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Baccalauréat International
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PHYSICS
STANDARD LEVEL
PAPER 3

Candidate session number

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Tuesday 7 May 2013 (afternoon)

1 hour

Examination code

2	2	1	3	–	6	5	1	2

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 eye and sight.

(a) Outline what is meant by additive colour mixing. *[1]*

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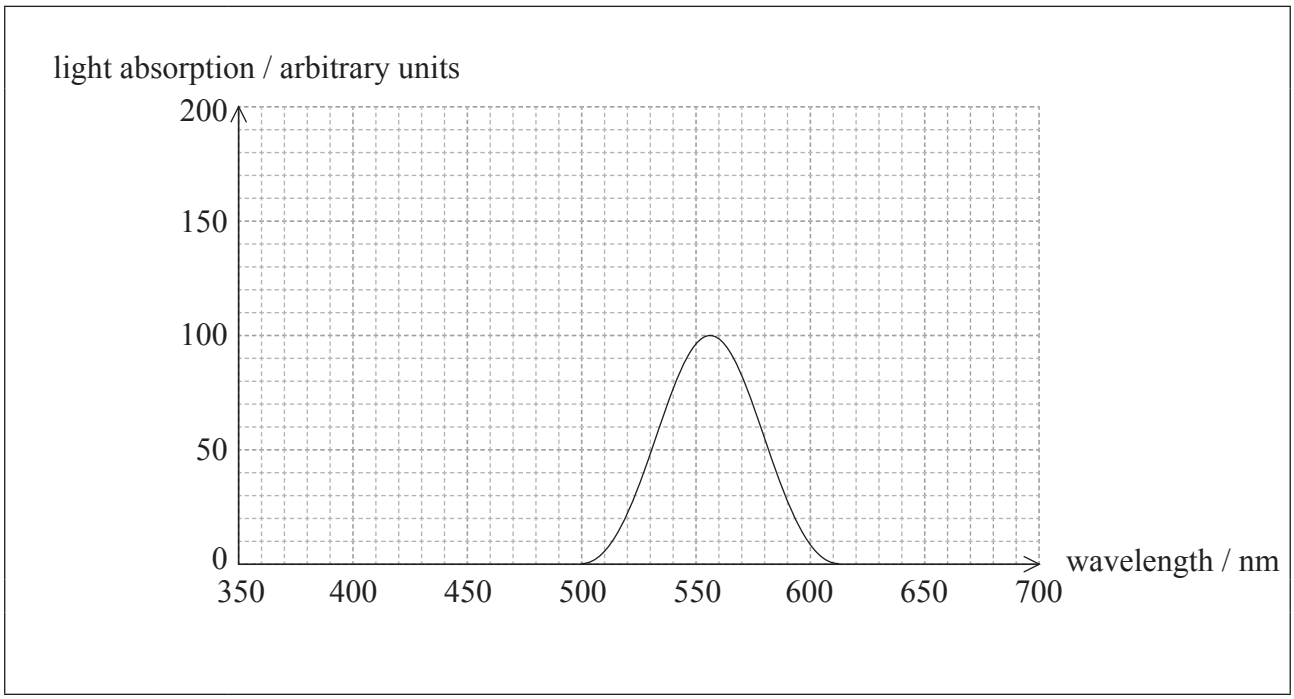
(This question continues on the following page)

(Question A1 continued)

(b) The graph shows the variation with wavelength of light absorption for the red-sensitive cone cells of a normal eye.



Aibhe has colour blindness with reduced quantities of pigment in her red-sensitive cones.

(i) Sketch on the graph the light absorption curve of the red-sensitive cones for Aibhe. *[2]*

(ii) State and explain the difference in the perceived colour, between Aibhe and a person with normal colour vision, when observing a magenta (purple) object in white light. *[3]*

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A2. This question is about radio telescopes.

A distant galaxy emits radio waves of frequency 6.0×10^{9} Hz and is moving with speed $6.0\times10^{6}\,\text{m s}^{-1}$ directly away from an observer on Earth.

(a) Determine the wavelength of the radio wave as measured by the observer on Earth. *[3]*

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(b) The radio signals from two stars on opposite sides of the galaxy are detected on Earth using a radio telescope. The telescope has a circular receiving dish.

(i) State the Rayleigh criterion for the images of two point sources to be just resolved. *[2]*

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(ii) The galaxy is 2.0×10^{21} m from Earth and the stars are separated by 5.0×10^{19} m. Determine the minimum size of the telescope dish required to resolve the images of the two stars at a wavelength of 5.1×10^{-2} m. *[2]*

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A3. This question is about standing waves in a vibrating string.

A guitar string vibrates at 330 Hz in its fundamental mode.

(a) Describe the formation of standing waves in a string fixed at both ends. *[2]*

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(b) The length of the string is 0.64 m. Calculate the velocity of the wave in the string. *[2]*

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A4. This question is about polarization.

Outline how polarization may be used in stress analysis. *[3]*

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Option B — Quantum physics and nuclear physics

B1. This question is about atomic energy levels.

(a) Explain how atomic spectra provide evidence for the quantization of energy in atoms. *[3]*

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(b) Outline how the de Broglie hypothesis explains the existence of a **discrete** set of wavefunctions for electrons confined in a box of length L. *[3]*

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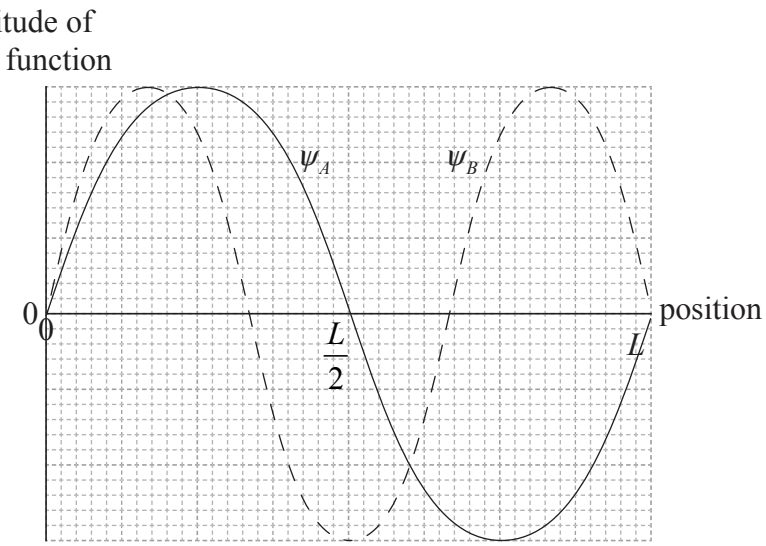
(This question continues on the following page)

(Question B1 continued)

(c) The diagram below shows the shape of two allowed wavefunctions ψ_A and ψ_B for an electron confined in a one-dimensional box of length L.



(i) With reference to the de Broglie hypothesis, suggest which wavefunction corresponds to the larger electron energy. *[3]*

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(This question continues on the following page)

(Question B1 continued)

(ii) Predict and explain which wavefunction indicates a larger probability of finding the electron near the position $\frac{L}{2}$ in the box. *[2]*

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(iii) On the graph in (c) on page 7, sketch a possible wavefunction for the **lowest** energy state of the electron. *[1]*

B2. This question is about radioactive decay.

Sodium-22 undergoes β^+ decay.

(a) Identify the missing entries in the following nuclear reaction. *[3]*

$$^{22}_{11}\text{Na} \rightarrow {}^{22}_{\ldots}\text{Ne} + {}^{0}_{\ldots}e + {}^{0}_{0}\ldots$$

(b) Define *half-life*. *[1]*

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(c) Sodium-22 has a decay constant of 0.27 yr^{-1}.

(i) Calculate, in years, the half-life of sodium-22. *[2]*

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(ii) A sample of sodium-22 has initially 5.0×10^{23} atoms. Calculate the number of sodium-22 atoms remaining in the sample after 5.0 years. *[2]*

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Option C — Digital technology

C1. 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: . . . . . .

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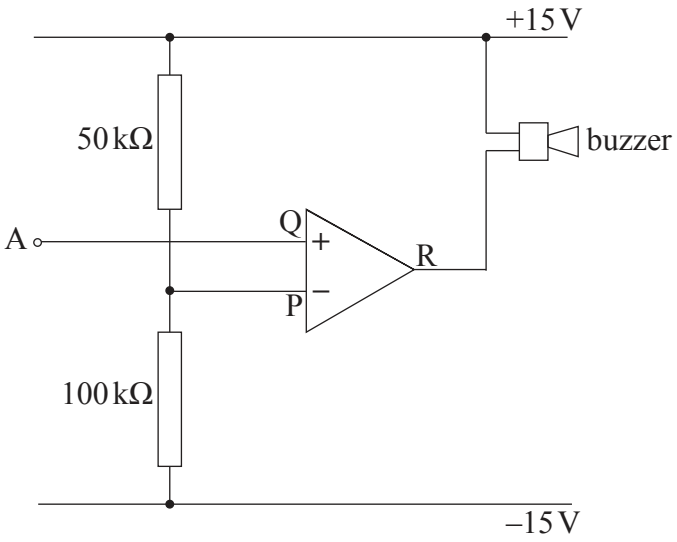
(b) An operational amplifier circuit is designed to switch on a warning buzzer when the potential difference (pd) at point A drops below a voltage V. P is connected to the supply rails via resistances of 50 kΩ and 100 kΩ. The warning buzzer sounds when the pd across it is 30 V.



(i) Show that the voltage at P is +5 V. *[2]*

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(This question continues on the following page)

(Question C1 continued)

(ii) State the value of V. *[1]*

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(iii) Explain why the buzzer will switch on when point A drops below voltage V. *[3]*

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C2. This question is about the use of mobile phones.

State **two** environmental issues that arise from the increased use of mobile phones. *[2]*

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C3. This question is about a charge-coupled device (CCD) in a digital camera.

(a) Monochromatic light is incident on a pixel in the CCD of a digital camera. Using the data, calculate the frequency of the monochromatic light incident on the pixel. *[3]*

Intensity of light	$= 1.8 \times 10^{-5}\,\text{W mm}^{-2}$
Duration of exposure	$= 2.5\,\text{ms}$
Area of pixel	$= 1.9 \times 10^{-5}\,\text{mm}^{2}$
Quantum efficiency of the pixel	$= 80\,\%$
Charge stored on pixel	$= 2.7 \times 10^{-13}\,\text{C}$

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(This question continues on the following page)

(Question C3 continued)

(b) Explain, with reference to the charge carriers in the pixel, how a potential difference (pd) is produced in the pixel. *[4]*

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(c) The digital information from the CCD is stored on a Digital Versatile Disc (DVD) that is read using laser light.

Outline, with reference to the properties of the laser light, how the DVD is read. *[3]*

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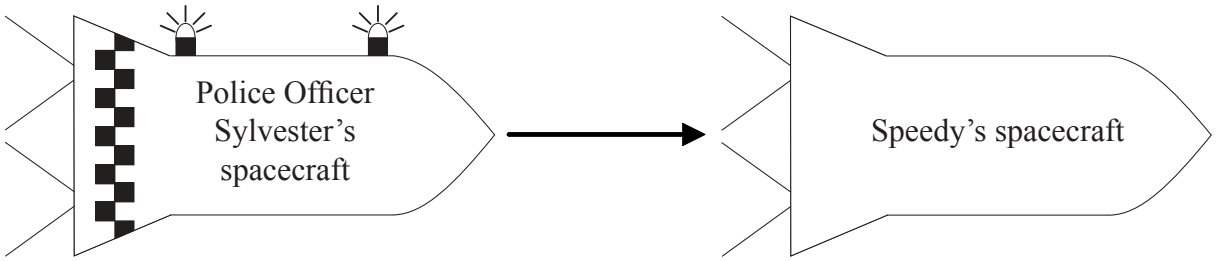
Option D — Relativity and particle physics

D1. This question is about relativistic kinematics.

Speedy is in a spacecraft being chased by Police Officer Sylvester. In Officer Sylvester's frame of reference, Speedy is moving directly towards Officer Sylvester at 0.25c.



(a) Describe what is meant by a frame of reference. *[2]*

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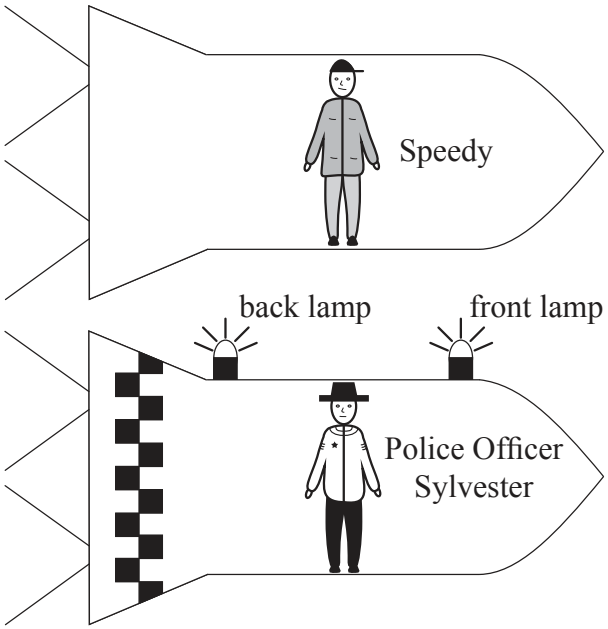
(This question continues on the following page)

(Question D1 continued)

(b) At a later time the police spacecraft is alongside Speedy's spacecraft. The police spacecraft is overtaking Speedy's spacecraft at a constant velocity.

Officer Sylvester is at a point midway between the flashing lamps, both of which he can see. At the instant when Officer Sylvester and Speedy are opposite each other, Speedy observes that the blue lamps flash simultaneously.



State and explain which lamp is observed to flash first by Officer Sylvester. *[4]*

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(This question continues on the following page)

(Question D1 continued)

(c) The police spacecraft is travelling at a constant speed of 0.5c relative to Speedy's frame of reference. The light from a flash of one of the lamps travels across the police spacecraft and is reflected back to the light source. Officer Sylvester measures the time taken for the light to return to the source as 1.2×10^{-8} s.

(i) Outline why the time interval measured by Officer Sylvester is a proper time interval. *[1]*

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(ii) Determine, as observed by Speedy, the time taken for the light to travel across the police spacecraft and back to its source. *[3]*

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D2. This question is about elementary particles.

The quark is said to be an elementary particle.

(a) State what is meant by the term elementary particle. *[1]*

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(b) The strong interaction between two nucleons has a range of about 10^{-15} m.

(i) Identify the boson that mediates the strong interaction. *[1]*

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(ii) Determine the approximate mass of the boson in (b)(i). *[2]*

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D3. This question is about the Ω^- particle.

The Ω^- particle is a baryon which contains only strange quarks.

(a) Deduce the strangeness of the Ω^- particle. *[1]*

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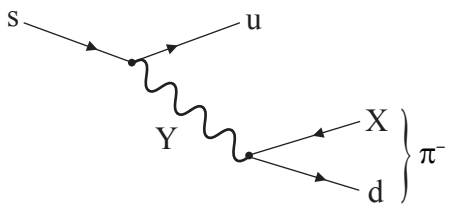
(b) The Feynman diagram shows a quark change that gives rise to a possible decay of the Ω^- particle.



(i) Identify X. *[1]*

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(ii) Identify Y. *[1]*

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(This question continues on the following page)

(Question D3 continued)

(c) Explain, with reference to the structure of the Ω^- particle, why the concept of quark colour was introduced. *[3]*

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Option E — Astrophysics

E1. This question is about asteroids.

(a) State the nature of an asteroid. *[1]*

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(b) State the position of the asteroid belt in the solar system. *[1]*

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E2. This question is about the properties of a star.

(a) The peak in the radiation spectrum of a star X is at a wavelength of 300 nm.

Show that the surface temperature of star X is about 10 000 K. *[2]*

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(This question continues on the following page)

(Question E2 continued)

(b) The radius of star X is $4.5\,R_S$ where R_S is the radius of the Sun. The surface temperature of the Sun is 5.7×10^3 K.

Determine the ratio $\frac{\text{luminosity of star X}}{\text{luminosity of the Sun}}$. *[3]*

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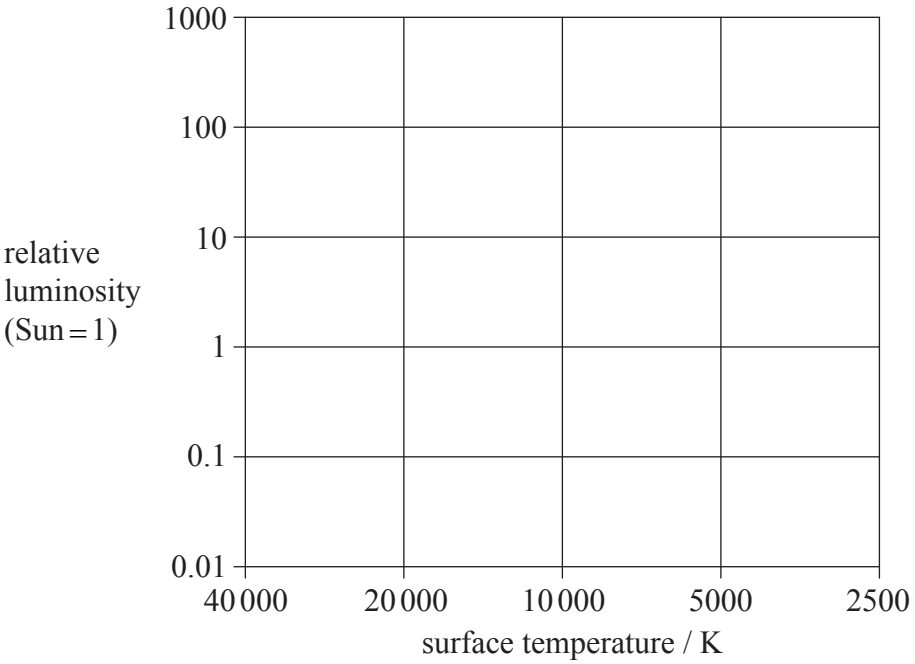
(c) On the Hertzsprung–Russell diagram, label the position of star X with the letter X. *[1]*



E3. This question is about variable stars and supernovae.

Cepheid variable stars are used as "standard candles" by astronomers.

(a) (i) State what is meant by a standard candle. *[1]*

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(ii) Outline the properties of a Cepheid star that allow it to be used as a standard candle. *[2]*

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(iii) Explain how astronomers use their observations of a Cepheid star to determine the distance from the star to Earth. *[3]*

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(Question E3 continued)

(b) Astronomers can also determine distance by observing supernovae.

A supernova was observed from Earth. At the peak of its emissions, the supernova had an absolute magnitude of –20 and an apparent magnitude of 13.

Determine, in parsec, the distance from Earth to the supernova. *[3]*

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E4. This question is about Newton's model of the universe.

Newton suggested that the universe is infinite, uniform and static.

For **each** of Newton's three suggestions, outline **one** piece of current astronomical evidence that contradicts the suggestion. *[3]*

Infinite: . . . . . .
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Uniform: . . . . . .
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Static: . . . . . .
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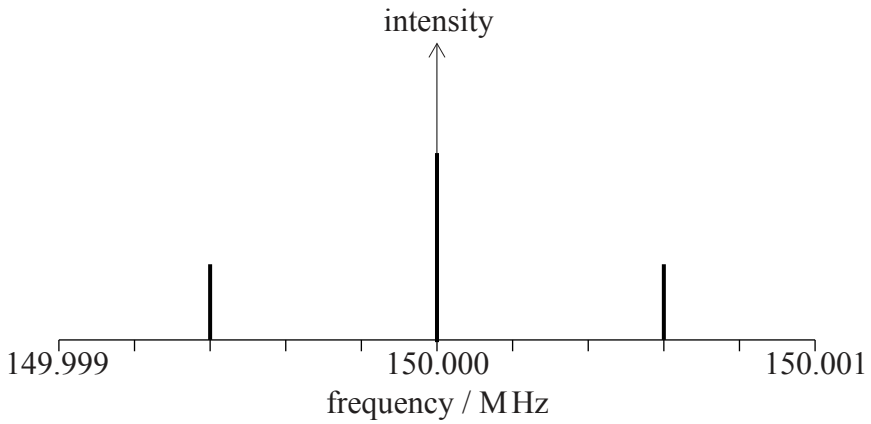
Option F — Communications

F1. This question is about amplitude modulation.

The graph shows the power spectrum of a carrier wave that has been amplitude modulated by a single-frequency information signal.



(a) State the

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

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(ii) bandwidth of the modulated signal. *[1]*

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(This question continues on the following page)

(Question F1 continued)

(b) Frequency modulated (FM) radio transmission is preferred to amplitude modulated (AM) radio transmission when high audio quality is required. Explain, with reference to the amplitude of the frequency modulated signal, why this is true. *[3]*

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(c) Outline **two** disadvantages in the use of FM transmission compared to AM transmission. *[2]*

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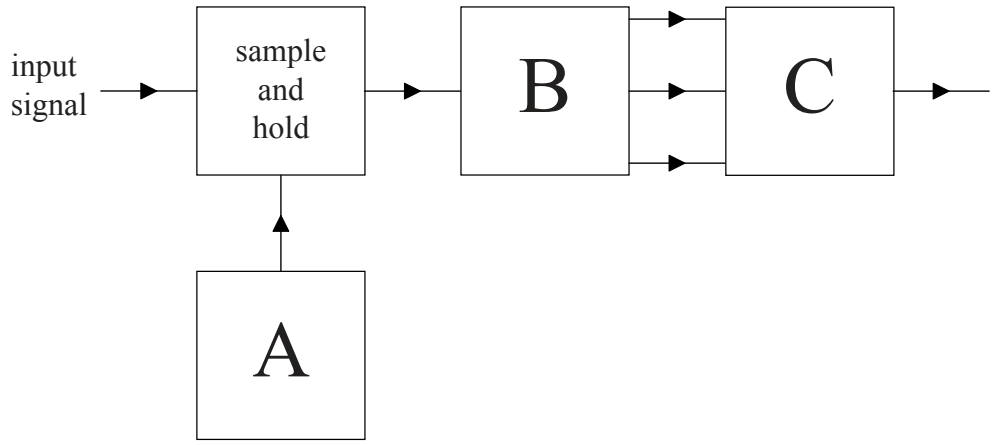
F2. This question is about analogue-to-digital conversion.

A 3-bit digital system for the conversion of an analogue signal into a digital signal is shown.



(a) Identify the blocks A, B and C. *[2]*

A: . . . . . .

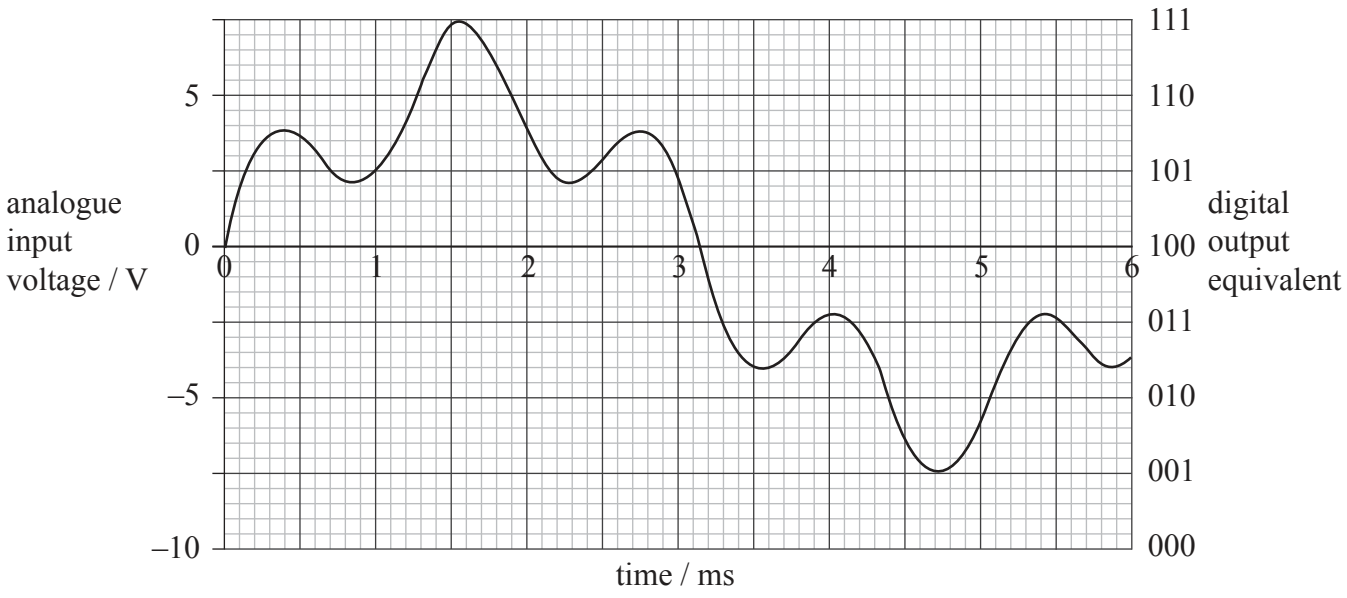
B: . . . . . .

C: . . . . . .

(This question continues on the following page)

(Question F2 continued)

(b) The graph shows the variation with time of an audio signal voltage that is being converted to digital form in a 3-bit system. The scale on the left-hand *y*-axis shows the analogue input to the converter. The scale on the right-hand *y*-axis shows the digital output equivalent to the analogue input. The signal is sampled every 1.0 ms, beginning at a sampling time $t = 0.0$ ms.



The conversion process rounds the signal down to the lower digital value. For example, when $t = 2.0$ ms the digital output value is 101.

The system is modified so that conversions are carried out at **twice** the original sampling rate.

(i) A sample is taken at 3.0 ms. Deduce the next **two** sampling times and the digital output equivalent values at these times. Record your answers in the table below. *[2]*

Time / ms	Digital output equivalent

(This question continues on the following page)

(Question F2 continued)

(ii) Outline why an increase in the number of bits per sample will improve the reproduction of the transmitted signal. *[1]*

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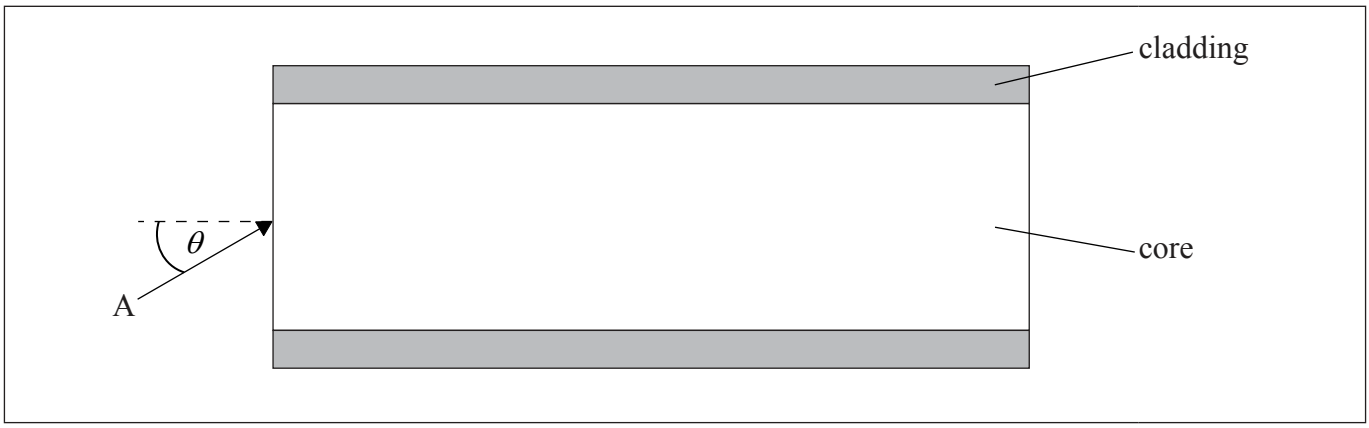
F3. This question is about an optic fibre.

Monochromatic light enters an optic fibre, from air, along direction A that is at an angle θ to the axis of the fibre.



The refractive index of the core is 1.62 and the refractive index of the cladding is 1.52. The critical angle at the core-cladding boundary is 70°.

(a) Calculate the greatest angle of incidence θ that can be used with this fibre. *[3]*

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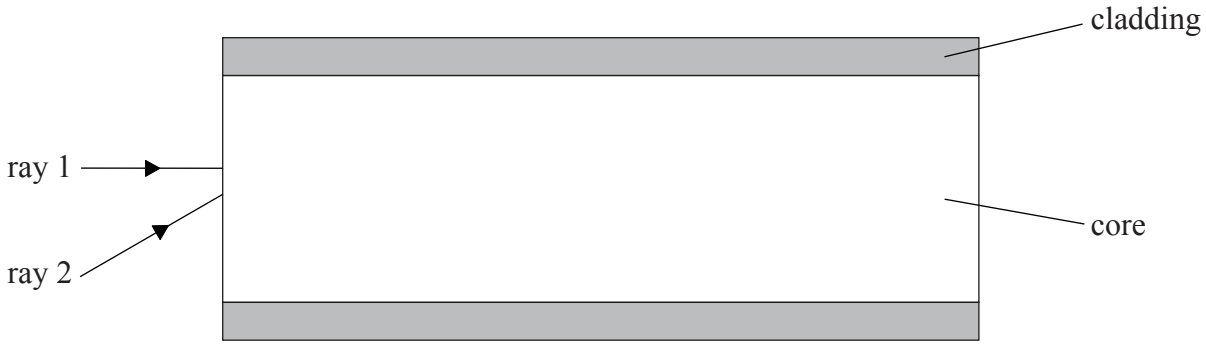
(b) Sketch the path of the light in the core on the diagram above. *[2]*

(This question continues on the following page)

(Question F3 continued)

(c) Information is transmitted along the fibre in the form of pulsed light. Two rays of this light enter the core at the same instant as shown in the diagram below.



Discuss the effect of modal dispersion on the subsequent transmission of the information along the fibre. *[3]*

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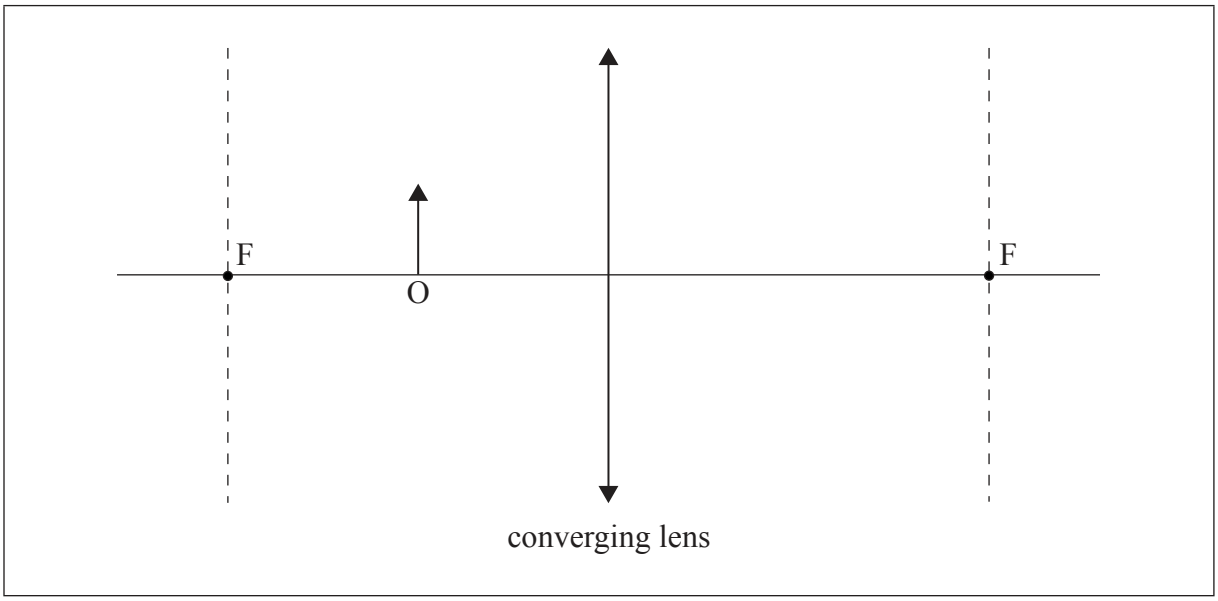
Option G — Electromagnetic waves

G1. This question is about light and optical instruments.

A thin converging glass lens has focal length $f = 0.20\,\text{m}$.

(a) An object is placed 0.10 m in front of the lens.

(i) On the diagram, construct rays to locate the image of the object, O. The focal points of the lens are labelled F. *[3]*



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

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(This question continues on the following page)

(Question G1 continued)

(b) The object in (a) is now moved so that it is located 0.40 m from the lens. Calculate

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

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(ii) the linear magnification. *[2]*

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(c) State typical wavelengths in a vacuum for

(i) blue light. *[1]*

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(ii) red light. *[1]*

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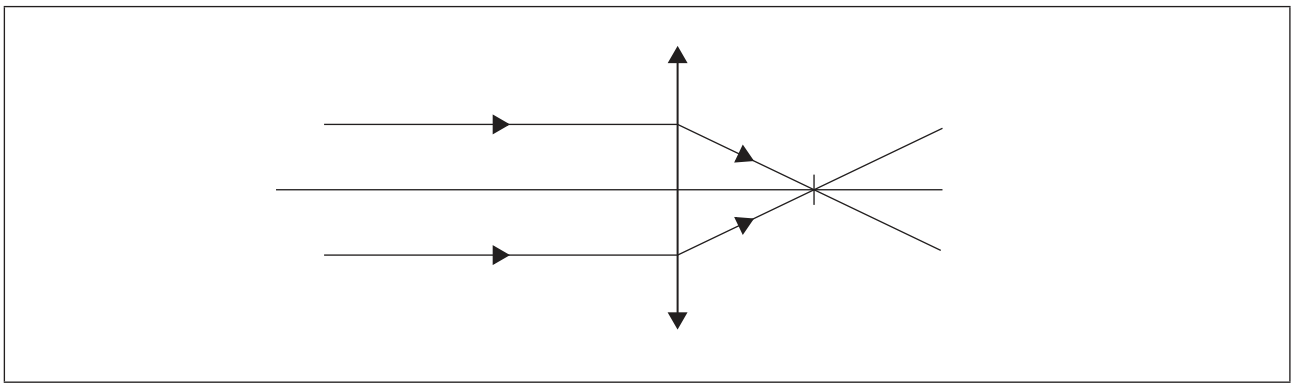
(This question continues on the following page)

(Question G1 continued)

(d) The refractive index of the glass in the lens is greater for blue wavelengths than for red wavelengths.

The diagram shows two rays of blue light incident on the lens.



On the diagram, sketch the paths of the rays if red light is used instead of blue light. *[1]*

G2. This question is about laser light.

(a) Laser light is monochromatic and coherent. Explain what is meant by

(i) monochromatic. *[1]*

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(ii) coherent. *[2]*

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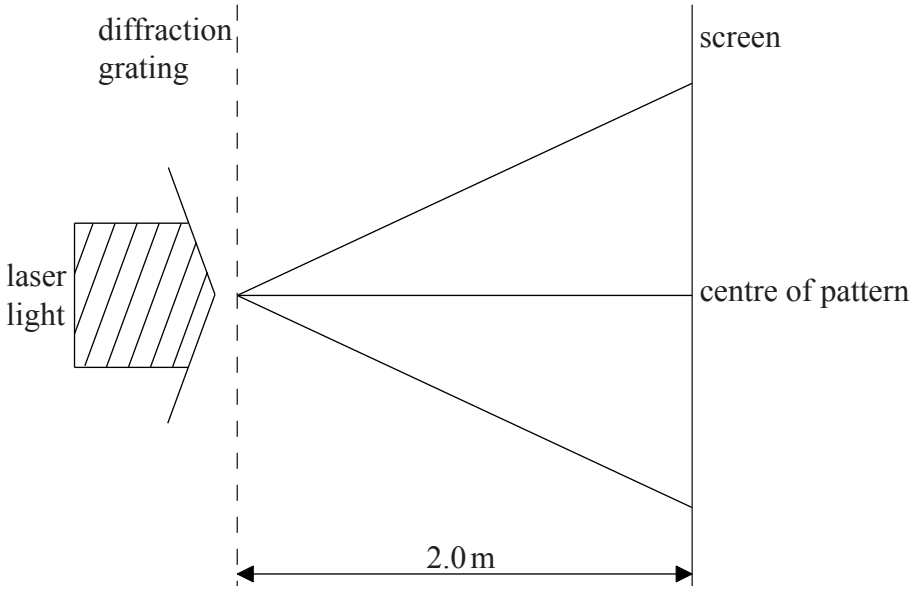
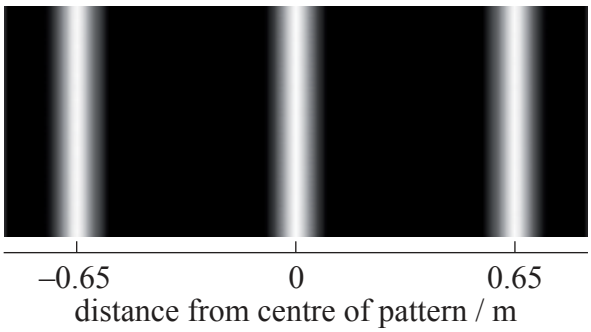
(This question continues on the following page)

(Question G2 continued)

(b) A beam of laser light is incident normally on a diffraction grating which has 600 lines per millimetre. A fringe pattern is formed on a screen 2.0 m from the diffraction grating.



The fringe pattern formed on the screen is shown below.



Determine the wavelength of the laser light. *[4]*

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(This question continues on the following page)

(Question G2 continued)

(c) The number of lines per millimetre in the diffraction grating in (b) is reduced. Describe the effects of this change on the fringe pattern in (b). *[2]*

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