M13/4/PHYSI/HP3/ENG/TZ1/XX

22136509

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

PHYSICS
HIGHER LEVEL
PAPER 3

Candidate session number

0	0							

Tuesday 7 May 2013 (afternoon)

1 hour 15 minutes

Examination code

2	2	1	3	–	6	5	0	9

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 *[60 marks]*.

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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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(Question E2 continued)

(b) (i) 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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(ii) Calculate, assuming that the power in the mass–luminosity relationship is 3.5, the ratio $\frac{\text{mass of star X}}{\text{mass of Sun}}$. *[3]*

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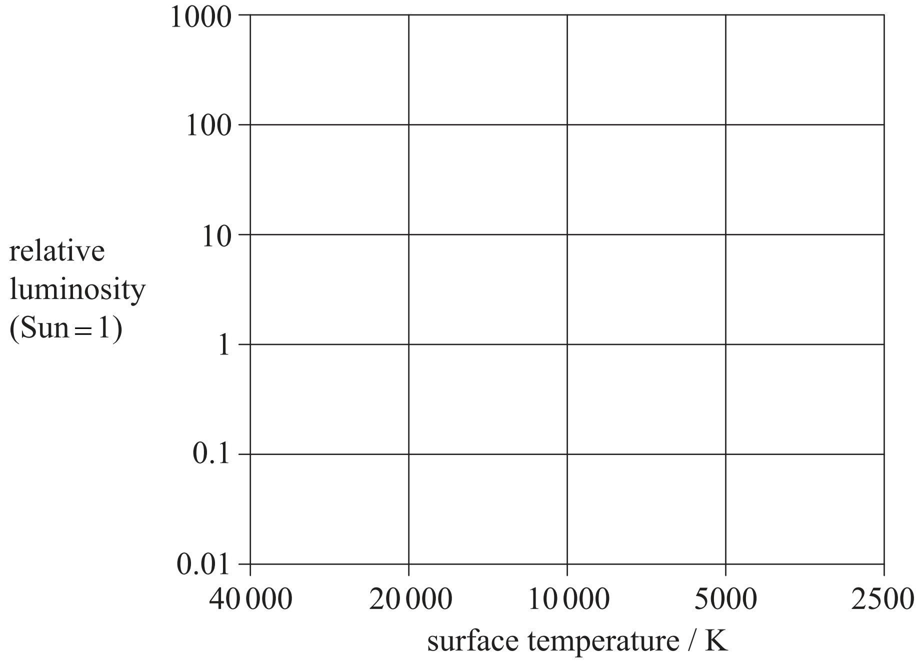
(Question E2 continued)

(c) On the Hertzsprung–Russell diagram, label

(i) the position of star X with the letter X. *[1]*

(ii) the position of the Sun with the letter S. *[1]*



(d) Explain, with reference to the Chandrasekhar limit, whether or not star X will become a white dwarf. *[2]*

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E3. This question is about variable stars.

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

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Uniform: . . . .

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Static: . . . .

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E5. This question is about red-shift.

The wavelengths of radio signals from galaxy A are found to be red-shifted from the wavelengths that would be observed from sources at rest relative to Earth.

(a) The fractional change in wavelength of the radio signals from galaxy A is 9.4×10^{-3}.

Calculate, in $km\,s^{-1}$, the average velocity of galaxy A relative to Earth. *[2]*

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(b) A supernova was observed within galaxy A. At the peak of its emissions, the supernova had an absolute magnitude of –20 and an apparent magnitude of 13.

Show that the distance from Earth to the supernova is about 40 Mpc. *[3]*

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(c) Estimate, using your answer to (a) and the result for (b), the age of the universe. ($1\,pc = 3.1\times10^{13}\,km$) *[2]*

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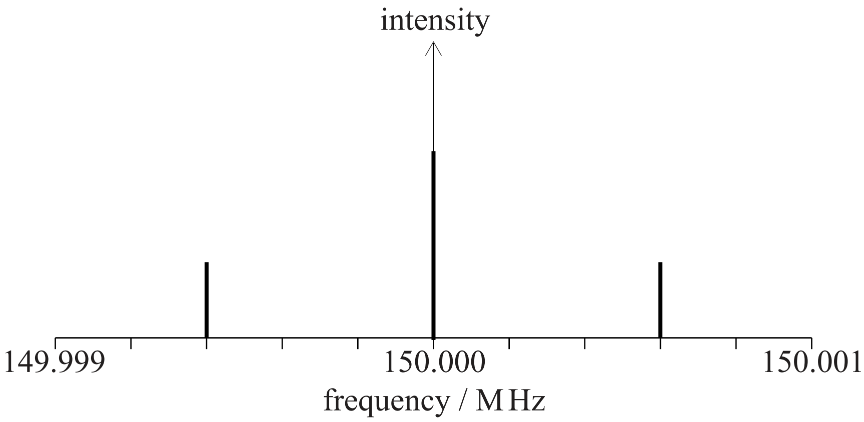
Option F — Communications

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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(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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2: . . . .

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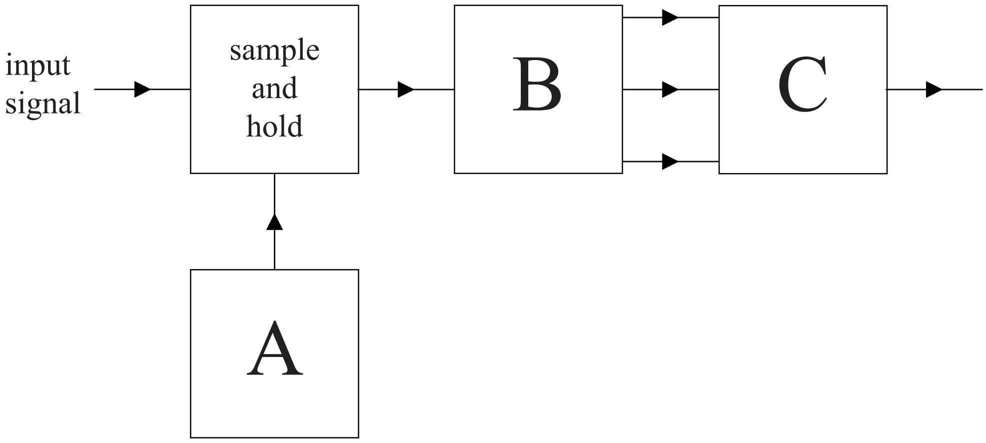
F2. This question is about analogue-to-digital conversion.

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: . . . .

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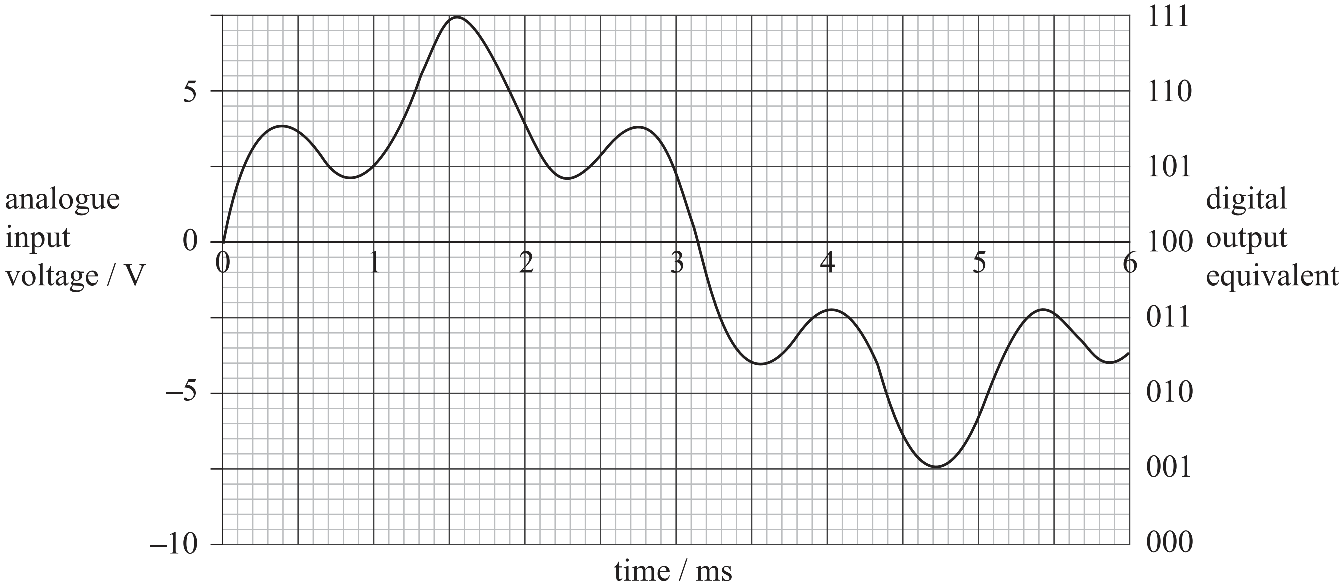
(Question F2 continued)

(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

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(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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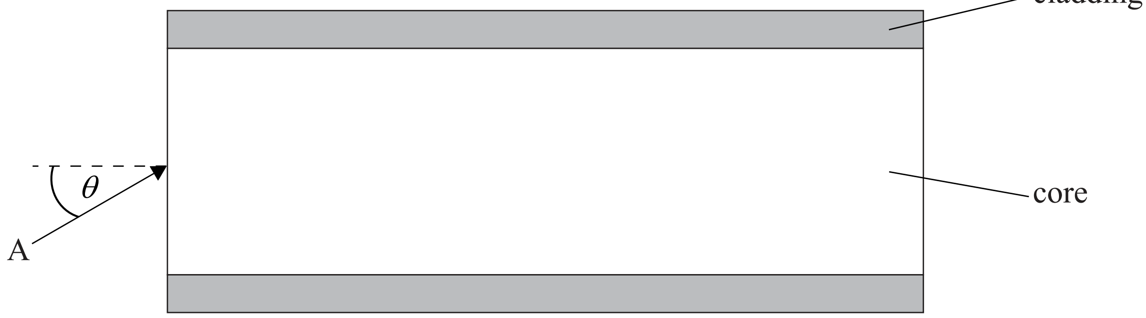
F3. This question is about an optic fibre.

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]*

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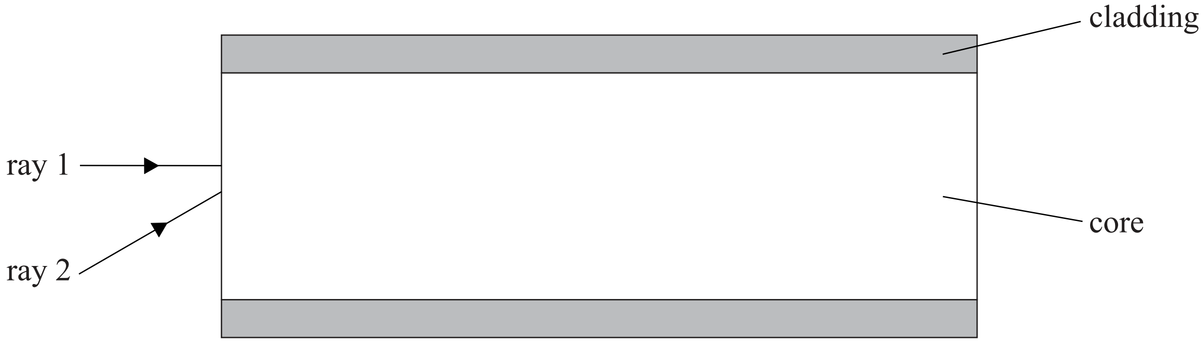
(Question F3 continued)

(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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(d) Outline **two** advantages in the use of optic fibres over coaxial metal cables for the transmission of data between continents. *[2]*

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2: . . . .

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F4. 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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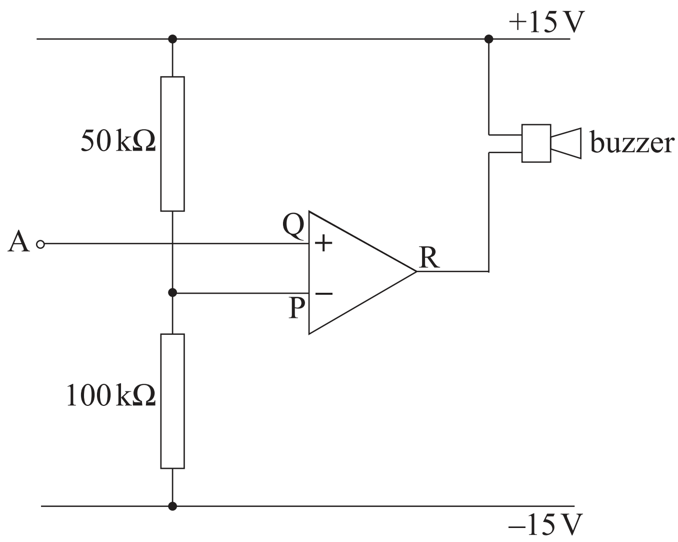
(b) An operational amplifier circuit is designed to switch on a warning buzzer when the potential difference (pd) at point A drops below a voltage V. P is connected to the supply rails via resistances of 50 kΩ and 100 kΩ. The warning buzzer sounds when the pd across it is 30 V.



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

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(Question F4 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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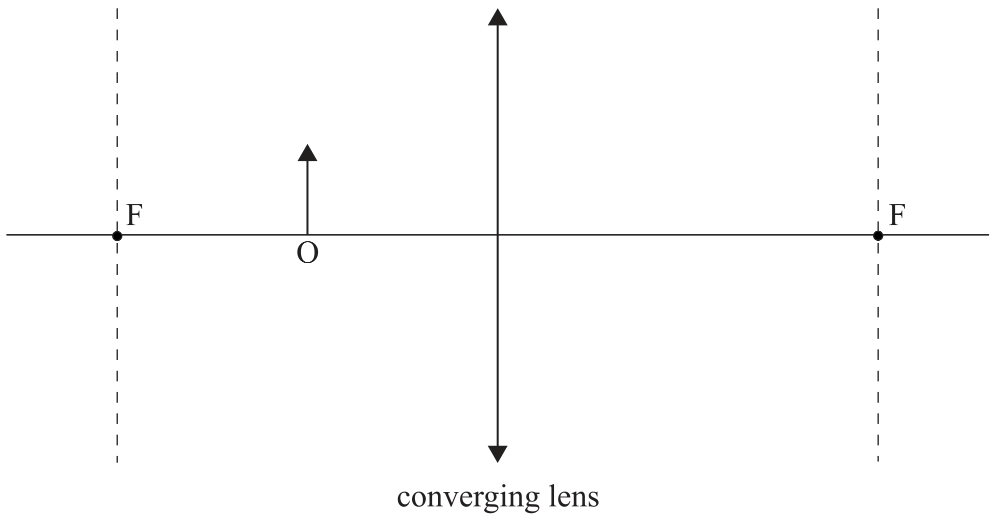
Option G — Electromagnetic waves

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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(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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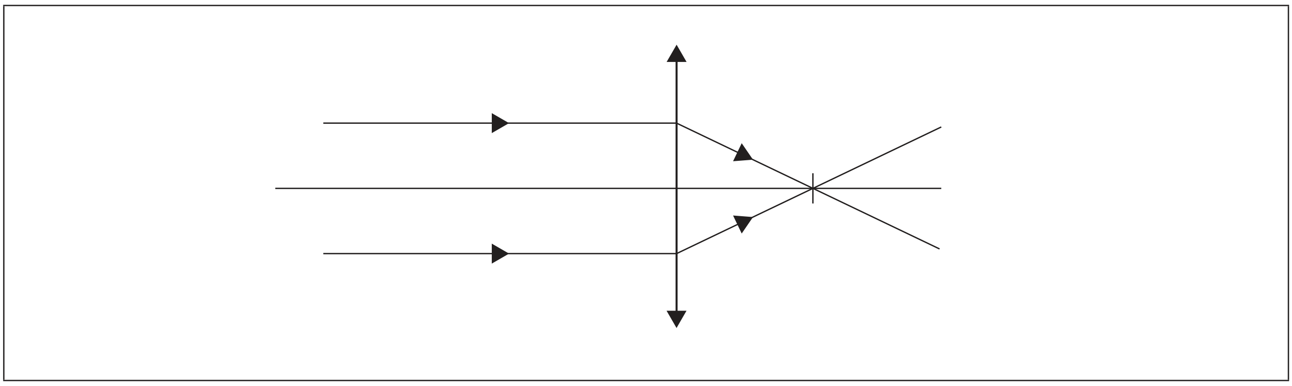
(Question G1 continued)

(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]*

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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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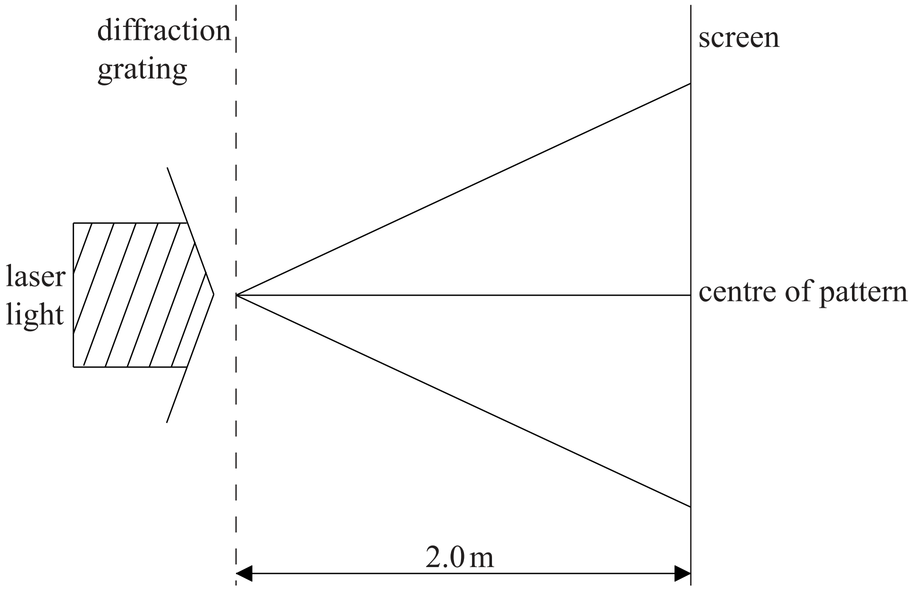
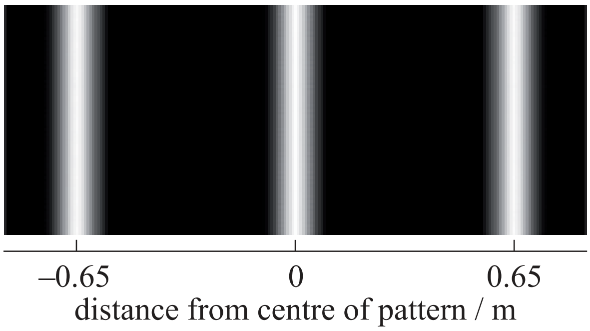
(Question G2 continued)

(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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G3. This question is about X-ray production and diffraction.

(a) Outline how X-rays are used to determine the atomic spacing in a crystal. *[3]*

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(b) Electrons are incident on the target of an X-ray tube after acceleration through a potential difference of 15 kV. Calculate the minimum wavelength of X-rays produced by the X-ray tube. *[2]*

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(c) X-rays are incident on a crystal which is thought to have an atomic spacing of 2.8×10^{-10} m. Calculate the maximum wavelength of X-rays that can be used to verify this value. *[3]*

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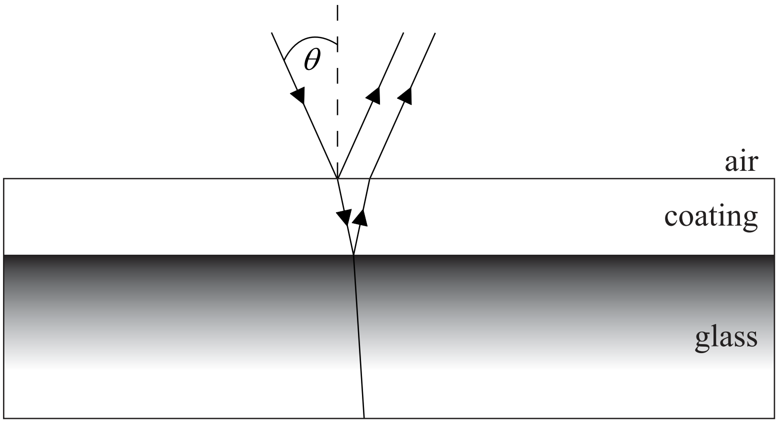
G4. This question is about thin-film interference.

The anti-reflective coating of a lens consists of a thin layer of a suitable material placed between the air and the glass of the lens.



The following data are available.

Refractive index of air	$=1.0$
Refractive index of coating	$=1.2$
Refractive index of glass	$=1.5$

(a) State what phase change occurs on reflection at the air-coating boundary and at the coating-glass boundary. *[1]*

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(b) The thickness d of the coating layer is 110 nm.

Determine the wavelength for which there is no resultant reflection from the surface of the lens for light at normal incidence ($\theta = 0^\circ$). *[3]*

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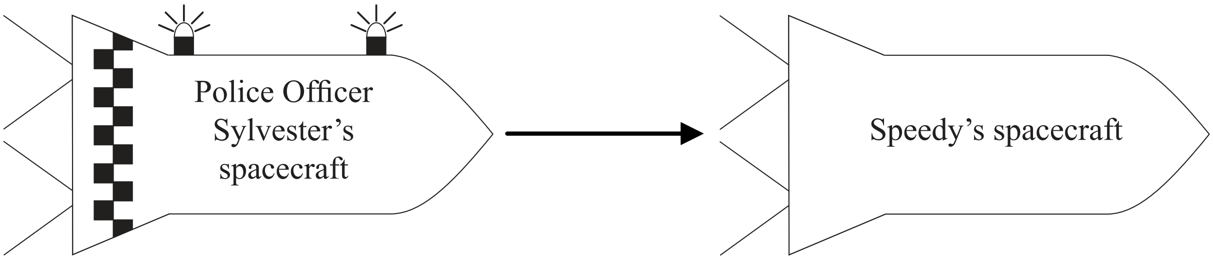
Option H — Relativity

H1. 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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(b) Officer Sylvester switches on the blue flashing lamps on his police spacecraft.

(i) Calculate, assuming that a Galilean transformation applies to this situation, the value of the speed of the light that Speedy would measure using the flashing lamps. *[1]*

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(Question H1 continued)

(ii) Speedy measures the speed of the light emitted by the flashing lamps. Deduce, using the relativistic addition of velocities, that Speedy will obtain a value for the speed of light equal to c. *[3]*

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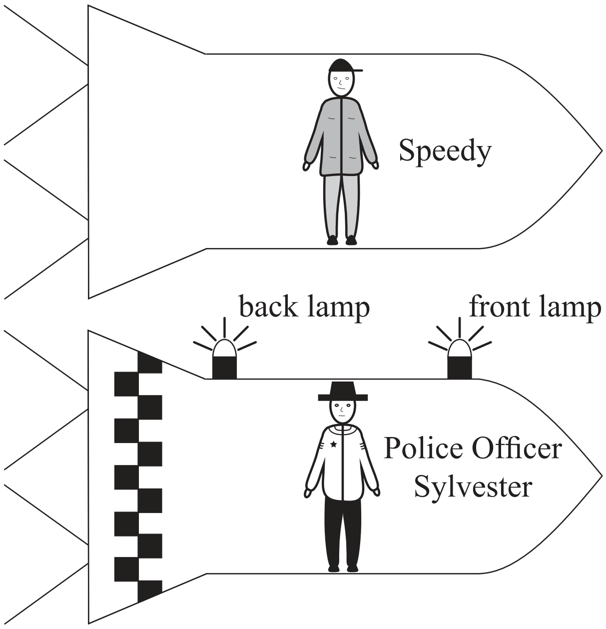
(Question H1 continued)

(c) 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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(Question H1 continued)

(d) 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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H2. This question is about relativistic dynamics.

A proton is accelerated from rest by a potential difference V and reaches a speed of $2.5 \times 10^{8}\,\mathrm{m\,s^{-1}}$. Calculate V. *[3]*

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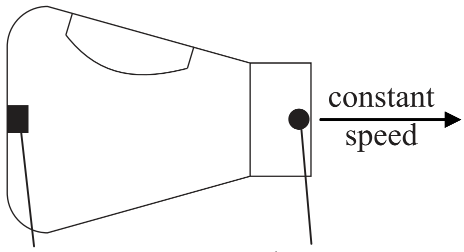
H3. This question is about gravitational red-shift.

An observer is in a space capsule moving at a constant speed in the absence of gravitational fields.



A monochromatic source of gamma rays is fixed to the rear wall of the capsule. An observer at the other end of the capsule measures the frequency of the gamma rays.

The capsule now starts to decelerate.

(a) Deduce the change in the frequency of the gamma rays, as measured by the observer, when the deceleration begins. *[3]*

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(b) Outline, with reference to the principle of equivalence, how the situation in (a) relates to the concept of gravitational red-shift. *[2]*

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H4. This question is about spacetime.

Explain, with reference to the warping of spacetime, the gravitational attraction between Earth and the Sun. *[3]*

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H5. This question is about the Michelson–Morley experiment.

Outline the implications of the Michelson–Morley experiment for our understanding of the propagation of light. *[3]*

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H6. This question is about black holes.

Sirius B has a mass of 2.0×10^{30} kg.

Calculate the minimum density required for Sirius B to become a black hole in the future. *[2]*

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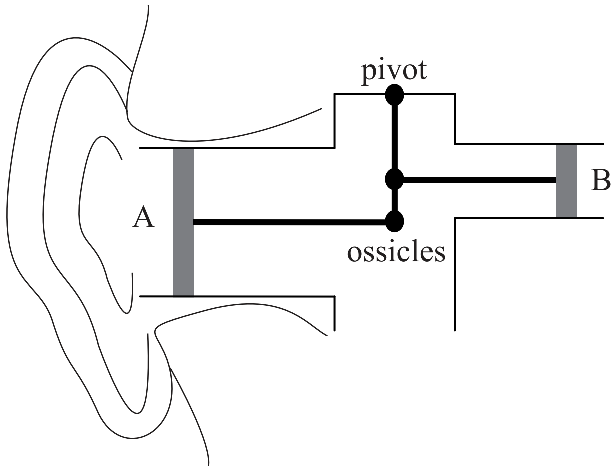
Option I — Medical physics

I1. This question is about the human ear.

(a) The diagram below is a schematic of a model to represent the ear.



(i) Identify the parts of the ear represented by A and B. *[1]*

A: . . . .

B: . . . .

(ii) Outline, with reference to the diagram, the mechanism by which amplification is carried out in the middle ear. *[2]*

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(Question I1 continued)

(b) Explain, with reference to the acoustic properties of the media concerned, why sound cannot be transmitted directly from air to the inner ear efficiently. *[2]*

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(c) Distinguish between loudness and intensity. *[2]*

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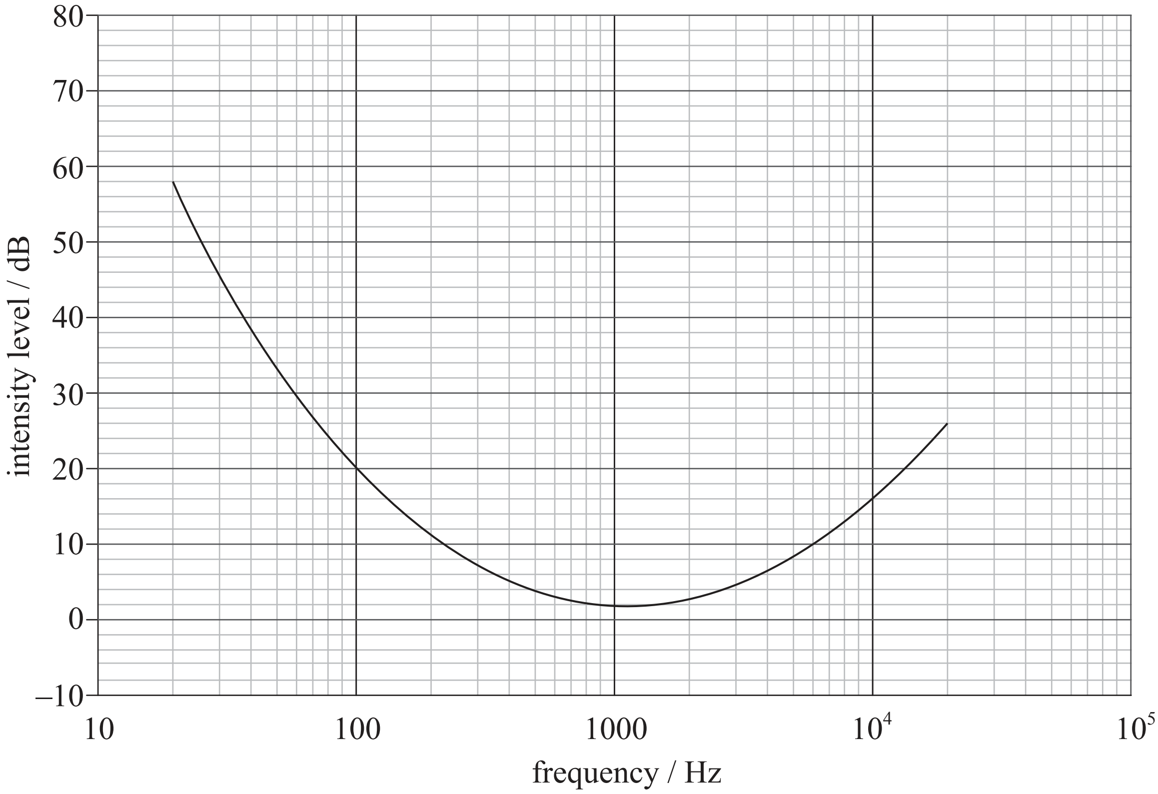
(Question I1 continued)

(d) As a result of exposure to noise, a person has suffered a hearing loss of 15 dB at 10 kHz. At low frequencies, the person's hearing remains normal.

The graph shows the variations with frequency of the threshold of hearing for this person.



Draw a line on the graph to show the threshold of hearing for a person with normal hearing. *[2]*

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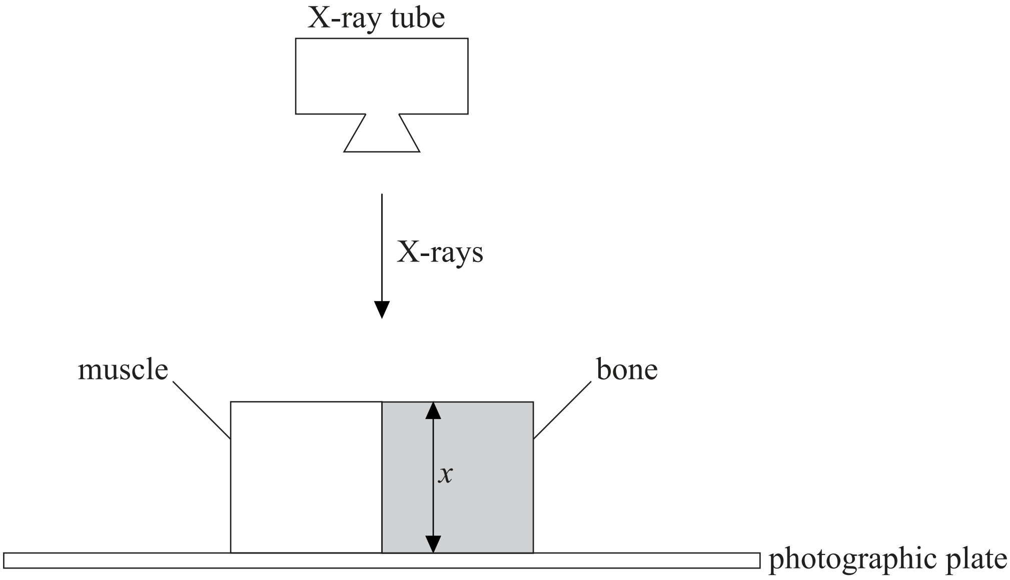
I2. This question is about the use of X-rays and ultrasound in medical imaging.

(a) The diagram below shows X-rays being used to scan a sample of bone and muscle.



(i) Outline how the arrangement differentiates between bone and muscle. *[2]*

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(Question I2 continued)

(ii) Use the data below to determine the ratio $\frac{I_b}{I_m}$ where I_b and I_m are the intensity of X-rays reaching the photographic plate through the bone and the muscle, respectively. *[3]*

Thickness x of sample	$= 10.0\,\text{cm}$
Linear attenuation coefficient of bone μ_b	$= 0.53\,\text{cm}^{-1}$
Linear attenuation coefficient of muscle μ_m	$= 0.30\,\text{cm}^{-1}$

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(iii) The half-value thickness of a material increases as the energy of the radiation increases.

Discuss, with reference to penetration and effect on tissue, why using low energy X-rays in medical imaging is highly desirable but is rare in practice. *[2]*

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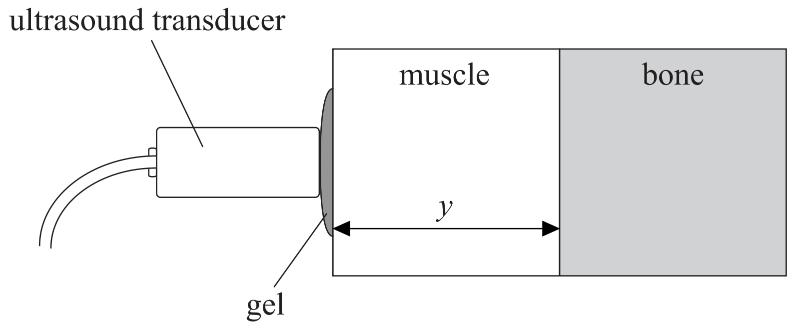
(Question I2 continued)

(b) The same sample is now investigated with an ultrasound A-scan from the side as shown.



(i) State **one** advantage of ultrasound over X-ray imaging. *[1]*

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(ii) State why gel is needed at the transducer-muscle boundary. *[1]*

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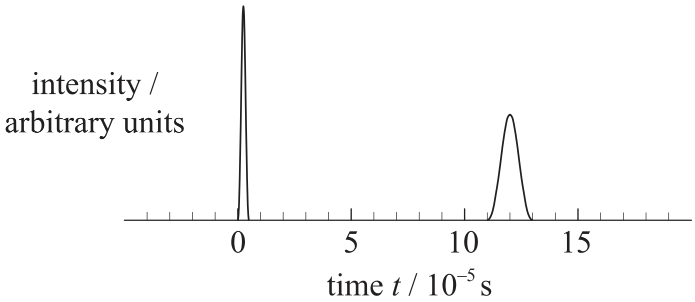
(Question I2 continued)

(iii) A short pulse is directed from the transducer into the sample at time $t = 0$. The graph shows how the intensity of the reflected signal from the muscle-bone boundary varies as a function of time. The speed of sound in muscle is $1.6 \times 10^3 \text{ m s}^{-1}$.



Calculate the thickness y of the sample of muscle. *[2]*

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I3. This question is about the effects of radiation on living organisms.

(a) State what is meant by absorbed dose. *[1]*

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(b) An X-ray CT scan delivers a dose equivalent of 500 μSv to a 70 kg patient. The quality factor of this radiation is 1. Determine the energy that will be required to be absorbed from alpha particles of quality factor 20 to produce the same biological effect in the same patient. *[3]*

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(Question I3 continued)

(c) An isotope of technetium used in medicine has a physical half-life of 6 hours.

(i) Define *effective half-life*. *[2]*

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(ii) A patient ingests some technetium. The biological half-life of the technetium is 12 hours. Determine the time required for the activity of the ingested dose to drop to 25% of its value at the moment of ingestion. *[3]*

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(d) State the property of radiation that enables it to be used as a cancer treatment. *[1]*

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Option J — Particle physics

J1. This question is about elementary particles.

The quark is said to be an elementary particle.

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

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(ii) Identify another elementary particle other than the quark. *[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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J2. This question is about the Ω^- particle.

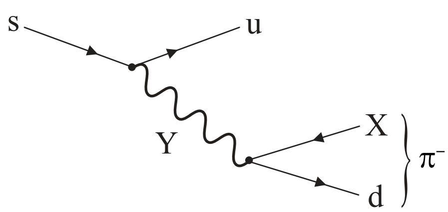
The Ω^- particle is a baryon which contains only strange quarks.

(a) Deduce the strangeness and spin of the Ω^- particle. *[2]*

Strangeness: . . . .

Spin: . . . .

(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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(Question J2 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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(d) The Ω^- particle was discovered in a bubble chamber.

(i) Outline how a bubble chamber is used to detect particles. *[3]*

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(ii) Explain how **two** properties of a particle can be estimated from data collected during bubble chamber experiments. *[2]*

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2: . . . .

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J3. This question is about hadrons.

(a) An electron and a positron can undergo an electromagnetic interaction resulting in the creation of a quark-antiquark pair according to

$$e^{-} + e^{+} \rightarrow q + \overline{q}$$

where q and $\overline{q}$ are quark and antiquark.

Outline, with reference to quark confinement, why hadrons are eventually observed in this reaction. *[3]*

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(b) State what is meant by a neutral current. *[1]*

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(c) The interaction in (a) can also occur via the weak interaction with neutral current mediation producing an up and anti-up quark pair.

(i) Draw a labelled Feynman diagram for this interaction. Time on your diagram should go from left to right. *[2]*

(ii) Outline how another neutral current can allow the exchange particle in the interaction to be detected. *[2]*

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J4. This question is about the early universe.

Determine the threshold temperature of the early universe below which electron–positron pair production becomes unlikely. *[3]*

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J5. This question is about string theory.

Suggest the features of string theory that make it a more fundamental theory than the standard model. *[2]*

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