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Centre number

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Candidate number

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Surname

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Forename(s)

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Astrophysics

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet
- a protractor.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
TOTAL	



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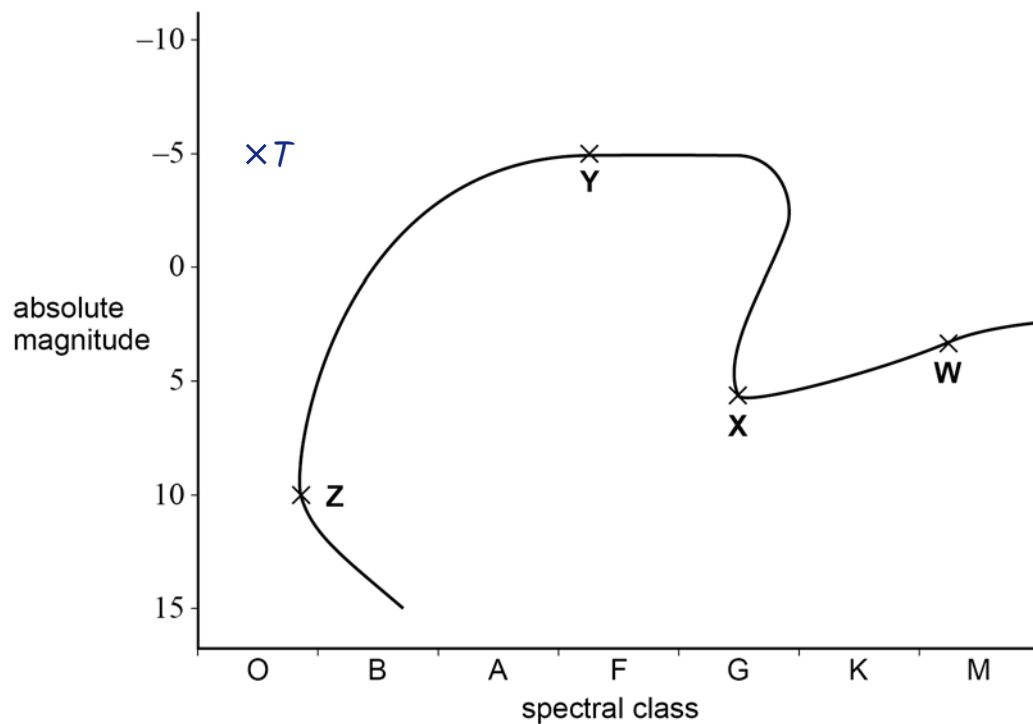
Section B

Answer **all** questions in this section.

0 1

Figure 1 shows the evolution of a star similar to the Sun on a Hertzsprung-Russell (HR) diagram.

Figure 1



0 1 . 1

State the evolutionary stage of the star at each of the points **W**, **X**, **Y** and **Z**.

[3 marks]

W *protostar (gas cloud contracting)*

X *main sequence star*

Y *red giant*

Z *white dwarf*

Theta Carinae is a star with a radius five times that of the Sun. It has a surface temperature of 31 000 K.

0 1 . 2

Annotate **Figure 1** with a **T** to show the position of Theta Carinae.

[1 mark]



An astronomer suggests that an Earth-sized planet orbits Theta Carinae.

0 1 . 3

Explain **one** difficulty with using the transit method to detect this planet.

[2 marks]

The transit method detects the planet by measuring the drop in light (intensity) from the star when the planet passes in front of it and blocks some of the light.

An Earth-sized planet is very small compared with Theta Carinae (radius 5 times the Sun's), so it blocks only a tiny fraction of the light and the dip in intensity is too small to detect.

0 1 . 4

The astronomer suggests that the Earth-sized planet receives a similar amount of power from Theta Carinae as the Earth does from the Sun.

The average power output of the Sun is 3.8×10^{26} W.

Determine the orbital radius of the Earth-sized planet orbiting Theta Carinae.

[5 marks]

$$P = \sigma AT^4 = \sigma \times 4\pi R^2 T^4, \text{ with } R = 5 \times 6.96 \times 10^8 = 3.48 \times 10^9 \text{ m}$$

$$P = 5.67 \times 10^{-8} \times 4\pi \times (3.48 \times 10^9)^2 \times 31\,000^4$$

$$P = 7.97 \times 10^{30} \text{ W}$$

Intensity received $I = P / 4\pi d^2$ (inverse square law), and the planet receives the same intensity as the Earth does from the Sun:

$$P_T / 4\pi d_T^2 = P_{\text{Sun}} / 4\pi d_E^2$$

$$\text{ratio of powers} = 7.97 \times 10^{30} / 3.8 \times 10^{26} = 2.10 \times 10^4$$

$$d_T = d_E \times \sqrt{(2.10 \times 10^4)} = 145 \times d_E$$

$$d_T = 145 \times 1.50 \times 10^{11} \text{ m (Earth to Sun distance)}$$

$$d_T = 2.2 \times 10^{13} \text{ m}$$

orbital radius = 2.2 × 10¹³ m

11

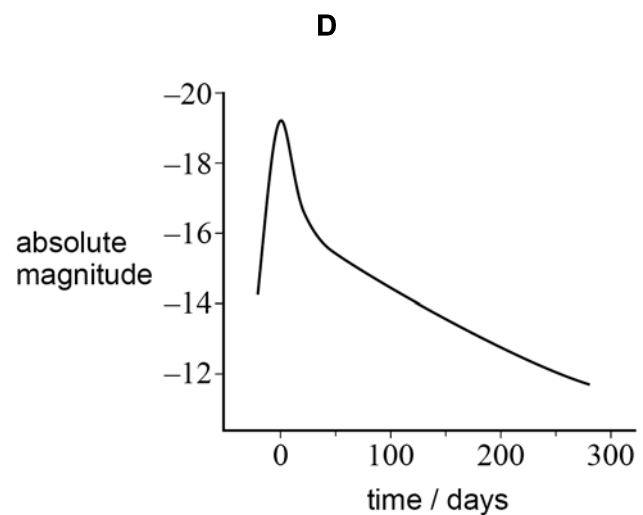
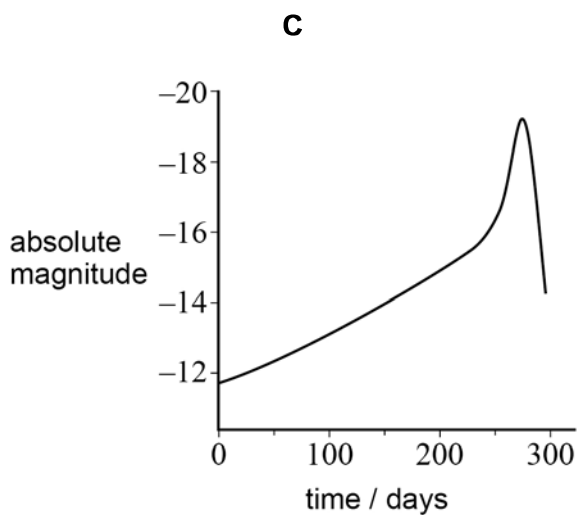
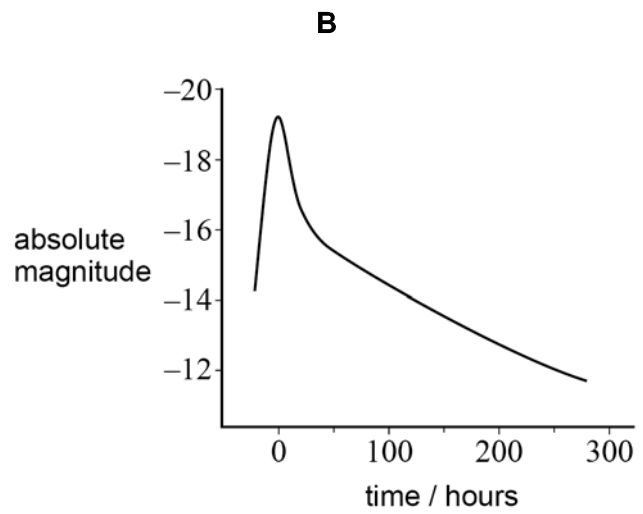
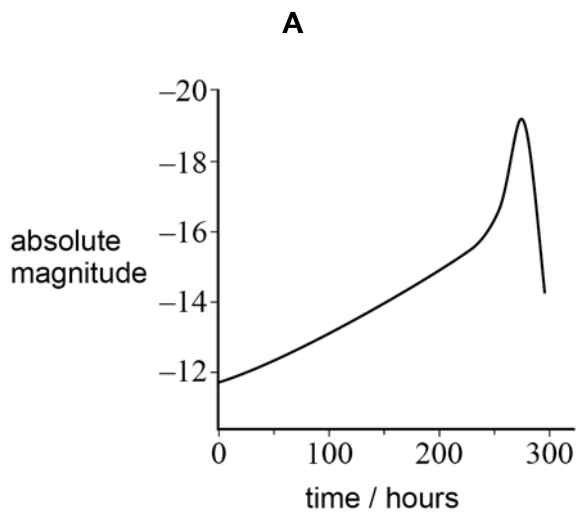
Turn over ►



0 2 . 1 Which graph shows the light curve for a typical type 1a supernova?

Tick (✓) **one** box.

[1 mark]



A

☐

B

☐

C

☐

D

☒


0 2 . 2

The Andromeda galaxy is approximately 7.7×10^5 pc from Earth.

Deduce whether a type 1a supernova which occurred in Andromeda can be observed from Earth with the naked eye.

[3 marks]

Peak absolute magnitude of a type 1a supernova $M = -19.3$

$d = 7.7 \times 10^5$ pc

$m - M = 5 \log(d/10)$

$m = 5 \log(7.7 \times 10^5 / 10) + M = 5 \log(7.7 \times 10^4) - 19.3$

$m = 24.4 - 19.3$

$m = 5.1$

At its peak the supernova would have an apparent magnitude of about

5.1.

The naked-eye limit is an apparent magnitude of about 6, and 5.1 is a smaller magnitude, so the supernova is brighter than this limit.

So yes, it could (just) be seen with the naked eye.

4

Turn over for the next question

Turn over ►

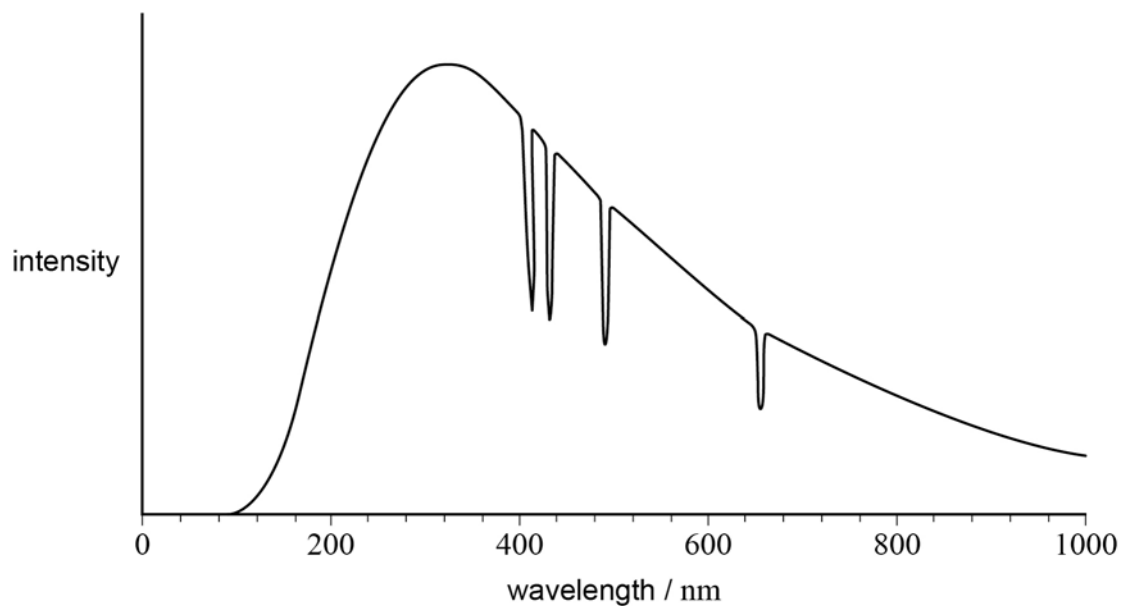


0 3

Miaplacidus and Avior are two stars in the constellation Carina.
Miaplacidus is a class A star.
Avior is a class K star.

Figure 2 shows how the intensity of radiation arriving at the Earth varies with wavelength for **one** of these stars. Only the important features of the variation are shown.

Figure 2



Deduce, with reference to **Figure 2**, the identity of the star.

In your answer you should:

- explain the overall shape of the graph
- describe the processes in the star that lead to the decreases in intensity
- state the identity of the star.

[6 marks]



The overall shape is a black-body curve: the star emits a continuous spectrum of thermal radiation from its surface (photosphere), and the intensity rises to a peak and then falls off at longer wavelengths.

The peak wavelength depends on the surface temperature by Wien's law, $\lambda_{\max}T = 2.9 \times 10^{-3} \text{ m K}$. The peak is at about 320 nm, so $T = 2.9 \times 10^{-3} / 320 \times 10^{-9} \approx 9000 \text{ K}$.

The dips are absorption lines. As the continuous radiation passes through the cooler gases in the outer layers (atmosphere) of the star, photons of particular wavelengths are absorbed, exciting electrons in the atoms to higher energy levels.

The excited atoms then de-excite and re-emit these photons in random directions, so much less of that wavelength travels towards the Earth, leaving dark lines (dips) at those wavelengths.

The dips are at about 410, 434, 486 and 656 nm, which are the hydrogen Balmer lines. These are produced when hydrogen atoms with electrons already in the $n = 2$ state absorb photons and are excited to higher levels.

For many hydrogen atoms to be in the $n = 2$ state the temperature must be about 10 000 K. Strong Balmer absorption lines are seen in class A stars but not in class K stars, which are too cool (about 4000 K).

A temperature of about 9000 K also fits class A (7500 to 10 000 K).

So the star is Miaplacidus, the class A star.

Turn over for the next question



0 4

IC2497 is a galaxy that contained a quasar. It is believed that the quasar stopped emitting radiation several thousand years ago.

0 4 . 1

Suggest why the quasar stopped emitting radiation.

[2 marks]

A quasar is powered by a supermassive black hole at the centre of the galaxy, with matter heating up as it falls into the black hole (accretion disc).

The black hole has used up the matter around it, so no more matter is falling into it (it is no longer feeding), so radiation is no longer emitted.

0 4 . 2

IC2497 has a red shift of 0.0516

Determine the distance from the Earth to IC2497.
Give an appropriate unit for your answer.

[4 marks]

$$z = v / c$$

$$v = zc = 0.0516 \times 3.00 \times 10^8$$

$$v = 1.55 \times 10^7 \text{ m s}^{-1} = 1.55 \times 10^4 \text{ km s}^{-1}$$

$$v = Hd, \text{ with } H = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$d = v / H = 1.55 \times 10^4 / 65$$

$$d = 238 \text{ Mpc}$$

distance = 238 unit = Mpc

6



0 5 . 1

Explain what is meant by the Rayleigh criterion.

[2 marks]

The Rayleigh criterion gives the minimum angle subtended at the telescope between two objects for their images to be (just) resolved, $\theta \approx \lambda/D$.

At this minimum angle, the central maximum of the diffraction pattern of light from one object coincides with the first minimum of the diffraction pattern of the second object.

0 5 . 2

A telescope uses wavelengths in the range 90 nm to 120 nm.

Explain why this telescope must be located in space.

Go on to discuss **one** advantage that this telescope has compared to a telescope with the same aperture that uses visible light.

[3 marks]

Wavelengths of 90 nm to 120 nm are ultraviolet, shorter than visible light.

UV radiation is absorbed by the atmosphere (by the ozone layer), so it would not reach a telescope on the ground; the telescope must be in space.

Advantage: the minimum angular resolution $\theta \approx \lambda/D$ is smaller for a shorter wavelength. UV wavelengths are about 4 to 7 times shorter than visible light (400 to 700 nm), so with the same aperture D there is less diffraction and the UV telescope has better resolving power: it can resolve objects that are closer together (more detail).

Question 5 continues on the next page

Turn over ►



0 5 . 3 **Table 1** shows information about two telescopes.

Table 1

Telescope	Diameter / m	Dish shape
Arecibo	305	spherical
Lovell	76	parabolic

Each telescope detects radio waves with a wavelength of 21 cm.

Compare the performances of the telescopes in **Table 1** when both are used to observe the same faint radio objects.

[3 marks]

$$\text{Collecting power} \propto D^2: 305^2 / 76^2 = 16$$

so Arecibo collects about 16 times more power (brighter image).

$$\text{Resolution } \theta \approx \lambda/D:$$

$$\text{Arecibo: } \theta = 0.21 / 305 = 6.9 \times 10^{-4} \text{ rad}$$

$$\text{Lovell: } \theta = 0.21 / 76 = 2.8 \times 10^{-3} \text{ rad}$$

Arecibo collects about 16 times more power, so its images of faint objects are brighter (it can detect fainter objects), and in theory its smaller minimum angle gives more detail.

However, Arecibo's dish is spherical, so it suffers from spherical aberration: waves hitting different parts of the dish are not brought to the same focus, so its image is blurred and less detailed.

Lovell's parabolic dish has no spherical aberration, so Lovell may give better detail even though its image is fainter.

END OF QUESTIONS



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1 6



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