22096509

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

PHYSICS
HIGHER LEVEL
PAPER 3

Wednesday 13 May 2009 (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.

22096509

Option E — Astrophysics

E1. This question is about stars.

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

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(b) The table gives information on three stars, Achernar, EG 129 and Mira.

	Absolute magnitude	**Apparent magnitude**	**Spectral class**
Achernar	–3.0	+0.50	B
EG 129	+13.0	+14.0	B
Mira	–3.0	+5.0	M

(i) State which **one** of the three stars appears brightest from Earth. *[1]*

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(ii) Estimate the ratio $\frac{L_A}{L_E}$ where L_A is the luminosity of Achernar and L_E is the luminosity of EG 129. *[3]*

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(iii) Show that the distance of the star Achernar from Earth is approximately 50 pc. *[2]*

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(Question E1 continued)

(c) The surface temperature of Mira is 5 times lower than that of Achernar. Estimate the ratio $\frac{R_M}{R_A}$ where R_M is the radius of Mira and R_A is the radius of Achernar. *[3]*

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(d) State and explain which of the stars in the table in (b) is a white dwarf. *[3]*

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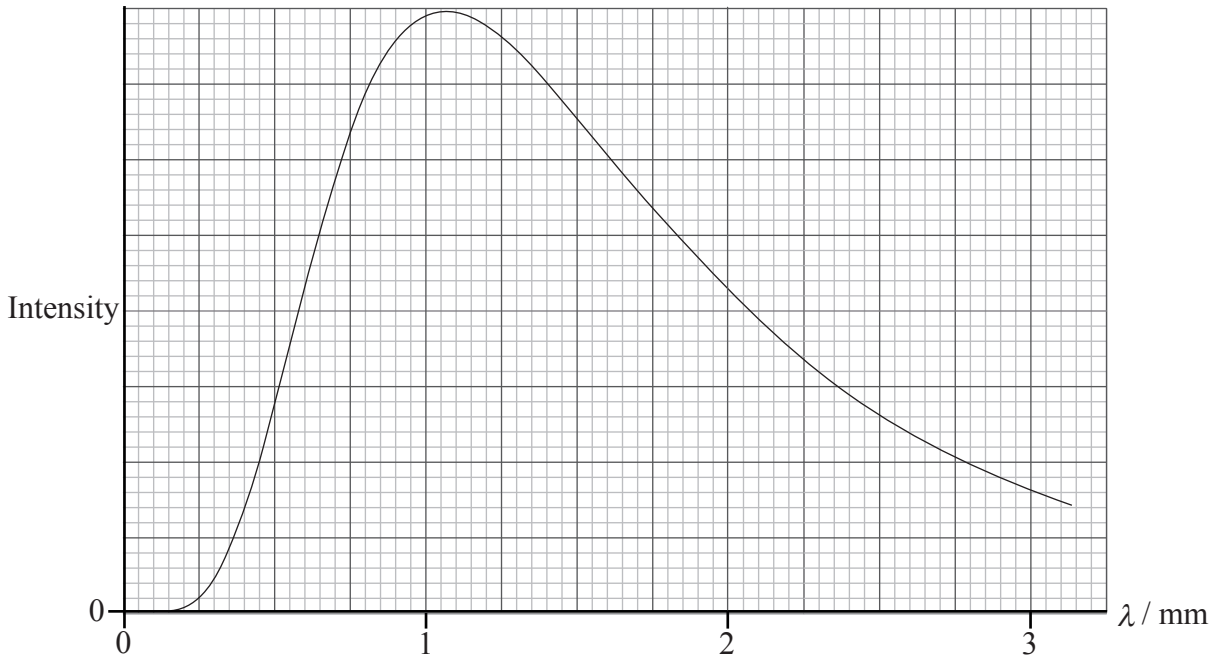
E2. This question is about cosmic microwave background radiation.

The graph shows the spectrum of the cosmic microwave background radiation.



The shape of the graph suggests a black body spectrum *i.e.* a spectrum to which the Wien displacement law applies.

(a) Use the graph to estimate the black body temperature. *[2]*

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(b) Explain how your answer to (a) is evidence in support of the Big Bang model. *[2]*

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(c) State and explain another piece of experimental evidence in support of the Big Bang model. *[2]*

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E3. This question is about stellar evolution.

(a) Outline what is meant by the Oppenheimer-Volkoff limit. *[1]*

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(b) Eta Carinae is a main sequence star whose mass is about 100 times larger than that of the Sun. The star will evolve to become a neutron star.

(i) By reference to the Oppenheimer-Volkoff limit, outline the evolution of Eta Carinae from when it leaves the main sequence until the neutron star stage. *[2]*

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(ii) State the reason why Eta Carinae will not undergo further collapse when it becomes a neutron star. *[1]*

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(c) The mass-luminosity relationship for stars such as Eta Carinae and the Sun is given by the expression $L = kM^{3.5}$ where k is a constant and M is the mass of the star. The mass of Eta Carinae is 100 times larger than that of the Sun.

(i) Calculate the ratio $\frac{l_{\text{Eta Carinae}}}{l_{\text{Sun}}}$, where $l = \frac{L}{M}$ is the luminosity per unit mass. *[2]*

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(ii) A star will leave the main sequence after it has converted 12% of its mass into energy. By reference to your answer to (i) suggest why Eta Carinae will spend less time on the main sequence than the Sun. *[1]*

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E4. This question is about Hubble's law.

(a) State Hubble's law. *[2]*

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(b) Suggest why, in verifying Hubble's law, data from nearby galaxies cannot be used. *[1]*

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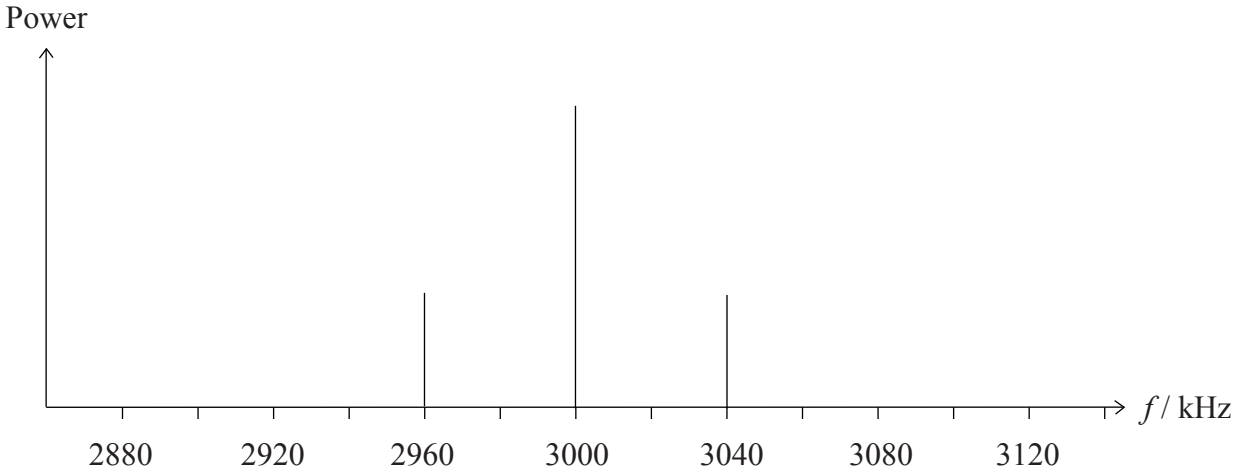
Option F— Communications

F1. This question is about amplitude modulation (AM).

The graph shows the power spectrum of an AM carrier wave.



(a) Use the graph to determine the

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

. . . . . .

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

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

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(b) A broadcasting company has been given permission to broadcast in a frequency range of 320 kHz. The transmissions have the bandwidth found in (a)(iii).

Determine how many radio stations the company can operate in this frequency range. *[1]*

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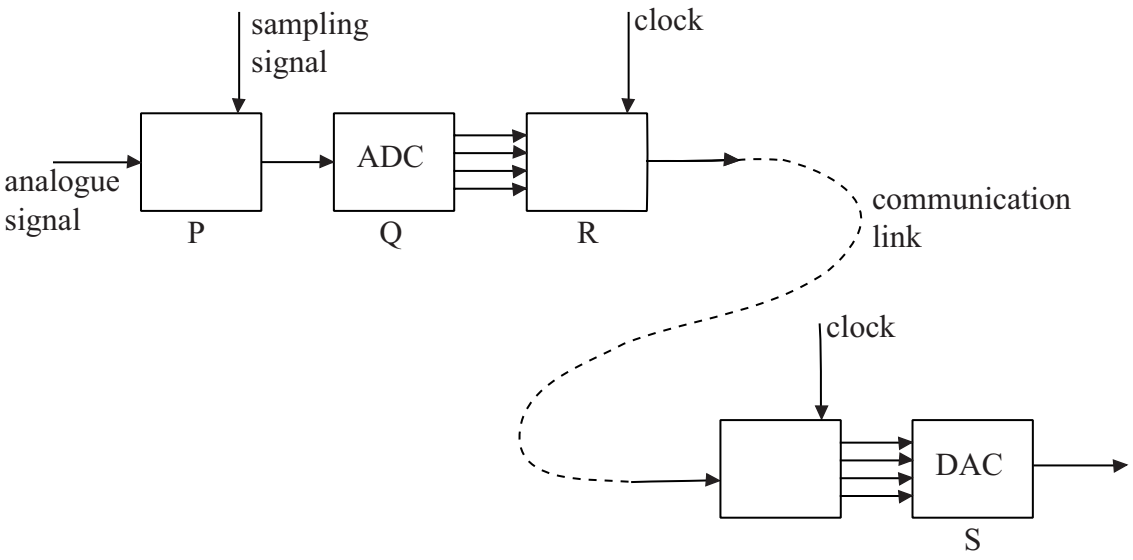
F2. This question is about transmission and sampling of signals.

(a) The block diagram illustrates the principles of the transmission and reception of digital signals.



Describe the function of each of the blocks labeled P, Q, R and S. *[4]*

P: . . . . . .
. . . . . .

Q: . . . . . .
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R: . . . . . .
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S: . . . . . .
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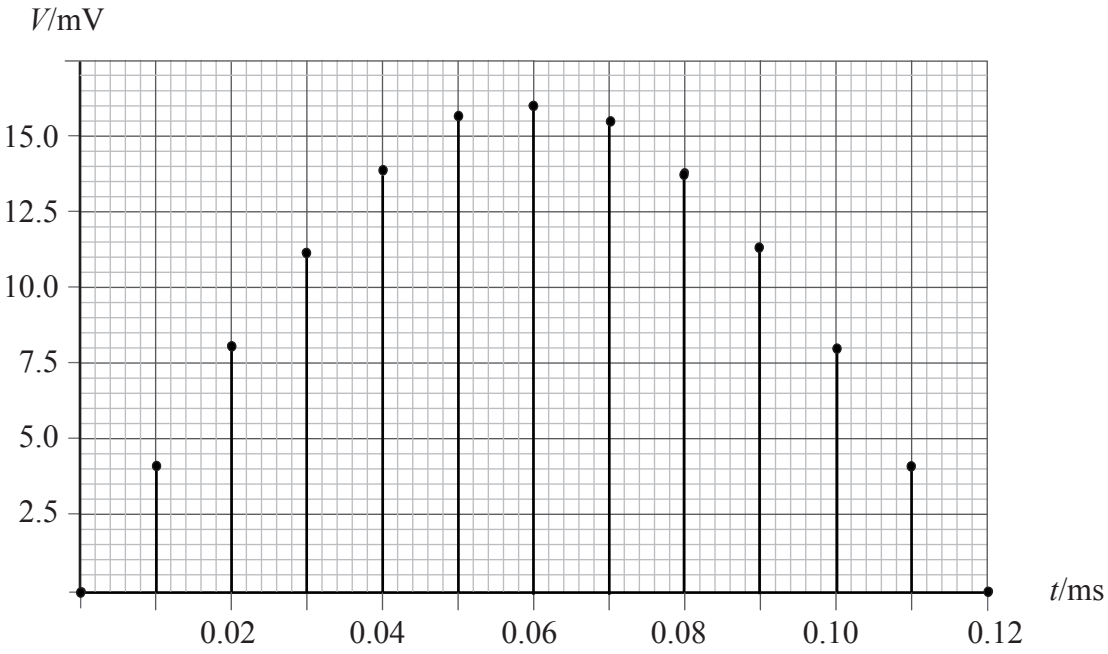
(Question F2 continued)

(b) The graph shows thirteen sampled values of an analogue signal as a function of the time at which the sampling took place.



Each sample is converted into a 4-bit binary number, according to the encoding scheme:

Signal / mV	**Sample / mV**	**4-bit binary number**
⋮	⋮	⋮
2.000 – 2.999	2	0010
3.000 – 3.999	3	0011
4.000 – 4.999	4	0100
⋮	⋮	⋮

(This question continues on the following page)

(Question F2 continued)

Determine the

(i) 4-bit binary number corresponding to the sample at $t = 0.07$ ms. *[1]*

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(ii) bit-rate of the digital transmission. *[2]*

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(c) State **one** advantage and **one** disadvantage of increasing the sampling frequency used to sample an analogue signal. *[2]*

Advantage: . . . . . .

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Disadvantage: . . . . . .

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F3. This question is about optical fibres.

(a) State **one** cause of attenuation and **one** cause of dispersion in an optical fibre. *[2]*

Attenuation: . . . . . .

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Dispersion: . . . . . .

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(b) An optical fibre of length 5.4 km has an attenuation per unit length of $2.8\,\text{dB km}^{-1}$. The signal power input is 80 mW.

(i) Calculate the output power of the signal. *[2]*

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(ii) In order for the power of the output signal to be equal to the input power an amplifier is installed at the end of the fibre.

State the gain, in decibels (dB), of the amplifier at the end of the fibre. *[1]*

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(c) The signal to noise ratio (SNR), in dB, is defined as $\text{SNR} = 10\log\frac{P_{\text{signal}}}{P_{\text{noise}}}$ where P_{signal} and P_{noise} are the powers of the signal and noise respectively.

The SNR of the signal in (b) before amplification was 20 dB. Calculate the SNR after amplification. *[2]*

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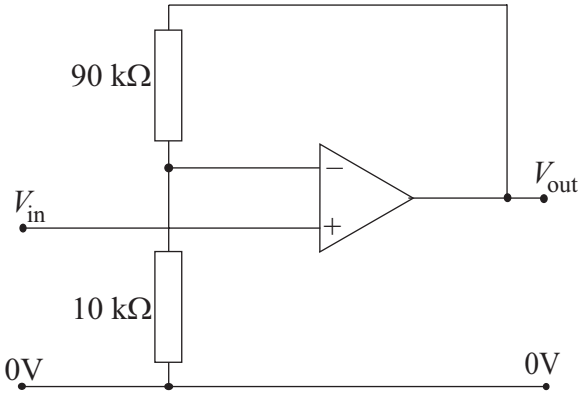
F4. This question is about the operational amplifier.

Diagram 1 shows a non-inverting amplifier circuit.

Diagram 1



(a) Suggest why the amplifier is referred to as non-inverting. *[1]*

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(b) The input voltage for the amplifier in (a) is $V_{in} = 2.0\ \text{mV}$.

Calculate the

(i) gain G of the amplifier. *[1]*

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(ii) output voltage V_{out}. *[1]*

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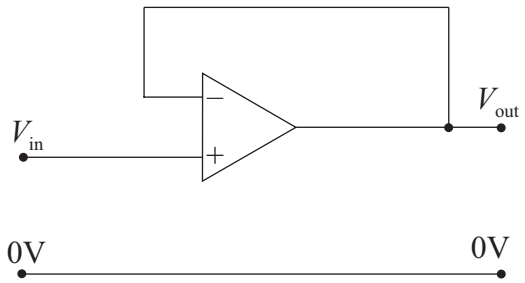
(Question F4 continued)

(c) Diagram 2 shows a particular non-inverting amplifier.

Diagram 2



Explain, in terms of the properties of an op-amp, why the gain of this non-inverting amplifier is equal to 1. *[3]*

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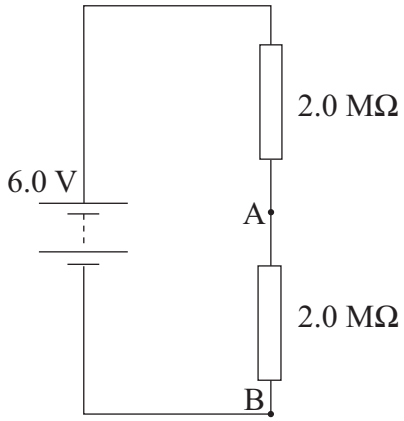
(Question F4 continued)

(d) Diagram 3 shows a circuit in which the battery has an emf of 6.0 V and negligible internal resistance. Two $2.0\ \text{M}\Omega$ resistors are connected in series to the battery.

Diagram 3



(i) State the value of the potential difference between points A and B. *[1]*

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(ii) A voltmeter of resistance $100\ \text{k}\Omega$ is used to measure the potential difference across points A and B.

State why the reading on the voltmeter is not equal to the value stated in (d)(i). *[1]*

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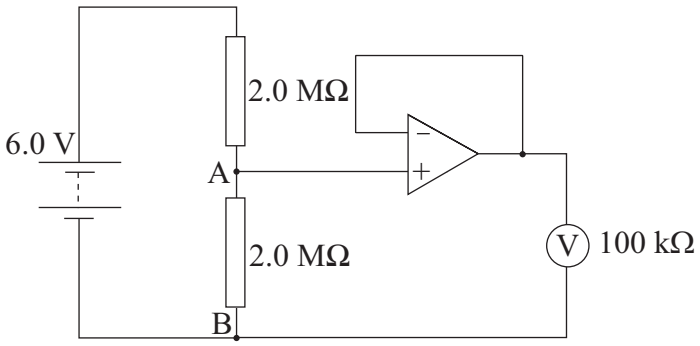
(iii) The circuit in diagram 3 is modified to include the circuit shown in diagram 2.

Diagram 4



Explain why the voltmeter reads the value of the potential difference as stated in (d)(i). *[2]*

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Option G — Electromagnetic waves

G1. This question is about the colour of the sky.

Outline why the sky appears blue during the day and red during a sunset.

Blue sky: . . . . . *[2]*

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Red sky: . . . . . *[2]*

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G2. This question is about image formation in a convex lens.

(a) Define *near point*. *[1]*

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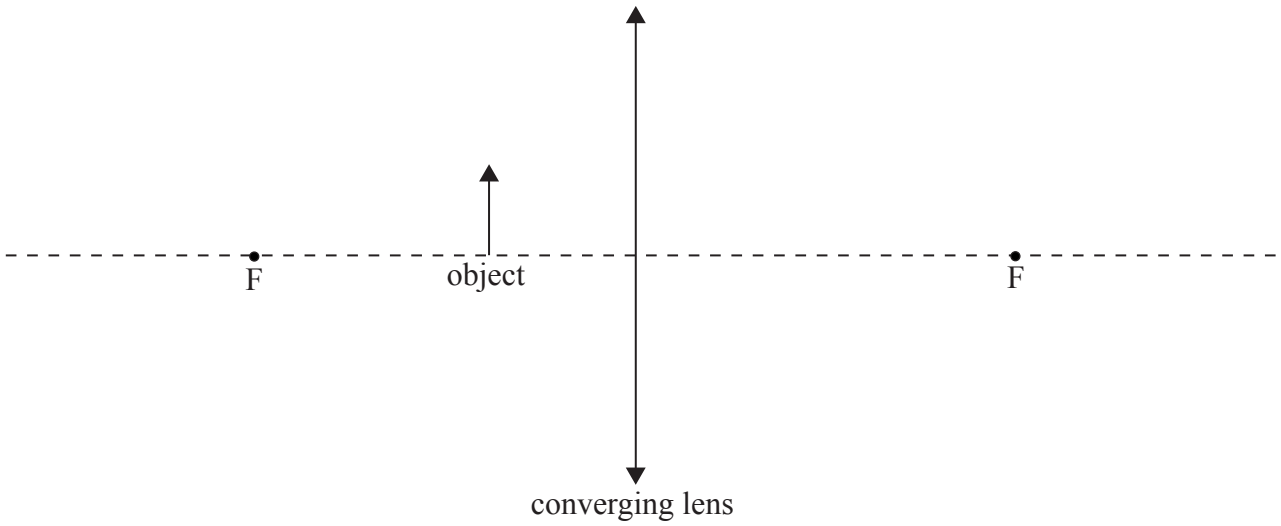
(b) A small object is placed in front of a converging lens that will act as a magnifier. The focal points of the lens are labeled with the letter F.



On the diagram construct rays to locate the image of the object. *[2]*

(This question continues on the following page)

(Question G2 continued)

(c) A particular lens has a focal length of 9.0 cm and the image is formed at the near point which is 25 cm from the lens.

Assuming that the eye is very close to the lens determine the

(i) distance of the object from the lens. *[2]*

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(ii) angular magnification of the lens. *[1]*

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(d) The angular magnification of the lens increases with decreasing focal length.

State **one** disadvantage of using very short focal length lenses. *[1]*

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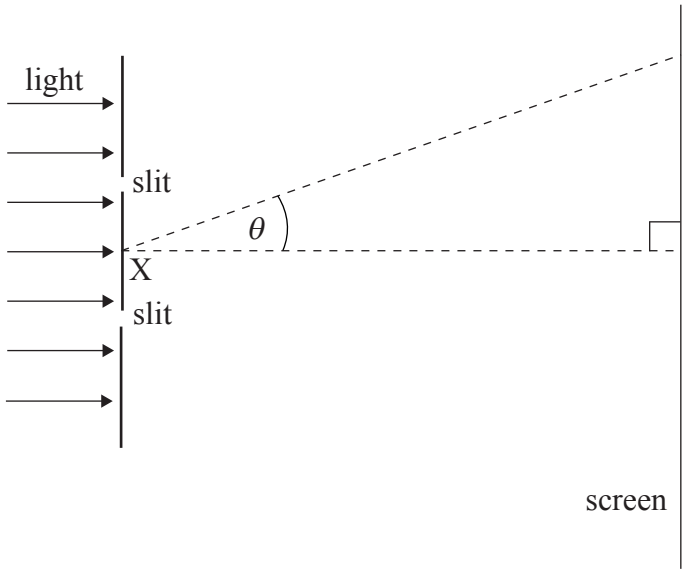
G3. This question is about interference.

Monochromatic, coherent light is incident on two narrow parallel slits whose widths are small compared to their separation. After passing through the slits the light is brought to a focus on a screen producing interference fringes. Point X is the midpoint of the slits.



The angular position of a point on the screen is determined by the angle θ.

(a) (i) Explain why the intensity of light at $\theta = 0$ will be a maximum. *[2]*

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(ii) The wavelength of light is 6.80×10^{-7} m and the separation of the slits is 1.13×10^{-4} m . Show that for the first order maximum $\theta = 6.02 \times 10^{-3}$ rad. *[1]*

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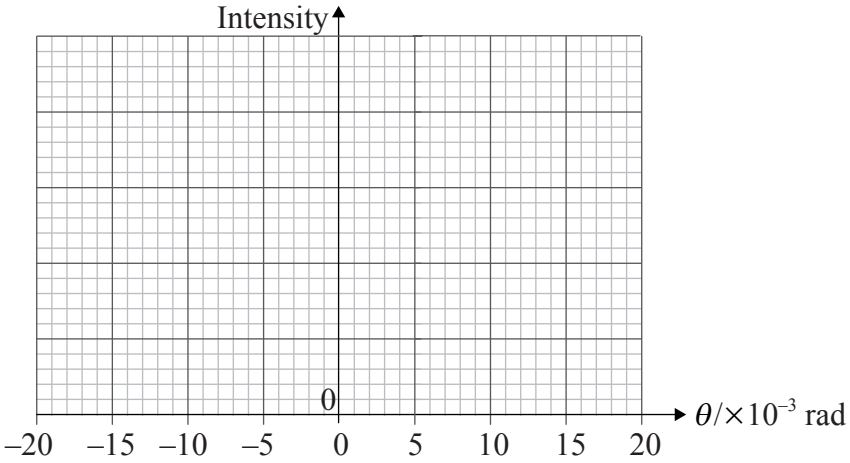
(Question G3 continued)

(iii) On the axes below draw a graph to show how the intensity of light observed on the screen varies with angle θ. (You do not have to put numbers on the vertical axis.) *[3]*



(b) The two slits are replaced by a large number of slits whose widths and separation are the same as in (a).

State the changes, if any, in the intensity pattern you drew in (a)(iii) with reference to

(i) the value of the intensity at $\theta = 0$. *[1]*

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(ii) the angular position of the points of maximum intensity. *[1]*

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(iii) the angular width of the fringes. *[1]*

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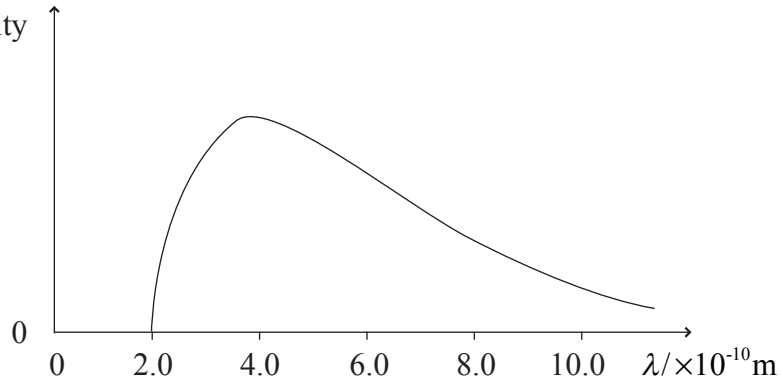
G4. This question is about X-ray spectra and X-ray diffraction.

(a) Electrons are accelerated from rest by a potential difference. They strike a metal target and the resulting X-ray spectrum is shown below.



(i) State and explain what may be deduced about the energy levels of the atoms of the metal from the fact that this spectrum does not contain any characteristic lines. *[2]*

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(ii) Outline the mechanism by which the photons of wavelength 2.0×10^{-10} m are produced. *[2]*

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(iii) Calculate the potential difference through which the electrons have been accelerated. *[2]*

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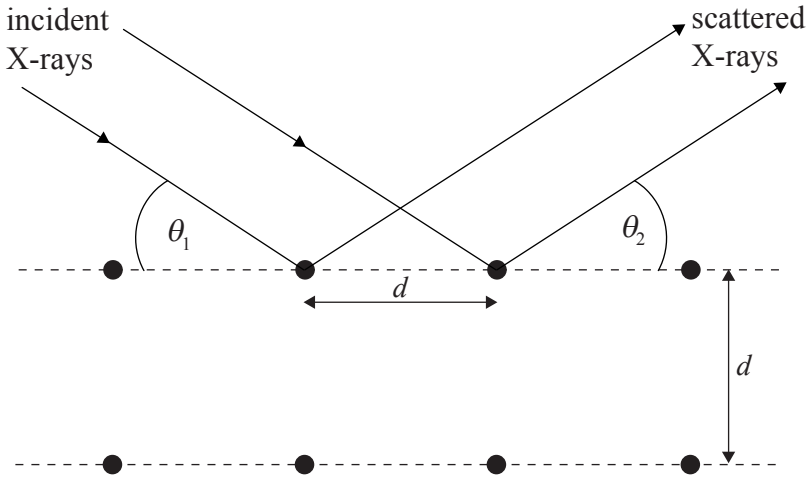
(This question continues on the following page)

(Question G4 continued)

(b) X-rays are incident on a crystal surface making an angle θ_1 with the surface. The scattered X-rays make an angle θ_2 with the surface. In the diagram below the circles, that are separated by a distance *d*, represent lattice ions of the crystal.



The path difference between the two scattered rays is $d(\cos\theta_1 - \cos\theta_2)$.

(i) State and explain the condition for constructive interference between the two scattered rays shown. *[2]*

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(ii) The wavelength of the X-rays is 4.20×10^{-10} m. A maximum in the intensity of the scattered X-rays is first observed at an angle $\theta = 34.5°$. Determine the separation of the atomic planes that give rise to this maximum. *[2]*

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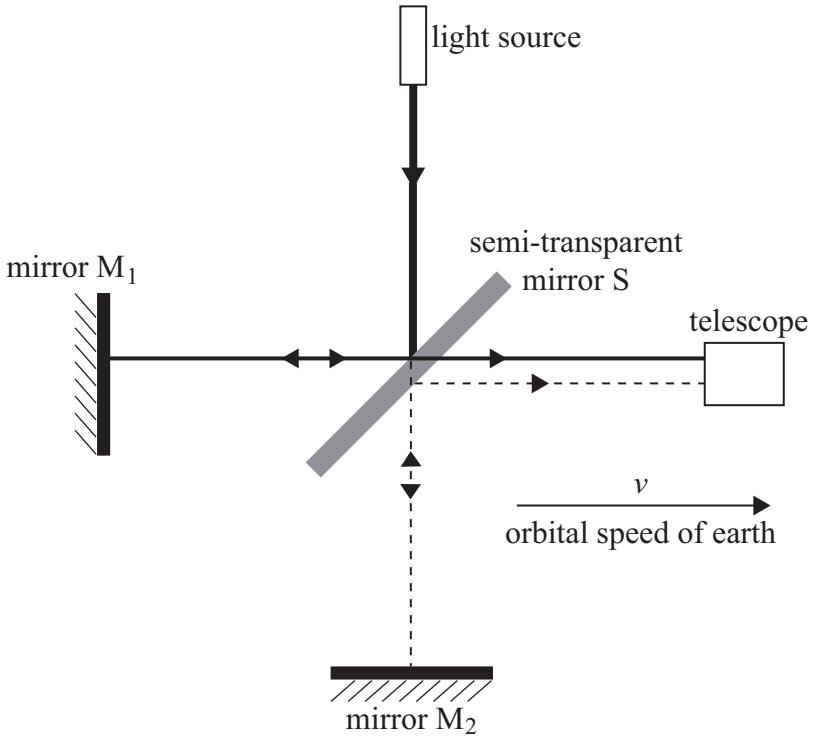
Option H — Relativity

H1. This question is about the Michelson-Morley experiment.

The diagram shows the type of arrangement that was used in the Michelson-Morley experiment.



The speed of light in free space is c and the orbital speed of Earth is v.

(a) State

(i) the purpose of the Michelson-Morley experiment. *[1]*

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(ii) using a Galilean transformation, the speed of light along the path **from** the mirror M_1 **to** the semi-transparent mirror S in terms of c and v. *[1]*

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(This question continues on the following page)

(Question H1 continued)

(b) With the apparatus in the position shown, an interference pattern was observed in the field of view of the telescope. The apparatus was then rotated by 90°.

State

(i) what was expected to be observed. *[1]*

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(ii) what was actually observed. *[1]*

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(iii) how the result of the Michelson-Morley experiment is explained in the theory of special relativity. *[1]*

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H2. This question is about simultaneity.

(a) Define what is meant by a *proper time interval*. *[1]*

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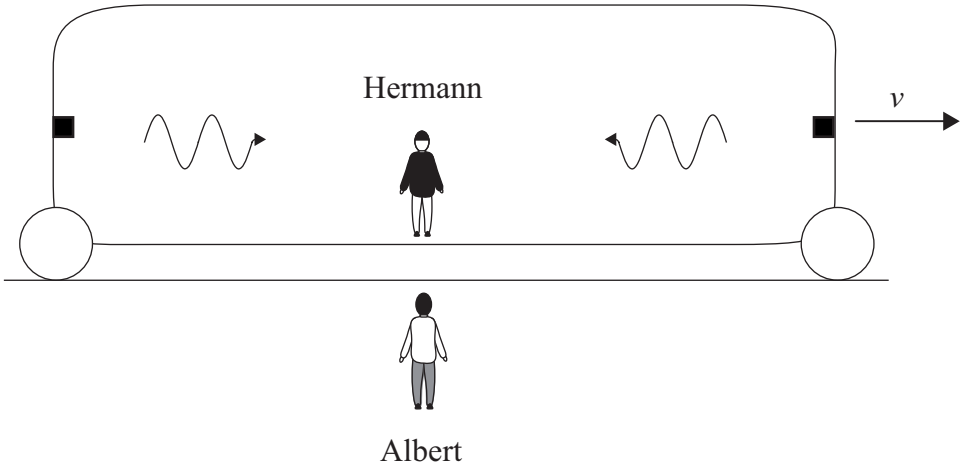
(b) Albert is at rest with respect to the ground. Hermann is in a carriage that is moving with speed v relative to Albert in the direction shown. Two flashes of light are emitted from the back and the front of the carriage. According to Hermann's clock they arrive at Hermann's position simultaneously.



Explain with reference to the concept of proper time, why the arrival of the light pulses at Hermann will also be simultaneous to Albert. *[3]*

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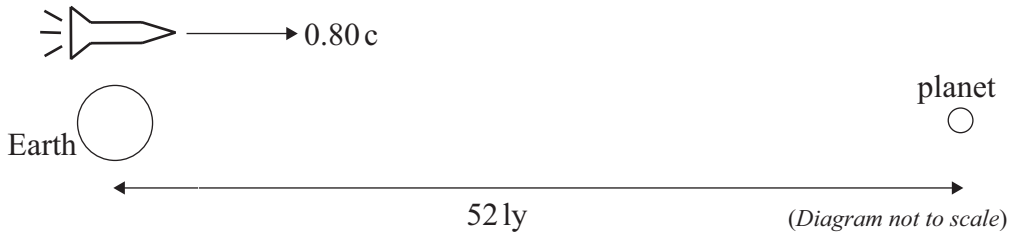
H3. This question is about relativistic kinematics.

A spacecraft leaves Earth at a speed of 0.80 c as measured by an observer on Earth. It heads towards, and continues beyond, a distant planet. The planet is 52 light years away from Earth as measured by an observer on Earth.



When the spacecraft leaves Earth, Amanda, one of the astronauts in the spacecraft, is 20 years old.

The Lorentz gamma factor for a speed of 0.80 c is $\gamma = \frac{5}{3}$.

(a) Calculate

(i) the time taken for the journey to the planet as measured by an observer on Earth. *[1]*

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(ii) the distance between the Earth and the planet, as measured by Amanda. *[1]*

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(iii) Amanda's age as the spacecraft goes past the planet, according to Amanda. *[2]*

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(b) As the spacecraft goes past the planet Amanda sends a radio signal to Earth. Calculate, as measured by the spacecraft observers, the time it takes for the signal to arrive at Earth. *[3]*

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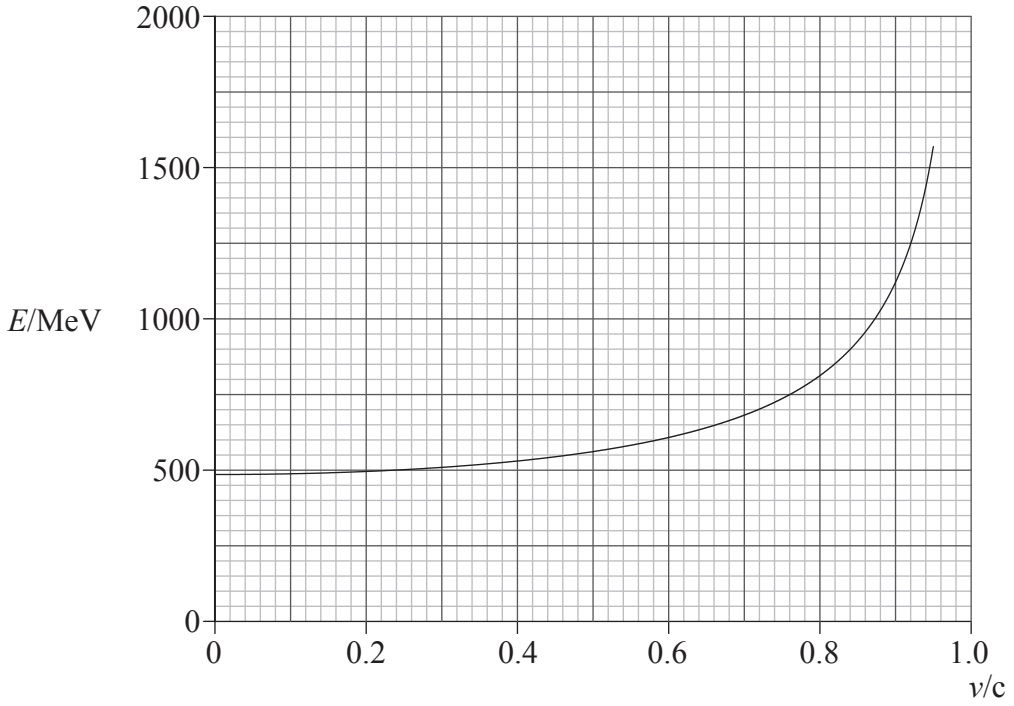
H4. This question is about relativistic mechanics.

The graph shows the variation with speed v of the total energy E of a particle called the kaon, K^-. The rest mass of the K^- is $490\,\text{MeV}\,c^{-2}$ and its electric charge is the same as that of the electron.



(a) Suggest how the graph may be used in order to obtain the rest mass of the K^-. *[1]*

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(b) Use the graph to determine the potential difference required to accelerate a K^- from rest to a speed of $0.95\,c$. *[2]*

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(This question continues on the following page)

(Question H4 continued)

(c) The K^- is unstable and decays into a muon and an antineutrino according to the reaction

$$K^- \rightarrow \mu^- + \bar{\nu}$$

The rest mass of the muon is $105\,\text{MeV}\,c^{-2}$. The rest mass of the antineutrino may be assumed to be zero.

The K^- is at rest when it decays.

(i) Show that total energy is conserved if the momentum of the muon is $234\,\text{MeV}\,c^{-1}$. *[2]*

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(ii) Determine the kinetic energy of the muon. *[3]*

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H5. This question is about black holes

(a) Define what is meant by the *Schwarzschild radius* of a black hole. *[1]*

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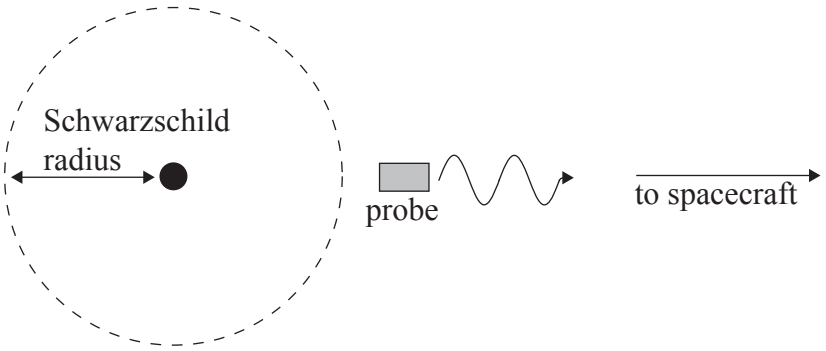
(b) A probe is at rest a small distance from a black hole of Schwarzschild radius 6.7×10^{4} m. The probe emits monochromatic light pulses that are received by a spacecraft very far from the black hole.



According to a clock in the probe the pulses have a frequency of 4.5×10^{14} Hz, with one pulse being emitted every two seconds. The frequency of the light as measured by a clock in the spacecraft is 3.0×10^{14} Hz.

(i) State the name of the phenomenon responsible for the observed change in the frequency of the light. *[1]*

. . . . . .

(ii) Determine, according to the spacecraft clock, how often the pulses are received by the spacecraft. *[2]*

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(iii) Determine the distance of the probe from the centre of the black hole. *[2]*

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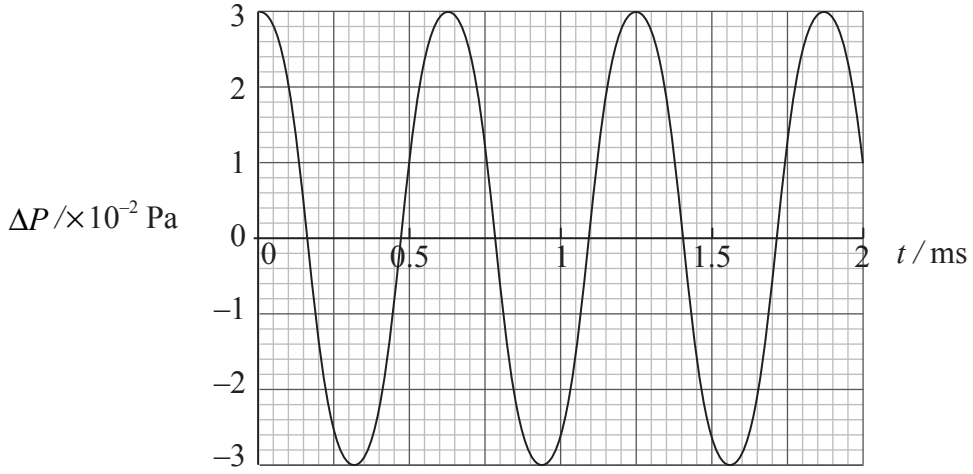
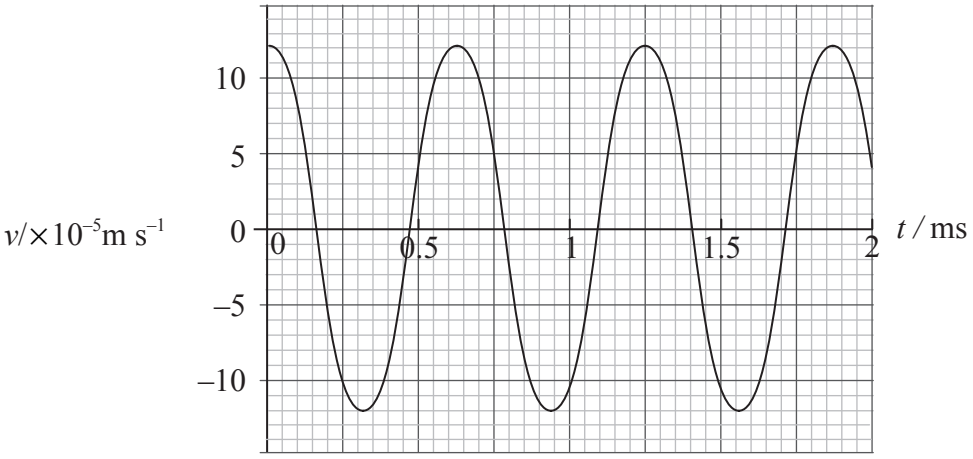
Option I — Medical physics

I1. This question is about the ear and hearing.

Sound waves are incident on the eardrum of a person. The graph shows the variation with time t of the difference ΔP between the pressure at the eardrum and atmospheric pressure.



(a) The graph below shows the variation with time t of the velocity v of the centre of the eardrum.



(This question continues on the following page)

(Question 11 continued)

The average power carried by the sound wave is given by $P_{av} = \frac{F_{max} v_{max}}{2}$ where F_{max} is the maximum force exerted on the eardrum.

Use data from the graphs opposite to

(i) show that the average intensity of the sound at the eardrum is approximately 1.8×10^{-6} W m^{-2}. The area of the eardrum, A, is 42 mm^2. *[3]*

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(ii) estimate the maximum sound intensity level, in dB, at the eardrum. *[1]*

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(b) The area of the oval window where the stirrup is attached is 3.2 mm^2. The ossicles amplify the force by a factor of 1.5.

Estimate the maximum pressure at the inner ear. *[2]*

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(c) Outline the role of the ossicles and the oval window in the transmission of sound to the inner ear. *[2]*

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I2. This question is about ultrasound imaging.

(a) Describe

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

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(ii) how ultrasound may be produced. *[2]*

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(b) The table gives information on the speed of sound, the density and the acoustic impedance for various materials.

Material	**Speed of sound / ms^{-1}**	**Density / kgm^{-3}**	**Acoustic impedance / $kg\ m^{-2}\ s^{-1}$**
Air	330	1.3	430
Bone	2800	1.5×10^{3}	
Tissue	1600	1.0×10^{3}	1.6×10^{6}

Calculate the acoustic impedance of bone and enter your answer in the table above. *[1]*

(This question continues on the following page)

(Question I2 continued)

(c) Ultrasound of intensity I_0 is traveling in a medium of impedance Z_1 and is incident on a medium of impedance Z_2. The **reflected** ultrasound has intensity I_R given by

$$I_R = I_0 \left(\frac{Z_1 - Z_2}{Z_1 + Z_2} \right)^2$$

(i) With reference to the equation above explain why ultrasound would not be an effective method for a brain scan. *[2]*

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(ii) Using data from the table in (b) determine the ratio $\frac{I_R}{I_0}$ of ultrasound entering tissue from air. *[2]*

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(iii) Using your answer to (c)(ii), explain the purpose of the gel that is applied to the skin before an ultrasound scan. *[2]*

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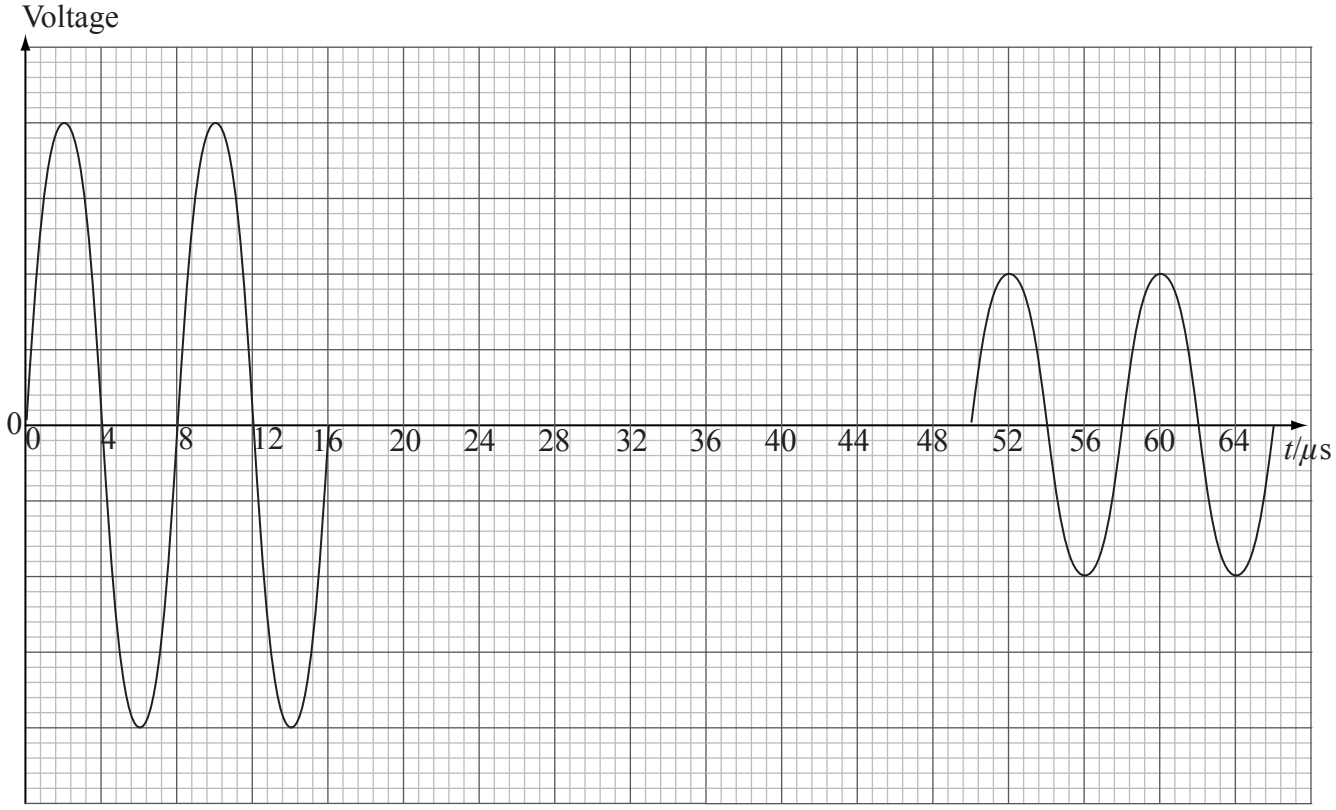
(This question continues on the following page)

(Question I2 continued)

(d) A pulse of ultrasound is emitted from a transducer placed on a patient's skin. The pulse is reflected by the stomach and is received back at the transducer. The graph (an A scan) shows how the voltage due to the transmitted and the reflected pulse varies with time. The speed of sound in tissue is 1600 ms^{-1}.



(i) Using data from the graph determine the distance between the stomach and the transducer. *[2]*

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(ii) Outline **two** differences between an A scan and a B scan. *[2]*

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I3. This question is about radiation therapy.

(a) To treat thyroid cancer, radioactive iodine-131 is administered to a patient.

(i) State how the radioactive iodine may be administered to the patient. *[1]*

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(ii) State the reason why iodine is used. *[1]*

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(iii) State **two** differences, compared with normal cells, in the response of cancerous cells to exposure to radiation. *[2]*

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(b) The physical half-life of iodine-131 is 8 days and its biological half-life is 12 days.

(i) Distinguish between physical and biological half-lives. *[2]*

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(ii) Calculate the effective half-life of iodine-131. *[1]*

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(iii) A patient who has received treatment with iodine-131 must remain in isolation until the activity of the iodine in the body reduces to about one fourth of its initial activity.

Estimate the number of days a patient must remain in isolation. *[1]*

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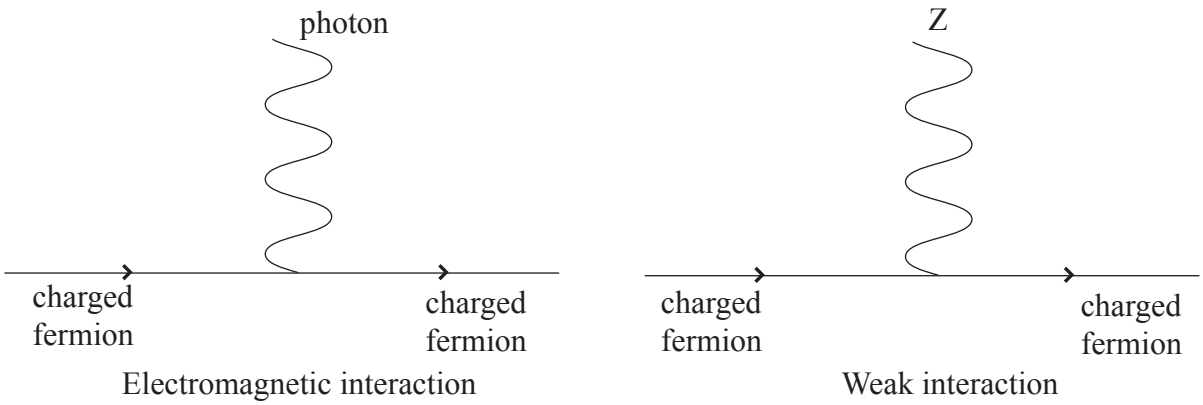
Option J — Particle physics

J1. This question is about fundamental interactions.

The diagram below shows two fundamental interaction vertices, one for the electromagnetic and the other for the weak interactions.



(a) Explain why in both vertices the incoming and the outgoing charged fermions above must have the same electric charge. *[2]*

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(b) The process $e^- + e^+ \rightarrow \mu^- + \mu^+$ occurs mostly via the electromagnetic interaction and less frequently via the weak interaction.

Draw a Feynman diagram for the process $e^- + e^+ \rightarrow \mu^- + \mu^+$ according to

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

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

(This question continues on the following page)

(Question J1 continued)

(iii) Identify the virtual particles in each of the Feynman diagrams that you drew in (i) and (ii). *[1]*

Virtual particle in (i): . . . . . .

Virtual particle in (ii): . . . . . .

(c) State one reason why the process $e^- + e^+ \rightarrow \mu^- + \mu^+$ is more likely to involve the electromagnetic interaction rather than the weak interaction. *[1]*

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(d) Electrons are accelerated to a total energy E and then collide with stationary positrons.

Determine the minimum total energy E of the electron for the reaction $e^- + e^+ \rightarrow \mu^- + \mu^+$ to take place. *[3]*

Electron rest mass = 0.511 MeVc^{-2}.
Muon rest mass = 105 MeVc^{-2}.

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J2. This question is about particle dectors.

(a) (i) Describe the operating principle of the bubble chamber. *[2]*

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(ii) Outline how **two** particle properties or characteristics are measured using a bubble chamber. *[2]*

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(b) The proportional wire spark chamber has now replaced the bubble chamber.

Outline **two** advantages of this detector compared to the bubble chamber. *[2]*

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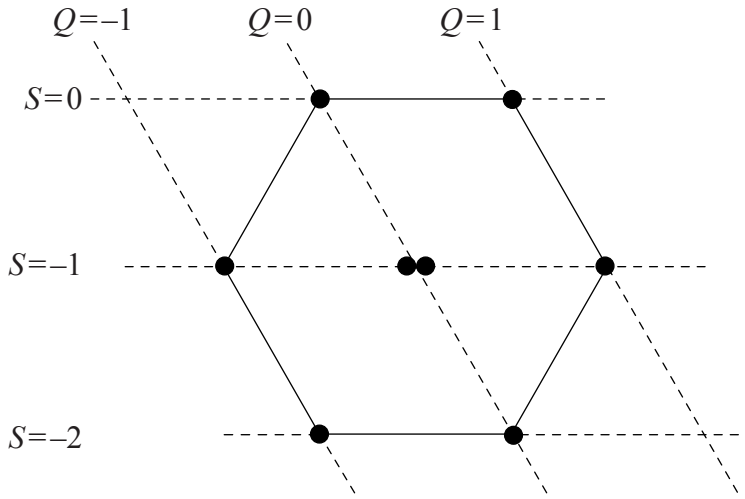
J3. This question is about quarks.

The diagram below shows the eight spin $\frac{1}{2}$ baryons made out of the three lightest quarks, the up (u), the down (d) and the strange (s). In this plot baryons belonging to the same horizontal line have the same strangeness (S) and those along the same slanted line have the same charge (Q).



(a) (i) On the diagram above draw a circle around the point representing the neutron. *[1]*

(ii) State the quark content of the neutron. *[1]*

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(b) The Ξ^- baryon is unstable and decays according to the reaction $\Xi^- \rightarrow \Lambda^0 + \pi^-$.

The quark content of the particles involved is $\Xi^- = \text{ssd}$, $\Lambda^0 = \text{uds}$ and $\pi^- = \text{d}\bar{\text{u}}$.

State and explain whether the interaction involved in this decay is electromagnetic, strong or weak. *[3]*

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J4. This question is about cosmology and strings.

(a) It is assumed that in the first 10^{-2} s after the Big Bang quarks behaved as free particles that could not bind into nucleons.

Suggest a reason for this. *[2]*

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(b) At a time of 10^{-2} s after the Big Bang the average thermal energy per particle in the universe was approximately 50 MeV.

Estimate the temperature of the universe 10^{-2} s after the Big Bang. *[2]*

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(c) In the very early universe it is thought that the total number of particles was only very slightly larger than the number of antiparticles.

Explain why the matter in the present universe is made predominantly by particles and not antiparticles. *[2]*

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(d) Outline why physicists were led to consider string theories. *[2]*

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(e) Many string theories suggest that space is 10 dimensional rather than the usual 3+1 dimensions (3 for space and 1 for time).

Assuming that string theory is correct, explain why we are not aware of the extra dimensions. *[2]*

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