light. Estimate, using the data below, the separation d between Diane and the car at which, according to the Rayleigh criterion, Diane will just be able to see the headlights as two separate sources. *[3]*

Distance between the headlights = 1.4 m
Average wavelength of light emitted by the headlights = 500 nm
Diameter of the pupils of Diane's eyes = 1.9 mm

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(c) The light from the car headlights in (b) is not polarized. State what is meant by polarized light. *[1]*

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(d) Light from the car headlights in (b) is reflected from the surface of a puddle of water. Calculate the angle to the surface at which the light will be completely polarized after reflection at the surface. The refractive index of water is 1.3. *[2]*

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End of Option A

Option B — Quantum physics and nuclear physics

4. This question is about the photoelectric effect.

(a) Monochromatic light of different frequencies is incident on a metal surface placed in a vacuum. As the frequency is increased a value is reached at which electrons are emitted from the surface. Below this frequency, no matter how intense the light, no electrons are emitted. Outline how the

(i) wave theory of light is unable to account for these observations. *[3]*

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(ii) Einstein model of the photoelectric effect is able to account for these observations. *[3]*

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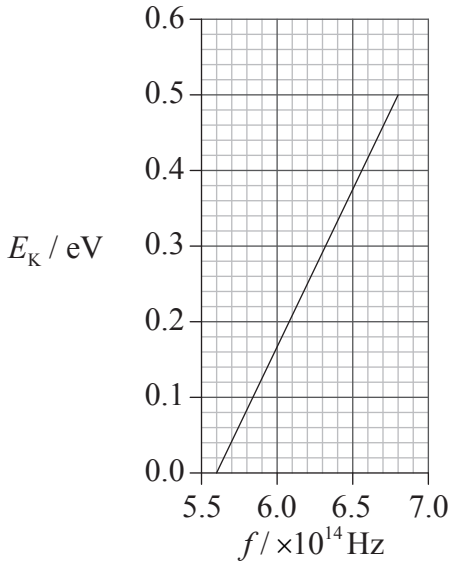
(Option B continues on the following page)

(Option B, question 4 continued)

(b) The graph shows how the maximum kinetic energy E_K of the ejected electrons in (a) varies with the frequency f of the incident light.



Use the graph to determine the

(i) Planck constant. *[3]*

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(ii) work function of the metal. *[2]*

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(Option B continues on the following page)

(Option B, question 4 continued)

(c) Show that electrons of energy 0.50 eV have a de Broglie wavelength of about 1.7×10^{-9} m. *[3]*

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(Option B continues on the following page)

(Option B continued)

5. This question is about radioactive decay.

(a) Potassium-40 (K-40) is a radioactive isotope that occurs naturally in many different types of rock. A very small percentage of the isotope undergoes β^+ decay to form an isotope of argon (Ar). Construct and complete the nuclear reaction equation for this decay. *[2]*

$$^{40}_{19}\mathrm{K} \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}\mathrm{Ar} + {}^{0}_{1}\beta^{+} + \cdots\cdots$$

(b) Overall about 10 % of a sample of K-40 will decay to argon. In a particular rock sample it is found that there are 1.6×10^{22} atoms of K-40 and 8.4×10^{21} atoms of argon. The half-life of K-40 is 1.2×10^{9} yr. Estimate the time elapsed since the rock sample was formed. *[4]*

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End of Option B

Option C — Digital technology

6. This question is about digitized pictures.

(a) Outline how photons incident on a pixel in a charge-coupled device (CCD) produce a voltage signal. *[3]*

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(b) A student wishes to store pictures taken with a digital camera on a memory stick. The camera sensor consists of an arrangement of 5200 pixels by 3500 pixels. Each pixel produces 3 bytes of information. The memory stick can store 1.6×10^{10} bytes of data. Determine the number of pictures that the student can store on the memory stick. *[3]*

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(Option C continues on the following page)

(Option C, question 6 continued)

(c) The student could also store digitized pictures on a compact disk (CD).

(i) Outline, with reference to light interference, how the information is recovered from a CD. *[3]*

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(ii) State **one** reason why the student may prefer to store the pictures on a memory stick **or** CD rather than as printed photographs. *[1]*

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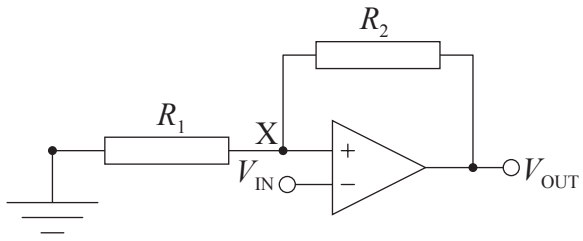
(Option C continues on the following page)

(Option C continued)

7. This question is about the Schmitt trigger.

The diagram shows the circuit of a Schmitt trigger.



The supply voltages to the operational amplifier are +15 V and –15 V. The resistors have the values $R_1 = 47\,\text{k}\Omega$ and $R_2 = 420\,\text{k}\Omega$.

(a) Explain, with reference to the voltages V_{IN} and V_{OUT} and the voltage at X, the operation of this circuit. *[4]*

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(b) Determine the switching voltages for this circuit. *[3]*

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(Option C continues on the following page)

(Option C continued)

8. This question is about mobile phones.

A passenger on a train uses a mobile phone to talk to a friend. During the conversation the phone moves between several cells in the phone network. There is no break in the communication. Outline, with reference to the cellular exchange and the base stations, how this is achieved. *[3]*

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End of Option C

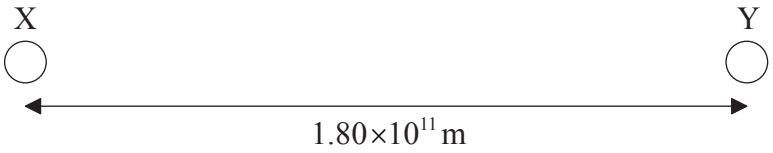
Please **do not** write on this page.

Answers written on this page
will not be marked.

Option D — Relativity and particle physics

9. This question is about time dilation.

(a) Two space stations X and Y are at rest relative to each other. The separation of X and Y as measured in their frame of reference is 1.80×10^{11} m.



State what is meant by a frame of reference. *[1]*

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(Option D continues on the following page)

(Option D, question 9 continued)

(b) A radio signal is sent to both space stations in (a) from a point midway between them. On receipt of the signal a clock in X and a clock in Y are each set to read zero. A spaceship S travels between X and Y at a speed of 0.750c as measured by X and Y. In the frame of reference of S, station X passes S at the instant that X's clock is set to zero. A clock in S is also set to zero at this instant.

(i) Calculate the time interval, as measured by the clock in X, that it takes S to travel from X to Y. *[2]*

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(ii) Calculate the time interval, as measured by the clock in S, that it takes S to travel from X to Y. *[2]*

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(iii) Explain whether the clock in X **or** the clock in S measures the proper time. *[2]*

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(Option D continues on the following page)

(Option D, question 9 continued)

(iv) Explain why, according to S, the setting of the clock in X and the setting of the clock in Y does not occur simultaneously. *[3]*

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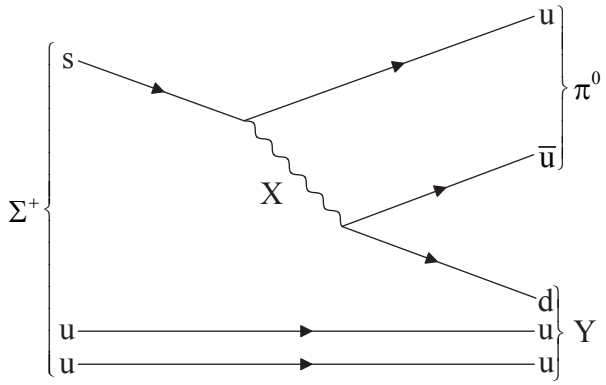
(Option D continues on the following page)

(Option D continued)

10. This question is about particles.

(a) The Σ^+ particle can decay into a π^0 particle and another particle Y as shown in the Feynman diagram.



(i) Identify the exchange particle X. *[1]*

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(ii) Identify particle Y. *[1]*

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(iii) Outline the nature of the π^0. *[2]*

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(Option D continues on the following page)

(Option D, question 10 continued)

(b) The exchange particle X in (a) has a range of 1.2 fm. Determine, in $\text{MeV}\,c^{-2}$, the mass of X. *[2]*

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(c) The π^0 particle can decay with the emission of two gamma rays, each one of which can subsequently produce an electron and a positron.

(i) State the process by which the electron and the positron are produced. *[1]*

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(ii) Sketch the Feynman diagram for the process in (c)(i). *[2]*

(Option D continues on the following page)

(Option D, question 10 continued)

(d) Discuss whether strangeness is conserved in the decay of the Σ^+ particle in (a). *[1]*

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End of Option D

Option E — Astrophysics

11. This question is about stars in the constellation Canis Minor.

(a) An astronomer in the northern hemisphere on Earth sees Canis Minor rise above the eastern horizon and subsequently set in the west. Explain this motion of Canis Minor as observed by the astronomer. *[2]*

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(b) Define *absolute magnitude*. *[2]*

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(Option E continues on the following page)

(Option E, question 11 continued)

(c) Luyten's star and Gomeisa are two stars associated with the constellation Canis Minor. The table gives data for these stars and for the Sun.

	Apparent magnitude	**Absolute magnitude**	**Surface temperature / K**
Luyten's star	+9.9	+11.9	3100
Gomeisa	+2.9	−0.7	11000
Sun	−26.7	+4.8	5800

(i) Explain, with reference to magnitude data from the table, why it is possible to use the stellar parallax technique to determine the distance of Luyten's star from Earth. *[3]*

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(ii) State, in parsecs, the distance range over which it is possible to use the spectroscopic parallax technique to measure galactic distances. *[1]*

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(Option E continues on the following page)

(Option E, question 11 continued)

(d) (i) Using the data in (c), calculate, in parsecs, the distance from Earth to Gomeisa. *[3]*

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(ii) Gomeisa has a radius four times that of the Sun. Use the data in (c) to show that the ratio

$$\frac{\text{luminosity of Gomeisa}}{\text{luminosity of Sun}}$$

is about 200. *[3]*

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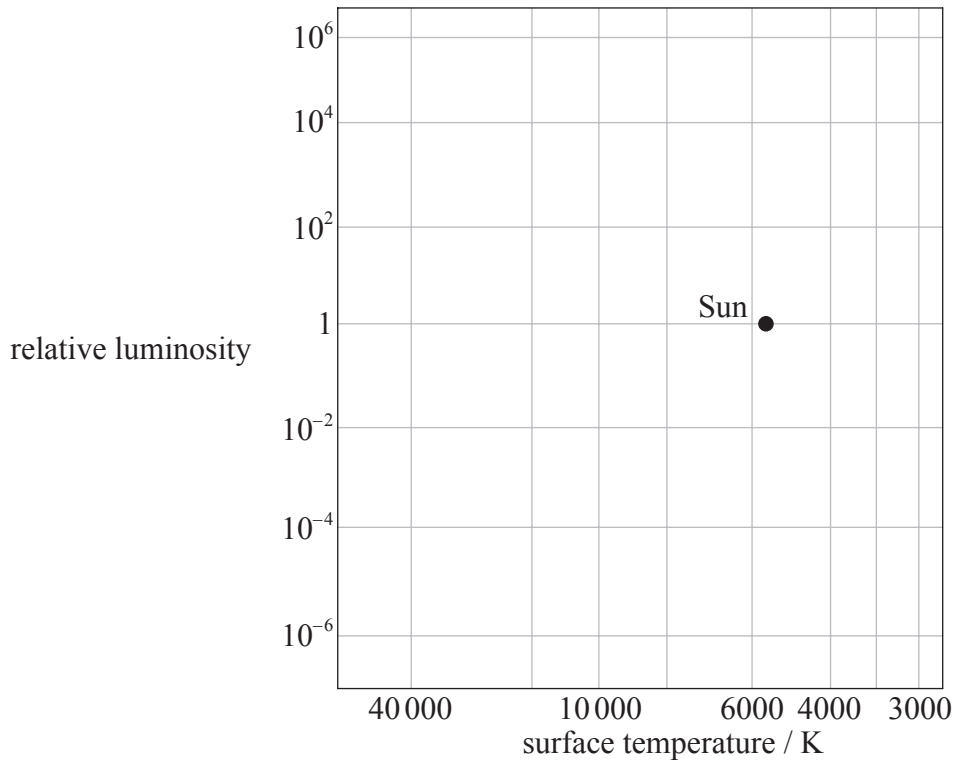
(Option E continues on the following page)

(Option E, question 11 continued)

(e) Gomeisa, Luyten's star and the Sun are main sequence stars. On the grid of the Hertzsprung–Russell (HR) diagram, identify the position of

(i) Gomeisa, with the letter G. *[1]*

(ii) Luyten's star, with the letter L. *[1]*



(Option E continues on the following page)

(Option E continued)

12. This question is about Newton's model of the universe.

Newton assumed a model of the universe that is static and infinite.

(a) State the other assumption about the universe that Newton made. *[1]*

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(b) Explain, with reference to red-shift, why the universe is not believed to be static. *[3]*

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End of Option E

Option F — Communications

13. This question is about frequency modulation.

(a) State what is meant by modulation. *[2]*

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(b) A sinusoidal carrier wave is frequency modulated by a signal wave in a radio transmitter. The table gives data about the two waves.

	Frequency of wave / Hz	**Wave amplitude / V**
Carrier wave	9.4×10^{7}	9.0
Signal wave	6.0×10^{3}	1.5

The frequency of the carrier wave is changed by 12 kHz when the amplitude of the signal wave changes by 1.0 V.

(Option F continues on the following page)

(Option F, question 13 continued)

For the modulated carrier wave,

(i) state how the amplitude varies with time. *[1]*

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(ii) determine how the frequency varies with time. *[3]*

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(c) Calculate the bandwidth of the transmitted signal in (b). *[1]*

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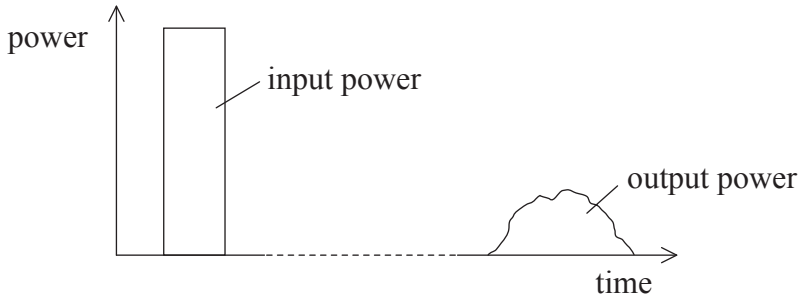
(Option F continues on the following page)

(Option F continued)

14. This question is about the transmission of signals.

(a) A single digital pulse is transmitted along an optic fibre. The graph shows the variation with time of the input power to the optic fibre and also the corresponding power output when the pulse has reached the end of the fibre.



(i) Suggest, with reference to effects occurring in the fibre, why the output pulse has a longer duration than the input pulse. *[3]*

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(ii) State why the increase in duration in the output pulse sets a limit on the rate at which the optic fibre can transmit pulses. *[1]*

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(Option F continues on the following page)

(Option F, question 14 continued)

(iii) Outline why the graph indicates that the pulse is attenuated as it travels through the fibre. *[2]*

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(b) Optic fibre communication channels often utilize time-division multiplexing. Outline why time-division multiplexing can be used to make the channel more cost-effective. *[3]*

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(Option F continues on the following page)

(Option F, question 14 continued)

(c) Optic fibres and satellites are used as channels of communication between continents.

(i) State **one** additional channel of communication that can be used for this purpose. *[1]*

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(ii) State **one** advantage of the channel you chose in (c)(i) over a channel involving satellite communication. *[1]*

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(iii) Suggest **two** advantages of communication using a polar-orbiting satellite compared to that using a geostationary satellite. *[2]*

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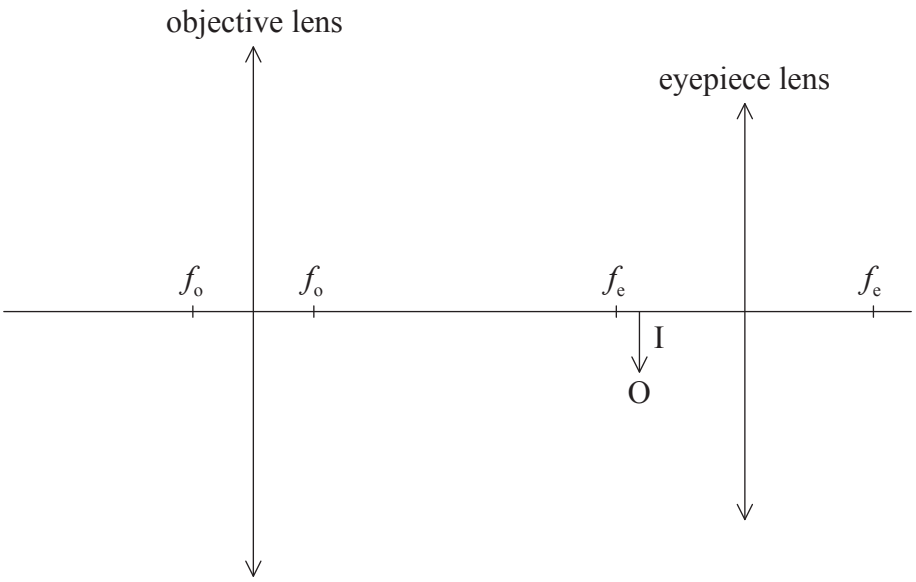
End of Option F

Option G — Electromagnetic waves

15. This question is about an optical microscope.

A compound microscope in normal adjustment consists of two lenses, an objective lens of focal length f_o and an eyepiece lens of focal length f_e. The diagram shows the position of the intermediate image I formed by the objective lens of the microscope.



(a) Construct rays on the diagram to show how the final image is formed. *[2]*

(Option G continues on the following page)

(Option G, question 15 continued)

(b) The intermediate image forms 14.8 cm from the objective lens. The distance between the lenses is 18.1 cm. The focal length of the eyepiece lens is 3.8 cm.

(i) Determine the distance of the final image from the eyepiece lens. *[3]*

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(ii) The angular magnification of the objective lens is ×6. Calculate the angular magnification of the microscope. *[2]*

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(c) Outline how the effects of chromatic aberration in the microscope eyepiece can be reduced by illuminating the object with light that has a narrow range of wavelengths. *[2]*

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(Option G continues on the following page)

(Option G continued)

16. This question is about waves.

(a) State the principle of superposition. *[2]*

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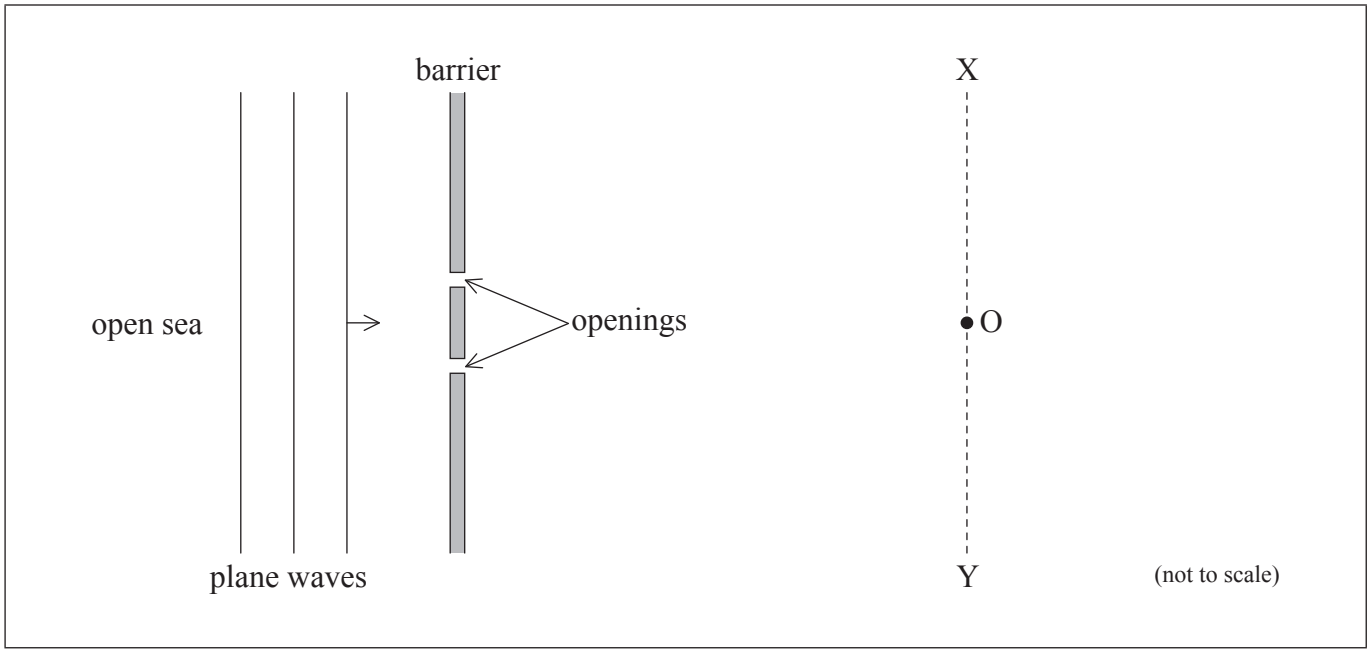
(Option G continues on the following page)

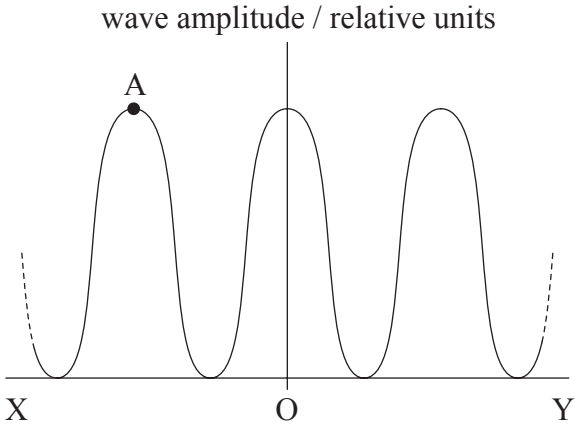
(Option G, question 16 continued)

(b) The diagram shows a plan view of a harbour with a floating barrier that has two openings of equal width.



Plane water waves from the open sea are incident on the barrier and the openings act as point sources of waves. The distance from the openings to XOY is much greater than the wavelength of the wave. O is equidistant from the openings.

The graph shows the variation of the magnitude of the wave amplitude that is observed along the line XOY.



(Option G continues on the following page)

(Option G, question 16 continued)

(i) State why the two sets of waves emerging from the openings are coherent. *[1]*

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(ii) Explain how the disturbance at point A arises. You may draw on the diagram **of the harbour** to illustrate your answer. *[3]*

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(iii) The wavelength of the waves is doubled. State and explain the effect that this change will have on the graph. *[3]*

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(Option G continues on the following page)

(Option G, question 16 continued)

(c) The harbour in (b) is modified to have many narrower openings. The total width of the openings remains the same. Outline **two** ways in which the variation of wave amplitude along XY changes from that shown on the graph in (b). *[2]*

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End of Option G