M10/4/PHYSI/HP3/ENG/TZ1/XX+

22106509

International Baccalaureate
Baccalauréat International
Bachillerato Internacional

PHYSICS
HIGHER LEVEL
PAPER 3

Tuesday 11 May 2010 (morning)

1 hour 15 minutes

Candidate session number

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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.

2210-6509

0128

28 pages

Option E — Astrophysics

E1. This question is about determining some properties of the star Wolf 359.

(a) The star Wolf 359 has a parallax angle of 0.419 arcseconds.

(i) Describe how this parallax angle is measured. *[4]*

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(ii) Calculate the distance in light-years from Earth to Wolf 359. *[2]*

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(iii) State why the method of parallax can only be used for stars at a distance of less than a few hundred parsecs from Earth. *[1]*

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(This question continues on the following page)

(Question E1 continued)

(b) The ratio

$$\frac{\text{apparent brightness of Wolf 359}}{\text{apparent brightness of the Sun}} \text{ is } 3.7\times10^{-15}.$$

Show that the ratio

$$\frac{\text{luminosity of Wolf 359}}{\text{luminosity of the Sun}} \text{ is } 8.9\times10^{-4}. \ (1\,\text{ly} = 6.3\times10^{4}\,\text{AU}).$$

[4]

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(c) The surface temperature of Wolf 359 is 2800 K and its luminosity is 3.5×10^{23} W. Calculate the radius of Wolf 359. *[2]*

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(d) By reference to the data in (c), suggest why Wolf 359 is neither a white dwarf nor a red giant. *[2]*

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

(a) Define *critical density*. *[1]*

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(b) Explain how the future of the universe may be predicted by comparing the estimated density of the universe to the critical density. *[3]*

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(c) Explain why the existence of dark matter makes it difficult to measure the density of the universe. *[1]*

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E3. This question is about stellar evolution.

(a) Describe how a large cloud of hydrogen gas can lead to conditions that initiate a fusion reaction. *[3]*

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(b) State the property of a main sequence star that determines for how long hydrogen in its core fuses into helium. *[1]*

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(c) State the end product of nuclear fusion processes in the core of

(i) a red giant. *[1]*

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(ii) the largest red super giants. *[1]*

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E4. This question is about galactic motion.

(a) The wavelength of the Lyman-alpha line in the hydrogen spectrum is measured in the laboratory to be 122 nm. In the hydrogen spectrum of a galaxy, the Lyman-alpha line is measured to be 147 nm. Determine the distance of this galaxy from the Earth. Assume that the Hubble constant H_0 is $75\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$. *[3]*

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(b) Suggest **one** reason why there is uncertainty in the value of the Hubble constant. *[1]*

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Option F — Communications

F1. This question is about modulation.

(a) A carrier wave may be amplitude modulated or frequency modulated.

State

(i) what is meant by modulation. *[1]*

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(ii) why carrier waves are modulated. *[1]*

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(b) A sinusoidal carrier wave has a frequency of 500 kHz and an amplitude of 8.0 V. The carrier wave is frequency modulated by a sinusoidal information signal of frequency 2.5 kHz and amplitude 1.2 V. The frequency deviation of the carrier wave is 15 kHz V^{-1}. Describe quantitatively the variation with time of the carrier wave. *[4]*

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F2. This question is about optic fibre transmission.

The variation with time *t* of the input power to an optic fibre is shown in Diagram 1. The variation with time *t* of the output power from the optic fibre is shown in Diagram 2.

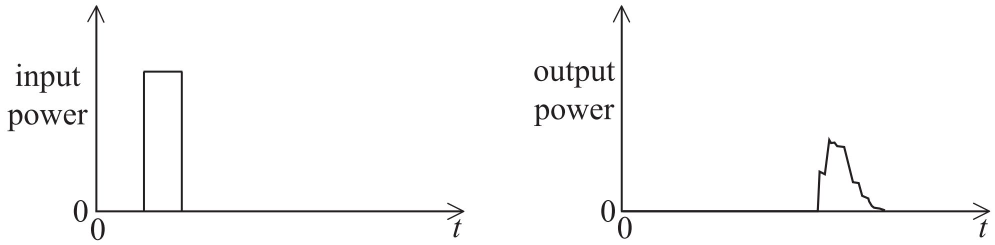

Diagram 1 Diagram 2

The scales are the same on both diagrams.

(a) State and explain the feature of the graphs that shows that there is

(i) attenuation of the signal. *[2]*

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(ii) signal noise. *[2]*

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(b) The duration (time width) of the signal increases as it travels along the optic fibre.

(i) State **two** reasons for this increased time duration. *[2]*

1: . . . .

2: . . . .

(ii) Suggest why this increase in the width of the pulse sets a limit on the frequency of pulses that can be transmitted along an uninterrupted length of optic fibre. *[1]*

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F3. This question is about the use of satellites for communication.

(a) (i) State what is meant by a geostationary satellite. *[2]*

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(ii) Explain the advantages of the use of geostationary satellites for communication. *[2]*

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(b) Explain the advantages of the use of polar-orbiting satellites for communication. *[3]*

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F4. This question is about a mobile phone network.

A passenger in a car is using a mobile phone.
State and explain the role of the base stations and the cellular exchange as the car moves from one cell to another. *[5]*

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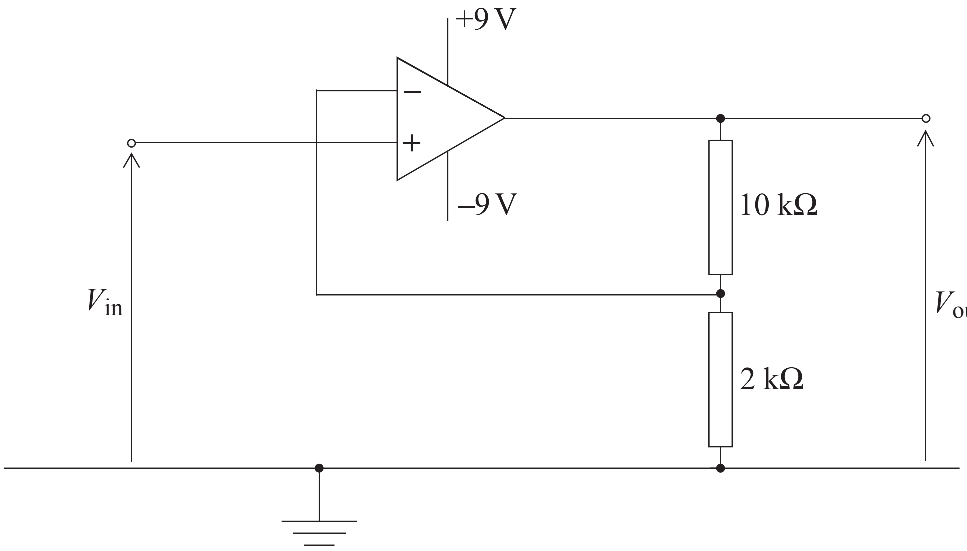
F5. This question is about an amplifier circuit.

The diagram below shows an amplifier circuit incorporating an ideal operational amplifier (op-amp).



The operational amplifier uses a +9 V / 0 / –9 V supply.

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

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(b) Determine the output potential V_{out} for values of input potential V_{in} equal to

(i) – 0.9 V. *[2]*

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(ii) + 2.0 V. *[1]*

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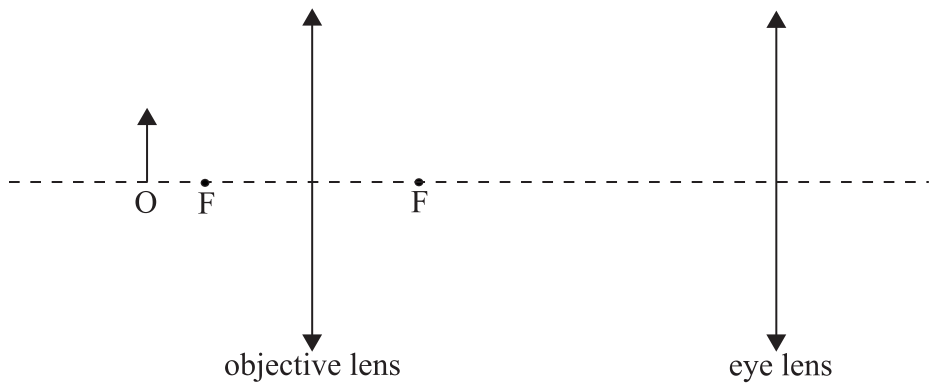
Option G — Electromagnetic waves

G1. This question is about a compound microscope, spherical aberration and chromatic aberration.

(a) An object O is placed in front of the objective lens of a compound microscope as shown below.



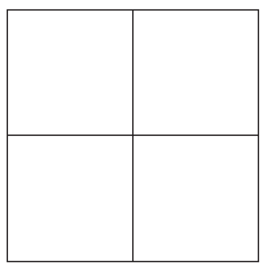
The focal points of the objective lens are at F. The microscope is in normal adjustment. Without drawing a ray diagram, label the approximate positions, on the principal axis, of

(i) the image produced by the objective lens (label this position X). *[1]*

(ii) the focal points of the eye lens (label these points E). *[1]*

(iii) the final image (label this image Y). *[1]*

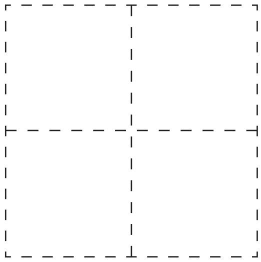
(b) An object is viewed through a convex lens that has been corrected for spherical aberration. For a particular object distance, the image of the object is as shown below.



(This question continues on the following page)

(Question G1 continued)

Another convex lens of the same focal length, but not corrected for spherical aberration, is now used to view the object. The object distance is unchanged.
In the space below, draw the image as it would be seen through this second lens.
The image as seen through the corrected lens is shown as a broken line. *[2]*



(c) Explain how chromatic aberration arises when an object is viewed through a single lens. *[2]*

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G2. This question is about the scattering of light.

(a) State an approximate wavelength for

(i) red light. *[1]*

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(ii) blue light. *[1]*

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(b) With reference to your answers in (a), explain why the setting Sun appears reddish in colour. *[3]*

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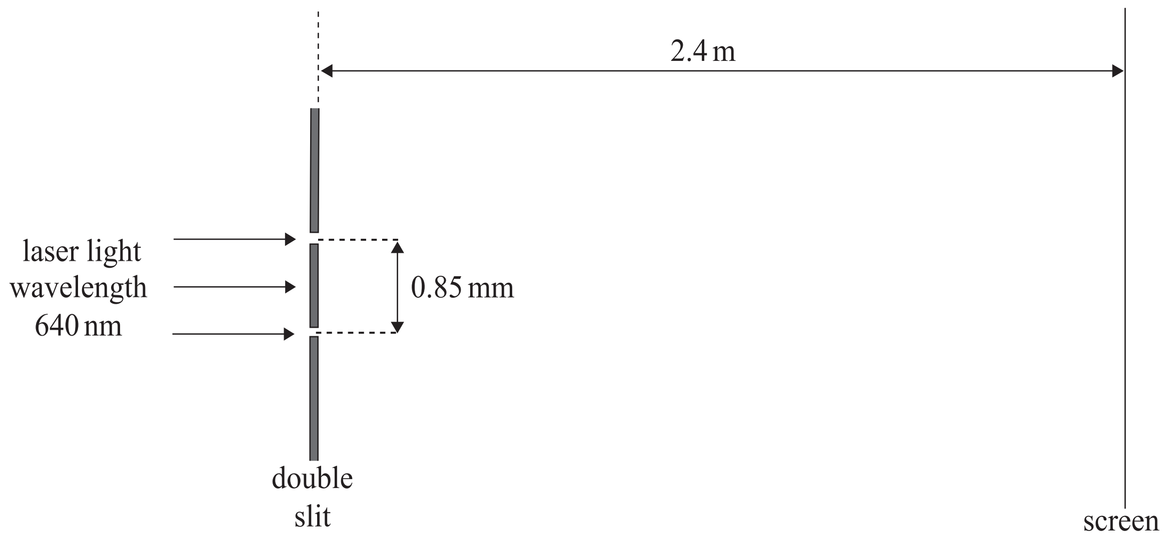
G3. This question is about two-source interference.

A double slit is arranged so that its plane is normal to a beam of laser light, as shown below.



The wavelength of the light is 640 nm. The slit separation in the double slit arrangement is 0.85 mm. Coherent light emerges from the slits and an interference pattern is observed on a screen. The screen is parallel to the plane of the double slits. The distance between the slits and the screen is 2.4 m.

(a) (i) State what is meant by coherent light. *[1]*

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(ii) Explain how an interference pattern is formed on the screen. *[3]*

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(b) Calculate the separation of the fringes in the interference pattern on the screen. *[2]*

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(This question continues on the following page)

(Question G3 continued)

(c) The interference pattern in (b) consists of a series of alternate light and dark fringes. The intensity of the light from one slit is now reduced. Suggest the effect on the appearance of the fringes. *[2]*

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G4. This question is about X-rays.

(a) In an X-ray tube having a tungsten target, electrons are accelerated from rest through a potential difference of 45 kV.
Calculate the range of wavelengths that will be observed in the X-ray spectrum produced by this bombardment. *[3]*

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(b) Explain the origins of the features of a characteristic X-ray spectrum. *[3]*

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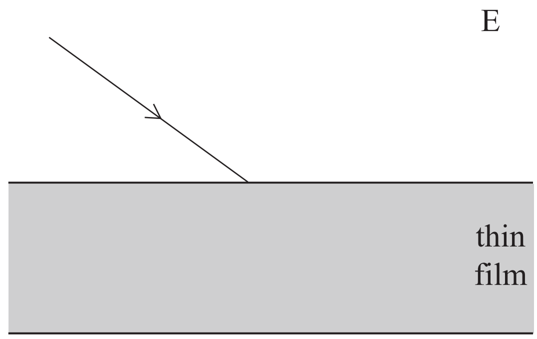
G5. This question is about thin film interference.

(a) The diagram below shows a ray of monochromatic light incident on a thin film in air.



On the diagram, draw the paths of rays that would give rise to interference as seen by an eye in the region near E. *[2]*

(b) White light is incident on a soap bubble. Explain why the soap film appears coloured. *[2]*

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Option H — Relativity

H1. This question is about relativistic kinematics.

(a) Define *inertial frame of reference*. *[2]*

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(b) Ann and Sue are twins. Sue remains on Earth. Ann travels to the star Sirius in a spaceship moving at a speed of 0.80c, as measured by Sue. The distance between Earth and Sirius is 8.8 ly, as measured by Sue.

(i) Calculate the time elapsed, as measured by Sue, between Ann leaving Earth and reaching Sirius. *[1]*

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(ii) State and explain whether Ann or Sue measures the proper time between Ann leaving Earth and arriving at Sirius. *[2]*

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(iii) Calculate the time taken for the spaceship to reach Sirius, as measured by Ann. *[2]*

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(iv) As Ann approaches Sirius, she sends a radio message back to Sue. The distance between Sirius and Earth, as measured by Ann, is 5.28 ly. Determine the time, as measured by Ann, that it takes for the signal to reach Sue. *[3]*

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(This question continues on the following page)

(Question H1 continued)

(c) As soon as Ann arrives at Sirius, she immediately turns around and returns to Earth at a speed of 0.80c, as measured by Sue. The return journey gives rise to the twin paradox.

(i) State what is meant by the twin paradox. *[1]*

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(ii) Outline how the twin paradox is resolved. *[2]*

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H2. This question is about relativistic mass and energy.

(a) Define *rest mass.* *[1]*

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(b) Explain why particles cannot be accelerated to the speed c. *[2]*

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(c) Two protons are travelling towards one another along the same straight line. The speed of each proton is 0.70c as measured by a laboratory observer. Calculate the relative velocity of approach, as measured in the frame of reference of one of the protons. *[3]*

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(This question continues on the following page)

(Question H2 continued)

(d) Determine the potential difference through which a proton must be accelerated in order to reach a speed of 0.70c. *[3]*

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H3. This question is about black holes.

(a) Define the *Schwarzschild radius*. *[1]*

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(b) Calculate the Schwarzschild radius for an object of mass 2.0×10^{31} kg. *[2]*

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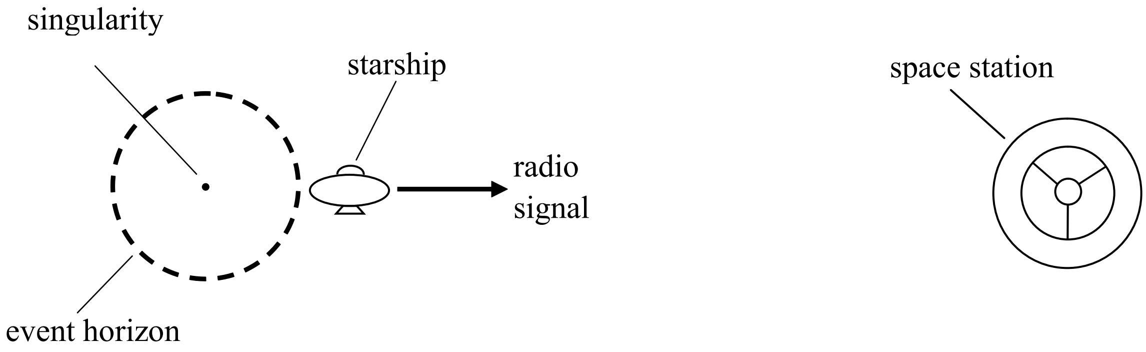
(This question continues on the following page)

(Question H3 continued)

(c) A starship is stationary just outside the event horizon of a black hole. A space station is also stationary and is located far away from the black hole and any other massive object.



(i) The starship transmits a radio signal to the space station. Explain why the signal received at the space station is shifted to a lower frequency than the transmitted frequency. *[2]*

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(ii) The starship remains stationary just outside the event horizon for one hour as measured by an observer in the starship. The time elapsed, as measured by an observer in the space station, is ten hours. Determine, in terms of the Schwarzschild radius R_s of the black hole, the distance of the starship from the event horizon of the black hole. *[3]*

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Option I — Medical physics

I1. This question is about hearing.

A student listens to music using a personal earphone. The power of the sound produced by the earphone is $0.19\,\mu W$. The power is evenly distributed over the tympanic membrane of area $54\,mm^2$.

(a) Calculate, for the surface of the tympanic membrane,

(i) the sound intensity. *[2]*

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(ii) the sound intensity level (*IL*). *[2]*

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(b) Comment, with respect to the effect on the hearing of the student, on the intensity level calculated in (a)(ii). *[2]*

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I2. This question is about ultrasound.

(a) Define *acoustic impedance*. *[1]*

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(b) The table gives values of the acoustic impedance for air and soft tissue.

	acoustic impedance / $\text{kg m}^{-2}\text{s}^{-1}$
air	430
soft tissue	1.63×10^6

The intensity reflection coefficient for two media of impedances Z_1 and Z_2 is

$$I_R = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2$$

(i) Determine the intensity reflection coefficient between air and soft tissue. *[2]*

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(ii) Explain why air between an ultrasound probe and the skin (soft tissue) of a person prevents ultrasound diagnosis taking place. *[3]*

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(iii) State and explain how the problem you have explained in (b)(ii) is overcome. *[2]*

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I3. This question is about nuclear magnetic resonance (NMR).

Outline the basic principles of nuclear magnetic resonance (NMR) imaging. *[6]*

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I4. This question is about radiation.

(a) State, in the context of radiation measurement, what is meant by

(i) exposure. *[1]*

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(ii) absorbed dose. *[1]*

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(iii) equivalent dose. *[1]*

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(This question continues on the following page)

(Question I4 continued)

(b) The energy required to produce one ion pair in air is 34 eV.

The exposure in a workplace is found to be $2.5\times10^{-3}\,\text{C kg}^{-1}$. Determine the energy given to 1.0 g of air as a result of this exposure. *[4]*

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(c) The exposure to X-ray radiation during a computed tomography (CT) scan imposes a finite risk for the patient.

(i) Suggest the nature of this risk. *[1]*

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(ii) Explain why such a risk is thought to be acceptable by both the patient and the medical profession. *[2]*

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Option J — Particle physics

J1. This question is about fundamental interactions.

(a) State an exchange particle for

(i) the weak interaction. *[1]*

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(ii) the electromagnetic interaction. *[1]*

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(b) Comment, with reference to the mass of the exchange particles, on the range of the weak and electromagnetic interactions. *[2]*

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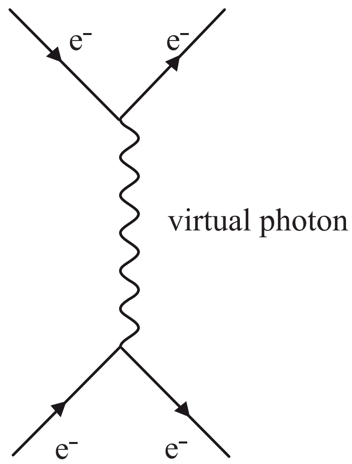
(c) Describe the process represented by the Feynman diagram below. *[1]*



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(This question continues on the following page)

(Question J1 continued)

(d) State what is meant by a virtual particle. *[1]*

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(e) Explain how the Heisenberg uncertainty principle for energy and time applies to the interaction in (c). *[2]*

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(f) The uncertainty in the time for the electromagnetic interaction between two electrons is 1.6×10^{-16} s. Determine the uncertainty in the energy of the virtual photon. *[2]*

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J2. This question is about particle detection.

(a) Outline how particles produce visible tracks in a bubble chamber. *[3]*

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(b) State **two** reasons why wire chambers are now used rather than bubble chambers. *[2]*

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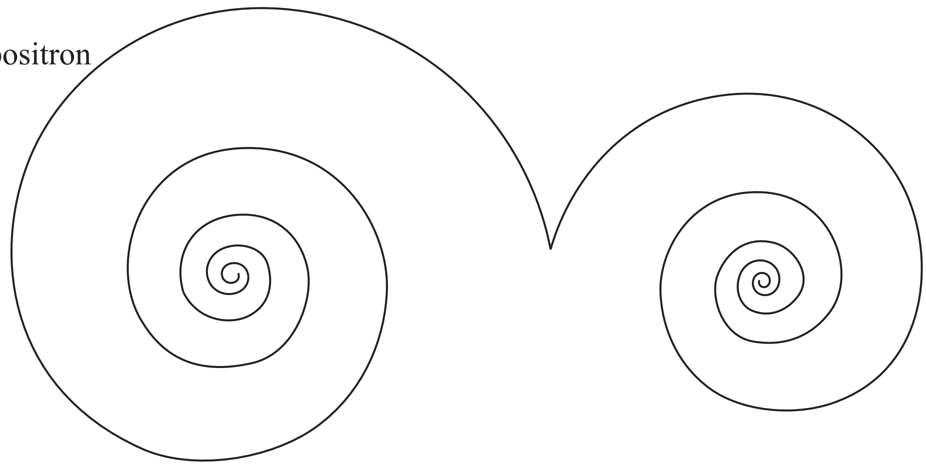
(This question continues on the following page)

(Question J2 continued)

(c) Below is a sketch of the tracks in a bubble chamber of an electron and a positron, produced by the annihilation of a photon.



There is a magnetic field directed normal to the plane of the paper.

Explain why the tracks of the particles are spirals. *[3]*

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J3. This question is about mesons and baryons.

(a) State the quark content of mesons and baryons. *[2]*

Mesons: . . . .

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Baryons: . . . .

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(This question continues on the following page)

(Question J3 continued)

(b) Explain why both mesons and baryons can be described as colourless. *[2]*

Mesons: . . . .

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Baryons: . . . .

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(c) A negative pion, π^-, collides with a stationary proton, producing a neutron and an unknown particle, X.

$$\pi^- + p \rightarrow n + X$$

(i) State the charge on particle X. *[1]*

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(ii) Deduce whether particle X is a meson or a baryon. *[2]*

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J4. This question is about pair production.

(a) Estimate the temperature below which spontaneous pair production of electrons and positrons cannot occur. *[3]*

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(b) It is suggested that, in the early universe, there was slightly more matter than anti-matter. Using your answer to (a), state why there is currently only stable matter in the universe. *[2]*

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