22096515

International Baccalaureate
Baccalauréat International
Bachillerato Internacional

PHYSICS
HIGHER LEVEL
PAPER 3

Wednesday 13 May 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.

22096515

Option E — Astrophysics

E1. This question is about the star Antares.

The star Antares is a red supergiant star in the constellation Scorpius.

(a) Describe **three** characteristics of a red supergiant star and state what is meant by a constellation. *[4]*

Red supergiant star:

. . . .

. . . .

. . . .

Constellation:

. . . .

. . . .

(b) The apparent magnitude of Antares is $+1.1$ and its absolute magnitude is -5.3.

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

. . . .

. . . .

. . . .

. . . .

(ii) Show that the distance of Antares from Earth is 3.9×10^{7} AU. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(iii) State the name of the method that is used to measure the distance of Antares from Earth. *[1]*

. . . .

(This question continues on the following page)

(Question E1 continued)

(c) The apparent brightness of Antares is 4.3×10^{-11} times the apparent brightness of the Sun.

(i) Define *apparent brightness*. *[1]*

. . . .

. . . .

(ii) Using the answer to (b)(ii), show that Antares is 6.5×10^{4} times more luminous than the Sun. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(d) Alnitak is a main sequence star with a luminosity similar to that of Antares. Use the value quoted in (c)(ii) to deduce that the mass of Alnitak is in the range $16\,M_S$ to $40\,M_S$, where M_S is the mass of the Sun. *[2]*

. . . .

. . . .

. . . .

. . . .

(e) Explain, in terms of the Chandrasekhar limit, why it unlikely that Alnitak will develop into a white dwarf. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(f) State the probable final evolutionary state of Alnitak *[1]*

. . . .

E2. This question is about models of the universe.

Observations of the night sky indicate that there are many regions of the universe that do not contain any stars.

(a) Explain why this observation contradicts Newton's model of the universe. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(b) Outline how the Big Bang model of the universe is consistent with this observation. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

E3. This question is about Hubble's law.

Hubble's law states that

$$v = H_0 d$$

where v is the relative recessional speed between galaxies, d is their separation and H_0 is the Hubble constant. Recent measurements place the value of H_0 in the range 60 to 90 $\text{km s}^{-1}\,\text{Mpc}^{-1}$.

(a) Suggest why a precise value of H_0 is not known. *[2]*

. . . .

. . . .

. . . .

. . . .

(b) Estimate, in seconds, the maximum known age of the universe. *[2]*

. . . .

. . . .

. . . .

. . . .

Option F — Communications

F1. This question is about radio communication.

(a) State the difference between

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

. . . .

. . . .

. . . .

. . . .

(ii) amplitude modulation and frequency modulation. *[2]*

. . . .

. . . .

. . . .

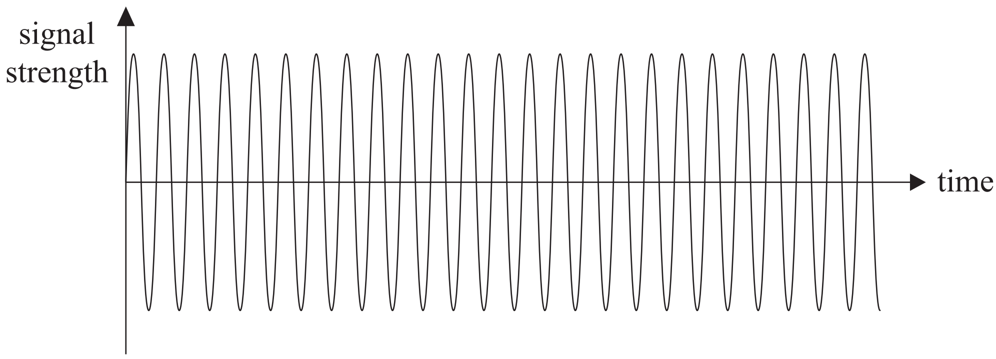
. . . .

(This question continues on the following page)

(Question F1 continued)

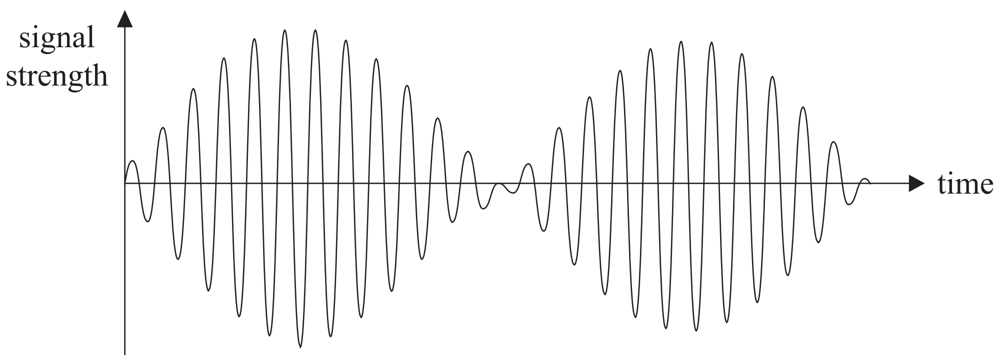
(b) Graph A shows a sketch of how the signal strength of a certain radio carrier wave varies with time at a particular point in space.

Graph A



Graph B shows how the signal strength of the wave is amplitude modulated by a signal wave.

Graph B



The time scale for both graphs is the same.

The frequency of the carrier wave is f_c and that of the signal wave f_s. Use both graphs to estimate the ratio $\frac{f_c}{f_s}$ and explain how you arrived at your answer. *[2]*

. . . .

. . . .

. . . .

. . . .

. . . .

(c) On graph B sketch the wave form of the signal wave. *[1]*

(This question continues on the following page)

(Question F1 continued)

(d) Describe **one** advantage and state **one** disadvantage of using amplitude modulation in radio transmission as compared to the use of frequency modulation. *[3]*

Advantage: . . . .

. . . .

. . . .

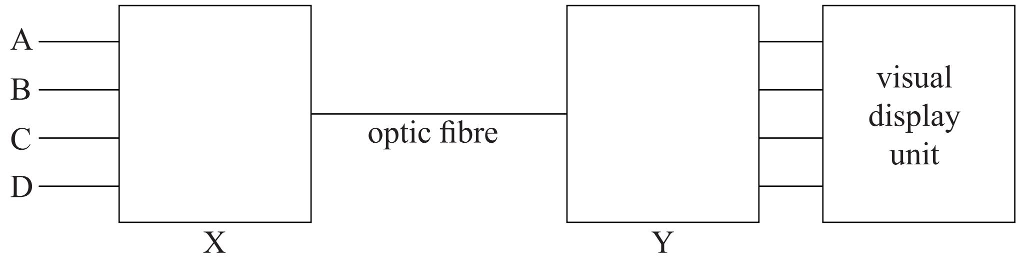
. . . .

Disadvantage: . . . .

. . . .

F2. This question is about transmission of signals.

In a particular transmission system a single piece of analogue information is converted into a 4-bit binary "word" represented by the letters ABCD. The word is transmitted along an optic fibre to the receiver. The block diagram shows the principle components for the transmission and reception of this word.



(a) On the diagram label the components X and Y and outline the function of each component. *[3]*

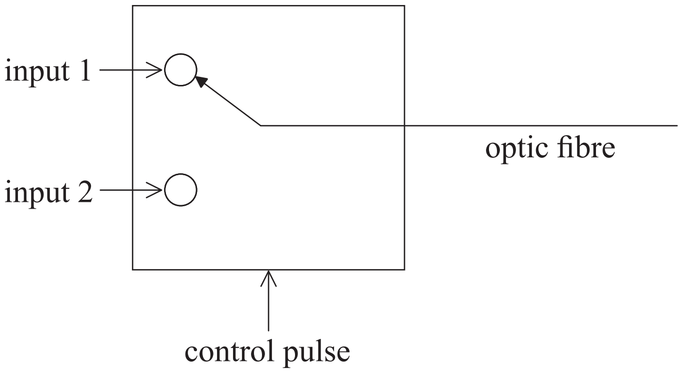
X: . . . .

. . . .

Y: . . . .

. . . .

(b) The diagram is a representation of a two-input time division multiplexer.



Outline, with reference to the diagram, how this device enables two sets of digital data to be transmitted apparently simultaneously along the same optic fibre. *[2]*

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question F2 continued)

(c) As a signal is transmitted along an optic fibre its signal strength is attenuated. For this reason amplifiers have to be placed at points along the fibre.

(i) Explain what is meant by attenuation. *[2]*

. . . .

. . . .

. . . .

(ii) In a particular fibre, the signal needs to be amplified when the signal power is 8.2×10^{-19} W. The fibre has an attenuation loss of 2.0 dB km^{-1}. Determine, for an input signal of power 5.0 mW, the separation of the amplifiers along the fibre. *[3]*

. . . .

. . . .

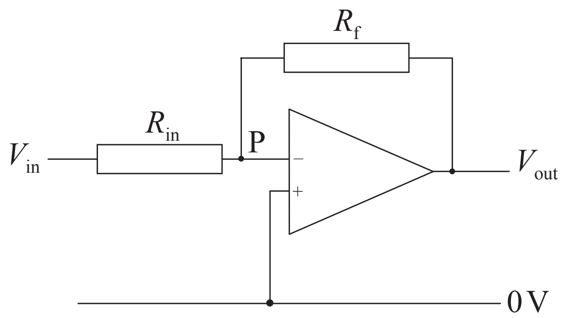
. . . .

. . . .

. . . .

F3. This question is about operational amplifiers.

(a) The diagram shows a circuit that uses an operational amplifier as an inverting amplifier.



The point P is a virtual earth, that is at the same potential (0 V) as the earth line.

(i) State the **two** properties of the operational amplifier which make P a virtual earth. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) In the circuit $R_f = 100\,\text{k}\Omega$ and $R_{in} = 10\,\text{k}\Omega$. Calculate the gain of the amplifier. *[1]*

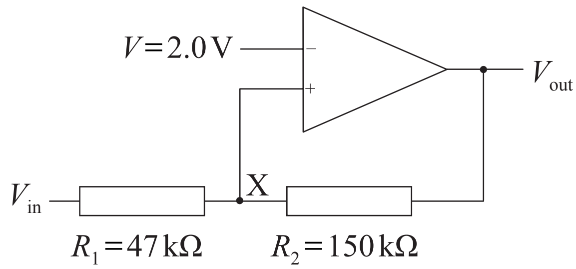
. . . .

. . . .

(This question continues on the following page)

(Question F3 continued)

(b) The diagram shows a circuit that uses an operational amplifier as a non-inverting Schmitt trigger.



In the situation shown, the potential at point X is 2.0 V and the output potential V_{out} is at its minimum value of –10 V. Show that for the output potential to switch to its maximum value of +10 V

(i) the current in the resistors R_1 and R_2 is 0.08 mA. *[1]*

. . . .

. . . .

(ii) V_{in} must rise to 5.8 V. *[2]*

. . . .

. . . .

. . . .

. . . .

F4. This question is about the mobile phone system.

(a) Suggest why mobile phones are sometimes referred to as cell phones. *[1]*

. . . .

. . . .

(b) Explain, based on your answer to (a), why mobile phones can be made small in size. *[2]*

. . . .

. . . .

. . . .

. . . .

(c) State a moral **or** ethical issue that you consider to arise from the use of mobile phones. *[1]*

. . . .

. . . .

Option G — Electromagnetic waves

G1. This question is about the nature of electromagnetic waves.

Explain why the daytime sky of the Earth is blue but the daytime sky of the Moon is black. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

G2. This question is about interference and lasers.

(a) Two overlapping beams of light from two flashlights (torches) fall on a screen. Explain why no interference pattern is observed. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(b) Light from a laser that passes through a double slit is incident on a screen and produces observable interference.

(i) Outline how the laser produces light. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) State the name of the property that enables the laser light to produce observable interference. *[1]*

. . . .

(c) Outline how a laser can be used to read the bar-code at the bottom of this page. *[2]*

. . . .

. . . .

. . . .

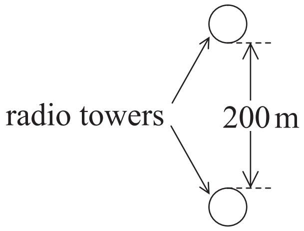
. . . .

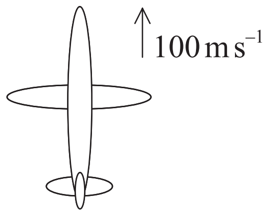
. . . .

(This question continues on the following page)

(Question G2 continued)

(d) A plane is flying at $100\,\mathrm{m\,s^{-1}}$ in a direction parallel to the line joining two identical radio towers as shown in the diagram.





(not to scale)

The two towers each emit a coherent radio signal of wavelength of 5.0 m. The separation of the towers is 200 m. To an observer on the plane the intensity of the received signal goes through a maximum every 5.0 s. Determine the distance from the plane to the line joining the radio towers. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

G3. This question is about optical instruments.

(a) Define *linear magnification*. *[1]*

. . . .

. . . .

(b) An object is placed a distance x from a converging (convex) lens of focal length 10 cm. An image of the object is formed on a screen at a distance 45 cm from the lens. Calculate the

(i) distance x. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) magnitude of the linear magnification. *[1]*

. . . .

. . . .

. . . .

. . . .

(c) State what is meant by spherical aberration for a lens and suggest how this may be reduced. *[2]*

. . . .

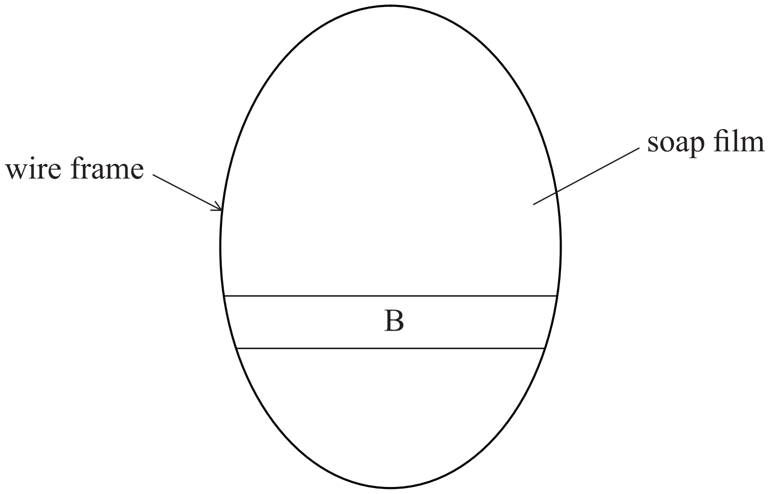
. . . .

. . . .

. . . .

G4. This question is about thin-film interference.

The diagram shows a soap film suspended on a wire frame which is aligned vertically.



The film is viewed in reflected white light. The lower part of the film exhibits a number of colours. The section marked B is 260 nm thick. The refractive index of water is $n = 1.33$. The table gives the wavelength range for the colours of the visible spectrum. Deduce the colour of the section B of the film. *[4]*

Colour	**Wavelength Range**
Violet	380 to 450 nm
Blue	450 to 495 nm
Green	495 to 570 nm
Yellow	570 to 590 nm
Orange	590 to 620 nm
Red	620 to 750 nm

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

G5. This question is about X-rays.

X-rays may be used to analyse the structure and properties of materials.

(a) Draw a labelled diagram showing a typical apparatus for the production of X-rays. *[3]*

(b) The X-ray spectrum for each element shows both a characteristic and continuous spectrum. Describe the origin of the characteristic spectrum. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

Option H — Relativity

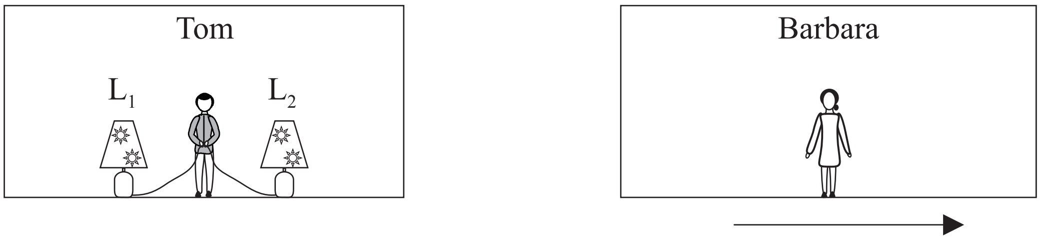
H1. This question is about simultaneity and length measurement.

(a) One of the two postulates of special relativity states that “the laws of physics are the same for all inertial observers”. State the other postulate. *[1]*

. . . .

. . . .

(b) Tom and Barbara are two observers each in a separate reference frame. The reference frames are moving relative to each other in the same straight line with constant velocity. Two lamps L_1 and L_2 are operated by the same switch. Tom is at the mid-point between the lamps as measured in his frame of reference.



direction of motion of Barbara’s reference frame relative to Tom’s reference frame

The lamps and the switch are at rest relative to Tom.

Tom switches on the lamps and to him they light simultaneously. Explain, based on your answer to (a), why the lamps will not light simultaneously, according to Barbara. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question H1 continued)

(c) Tom measures the separation of L_1 and L_2 to be 1.5 m whereas Barbara measures the separation to be 0.5 m.

(i) State and explain which observer measures the proper length between L_1 and L_2. *[1]*

. . . .

. . . .

(ii) Calculate, in terms of the free space speed of light c, the relative speed between Tom and Barbara. *[3]*

. . . .

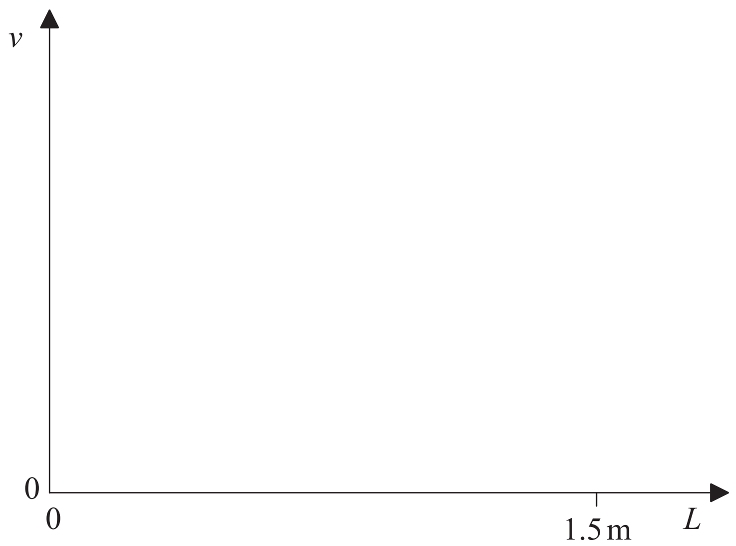
. . . .

. . . .

. . . .

. . . .

(iii) Sketch a graph to show how the relative speed v between Tom and Barbara varies with the length L between L_1 and L_2 as measured by Barbara. The data point (1.5, 0) is shown. On the v axis, label the point $v = c$. *[3]*



(This question continues on the following page)

(Question H1 continued)

(d) In another situation, Tom is at rest on the surface of Earth. Barbara is in a spaceship travelling at constant velocity, with respect to Earth, towards a distant planetary system. After reaching the system she returns to Earth. Outline how this situation leads to the so-called twin paradox. *[3]*

. . . .

. . . .

. . . .

. . . .

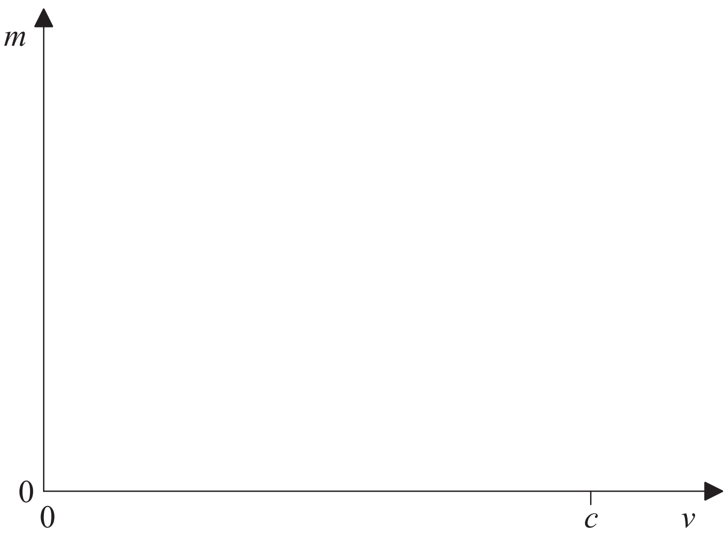
. . . .

. . . .

H2. This question is about some consequences of special relativity.

A proton is accelerated from rest through a potential difference V. After acceleration its speed is close to that of the speed of light in free space c.

(a) On the axes sketch a graph to show the variation with speed v of the mass m of the proton. *[3]*



(b) The potential difference V is 8.50×10^{8} V. As measured in the laboratory frame of reference,

(i) calculate the total energy of the proton after acceleration. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) show that the final speed of the proton is 0.852c. *[2]*

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question H2 continued)

(c) After acceleration the proton approaches an antiproton (proton with a negative charge) that is moving along the same straight line but in the opposite direction. The relative speed of approach of the particles, as measured in the laboratory frame of reference, is 0.987c. Deduce that the speed of the antiproton is about the same as the speed of the proton in (b)(ii). *[2]*

. . . .

. . . .

. . . .

. . . .

H3. This question is about gravitational red-shift and black holes.

The concept of gravitational red-shift indicates that clocks run slower as they approach a black hole.

(a) Describe what is meant by

(i) gravitational red-shift. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) spacetime. *[1]*

. . . .

. . . .

(iii) a black hole with reference to the concept of spacetime. *[2]*

. . . .

. . . .

. . . .

. . . .

. . . .

(b) A particular black hole has a Schwarzschild radius R. A person at a distance of $2R$ from the event horizon of the black hole measures the time between two events to be 10 s. Deduce that for a person a very long way from the black hole the time between the events will be measured as 12 s. *[1]*

. . . .

. . . .

. . . .

Option I — Medical physics

I1. This question is about the mechanism of hearing.

Sound that is incident on the eardrum (tympanic membrane) in the middle ear, sets the membrane oscillating. These oscillations pass, via three small bones that act as a lever system, to the oval window. The pressure resulting from the vibrations at the oval window is greater than that created at the eardrum.

(a) State the name of the three small bones that form the lever system. *[1]*

. . . .

(b) Explain how the pressure at the oval window is increased by

(i) the lever system. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) a particular physical difference between the eardrum and oval window. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(c) State how reflection of sound at the inner ear is minimized. *[1]*

. . . .

. . . .

(d) A person can just hear a sound of a particular frequency that is incident on an area of their eardrum equal to $2.0\,\text{mm}^2$. The intensity level of the sound is 20 dB. Calculate the power that the sound creates at the eardrum. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

I2. This question is about X-rays and ultrasound imaging techniques.

(a) Define the term *attenuation coefficient* as used in X-ray imaging. *[2]*

. . . .

. . . .

. . . .

(b) An X-ray beam that consists of photons of the same energy is used to image a possible bone fracture in the leg of a patient. At this photon energy

attenuation coefficient of bone $= 0.62\,\text{cm}^{-1}$
attenuation coefficient of tissue $= 0.12\,\text{cm}^{-1}$.

In passing through the leg, the X-rays effectively encounter a thickness of tissue equal to 14 cm and thickness of bone equal to 8.0 cm.

Use the above data to explain why X-rays of this energy are suitable for imaging a possible leg fracture. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(c) State **two** reasons why it is preferable to use ultrasound rather than X-rays for imaging a fetus. *[2]*

1. . . . .

2. . . . .

(This question continues on the following page)

(Question I2 continued)

(d) The table gives some data about air and human soft tissue.

	Speed of sound / $m\,s^{-1}$	**Density / $kg\,m^{-3}$**
Air	330	1.3
Tissue	1.5×10^{3}	1.1×10^{3}

With reference to the concept of acoustic impedance, use the data to explain why a layer of gel is placed between the skin and the end of the ultrasound generator. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

I3. This question is about radio-isotopes.

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

. . . .

. . . .

. . . .

. . . .

(b) A person is involved in an accident that causes severe blood loss. Before a blood transfusion can be given it is necessary to measure how much blood has been lost. This can be done by measuring the total volume of blood remaining using an isotope of iodine. Data for two different isotopes of iodine are given in the table.

	Iodine-131	**Iodine-123**
Physical half-life	8 days	13 hours
Biological half-life	12 days	12 days
Radiation emitted	beta	gamma

Suggest, based on the data given in the table, why iodine-123 is a better choice for use in measuring the total volume of blood in the body. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(c) The person in (b) is given an injection of 5.0 ml of a solution containing iodine-123. The initial activity of the solution is 2.5×10^5 Bq. After 0.50 hours it is assumed that the 5.0 ml sample will be distributed evenly throughout the blood system.

The activity of a 5.0 ml sample of the blood after 0.50 hours has an activity of 2.1×10^2 Bq. Deduce that the total blood volume is about 6 litres. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

Option J — Particle physics

J1. This question is about fundamental interactions and elementary particles.

(a) In the table identify the exchange particle(s) associated with the two fundamental interactions given. *[2]*

Interaction	**Exchange particle(s)**
Electro-weak	
Strong	

(b) State why the exchange particles are known as elementary particles. *[1]*

. . . .

. . . .

(c) An exchange particle associated with the weak interaction has a mass of about $90\,\text{GeV}c^{-2}$.

Estimate

(i) the life-time of the particle. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) its range. *[2]*

. . . .

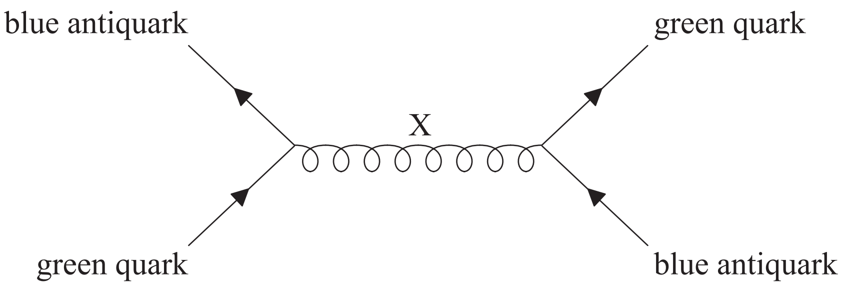
. . . .

. . . .

(This question continues on the following page)

(Question J1 continued)

(d) The diagram is a Feynman diagram that represents the strong interaction between quarks.



(i) Identify the exchange particle X. *[1]*

. . . .

(ii) Explain why the quarks have a colour associated with them. *[2]*

. . . .

. . . .

. . . .

. . . .

J2. This question is about particle accelerators.

Particle accelerators may be used to accelerate protons. If the energy of the accelerated protons is high enough then, when these protons collide with stationary protons, different types of particles of large mass may be produced.

(a) Explain why high energies are required to produce particles of large mass. *[2]*

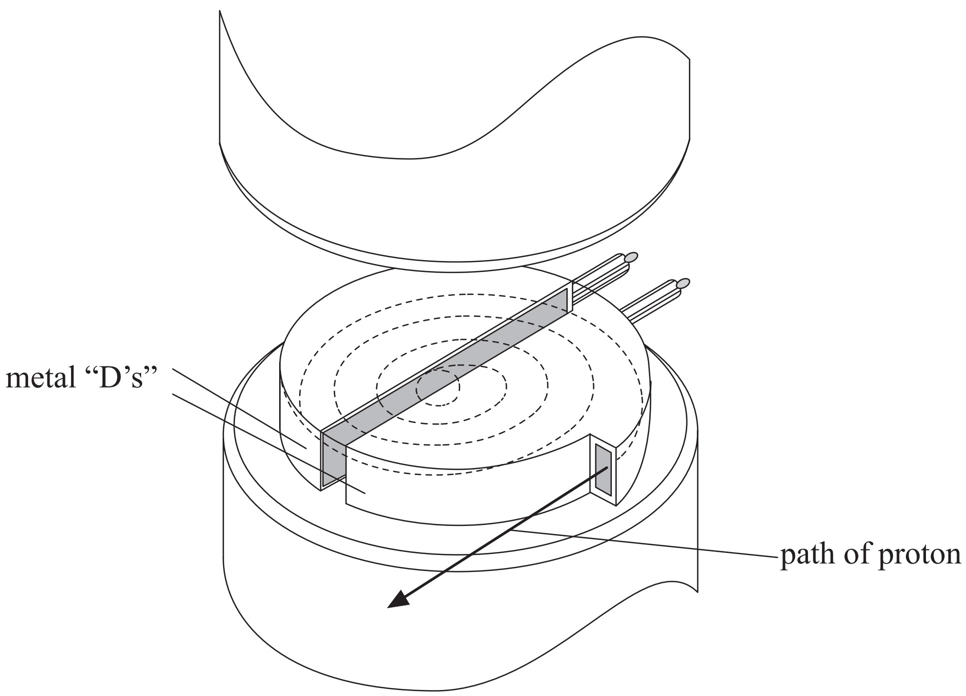
. . . .

. . . .

. . . .

. . . .

(b) The diagram shows the basic structure of a cyclotron in which protons are accelerated.



Add labels to the diagram above to show the

(i) magnets and their polarity. *[1]*

(ii) points where the alternating electric potential difference is applied. *[1]*

(This question continues on the following page)

(Question J2 continued)

(c) Outline why the frequency of the alternating electric potential difference is made equal to the frequency of orbit of the protons. *[2]*

. . . .

. . . .

. . . .

. . . .

(d) Explain the effect of the increasing energy of the protons on their frequency of orbit and state how this effect is dealt with in the cyclotron. *[2]*

. . . .

. . . .

. . . .

. . . .

(e) Protons of much higher energy than those produced in a cyclotron can be produced in a synchrotron. In a particular experiment protons leave a synchroton with energy 28 GeV. They enter a bubble chamber where some of them collide with stationary protons. Deduce that the energy available to produce other particles from these collisions is about 7 GeV. *[2]*

. . . .

. . . .

. . . .

. . . .

(f) Suggest, based on the answer to (e) and conservation of momentum, why it is better to arrange for two protons of total energy 28 GeV, moving in opposite directions, to collide. *[2]*

. . . .

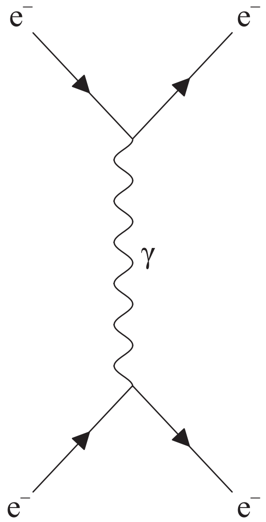
. . . .

. . . .

. . . .

J3. This question is about electrons and positrons.

The Feynman diagram represents the electromagnetic interaction between two electrons.



Another possible interaction between the electrons involves a neutral current.

(a) Describe

(i) with reference to the interaction between the electrons, what is meant by a neutral current. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) with reference to your answer in (a)(i), how experimental evidence supports the standard model. *[2]*

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question J3 continued)

(b) Draw a Feynman diagram to show the production of an electron positron pair. *[1]*

(c) According to the Big Bang theory, the production of electron positron pairs became possible when the universe had cooled to a temperature T. Determine, to the nearest power of ten, the value of T. *[2]*

. . . .

. . . .

. . . .

. . . .