Option F — Astrophysics

F1. (a) State where in the solar system, with respect to the planetary orbits, the greatest concentration of asteroids is found. *[1]*

. . . . . .

(b) Some constellations are not visible in the night sky for the whole of the year. Suggest **one** reason for this observation. *[2]*

. . . . . .

. . . . . .

. . . . . .

F2. This question is about stellar observations.

(a) Define the following terms.

(i) *Luminosity* *[1]*

. . . . . .

. . . . . .

(ii) *Apparent brightness* *[1]*

. . . . . .

. . . . . .

(b) The spectrum and temperature of a certain star are used to determine its luminosity to be approximately 5.0×10^{31} W. The apparent brightness of the star is 1.4×10^{-9} W m^{-2}. These data can be used to determine the distance of the star from Earth.

(i) State the name of this technique used to determine distances to stars. *[1]*

. . . . . .

. . . . . .

(ii) Calculate the distance of the star from Earth in parsec. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question F2 continued)

(c) Distances to some stars can be measured by using the method of stellar parallax.

(i) Outline this method. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Modern techniques enable stellar parallax angles as small as 5.0×10^{-3} arc-second to be measured. Calculate the maximum distance that can be measured using the method of stellar parallax. *[1]*

. . . . . .

. . . . . .

. . . . . .

F3. This question is about cosmology.

(a) Describe the observational evidence in support of an expanding universe. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) Define the term *critical density* of the universe. *[1]*

. . . . . .

. . . . . .

(c) Discuss the significance of comparing the density of the universe to the critical density for determining the future of the universe. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

F4. This question is about the Hubble constant.

(a) The value of the Hubble constant H_0 is accepted by some astronomers to be in the range $60\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$ to $90\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$.

(i) State and explain why it is difficult to determine a precise value of H_0. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) State **one** reason why it would be desirable to have a precise value of H_0. *[1]*

. . . . . .

. . . . . .

(b) The line spectrum of the light from the quasar 3C 273 contains a spectral line of wavelength 750 nm. The wavelength of the same line measured in the laboratory is 660 nm.

Using a value of H_0 equal to $75\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$, estimate the distance of the quasar from Earth. *[3]*

. . . . . .

. . . . . .

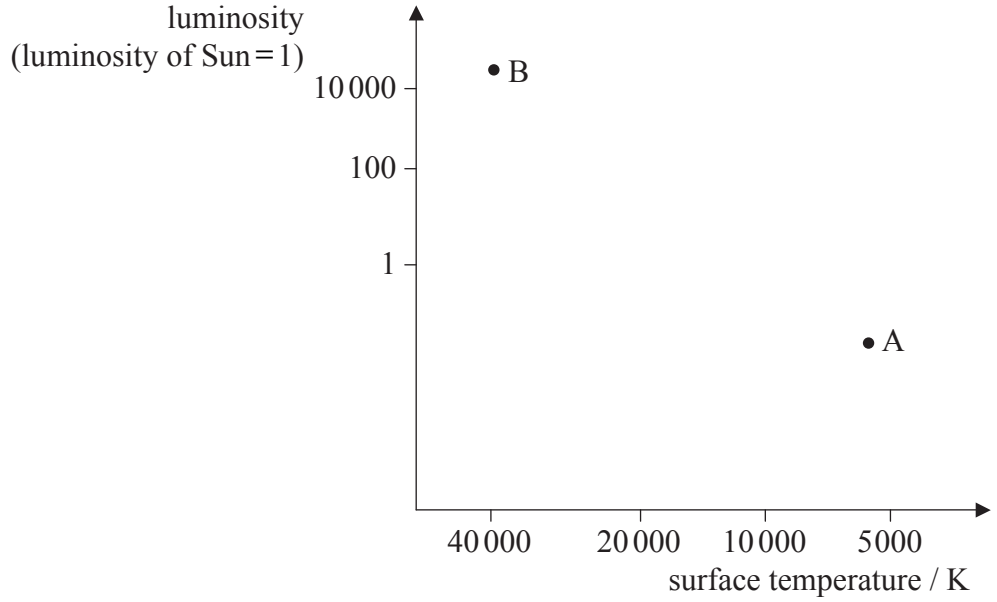
. . . . . .

. . . . . .

. . . . . .

F5. This question is about two different stars.

The diagram below shows the position of two main-sequence stars A and B with respect to the labelled axes of a Hertzsprung-Russell diagram.



(a) Suggest which of the stars has the larger mass. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) State **one** difference between the changes in nucleosynthesis that take place in star B compared to star A after both stars leave the main sequence. *[1]*

. . . . . .

. . . . . .

(c) On the diagram above, mark with the letter X, the approximate final position of star A after it has left the main sequence. *[1]*

Option G — Relativity

G1. This question is about relativistic kinematics and mechanics.

(a) Explain what is meant by an *inertial frame of reference*. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) State the **two** postulates of Special Relativity. *[3]*

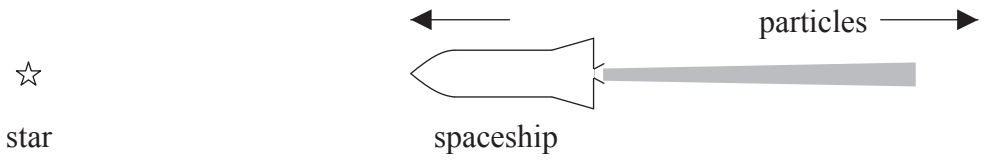
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) A spaceship with a proper length of 240 m is travelling towards a star with a speed of 0.80c relative to the star. The exhaust from its rocket engine is a high-energy beam of particles. The particles move at a speed of 0.60c as measured by an observer in the spaceship.



Another observer is in the inertial reference frame of the star.

For this observer

(i) calculate the length of the spaceship. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) calculate the speed of the particles. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question G1(c) continued)

(iii) state the direction of the relative motion of the particles. *[1]*

. . . . . .

(d) The rest mass of the spaceship is 3.0×10^3 kg. Determine the total energy, in joule, of the spaceship as measured by the observer in the inertial reference frame of the star. *[2]*

. . . . . .

. . . . . .

. . . . . .

G2. This question is about muon decay.

(a) Explain what is meant by *time dilation*. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Discuss how observations of muons created in the upper atmosphere of Earth are used as evidence for time dilation. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) A particular muon created in the upper atmosphere of Earth has a lifetime of 2.20 μs as measured in the muon's reference frame. The speed, as measured by an observer on the ground, is 0.995c ($\gamma = 10$). Calculate the distance moved by the muon during its lifetime as measured by an observer on the ground. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

G3. This question is about relativistic mechanics.

(a) A particle has rest mass m_0 and kinetic energy E_K. Deduce that

$$m_0c^2(\gamma - 1) = E_K$$

where $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ and c is the speed of light in a vacuum. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) A photon of energy 2.90 MeV passing close to an atom of lead becomes an electron-positron pair. The kinetic energies of the created electron and the positron are the same.

Using the expression in (a) and ignoring any recoil energy of the lead atom, determine the speed of the electron and positron. *[3]*

(rest mass of electron = rest mass of positron $= 0.510\ \text{MeV}\,\text{c}^{-2}$)

. . . . . .

. . . . . .

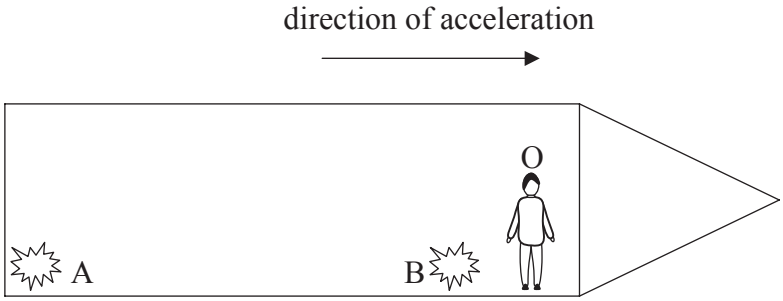
. . . . . .

. . . . . .

. . . . . .

G4. This question is about general relativity.

(a) The diagram below shows a spaceship that is accelerating in the direction shown.



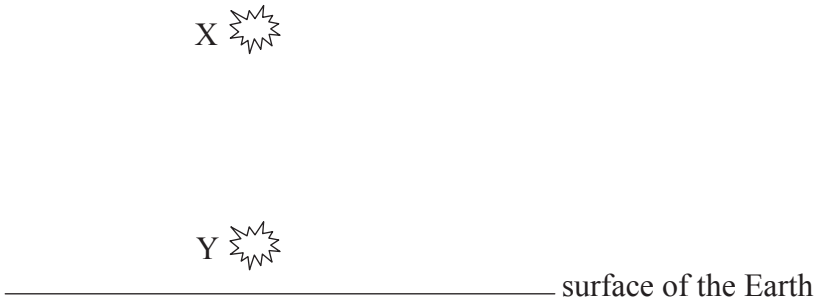
A and B are two identical monochromatic light sources. The observer O is standing next to the light source B and he measures the frequencies of the light emitted by the two sources.

State how the frequency of the light from source A compares to the frequency of the light from source B as measured by O. *[1]*

. . . . . .

. . . . . .

(b) The diagram below shows two identical monochromatic light sources X and Y that are at different heights above the surface of the Earth.



Explain how Einstein's principle of equivalence relates the situation in (a) to the frequency of the light emitted from the two sources as measured by an observer at X. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question G4 continued)

(c) An aircraft is flying at a height of 1.40×10^4 m above the surface of Earth. A warning light on the surface of Earth emits a signal of wavelength 660 nm as measured by an observer on the surface of Earth.

Estimate the difference in **frequency** of the signal as measured by the pilot of the aircraft. *[2]*

. . . . . .

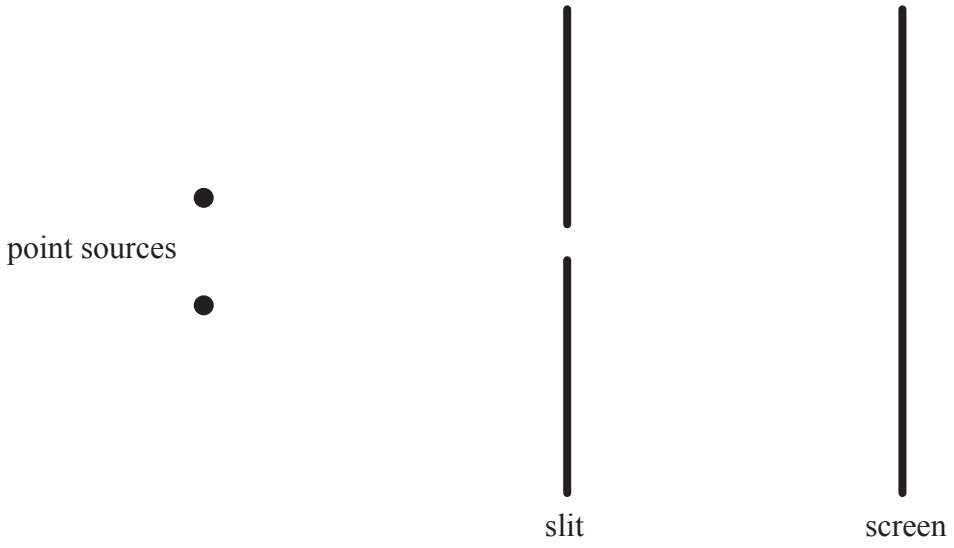
. . . . . .

. . . . . .

. . . . . .

H3. This question is about resolution.

Monochromatic light from two identical point sources is incident on a narrow slit as shown below (not to scale). After passing through the slit, the light is brought to a focus on a screen.

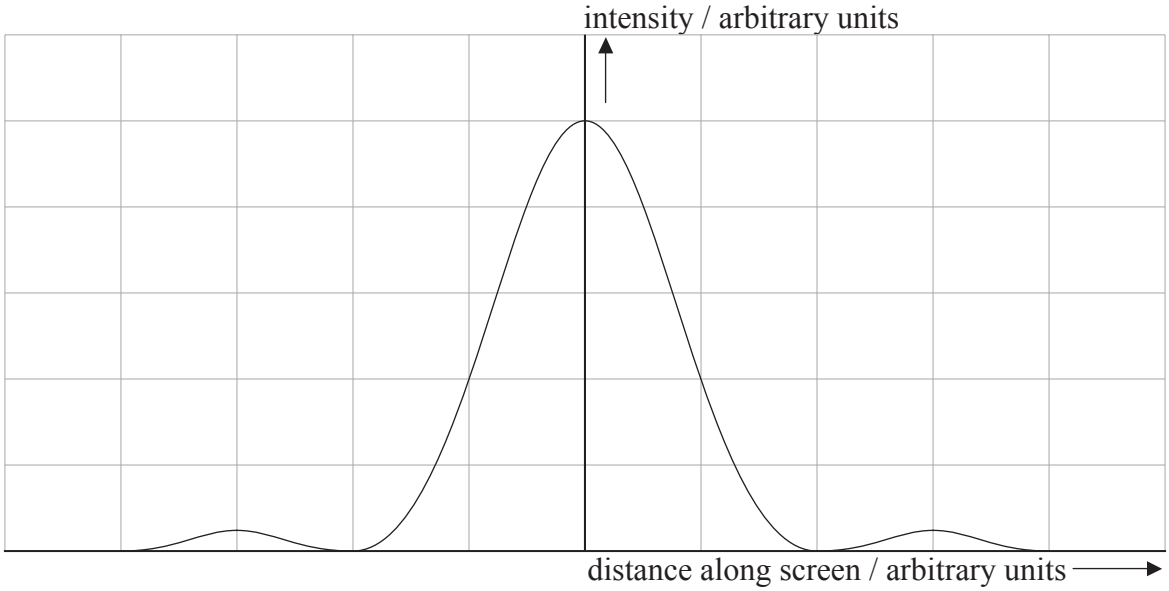


The images of the two sources on the screen are just resolved according to the Rayleigh criterion.

(This question continues on the following page)

(Question H3 continued)

The diagram below shows the intensity distribution on the screen of the light from one of the point sources.



(a) On the diagram above, draw the intensity distribution on the screen of the light due to the second source. *[2]*

(b) The planet Pluto is 4.5×10^{12} m from Earth and the diameter of Pluto is 2.3×10^{6} m. The average wavelength of the light received by the Earth from Pluto is 500 nm.

Deduce, whether the human eye should be able to see Pluto as a disc or only as a point source of light. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .