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Centre number

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Candidate number

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Surname

StemUp Model Solution

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Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Astrophysics

Tuesday 17 June 2025

Morning

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.

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.

For Examiner's Use

Question	Mark
1	
2	
3	
4	
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TOTAL	



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Section B

Answer **all** questions in this section.

0 1

HIP 56948 is a star with a black-body temperature of 5800 K. The star is at a distance of 210 ly from the Sun.

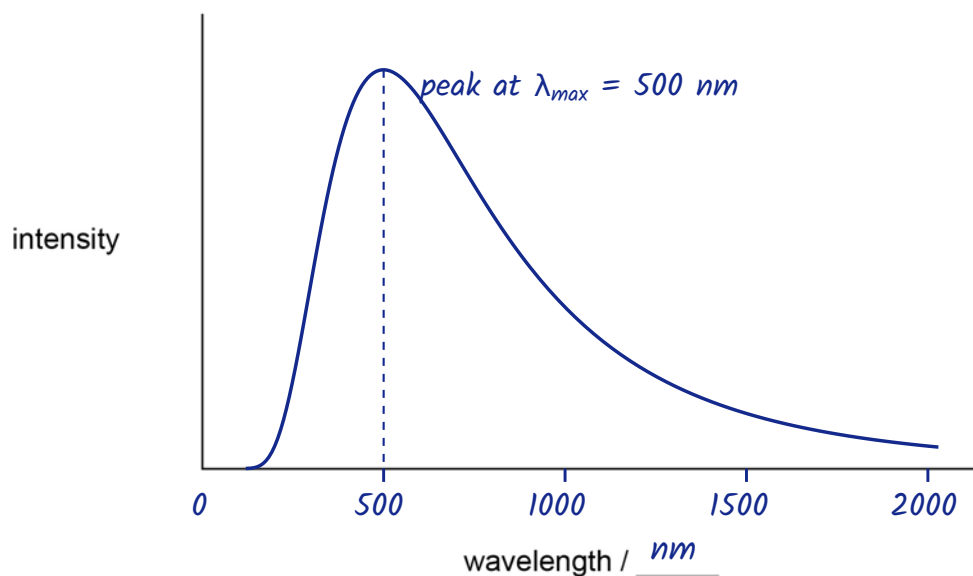
0 1 . 1

Sketch, on **Figure 1**, the black-body curve for HIP 56948. Label the wavelength axis with a suitable scale and unit.

[3 marks]

$$\lambda_{\max} = 2.9 \times 10^{-3} \div 5800 = 5.0 \times 10^{-7} \text{ m} = 500 \text{ nm}$$

Figure 1



0 1 . 2

The diameter of HIP 56948 is the same as the diameter of the Sun.

Suggest a value for the absolute magnitude of HIP 56948.

[1 mark]

absolute magnitude = 5

0 1 . 3

Astronomers study HIP 56948 in their search for Earth-like exoplanets because HIP 56948 is similar to the Sun.

Suggest **one** difficulty in detecting an Earth-like planet around HIP 56948.

[1 mark]

The planet is very small (and low mass) compared with the star, so the dip in the star's intensity when it transits in front of the star is tiny, and so is the Doppler shift (radial velocity) of the star's spectrum.

5

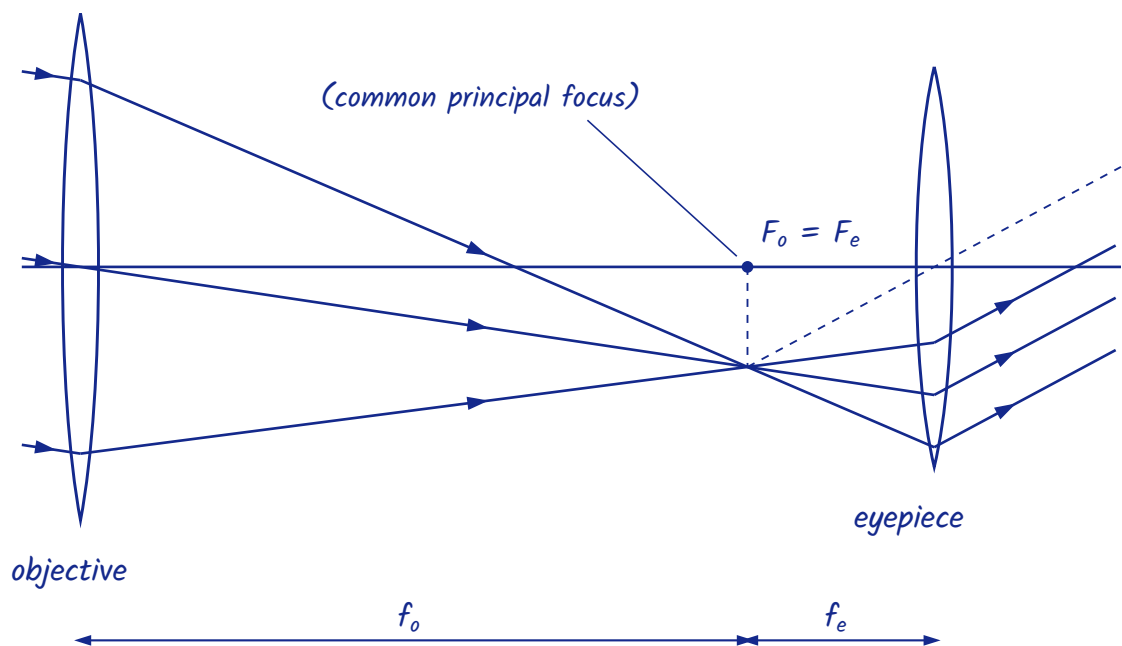


0 2 . 1

Draw a ray diagram for an astronomical telescope in normal adjustment.

Include in your diagram:

- three non-axial rays
- labelled principal foci for the lenses.

[2 marks]*Rays from a distant object enter parallel and leave parallel (image at infinity).*

Question 2 continues on the next page

Turn over ►



0 2 . 2

An astronomer has two telescopes **A** and **B**.

The astronomer uses each telescope to make observations of Mars when Mars is 0.55 AU from the Earth.

Table 1 gives information about **A** and **B**.

Table 1

Telescope	Type	Objective diameter / m	Angular magnification
A	refractor	0.12	25
B	reflector	0.18	40

diameter of Mars = 6.8×10^3 km

angular resolution of the eye $\approx 3 \times 10^{-4}$ rad

Compare the images formed by **A** and **B**.

In your answer, refer to:

- the relative brightness of the images
- the ability of each telescope to show features on Mars
- the effect of any aberrations caused by each type of telescope.

[6 marks]

Brightness: collecting power is proportional to (objective diameter)², so

collecting power of B $\div$ collecting power of A = $(0.18 \div 0.12)^2 = 2.25$.

B has the greater collecting power, so the image formed by B is

brighter (2.25 times brighter) than the image formed by A.

Showing features: the angular size of Mars = $6.8 \times 10^6 \div (0.55 \times 1.50$

$\times 10^{11}) = 8.2 \times 10^{-5}$ rad. Magnified by A: $25 \times 8.2 \times 10^{-5} = 2.1 \times 10^{-3}$



rad; magnified by B: $40 \times 8.2 \times 10^{-5} = 3.3 \times 10^{-3}$ rad. Both are much bigger than the resolution of the eye (3×10^{-4} rad), so both show Mars as a disc with surface features, and the image in B appears $40 \div 25 = 1.6$ times larger than in A.

The minimum angle resolvable by the eye using each telescope is $3 \times 10^{-4} \div 25 = 1.2 \times 10^{-5}$ rad for A and $3 \times 10^{-4} \div 40 = 7.5 \times 10^{-6}$ rad for B. On Mars this is a separation of $1.2 \times 10^{-5} \times 8.25 \times 10^{10}$ m = 990 km (about 15% of the diameter of Mars) for A, but only 620 km (about 9% of the diameter) for B.

Also, the diffraction-limited angular resolution $\theta \approx \lambda/D$ ($\lambda \approx 500$ nm) is 4.2×10^{-6} rad for A and 2.8×10^{-6} rad for B, so the resolution of B is 1.5 times better than A. So B can show finer (smaller) features on Mars than A.

Aberrations: A is a refractor, so the lens causes dispersion: the refractive index depends on wavelength, so different colours are brought to a focus at different points, giving chromatic aberration (coloured fringes and blurring) in the image formed by A. A lens with spherical surfaces can also cause spherical aberration.

B is a reflector: reflection does not depend on wavelength, so there is no chromatic aberration, and if it uses a parabolic mirror all parallel rays are focused at the same point, so there is no spherical aberration with B. (The secondary mirror blocks a little light.)

Overall, B gives the better image: it is brighter, larger, shows smaller features on Mars and is better for aberrations.

Question 2 continues on the next page

Turn over ►



0 2 . 3

One advantage of using a CCD with a telescope is that the data can be stored and processed on a computer.

Explain **two** other advantages of using a CCD rather than the eye when making an observation with a telescope.

[2 marks]

1 *Higher quantum efficiency (about 80% compared with about 1% for the eye), so a greater fraction of the incident photons are detected per second, so fainter objects can be seen.*

2 *Longer exposure times are possible (light is collected over minutes or hours), so more photons are detected and very faint objects can be observed.*

10



0 3 . 1

The galaxy M87 is at a distance of 5.3×10^7 ly from the Earth.

Determine, in m s^{-1} , the recessional velocity of M87 relative to the Earth.

[3 marks]

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

$$d = 5.3 \times 10^7 \text{ ly} \div 3.26 = 1.63 \times 10^7 \text{ pc} = 16.3 \text{ Mpc}$$

$$v = 65 \times 16.3 = 1.06 \times 10^3 \text{ km s}^{-1}$$

$$v = 1.06 \times 10^3 \times 10^3 = 1.06 \times 10^6 \text{ m s}^{-1}$$

recessional velocity = 1.06×10^6 m s^{-1}

0 3 . 2

Astronomers believe that M87 has an active supermassive black hole at its centre.

Suggest **one** observation that leads to this conclusion.

[1 mark]

*A very intense source of radio waves (and a bright X-ray source) is
observed at the centre of M87 (jets of radiation, as in a quasar).*

0 3 . 3

Which provides evidence for the existence of dark energy?

Tick (✓) **one** box.

[1 mark]

Some type 1a supernovae are brighter than expected.

☒

Hubble's constant changes with time.

☐

The light from some galaxies is blue-shifted.

☐

5

Turn over ►



0 4

Mintaka Aa1 and Mintaka Aa2 are two stars in a binary system. This means that they orbit their common centre of mass with the same period.

Table 2 gives information about the two stars.

Table 2

Star	Absolute magnitude	Apparent magnitude	Spectral class
Mintaka Aa1	−5.4	2.5	O
Mintaka Aa2	−2.9	5.0	B

0 4 . 1

Show that the data in **Table 2** are consistent with the two stars being in a binary system.

[3 marks]

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

$$\text{Aa1: } m - M = 2.5 - (-5.4) = 7.9$$

$$\text{Aa2: } m - M = 5.0 - (-2.9) = 7.9$$

$$d = 10 \times 10^{(m-M)/5} = 10 \times 10^{7.9/5} = 10^{2.58} = 380 \text{ pc}$$

$$\text{Aa1: } d = 380 \text{ pc, Aa2: } d = 380 \text{ pc}$$

$m - M = 7.9$ for both stars, so both stars are the same distance (380 pc) from the Earth, which is consistent with them being in the same binary system.

0 4 . 2

State the most prominent absorption lines in the spectrum of Mintaka Aa2.

[1 mark]

Hydrogen (Balmer lines) and helium (He) absorption lines.



0	4	.	3
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Explain which star in **Table 2** has the greater temperature.

[1 mark]

Mintaka Aa1, because it is spectral class O and O-type stars are hotter than B-type stars (Aa2).

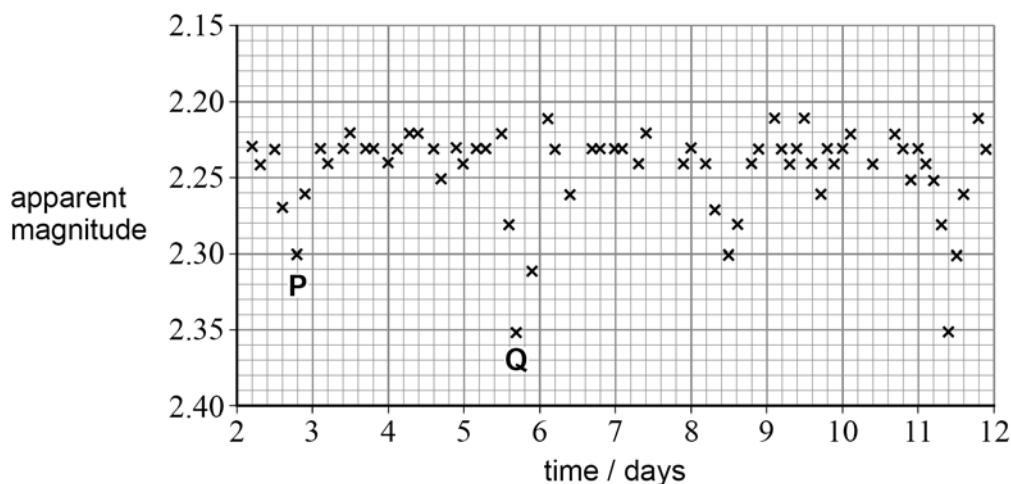
Question 4 continues on the next page

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Figure 2 shows how the apparent magnitude of the binary system varies with time.

Figure 2



0 4 . 4

Explain the variation in apparent magnitude shown in **Figure 2**.

In your answer you should explain:

- the changes in observed brightness at **P** and **Q**, as shown in **Figure 2**
- why the observed brightness at **P** is different from the observed brightness at **Q**.

[3 marks]

This is an eclipsing binary: when one star passes in front of the other, part of the light from the star behind is blocked, so the amount of light received falls, the intensity dips and the apparent magnitude increases, at P and Q.

The brightest observed values (lowest apparent magnitude, about 2.23) occur when both stars can be seen fully, with neither in front of the other.

The dips are different because the stars have different temperatures and brightnesses (Aa1 is class O and hotter, so brighter per unit area). The biggest dip, Q, is when the cooler, dimmer star Aa2 passes in front of the hotter, brighter star Aa1. The smaller dip, P, is when the hotter star Aa1 is in front of the cooler star Aa2.



0 4 . 5

Determine the angular velocity of the binary system.

[2 marks]*Q occurs at 5.7 days and again at 11.4 days, so**period $T = 11.4 - 5.7 = 5.7$ days*

$$T = 5.7 \times 24 \times 60 \times 60 = 4.92 \times 10^5 \text{ s}$$

$$\omega = 2\pi / T = 2\pi / (4.92 \times 10^5)$$

$$\omega = 1.28 \times 10^{-5} \text{ rad s}^{-1}$$

angular velocity = 1.3 × 10⁻⁵ rad s⁻¹**10****Turn over for the next question****Turn over ►**

0 5

Early observations of the star Betelgeuse indicated that:

radius r of Betelgeuse = $700 \times$ radius of the Sun
 distance d of Betelgeuse from the Earth = 548 ly
 intensity received from Betelgeuse = I .

Recent data suggest that the intensity received from Betelgeuse is actually 1.15 I .

Based on these recent data, two groups of students reach different conclusions.

Group X suggest that:

- r is correct
- d is actually 530 ly.

Group Y suggest that:

- d is correct
- r is actually $750 \times$ radius of the Sun.

Discuss for each group whether their conclusion could be correct.
 Assume that the measured temperature of Betelgeuse is constant.

[5 marks]

The temperature is constant, so $P = \sigma AT^4 = \sigma(4\pi r^2)T^4$ gives $P \propto r^2$,

and the intensity received $I = P / 4\pi d^2$, so $I \propto r^2 / d^2$.

Group X: r (and T) unchanged, so P is unchanged and $I \propto 1/d^2$.

$$I_{\text{new}} / I_{\text{old}} = 548^2 / 530^2 = 1.07, \text{ so } I_{\text{new}} = 1.07 I$$

This is not 1.15 I . (For 1.15 I : $d = 548 \div \sqrt{1.15} = 511$ ly, not 530 ly.)

So Group X cannot be correct.

Group Y: d unchanged, so $I \propto P \propto r^2$.

$$P_{\text{new}} / P_{\text{old}} = 750^2 / 700^2 = 1.15, \text{ so } P_{\text{new}} = 1.15 P$$

Intensity received $\propto P$, so $I_{\text{new}} = 1.15 I$, which matches the recent data.

(Check: $r = 700 \times \sqrt{1.15} = 750 \times$ radius of the Sun.)

So Group Y could be correct.



Conclusion: Group Y could be correct, since a radius of $750 \times$ radius of the Sun at 548 ly gives an intensity of 1.15 l. Group X is not correct, since a distance of 530 ly only gives 1.07 l; the distance would need to be 511 ly.

5

END OF QUESTIONS



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