



**PHYSICS
HIGHER LEVEL
PAPER 3**

SPECIMEN PAPER

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.

Option E — Astrophysics

E1. This question is about stars.

Betelgeuse and Rigel are two super giants in the constellation of Orion.

(a) Distinguish between a *constellation* and a *stellar cluster*. [2]

Constellation:

Stellar cluster:

(b) The star Betelgeuse has a parallax of 0.0077 arc second. Deduce that its distance from Earth is approximately 130 pc. [1]

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(c) State why the Hipparcos satellite which orbits Earth is able to measure stellar parallaxes for stars at considerably greater distances than 130 pc. [1]

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(This question continues on the following page)

(Question E1 continued)

- (d) The table below gives some information about the types and magnitudes of Betelgeuse and Rigel.

Star	Type	Apparent magnitude	Colour	Apparent brightness
Betelgeuse	M	-0.04		$2.0 \times 10^{-7} \text{ W m}^{-2}$
Rigel	B	0.12		$3.4 \times 10^{-8} \text{ W m}^{-2}$

- (i) Complete the above table for the colours of the stars. [2]

- (ii) State why Betelgeuse has a lower apparent magnitude than Rigel. [1]

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- (iii) Given that the distance of Betelgeuse from Earth is 130 pc, calculate the luminosity of Betelgeuse. [4]

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- (iv) The luminosity of Rigel is $2.3 \times 10^{31} \text{ W}$. Without any further calculation, explain whether Rigel is closer or further than Betelgeuse from Earth. [3]

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E2. This question is about Olbers' paradox.

(a) Newton assumed that the universe is static and that the stars are uniformly distributed. State **one** further assumption of the Newtonian universe. [1]

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(b) Explain how Newton's assumptions led to Olbers' paradox. [5]

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E3. This question is about stars.

Describe the final nuclear reaction in the core, and the final evolutionary state, of

(a) a low-mass star (of the order of 1 solar mass). [2]

nuclear reaction:

evolutionary state:

(b) a high-mass star (of approximately 15 solar masses). [2]

nuclear reaction:

evolutionary state:

E4. This question is about extragalactic astrophysics.

- (a) In an observation of a distant galaxy, spectral lines are recorded. Spectral lines at these wavelengths cannot be produced in the laboratory. Explain this phenomenon. [2]

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- (b) Describe how Hubble’s law is used to determine the distance from the Earth to distant galaxies. [2]

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- (c) Explain why Hubble’s law is not used to measure distances to nearby stars or nearby galaxies (such as Andromeda). [2]

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Option H — Relativity

H1. This question is about relativistic kinematics.

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

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- (b) A spacecraft is moving with a speed of $0.80c$ with respect to observers on Earth. After 6.0 years of travel, according to the spacecraft clocks, the spacecraft arrives at a distant solar system.

- (i) Calculate the time the journey has taken according to an observer on Earth. [3]

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- (ii) Calculate the distance between the Earth and the solar system according to an observer on Earth. [2]

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- (iii) The spacecraft observers send a signal to Earth to announce that they have arrived at the solar system. The spacecraft continues to move. Determine how long it will take the signal to arrive on Earth according to the **spacecraft** observers. [3]

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H2. Two electrons are travelling directly towards one another. Each has a speed of $0.80c$ relative to a stationary observer. Calculate the relative velocity of approach, as measured in the frame of reference of one of the electrons. [3]

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H3. This question is about mass-energy.

(a) Distinguish between the rest mass-energy of a particle and its total energy. [2]

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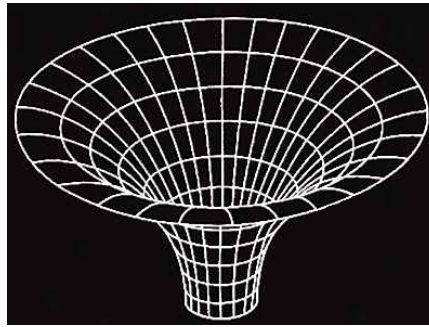
(b) The rest mass of a proton is $938 \text{ MeV } c^{-2}$. State the value of its rest mass-energy. [1]

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(c) A proton is accelerated from rest through a potential difference V until it reaches a speed of $0.980c$. Determine the potential difference V as measured by an observer at rest in the laboratory frame of reference. [4]

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H4. The diagram below illustrates the distortion of space by the gravitational field of a black hole.



(a) (i) Describe what is meant by the *centre* and the *surface* of a black hole. [3]

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(ii) With reference to your answer in (a)(i), define the *Schwarzschild radius*. [1]

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(iii) Calculate the Schwarzschild radius for an object having a mass of 2.0×10^{31} kg (ten solar masses). [2]

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(iv) Science fiction frequently portrays black holes as objects that “swallow” everything in the universe.

A spacecraft is travelling towards the object in (a)(iii) such that, if it continues in a straight-line, its distance of closest approach would be about 10^7 m. By reference to the diagram and your answer in (a)(iii), suggest whether the fate of the spacecraft is consistent with the fate as portrayed in science fiction. [2]

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(Question H4 continued)

- (b) In 1979, Wahl, Carswell and Weymann discovered “two” very distant quasars separated by a small angle. Spectroscopic examination of the images showed that they were identical.

Outline how these observations give support to the theory of General Relativity.

[2]

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