M10/4/PHYSI/SP3/ENG/TZ2/XX

22106518

International Baccalaureate
Baccalauréat International
Bachillerato Internacional

PHYSICS
STANDARD LEVEL
PAPER 3

Tuesday 11 May 2010 (morning)

1 hour

Candidate session number

0	0							

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 vision and the eye.

(a) State **one** function of

(i) cone cells. *[1]*

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(ii) rod cells. *[1]*

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(b) Describe the distribution of cone and rod cells on the retina. *[2]*

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(c) An object is to be viewed in very dim light. With reference to your answer to (b) explain why the object is most clearly seen when looked at sideways rather than directly. *[2]*

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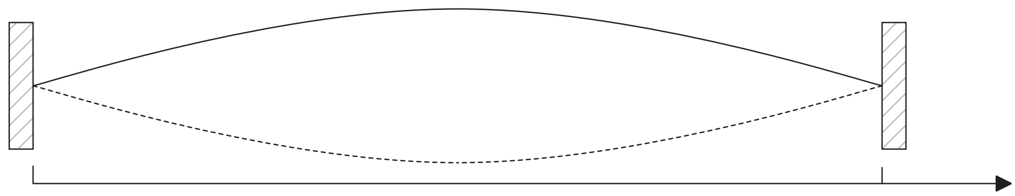
A2. This question is about standing waves.

A string that is fixed at both ends is made to vibrate in the fundamental (first harmonic) mode.



The fixed ends of the string are at $x=0$ and $x=L$.

Each point on the string oscillates in simple harmonic motion. The displacement y of the string at a point x at time t is given by the equation

$$y = A\cos(500\pi t)$$

where $A = 12\sin\left(\frac{\pi x}{2}\right)$.

In these formulae x is in metres and t is in seconds. Using this equation,

(a) explain why the amplitude of the standing wave is not constant. *[1]*

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(b) calculate the frequency of the standing wave. *[2]*

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(c) show that $L=2.0$ m. *[1]*

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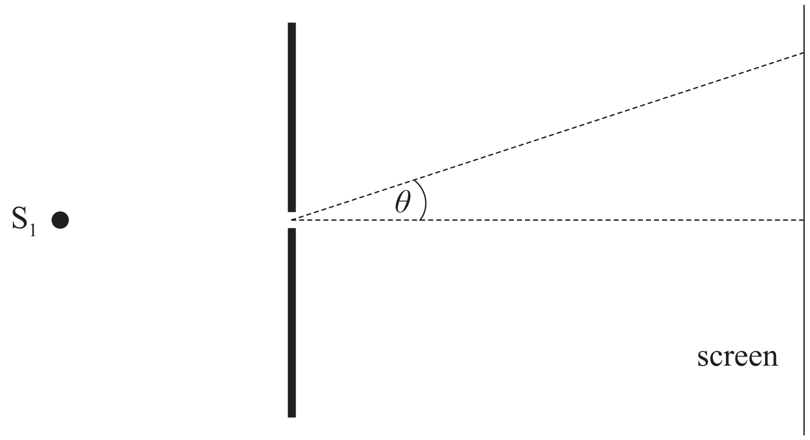
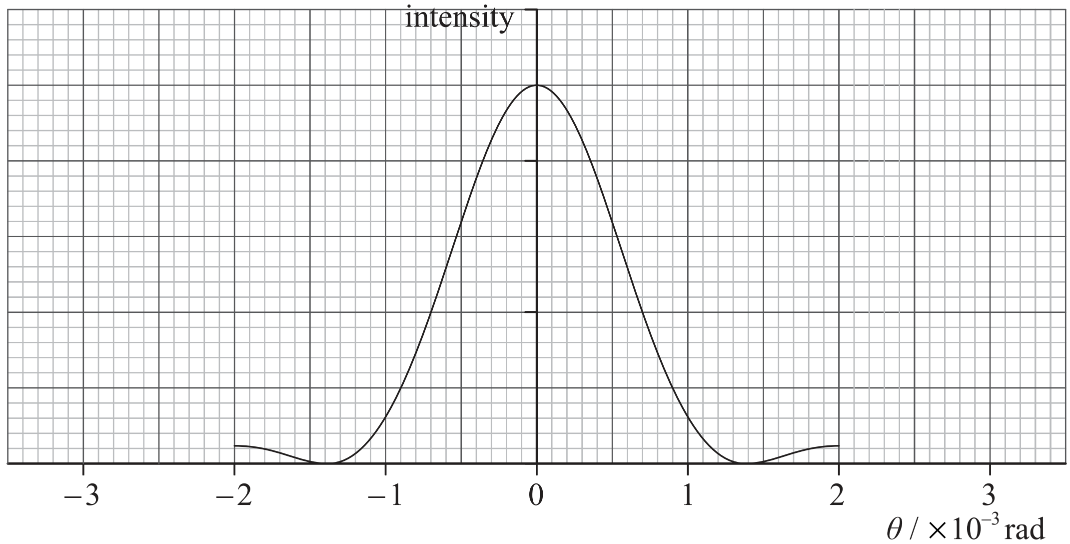
A3. This question is about diffraction and resolution.

(a) Light from a monochromatic point source S_1 is incident on a narrow rectangular slit.



After passing through the slit, the light is incident on a screen some distance away from the slit. The graph shows how the intensity distribution on the screen varies with the angle θ shown in the diagram.



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(Question A3 continued)

(i) The width of the slit is 4.0×10^{-4} m. Use data from the graph to calculate the wavelength of the light. *[2]*

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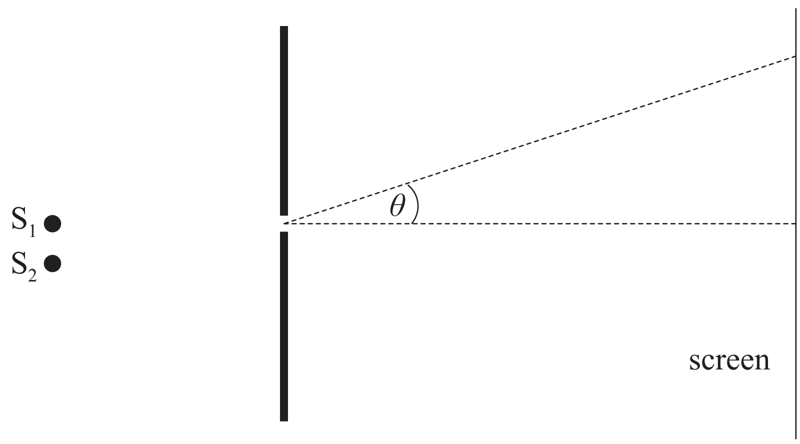
(ii) An identical source S_2 is placed close to S_1 as shown.



The images of the two sources on the screen are just resolved according to the Rayleigh criterion. On the graph opposite, draw the intensity distribution of the second source. *[1]*

(b) The Very Large Array (VLA) is used to analyse radio signals from distant galaxies. The combined diameter of the VLA is 36 km. A region of linear size L inside the radio galaxy M87 emits radio waves with a frequency of 43 GHz. The galaxy is a distance 4.7×10^{23} m from Earth. The VLA can just resolve the radio emitting region. Estimate the value of L. *[3]*

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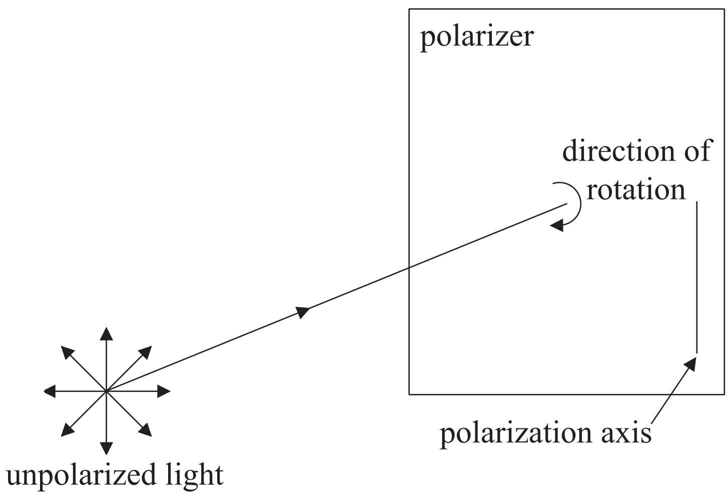
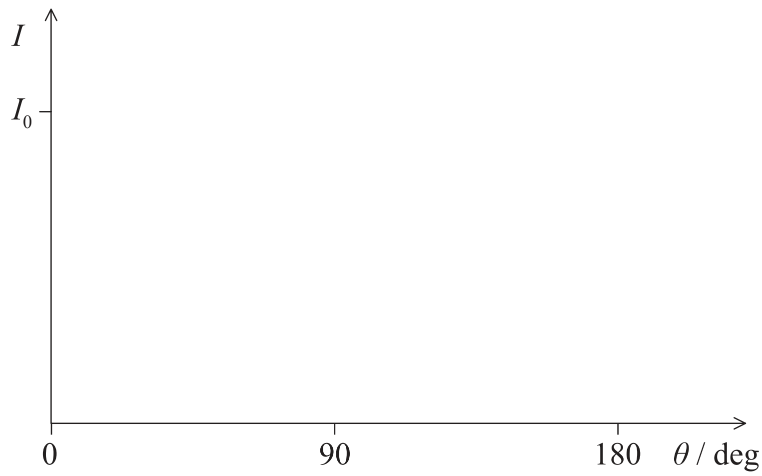
A4. This question is about polarization.

(a) A beam of unpolarized light of intensity I_0 is incident on a polarizer. The polarization axis of the polarizer is initially vertical as shown.



The polarizer is then rotated by 180° in the direction shown. On the axes below, sketch a graph to show the variation with the rotation angle θ, of the transmitted light intensity I, as θ varies from 0° to 180°. Label your sketch-graph with the letter U. *[2]*



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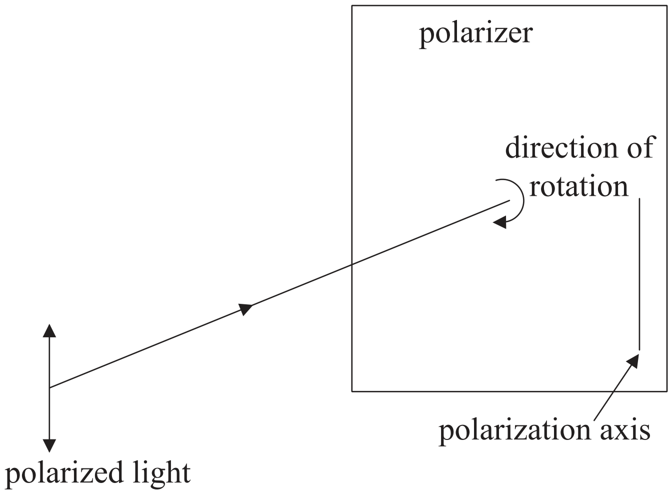
(Question A4 continued)

(b) The beam in (a) is now replaced with a polarized beam of light of the same intensity. The plane of polarization of the light is initially parallel to the polarization axis of the polarizer.



The polarizer is then rotated by 180° in the direction shown. On the same axes in (a), sketch a graph to show the variation with the rotation angle θ, of the transmitted light intensity I, as θ varies from 0° to 180°. Label your sketch-graph with the letter P. *[2]*

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 metal surface almost immediately after light is incident on the surface, *i.e.* without any time delay. Explain this observation with reference to Einstein's theory of the photoelectric effect. *[2]*

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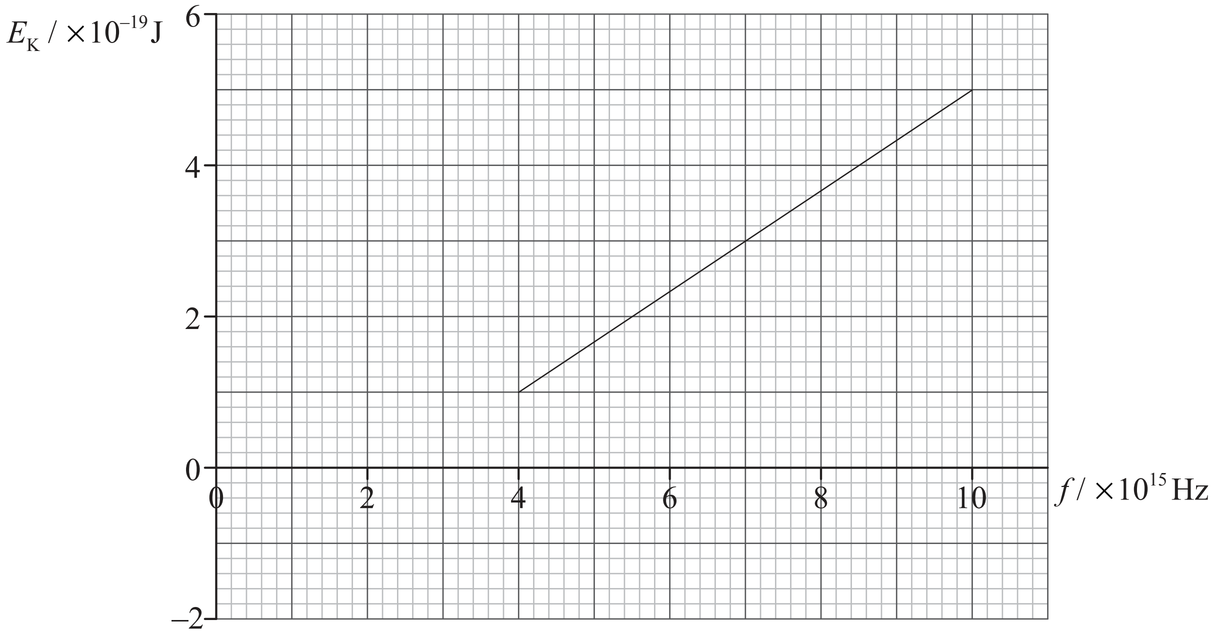
(Question B1 continued)

(b) The graph shows the variation with incident light frequency f of the maximum kinetic energy E_K of the emitted electrons.



Use the graph to

(i) estimate the work function of the metal surface. *[1]*

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(ii) calculate the maximum speed of the emitted electrons for incident light of frequency 5.0×10^{15} Hz. *[3]*

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

(a) The energy of electrons in atoms is said to be quantized. State what is meant by quantized energy. *[1]*

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(b) An electron that is confined to move in a region of length L can only have energies given by the equation

$$E_n = \frac{h^2 n^2}{8\pi m L^2}$$

where n is a positive integer.

For $L = 1.0 \times 10^{-10}$ m, use the equation above to

(i) calculate that the smallest difference between the allowed energies of the electron is 5.8×10^{-18} J. *[2]*

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(ii) determine the wavelength of the photon whose energy is 5.8×10^{-18} J. *[3]*

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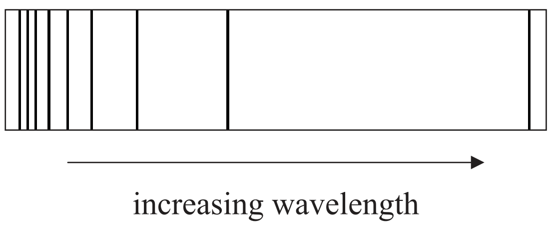
(c) Part of the emission spectrum of hydrogen is shown in the diagram.



Suggest whether this spectrum can be explained by the model in (b). *[2]*

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B3. This question is about radioactive decay.

(a) The decay constant for a particular isotope is $\lambda = 0.048\,s^{-1}$. A sample of the isotope initially contains 2.0×10^{12} nuclei of this isotope.

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

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(ii) Estimate the number of nuclei that will decay in the first second. *[1]*

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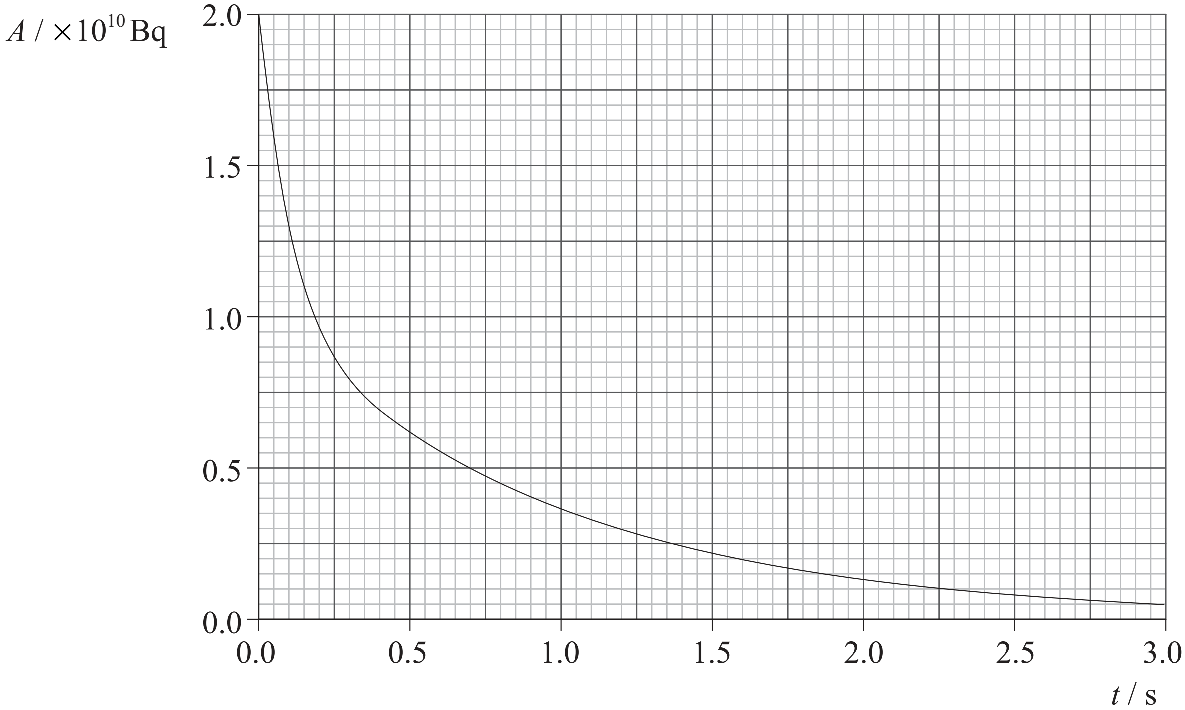
(Question B3 continued)

(b) The graph shows the variation with time t of the activity A of a sample containing radioactive material that consists of two different isotopes. Each isotope decays into a stable daughter isotope.



(i) Use the graph to explain how it may be deduced that the sample contains more than one isotope. *[2]*

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(ii) One of the isotopes in the sample has a half-life that is shorter than 0.20 s. Use the graph to estimate the half-life of the other isotope. Explain your working. *[2]*

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Option C — Digital technology

C1. This question is about charge-coupled devices (CCDs).

(a) Light from an object that is incident on the pixels of a CCD gives rise to potential differences across the pixels. Outline how these potential differences are used to produce an image of the object. *[2]*

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(b) The CCD of a particular digital camera has 5.0×10^6 pixels and a collecting area of $22\,mm^2$. Light of intensity $1.4\,Wm^{-2}$ is incident on the collecting area of the CCD for a time of 85 ms. The average energy of the photons of the incident light is 3.6×10^{-19} J. The quantum efficiency of the CCD is 75 %.

(i) State what is meant by quantum efficiency. *[1]*

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(ii) Show that the number of photons incident on **one** pixel of the CCD in the time interval of 85 ms is approximately 1.5×10^6. *[3]*

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(iii) The capacitance of a pixel of the CCD is 12 pF. Show that the potential difference established across the pixel is approximately 15 mV. *[2]*

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(iv) The voltage in (b)(iii) is digitized into a four bit binary number. Determine the binary equivalent of this voltage. *[1]*

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(Question C1 continued)

(c) CCDs detecting X-rays are now used in medical diagnosis. State the advantage to the patient of an X-ray CCD detector with high quantum efficiency. *[1]*

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C2. This question is about the mobile phone system.

In the mobile phone system, a particular geographic area is divided into a number of cells with a base station in each cell, each connected to a cellular exchange.

Describe the function of the base stations and the cellular exchange. *[4]*

Base stations: . . . .

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Cellular exchange: . . . .

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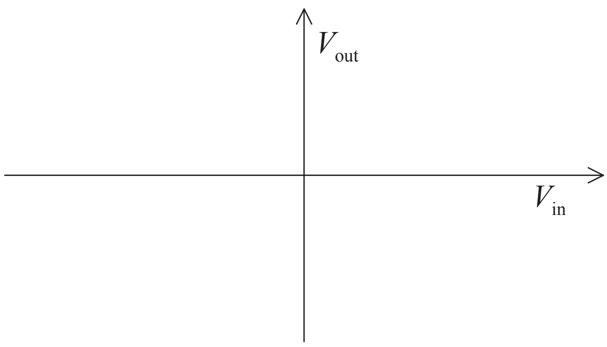
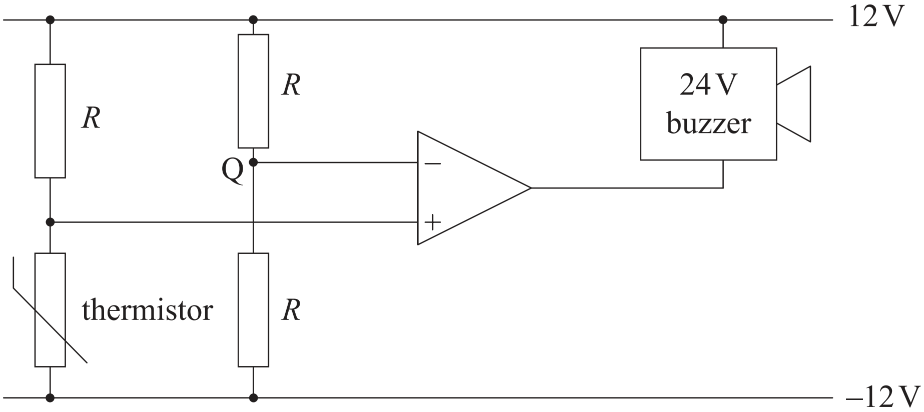
C3. This question is about the operational amplifier.

(a) On the axes below draw a sketch graph to show the variation with input voltage V_{in} of the output voltage V_{out} of a non-inverting operational amplifier. *[2]*



(b) A temperature warning device makes use of a buzzer that sounds when the potential difference across it is 24 V. The circuit in the warning device is shown.



It is required that the buzzer should sound when the temperature of the thermistor rises above 50 °C.

(i) State the voltage at point Q. *[1]*

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(ii) At a temperature of 50 °C the resistance of the thermistor is *R*. Explain why the buzzer will sound when the temperature rises above 50 °C. *[3]*

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Option D — Relativity and particle physics

D1. This question is about relativistic kinematics.

(a) State what is meant by proper length and proper time interval. *[2]*

Proper length: . . . .

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Proper time interval: . . . .

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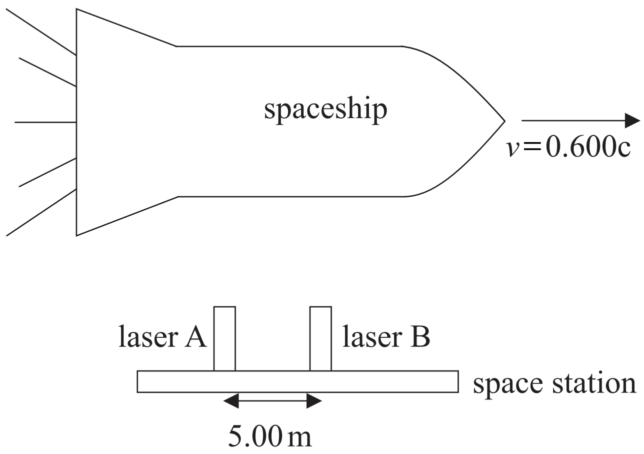
(b) A spaceship moves with speed $v=0.600c$ relative to a space station. Two lasers, A and B, on the space station are 5.00 m apart as measured by the space station observers. The gamma factor for a speed of $v=0.600c$ is $\gamma=1.25$.



(i) A radio signal is sent to the spaceship from the space station. The transmission lasts for 6.00 s according to space station clocks. Calculate the duration of the transmission according to the spaceship observers. *[2]*

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(ii) Calculate the distance between the lasers A and B according to the spaceship observers. *[2]*

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(This question continues on the following page)

(Question D1 continued)

(c) The lasers in (b) are fired **simultaneously** according to the **space station** observers. Light from each laser makes a mark on the spaceship. The spaceship observers measure the distance between the two marks to be 6.25 m. According to the spaceship observers

(i) state which laser was fired first. *[1]*

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(ii) determine the difference in time between the firings of the two lasers. *[2]*

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D2. This question is about quarks.

The table below gives the electric charge of the three lightest quarks in terms of e, the charge of the proton.

Quark flavour	up u	down d	strange s
Electric charge / *e*	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$

(a) Using the data in the table, determine the

(i) quark content of a meson with charge +1 and strangeness 0 and that of a baryon with charge –1 and strangeness –3. *[2]*

Meson: . . . .

Baryon: . . . .

(ii) possible spin values of the meson in (a)(i). *[1]*

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

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(c) Explain how the baryon with quark content uuu and spin $\frac{3}{2}$ does not violate the Pauli exclusion principle. *[1]*

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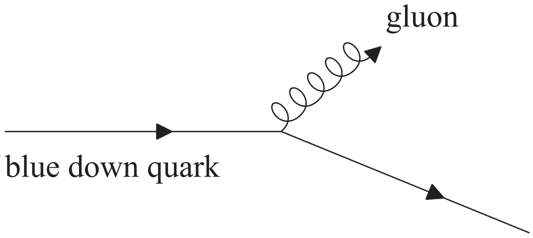
(Question D2 continued)

(d) In the Feynman diagram shown a blue down quark emits a gluon and produces a red quark.



Deduce the

(i) quark flavour (type) of the produced quark. *[1]*

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(ii) colour quantum numbers of the emitted gluon. *[1]*

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(e) The positive kaon K^+ (quark content $u\bar{s}$) decays into an anti-muon and a neutrino according to the reaction below.

$$K^+ \rightarrow \mu^+ + \nu$$

Explain how it may be deduced that this decay is a weak interaction process. *[1]*

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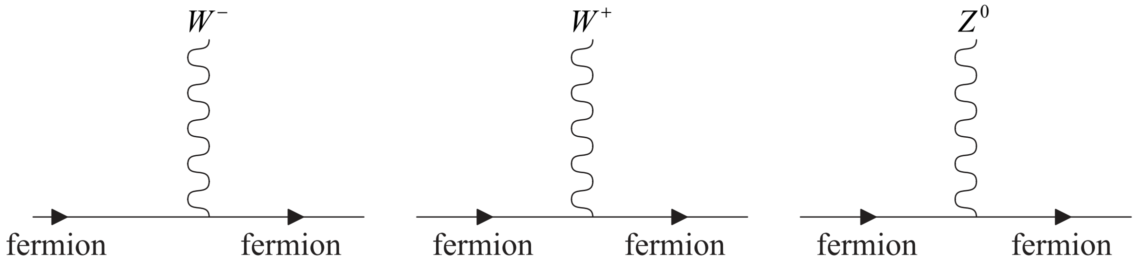
(Question D2 continued)

(f) The diagram shows three of the interaction vertices for the weak interaction.



Using the appropriate vertex, draw a Feynman diagram for the decay $K^+ \rightarrow \mu^+ + \nu$ labelling all particles involved. *[3]*

Option E — Astrophysics

E1. This question is about the relative population density of stars and galaxies.

The number of stars around the Sun, within a distance of 17 ly, is 75. The number of galaxies in the local group, within a distance of 4.0×10^6 ly from the Sun, is 26.

(a) Calculate the average population density, per ly^3, of stars and galaxies. *[2]*

Stars: . . . .

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Galaxies: . . . .

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(b) Use your answer to (a) to determine the ratio

$$\frac{\text{average population density of stars}}{\text{average population density of galaxies}}.$$ *[1]*

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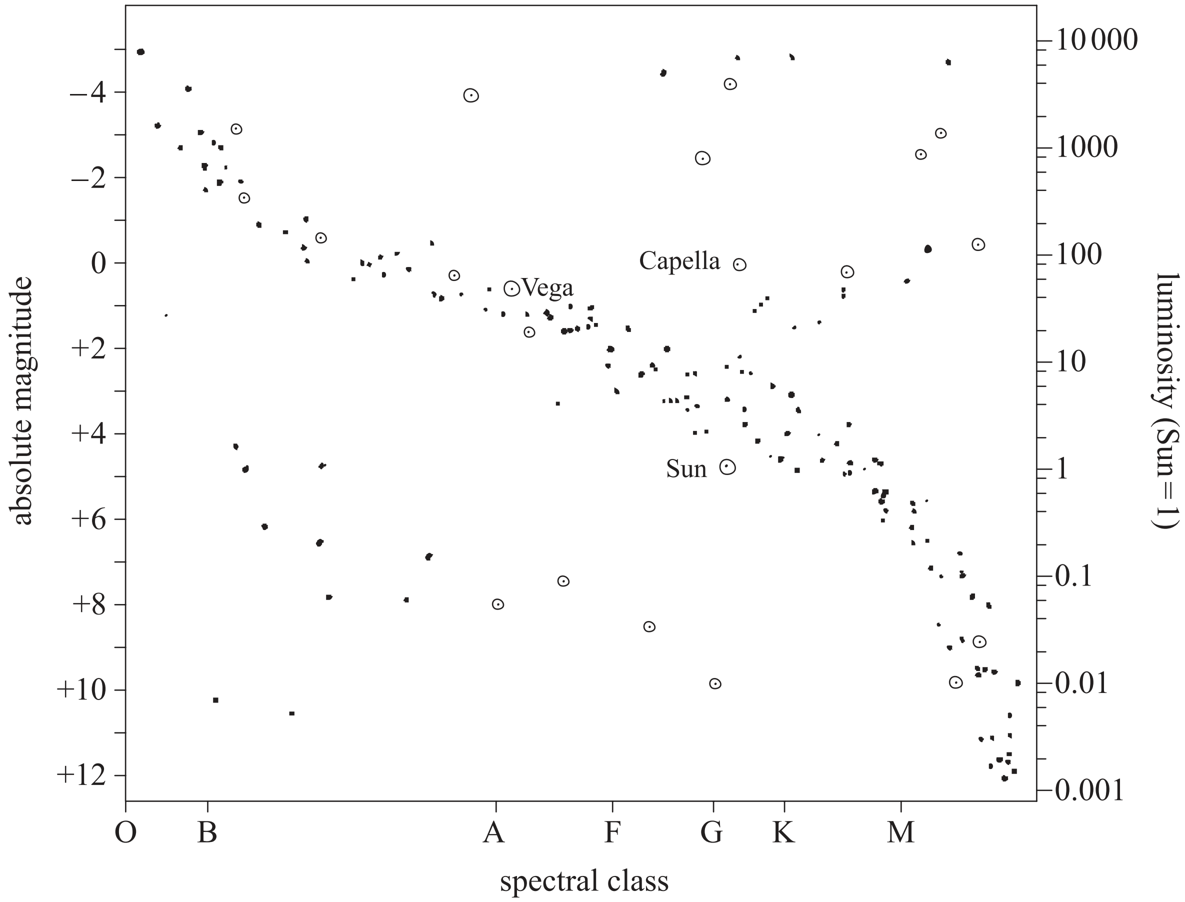
E2. This question is about the luminosity, size and distance of stars.

The Hertzsprung–Russell (HR) diagram shows the variation with spectral class of the absolute magnitude of stars.



The star Capella and the Sun are in the same spectral class (G). Using the HR diagram,

(a) (i) suggest why Capella has a greater surface area than the Sun. *[2]*

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(ii) estimate the luminosity of Capella in terms of that of the Sun. *[1]*

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(Question E2 continued)

(iii) calculate the radius of Capella in terms of that of the Sun. *[2]*

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(b) The spectroscopic parallax method can be used to measure the distance of star Vega.

(i) Using the HR diagram, state the absolute magnitude of Vega. *[1]*

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(ii) The apparent magnitude of Vega is 0.0. Determine (in parsec) the distance of Vega from Earth. *[3]*

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(iii) Light from Vega is absorbed by a dust cloud between Vega and Earth. Suggest the effect, if any, this will have on determining the distance of Vega from Earth. *[2]*

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(c) Vega is a very massive star. State why Vega does not undergo gravitational collapse. *[1]*

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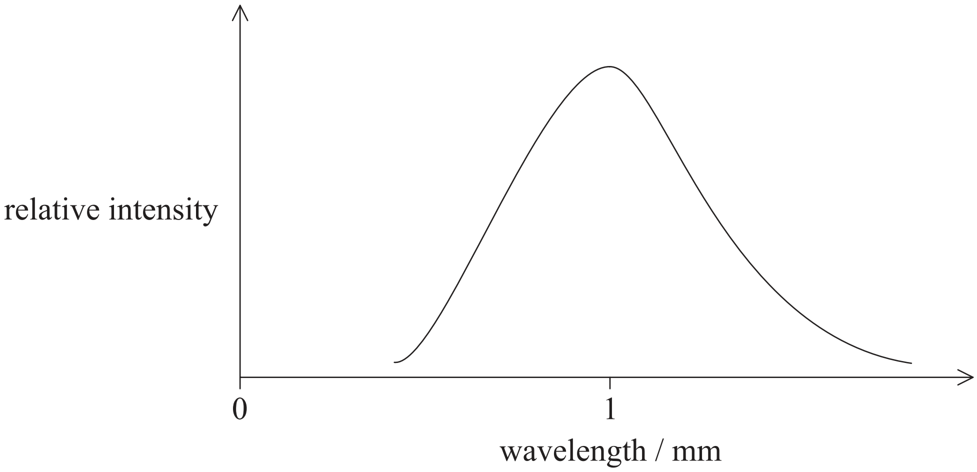
E3. This question is about cosmic microwave background radiation (CMB) and the density of the universe.

The graph shows the relative intensity of the CMB as a function of wavelength.



(a) Explain how this graph is consistent with the Big Bang model of the universe. *[3]*

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(b) The density of the universe will determine its ultimate fate. Outline the problems associated with determining the density of the universe. *[2]*

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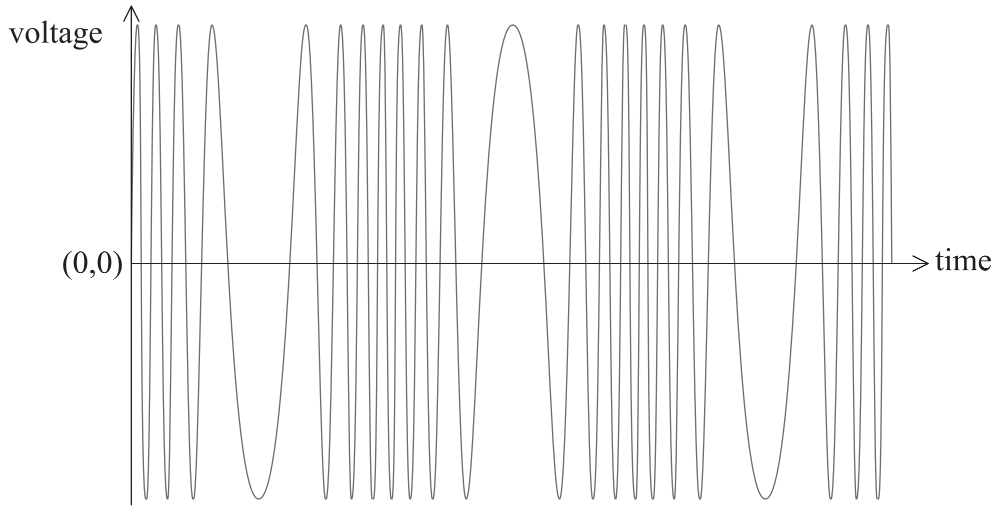
Option F — Communications

F1. This question is about modulation.

(a) The diagram shows how the voltage signal of a frequency modulated (FM) carrier wave varies with time.



The carrier wave is modulated by a single frequency signal.

On the above axes sketch the information signal. *[1]*

(b) State and explain **one** advantage of using FM modulation rather than amplitude modulation (AM). *[2]*

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F2. This question is about sampling.

A telephone call is sampled with a sampling frequency of 8.0 kHz. Each sample is stored as a four bit binary number. The duration of each bit in the sample is 4.0 μs.

(a) Calculate the time interval between the end of one sample and the beginning of the next. *[3]*

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(b) Outline, with reference to your answer in (a), what is meant by time-division multiplexing. *[2]*

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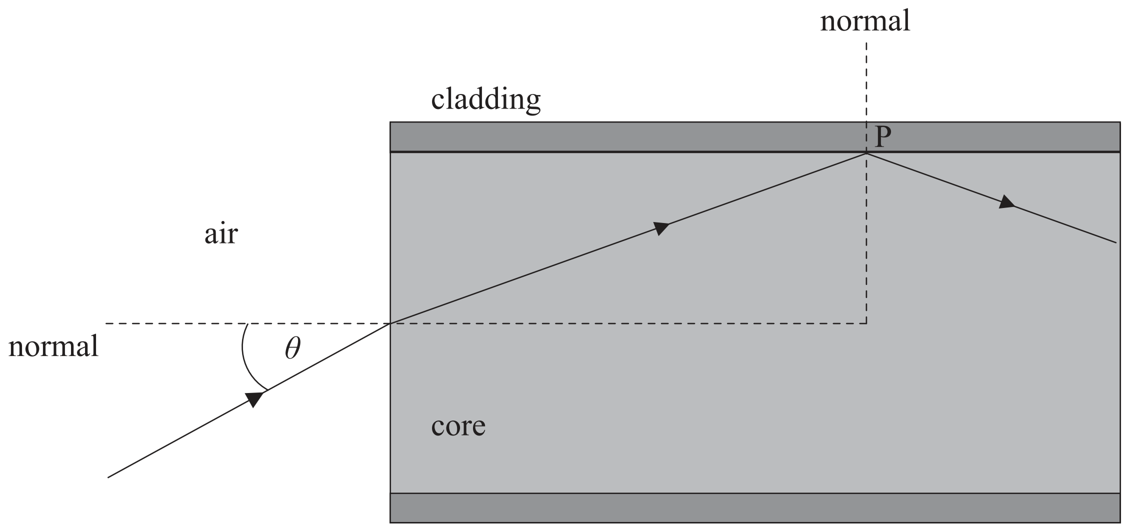
F3. This question is about the transmission of signals along an optic fibre.

(a) A ray of light enters an optic fibre from air. The ray makes an angle θ with the normal. The ray undergoes total internal reflection at point P.



The refractive index of the core is 1.56 and that of the cladding is 1.38.

(i) Calculate the critical angle of the cladding-core boundary. *[2]*

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(ii) Show that the largest angle of incidence θ in air, at which total internal reflection at the cladding-core boundary takes place, is 46.7°. *[2]*

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(This question continues on the following page)

(Question F3 continued)

(b) Distinguish between modal dispersion and material dispersion in an optic fibre. *[2]*

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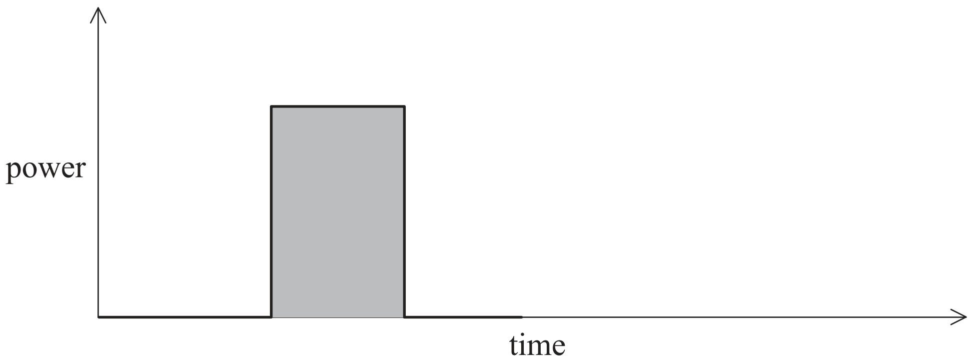
(c) The signal shown is fed into a monomode optic fibre.



(i) State what the shaded area represents. *[1]*

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(ii) Use the axes above to draw the shape of the signal after it has travelled a large distance in the fibre. *[2]*

(iii) The input signal power in a monomode fibre is 15.0 mW. The attenuation per unit length for this fibre is 1.24 dB km^{-1}. Determine the power of the output signal after the signal has travelled a distance of 3.40 km in the fibre. *[3]*

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Option G — Electromagnetic waves

G1. This question is about laser light.

(a) Outline how laser light is produced. *[3]*

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(b) State **two** ways in which light emitted by a laser differs from light emitted from an ordinary filament lamp. *[2]*

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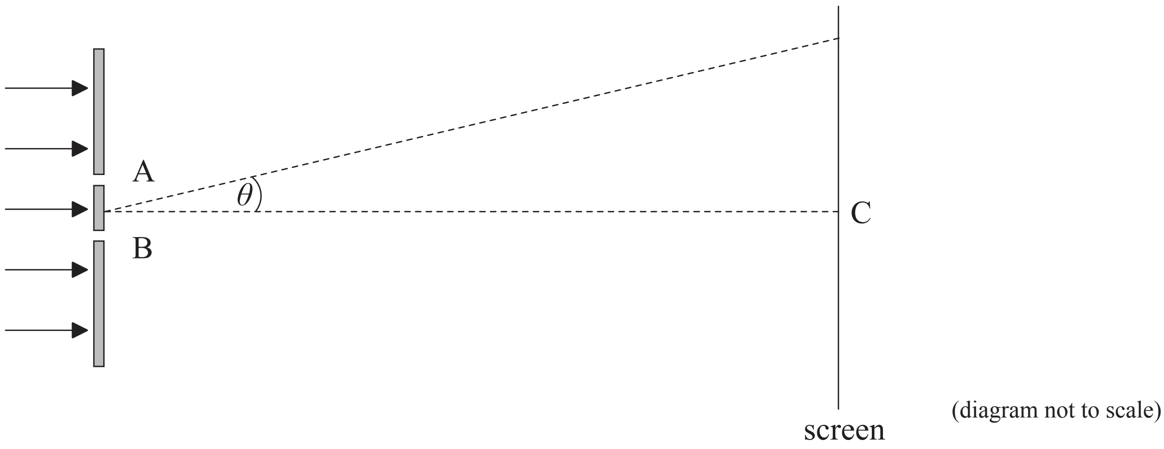
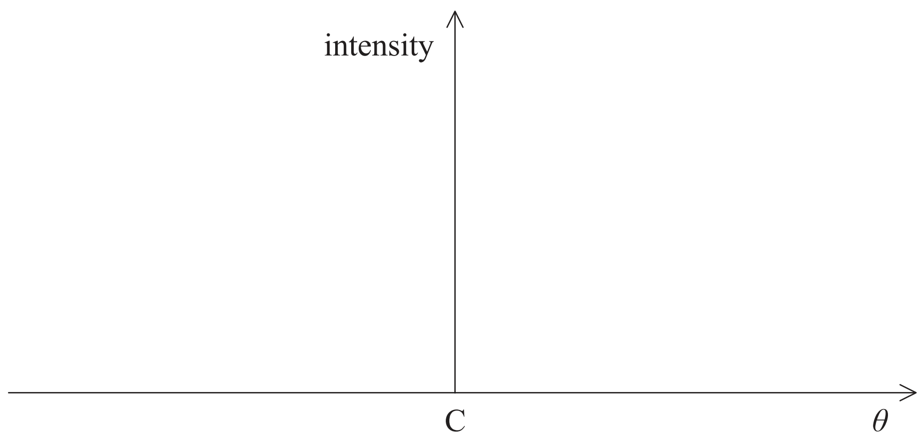
G2. This question is about interference.

(a) Light from a laser is incident on two very narrow slits A and B.



Point C on the screen is directly opposite the midpoint of the slits.

(i) On the axes below, sketch the variation with angle θ of the intensity of the light on the screen. *[2]*



(ii) The separation of the slits is 0.120 mm and the wavelength of the light is 6.80×10^{-7} m. The distance between the slits and the screen is 1.40 m. Calculate the separation of the bright fringes on the screen. *[2]*

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(This question continues on the following page)

(Question G2 continued)

(b) Slit A is covered with a transparent piece of glass. The effect of the glass is to increase the path length of the light from the slit to the screen by half a wavelength. It may be assumed that the amount of light absorbed by the glass is negligible. State and explain the effect(s), if any, of the glass on the

(i) intensity pattern you have drawn in (a)(i). *[2]*

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(ii) separation of the bright fringes calculated in (a)(ii). *[2]*

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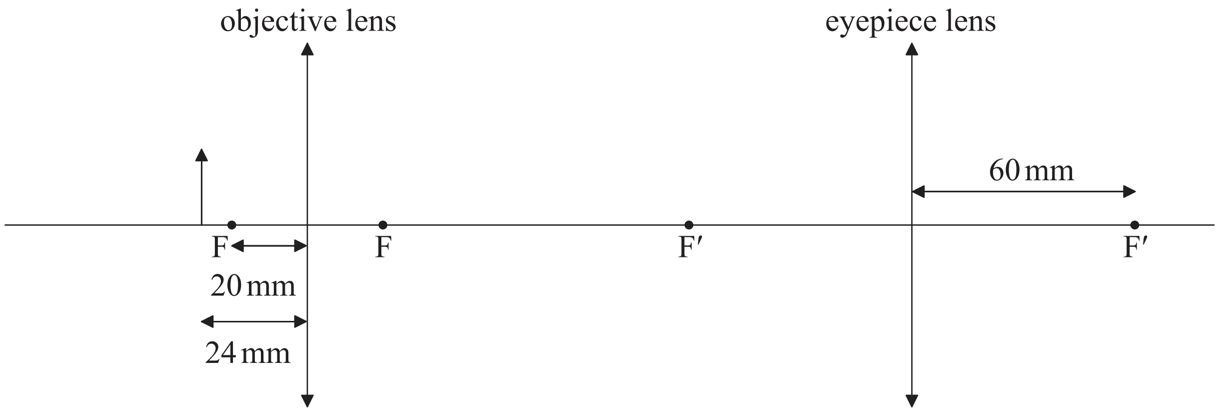
G3. This question is about a compound microscope.

The diagram (not to scale) is of a compound microscope.



The focal length of the objective lens is 20 mm and that of the eyepiece lens is 60 mm. A small object is placed at a distance of 24 mm from the objective lens. The microscope produces a final virtual image of the object at a distance of 240 mm from the eyepiece lens.

(a) (i) Determine, by calculation, the distance from the objective lens of the image formed by the objective lens. *[2]*

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(ii) Explain why the image in (a)(i) is real. *[1]*

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(iii) Determine the distance of the image formed by the objective lens from the eyepiece lens. *[2]*

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(b) Determine the overall magnification of the microscope. *[2]*

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