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PHYSICS
STANDARD LEVEL
PAPER 3

Candidate session number

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Wednesday 14 November 2012 (morning)

1 hour

Examination code

8	8	1	2	–	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]*.

Option A — Sight and wave phenomena

A1. This question is about the functioning of the human eye.

(a) Outline the differences between the functions performed by rod and cone cells in the human eye. *[3]*

Rods: . . . . . .

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Cones: . . . . . .

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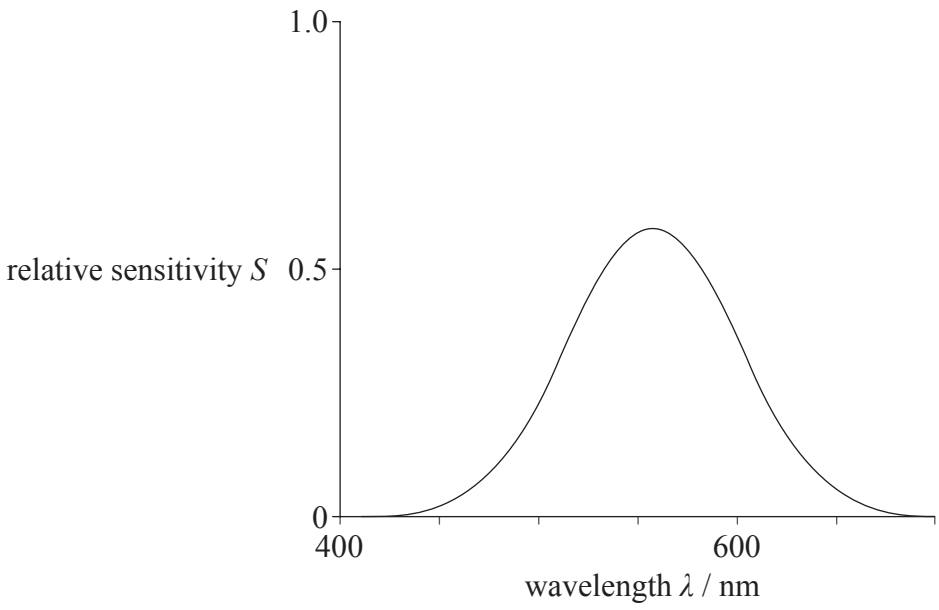
(b) The sketch graph shows how the relative sensitivity S of the cone cells in a human eye varies with the wavelength λ of the incident radiation. On the same axes, sketch the corresponding curve for rod cells. *[2]*



(This question continues on the following page)

(Question A1 continued)

(c) State the effect on the appearance of a red object when it is illuminated with red light only and blue light only. *[2]*

Red light: . . . . . .

Blue light: . . . . . .

A2. This question is about the Doppler effect in sound.

(a) A fire engine is travelling at a constant velocity towards a stationary observer. Its siren emits a note of constant frequency. As the engine passes close to the observer, the frequency of the note perceived by the observer decreases. Explain this decrease in terms of the wavefronts of the note emitted by the siren. *[3]*

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(This question continues on the following page)

(Question A2 continued)

(b) The frequency of the note emitted by the siren is 400 Hz. After the fire engine has passed, the frequency of the note detected by the observer is 360 Hz. Calculate the speed of the fire engine. (Take the speed of sound in air to be 340 $m\,s^{-1}$.) *[2]*

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A3. This question is about polarized light.

(a) Describe what is meant by polarized light. *[1]*

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(b) (i) State Brewster's law. *[1]*

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(ii) When light is incident on a plastic surface the angle between the reflected and refracted ray is 90°. The angle of incidence is 56°. Calculate the refractive index of the plastic. *[2]*

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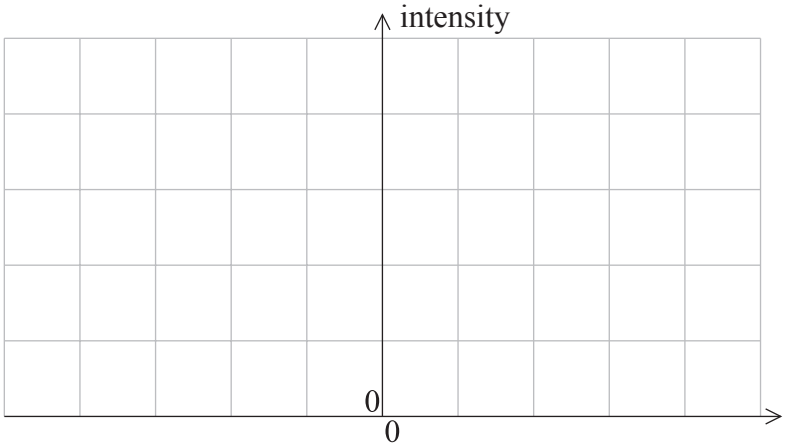
A4. This question is about resolution.

A car is travelling along a straight road at night. To a distant observer the two headlamps of the car appear as a single point source. With the aid of an appropriately labelled sketch graph, explain this observation. *[4]*



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Option B — Quantum physics and nuclear physics

B1. This question is about atomic energy levels.

(a) Outline a laboratory procedure for producing and observing the atomic absorption spectrum of a gas. *[3]*

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(b) (i) Describe the appearance of an atomic absorption spectrum. *[1]*

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(This question continues on the following page)

(Question B1 continued)

(ii) Explain why the spectrum in (a) provides evidence for quantization of energy in atoms. *[3]*

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(c) The principal energy levels of the hydrogen atom in electronvolt (eV) are given by

$$E_n = \frac{13.6}{n^2}$$

where n is a positive integer.

Determine the wavelength of the absorption line that corresponds to an electron transition from the energy level given by $n = 1$ to the level given by $n = 3$. *[3]*

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B2. This question is about radioactive decay.

(a) A nuclide of the isotope potassium-40 $\left({}^{40}_{19}\mathrm{K}\right)$ decays into a stable nuclide of the isotope argon-40 $\left({}^{40}_{18}\mathrm{Ar}\right)$. Identify the particles X and Y in the nuclear equation below. *[2]*

$$ {}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{Ar} + \mathrm{X} + \mathrm{Y} $$

X: . . . . . .

Y: . . . . . .

(b) The half-life of potassium-40 is 1.3×10^{9} yr. In a particular rock sample it is found that 85 % of the original potassium-40 nuclei have decayed. Determine the age of the rock. *[3]*

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(c) State the quantities that need to be measured in order to determine the half-life of a long-lived isotope such as potassium-40. *[2]*

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B3. This question is about neutrinos.

The spectrum of electron energies emitted in a typical β-decay is continuous. Describe how this observation led physicists to propose the existence of the particles now called neutrinos. *[3]*

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Option C — Digital technology

C1. This question is about the compact disc (CD).

(a) (i) Explain how a laser beam is used to read a CD. *[2]*

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(ii) State **one** advantage of storing information in digital rather than analogue form. *[1]*

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(b) The information stored on a CD is sampled at a frequency of 44 100 samples per second. Each sample consists of 32 bits and the maximum playing time of the CD is 80 minutes. Determine the storage capacity of the CD in megabytes. (1 byte = 8 bits) *[2]*

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C2. This question is about charge-coupled devices (CCDs).

(a) Define the *quantum efficiency* of a CCD. *[1]*

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(b) Each pixel of a CCD has a quantum efficiency of 78 % and a capacitance of 12 pF. The number of photons incident on a pixel per second is 4.2×10^6. Calculate the potential difference across the pixel after light has been incident on the pixel for 30 ms. *[3]*

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(c) State **one** advantage of a CCD image over an image formed on photographic film. *[1]*

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C3. This question is about the operational amplifier (op-amp).

(a) State **two** properties of an ideal operational amplifier (op-amp). *[2]*

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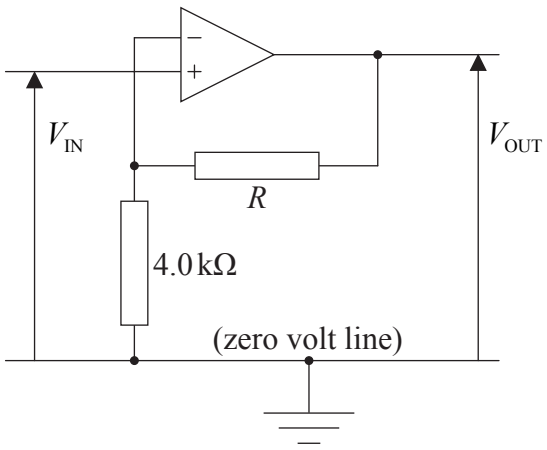
2. . . . . .

(b) The diagram shows a circuit that includes an op-amp.



The overall gain of this circuit is $\frac{V_{OUT}}{V_{IN}} = 26$. Calculate the resistance of resistor R. *[2]*

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(This question continues on the following page)

(Question C3 continued)

(c) The op-amp operates with a ±9.0 V supply. Determine the value of the output voltage V_{OUT} for input voltages V_{IN} of

(i) – 0.30 V. *[1]*

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(ii) +3.0 V. *[1]*

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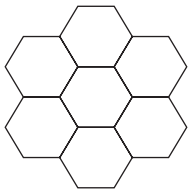
C4. This question is about the mobile phone system.

The diagram shows a few of the cells in a mobile phone system. Each cell has its own base station. The base stations are connected to a cellular exchange.



(a) Suggest why the size of each cell is usually limited to no more than a few kilometres. *[2]*

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(b) Describe how, at any one instant, many mobile phones may be communicating with the same base station. *[2]*

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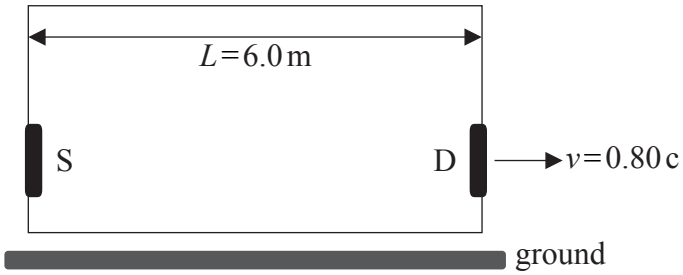
Option D — Relativity and particle physics

D1. This question is about relativistic kinematics.

A source of light S and a detector of light D are placed on opposite walls of a box as shown in the diagram.



According to an observer in the box the distance L between S and D is 6.0 m. The box moves with speed $v = 0.80\,c$ relative to the ground.

Consider the following events.

Event 1: a photon is emitted by S towards D
Event 2: the photon arrives at D

(a) In the context of the theory of relativity, state what is meant by an event. *[1]*

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(This question continues on the following page)

(Question D1 continued)

(b) (i) Calculate the time interval t between event 1 and event 2 according to an observer in the box. *[1]*

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(ii) According to an observer on the ground the time interval between event 1 and event 2 is T. One student claims that $T = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$ and another that $T = t\sqrt{1-\frac{v^2}{c^2}}$.

Explain why both students are wrong. *[2]*

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(This question continues on the following page)

(Question D1 continued)

(c) Relative to an observer on the **ground**,

(i) calculate the distance between S and D. *[2]*

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(ii) state the speed of the photon leaving S. *[1]*

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(iii) state an expression for the distance travelled by detector D in the time interval T (T is the interval in (b)(ii)). *[1]*

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(iv) determine T, using your answers to (c)(i), (ii) and (iii). *[2]*

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D2. This question is about quarks.

(a) State the name of a particle that is its own antiparticle. *[1]*

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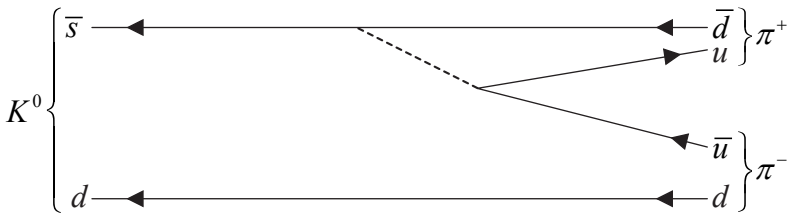
(b) The meson K^0 consists of a d quark and an anti s quark. The K^0 decays into two pions as shown in the Feynman diagram.



(i) State a reason why the kaon K^0 cannot be its own antiparticle. *[1]*

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(ii) Explain how it may be deduced that this decay is a weak interaction process. *[2]*

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(This question continues on the following page)

(Question D2 continued)

(iii) State the name of the particle denoted by the dotted line in the diagram. *[1]*

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(iv) The mass of the particle in (b)(iii) is approximately 1.6×10^{-25} kg. Determine the range of the weak interaction. *[2]*

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(c) (i) Explain why the meson K^0 does not have any colour quantum number. *[2]*

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(ii) The decay $K^0 \rightarrow p^+ + \pi^-$ is not observed. State **one** conservation law that would be violated if this decay were to occur. *[1]*

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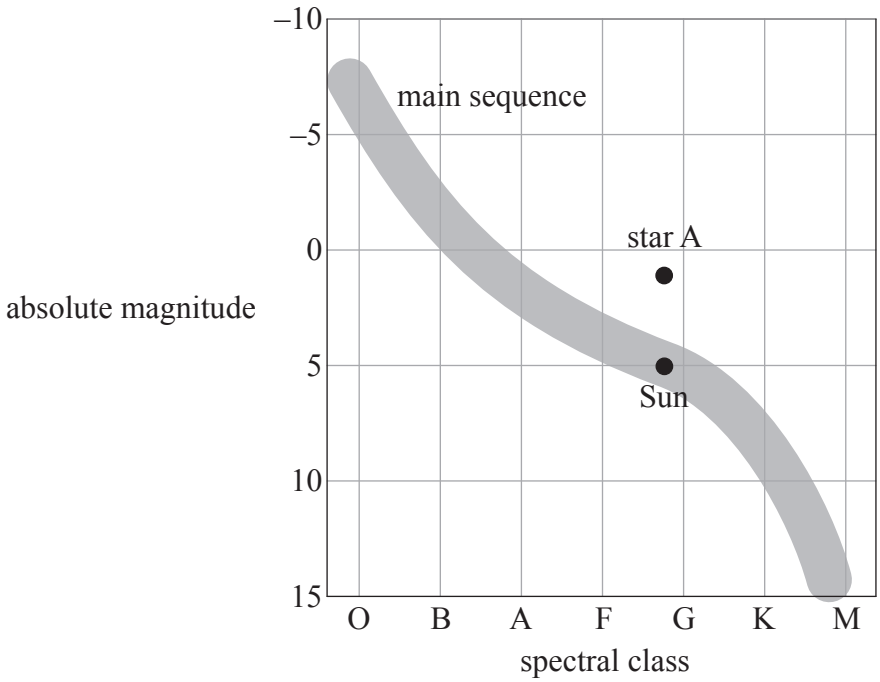
Option E — Astrophysics

E1. This question is about stars.

The Hertzsprung–Russell (HR) diagram shows the Sun, a star labelled A and the main sequence.



(a) (i) Define *absolute magnitude*. *[1]*

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(ii) State **one** physical property of a star that is determined by its spectral class. *[1]*

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(This question continues on the following page)

(Question E1 continued)

(iii) Suggest why star A has a greater radius than the Sun. *[1]*

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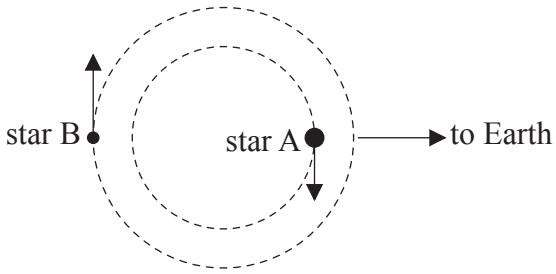
(b) Star A is part of a binary star system. The diagram shows the orbit of star A and the orbit of its companion, star B.



The temperature of star A is T_A, the temperature of star B is T_B and $\frac{T_A}{T_B} = 0.60$. The radius of star A is R_A, the radius of star B is R_B and $\frac{R_A}{R_B} = 270$.

(i) Show that the luminosity of star A is 9.4×10^3 times greater than the luminosity of star B. *[2]*

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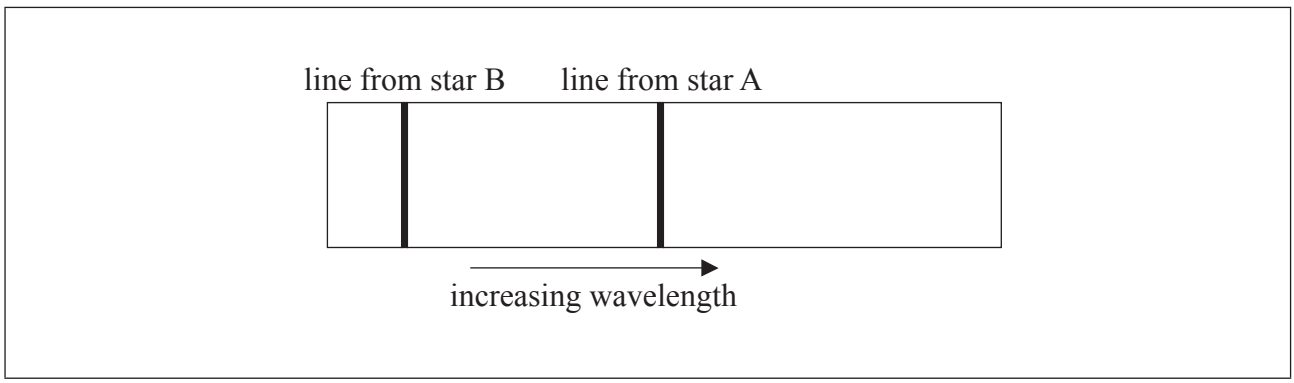
(ii) Draw the approximate position of star B onto the HR diagram on page 22. *[1]*

(This question continues on the following page)

(Question E1 continued)

(c) The diagram below shows the spectrum of the stars as observed from Earth. The spectrum shows one line from star A and one line from star B, when the stars are in the position shown in the diagram (b).



On the spectrum draw lines to show the approximate positions of these spectral lines after the stars have completed one quarter of a revolution. *[2]*

E2. This question is about Cepheid stars.

(a) The star η Aquilae is a Cepheid star. Its apparent magnitude varies from 3.6 to 4.4 with a period of 7.2 days.

(i) State the reason for the variation of the Cepheid's brightness. *[1]*

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(ii) The average absolute magnitude M of a Cepheid star and the period T in days of the variation of its brightness are related by the equation below.

$$M = -2.83 \log_{10} T - 1.81$$

Determine the distance to η Aquilae. *[3]*

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(b) A Cepheid star and non-Cepheid star both belong to the same distant galaxy. Explain, stating the quantities that need to be measured, how the luminosity of the non-Cepheid star may be determined. *[2]*

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E3. This question is about cosmology.

(a) Theoretical studies indicate that the universe may be open, closed or flat.

(i) State, by reference to critical density, the condition that must be satisfied for the universe to be flat. *[1]*

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(ii) In a flat universe, the rate of expansion would be slowing down. Suggest a reason for this. *[1]*

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(iii) Outline why it has been difficult to determine whether the universe is open, closed or flat. *[2]*

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(This question continues on the following page)

(Question E3 continued)

(b) Outline **one** piece of experimental evidence that supports the fact that the universe is expanding. *[2]*

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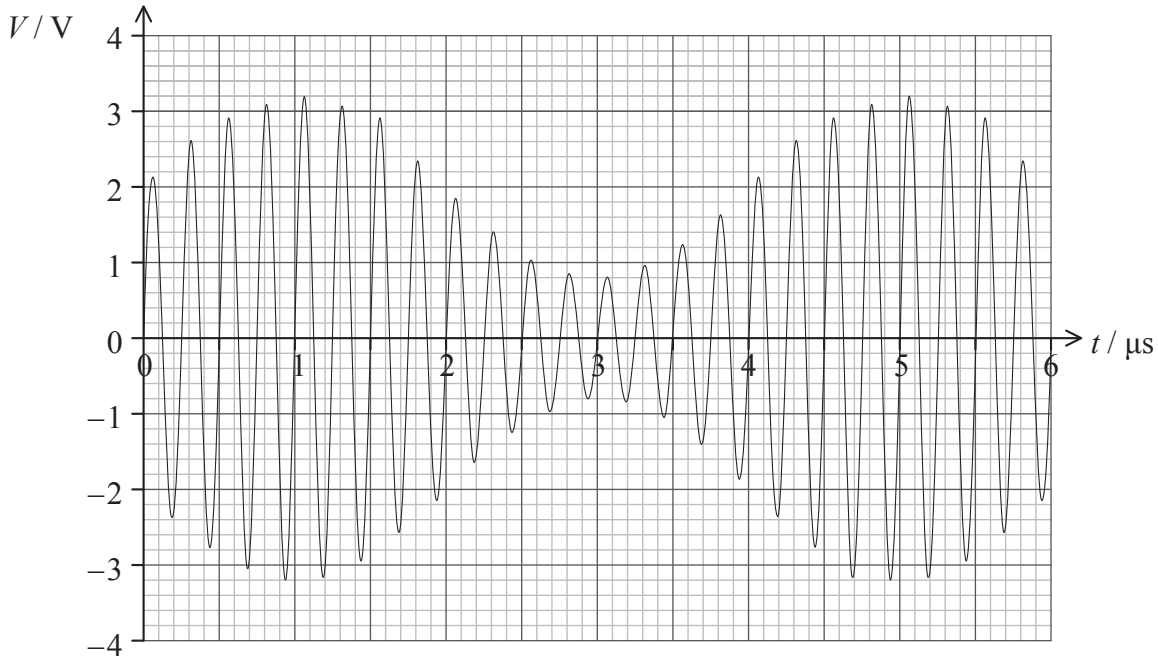
Option F — Communications

F1. This question is about modulation.

The diagram shows the variation with time t of the voltage signal V of an amplitude modulated carrier wave.



(a) Determine the

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

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

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(This question continues on the following page)

(Question F1 continued)

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

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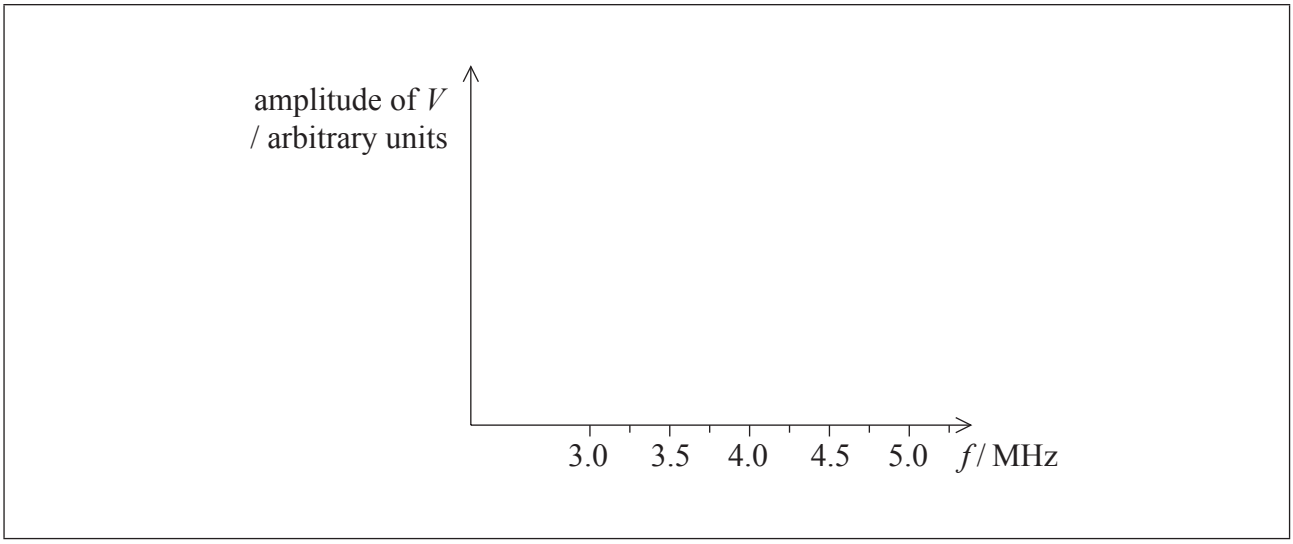
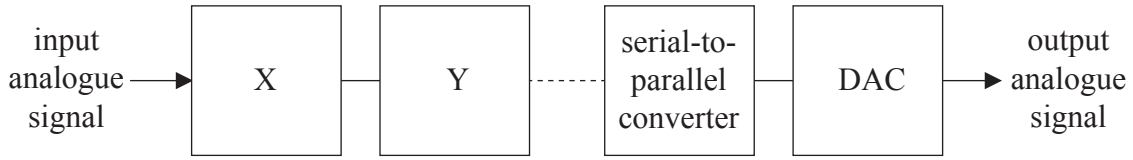
(b) On the axes below, draw the spectrum of the modulated wave, *i.e.* the variation with frequency f of the amplitude of the voltage V. *[2]*



F2. This question is about digital transmission.

(a) The diagram below is a block diagram for the digital transmission of an analogue signal.



(i) State the names of blocks X and Y. *[2]*

X: . . . . . .

Y: . . . . . .

(ii) Describe the function of the serial-to-parallel converter. *[2]*

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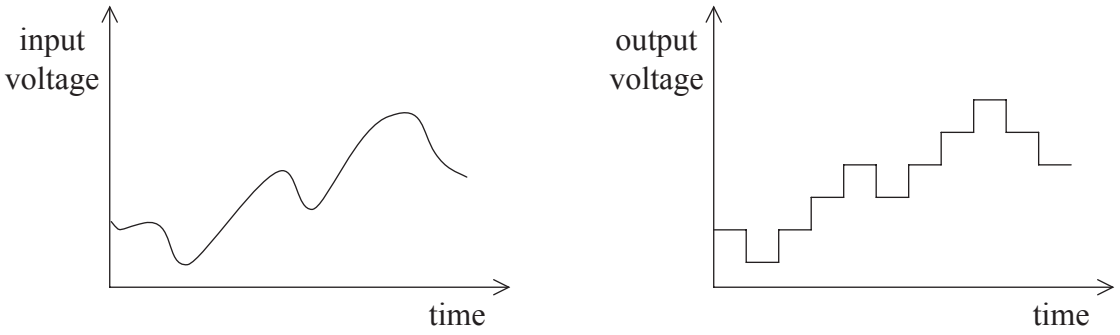
(Question F2 continued)

(b) The diagrams show the variation with time of the input and output analogue signal voltages.



State and explain **two** ways in which the output signal could be made to be a more accurate reproduction of the input signal. *[4]*

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F3. This question is about optic fibres.

(a) State **one** advantage of the use of an optic fibre rather than a coaxial cable for the transmission of information. *[1]*

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(b) Suggest why, in transmitting information in an optic fibre, infrared electromagnetic radiation rather than visible light is used. *[2]*

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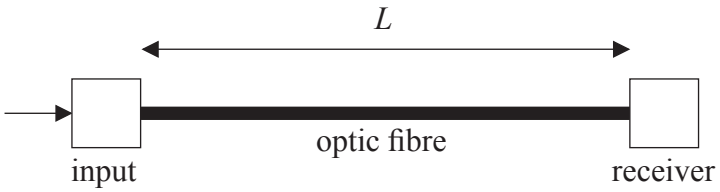
(c) A signal is fed into an optic fibre of length L.



The noise power at the receiver is $P_{\text{noise}} = 4.2\,\mu\text{W}$. The signal to noise ratio $\left(i.e.\, 10 \log \frac{P_{\text{signal}}}{P_{\text{noise}}} \right)$ at the receiver must exceed 25 dB.

(i) Show that the minimum signal power at the receiver is 1.3 mW. *[1]*

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(This question continues on the following page)

(Question F3 continued)

(ii) A signal of power 25 mW is input to the optic fibre. The attenuation per unit length of the optic fibre is 0.30 dB km^{-1}. Determine the maximum length L of the optic fibre. *[3]*

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Option G — Electromagnetic waves

G1. This question is about interference of light at two parallel slits.

(a) State the condition necessary to observe interference between two light sources. *[1]*

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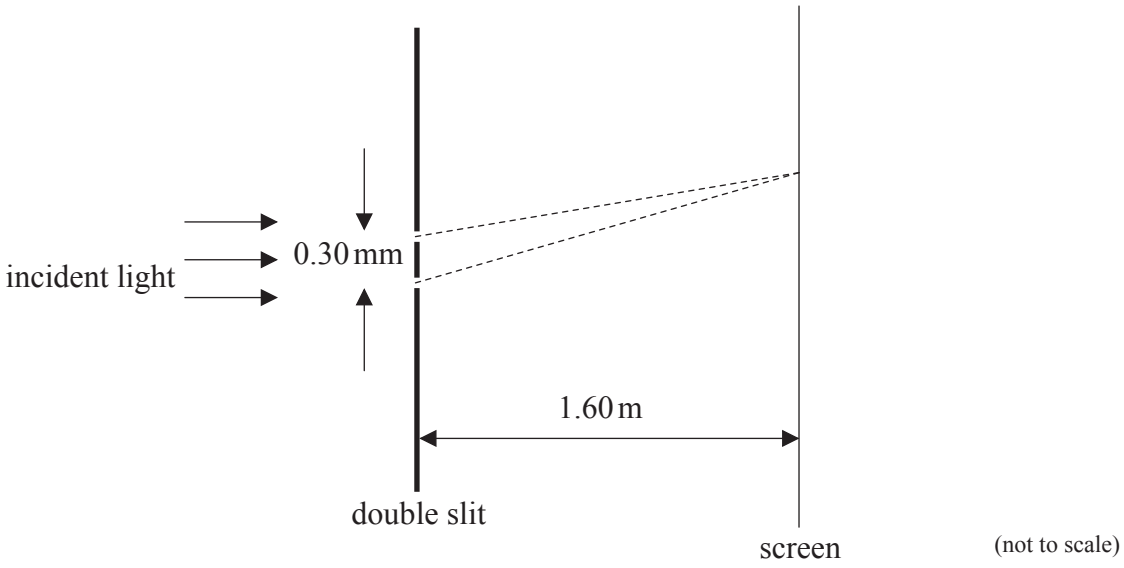
(b) The diagram below shows an arrangement for observing a double slit interference pattern. A parallel beam of coherent light of wavelength 410 nm is incident on two parallel narrow slits separated by 0.30 mm. A screen is placed 1.60 m beyond the slits.



Calculate the fringe spacing on the screen. *[2]*

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(This question continues on the following page)

(Question G1 continued)

(c) The slits in (b) are replaced by a large number of slits of the same width and separation as the double slit. Describe the effects that this change will have on the appearance of the fringes on the screen. *[3]*

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G2. This question is about the simple magnifying glass and the compound microscope.

(a) Define, for the unaided eye, the term *near point*. *[1]*

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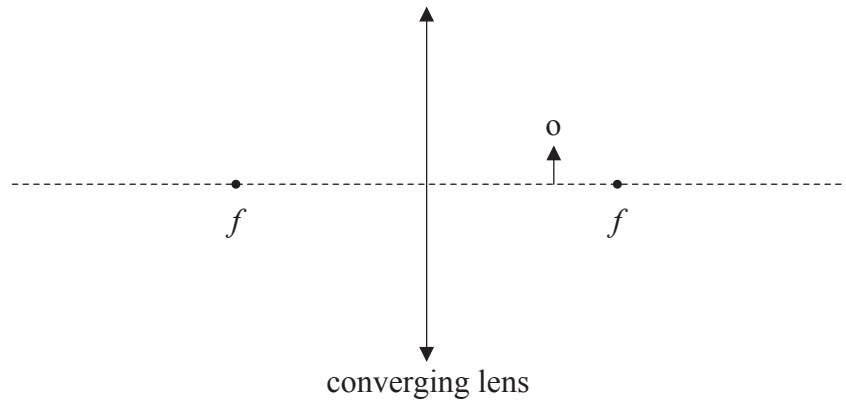
(b) A converging lens is used as a magnifying glass. On the diagram draw rays to construct the image of the object, o. *[3]*



(This question continues on the following page)

(Question G2 continued)

(c) The lens has a focal length f. When the image is formed at the near point, the distance u of the object from the lens is given by

$$u = \frac{fD}{D+f}$$

where D is the near point distance.

Deduce that the angular magnification M is given by

$$M = 1 + \frac{D}{f}.$$ *[2]*

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(This question continues on the following page)

(Question G2 continued)

(d) A compound microscope consists of an eyepiece lens of focal length 6.0 cm and an objective lens of focal length 2.8 cm. An object is placed 3.4 cm from the objective lens and the final image of the object is formed by the microscope at the near point.

Determine the

(i) angular magnification of the eyepiece. Take the near point distance to be 25 cm. *[1]*

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(ii) distance from the objective lens of the intermediate image formed by this lens. *[2]*

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(iii) overall magnification of the compound microscope. *[2]*

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G3. This question is about the scattering of light.

Explain, with reference to the scattering of light, why the sky appears red at sunset. *[3]*

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

Answers written on this page
will not be marked.