N09/4/PHYSI/HP3/ENG/TZ0/XX+

88096503

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

PHYSICS
HIGHER LEVEL
PAPER 3

Tuesday 17 November 2009 (morning)

1 hour 15 minutes

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 E — Astrophysics

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

(a) Describe what is meant by

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

. . . .

. . . .

. . . .

. . . .

(ii) absolute magnitude. *[1]*

. . . .

. . . .

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

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

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

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

. . . .

. . . .

. . . .

. . . .

. . . .

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

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question E1 continued)

(c) Given that the power in the mass–luminosity relationship is 3.5, show that the mass of Becruz is about $10\,M_{\mathrm{Sun}}$ where M_{Sun} is the mass of the Sun. *[2]*

. . . .

. . . .

. . . .

. . . .

(d) State the differences between the eventual fate of the Sun and Becrux after they leave the main sequence. *[2]*

Sun: . . . .

. . . .

Becrux: . . . .

. . . .

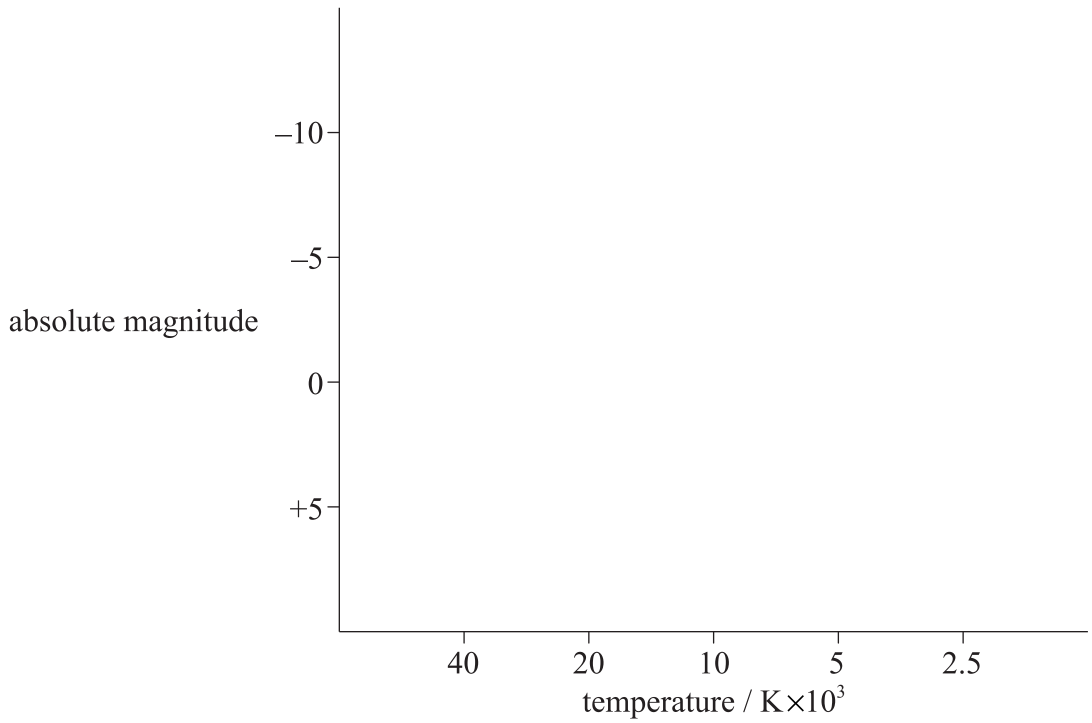
(This question continues on the following page)

(Question E1 continued)

(e) Becrux is a spectral class B star. On the axes of the Hertzsprung–Russell diagram

(i) label, with the letter B, the approximate position of Becrux. *[1]*

(ii) draw the evolutionary path of Becrux after it leaves the main sequence. *[1]*



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

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

. . . .

. . . .

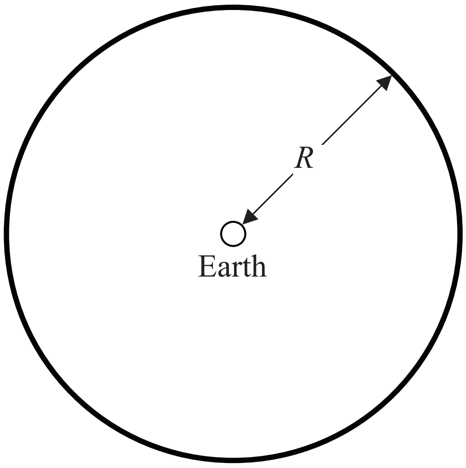
(h) State the **two** quantities that need to be measured in order to use a Cepheid variable as a "standard candle" to determine the distance to the galaxy in which the Cepheid is located. *[2]*

1. . . . .

2. . . . .

E2. This question is about cosmology.

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



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

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question E2 continued)

(b) The Big Bang theory provides a resolution to Olbers' paradox. Two pieces of evidence to support the theory are the existence of cosmic microwave background radiation (CMB) and the red-shifted light from distant galaxies.

(i) Outline how CMB is consistent with the Big Bang theory. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) The following data are available for the red-shift of light from a distant galaxy.

Wavelength of light from galaxy	= 130 nm
Wavelength measured in laboratory	= 120 nm
Hubble constant	= $74\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$

Use the data to determine the distance of the galaxy from Earth. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Blank page

Option F — Communications

F1. This question is about modulation.

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

Signal wave: . . . .

. . . .

Carrier wave: . . . .

. . . .

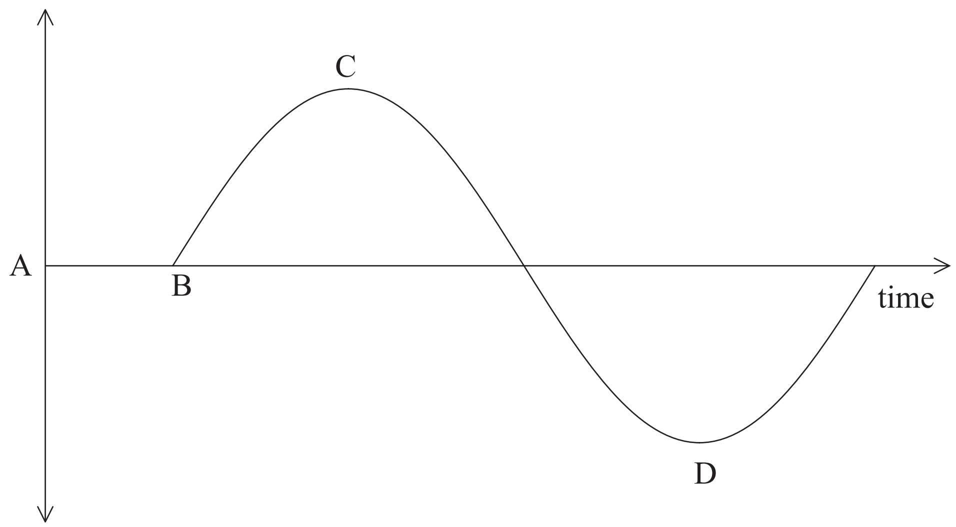
(b) With reference to a carrier wave, distinguish between amplitude modulation and frequency modulation. *[1]*

. . . .

. . . .

. . . .

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



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

A→B . . . .

B→C . . . .

C→D . . . .

(This question continues on the following page)

(Question F1 continued)

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

(i) signal wave. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) carrier wave. *[2]*

. . . .

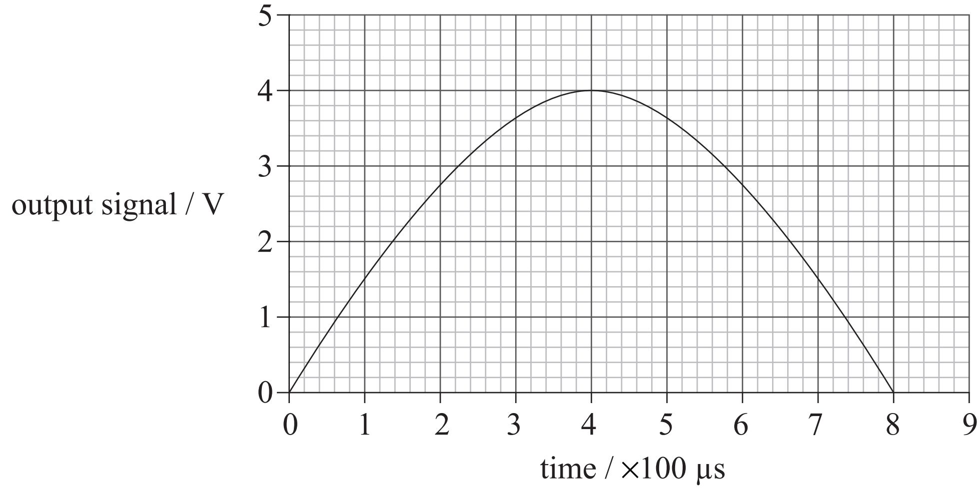
. . . .

. . . .

. . . .

F2. This question is about digital signals.

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



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

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

(This question continues on the following page)

(Question F2 continued)

Determine, explaining your answer, the

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

. . . .

. . . .

. . . .

. . . .

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

. . . .

. . . .

. . . .

. . . .

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

. . . .

. . . .

. . . .

. . . .

. . . .

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

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

. . . .

. . . .

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

. . . .

. . . .

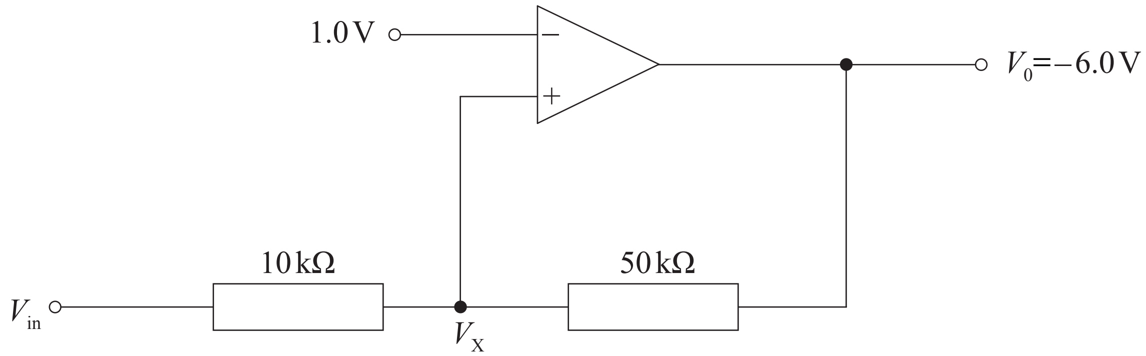
. . . .

. . . .

(This question continues on the following page)

(Question F2 continued)

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



(i) State **two** essential properties of an operational amplifier. *[2]*

. . . .

. . . .

. . . .

(ii) In the situation shown the output voltage V_0 of the amplifier is at its minimum value of –6.0 V. The voltage at the non-inverting input to the amplifier is equal to 1.0 V and at the inverting input it is V_X. The output voltage will switch to its maximum value +6.0 V if the voltage V_X just exceeds +1.0 V. Determine the minimum voltage V_{in} that will result in an output voltage of +6.0 V. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

F3. Outline **one** moral **or** ethical issue and **one** environmental issue that arise from the use of mobile phones. *[4]*

Moral **or** ethical issue: . . . .

. . . .

. . . .

. . . .

Environmental issue: . . . .

. . . .

. . . .

. . . .

Blank page

Option G — Electromagnetic waves

G1. This question is about the electromagnetic spectrum.

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

. . . .

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

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

. . . .

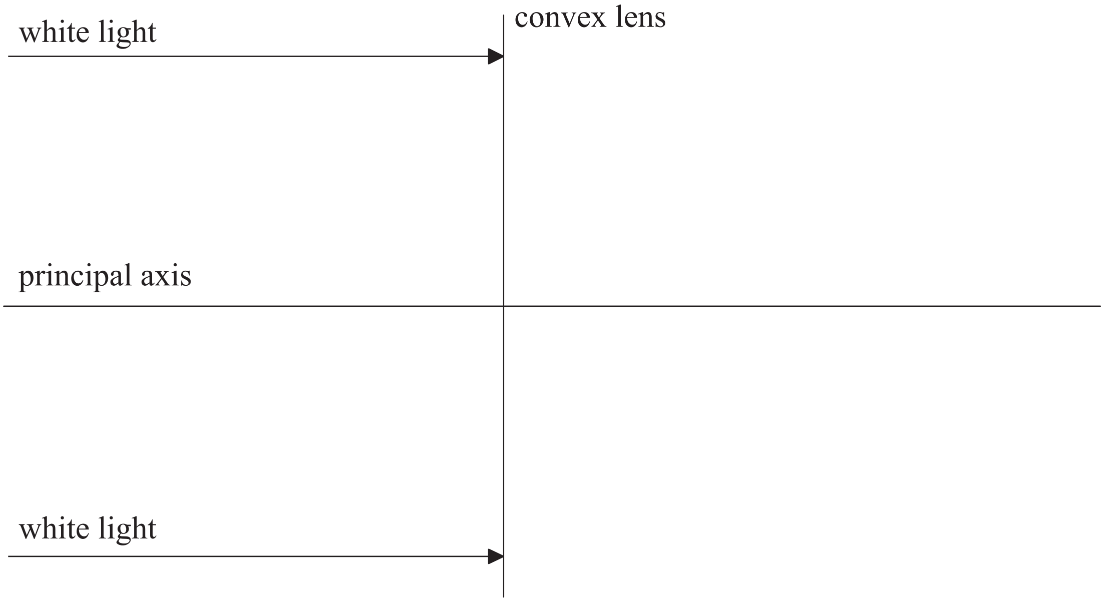
(ii) Suggest **one** disadvantage of using gamma-rays for television transmission. *[1]*

. . . .

. . . .

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

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



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

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

. . . .

. . . .

. . . .

. . . .

. . . .

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

. . . .

. . . .

(This question continues on the following page)

(Question G2 continued)

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

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

. . . .

. . . .

. . . .

. . . .

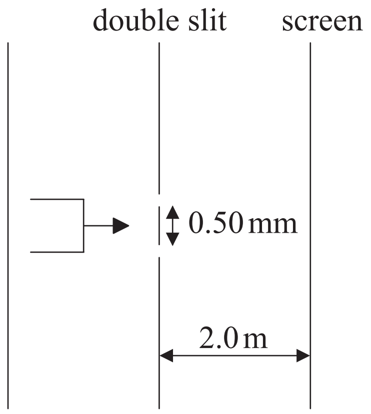
(ii) linear magnification. *[1]*

. . . .

. . . .

G3. This question is about two-source interference.

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



(diagram not to scale)

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

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

. . . .

. . . .

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

. . . .

. . . .

. . . .

. . . .

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

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question G3 continued)

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

. . . .

. . . .

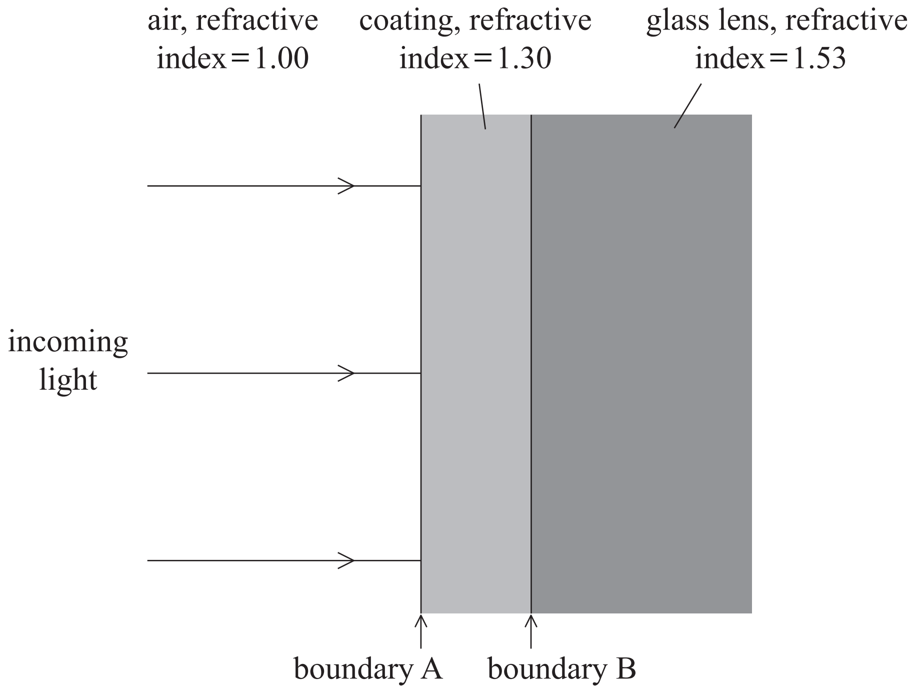
. . . .

. . . .

. . . .

G4. This question is about thin film interference.

A transparent thin film is sometimes used to coat spectacle lenses as shown in the diagram below.



(a) State the phase change which occurs to light that

(i) is transmitted at boundary A into the film. *[1]*

. . . .

(ii) is reflected at boundary B. *[1]*

. . . .

(iii) is transmitted at boundary A from the film into the air. *[1]*

. . . .

(b) Light of wavelength 570 nm in air is incident on the coating. Determine the smallest thickness of the coating required so that the reflection is minimized for normal incidence. *[2]*

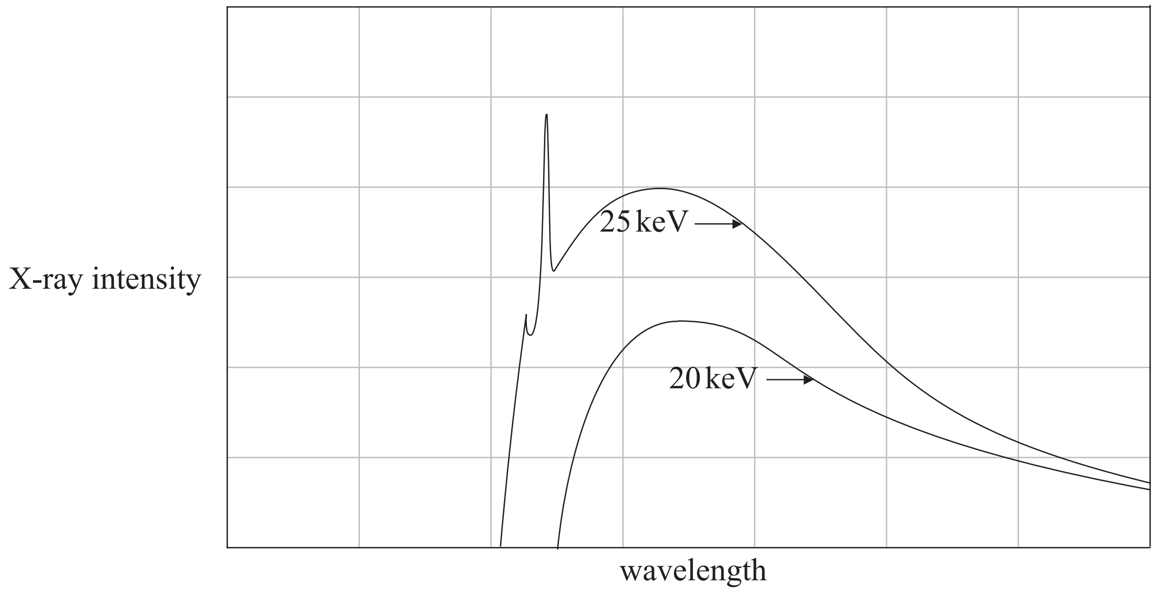
. . . .

. . . .

. . . .

G5. This question is about X-rays.

(a) The diagram below is a sketch that shows the X-ray spectra produced by electrons of energy 25 keV and of energy 20 keV striking a molybdenum target.



Suggest why **no** characteristic spectra are produced by the 20 keV electrons. *[2]*

. . . .

. . . .

. . . .

. . . .

. . . .

(b) Show that the minimum X-ray wavelength produced by the 25 keV electrons in (a) is 0.050 nm. *[2]*

. . . .

. . . .

. . . .

. . . .

(c) The wavelengths of the X-rays in (a) are measured by scattering them from the surface of a crystal that has a cubic lattice structure. The spacing of the lattice ions is 0.28 nm. Calculate the wavelength of the X-rays that produce a first order Bragg angle of 21°. *[1]*

. . . .

. . . .

Option H — Relativity

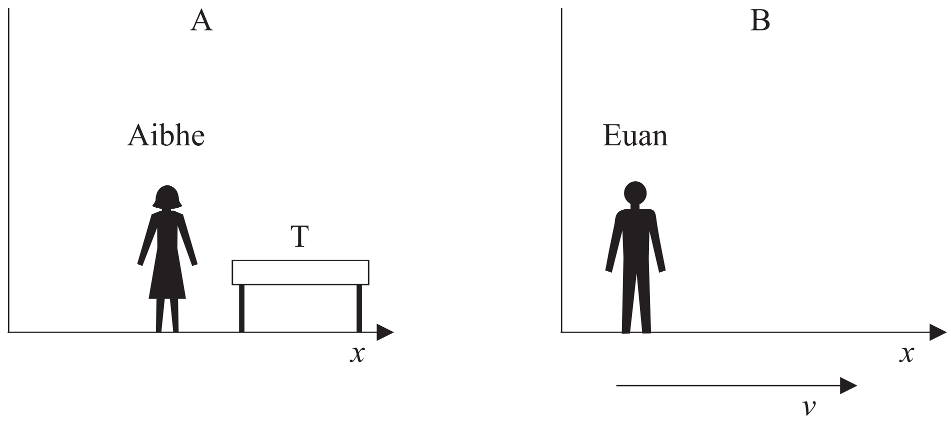
H1. This question is about special relativity.

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

. . . .

. . . .

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



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

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

. . . .

. . . .

. . . .

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

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question H1 continued)

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

. . . .

. . . .

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

. . . .

. . . .

. . . .

. . . .

. . . .

(e) Muons are produced in the upper atmosphere by the bombardment of cosmic rays. The muons travel close to the speed of light and are unstable. They have a very short half-life as measured in a muon's frame of reference. Explain how the detection of muons at the surface of the Earth provides evidence for the special theory of relativity. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

H2. This question is about relativistic energy and momentum.

(a) Particle A is at rest with respect to an observer. Another identical particle B is moving with respect to the observer. Distinguish between the total energy of particle A and the total energy of particle B as measured by the observer. *[2]*

Particle A: . . . .

. . . .

Particle B: . . . .

. . . .

(b) Two protons are travelling towards each other along the same straight line in a vacuum.

The speed of each proton, as measured in the laboratory frame of reference, is 0.960c.

(i) Calculate the relative speed of one proton with respect to the other proton. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) Show that the total energy of one of the protons, according to an observer at rest in the laboratory, is 3.35 GeV. *[2]*

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question H2 continued)

(c) The collision of the two protons results in the following reaction

$$p^+ + p^+ = p^+ + n^0 + \pi^+$$

where π^+ is a particle called a pion and has a rest mass of $140\,\text{MeV}\,c^{-2}$. The total energy of the pion is 502 MeV. Determine, according to an observer at rest in the laboratory, the

(i) total energy of the proton formed plus the total energy of the neutron formed by the collision. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) momentum of the pion. *[2]*

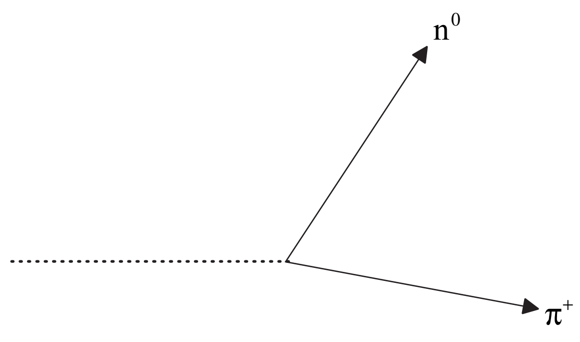
. . . .

. . . .

. . . .

. . . .

(d) The diagram shows the paths followed by the neutron and pion in (c).



The dotted line shows the path of the original collision of the protons in (b). On the diagram, draw the direction of the proton formed in the collision. *[1]*

H3. This question is about spacetime and black holes.

(a) State what is meant by the concept of spacetime. *[2]*

. . . .

. . . .

. . . .

. . . .

(b) Outline, with reference to the motion of photons in spacetime, what is meant by the Schwarzschild radius. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(c) The mass of the Sun is about 2×10^{30} kg. Show that, if the Sun were to become a black hole, its radius would be about 3 km. *[1]*

. . . .

. . . .

. . . .

Option I — Medical physics

I1. This question is about hearing.

(a) Outline how variations in sound pressure in the air are amplified in the middle ear. *[2]*

. . . .

. . . .

. . . .

. . . .

. . . .

(b) A sound of intensity $I = 2.0 \times 10^{-6}\,\text{W m}^{-2}$ is incident on the ear. The loudness detected by the ear due to this sound is L.

(i) Suggest why the loudness of a sound of intensity $4.0 \times 10^{-6}\,\text{W m}^{-2}$ detected by the ear is **not** $2L$. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) Use the decibel scale to determine to what value the intensity I must be increased in order that the loudness detected by the ear is $2L$. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(iii) In light of your answer to (b)(ii), outline possible effects of long-term exposure of sound at this loudness. *[3]*

. . . .

. . . .

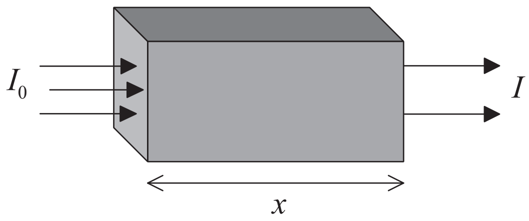
. . . .

. . . .

. . . .

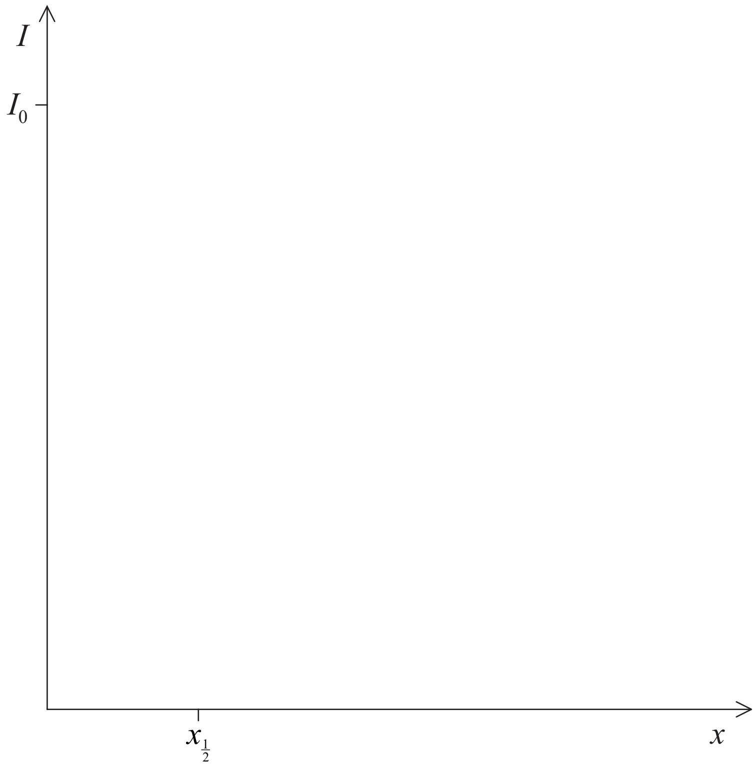
I2. This question is about the use of X-rays and the use of laser light in clinical diagnosis.

(a) A parallel beam of X-rays of intensity I_0 is incident on a block of material of thickness x.



The intensity of the X-rays emerging from the block is I and the half-value thickness of the material is $x_{\frac{1}{2}}$.

Using the axes below, sketch a graph showing four data points, to show how I varies with x for blocks of the same material but differing thicknesses. The position of I_0 and of $x_{\frac{1}{2}}$ are shown marked on the respective axes. *[2]*



(This question continues on the following page)

(Question I2 continued)

(b) The attenuation coefficient for bone is μ_b and for tissue μ_t. The table shows the ratio $\frac{\mu_b}{\mu_t}$ for X-rays of three different photon energies.

Photon energy / MeV	$\frac{\mu_b}{\mu_t}$
0.08	3.0
0.01	8.0
1.00	1.0

(i) Explain why X-rays of photon energy 0.01 MeV are the most suitable for use in detecting a bone fracture. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) The attenuation coefficient of bone for X-rays with photon energy 0.01 MeV is $0.60\,\text{cm}^{-1}$. X-rays of this energy used to image a suspected leg bone fracture pass through bone thickness of 6.0 cm and tissue thickness 9.6 cm. Determine the following ratio. *[4]*

$$\frac{\text{final intensity of x-rays after passing through bone}}{\text{final intensity of x-rays after passing through tissue}}$$

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question I2 continued)

(c) Regions of the electromagnetic spectrum other than the X-ray region, can also be used in clinical diagnosis. In this respect, light from two lasers is used in pulse oximetry.

(i) Identify the **two** regions of the electromagnetic spectrum in which the wavelength of the light emitted by each laser is found. *[1]*

. . . .

. . . .

(ii) Outline how the laser light is used to measure hemoglobin saturation in the blood. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

I3. This question is about radioactive isotopes used as tracers.

(a) Define *biological half-life* and *physical half-life*. *[2]*

Biological half-life: . . . .

. . . .

Physical half-life: . . . .

. . . .

(b) Radioactive isotopes can be used as "tracers" in order to study certain physiological processes in the body. State, for these isotopes, **one** reason why

(i) it is important that such isotopes have a short biological half-life. *[1]*

. . . .

. . . .

(ii) the physical half-life is greater than the biological half-life. *[1]*

. . . .

. . . .

(c) The physical half-life of a particular isotope used as a tracer is 4.0 days and its biological half-life is 2.0 days. Calculate the percentage decrease in the activity of the isotope 4.0 days after it is introduced into the body. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

Option J — Particle physics

J1. This question is about fermions and bosons.

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

. . . .

. . . .

. . . .

. . . .

(b) Identify the boson that mediates the

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

. . . .

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

. . . .

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

. . . .

. . . .

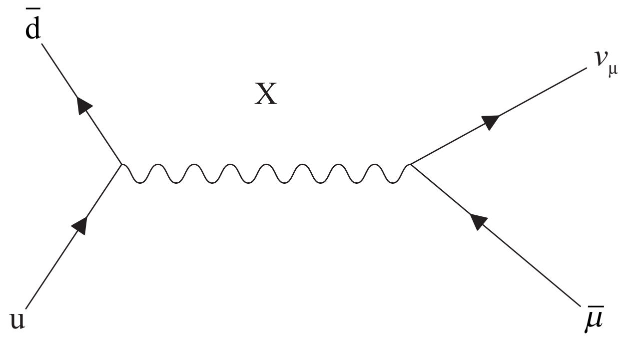
. . . .

. . . .

(This question continues on the following page)

(Question J1 continued)

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



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

Meson: . . . .

. . . .

Anti-muon: . . . .

. . . .

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

. . . .

J2. This question is about particle accelerators.

(a) Different types of particles may be produced by the collision of accelerated protons with stationary protons. Explain why the accelerated protons must have high energy. *[2]*

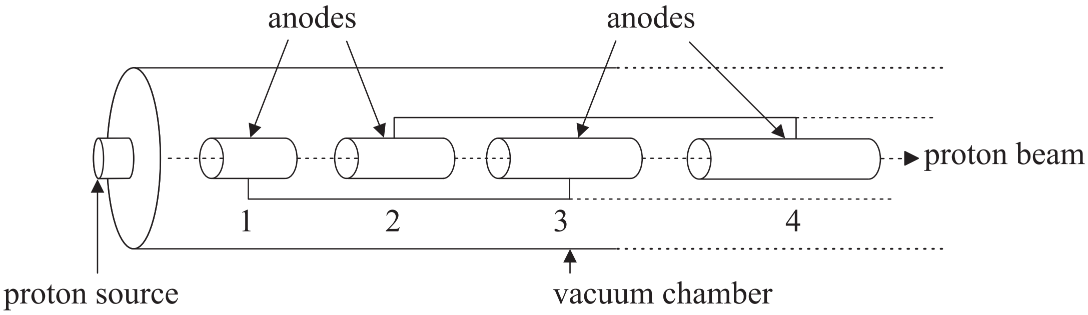
. . . .

. . . .

. . . .

. . . .

(b) The diagram shows some of the features of a linear particle accelerator used to accelerate protons.



The vacuum chamber contains a succession of cylindrical anodes of which only four are shown, anodes 1, 2, 3 and 4.

(i) State why the protons are **not** accelerated whilst travelling inside the anodes. *[1]*

. . . .

. . . .

(ii) Describe the mechanism by which the protons are accelerated by the anodes. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question J2 continued)

(c) The minimum energy required to produce a K^- meson in the collision between a high energy proton and a stationary proton is 1890 MeV. Determine the minimum kinetic energy E_K that the high energy proton must have in order to produce a K^- meson. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(d) In particle accelerators such as synchrotrons, it can be arranged to have collisions between protons and antiprotons travelling in opposite directions. State **one** advantage and **one** disadvantage of this arrangement in terms of particle production as compared with that described in (c). *[2]*

Advantage: . . . .

. . . .

Disadvantage: . . . .

. . . .

J3. This question is about quarks.

(a) The strangeness of the Ω^- hadron is –3 and its spin is $+\frac{3}{2}$.

(i) Explain how it is known that the quark structure of the Ω^- hadron is sss. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) Explain, with reference to the quark structure of the Ω^- hadron, why the concept of the colour of quarks was introduced. *[2]*

. . . .

. . . .

. . . .

. . . .

(iii) State why the Ω^- hadron has **no** colour. *[1]*

. . . .

. . . .

(b) As well as providing evidence for the existence of quarks, deep inelastic scattering experiments also provide evidence for the existence of gluons.

(i) State what is meant by deep inelastic scattering. *[1]*

. . . .

. . . .

(ii) Outline how the experiments provide evidence for the existence of gluons. *[2]*

. . . .

. . . .

. . . .

. . . .