22126509

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

PHYSICS
HIGHER LEVEL
PAPER 3

Candidate session number

0	0							

Friday 11 May 2012 (morning)

1 hour 15 minutes

Examination code

2	2	1	2	–	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]*.

Option E — Astrophysics

E1. This question is about the star Naos (Zeta Puppis).

The following data are available for the star Naos.

Surface temperature	$= 4.24 \times 10^{4}$ K
Radius	$= 7.70 \times 10^{9}$ m
Apparent magnitude	$= +2.21$
Parallax angle	$= 3.36 \times 10^{-3}$ arcseconds

(a) State the spectral class of Naos. *[1]*

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(b) State what is meant by apparent magnitude. *[1]*

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(c) Determine, for Naos, its

(i) distance from Earth, in parsec. *[1]*

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(ii) absolute magnitude. *[2]*

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(This question continues on the following page)

(Question E1 continued)

(d) The distance to Naos may be determined by the method of stellar parallax. The diagram shows the star Naos and the Earth in its orbit around the Sun.

(i) Draw lines on the diagram above in order to indicate the parallax angle of Naos. *[1]*

(ii) Outline how the parallax angle of Naos may be measured. *[2]*

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(This question continues on the following page)

(Question E1 continued)

(e) Determine, using the data given,

(i) the luminosity of Naos. *[2]*

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(ii) the wavelength at which Naos emits most of its energy. *[1]*

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(f) The star Mizar has the same apparent brightness as Naos and a much lower temperature. To the **naked eye** Naos does not appear as bright as Mizar.

By reference to your answer to (e)(ii), suggest an explanation of this fact. *[2]*

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E2. This question is about Olbers' paradox.

(a) State **two** postulates of the Newtonian model of the universe. *[2]*

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(b) Describe quantitatively how Olbers' paradox arises in the Newtonian model of the universe. *[3]*

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(c) Suggest how the paradox is resolved in the standard Big Bang model of the universe. *[2]*

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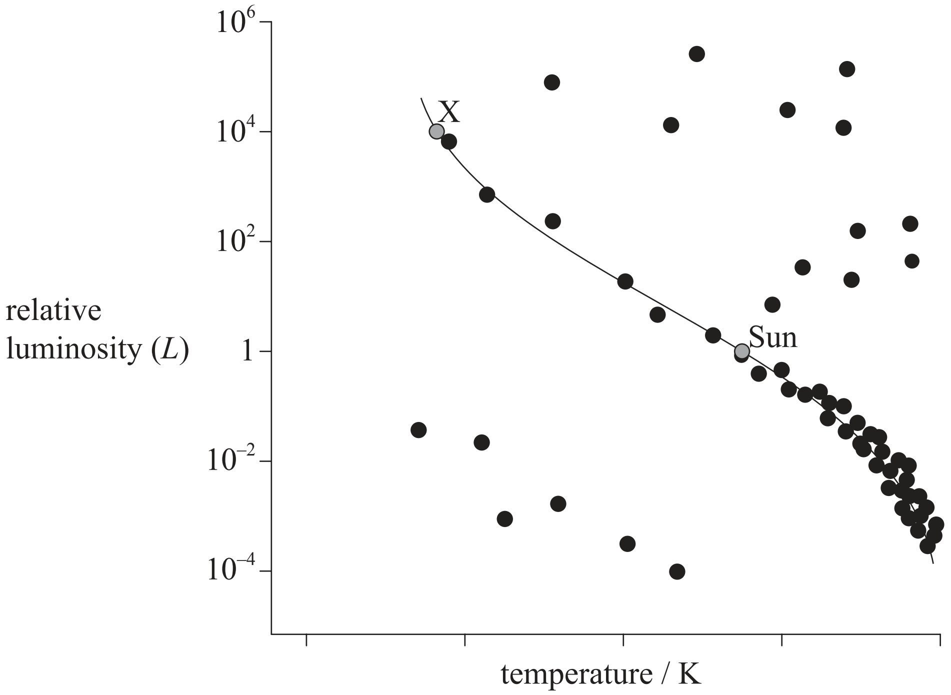
E3. This question is about stellar evolution.

In the HR diagram below, the Sun and another main sequence star, X, have been marked.



(a) (i) On the diagram above, draw a line to show the evolutionary path of the Sun from its present position on the main sequence to the final stage in its evolution. *[1]*

(ii) Explain, by reference to the Chandrasekhar limit, why the final stage in the evolution of the Sun is the one you indicated in (a)(i). *[2]*

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(This question continues on the following page)

(Question E3 continued)

(b) (i) Show that the mass of star X is approximately 14 solar masses. (Assume that $n = 3.5$ in the mass–luminosity relation.) *[2]*

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(ii) State the likely final stage of star X. *[1]*

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E4. This question is about Hubble's law.

(a) State

(i) Hubble's law. *[1]*

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(ii) the significance of the reciprocal of the Hubble constant. *[1]*

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(b) The wavelength of a certain line in the hydrogen spectrum is measured to be 434 nm in the laboratory. The same line in the hydrogen spectrum of the galaxy 3C-273 is measured on Earth to be 504 nm.

Determine the distance of 3C-273 from Earth using a Hubble constant of 72 $\text{km s}^{-1}\text{ Mpc}^{-1}$. *[2]*

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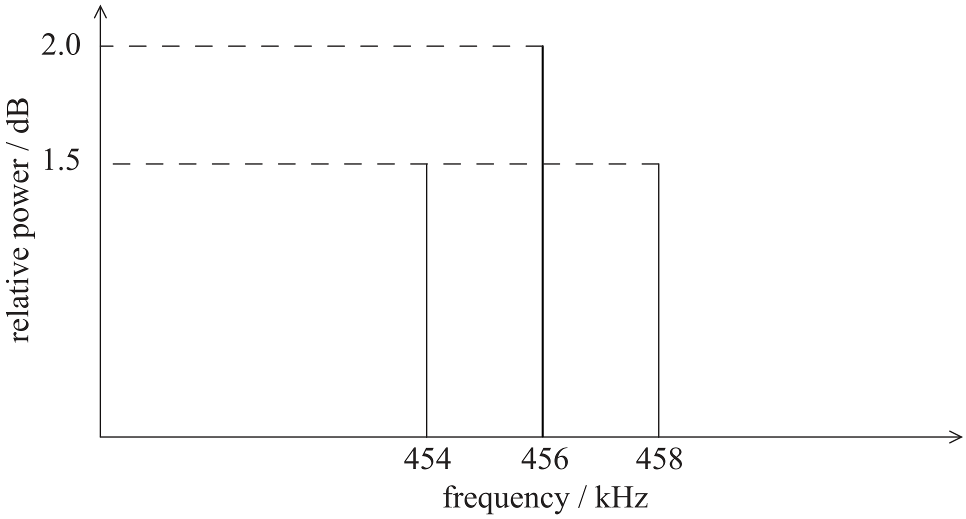
Option F — Communications

F1. This question is about radio transmission and reception.

(a) The diagram shows a power spectrum for an amplitude modulated (AM) radio signal.



(i) State the frequency of the carrier wave. *[1]*

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(ii) Calculate the frequency of the signal. *[1]*

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(iii) Calculate the bandwidth of the signal. *[1]*

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(This question continues on the following page)

(Question F1 continued)

(iv) The relative power is expressed in dB according to the equation

$$\text{relative power (in dB)} = 10 \times \lg\left(\frac{P_{\text{wave}}}{P_0}\right)$$

where P_0 is the power of a reference wave.

Determine the ratio of the power of the carrier wave to that of the signal. *[3]*

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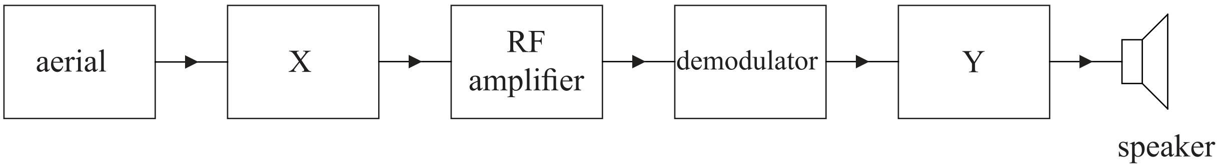
(Question F1 continued)

(b) The diagram below shows an incomplete block diagram for an AM radio receiver.



(i) Identify components X and Y. *[2]*

X: . . . .

Y: . . . .

(ii) Explain the function of components X and Y. *[2]*

X: . . . .

. . . .

Y: . . . .

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(c) Discuss an advantage and a disadvantage of using amplitude modulation compared with frequency modulation when transmitting and receiving a radio signal. *[3]*

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F2. This question is about the sampling of analogue signals.

(a) In a sound recording system a microphone is plugged into a computer sound card. Two possible sampling frequencies are 44.1 kHz and 8.0 kHz.

(i) Explain the advantage of using 44.1 kHz rather than 8.0 kHz as the sampling frequency. *[2]*

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(ii) Suggest the implication for storing the sampled data when using a sampling frequency of 44.1 kHz. *[1]*

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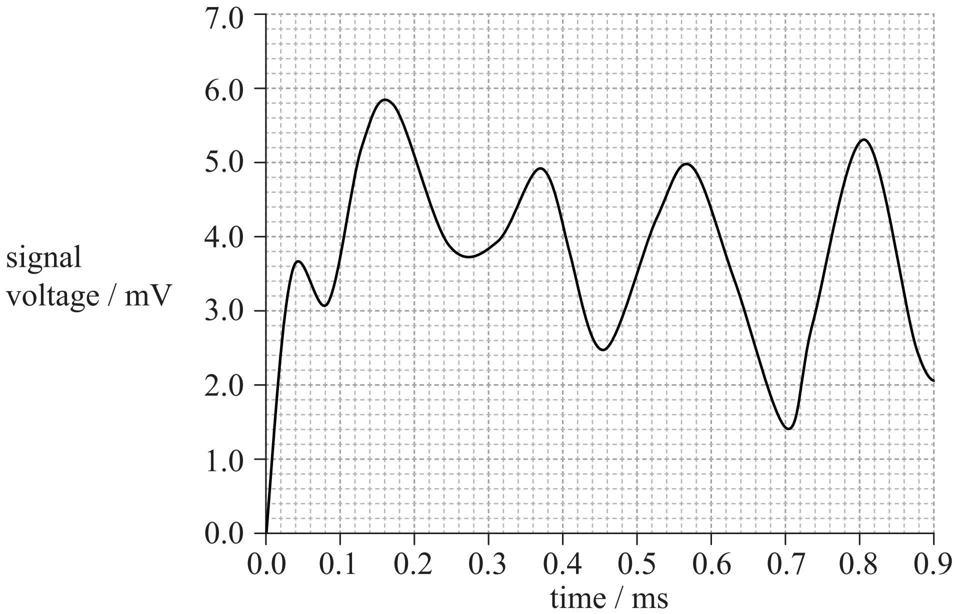
(This question continues on the following page)

(Question F2 continued)

(b) The graph shows an analogue signal which is to be sampled. The voltages of the sampled values are then recorded as binary numbers with 0000 representing the range from 0.00 to 0.99 mV, 0001 representing from 1.00 mV to 1.99 mV, *etc*.



(i) The first sample takes place at 0.0 ms and the sampling rate is 5.0 kHz. On the graph above, draw the points where the next **two** samples occur. Label these as S1 and S2. *[2]*

(ii) State the binary numbers representing these two samples. *[2]*

S1: . . . .

S2: . . . .

(This question continues on the following page)

(Question F2 continued)

(c) Explain how time-division multiplexing allows transmission of different signals on the same line. *[3]*

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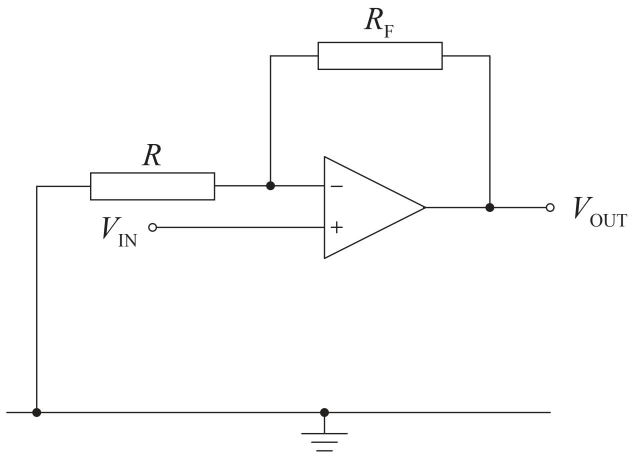
will not be marked.

F3. This question is about operational amplifiers.

(a) State the properties of an ideal operational amplifier by using the words “zero” or “infinite” in the table below. *[2]*

input impedance (resistance)	
output impedance (resistance)	
(open loop) gain	

(b) The circuit below shows a non-inverting amplifier.



Show that the gain of this amplifier is given by $G = 1 + \frac{R_F}{R}$. *[3]*

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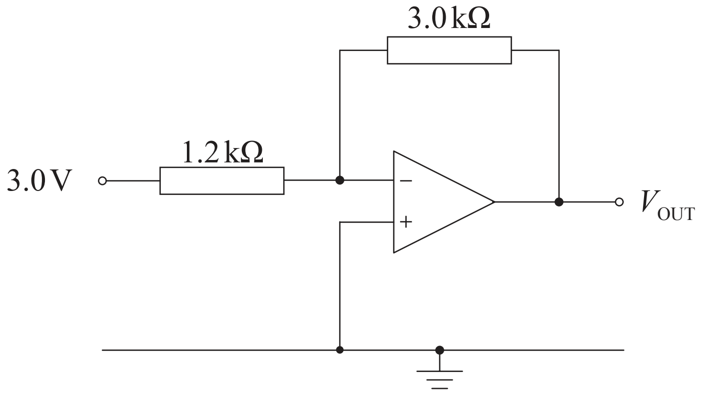
(Question F3 continued)

(c) The circuit below shows an inverting amplifier.



Calculate the output voltage V_{OUT}. *[2]*

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Option G — Electromagnetic waves

G1. This question is about a magnifying glass.

(a) (i) Define the *angular magnification* of a magnifying glass. *[1]*

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(ii) Derive an equation for the angular magnification of a magnifying glass with the image at infinity. *[3]*

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(This question continues on the following page)

(Question G1 continued)

(b) An object is positioned 8.00 cm from a magnifying glass of focal length 15.0 cm.

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

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(ii) Calculate the linear magnification. *[1]*

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(iii) The image is upright and magnified. State a further property of the image. *[1]*

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G2. This question is about lasers and diffraction gratings.

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

1: . . . .

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2: . . . .

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(ii) Outline the main mechanisms in the production of laser light. *[4]*

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(This question continues on the following page)

(Question G2 continued)

(b) (i) Describe the pattern produced on a screen by a red laser beam incident on a diffraction grating. *[2]*

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(ii) Laser light of wavelength 632 nm is incident on a diffraction grating having 600 lines per mm. Determine the angular separation between the first and second order maxima. *[4]*

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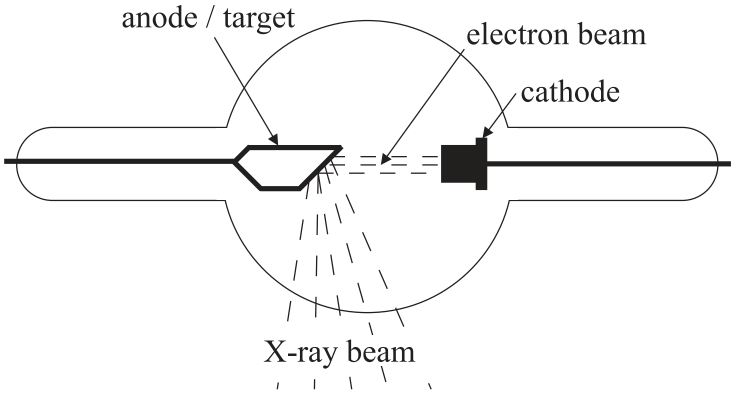
G3. This question is about production and diffraction of X-rays.

(a) The diagram shows some of the main components of an X-ray tube.



(i) Draw a correctly connected power supply on the diagram. *[1]*

(ii) The energy spectrum of the X-rays shows characteristic lines. Explain the origin of these lines. *[3]*

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(This question continues on the following page)

(Question G3 continued)

(iii) Deduce the minimum wavelength of X-rays produced when a beam of electrons of energy 25.0 keV is incident on the target of the X-ray tube. *[2]*

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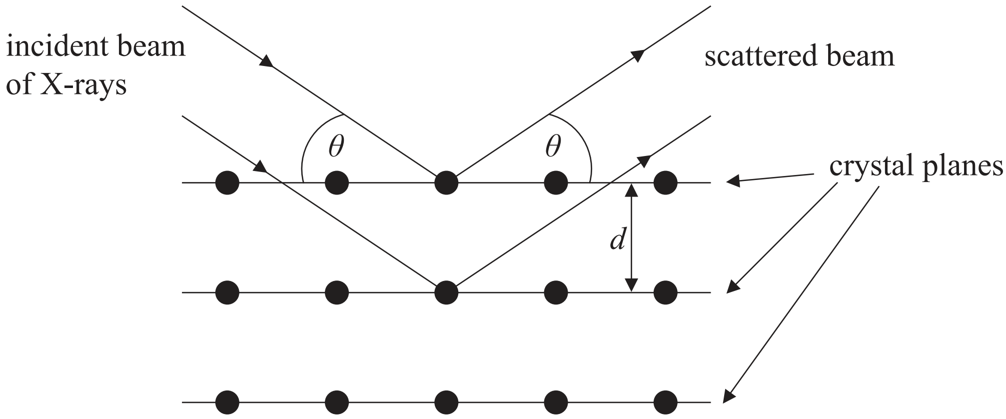
(Question G3 continued)

(b) The diagram shows X-rays scattering in a crystal.



(i) For certain scattering angles θ a very intense scattered beam is detected. Explain this observation. *[2]*

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(ii) X-rays of wavelength 4.00×10^{-11} m produce the first maximum with a scattering angle of 26.4°. Calculate the spacing of the crystal planes d. *[2]*

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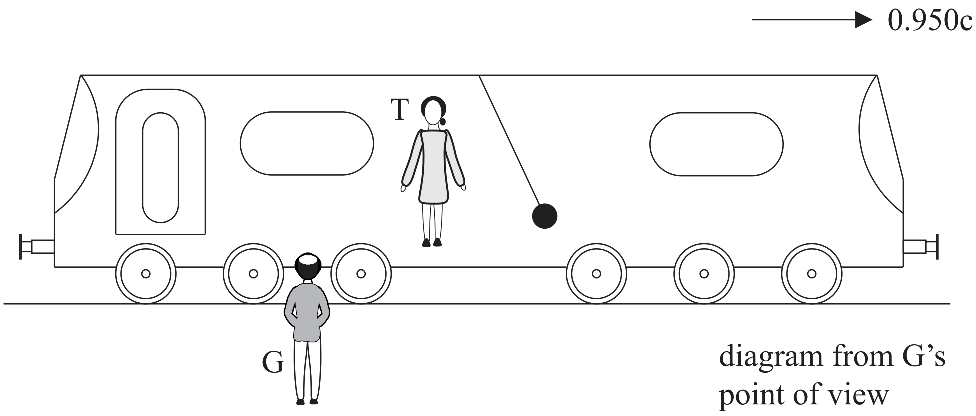
Option H — Relativity

H1. This question is about relativistic kinematics.

In a thought experiment, a train is moving at a speed of 0.950c relative to the ground. A pendulum attached to the ceiling of the train is set into oscillation.



An observer T on the train and an observer G on the ground measure the period of oscillation of the pendulum.

(a) State and explain whether the pendulum period is a proper time interval for observer T, observer G **or** both T and G. *[2]*

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(b) Observer T measures the period of oscillations of the pendulum to be 0.850 s. Calculate the period of oscillations according to observer G. *[2]*

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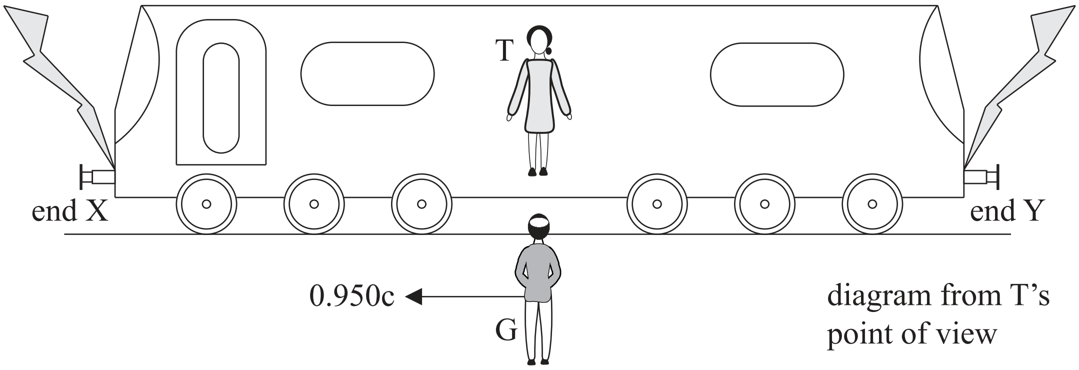
(This question continues on the following page)

(Question H1 continued)

(c) Observer T is standing in the middle of the train. Two lightning strikes hit the ends of the train. The strikes are simultaneous **according to observer T**.



Light from the strikes reaches both observers.

(i) Explain why, according to observer G, light from the two strikes reaches observer T at the same time. *[2]*

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(ii) Using your answer to (i), explain why, according to observer G, end X of the train was hit by lightning first. *[2]*

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(This question continues on the following page)

(Question H1 continued)

(d) The lightning strikes in (c) make marks on both the train and the ground. The proper length of the train is 160 m.

Determine, according to observer G, the distance between the marks made

(i) on the train. *[2]*

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(ii) on the ground. *[2]*

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(e) Observer G sees a second train moving towards the first train (*i.e.* towards the left) at a speed of 0.950c with respect to the ground. Calculate the relative speed of the trains. *[2]*

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H2. This question is about relativistic mechanics.

(a) In an experiment at CERN in 1964, a neutral pion moving at a speed of 0.99975c with respect to the laboratory decayed into two photons. The speed of each photon was measured with respect to the laboratory.

Describe how the result of this experiment provided support for special relativity. *[2]*

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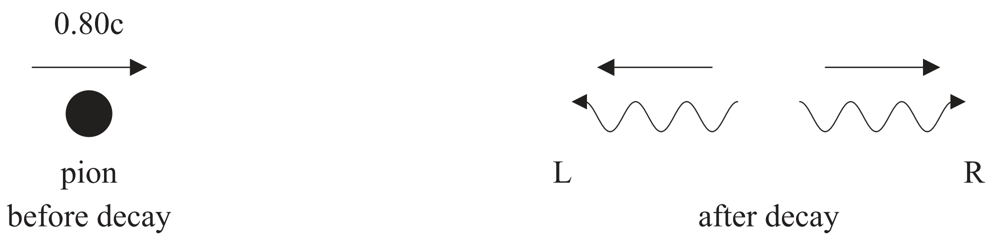
(b) In another experiment, a neutral pion moving at 0.80c relative to a laboratory decayed into two photons as shown in the diagram.



Photon R moved in the direction of the pion and photon L in the opposite direction. The rest mass of the pion is 135 MeV c^{-2}.

According to a laboratory observer,

(i) determine the total energy of the pion in MeV. *[2]*

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(This question continues on the following page)

(Question H2 continued)

(ii) determine the momentum of the pion, in $\text{MeV}\,c^{-1}$. *[2]*

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(iii) state and explain which photon, R **or** L, has the greater energy. *[2]*

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H3. This question is about the equivalence principle and black holes.

(a) State the principle of equivalence. *[1]*

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(b) The gravitational field strength near the surface of a neutron star is $1.2\times10^{13}\,\text{N kg}^{-1}$. A light ray is emitted from a stationary probe at a height of 250 m above the surface. The frequency of the light measured in the probe is 4.8×10^{14} Hz.

(i) Determine the frequency of the light received at the surface of the star according to an observer at the surface. *[2]*

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(ii) Describe how gravitational red-shift leads to the concept of gravitational time dilation. *[2]*

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(This question continues on the following page)

(Question H3 continued)

(c) General relativity predicts the existence of black holes.

(i) State what is meant by a black hole. *[1]*

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(ii) Suggest **two** ways in which a black hole may be detected. *[2]*

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2: . . . .

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will not be marked.

Option I — Medical physics

I1. This question is about hearing and hearing defects.

(a) State what is meant by the term threshold of hearing. *[1]*

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(b) (i) A buzzer with power output of 5.0 W emits sounds in all directions. Show that the intensity for this sound at a distance of 8.4 m from the speaker is approximately $6\times10^{-3}\,\mathrm{W\,m^{-2}}$. *[2]*

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(ii) Deduce the intensity level for a sound of intensity $6\times10^{-3}\,\mathrm{W\,m^{-2}}$. *[2]*

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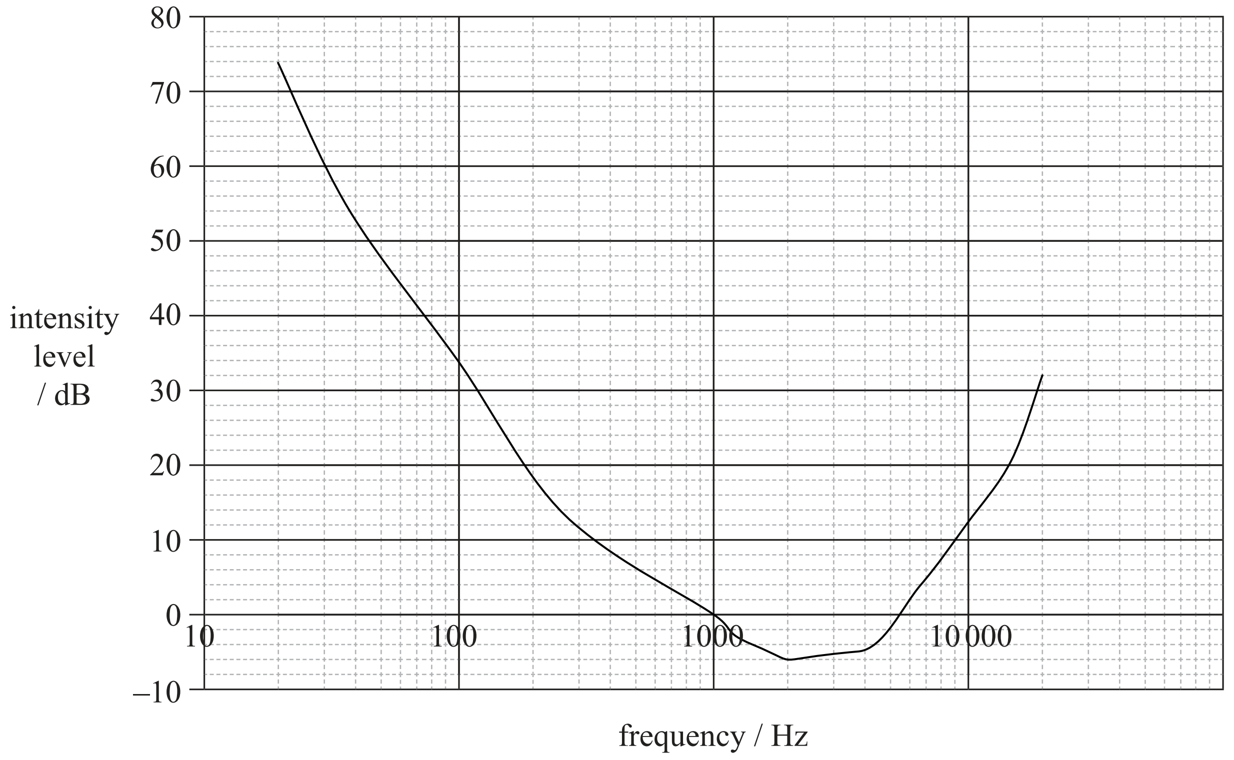
(This question continues on the following page)

(Question I1 continued)

(c) The graph shows the threshold hearing curve for a young person with normal hearing.



(i) State the frequency at which the ear is most sensitive. *[1]*

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(ii) State the significance of negative values of intensity level. *[1]*

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(This question continues on the following page)

(Question I1 continued)

(iii) State the frequency range of the ear. *[1]*

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(iv) On the graph opposite, draw the shape of the threshold hearing curve that you would expect for an elderly person. *[2]*

I2. This question is about ultrasonic imaging.

(a) Describe how a piezoelectric crystal in an ultrasound transmitter is made to generate a pulse of ultrasound. *[2]*

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(b) The table gives the velocity of sound in, and the densities of, the materials.

	Velocity of sound / $m\,s^{-1}$	**Density / $kg\,m^{-3}$**	**Acoustic impedance**
Air	330	1.3	
Gel	1420	980	
Muscle tissue	1580	1080	

(i) State the SI unit for acoustic impedance. *[1]*

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(ii) Calculate the acoustic impedance for each material and write your answers in the table above. *[2]*

(This question continues on the following page)

(Question I2 continued)

(iii) The fraction of the reflected intensity when ultrasound in a medium of impedance Z_1 is incident on a medium of impedance Z_2 is given by the following equation.

$$\frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$$

This is called the reflection coefficient. Calculate the reflection coefficient for ultrasound that is incident on muscle tissue from air. *[2]*

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(iv) Using your answer to (iii), explain why it is necessary to use gel in between an ultrasound transducer and a patient's skin. *[2]*

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I3. This question is about the use of therapeutic radiation.

(a) State the difference between diagnostic and therapeutic uses of radiation. *[2]*

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(b) (i) Explain what is meant by the quality factor (relative biological effectiveness) in relation to radiation dosimetry. *[2]*

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(ii) A medical physicist is exposed to alpha radiation amounting to a total dose equivalent of 48 mSv. Assume that the physicist is exposed to the radiation for 45 weeks and she works for an average of 35 hours each week. The quality factor for the alpha radiation is 15. Deduce the average absorbed dose rate. *[4]*

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(This question continues on the following page)

(Question I3 continued)

(c) List **three** key issues that a medical professional would need to mention to a patient when considering the use of therapeutic radiation. *[3]*

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2: . . . .

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3: . . . .

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Option J — Particle physics

J1. This question is about quarks and interactions.

(a) Outline how interactions in particle physics are understood in terms of exchange particles. *[2]*

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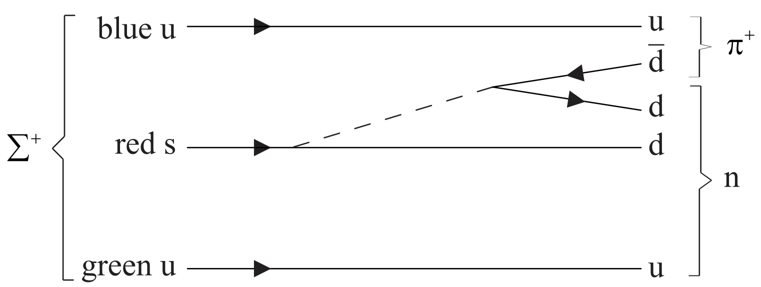
(b) The sigma ($\Sigma^+ = \text{u u s}$) decays into a positive pion ($\pi^+ = \text{u}\,\bar{\text{d}}$) and a neutron according to the following reaction.

$$\Sigma^+ \rightarrow \text{n} + \pi^+$$

The colour of each of the quarks in Σ^+ is indicated in the diagram below.



Deduce

(i) the colour of the $\bar{\text{d}}$ in π^+. *[1]*

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(ii) the electric charge of the particle represented by the dotted line. *[1]*

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(This question continues on the following page)

(Question J1 continued)

(c) Determine whether or not strangeness is conserved in this decay. *[2]*

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(d) The total energy of the particle represented by the dotted line is 1.2 GeV more than what is allowed by energy conservation. Determine the time interval from the emission of the particle from the s quark to its conversion into the d $\overline{\text{d}}$ pair. *[2]*

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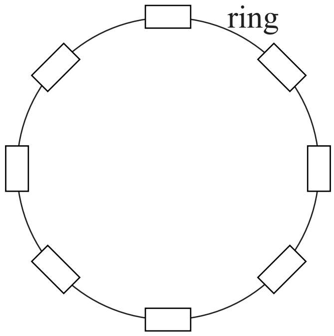
(e) The pion is unstable and decays through the weak interaction into a neutrino and an anti-muon.

Draw a Feynman diagram for the decay of the pion, labelling all particles in the diagram. *[2]*

J2. This question is about accelerators and available energy.

(a) The diagram shows the ring of a synchrotron and a few of the electromagnets around the ring.



(i) State why the ring is evacuated. *[1]*

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(ii) Explain why the magnets are electromagnets rather than permanent magnets. *[2]*

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(iii) A proton is accelerated in a synchrotron to a total energy E. The energy that must be supplied to the proton is much greater than E.

Suggest what happens to the extra energy supplied. *[1]*

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(This question continues on the following page)

(Question J2 continued)

(b) A proton of total energy 30 GeV collides with a proton of the same total energy moving in the opposite direction.

(i) State what is meant by available energy. *[1]*

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(ii) State the value of the available energy in this collision. *[1]*

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(c) A proton of total energy 60 GeV collides with a stationary proton.

(i) Determine the available energy for this collision. *[2]*

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(ii) Suggest why the answers to (b)(ii) and (c)(i) are very different. *[1]*

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J3. This question is about conservation laws and the standard model.

(a) A muon decays into an electron and two other particles according to the reaction equation $\mu^- \rightarrow e^- + ? + ?$.

State the names of the **two** other particles that are produced in this decay explaining your answer. *[3]*

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(b) State the role of the Higgs boson in the standard model. *[1]*

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J4. This question is about the early universe.

The universe became transparent to radiation when the average thermal energy per particle dropped to about 0.40 eV.

(a) Outline what is meant by the early universe becoming transparent to radiation. *[2]*

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(This question continues on the following page)

(Question J4 continued)

(b) Determine the temperature at which the universe became transparent to radiation. *[2]*

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J5. This question is about strings.

(a) State **two** ways in which string theories differ from the standard model. *[2]*

1: . . . .
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2: . . . .
. . . .

(b) Outline how the existence of particles is explained in string theories. *[1]*

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