Option F — Astrophysics

F1. This question is about luminosity.

(a) Define *luminosity*. *[1]*

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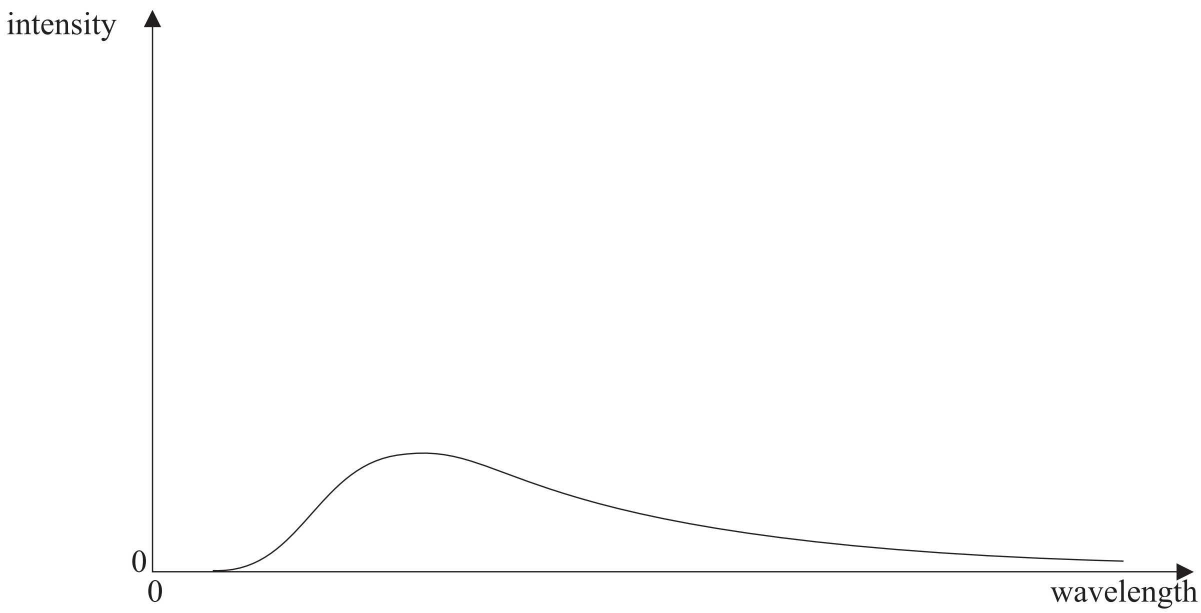
(b) The sketch-graph below shows the intensity spectrum for a black-body at a temperature of 6000 K.



On the axes above, draw a sketch-graph showing the intensity spectrum for a black-body at 8000 K. *[2]*

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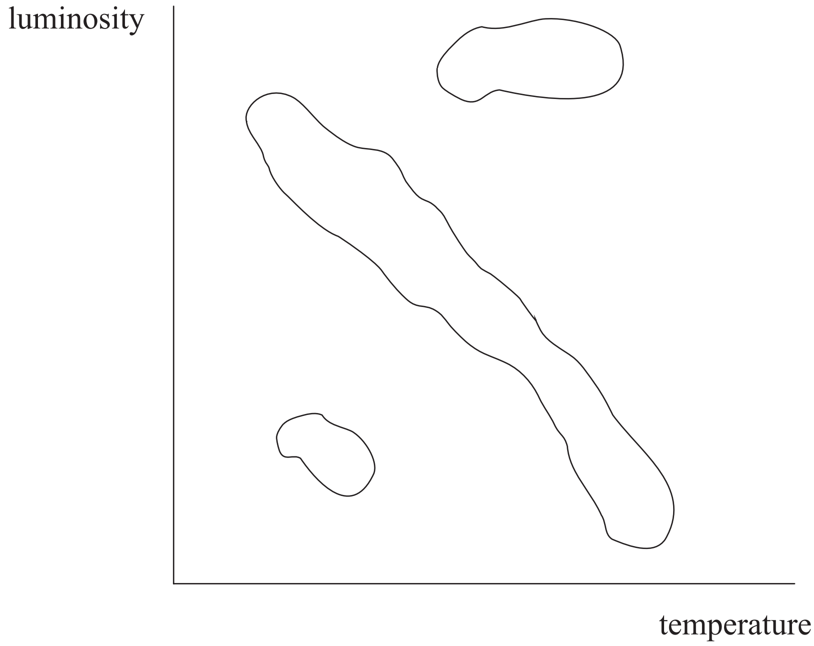
(Question F1 continued)

(c) A sketch of a Hertzsprung-Russell diagram is shown below.



On the diagram above, identify the

(i) main sequence (label this M),
(ii) red giant region (label this R),
(iii) white dwarf region (label this W). *[2]*

(d) In a Hertzsprung-Russell diagram, luminosity is plotted against temperature. Explain why the diagram alone does not enable the luminosity of a particular star to be determined from its temperature. *[3]*

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F2. This question is about stellar magnitudes and stellar distances.

(a) Define

(i) *apparent magnitude*. *[1]*

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(ii) *absolute magnitude*. *[1]*

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(b) Star A has an apparent magnitude of 5.0 and is 100 pc from Earth. The luminosity of star A is 4.0 times the luminosity of star B. The apparent brightness of star A is 100 times greater than the apparent brightness of star B.

Deduce that

(i) star B is 500 pc from Earth. *[3]*

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(ii) the absolute magnitude of star A is 0. *[2]*

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F3. This question is about cosmology.

(a) State **one** piece of evidence that indicates that the Universe is expanding. *[1]*

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(b) The rate at which the Universe is expanding depends on the density of the Universe.

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

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(ii) Explain the importance of comparing the density of the Universe to the critical density in predicting the future of the Universe. *[3]*

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F4. This question is about stellar evolution.

(a) Outline the late stages in the evolution of a high-mass star that leads it to end its life as a neutron star. *[3]*

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(b) Outline the mechanism that enables a neutron star to be detected from Earth. *[3]*

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F5. This question is about galactic motion.

The K-line of light from singly ionised calcium has a wavelength of 393.3 nm when measured in a laboratory. The same line in the spectrum of galaxy NGC 4889 has a wavelength of 401.8 nm. The value of the Hubble constant may be assumed to be 70 km s^{-1} Mpc^{-1}.

Deduce a value for the distance of NGC 4889 from Earth. *[4]*

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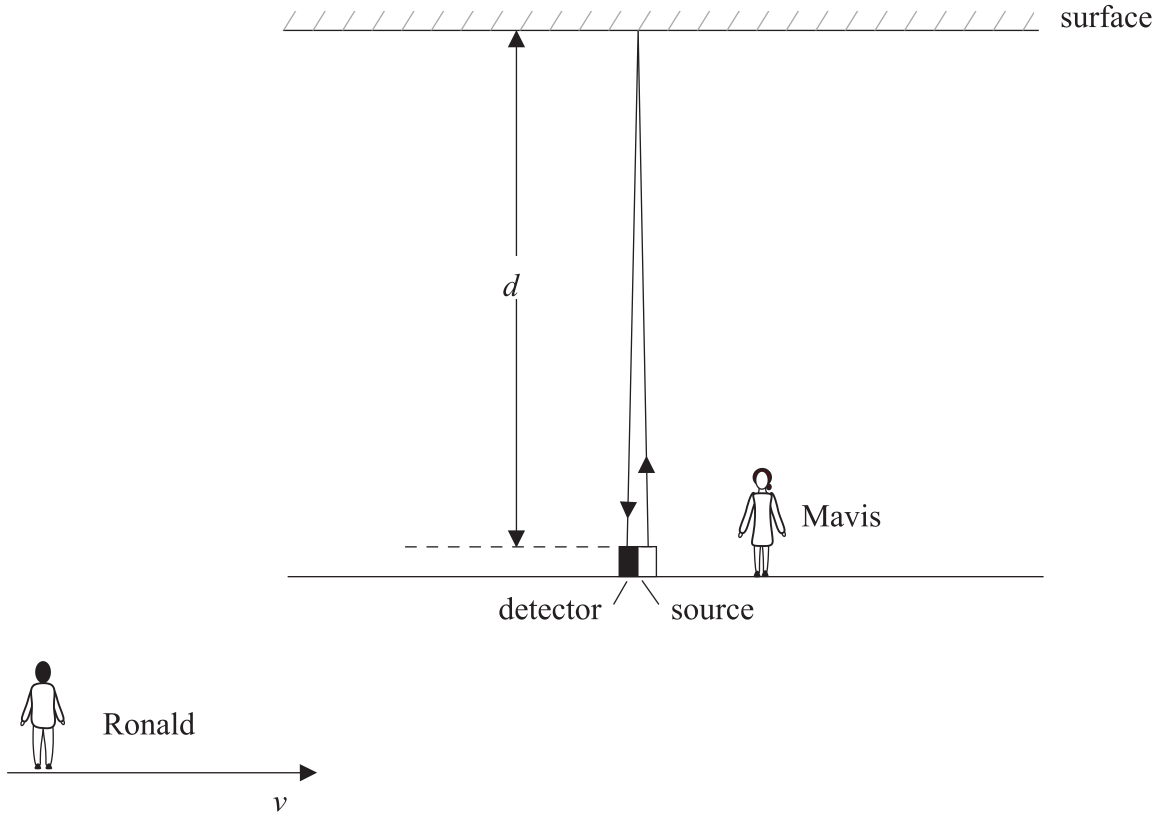
Option G — Relativity

G1. This question is about the measurement of time.

Mavis is stationary with respect to a source that produces a light pulse. The light pulse is reflected at a surface, and returns to a detector located very close to the source. The distance between the source and the surface is *d*.



Ronald is moving with constant speed *v* relative to the source in a direction parallel to the surface.

(a) On the diagram above, draw the path of the pulse as seen by Ronald. *[2]*

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(Question G1 continued)

(b) The time taken for the light to travel from the source to the detector, as measured by Ronald, is t. Use your diagram in (a) to deduce that the distance L travelled by the pulse, as measured by Ronald, is given by the expression

$$L = 2\sqrt{d^2 + \left(\frac{vt}{2}\right)^2}.$$ *[3]*

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(c) The time taken for the pulse to travel from the source to the detector, as measured by Mavis, is t_0.

(i) State the relation between t_0, d and c where c is the speed of light. *[1]*

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(ii) Use your answer in (b) and (c) (i) to deduce that $t = \dfrac{t_0}{\sqrt{1 - \dfrac{v^2}{c^2}}}$. *[3]*

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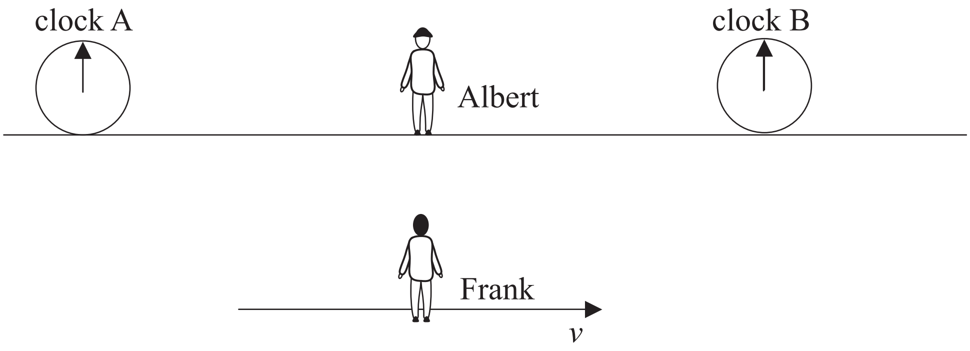
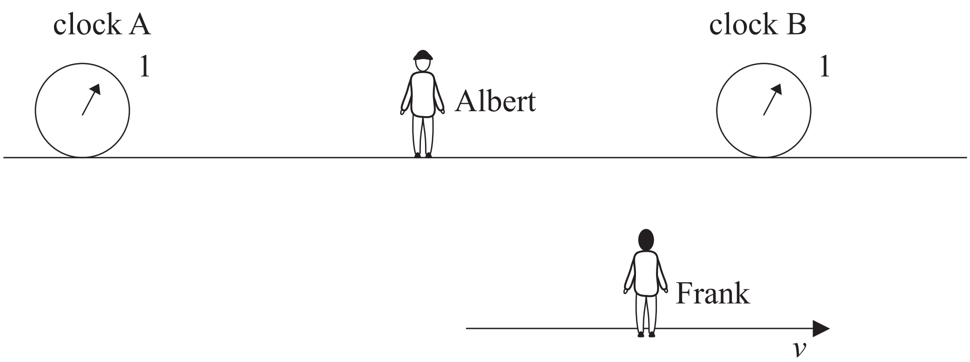
G2. This question is about the observation of clocks.

Albert is standing equal distances from two clocks A and B. Frank is moving with constant speed v from clock A towards clock B.



At the instant that Frank is opposite Albert, Albert observes the second-hand of both clocks to be at 0.

At some time later, Albert observes the second-hand of both clocks change position to be at 1, as shown in the diagram below. At this instant, Frank is in the position shown in the diagram below.



Discuss whether, at this instant, Frank observes the second-hand of each clock to be at 1. *[4]*

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G3. This question is about muons.

(a) A muon is formed 4500 m above the surface of the Earth, as measured by an observer on Earth. This muon takes 2.2 μs, as measured in its frame of reference, to reach the Earth's surface. Describe how these observations support the concept of length contraction. *[4]*

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(b) A muon created in the laboratory is accelerated from rest through a potential difference of 2.1×10^{8} V. The rest mass of the muon is $105\,\text{MeV}\,\text{c}^{-2}$. Calculate the mass of the accelerated muon, as measured in the laboratory frame of reference. The charge on a muon is the elementary charge *e*. *[3]*

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G4. This question is about relativistic energy and momentum.

Two protons, each with the same total energy, collide head-on. The following reaction occurs.

$$p^{+} + p^{+} \rightarrow p^{+} + p^{+} + p^{+} + p^{-}$$

p^{+} is a proton and p^{-} is an antiproton. They each have a rest mass of 930 MeV c^{-2}.

(a) Deduce that, for this reaction to occur, the **minimum total** energy of each colliding proton is 1860 MeV. State any assumption you make. *[2]*

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(b) Calculate the momentum, in MeV c^{-1}, of a proton that has a total energy of 1860 MeV. *[4]*

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G5. This question is about spacetime.

Use the concept of spacetime to

(a) explain the gravitational attraction between the Earth and an orbiting satellite. *[2]*

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(b) describe what is meant by a black hole. *[2]*

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