N10/4/PHYSI/SP3/ENG/TZ0/XX

88106506

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PHYSICS
STANDARD LEVEL
PAPER 3

Tuesday 9 November 2010 (morning)

1 hour

Candidate session number

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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 in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your cover sheet.

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0131

31 pages

Option A — Sight and wave phenomena

A1. This question is about the eye.

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

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(b) Explain how accommodation is achieved by the eye. *[2]*

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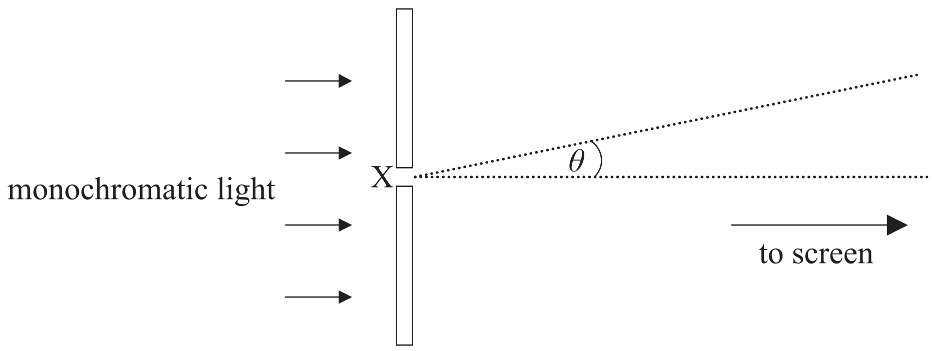
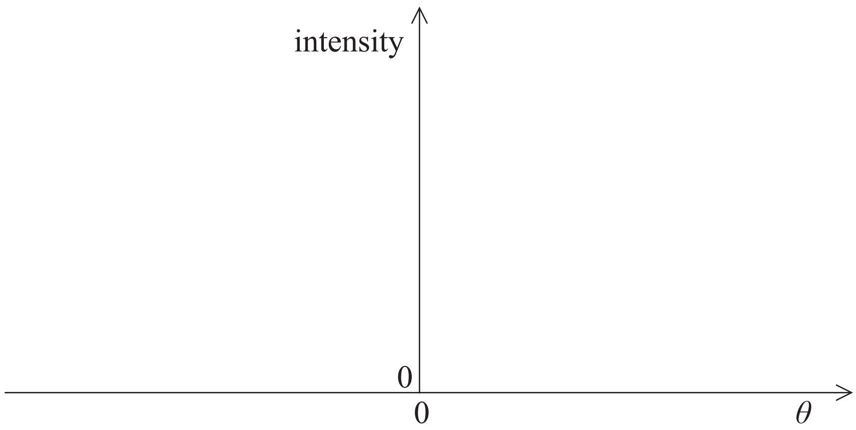
A2. This question is about diffraction and resolution.

(a) A parallel beam of monochromatic light is incident on a narrow rectangular slit. After passing through the slit, the light is incident on a distant screen.



Point X is the midpoint of the slit.

(i) On the axes below, sketch a graph to show how the intensity of the light on the screen varies with the angle θ shown in the diagram. *[3]*



(ii) The wavelength of the light is 520 nm, the width of the slit is 0.04 mm and the screen is 1.2 m from the slit. Show that the width of the central maximum of intensity on the screen is about 3 cm. *[2]*

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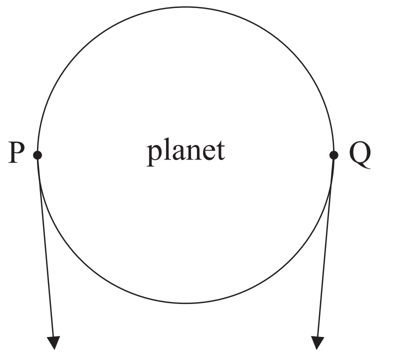
(Question A2 continued)

(b) Points P and Q are on the circumference of a planet as shown.



By considering the two points, outline why diffraction limits the ability of an astronomical telescope to resolve the image of the planet as a disc. *[3]*

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A3. This question is about standing waves and organ pipes.

(a) State **one** way in which a standing wave differs from a travelling wave. *[1]*

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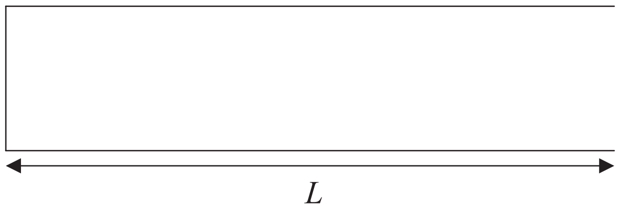
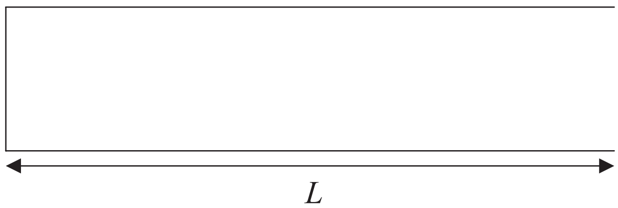
(b) An organ pipe of length L is closed at one end. On the diagrams, draw a representation of the displacement of the air in the pipe when the frequency of the note emitted by the pipe is the

(i) fundamental (first harmonic) frequency f_1. *[1]*



(ii) second harmonic frequency f_2. *[1]*



(c) Use your answer to (b) to deduce an expression for the ratio $\frac{f_1}{f_2}$. *[3]*

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(d) State, in terms of the boundary conditions of the standing waves that can be formed in the pipe, the reason why the ratio of the higher frequencies of the harmonics to that of the fundamental must always be an integer number. *[1]*

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Option B — Quantum physics and nuclear physics

B1. This question is about wave–particle duality.

(a) In the photoelectric effect, electrons are not emitted from the surface of a metal if the frequency of the incident light is below a certain value called the threshold frequency.

(i) Explain, with reference to the Einstein model of the photoelectric effect, the existence of the threshold frequency. *[4]*

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(ii) State, with reference to your answer in (a)(i), the reason why the threshold frequency is different for different metals. *[1]*

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(This question continues on the following page)

(Question B1 continued)

(b) Light of frequency 1.0×10^{15} Hz is incident on the surface of a metal. The work function of the metal is 3.2×10^{-19} J.

(i) Show that the maximum kinetic energy of the emitted electrons is 3.4×10^{-19} J. *[2]*

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(ii) Determine the de Broglie wavelength of the electrons in (b)(i). *[3]*

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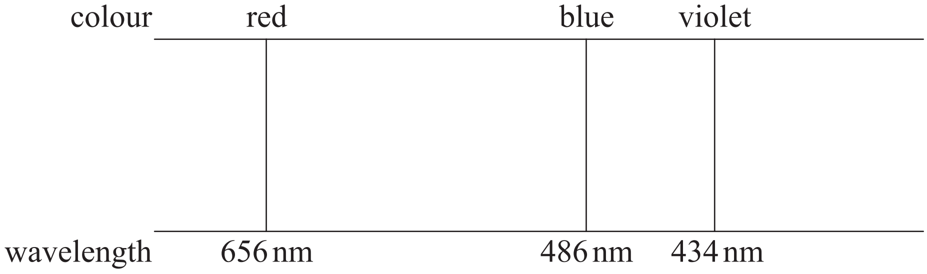
B2. This question is about the spectrum of atomic hydrogen.

(a) The diagram represents the principal lines in the visible spectrum of atomic hydrogen.



Outline how the spectrum can be produced and observed in the laboratory. *[3]*

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(b) Calculate the difference in energy in eV between the energy levels in the hydrogen atom that give rise to the red line in the spectrum. *[2]*

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B3. This question is about radioactive decay.

(a) A nucleus of a radioactive isotope of gold (Au-189) emits a neutrino in the decay to a nucleus of an isotope of platinum (Pt).

In the nuclear reaction equation below, state the name of the particle X and identify the nucleon number *A* and proton number *Z* of the nucleus of the isotope of platinum. *[2]*

$$^{189}_{79}Au \rightarrow {}^{A}_{Z}Pt + X + \nu$$

X: . . . .

A: . . . .

Z: . . . .

(b) The half-life of Au-189 is 8.84 minutes. A freshly prepared sample of the isotope has an activity of 124 Bq.

(i) Calculate the decay constant of Au-189. *[1]*

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(ii) Determine the activity of the sample after 12.0 min. *[2]*

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Option C — Digital technology

C1. This question is about CDs and CCDs.

(a) Analogue signals are stored on a CD as a digital, binary signal. For an analogue signal of strength 11 V,

(i) state the magnitude of the signal strength as a binary number. *[1]*

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(ii) describe how a digital signal, such as that in (a)(i), is stored on the CD. *[2]*

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(iii) outline how the stored digit one (1) in a digital signal is read from the CD using laser light reflected from the surface of the CD. *[2]*

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(Question C1 continued)

(b) Unlike a CD, a CCD stores light incident on its surface in a digital form by dividing the surface into a large number of pixels. Each pixel has a fixed value of capacitance.

(i) Define what is meant by the *capacitance* of a pixel. *[1]*

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(ii) Pixels of a particular CCD have an area of $2.8\times10^{-10}\,m^2$ and a capacitance of 20 pF. A beam of monochromatic light is incident on the CCD. The number of photons per square metre arriving at the CCD is 4.0×10^{13}. The quantum efficiency of a pixel is 74 %.

Determine the increase in potential difference across a pixel as a result of the incident light. *[4]*

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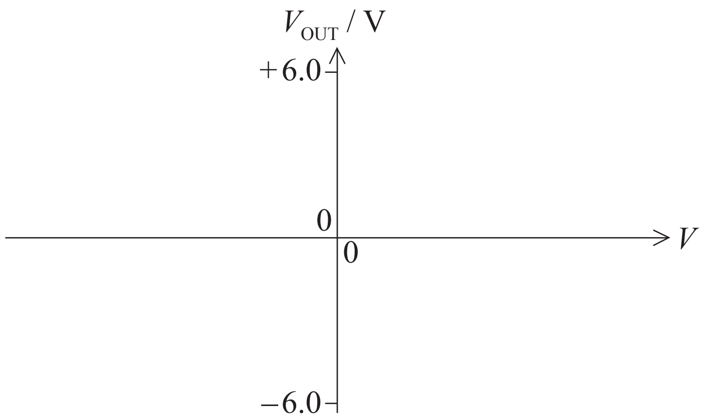
C2. This question is about an operational amplifier used in a Schmitt trigger circuit.

(a) An operational amplifier uses a ±6.0 V supply. The operational amplifier operates in the non-inverting mode.

(i) On the axes below, sketch a graph to show how the output voltage V_{OUT} of the amplifier varies with the potential difference V between the two inputs of the amplifier. *[2]*



(ii) With reference to the graph sketched in (a)(i), explain why the operational amplifier is said to act as a comparator. *[2]*

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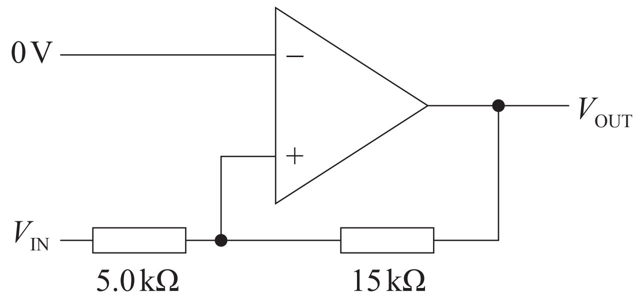
(Question C2 continued)

(b) The diagram shows an operational amplifier connected as a Schmitt trigger. The output of the amplifier is ± 6.0 V.



(i) Show that the upper switching voltage of the trigger, *i.e.* the input voltage V_{IN} for which the output voltage V_{OUT} switches from −6.0 V to +6.0 V, is 2.0 V. *[2]*

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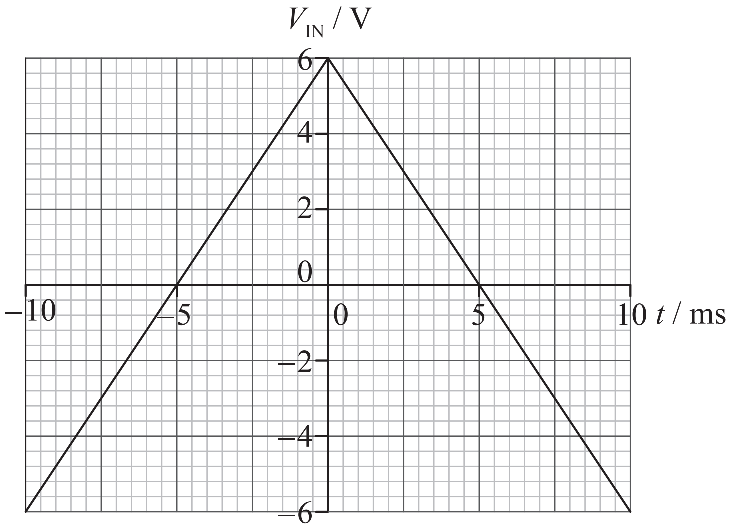
(Question C2 continued)

(ii) The input signal V_{IN} to the trigger is shown in the graph.



The switching voltages of the trigger are ± 2.0 V.

On the axes above, sketch a graph to show how the output voltage V_{OUT} varies with time t. *[2]*

(c) Explain the use of a Schmitt trigger in the transmission of digital signals. *[2]*

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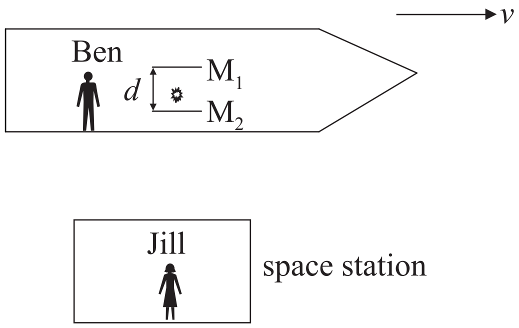
Option D — Relativity and particle physics

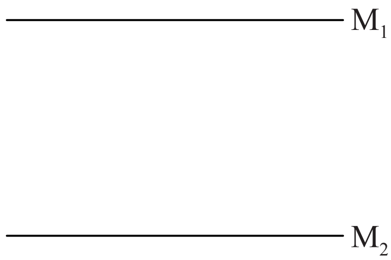
D1. This question is about a Galilean transformation and time dilation.

Ben is in a spaceship that is travelling in a straight-line with constant speed v as measured by Jill who is in a space station.



Ben switches on a light pulse that bounces vertically (as observed by Ben) between two horizontal mirrors M_1 and M_2 separated by a distance d. At the instant that the mirrors are opposite Jill, the pulse is just leaving the mirror M_2. The speed of light in air is c.

(a) On the diagram, sketch the path of the light pulse between M_1 and M_2 as observed by Jill. *[1]*



(b) The time for the light pulse to travel from M_2 to M_1 as measured by Jill is Δt.

(i) State, according to Jill, the distance moved by the spaceship in time Δt. *[1]*

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(ii) Using a Galilean transformation, derive an expression for the length of the path of the light between M_2 and M_1. *[2]*

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(Question D1 continued)

(c) State, according to special relativity, the length of the path of the light between M_2 and M_1 as measured by Jill in terms of c and Δt. *[1]*

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(d) The time for the pulse to travel from M_2 to M_1 as measured by Ben is $\Delta t'$. Use your answer to (b)(i) and (c) to derive a relationship between Δt and $\Delta t'$. *[3]*

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(e) According to a clock at rest with respect to Jill, a clock in the spaceship runs slow by a factor of 2.3. Show that the speed v of the spaceship is 0.90c. *[2]*

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D2. This question is about leptons and mesons.

(a) Leptons are a class of elementary particles and each lepton has its own antiparticle. State what is meant by an

(i) elementary particle. *[1]*

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(ii) antiparticle of a lepton. *[1]*

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(b) The electron is a lepton and its antiparticle is the positron. The following reaction can take place between an electron and positron.

$$e^{-} + e^{+} \rightarrow \gamma + \gamma$$

Sketch the Feynman diagram for this reaction and identify on your diagram any virtual particles. *[3]*

(This question continues on the following page)

(Question D2 continued)

(c) Unlike leptons, the π^+ meson is not an elementary particle. State the

(i) quark structure of the π^+ meson. *[1]*

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(ii) reason why the following reaction does not occur. *[1]*

$$p^+ + p^+ \rightarrow p^+ + \pi^+$$

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(d) State the Pauli exclusion principle. *[1]*

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(e) Explain, with reference to your answer to (d), why quarks are assigned the property of colour. *[2]*

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Option E — Astrophysics

E1. This question is about the characteristics of the stars Procyon A and Procyon B.

(a) The stars Procyon A and Procyon B are both located in the same stellar cluster in the constellation Canis Minor. Distinguish between a constellation and a stellar cluster. *[2]*

Constellation: . . . .

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Stellar cluster: . . . .

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(b) The table shows some data for Procyon A and Procyon B.

	Apparent magnitude	**Absolute magnitude**	**Apparent brightness / $W\,m^{-2}$**
Procyon A (P_A)	$+0.400$	$+2.68$	2.06×10^{-8}
Procyon B (P_B)	$+10.7$	$+13.0$	1.46×10^{-12}

Explain, using data from the table, why

(i) as viewed from Earth, P_A is much brighter than P_B. *[2]*

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(ii) the luminosity of P_A is much greater than that of P_B. *[3]*

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(Question E1 continued)

(c) Deduce, using data from the table in (b), that P_A and P_B are approximately the same distance from Earth. *[2]*

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(d) State, using your answers to (a) and (c), why P_A and P_B might be binary stars. *[1]*

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(e) Calculate, using data from the table in (b), the ratio $\frac{L_A}{L_B}$ where L_A is the luminosity of P_A and L_B is the luminosity of P_B. *[2]*

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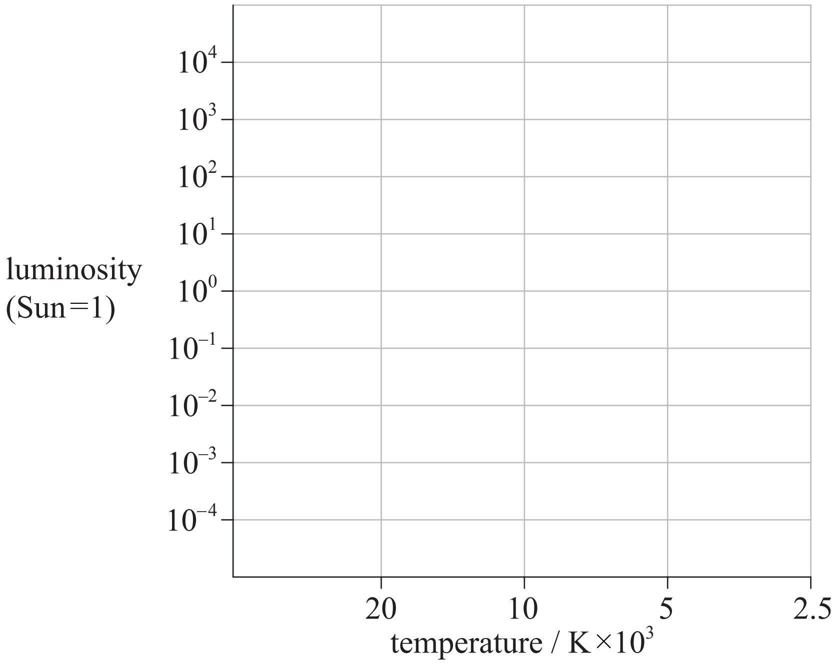
(Question E1 continued)

(f) The surface temperature of both P_A and P_B is of the order of 10^4 K. The luminosity of P_A is of the order of $10L_S$, where L_S is the luminosity of the Sun. The diagram shows the grid of a Hertzsprung–Russell diagram.



Label, on the grid above, the approximate position of

(i) star P_A with the letter A. *[1]*

(ii) star P_B with the letter B. *[1]*

(g) Identify the nature of star P_B. *[1]*

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E2. This question is about the Big Bang model and red-shift.

(a) Describe what is meant by the Big Bang model. *[1]*

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(b) In the 1960s, Penzias and Wilson discovered a uniform cosmic background radiation (CMB) in the microwave region of the electromagnetic spectrum.

(i) Explain how the CMB is consistent with the Big Bang model. *[3]*

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(ii) State why the red-shift of light from galaxies supports the Big Bang model. *[1]*

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Option F — Communications

F1. This question is about modulation.

(a) State what is meant by the modulation of a carrier wave. *[1]*

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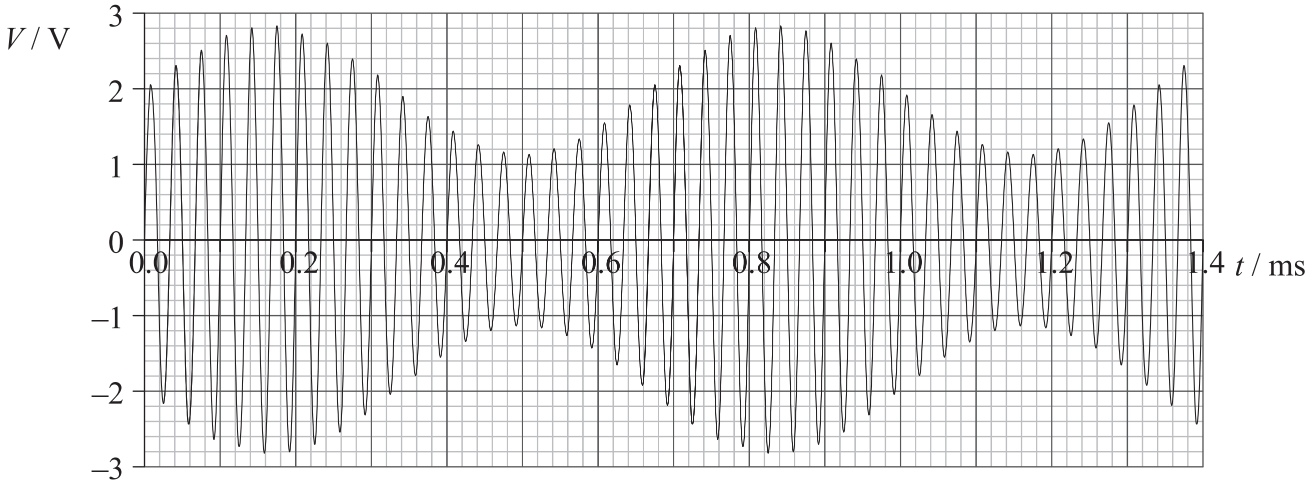
(Question F1 continued)

(b) The graph shows how the voltage signal strength V of an amplitude modulated (AM) carrier wave varies with time t.



Use the graph to determine the

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

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

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(iii) amplitude of the signal wave. *[2]*

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(iv) bandwidth. *[1]*

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(c) A carrier wave may also be frequency modulated (FM). State and explain **one** advantage of FM compared to AM. *[2]*

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F2. This question is about optical fibres.

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

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(b) Suggest why material dispersion sets a limit on the bit-rate of transmission. *[1]*

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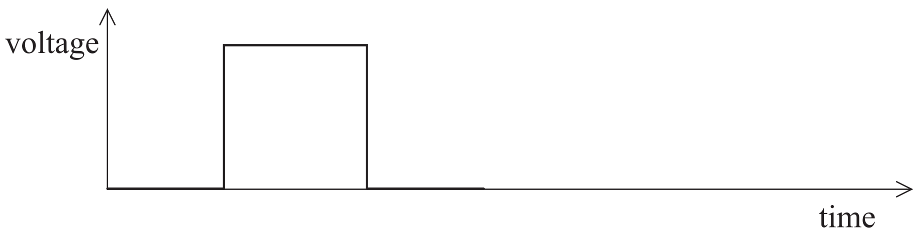
(c) (i) The signal shown below is fed into a monomode optical fibre.



On the diagram above, show the effects of material dispersion on the input signal by drawing the shape of the signal after it has travelled a long distance in the optical fibre. *[1]*

(ii) State and explain how the effects on the signal drawn in (c)(i) may be reduced. *[2]*

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(This question continues on the following page)

(Question F2 continued)

(d) Digital data are transmitted in an optical fibre with a glass core which has a refractive index of 1.5. The duration of one bit in the transmission is 0.50 ns and each sample in the signal consists of 32 bits.

(i) Calculate the time required for the signal to travel a distance of 500 km. *[2]*

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(ii) Determine the sampling frequency. *[2]*

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(e) The data in (d) are confidential and must be protected. Without taking financial costs into account, outline whether a direct optical fibre connection **or** a transmission through a geosynchronous satellite would be more suitable for the transfer of these data. *[2]*

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Option G — Electromagnetic waves

G1. This question is about lasers.

(a) With reference to the light waves emitted by a laser, state what is meant by the terms

(i) monochromatic. *[1]*

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(ii) coherent. *[1]*

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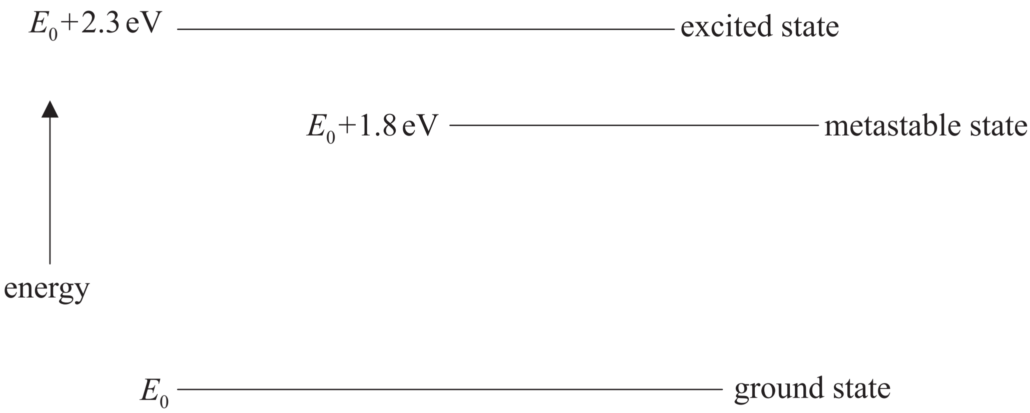
(Question G1 continued)

(b) The diagram (not to scale) shows three of the energy levels of a substance used to produce laser light.



The energy of the ground state is E_0.

(i) State what is meant by population inversion. *[1]*

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(ii) Draw an arrow on the diagram to indicate the transition that results in a population inversion. Label the arrow P. *[1]*

(iii) Draw an arrow on the diagram to indicate the transition that results in a pulse of laser light. Label the arrow L. *[1]*

(iv) Deduce that the wavelength of the emitted laser light is 690 nm. *[1]*

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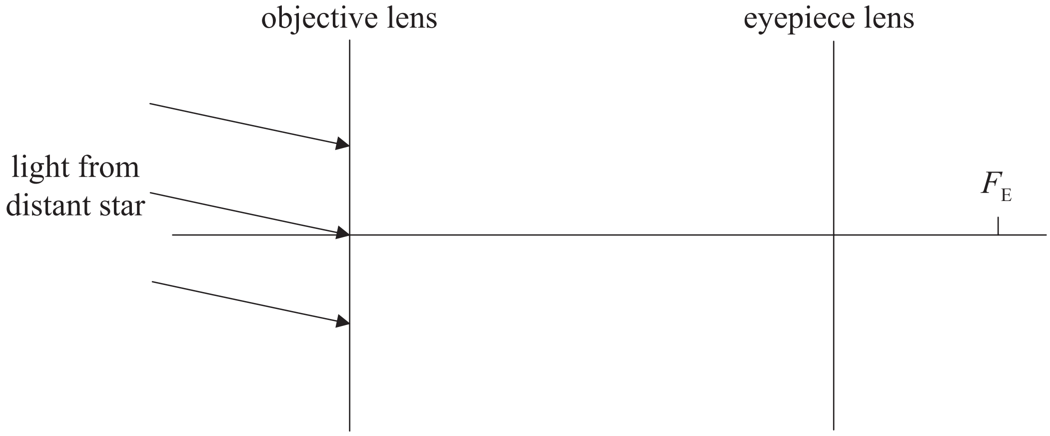
G2. This question is about an astronomical telescope.

The diagram (not to scale) shows the arrangement of the two convex lenses in an astronomical telescope in normal adjustment.



The telescope is used to observe a distant star. One of the focal points of the eyepiece lens is labelled F_E.

(a) On the diagram above,

(i) label, with the symbol F_E, the position of the other focal point of the eyepiece lens. *[1]*

(ii) label, with the symbol F_O, the position of the focal point of the objective lens that is in between the two lenses. *[1]*

(iii) construct rays to locate the final image of the star. *[3]*

(b) In a particular astronomical telescope, the eyepiece lens has a power of 40 dioptres and the objective lens a power of 0.80 dioptres. Determine the angular magnification of the telescope in normal adjustment. *[2]*

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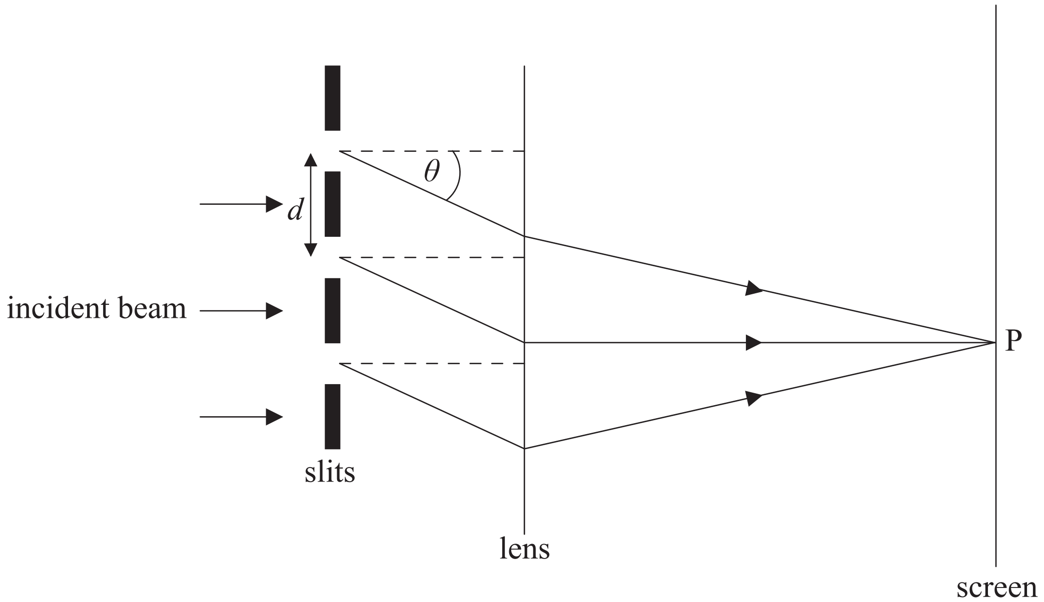
(c) In an astronomical telescope the objective is often made up from a diverging and a converging lens, whereas the aperture of the eyepiece is usually restricted such that only rays close to the principal axis are viewed. State the reasons for this. *[2]*

Objective lens: . . . .

Eyepiece lens: . . . .

G3. This question is about a diffraction grating.

(a) A parallel beam of monochromatic light is incident normally on a diffraction grating. After passing through the grating it is brought to a focus on a screen by a lens. The diagram shows a few of the slits of the diffraction grating and the path of the light that is diffracted at an angle θ to each slit.



The distance between the slits is d and the wavelength of the light is λ.

(i) On the diagram, construct a line that enables the path difference between the rays from two adjacent slits to be shown. Label the path distance L. *[1]*

(ii) Use your answer to (a)(i) to derive the condition, in terms of d and θ, for there to be a maximum of intensity at the point P on the screen. *[2]*

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(b) For a particular grating, the distance between adjacent slits is 2.0×10^{-6} m. Determine, for light of wavelength 520 nm, the maximum theoretical order of diffraction. *[2]*

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