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PHYSICS
STANDARD LEVEL
PAPER 3

Candidate session number

Thursday 8 May 2014 (afternoon)

1 hour

Examination code

2 2 1 4 – 6 5 1 2

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]*.

Option	Questions
Option A — Sight and wave phenomena	1 – 3
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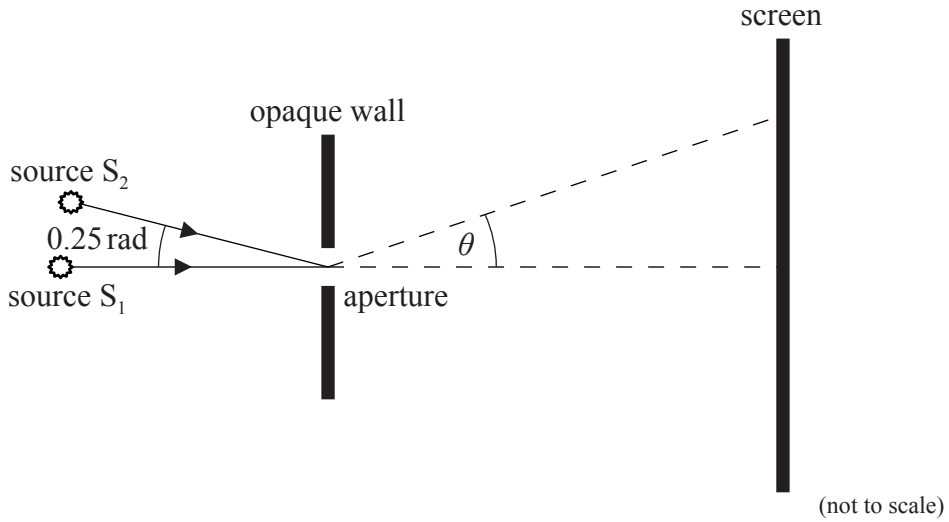
Option A — Sight and wave phenomena

1. This question is about diffraction and resolution.

Two identical sources of electromagnetic radiation, S_1 and S_2, emit monochromatic coherent waves of wavelength 59 μm. The waves pass through a circular aperture and are incident on a screen.



S_1 and S_2 are at the same distance from the aperture. The diameter of the aperture is 0.18 mm. The angle between the lines joining the sources to the aperture is 0.25 rad.

(a) S_1 is turned on and S_2 is turned off.

(i) Show that the angle at which the first minimum of the diffraction pattern occurs is 0.40 rad. *[1]*

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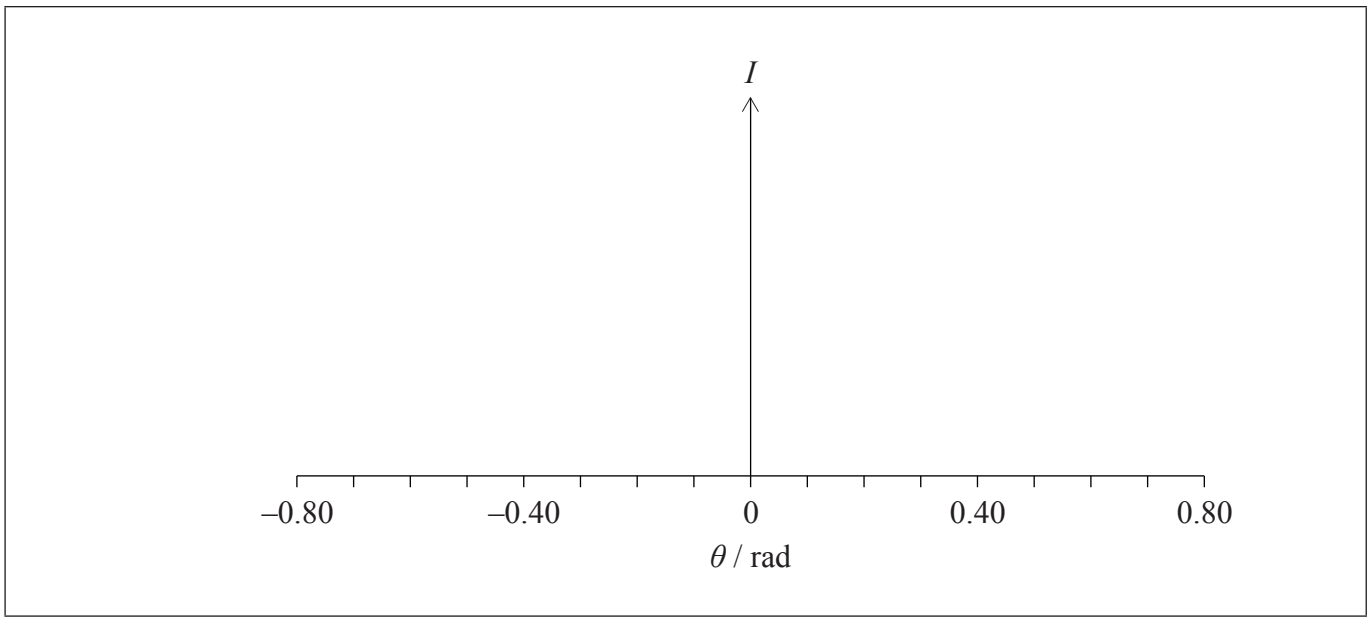
(Option A continues on the following page)

(Option A, question 1 continued)

(ii) On the axes below, sketch a graph to show how the intensity I of the radiation from S_1 varies with the diffraction angle θ. *[3]*



(b) S_1 is turned off and S_2 is turned on. On the same set of axes in (a)(ii), sketch the intensity of the light emitted by source S_2 reaching the screen. *[1]*

(c) S_1 and S_2 are both turned on.

(i) State the Rayleigh criterion for the images of two sources to be just resolved. *[1]*

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(ii) State and explain whether the images of the two sources, S_1 and S_2, are resolved. *[2]*

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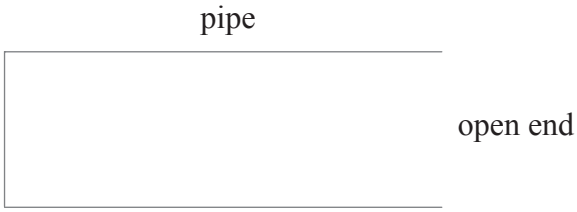
(Option A continues on the following page)

(Option A continued)

2. This question is about standing waves and the Doppler effect.

The horn of a train can be modeled as a pipe with one open end and one closed end. The speed of sound in air is $330\,m\,s^{-1}$.



(a) On leaving the station, the train blows its horn. Both the first harmonic (fundamental) and the next highest harmonic are produced by the horn. The difference in frequency between the harmonics emitted by the horn is measured as 820 Hz.

(i) Deduce that the length of the horn is about 0.20 m. *[3]*

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(ii) Show that the frequency of the first harmonic is about 410 Hz. *[2]*

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(Option A continues on the following page)

(Option A, question 2 continued)

(b) (i) Describe what is meant by the Doppler effect. *[2]*

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(ii) The train approaches a stationary observer at a constant velocity of $50\,m\,s^{-1}$ and sounds its horn at the same frequency as in (a)(ii). Calculate the frequency of the sound as measured by the observer. *[2]*

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(Option A continues on the following page)

(Option A continued)

3. This question is about the eye and sight.

Distinguish between photopic and scotopic vision. *[3]*

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End of Option A

Option B — Quantum physics and nuclear physics

4. This question is about quantum physics.

(a) Describe the de Broglie hypothesis. *[2]*

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(b) An electron is accelerated from rest through a potential difference of 5.0 kV.

(i) Calculate the momentum of the electron after acceleration. *[2]*

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(ii) Calculate the wavelength of the electron. *[2]*

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(Option B continues on the following page)

(Option B, question 4 continued)

(iii) Determine the energy of a photon that has the same wavelength as the electron in (b)(ii). *[2]*

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(c) The momentum of the electron is known precisely. Deduce that all the information on its position is lost. *[2]*

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(d) With reference to Schrödinger's model, state the meaning of the amplitude of the wavefunction for the electron. *[1]*

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(Option B continues on the following page)

(Option B continued)

5. This question is about nuclear physics and radioactive decay.

(a) Define *decay constant*. *[1]*

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(b) A sample of 1.6 mol of the radioactive nuclide radon-210 $\left({}^{210}_{86}\mathrm{Rn}\right)$ decays into polonium-206 $\left({}^{206}_{84}\mathrm{Po}\right)$ with the production of one other particle.

$$^{210}_{86}\mathrm{Rn} \rightarrow {}^{206}_{84}\mathrm{Po} + \mathrm{X}$$

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

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(ii) The radioactive decay constant of radon-210 is $8.0 \times 10^{-5}\,\mathrm{s}^{-1}$. Determine the time required to produce 1.1 mol of polonium-206. *[4]*

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(Option B continues on the following page)

(Option B, question 5 continued)

(c) Particle X has an initial kinetic energy of 6.2 MeV after the decay in (b). In a scattering experiment, particle X is aimed head-on at a stationary gold-197 $\left({}^{197}_{79}\text{Au}\right)$ nucleus.

Determine the distance of closest approach of particle X to the Au nucleus. *[3]*

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End of Option B

Option C — Digital technology

6. This question is about digital imaging and storage.

(a) Outline how an image stored in a charge-coupled device (CCD) is retrieved. *[2]*

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(b) (i) A black-and-white camera is equipped with a 12 mm × 18 mm CCD. The length of the side of each square pixel is 8.4×10^{-6} m. Show that the number of pixels on the CCD is about 3.1×10^{6}. *[2]*

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(ii) A clip of duration 12.0 s is taken with the camera. The camera takes 25 frames a second and each pixel produces 16 bits of data. The typical storage capacity of a compact disc (CD) is about 680 Mb. Calculate the number of CDs required to store the clip (1 byte = 8 bits). *[2]*

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(Option C continues on the following page)

(Option C, question 6 continued)

(c) Explain how the interference of light is used to recover information stored on optical discs. *[3]*

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(d) A new technology for digital data storage on optical discs makes use of laser light of wavelength 405 nm. Calculate an appropriate depth for the pits used with this new technology. The refractive index of the disc material is 1.61. *[2]*

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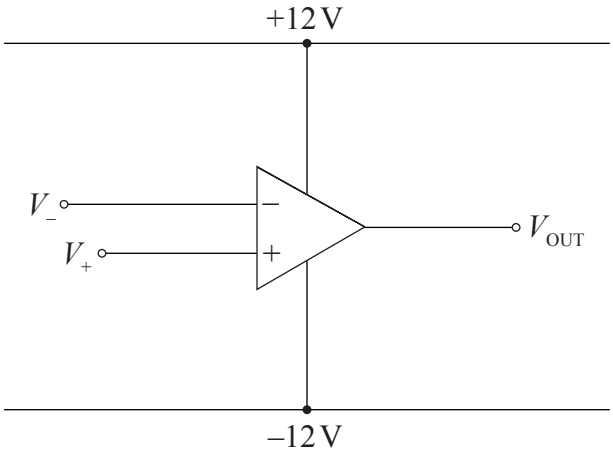
(Option C continues on the following page)

(Option C continued)

7. This question is about the operational amplifier (op-amp).

A non-ideal op-amp has a supply voltage of ±12 V and an open-loop gain of 10^6. In the diagram, the non-inverting and inverting inputs are V_+ and V_- respectively, and V_{OUT} is the output voltage.



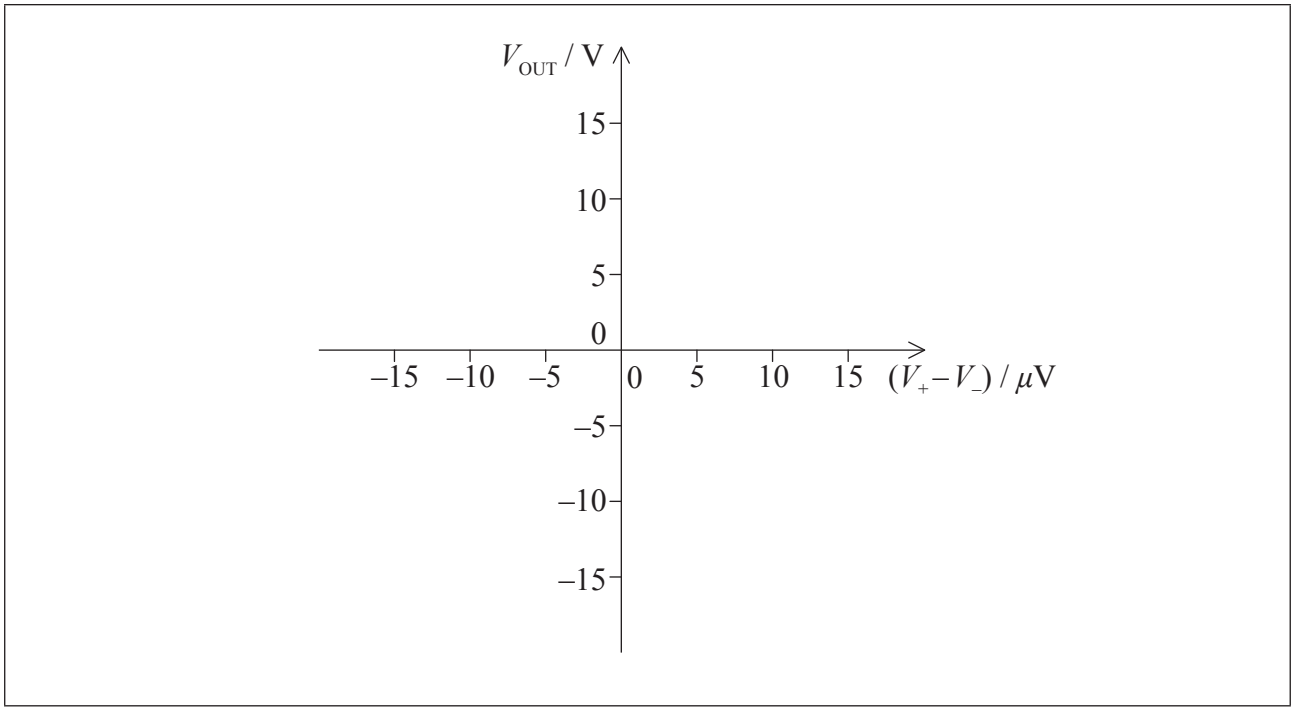
(a) In the table below, calculate the missing entries for the circuit in (a). The first row has been completed for you. *[2]*

$V_+ - V_-$	V_{OUT}
0 μV	0 V
8 μV	
−15 μV	

(Option C continues on the following page)

(Option C, question 7 continued)

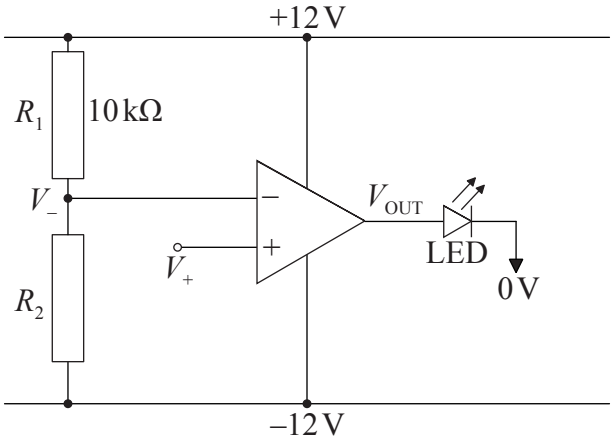
(b) On the axes below, sketch the variation of the output voltage V_{OUT} with the input voltage $(V_+ - V_-)$. *[3]*



(Option C continues on the following page)

(Option C, question 7 continued)

(c) Two resistors, R_1 and R_2, and a light emitting diode (LED) are added to the circuit in (a) as shown below.



(i) State the name of this configuration for the op-amp. *[1]*

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(ii) The circuit in (c) is designed so that the LED turns on when V_+ is greater than 6 V. The resistance $R_1 = 10\,\text{k}\Omega$. Determine the value of resistance R_2, assuming that the op-amp is ideal. *[3]*

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End of Option C

Option D — Relativity and particle physics

8. This question is about relativistic kinematics.

(a) State what is meant by an inertial frame of reference. *[2]*

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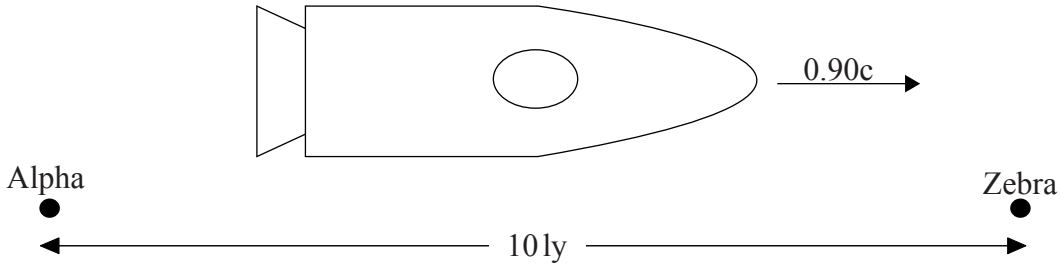
(b) A spaceship travels from space station Alpha to space station Zebra at a constant speed of 0.90c relative to the space stations. The distance from Alpha to Zebra is 10 ly according to space station observers. At this speed $\gamma = 2.3$.



Calculate the time taken to travel between Alpha and Zebra in the frame of reference of an observer

(i) on the Alpha space station. *[1]*

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(ii) on the spaceship. *[2]*

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(Option D continues on the following page)

(Option D, question 8 continued)

(c) Explain which of the time measurements in (b)(i) and (b)(ii) is a proper time interval. *[2]*

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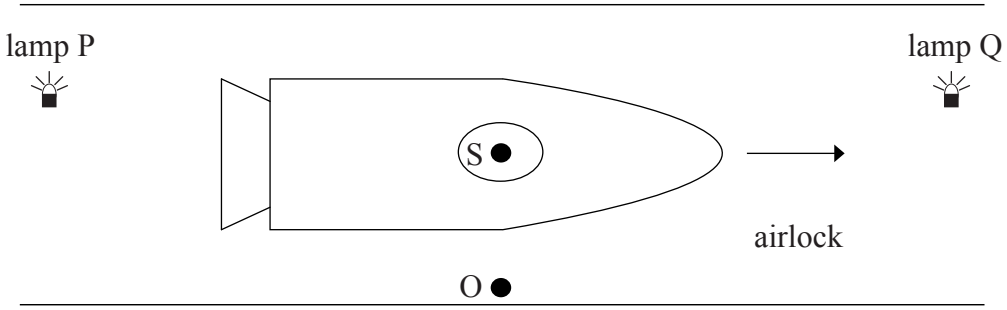
(d) The spaceship arrives at Zebra and enters an airlock at constant speed. O is an observer at rest relative to the airlock. Two lamps P and Q emit a flash simultaneously according to the observer S in the spaceship. At that instant, O and S are opposite each other and midway between the lamps.



Discuss whether the lamps flash simultaneously according to observer O. *[3]*

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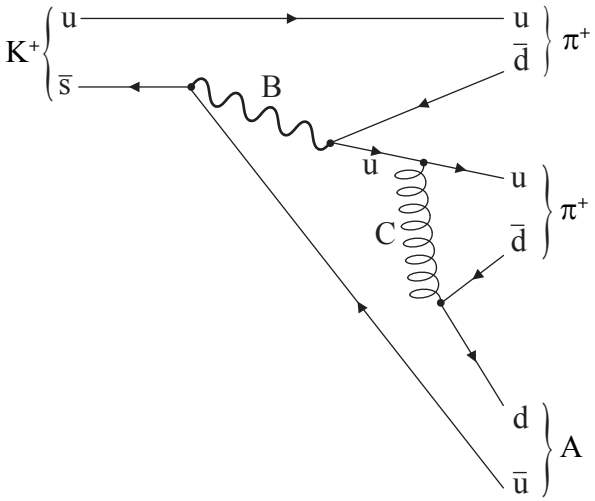
(Option D continues on the following page)

(Option D continued)

9. This question is about fundamental interactions.

The Feynman diagram shows the decay of a K^+ meson into three other particles.



(a) Identify particle A. *[1]*

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(b) (i) Identify the interaction whose exchange particle is represented by B. *[1]*

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(ii) Identify the exchange particle labelled C. *[1]*

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(Option D continues on the following page)

(Option D, question 9 continued)

(c) Outline how the concept of strangeness applies to the decay of a K^+ meson shown in this Feynman diagram. *[2]*

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(Option D continues on the following page)

(Option D continued)

10. This question is about mesons.

The π^0 meson has a mass of about 135 MeV c^{-2}.

(a) The π^0 meson is considered to be the exchange particle of the strong interaction.

(i) State what is meant by an exchange particle. *[1]*

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(ii) Show that the range of the strong interaction is approximately equal to the diameter of a proton. *[2]*

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(b) Energy is supplied to a meson in order to separate the quark from the antiquark. With reference to quark confinement, predict the likely outcome of this experiment. *[2]*

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End of Option D

Option E — Astrophysics

11. This question is about comets.

Outline the nature of a comet. *[2]*

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12. This question is about the life history of stars.

Outline, with reference to pressure, how a star on the main sequence maintains its stability. *[3]*

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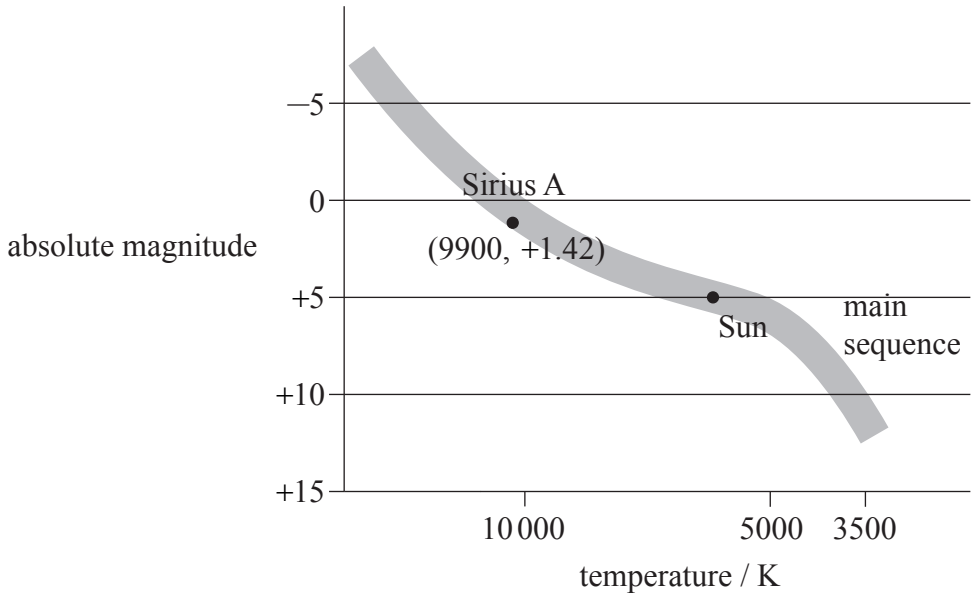
(Option E continues on the following page)

(Option E continued)

13. This question is about stellar distances.

The Hertzsprung–Russell (HR) diagram below shows the position of Sirius A on the main sequence.



(a) The apparent magnitude of Sirius A is –1.47. Use the HR diagram to show that Sirius A is about 2.6 pc from Earth. *[3]*

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(Option E continues on the following page)

(Option E, question 13 continued)

(b) The apparent brightness of Sirius A is $1.2 \times 10^{-7}\,\text{W m}^{-2}$. Use the result in (a) to determine the luminosity of Sirius A. *[2]*

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(c) Use the HR diagram to state and explain whether the mass of Sirius is greater than, equal to or less than the mass of the Sun. *[2]*

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(Option E continues on the following page)

(Option E, question 13 continued)

(d) State and outline another technique that will allow astronomers to confirm the distance estimate in (a). *[4]*

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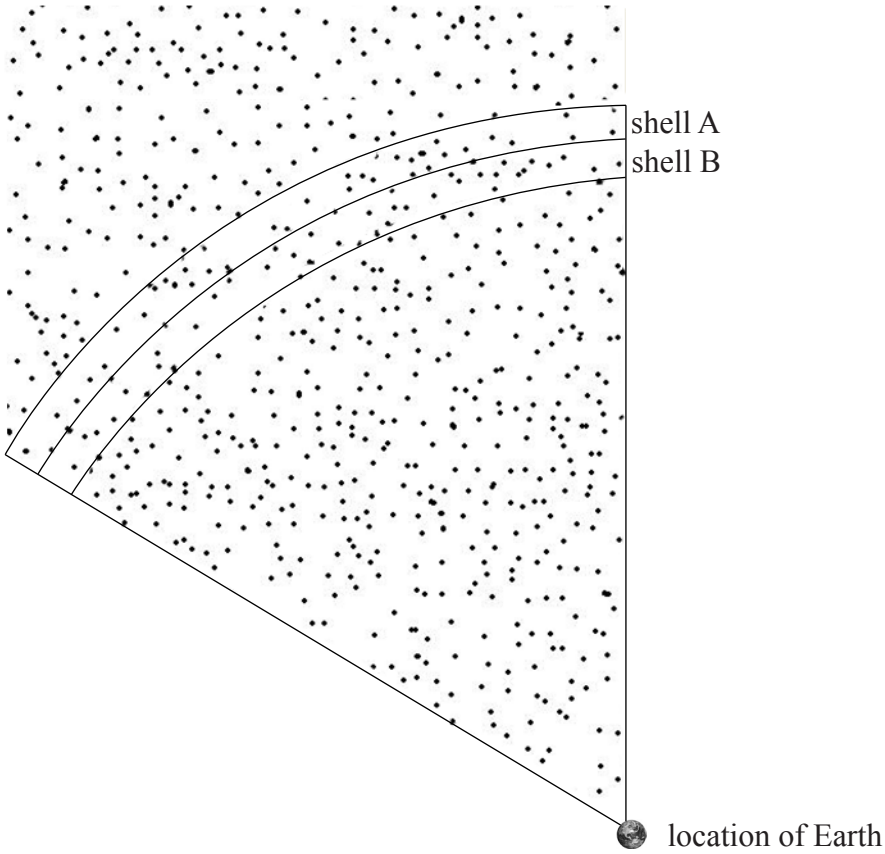
(Option E continues on the following page)

(Option E continued)

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

The diagram below shows a part of a series of thin spherical shells of equal thickness with the Earth at their centre.



Explain quantitatively, with reference to the assumptions Newton made in his model of the universe, how Olbers' paradox arises. *[4]*

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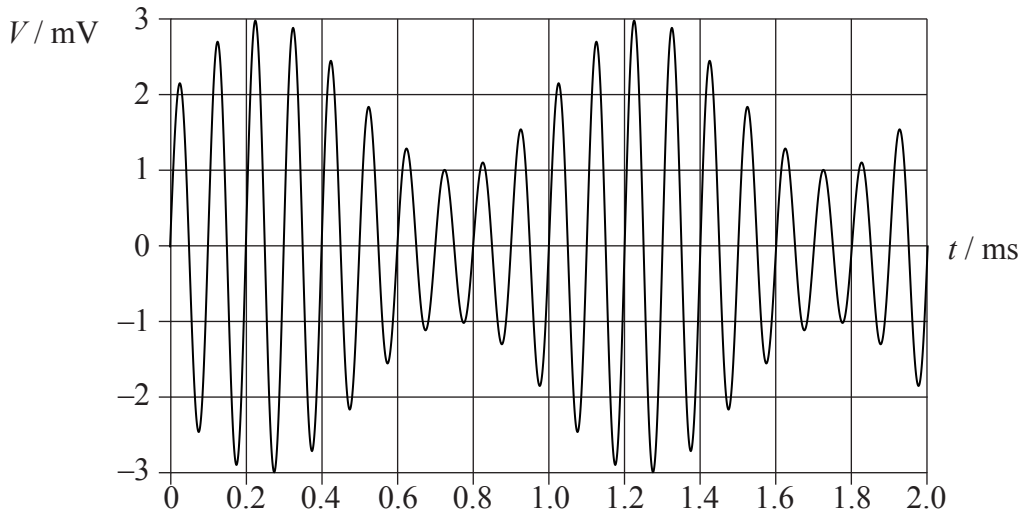
End of Option E

Option F — Communications

15. This question is about radio communication.

A signal wave is used to modulate a carrier wave. The amplitude of the carrier wave is 2 mV. The graph below shows how the amplitude V of the modulated wave varies with time t.



(a) State what type of modulation has been applied to the carrier wave. *[1]*

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(Option F continues on the following page)

(Option F, question 15 continued)

(b) Using the graph opposite, estimate

(i) the frequency of the carrier wave. *[1]*

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(ii) the amplitude of the signal wave. *[1]*

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(iii) the frequency of the signal wave. *[1]*

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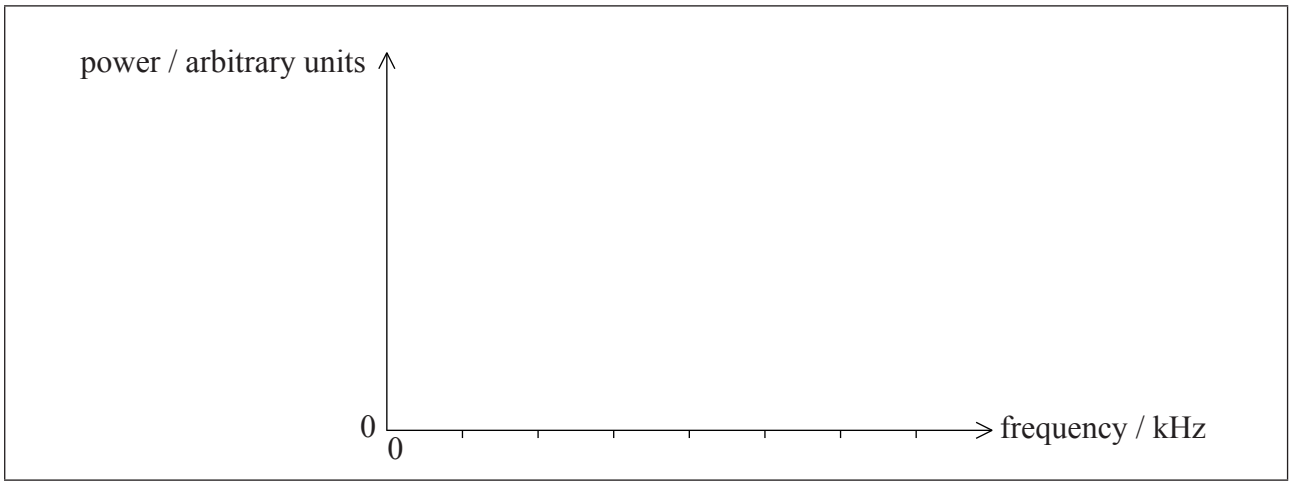
(c) On the axes below, sketch the power spectrum of the modulated wave. *[3]*

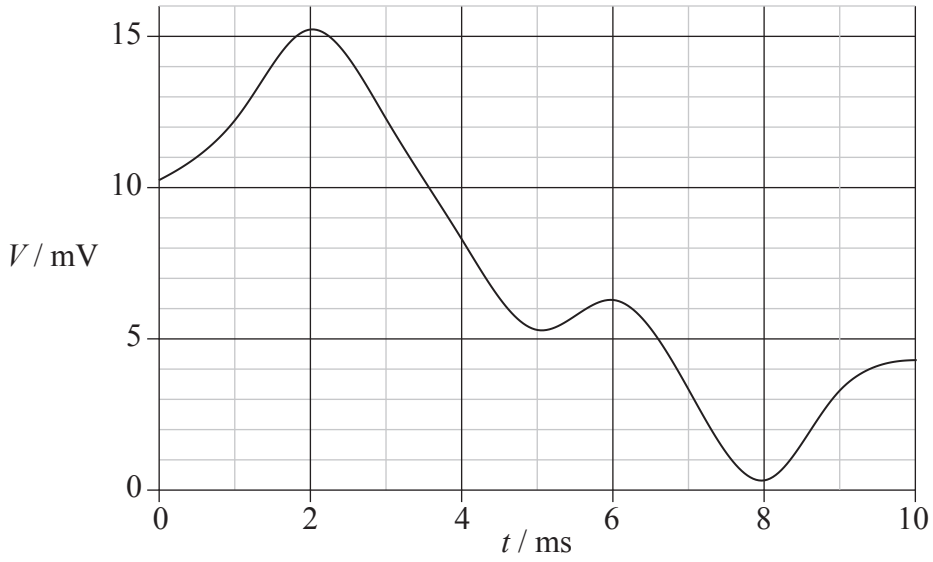


(Option F continues on the following page)

(Option F continued)

16. This question is about the transmission of digital signals.

A piece of music sung by a famous soprano is to be digitally recorded. Part of the variation of the output V of the microphone with time t is shown below.



A sound engineer samples the signal using an analogue-to-digital converter (ADC) that has 16 output levels.

(a) State the number of bits required for each sample. *[1]*

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(Option F continues on the following page)

(Option F, question 16 continued)

(b) The system rounds down each analogue sample to the nearest mV before each digital conversion (for example 0.8 mV becomes 0 mV and 15.1 mV becomes 15 mV).

The level of the signal at $t = 2$ ms is converted to the maximum digital output and the level of the signal at $t = 8$ ms is converted to a zero digital output.

The signal is sampled at a rate of 1000 Hz starting at $t = 0$. Calculate the binary output for the first two samples. *[2]*

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(c) With reference to sampling, suggest **two** reasons why the quality of the recording is poor. *[2]*

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(d) The full song is digitally recorded on a computer, where it occupies about 120 kilobytes of memory (1 byte = 8 bits). The soprano then sends the song to a friend by email. It takes 1.3 s for the file to reach the friend's computer. Calculate, in kbit s^{-1}, the bit-rate of this transmission. *[2]*

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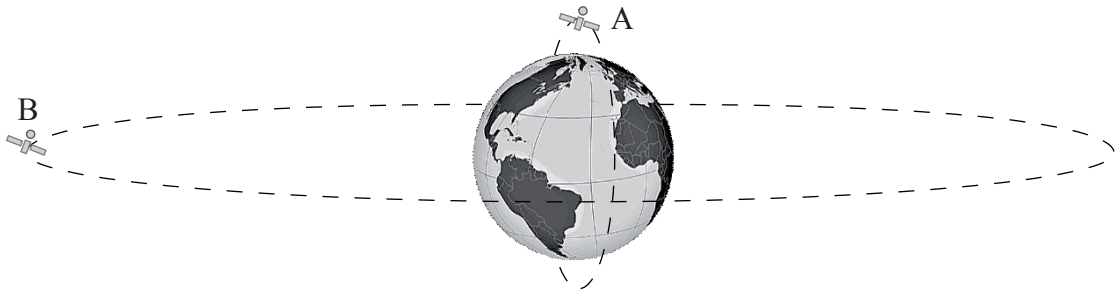
(Option F continues on the following page)

(Option F continued)

17. This question is about satellite communication.

The diagram below shows two communications satellites, A and B.



(not to scale)

(a) Identify the type of orbit of each satellite. *[2]*

A: . . . . . .

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B: . . . . . .

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(b) Suggest whether type A or type B satellites are more suitable for unbroken communication. *[2]*

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(Option F continues on the following page)

(Option F, question 17 continued)

(c) Explain why satellites require more than one frequency for two-way communication with a ground station. *[2]*

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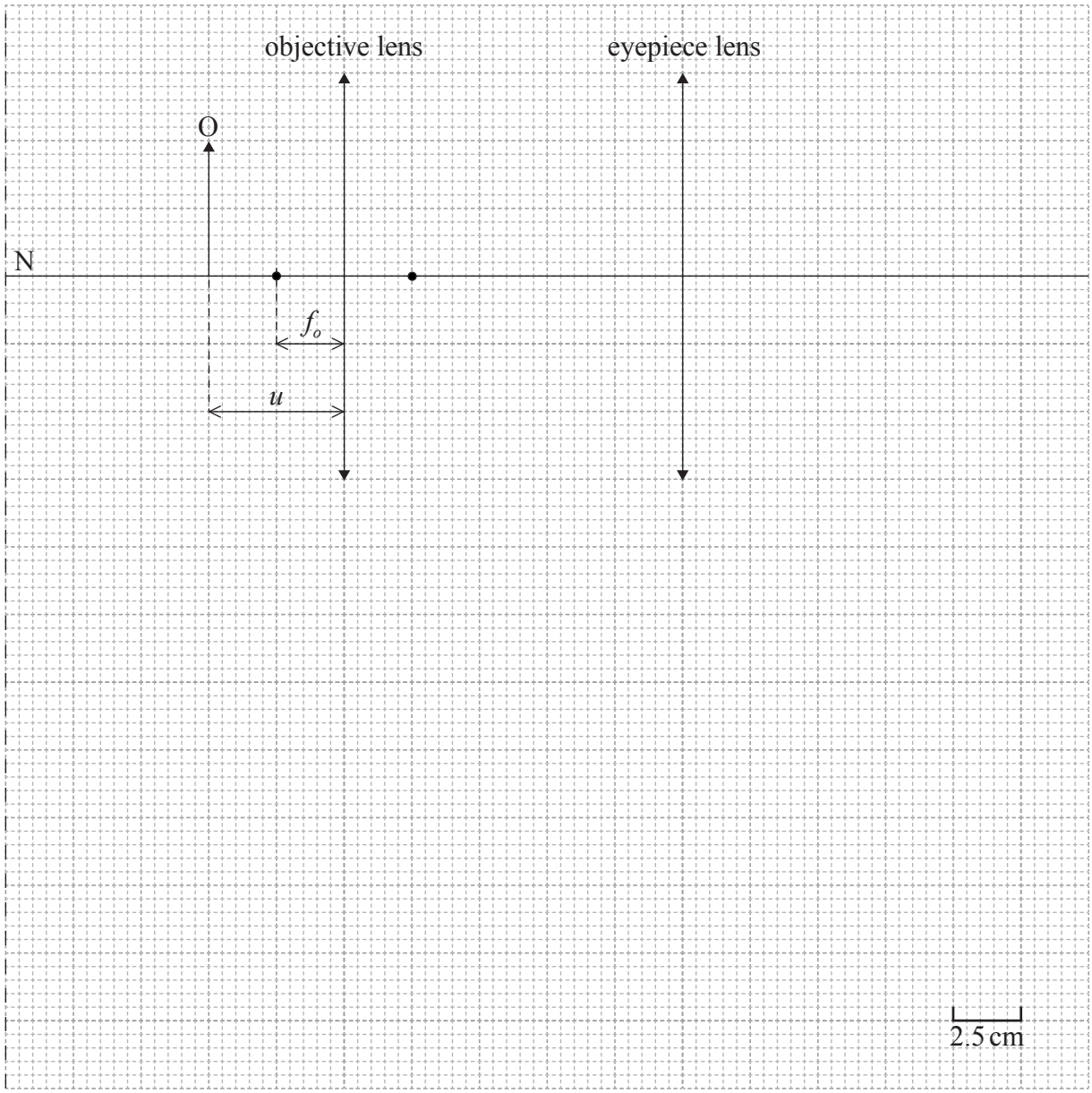
End of Option F

Option G — Electromagnetic waves

18. This question is about a compound microscope.

The diagram below shows two thin converging lenses in a compound microscope. The focal length of the objective lens is f_o. The object O is placed at a distance u from the objective lens.



(a) (i) On the diagram above, construct a ray diagram to locate the position of the image formed by the objective lens. Label this image I. *[2]*

(Option G continues on the following page)

(Option G, question 18 continued)

(ii) Outline whether the image I is real. *[1]*

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(b) The compound microscope in (a) is in normal adjustment so that the final image is formed at the near point of an unaided eye. The position of the near point of the eye is located at N.

(i) Define *near point*. *[1]*

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(ii) Deduce that the focal length of the eyepiece is around 10.7 cm. *[3]*

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(iii) Estimate the total linear magnification of the microscope. *[2]*

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(Option G continues on the following page)

(Option G continued)

19. This question is about the nature and properties of electromagnetic waves.

(a) Electromagnetic waves propagating in a medium suffer dispersion. Describe what is meant by dispersion. *[2]*

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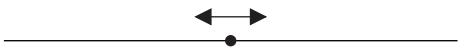
(b) A charge moves backwards and forwards along a wire, as shown in the diagram below.



charge

Outline, with reference to the motion of the charge, why electromagnetic radiation is produced by the moving charge. *[2]*

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(Option G continues on page 36)

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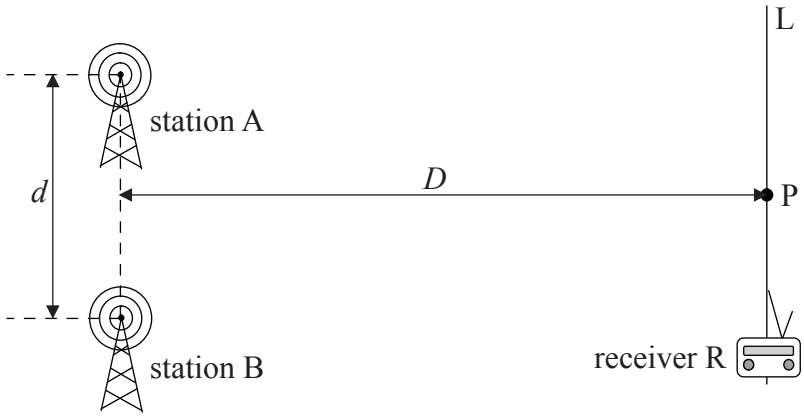
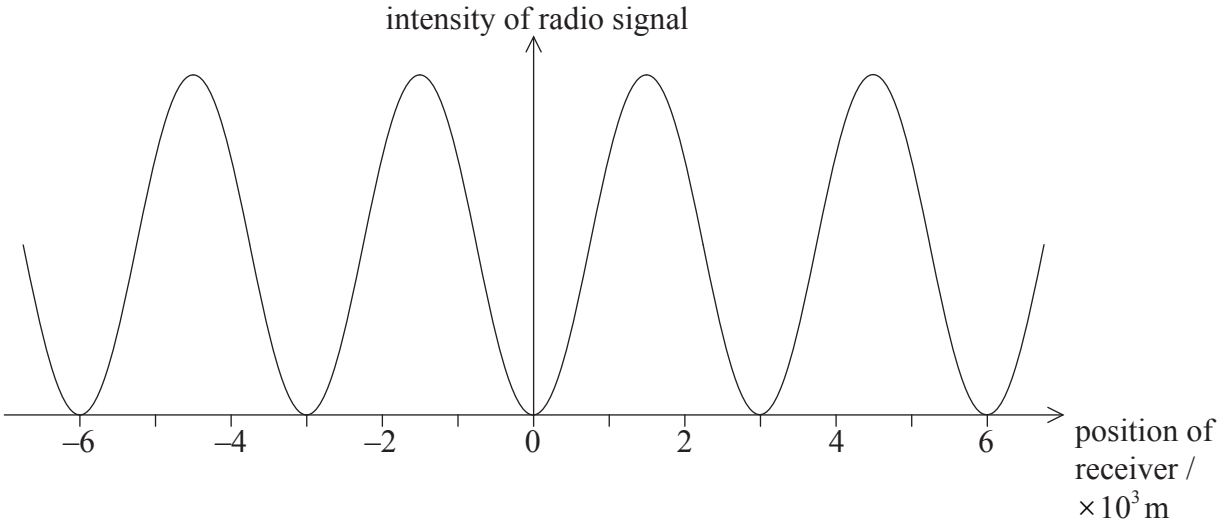
(Option G continued)

20. This question is about interference.

(a) Two radio stations, A and B, broadcast two coherent signals. The separation *d* between A and B is much less than the distance *D* from the stations to the receiver R. Point P is at the same distance from A and B.



The graph shows how the intensity of the radio signal varies with position as the receiver is moved along line L. The position of the receiver is zero when the receiver is at P.



(Option G continues on the following page)

(Option G, question 20 continued)

(i) Deduce that the two sources A and B are 180° out-of-phase. *[3]*

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(ii) The wavelength of the radio signal is 40 m. Calculate the ratio $\frac{D}{d}$. *[2]*

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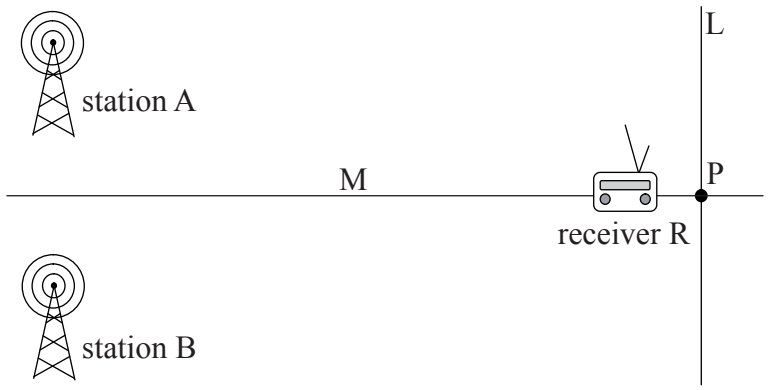
(Option G continues on the following page)

(Option G, Question 20 continued)

(b) The receiver R then moves along a different line M which is at 90° to line L.



Discuss the variation of the intensity of the radio signal with position as the receiver is moved along line M. *[2]*

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End of Option G

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