M11/4/PHYSI/HP3/ENG/TZ2/XX

22116515

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

PHYSICS
HIGHER LEVEL
PAPER 3

Candidate session number

0	0							

Thursday 12 May 2011 (morning)

1 hour 15 minutes

Examination code

2	2	1	1	–	6	5	1	5

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.

0140

40 pages

Option E — Astrophysics

E1. This question is about the properties of a star.

(a) Describe what is meant by a

(i) constellation. *[2]*

. . . .

. . . .

. . . .

(ii) stellar cluster. *[1]*

. . . .

. . . .

(This question continues on the following page)

(Question E1 continued)

(b) Some data for the variable star Betelgeuse are given below.

Average absolute magnitude $= -5.1$
Average apparent magnitude $= +0.60$
Average apparent brightness $= 1.6 \quad 10^{-7}\,\text{W m}^{-2}$
Radius $= 790$ solar radii

The luminosity of the Sun is $3.8 \quad 10^{26}\,\text{W}$ and it has a surface temperature of 5700 K.

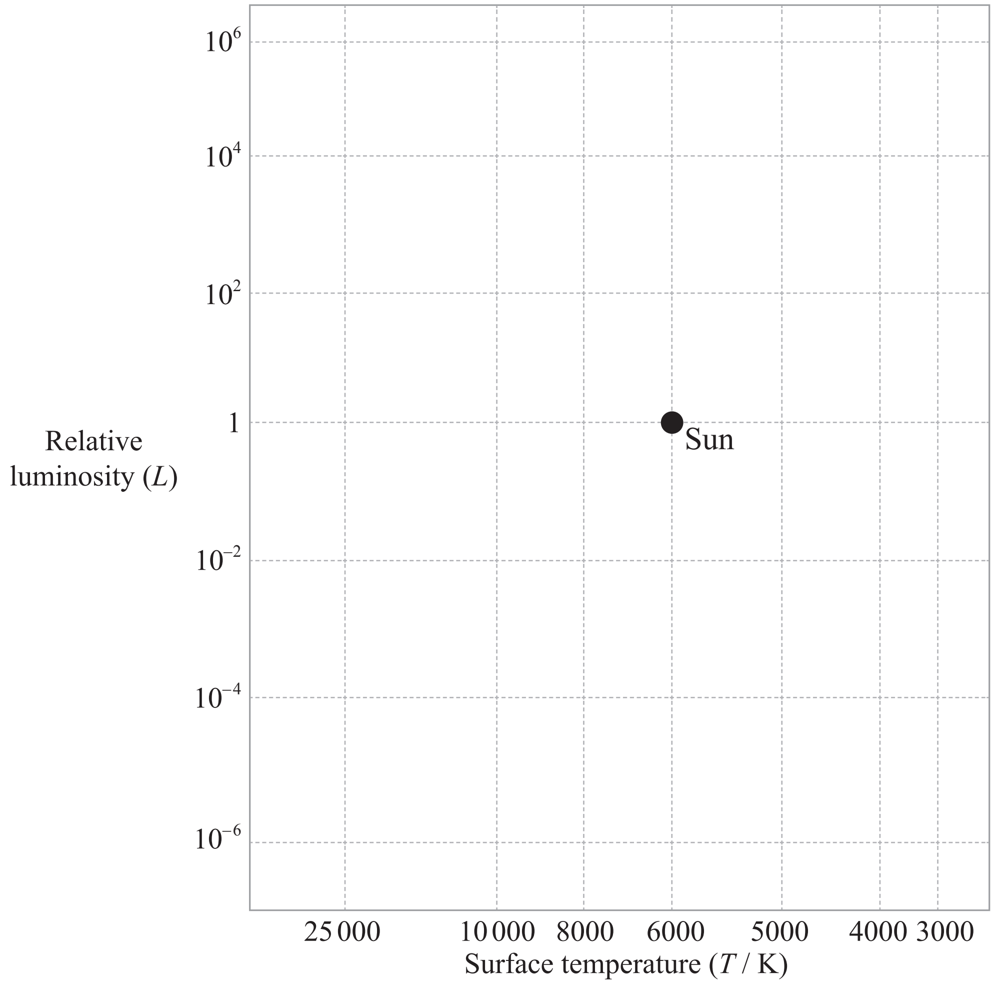
(i) Show that the distance from Earth to Betelgeuse is about $4 \quad 10^{18}\,\text{m}$. *[3]*

(ii) Determine, in terms of the luminosity of the Sun, the luminosity of Betelgeuse. *[2]*

(iii) Calculate the surface temperature of Betelgeuse. *[2]*

(This question continues on the following page)

(Question E1 continued)



(c) On the Hertzsprung–Russell diagram above,

(i) label the position of Betelgeuse with the letter B. *[1]*

(ii) sketch likely evolutionary path. *[1]*

(This question continues on the following page)

(Question E1 continued)

(d) Some stars, such as Betelgeuse, are in combination with a companion star forming a spectroscopic binary system. Describe and explain the characteristics of a spectroscopic binary system. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

E2. This question is about the density of the universe.

(a) Explain, with reference to the possible fate of the universe, the significance of the critical density of matter in the universe. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(b) Suggest **one** reason why it is difficult to estimate the density of matter in the universe. *[2]*

. . . .

. . . .

. . . .

. . . .

E3. This question is about the evolution of stars.

(a) State what is meant by the

(i) Chandrasekhar limit. *[1]*

. . . .

. . . .

(ii) Oppenheimer–Volkoff limit. *[1]*

. . . .

. . . .

(b) Suggest how your answers in (a) can be used to predict the fate of a main sequence star. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

E4. This question is about the Hubble constant.

(a) Outline the measurements that must be taken in order to determine a value for the Hubble constant. *[3]*

(b) One estimate of the Hubble constant is $60\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. Cygnus A is a radio galaxy at a distance of $6.0 \quad 10^{8}$ ly from Earth. Calculate, in $\text{km}\,\text{s}^{-1}$, the recessional speed of Cygnus A relative to the Earth. *[2]*

Option F — Communications

F1. This question is about modulation.

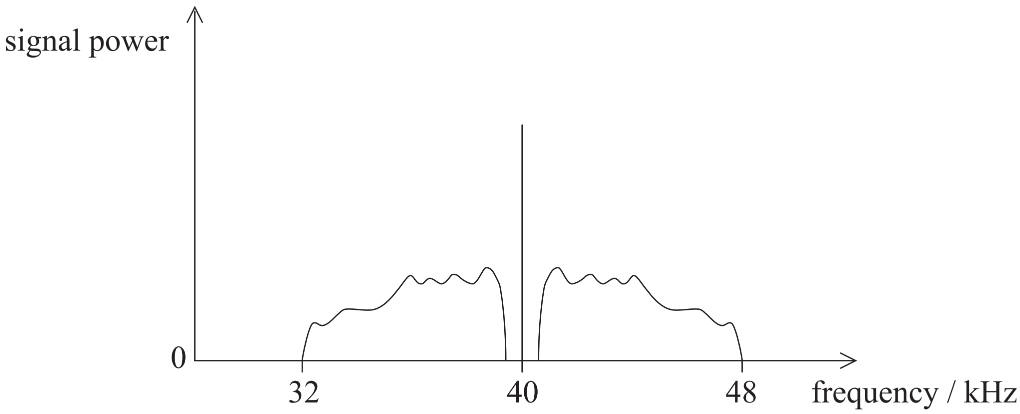
(a) Outline what is meant by the modulation of a wave. *[2]*

. . . .

. . . .

. . . .

(b) The frequency spectrum of the signal from a radio transmitter is shown below.



(i) State the name of this form of radio transmission. *[1]*

. . . .

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

. . . .

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

. . . .

F2. This question is about a mobile phone network.

Describe the role of the cellular exchange during the making of a call from a mobile phone. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

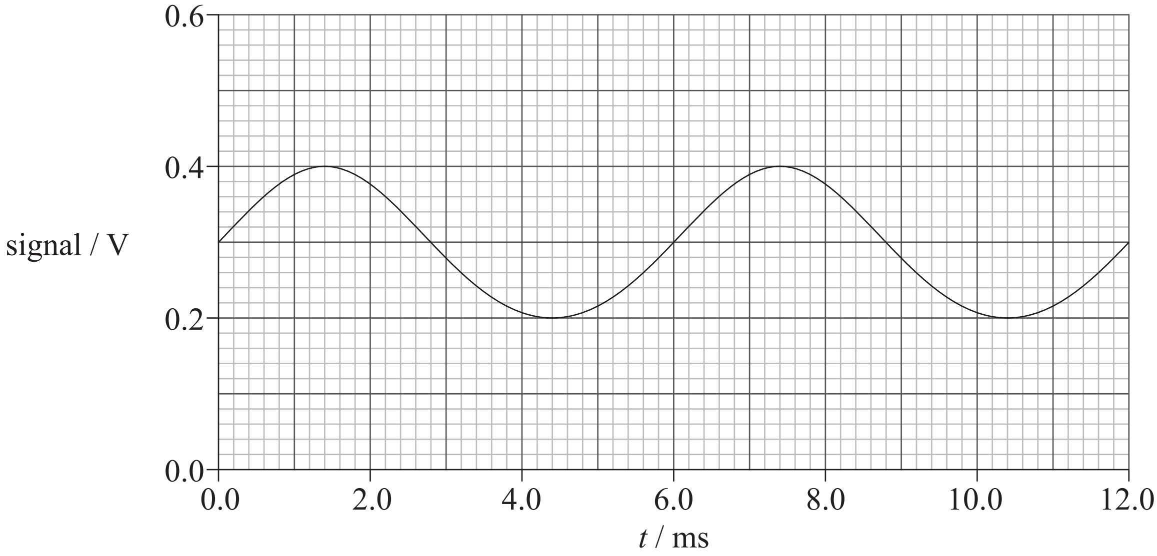
. . . .

. . . .

. . . .

F3. This question is about the transmission of signals.

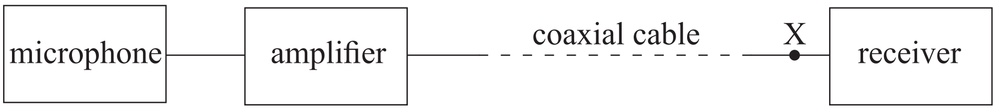
The signal from a microphone is amplified and then transmitted to a distant receiver. The variation with time t of the amplified signal before transmission is shown below.



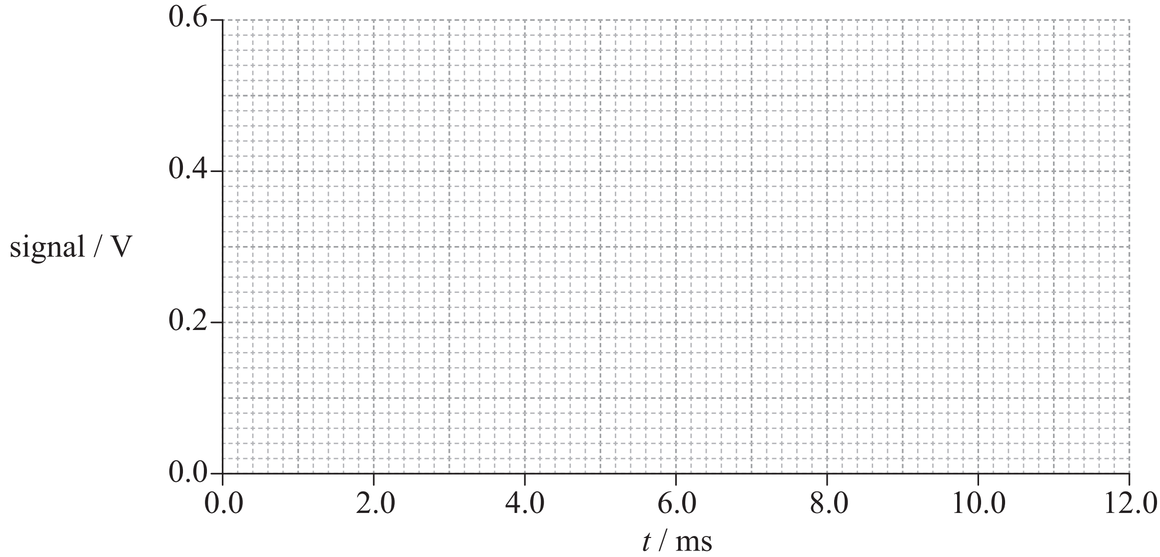
(This question continues on the following page)

(Question F3 continued)

(a) The amplified signal is transmitted using a coaxial cable as illustrated.



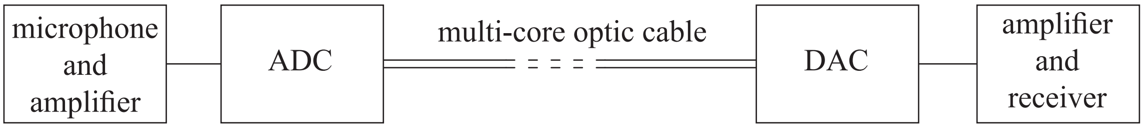
On the axes below, sketch the waveform of the signal at point X after transmission along the coaxial cable. *[3]*



(This question continues on the following page)

(Question F3 continued)

(b) A second transmission system, as shown below, uses a cable containing many separate fibres (multi-core optic cable).



(i) Suggest why a multi-core optic cable is required rather than a single-core optic fibre. *[1]*

. . . .

(ii) State what circuits should be included in the transmission system so that a single-core optic fibre may be used. *[1]*

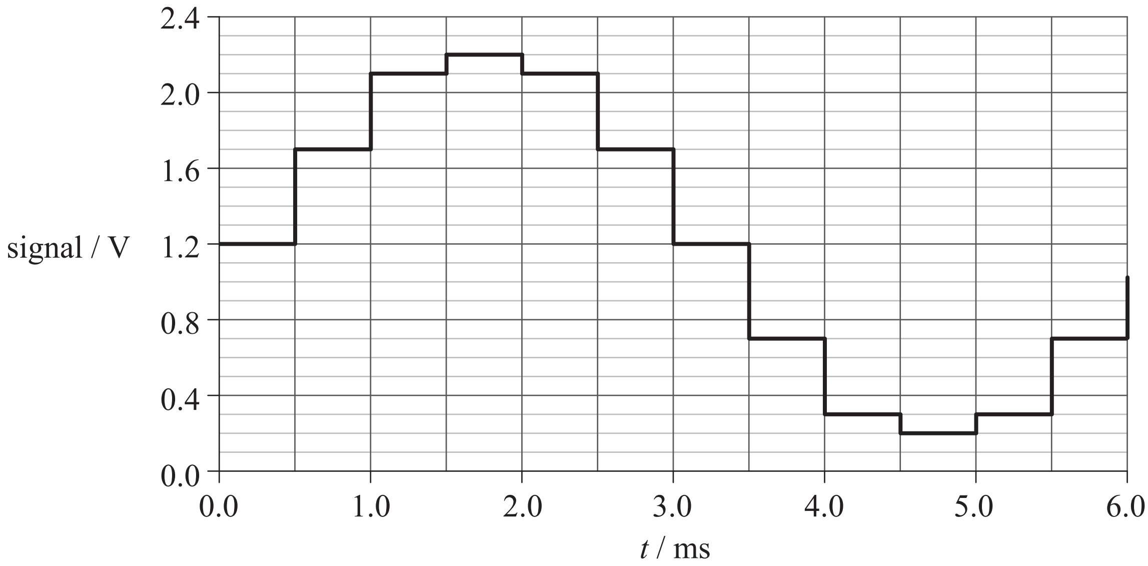
. . . .

. . . .

(This question continues on the following page)

(Question F3 continued)

(c) The received signal of the second transmission system is shown below.



Calculate the

(i) minimum number of output bits of the ADC. *[2]*

. . . .

. . . .

(ii) sampling frequency of the ADC. *[2]*

. . . .

. . . .

(This question continues on the following page)

(Question F3 continued)

(d) State **one** advantage and **one** disadvantage of the coaxial cable transmission as compared with the fibre optic cable. *[2]*

Advantage: ....

....

Disadvantage: ....

....

F4. This question is about signal power and attenuation.

An optic fibre in a telephone system has length 48 km. The noise power in the optic fibre is $2.5 \quad 10^{-18}$ W.

(a) The signal-to-noise ratio is not to fall below 25 dB. Show that the minimum signal power in the fibre is $7.9 \quad 10^{-16}$ W. *[2]*

....

....

....

....

(b) The attenuation per unit length of the signal in the fibre is 2.7 dB km^{-1}. Use the data in (a) to determine the power of the input signal to the fibre so that the signal-to-noise ratio does not fall below 25 dB. *[2]*

....

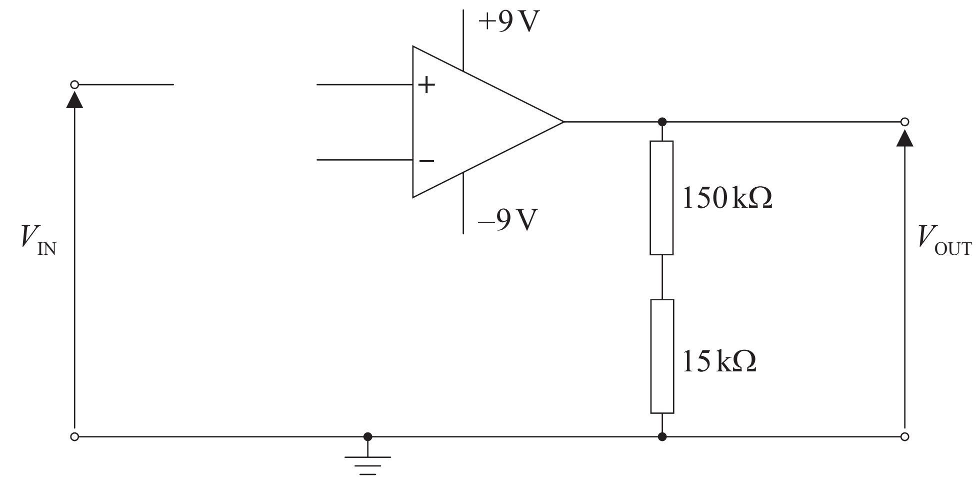
....

....

....

F5. This question is about an operational amplifier (op-amp) circuit.

The diagram shows an incomplete circuit.



The operational amplifier is ideal.

(a) On the incomplete diagram above, design a circuit for a non-inverting amplifier. *[2]*

(b) Calculate the

(i) gain of the amplifier circuit. *[2]*

. . . .

. . . .

. . . .

(ii) input potential V_{IN} at which the amplifier saturates. *[2]*

. . . .

. . . .

. . . .

Option G — Electromagnetic waves

G1. This question is about properties of electromagnetic waves.

(a) State **two** properties that are common to all electromagnetic waves. *[2]*

1. . . . .

2. . . . .

(b) A single lens is used to form a magnified real image of an object. Explain, with reference to the dispersion of light, why the image has coloured edges. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(c) Outline why a clear sky is blue in colour. *[2]*

. . . .

. . . .

. . . .

. . . .

G2. This question is about a converging lens.

(a) Define *angular magnification*. *[2]*

. . . .

. . . .

. . . .

(b) A thin converging lens of focal length 4.5 cm is to be used as a magnifying glass. The observer places the lens close to her eye. The least distance of distinct vision is 24 cm.

(i) Show that the distance of the object from the lens is 3.8 cm. *[1]*

. . . .

. . . .

. . . .

(ii) Determine the angular magnification produced by the lens. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

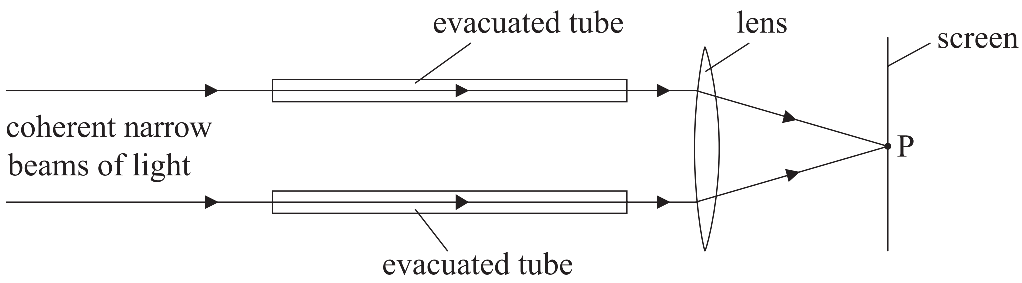
(Question G2 continued)

(c) Suggest **two** reasons why, for high magnifications, a combination of lenses is used rather than a single lens. *[2]*

1. . . . .
   . . . .
2. . . . .
   . . . .

G3. This question is about interference of light.

Two coherent narrow beams of light pass through two identical evacuated tubes, as shown below.



The two coherent narrow beams are brought to a focus at point P on a screen.

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

. . . .

. . . .

(This question continues on the following page)

(Question G3 continued)

(b) State, with reference to the wavelength, the condition that must be satisfied for a bright fringe to be formed on the screen at point P. *[1]*

. . . .

. . . .

(c) Air is allowed to enter gradually into one of the evacuated tubes. The brightness of the light at point P is seen to decrease and then increase again repeatedly.

(i) State the effect on the wavelength of the light in the evacuated tube as the air is introduced. *[1]*

. . . .

(ii) Suggest why there is a variation in the brightness of the light at point P. *[1]*

. . . .

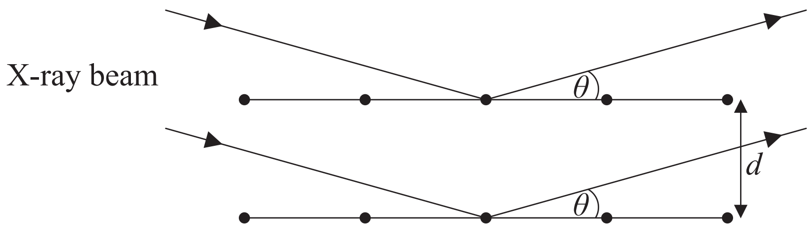
. . . .

G4. This question is about X-ray diffraction.

An X-ray tube fitted with a copper target emits radiation with a characteristic wavelength of $1.54 \quad 10^{-10}$ m.

(a) Explain why the characteristic wavelength is dependent on the target material. *[3]*

(b) The X-ray beam is incident on a sodium chloride crystal. The minimum angle θ at which the X-rays of wavelength $1.54 \quad 10^{-10}$ m reinforce constructively when scattered from a plane of atoms in the crystal is 15.9°, as shown below.



(i) Calculate the distance d between neighbouring planes of atoms. *[3]*

(This question continues on the following page)

(Question G4 continued)

(ii) Determine any other values of θ at which maximum intensity occurs for the X-ray beam scattered from the crystal. *[2]*

. . . .

. . . .

. . . .

. . . .

(c) State why it is preferable to measure more than one angle θ in order to determine the spacing of the planes of atoms. *[2]*

. . . .

. . . .

. . . .

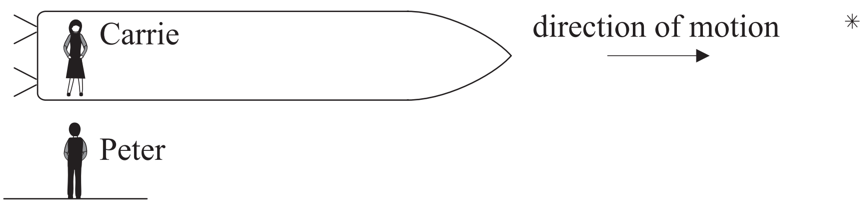
. . . .

Option H — Relativity

H1. This question is about relativity.

Carrie is in a spaceship that is travelling towards a star in a straight-line at constant velocity as observed by Peter. Peter is at rest relative to the star.

(a) Carrie measures her spaceship to have a length of 100 m. Peter measures Carrie's spaceship to have a length of 91 m.



(i) Explain why Carrie measures the proper length of the spaceship. *[1]*

. . . .
. . . .
. . . .

(ii) Show that Carrie travels at a speed of approximately 0.4 c relative to Peter. *[2]*

. . . .
. . . .
. . . .
. . . .

(This question continues on the following page)

(Question H1 continued)

(b) According to Carrie, it takes the star ten years to reach her. Using your answer to (a)(ii), calculate the distance to the star as measured by Peter. *[2]*

. . . .

. . . .

. . . .

. . . .

(c) According to Peter, as Carrie passes the star she sends a radio signal. Determine the time, as measured by Carrie, for the message to reach Peter. *[3]*

. . . .

. . . .

. . . .

. . . .

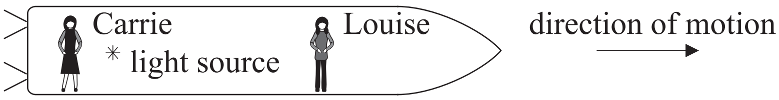
. . . .

. . . .

(This question continues on the following page)

(Question H1 continued)

(d) Carrie and Louise, two observers in a spaceship, view a light source placed close to Carrie. When the spaceship is travelling at a constant velocity, they both measure the frequency of the light source and obtain identical values.



The magnitude of the velocity of the spaceship increases.

State and explain any changes to the frequency of the light source, as measured by Louise, that occur during the acceleration. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

H2. This question is about relativistic mechanics.

(a) Calculate the potential difference through which a proton, starting from rest, must be accelerated for its mass–energy to be equal to three times its rest mass energy. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(b) Calculate the momentum of the proton after acceleration. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

H3. This question is about the Michelson–Morley experiment.

(a) (i) Outline the purpose of the experiment. *[1]*

. . . .

. . . .

. . . .

(ii) State and explain why Michelson and Morley rotated the apparatus through 90°. *[2]*

. . . .

. . . .

. . . .

. . . .

(b) State and explain the significance of the result of the experiment. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

H4. This question is about spacetime.

(a) Describe what is meant by spacetime. *[2]*

. . . .

. . . .

. . . .

(b) State the shape of the path in spacetime of a body

(i) moving at constant velocity. *[1]*

. . . .

. . . .

(ii) orbiting the Earth. *[1]*

. . . .

. . . .

(c) Explain how spacetime is used to describe the gravitational attraction between Earth and a satellite orbiting the Earth. *[2]*

. . . .

. . . .

. . . .

. . . .

Option I — Medical physics

I1. This question is about hearing.

(a) State what is meant by the

(i) intensity I of a sound wave. *[1]*

. . . .

. . . .

(ii) threshold intensity I_0 of hearing. *[2]*

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question I1 continued)

(b) A pneumatic drill produces noise of intensity level 98 dB at the ear of a worker.

(i) Calculate the intensity of the noise at the ear. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) The intensity level at which discomfort is felt is 108 dB. Several pneumatic drills, each one producing an intensity level of noise of 98 dB at the ear, are being used at the same time. Determine the number of pneumatic drills that must be in use before the worker, who has no hearing protection, experiences discomfort. *[3]*

. . . .

. . . .

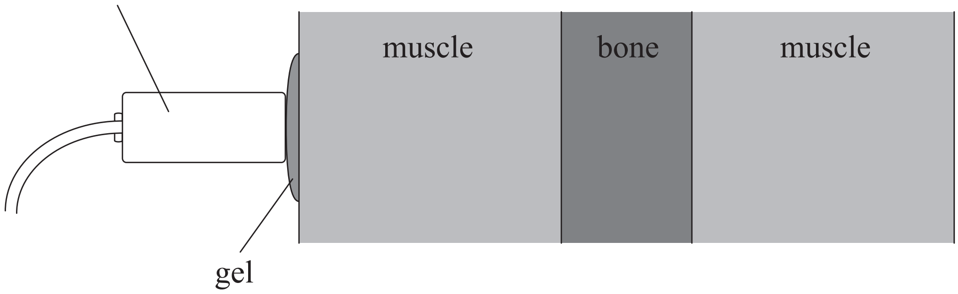
. . . .

. . . .

. . . .

I2. This question is about ultrasound.

The diagram shows part of a cross-section through the leg of a patient who is undergoing an ultrasound scan.



Data for the speed *c* of ultrasound in different media are shown below, together with values for the acoustic impedance *Z*.

	c / m s^{-1}	Z / kg m^{-2} s^{-1}
air	3.3 10^{2}	4.3 10^{2}
gel	1.5 10^{3}	1.5 10^{6}
muscle	1.5 10^{3}	1.4 10^{6}
bone	4.1 10^{3}	7.8 10^{6}

(a) Use the data from the table to calculate a value for the density of bone. *[2]*

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question I2 continued)

(b) The fraction F of the intensity of an ultrasound wave reflected at the boundary between two media having acoustic impedances Z_1 and Z_2 is given by the following equation.

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

Determine the fraction F for the boundary between

(i) air and muscle. *[2]*

. . . .

. . . .

. . . .

(ii) gel and muscle. *[2]*

. . . .

. . . .

. . . .

(c) Use your answers in (b) to explain the need for a gel on the patient's skin. *[2]*

. . . .

. . . .

. . . .

. . . .

I3. Outline the principles of the production of an image using computed tomography (CT). *[5]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

I4. This question is about radiation exposure.

(a) A radiation worker is accidentally exposed to a source of radiation. State why it is easier to measure the exposure rather than the absorbed dose for the worker. *[2]*

. . . .

. . . .

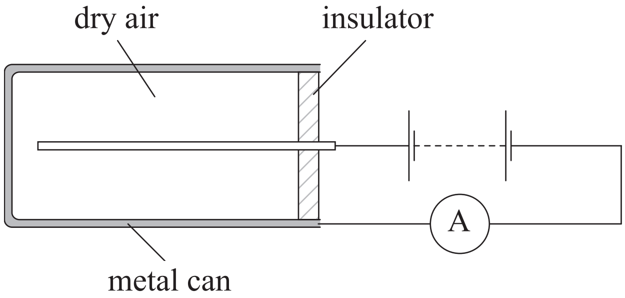
. . . .

. . . .

(This question continues on the following page)

(Question I4 continued)

(b) Exposure to γ-radiation may be measured using a small metal can. The can contains 3.6 10^{-3} g of dry air at atmospheric pressure. A metal wire, insulated from the can, is situated along the axis of the can, as shown below.



A potential difference is applied between the can and the central wire. The can is exposed to γ-radiation for a time of 90 s. During this time, the sensitive ammeter records a current of 4.8 10^{-7} A.

(i) Determine the exposure produced by the γ-radiation. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) The energy required to produce one ion-pair in air is 34 eV. Determine the rate, in watts, of deposition of energy in the air in the can. *[3]*

. . . .

. . . .

. . . .

. . . .

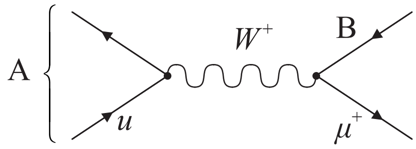
. . . .

Option J — Particle physics

J1. This question is about quarks.

The quark content of a π^+ meson includes an up quark.

The Feynman diagram represents the decay of a π^+ meson.



(a) Identify the particles labelled A and B. *[2]*

A: . . . .

B: . . . .

(b) State, with reference to their properties, **two** differences between a photon and a W boson. *[2]*

1. . . . .

. . . .

2. . . . .

. . . .

(c) The approximate range of the weak interaction is 10^{-18} m. Determine, in kg, the likely mass of the W boson. *[2]*

. . . .

. . . .

. . . .

. . . .

J2. This question is about a synchrotron.

(a) State and explain how the particles in a synchrotron beam are accelerated. *[4]*

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

(This question continues on the following page)

(Question J2 continued)

(b) In a synchrotron, beams of protons and antiprotons attain energies of 1400 GeV. The radius of the synchrotron is 4.9 km.

(i) The magnetic field strength in the synchrotron is 0.95 T. Determine, stating any assumptions you make, the mass of a proton in the beam. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) Outline why, even at the very high energies of this particle beam, the collisions are unlikely to lead to the creation of a single unbound quark. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question J2 continued)

(c) Outline **two** benefits of international cooperation in the construction and use of high-energy particle accelerators. *[2]*

1. . . . .

. . . .

. . . .

2. . . . .

. . . .

. . . .

J3. This question is about strangeness.

(a) Outline **two** properties of strangeness. *[2]*

1. . . . .
. . . .
2. . . . .
. . . .

(b) The following particle interaction is proposed.

$$p + \pi^- \rightarrow K^- + \pi^+$$

In this interaction, charge is conserved.

State, in terms of baryon and strangeness conservation, whether the interaction is possible. *[2]*

. . . .
. . . .
. . . .
. . . .

J4. This question is about deep inelastic scattering.

(a) Outline what is meant by deep inelastic scattering. *[1]*

. . . .

. . . .

(b) Suggest, with reference to asymptotic freedom, why deep inelastic scattering experiments indicate that quarks behave as free particles within a nucleon. *[2]*

. . . .

. . . .

. . . .

. . . .

J5. This question is about conditions in the early universe.

At one moment in the early universe the average particle energy was 500 keV. Nucleosynthesis is thought to have been the dominant mechanism for particle interaction at this time.

(a) Show that the temperature of the universe at which nucleosynthesis occurred is $4 \quad 10^{9}$ K. *[2]*

(b) Nucleosynthesis was only dominant for a short time in the early universe. Explain why the time was short and why nucleosynthesis did not re-occur. *[2]*