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PHYSICS
STANDARD LEVEL
PAPER 3

Tuesday 17 November 2009 (morning)

1 hour

Candidate session number

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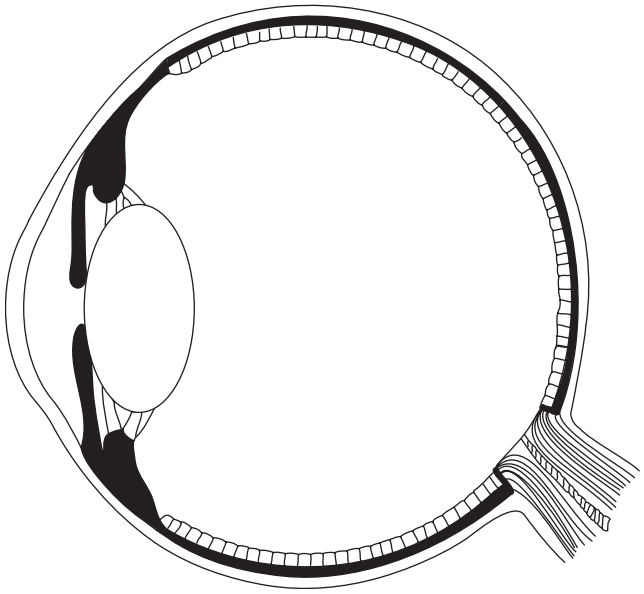
INSTRUCTIONS TO CANDIDATES

- 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.

Option A — Sight and wave phenomena

A1. This question is about the human eye.

(a) (i) Label the diagram of the human eye to show the lens, retina and optic nerve. *[1]*



(ii) Outline the function of the rods and the cones in the retina. *[3]*

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(b) Outline what is meant by accommodation in the eye. *[3]*

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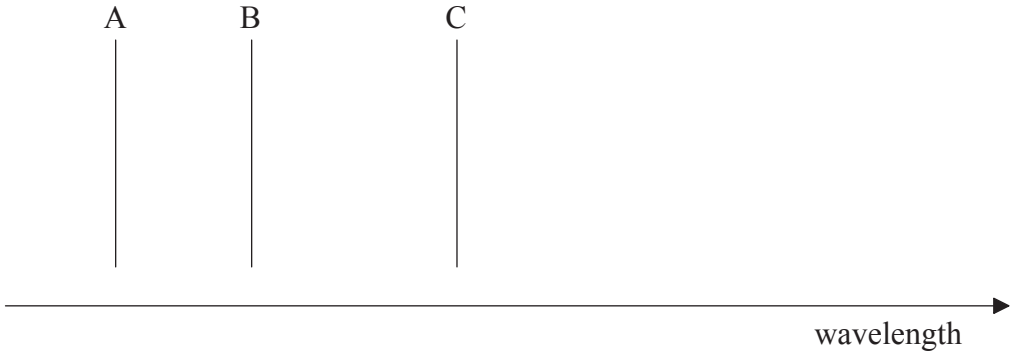
A2. This question is about the Doppler effect.

The wavelength diagram shown represents three lines in the emission spectrum sample of calcium in a laboratory.



A distant star is known to be moving directly away from the Earth at a speed of 0.1 c. The light emitted from the star contains the emission spectra of calcium. On the diagram sketch the emission spectrum of the star as observed in the laboratory. Label the lines that correspond to A, B, and C with the letters A*, B*, and C*. Numerical values of the wavelengths are **not** required. *[3]*

A3. This question is about optical resolution.

(a) The separation of two objects on the surface of Earth is d. The objects are photographed by a camera in a spy satellite orbiting Earth. The photographic images of the objects are just resolved. Use the following data to determine d. *[3]*

Wavelength of light emitted by the objects $= 500\,\text{nm}$
Distance of satellite above surface of Earth $= 4.0 \times 10^5\,\text{m}$
Diameter of camera lens $= 0.10\,\text{m}$

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(b) State **one** way in which the resolution of the camera could be improved. *[1]*

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A4. This question is about polarizing filters and sources.

You are given two unlabelled light sources, one of which emits polarized light and the other does not. You are also given two unlabelled transparent plastic sheets, one of which is a polarizer and the other is not.

(a) Describe how you would determine which one of the sources emits polarized light and which sheet is a polarizing filter. *[2]*

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(b) You are given a glass tube that contains an optically active solution. Explain how you would use the apparatus in (a) to measure the concentration of the solution. *[4]*

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Option B — Quantum physics and nuclear physics

B1. This question is about quantum physics and electrons.

(a) Photons of frequency 2.1×10^{15} Hz strike the surface of uranium and electrons are emitted from the surface. The work function of uranium is 3.6 eV.

(i) Show that the maximum kinetic energy of the emitted electrons is about 5.0 eV. *[1]*

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(ii) Explain what change to this energy would occur if the light intensity was doubled. *[1]*

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(b) The de Broglie wavelength of an electron with energy 5.0 keV is λ.

(i) Determine λ. *[4]*

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(ii) A student makes the statement "The electron wavelength is not real, it is just a mathematical construction. Electrons are particles and never waves." Outline evidence which suggests that the student's statement is **not** correct. *[2]*

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(This question continues on the following page)

(Question B1 continued)

(c) Outline how the

(i) "electron in a box" model accounts for the existence of discrete energy levels in the hydrogen atom. *[3]*

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(ii) line spectra of atomic hydrogen provide evidence for electron energy levels in the atom. *[3]*

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B2. This question is about radioactive decay.

A nucleus of the isotope iodine-124 (I-124) (proton number 53) may undergo positive beta decay to a nucleus of an isotope X.

(a) State the nuclear reaction equation for this decay. *[3]*

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(b) The half-life of iodine-124 is 4.2 days. A freshly prepared sample of the isotope has an activity of 810 Bq. Determine the activity of the sample after 6.0 days. *[3]*

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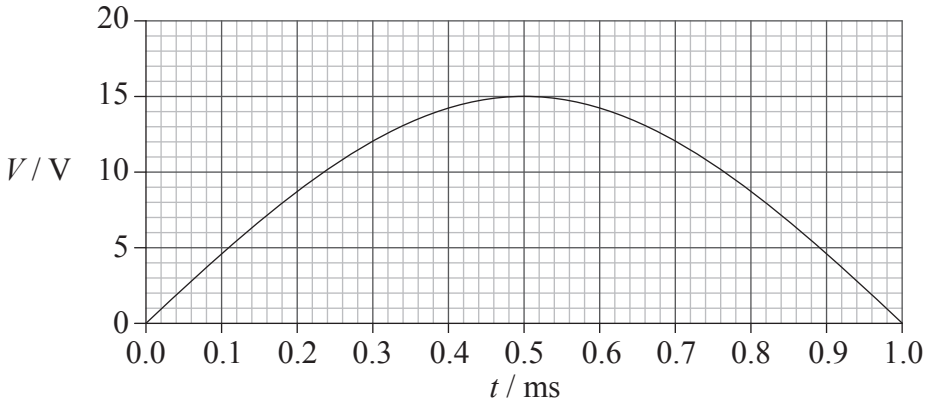
Option C— Digital technology

C1. This question is about storing information on a CD.

The graph shows how the voltage V of part of an analogue signal varies with a time t.



In order to convert this signal to a digital signal that can be stored on a CD, the signal voltage is measured at regular time intervals. The measured value is then converted into four-bit binary number by dividing the signal into 1 V levels.

(a) State

(i) the value of the voltage at 0.30 ms. *[1]*

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(ii) the four-bit binary number corresponding to the value of the voltage at 0.30 ms. *[1]*

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(iii) and explain the value of the least significant bit of the four-bit binary number in (a)(ii). *[2]*

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(This question continues on the following page)

(Question C1 continued)

(b) The binary number in (a) is encoded onto the surface of a CD as a series of pits. Outline, with the use of an appropriate diagram, how light from a laser is used to distinguish between a binary 0 and a binary 1. *[4]*

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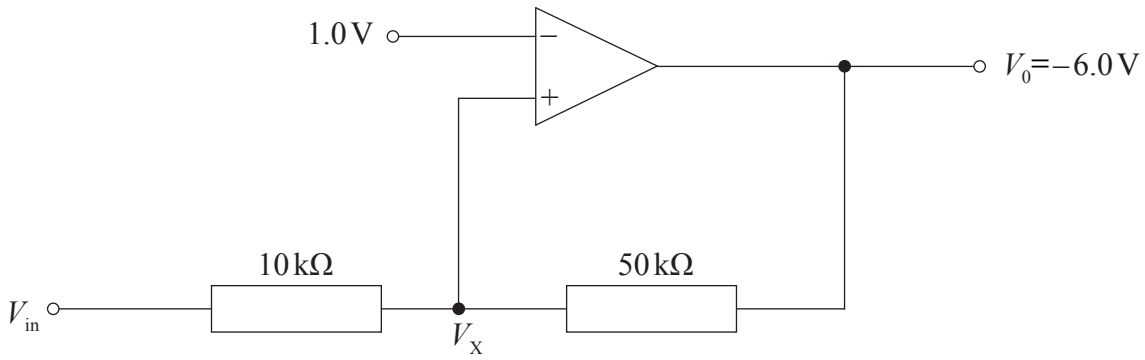
(This question continues on the following page)

(Question C1 continued)

(c) As a result of noise in electric circuits, digital pulses can often lose their shape and hence distort the information that they carry. The pulses can be re-shaped using a circuit called a Schmitt trigger.

In the situation shown the output voltage V_0 of the amplifier is at its minimum value of $-6.0\,\text{V}$. The voltage at the non-inverting input to the amplifier is equal to $1.0\,\text{V}$ and at the inverting input it is V_X. The output voltage will switch to its maximum value $+6.0\,\text{V}$ if the voltage V_X just exceeds $+1.0\,\text{V}$.



Determine the minimum voltage V_{in} that will result in an output voltage of $+6.0\,\text{V}$. *[4]*

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C2. This question is about CCDs.

(a) Define *capacitance*. *[1]*

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(b) Light of a particular frequency and intensity $1.2\,\text{mW}\,\text{m}^{-2}$ is reflected from an object on to a pixel of a CCD. The area of the pixel is $5.5\times10^{-10}\,\text{m}^2$ and its capacitance is 2.2 pF. The energy of a photon of the light is 4.6×10^{-19} J.

(i) Deduce that the rate at which photons are incident on the pixel is $1.4\times10^{6}\,\text{s}^{-1}$. *[2]*

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(ii) Using the answer to (b)(i), determine the time it takes the potential across the pixel to change by $40\,\mu\text{V}$. *[4]*

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(iii) State **one** assumption that you have made in arriving at your answer in (b)(ii). *[1]*

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Option D — Relativity and particle physics

D1. This question is about special relativity.

(a) State what is meant by an inertial frame of reference. *[1]*

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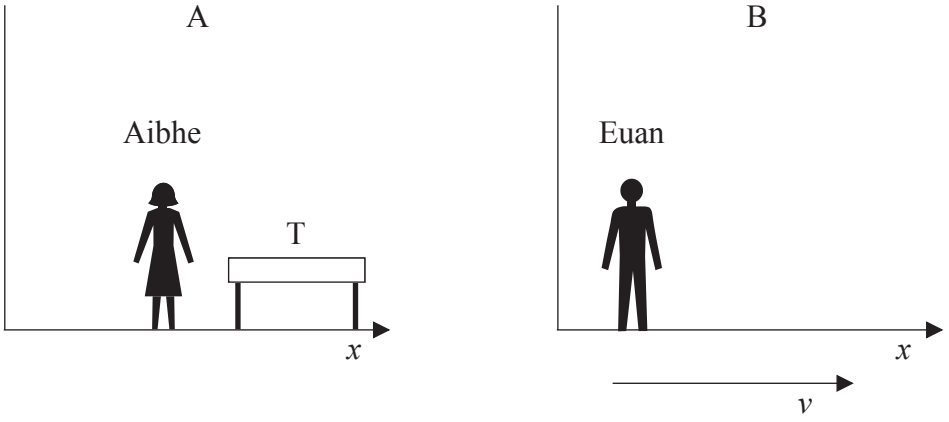
(b) Aibhe is at rest in an inertial frame of reference A and Euan is at rest in an inertial frame of reference B. B is moving in the *x*-direction, with speed *v,* relative to A. The table T is at rest with respect to Aibhe.



Aibhe measures the length of T to be 1.5 m and Euan measures it to be 1.2 m.

(i) Explain which observer measures the proper length of T. *[1]*

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(ii) Determine the speed *v*. *[4]*

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(This question continues on the following page)

(Question D1 continued)

(c) Two insects land at the same point on T. According to a clock at rest with respect to Aibhe, one of the insects lands 2.4 seconds after the other. Calculate, according to Euan, the time interval between the landings of each insect. *[1]*

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(d) Two other insects land at either end of the table. These two events may occur at the same time as measured by one of the observers (Aibhe or Euan) but not to the other. Outline, with reference to the postulates of relativity, why these times differ. *[3]*

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D2. This question is about fermions and bosons.

(a) Distinguish, with reference to the Pauli exclusion principle, the difference between fermions and bosons. *[2]*

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(b) Identify the boson that mediates the

(i) electromagnetic interaction between electrons. *[1]*

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(ii) strong interaction between nucleons. *[1]*

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(c) The strong interaction between nucleons has a range of the order of 10^{-15} m. Show that the mass of the boson in (b)(ii) is about 100 MeV c^{-2}. *[3]*

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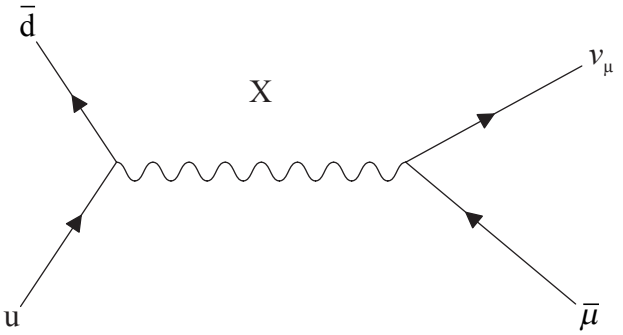
(Question D2 continued)

(d) The Feynman diagram shows the decay of a meson into an anti-muon and a neutrino.



(i) State the charge on the meson and on the anti-muon and explain your answers. *[2]*

Meson: . . . . . .

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Anti-muon: . . . . . .

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

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Option E — Astrophysics

E1. This question is about the star Becrux and Cepheid variables.

(a) Describe what is meant by

(i) the apparent magnitude scale. *[2]*

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(ii) absolute magnitude. *[1]*

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(b) Becrux is a main sequence star and is one of the stars that make up the Southern Cross. The following data are available for Becrux.

Apparent magnitude $= 1.25$
Absolute magnitude $= -3.92$
Apparent brightness $= 7.00 \times 10^{-12} b_{\text{Sun}}$

b_{Sun} is the apparent brightness of the Sun. Use the data to deduce that the

(i) distance of Becrux from Earth is 108 pc. *[3]*

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(ii) luminosity of Becrux is $3.43 \times 10^3 L_{\text{Sun}}$ where L_{Sun} is the luminosity of the Sun. ($1\,\text{pc} = 2.05 \times 10^5\,\text{AU}$) *[3]*

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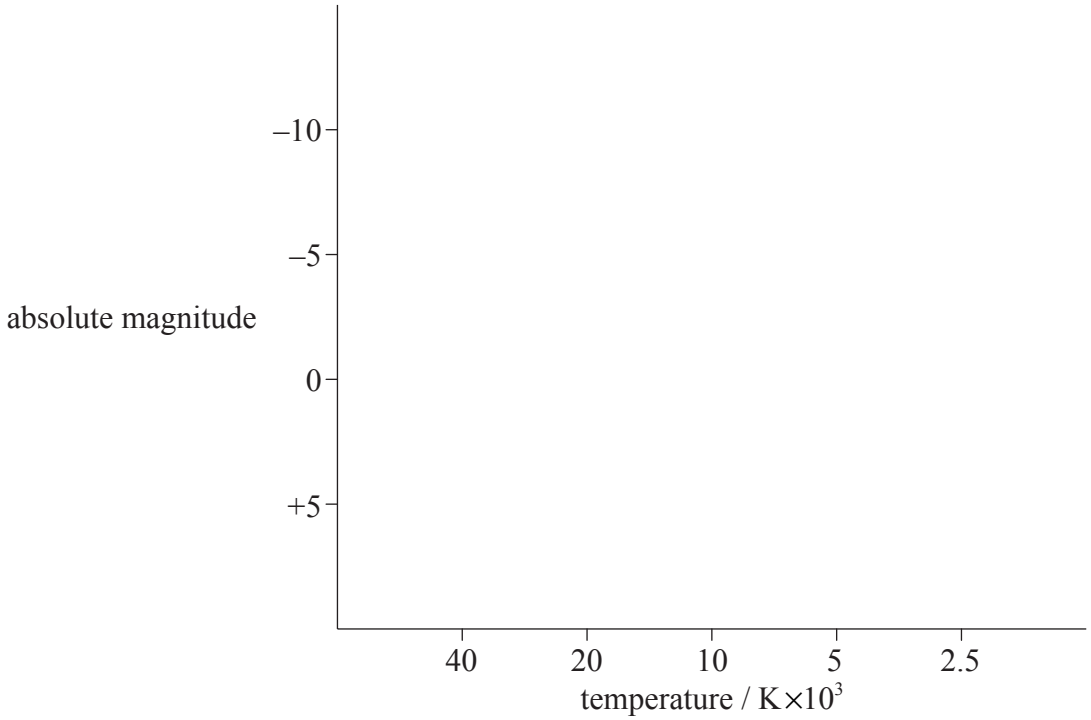
(This question continues on the following page)

(Question E1 continued)

(c) Becrux is a spectral class B star. On the axes of the Hertzsprung–Russell diagram label with the letter B the approximate position of Becrux. *[1]*



(d) On the axes of the Hertzsprung–Russell diagram above, draw the approximate region in which Cepheid variable stars are located. *[1]*

(e) State the reason for the periodic variation in luminosity of a Cepheid variable. *[1]*

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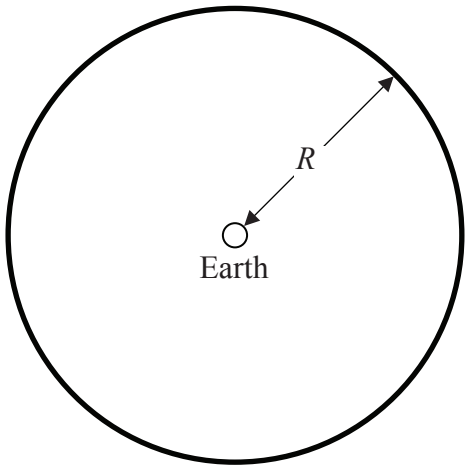
(f) State the **two** quantities that need to be measured in order to use a Cepheid variable as a "standard candle" to determine the distance to the galaxy in which the Cepheid is located. *[2]*

1. . . . . .

2. . . . . .

E2. This question is about cosmology.

(a) The diagram below represents a spherical region of space based on Newton's model of the universe. Earth is at the centre of the region. The dark line represents a very thin spherical shell of space distance R from Earth.



With reference to the diagram and Newton's model of the universe explain **quantitatively** Olbers' paradox. *[4]*

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(b) Outline how the Big Bang theory provides a resolution to Olbers' paradox. *[2]*

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Option F— Communications

F1. This question is about modulation.

(a) Distinguish between a signal wave and carrier wave. *[2]*

Signal wave: . . . . . .

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Carrier wave: . . . . . .

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(b) With reference to a carrier wave, distinguish between amplitude modulation and frequency modulation. *[1]*

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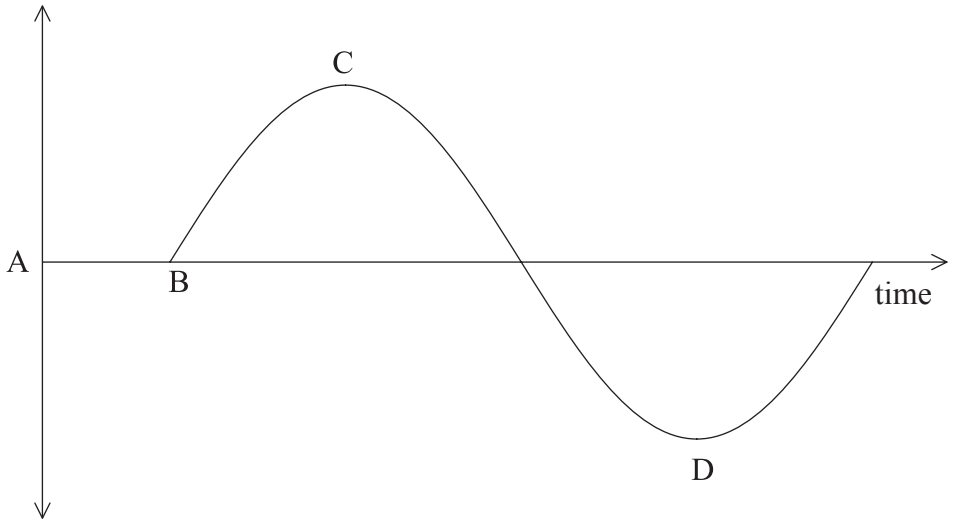
(c) The diagram is a sketch of an audio frequency signal.



A radio wave is frequency modulated by the audio frequency signal. State the changes, if any, in the frequency of the modulated signal in the following time intervals. *[3]*

A → B . . . . . .

B → C . . . . . .

C → D . . . . . .

(This question continues on the following page)

(Question F1 continued)

(d) For a particular frequency modulated carrier wave, the maximum frequency occurs every 1.2 ms. There are 2.2×10^5 oscillations between each maximum frequency. Determine the frequency of the

(i) signal wave. *[2]*

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(ii) carrier wave. *[2]*

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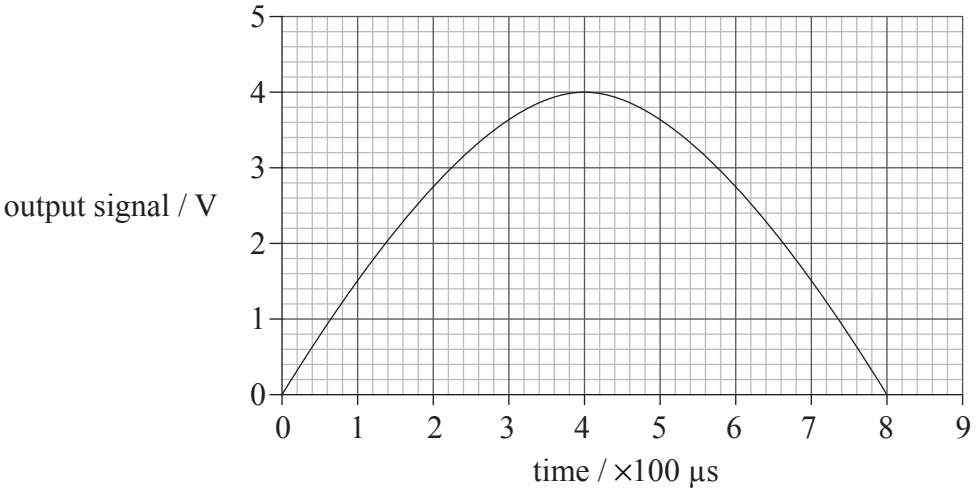
F2. This question is about digital signals.

(a) The graph shows the variation with time of an analogue signal.



In order to convert the analogue signal into a 3-bit digital signal it is sampled every 100 μs. The possible output voltages of the analogue to digital converter that is used are shown below.

Analogue signal / V	Binary output
0 – < 0.5	000
0.5 – < 1.0	001
1.0 – < 1.5	010
1.5 – < 2.0	011
2.0 – < 2.5	100
2.5 – < 3.0	101
3.0 – < 3.5	110
3.5 – < 4.0	111

(This question continues on the following page)

(Question F2 continued)

Determine, explaining your answer, the

(i) bit-rate (data transfer rate). *[2]*

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(ii) digital output of the signal for the sixth sample starting from $t = 0\,\text{s}$. *[2]*

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(b) Explain the effects that increasing the sampling frequency and number of bits will have on the quality of the representation of the analogue signal. *[3]*

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(c) The digital signal in (a) is to be transmitted along an optic fibre that has a power loss of $2.0\,\text{dB}\,\text{km}^{-1}$.

(i) State, in watts, how power loss is defined on the decibel scale. *[1]*

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(ii) Calculate the distance travelled by the signal that will result in a power loss of 75 %. *[2]*

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Option G — Electromagnetic waves

G1. This question is about the electromagnetic spectrum.

(a) The transmission from a television station has a frequency of 100 MHz. It is known that the electromagnetic waves associated with this transmission produce a magnetic field. State **one** reason why a compass does **not** respond to this field. *[1]*

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(b) It is proposed that instead of using radio waves for television transmission gamma-rays are used.

(i) State a typical gamma-ray frequency. *[1]*

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(ii) Suggest **one** disadvantage of using gamma-rays for television transmission. *[1]*

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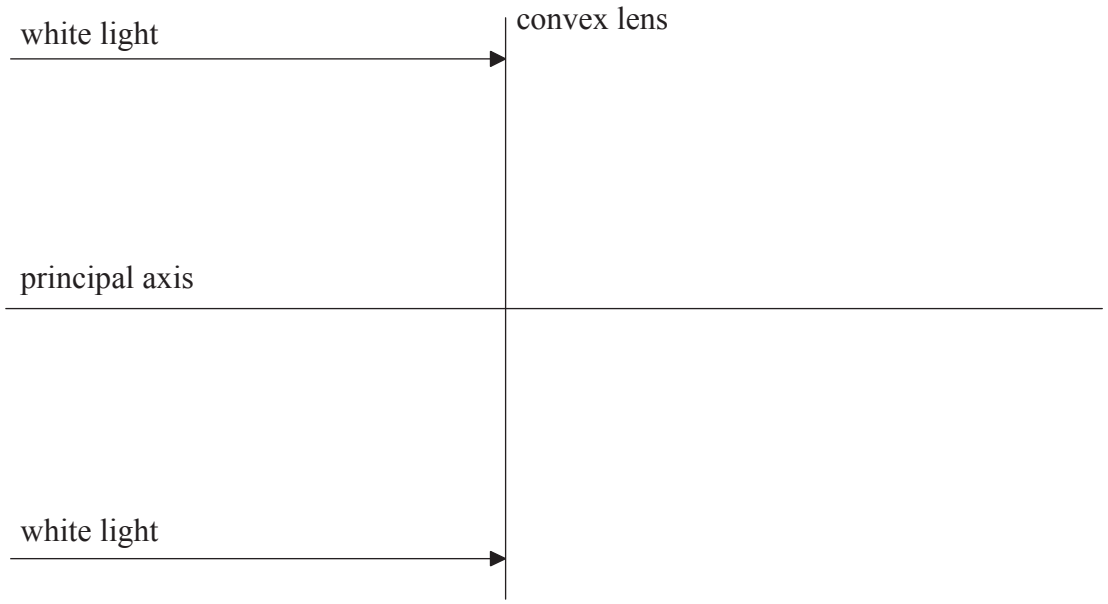
G2. This question is about chromatic aberration and a lens.

(a) Two parallel rays of white light are incident on a convex lens.



On the diagram, after refraction in the lens, draw the paths for the rays of red light and blue light present in the white light. *[2]*

(b) Use your diagram in (a) to explain chromatic aberration. *[3]*

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(c) State **one** way in which chromatic aberration may be reduced. *[1]*

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(This question continues on the following page)

(Question G2 continued)

(d) An object is placed 5.0 cm from the lens and is illuminated with red light. The focal length of the lens for red light is 8.0 cm. Calculate the

(i) position of the image. *[2]*

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(ii) linear magnification. *[1]*

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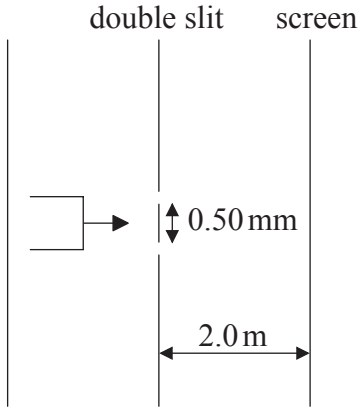
G3. This question is about two-source interference.

(a) Light from a laser is incident on two identical parallel slits whose width is small compared to their separation.



(diagram not to scale)

After passing through the slits the light is incident on a screen. The separation of the slits is 0.50 mm and the distance between slits and screen is 2.0 m. The wavelength of the light is 700 nm.

(i) State why a laser is used as the light source. *[1]*

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(ii) Determine the separation of points of maximum intensity on the screen. *[2]*

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(iii) Describe the effect that increasing the number of slits would have on the intensity pattern on the screen. *[2]*

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(This question continues on the following page)

(Question G3 continued)

(b) The slits in (a) are replaced with a diffraction grating that has 3.5×10^5 lines per metre. Determine the number of positions of maximum intensity that will be observed on the screen. *[3]*

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