22096512

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Baccalauréat International
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PHYSICS
STANDARD LEVEL
PAPER 3

Wednesday 13 May 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.

22096512

Option A — Sight and wave phenomena

A1. This question is about vision and resolution.

(a) Compare scotopic with photopic vision. *[2]*

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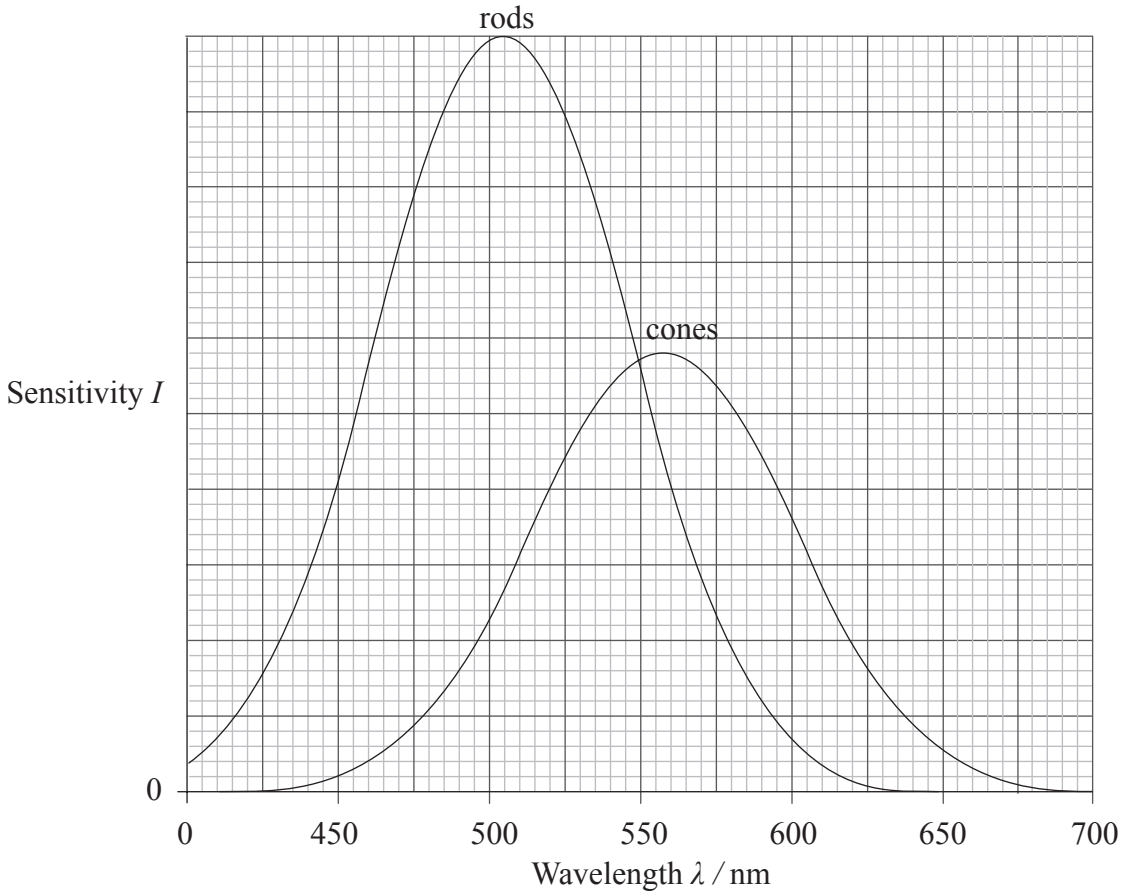
(b) The graph shows the variation with wavelength λ of the sensitivity I, of the rod and the cone cells of a human eye.



(This question continues on the following page)

(Question A1 continued)

A red piece of paper and a blue piece of paper are both viewed in very low intensity light. Each piece of paper reflects the same intensity of light.

With reference to the graph, state and explain which one of the two pieces of paper will be more clearly visible. *[3]*

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(c) The diameter of the pupil of a human eye is 1.5 mm.

(i) Calculate the minimum angular separation of two points that can be resolved by the human eye for light of wavelength 680 nm. *[1]*

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(ii) Two stars, the same distance from Earth, are separated by a distance of 4.0×10^{13} m . Both stars emit light of wavelength 680 nm.

The two stars are just resolved by an observer on Earth. Estimate the distance to the two stars. *[2]*

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A2. This question is about polarization.

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

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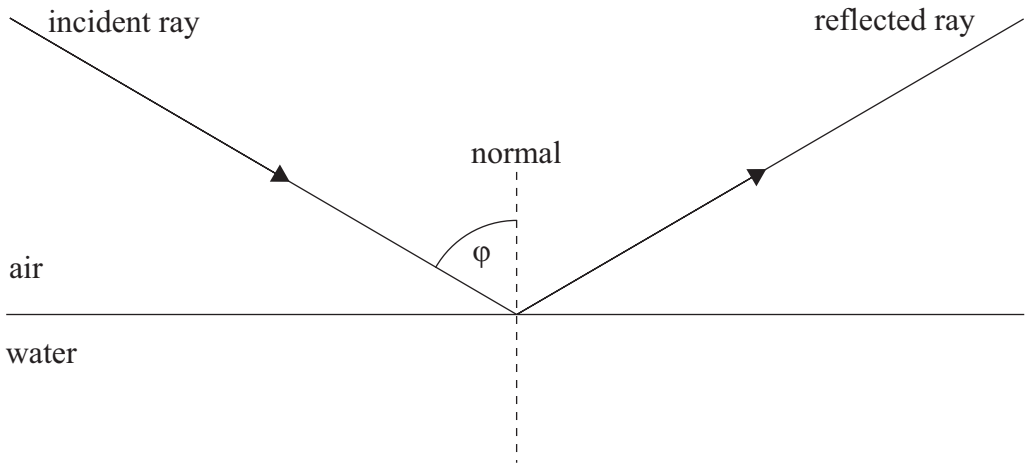
(b) A ray of light is incident on the surface of a lake. The angle of incidence is φ.



The reflected light is completely polarized horizontally.
The refractive index of water is *n*.

(i) On the diagram above draw the refracted ray. *[1]*

(ii) Use the diagram to deduce the relationship between *φ* and *n*. *[3]*

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(iii) The refractive index of the water is 1.3. Calculate the value of φ. *[1]*

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A3. This question is about the Doppler effect.

(a) State what is meant by the Doppler effect. *[2]*

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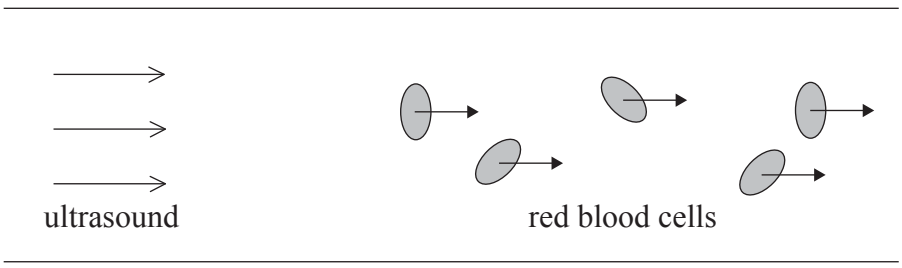
(b) Ultrasound of frequency 5.2 MHz is directed from a stationary source towards red blood cells in an artery. A simplified diagram is shown below in which the blood cells are travelling in the same direction.



The ultrasound is reflected from the cells and is received back at the source. The measured frequency shift is 3.5 kHz. The speed of ultrasound in blood is $1.5\times10^{3}\ \text{m s}^{-1}$. The frequency shift is determined from $\frac{\Delta f}{f}=\frac{2v}{c}$.

(i) State the significance of the factor of 2 in the formula for the frequency shift. *[1]*

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(ii) Determine the speed of the red blood cells. *[1]*

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(iii) State **two** reasons why, in practice, the frequency shift will have a range of values. *[2]*

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Option B — Quantum physics and nuclear physics

B1. This question is about the photoelectric effect.

(a) In the photoelectric effect, electrons are emitted from a metallic surface only if the wavelength of the light incident on the surface is below a certain value called the threshold wavelength.

Explain this observation. *[3]*

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(b) A monochromatic source of power 3.0 W emits light of wavelength 4.60×10^{-7} m. All of the light is incident on a metal surface and causes electrons to be emitted at a rate of 4.0×10^{10} s^{-1}. The threshold wavelength of the metal is 5.50×10^{-7} m.

Calculate

(i) the photoelectric current. *[1]*

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

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(iii) the ratio of the rate of electron emission to the rate at which the photons are incident on the metal. *[3]*

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(Question B1 continued)

(c) Light from a different source is incident on the metal in (b). The new source has power 6.0 W and emits light of wavelength 9.00×10^{-7} m.

State the effect of these changes, if any, on your answer to (b)(i). *[1]*

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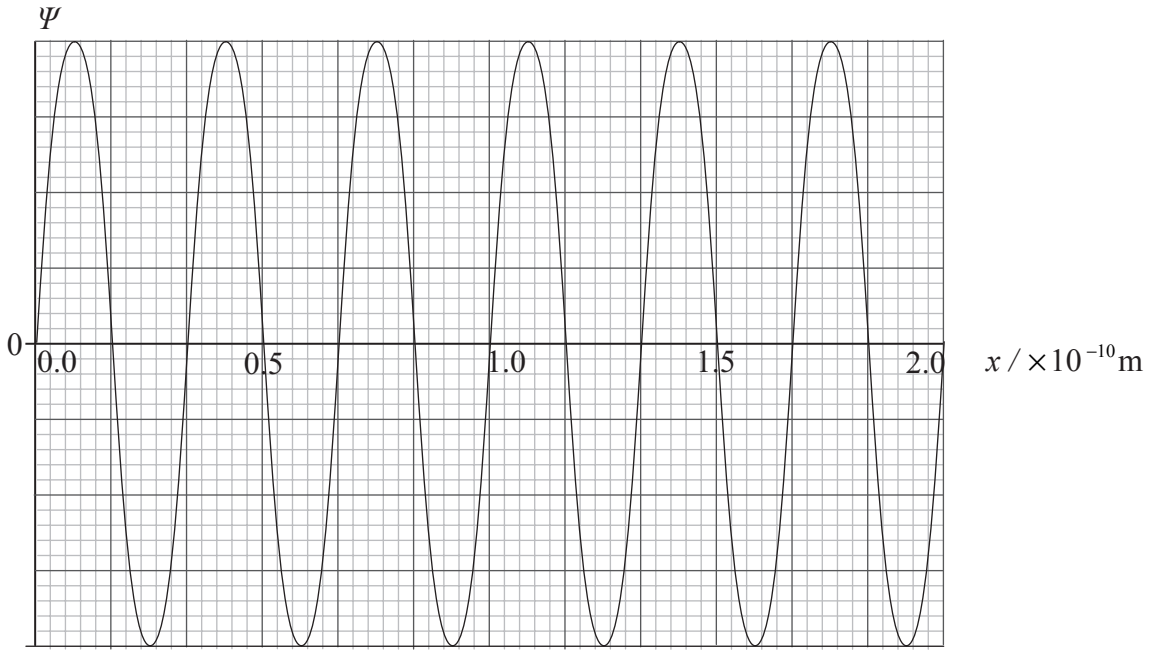
B2. This question is about quantum aspects of the electron.

The graph shows the variation with distance x of the wavefunction Ψ of an electron at a particular instant of time. The electron is confined within a region of length 2.0×10^{-10} m.



(a) State what is meant by the wavefunction of an electron. *[1]*

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(b) Using data from the graph estimate, for this electron,

(i) its momentum. *[2]*

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(ii) the uncertainty in its momentum. *[2]*

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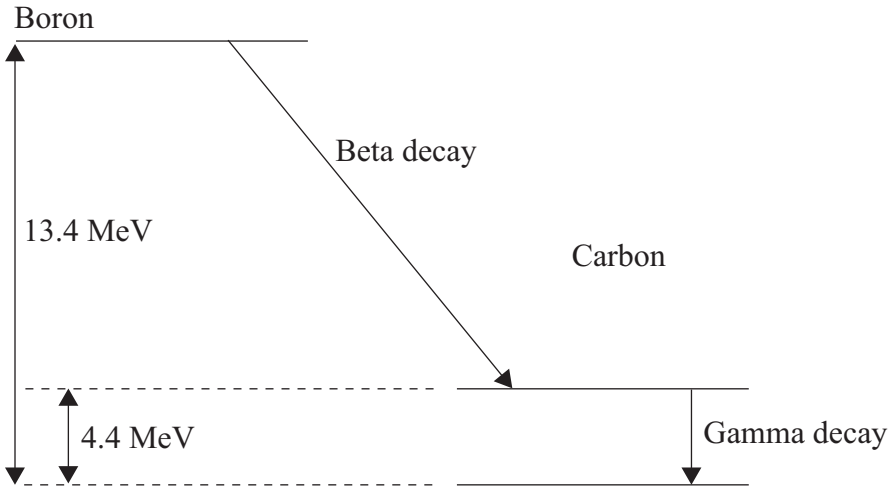
B3. This question is about nuclear energy levels and radioactive decay.

The diagram shows some of the nuclear energy levels of the boron isotope ${}^{12}_{5}\mathrm{B}$ and the carbon isotope ${}^{12}_{6}\mathrm{C}$. Differences in energy between the levels are indicated on the diagram. A particular beta decay of boron and a gamma decay of carbon are marked on the diagram.



(a) Calculate the wavelength of the photon emitted in the gamma decay. *[2]*

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(b) Calculate the maximum kinetic energy of the electron emitted in the beta decay indicated. *[1]*

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(c) Explain why the electrons emitted in the indicated beta decay of boron do not always have the kinetic energy calculated in (b). *[2]*

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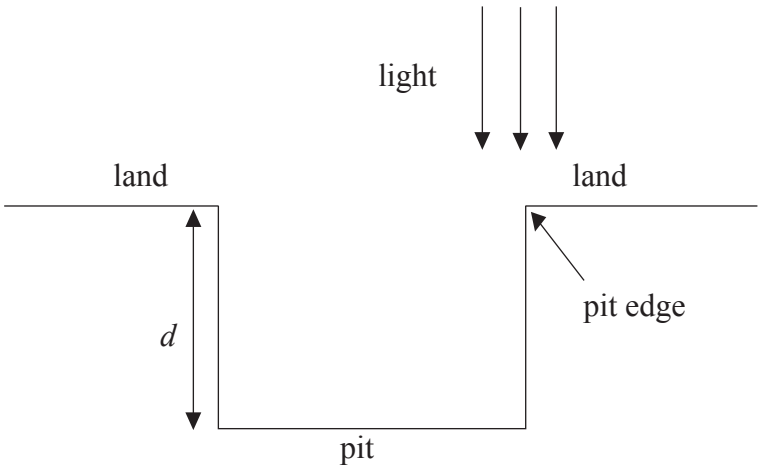
Option C— Digital technology

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

The diagram shows light from a laser that is incident on a CD.



The reflected light is used to read the data stored on the CD. The depth of the pits is d and the wavelength of the light is λ.

(a) Explain the relationship between λ and d that allows the laser beam to detect the edge of a pit. *[4]*

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(b) The wavelength of the laser light is 640 nm. Calculate the pit depth d. *[1]*

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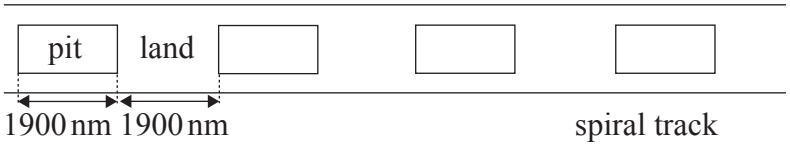
(Question C1 continued)

(c) The diagram shows a series of pits on one part of the spiral track of an audio CD. The average length of one pit and the average length of one land are both 1900 nm.



Information is stored on the CD with a sampling frequency of 44.1 kHz. Each sample consists of **two** 16 bit binary numbers.

(i) The total length of the spiral on the CD is approximately 5 km. On average the number of bits stored on a CD is equal to four times the number of pits. Show that the storage capacity of this CD is approximately 5×10^9 bits. *[2]*

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(ii) Using the answer to (c)(i) calculate the playing time of this audio CD. *[2]*

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(d) Describe **one** advantage, other than amount of data, of storing music on a CD rather than on a vinyl LP record. *[1]*

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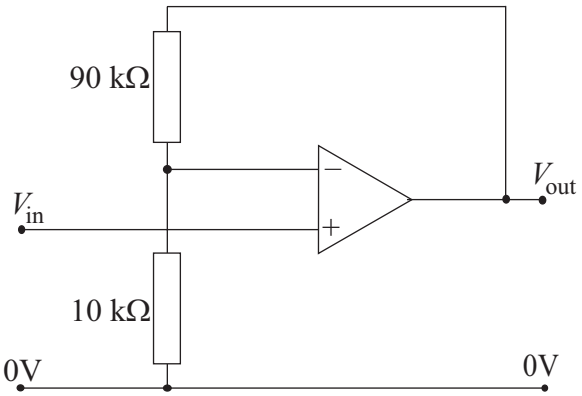
C2. This question is about the operational amplifier.

Diagram 1 shows a non-inverting amplifier circuit.

Diagram 1



(a) Suggest why the amplifier is referred to as non-inverting. *[1]*

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(b) The input voltage for the amplifier in (a) is $V_{in} = 2.0\ \text{mV}$.

Calculate

(i) the gain G of the amplifier. *[1]*

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(ii) the output voltage V_{out}. *[1]*

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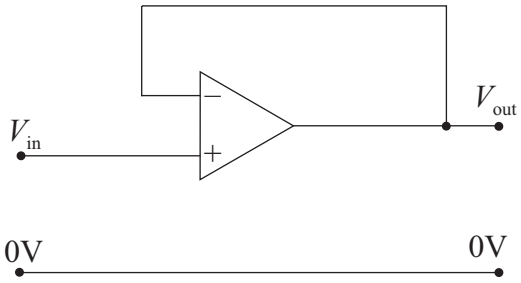
(Question C2 continued)

(c) Diagram 2 shows a particular non-inverting amplifier.

Diagram 2



Explain, in terms of the properties of an op-amp, why the gain of this non-inverting amplifier is equal to 1. *[3]*

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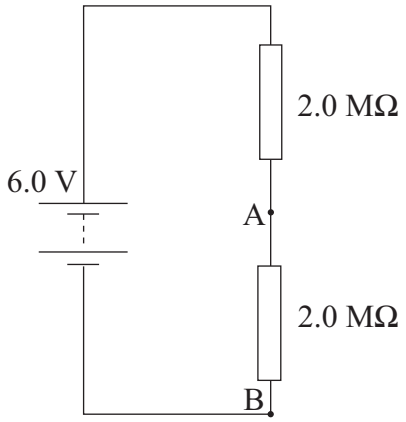
(Question C2 continued)

(d) Diagram 3 shows a circuit in which the battery has an emf of 6.0 V and negligible internal resistance. Two $2.0\ \text{M}\Omega$ resistors are connected in series to the battery.

Diagram 3



(i) State the value of the potential difference between points A and B. *[1]*

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(ii) A voltmeter of resistance $100\ \text{k}\Omega$ is used to measure the potential difference across points A and B.

State why the reading on the voltmeter is **not** equal to the value stated in (d)(i). *[1]*

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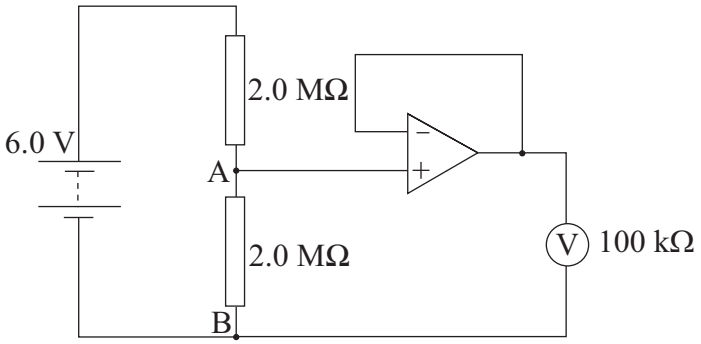
(Question C2 continued)

(iii) The circuit in diagram 3 is modified to include the circuit shown in diagram 2.

Diagram 4



Explain why the voltmeter reads the value of the potential difference as stated in (d)(i). *[2]*

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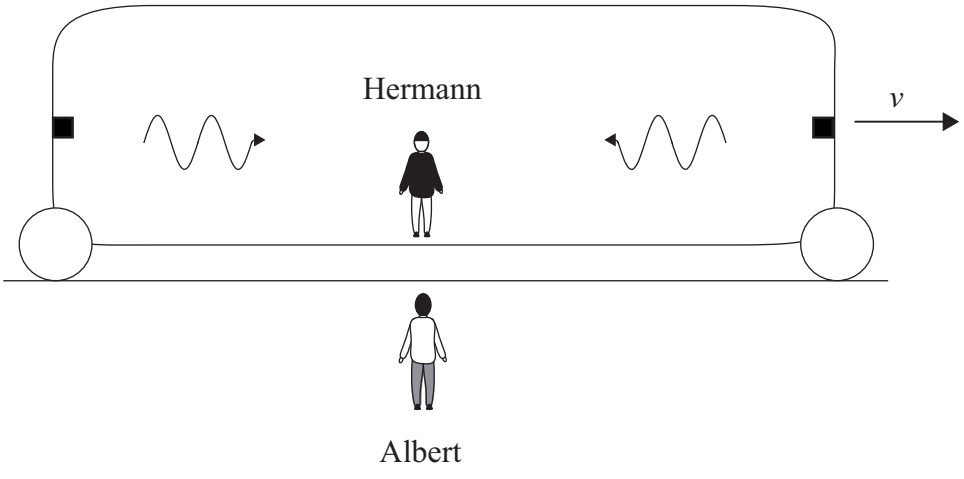
Option D — Relativity and particle physics

D1. This question is about simultaneity.

Albert is at rest with respect to the ground. Hermann is in a carriage that is moving with speed v relative to Albert in the direction shown. Two flashes of light are emitted from the back and the front of the carriage. According to Hermann's clock they arrive at Hermann's position simultaneously.



Explain with reference to the concept of proper time, why the arrival of the light pulses at Hermann will also be simultaneous to Albert. *[3]*

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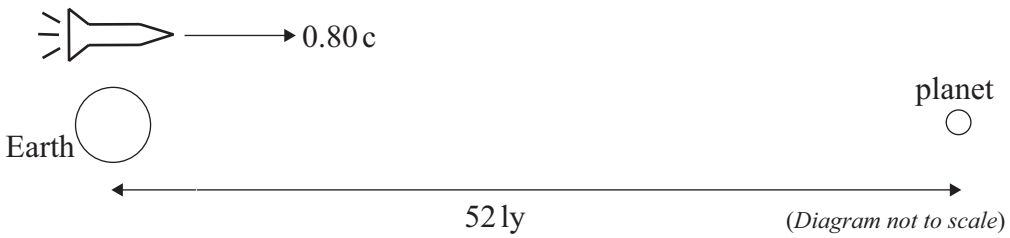
D2. This question is about relativistic kinematics.

A spacecraft leaves Earth at a speed of 0.80c as measured by an observer on Earth. It heads towards, and continues beyond, a distant planet. The planet is 52 light years away from Earth as measured by an observer on Earth.



(*Diagram not to scale*)

When the spacecraft leaves Earth, Amanda, one of the astronauts in the spacecraft, is 20 years old.

The Lorentz gamma factor for a speed of 0.80c is $\gamma = \frac{5}{3}$.

(a) Calculate

(i) the time taken for the journey to the planet as measured by an observer on Earth. *[1]*

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(ii) the distance between the Earth and the planet, as measured by Amanda. *[1]*

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(iii) Amanda's age as the spacecraft goes past the planet, according to Amanda. *[2]*

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(b) As the spacecraft goes past the planet Amanda sends a radio signal to Earth. Calculate, as measured by the spacecraft observers, the time it takes for the signal to arrive at Earth. *[3]*

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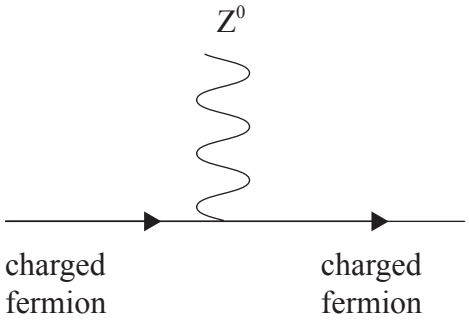
D3. This question is about fundamental interactions.

The diagram below shows an interaction vertex of the weak interaction.



(a) (i) Draw a Feynman diagram, for the process $e^- + e^+ \rightarrow \mu^- + \mu^+$ using the information given in the diagram above. *[1]*

(ii) Identify the virtual particle in the Feynman diagram that you drew in (a)(i). *[1]*

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(b) The closest distance between the electron-positron pair and the muon-antimuon pair in the reaction $e^- + e^+ \rightarrow \mu^- + \mu^+$ is approximately $9 \times 10^{-19}\,\text{m}$.

Use this information to estimate the mass of the virtual particle in (a)(ii). *[3]*

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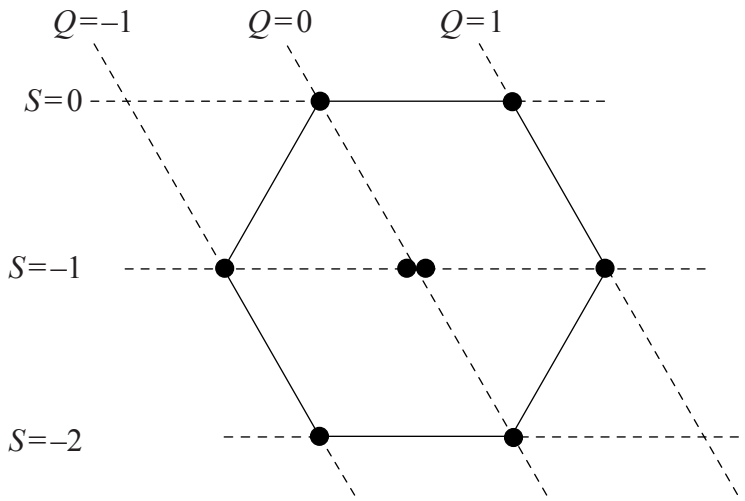
D4. This question is about quarks.

The diagram below shows the eight spin $\frac{1}{2}$ baryons made out of the three lightest quarks, the up (u), the down (d) and the strange (s). In this plot baryons belonging to the same horizontal line have the same strangeness (S) and those along the same slanted line have the same charge (Q).



(a) (i) On the diagram above draw a circle around the point representing the neutron. *[1]*

(ii) State the quark content of the neutron. *[1]*

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(b) The Ξ^- baryon is unstable and decays according to the reaction $\Xi^- \rightarrow \Lambda^0 + \pi^-$.

The quark content of the particles involved is $\Xi^- = \text{ssd}$, $\Lambda^0 = \text{uds}$ and $\pi^- = \text{d}\bar{\text{u}}$.

State and explain whether the interaction involved in this decay is electromagnetic, strong or weak. *[3]*

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Option E — Astrophysics

E1. This question is about stars.

(a) Distinguish between apparent magnitude and absolute magnitude. *[2]*

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(b) The table gives information on three stars, Achernar, EG 129 and Mira.

	Absolute magnitude	**Apparent magnitude**	**Spectral class**
Achernar	–3.0	+0.50	B
EG 129	+13.0	+14.0	B
Mira	–3.0	+5.0	M

(i) State which **one** of the three stars appears brightest from Earth. *[1]*

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(ii) Estimate the ratio $\frac{L_A}{L_E}$ where L_A is the luminosity of Achernar and L_E is the luminosity of EG 129. *[3]*

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(iii) Show that the distance of the star Achernar from Earth is approximately 50 pc. *[2]*

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(This question continues on the following page)

(Question E1 continued)

(c) The surface temperature of Mira is 5 times lower than that of Achernar. Estimate the ratio $\frac{R_M}{R_A}$ where R_M is the radius of Mira and R_A is the radius of Achernar. *[3]*

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(d) State and explain which of the stars in the table in (b) is a white dwarf. *[3]*

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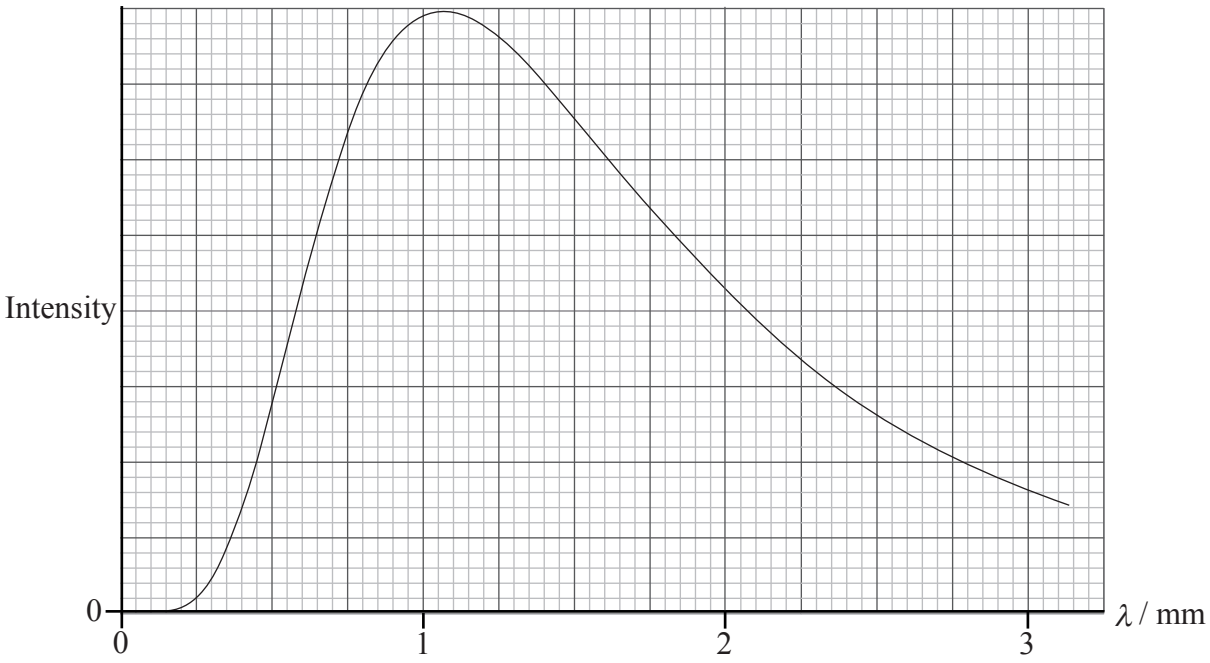
E2. This question is about cosmic microwave background radiation.

The graph shows the spectrum of the cosmic microwave background radiation.



The shape of the graph suggests a black body spectrum *i.e.* a spectrum to which the Wien displacement law applies.

(a) Use the graph to estimate the black body temperature. *[2]*

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(b) Explain how your answer to (a) is evidence in support of the Big Bang model. *[2]*

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(c) State and explain another piece of experimental evidence in support of the Big Bang model. *[2]*

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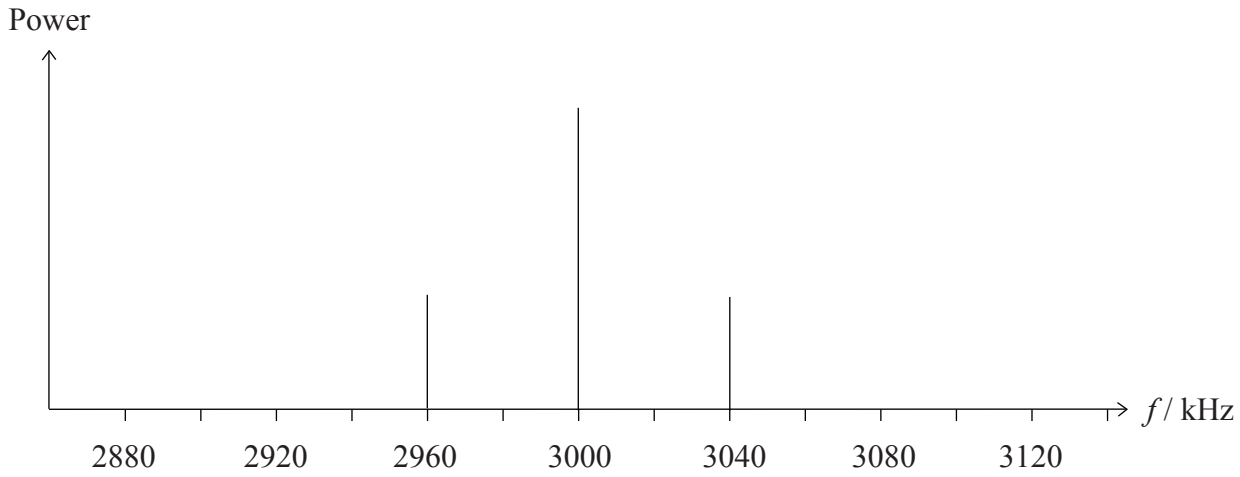
Option F— Communications

F1. This question is about amplitude modulation (AM).

The graph shows the power spectrum of an AM carrier wave.



(a) Use the graph to determine

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

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

. . . . . .

(iii) the bandwidth of the transmitted signal. *[1]*

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(b) A broadcasting company has been given permission to broadcast in a frequency range of 320 kHz. The transmissions have the bandwidth found in (a)(iii).

Determine how many radio stations the company can operate in this frequency range. *[1]*

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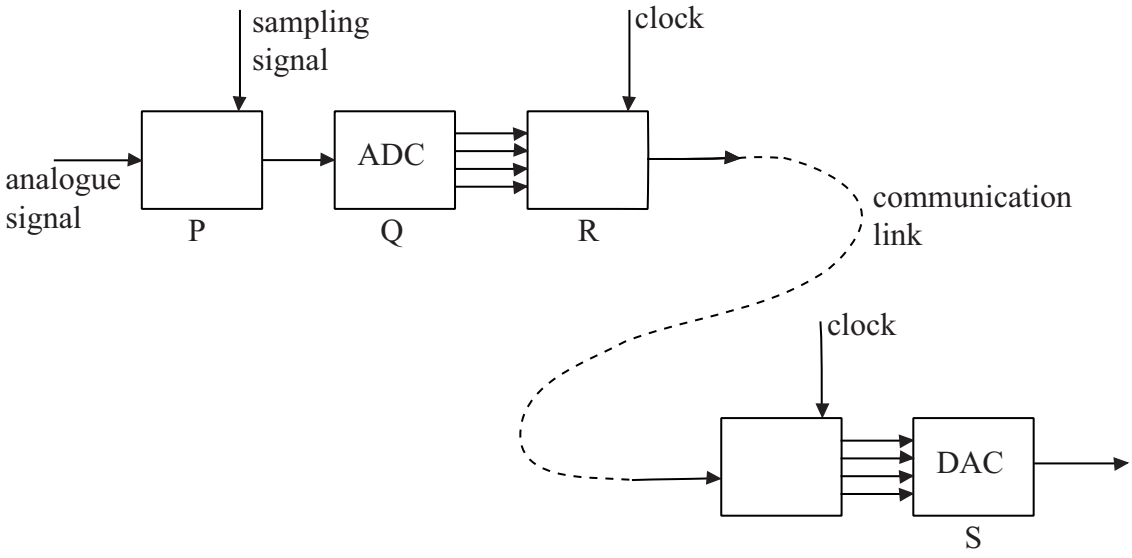
F2. This question is about transmission and sampling of signals.

(a) The block diagram illustrates the principles of the transmission and reception of digital signals.



Describe the function of each of the blocks labeled P, Q, R and S. *[4]*

P: . . . . . .
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Q: . . . . . .
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R: . . . . . .
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S: . . . . . .
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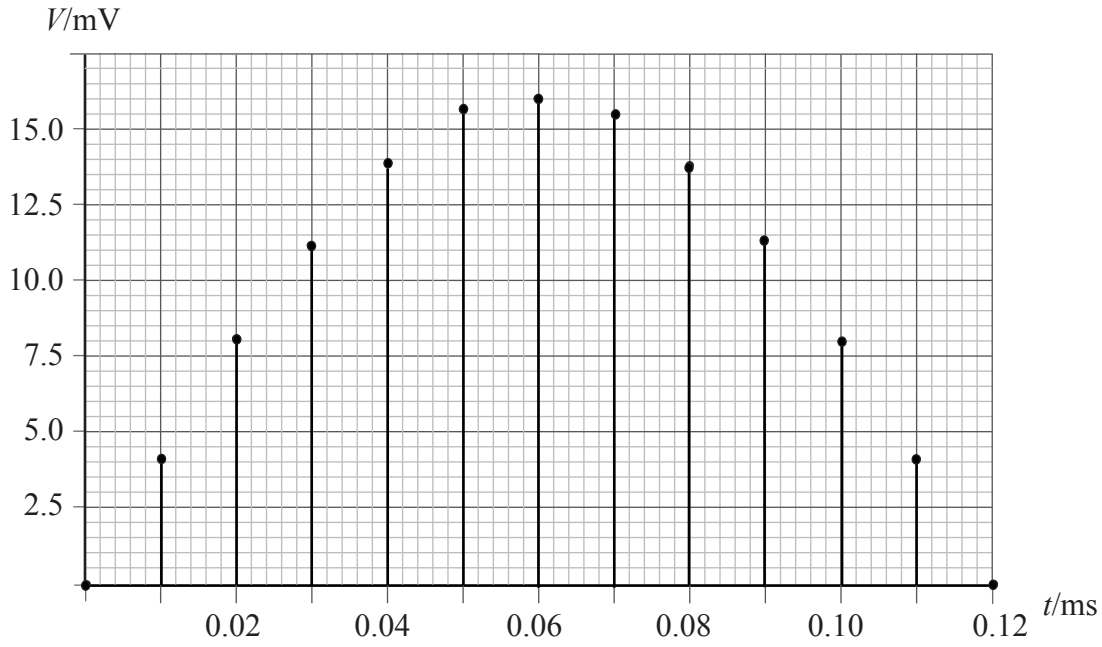
(Question F2 continued)

(b) The graph shows thirteen sampled values of an analogue signal as a function of the time at which the sampling took place.



Each sample is converted into a 4-bit binary number, according to the encoding scheme:

Signal / mV	**Sample / mV**	**4-bit binary number**
⋮	⋮	⋮
2.000–2.999	2	0010
3.000–3.999	3	0011
4.000–4.999	4	0100
⋮	⋮	⋮

(This question continues on the following page)

(Question F2 continued)

Determine

(i) the 4-bit binary number corresponding to the sample at $t = 0.07$ ms. *[1]*

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(ii) the bit-rate of the digital transmission. *[2]*

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(c) State **one** advantage and **one** disadvantage of increasing the sampling frequency used to sample an analogue signal. *[2]*

Advantage: . . . . . .

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Disadvantage: . . . . . .

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F3. This question is about optical fibres.

(a) State **one** cause of attenuation and **one** cause of dispersion in an optical fibre. *[2]*

Attenuation: . . . . . .

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Dispersion: . . . . . .

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(b) An optical fibre of length 5.4 km has an attenuation per unit length of $2.8\,\text{dB km}^{-1}$. The signal power input is 80 mW.

(i) Calculate the output power of the signal. *[2]*

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(ii) In order for the power of the output signal to be equal to the input power an amplifier is installed at the end of the fibre.

State the gain, in decibels (dB), of the amplifier at the end of the fibre. *[1]*

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(c) The signal to noise ratio (SNR), in dB, is defined as $\text{SNR} = 10\log\frac{P_{\text{signal}}}{P_{\text{noise}}}$ where P_{signal} and P_{noise} are the powers of the signal and noise respectively.

The SNR of the signal in (b) before amplification was 20 dB. Calculate the SNR after amplification. *[2]*

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Option G — Electromagnetic waves

G1. This question is about the colour of the sky.

Outline why the sky appears blue during the day and red during a sunset.

Blue sky: . . . . . *[2]*

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Red sky: . . . . . *[2]*

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G2. This question is about image formation in a convex lens.

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

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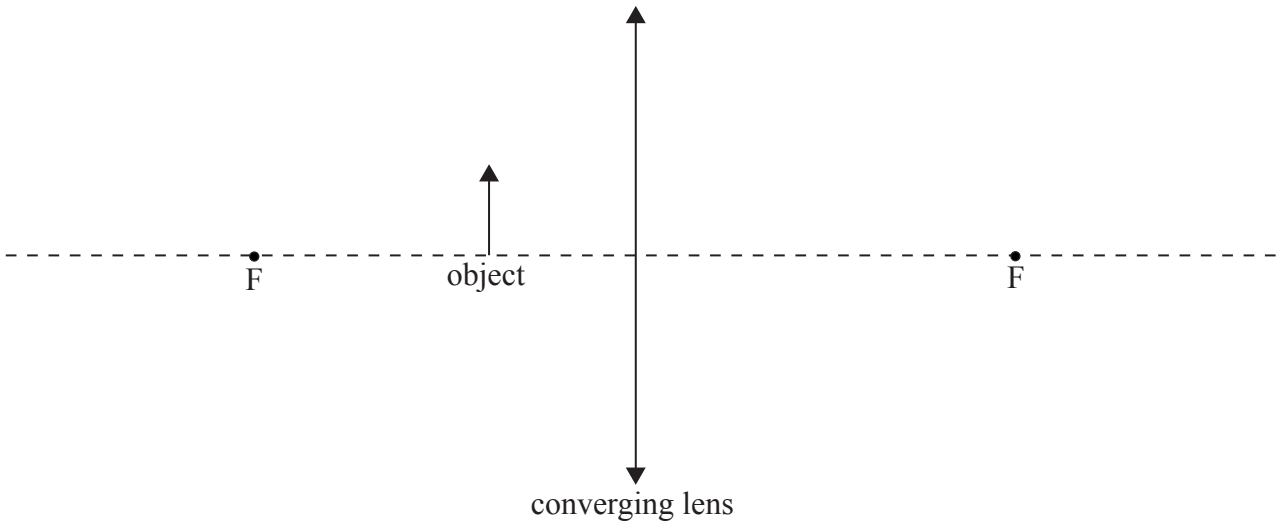
(b) A small object is placed in front of a converging lens that will act as a magnifier. The focal points of the lens are labeled with the letter F.



On the diagram construct rays to locate the image of the object. *[2]*

(This question continues on the following page)

(Question G2 continued)

(c) A particular lens has a focal length of 9.0 cm and the image is formed at the near point which is 25 cm from the lens.

Assuming that the eye is very close to the lens determine

(i) the distance of the object from the lens. *[2]*

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(ii) the angular magnification of the lens. *[1]*

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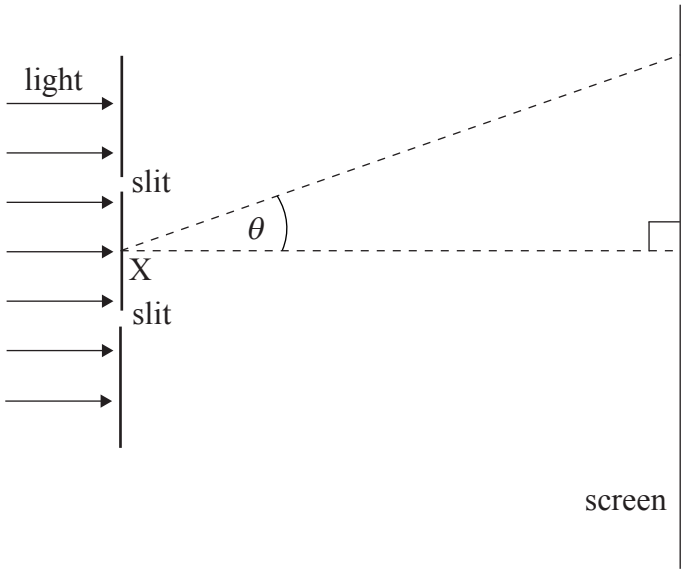
(d) The angular magnification of the lens increases with decreasing focal length.

State **one** disadvantage of using very short focal length lenses. *[1]*

. . . . . .

G3. This question is about interference.

Monochromatic, coherent light is incident on two narrow parallel slits whose widths are small compared to their separation. After passing through the slits the light is brought to a focus on a screen producing interference fringes. Point X is the midpoint of the slits.



The angular position of a point on the screen is determined by the angle θ.

(a) (i) Explain why the intensity of light at $\theta = 0$ will be a maximum. *[2]*

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(ii) The wavelength of light is 6.80×10^{-7} m and the separation of the slits is 1.13×10^{-4} m . Show that for the first order maximum $\theta = 6.02 \times 10^{-3}$ rad . *[1]*

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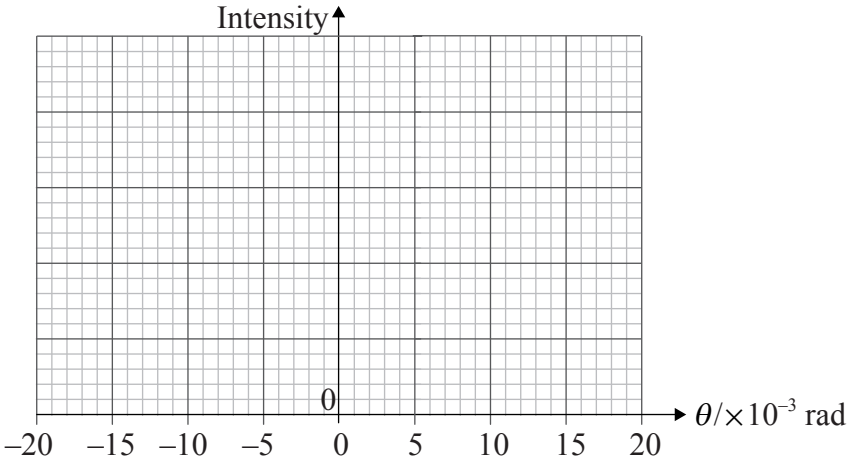
(This question continues on the following page)

(Question G3 continued)

(iii) On the axes below draw a graph to show how the intensity of light observed on the screen varies with angle θ. (You do not have to put numbers on the vertical axis.) *[3]*



(b) The two slits are replaced by a large number of slits whose widths and separation are the same as in (a).

State the changes, if any, in the intensity pattern you drew in (a)(iii) with reference to

(i) the value of the intensity at $\theta = 0$. *[1]*

. . . . . .

(ii) the angular position of the points of maximum intensity. *[1]*

. . . . . .

(iii) the angular width of the fringes. *[1]*

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