SPECIMEN MATERIAL

A-level
PHYSICS
(7408/3BA)

Paper 3 - Section B (Astrophysics)

Specimen 2014 Morning Time allowed: 2 hours

Materials
For this paper you must have:
- a pencil
- a ruler
- a calculator
- a data and formulae booklet
- a question paper / answer book for Section A.

Instructions
- Answer **all** questions.
- Show all your working.
- The total time for both sections of this paper is 2 hours.

Information
- The maximum mark for this section is 35.

Please write clearly, in block capitals, to allow character computer recognition.

Centre number ☐☐☐☐☐ Candidate number ☐☐☐☐

Surname

Forename(s)

Candidate signature _____

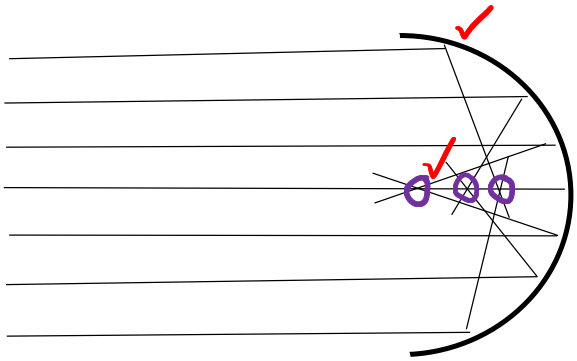
Section B

Answer **all** questions in this section.

0 1 The concave mirrors used in some reflecting telescopes can suffer from spherical aberration.

0 1 . 1 Draw a diagram to show what is meant by spherical aberration when produced by a concave mirror.

[2 marks]



0 1 . 2 The International Ultraviolet Explorer (IUE) and the Gran Telescopio Canarias (GTC) are two examples of reflecting telescopes.

Table 1 summarises some of the properties of the two telescopes.

Table 1

$P \propto D^2$

Name	IUE	GTC
Objective Diameter	0.45 m	10.4 m
Location	Geosynchronous Earth orbit	Earth's surface, 2300 m above sea level.
Spectrum detected	Ultraviolet	Visible and Infrared
Typical wavelength detected	2.0×10^{-7} m	1.0×10^{-6} m

Compare the two telescopes in terms of their location, collecting power and minimum angular resolution.

Include calculations to support your comparisons.

[6 marks]

Location

- Light needs to travel through the atmosphere to reach the GTC (but not the IUE), so less light received
- IUE requires its own power source (whereas GTC does not), and is more difficult to access

Collecting Power

$D_{GTC} = \frac{10.4}{0.45} \times D_{IUE} \Rightarrow P_{GTC} = \left(\frac{10.4}{0.45}\right)^2 \times P_{IUE} = 530 P_{IUE}$

Collecting power of GTC is 530 times that of IUE

$\Rightarrow$ Collects much brighter images

Minimum Angular Resolution

$AR_{min} \propto \frac{1}{D} \qquad \theta = \frac{\lambda}{D}$

$$\frac{\theta_{IUE}}{\theta_{GTC}} = \frac{\lambda_{IUE}/D_{IUE}}{\lambda_{GTC}/D_{GTC}} = \frac{\lambda_{IUE} D_{GTC}}{\lambda_{GTC} D_{IUE}}$$

$$= \frac{2 \times 10^{-7} \times 10.4}{1 \times 10^{-6} \times 0.45} = 4.6$$

- θ_{GTC} is 4.6 times better at resolving an image
- Larger diameter gives a clearer image, so GTC is preferred.

QWC ✓

Missing a section (or not giving a strong enough argument) would lose 1-2 marks (per section)

Turn over ▸

0 1 . 3 The Charge Coupled Device (CCD) is an important part of the detection system of many modern telescopes due to its high quantum efficiency.

Explain what is meant by quantum efficiency and compare the quantum efficiency of a CCD with that of the eye.

[2 marks]

Quantum efficiency = $\frac{\text{number of arriving photons being detected}}{\text{total number of arriving photons}}$ ✓

QE of CCD > 80%, QE of eye ≃ 1% ✓

Turn over for the next question

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ANSWER IN THE SPACES PROVIDED

0 2 The Summer Triangle consists of three stars, Altair, Deneb and Vega. Some of the properties of the three stars are summarised in **Table 2**.

apparent magnitude — $m - M = 5\log(d/10)$ — distance in parsecs

absolute magnitude

Table 2

	Altair	Deneb	Vega
surface temperature / K	7700	8500	9600
apparent magnitude	0.77	1.25	0.03
absolute magnitude	2.21	−8.38	0.60

$0.77 - 2.21 = -1.44$ $1.25 - (-8.38) = 9.63$ $0.03 - 0.60 = -0.57$

0 2 . 1 The three stars belong to the same spectral class.

State and explain which spectral class they belong to.

[2 marks]

- Spectral class A ✓
- This class has a temperature range of 7500K to 11,000K ✓

0 2 . 2 Deduce which of the three stars appears brightest.

[2 marks]

- Lowest apparent magnitude gives brightest star ✓
- Vega is brightest (as its apparent magnitude is lowest) ✓

0 2 . 3 Calculate the distance from Earth to the closest of the three stars.

[3 marks]

$m - M = 5\log_{10}(d/10)$

Altair is closest, as its "m-M" is most negative ✓

$0.77 - 2.21 = -1.44$ ✓ $= 5\log_{10}(d/10)$

$\frac{-1.44}{5} = \log_{10}(d/10)$

$\frac{d}{10} = 10^{-1.44/5}$

$d = 10 \times 10^{-1.44/5} = 5.152\text{pc}$

distance = 5.2 ✓ pc

0 2 . 4 Deduce which of the three stars is the largest.

[3 marks]

$P = \sigma A T^4$ — temperature

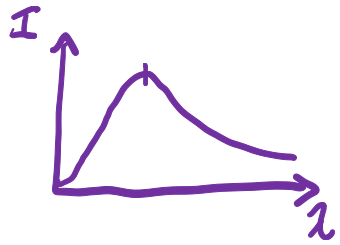
power — Stefan constant — surface area

- Deneb has the largest power output, as its absolute magnitude is the most negative (so it is the brightest) ✓
- A more powerful star at the same temperature must have a larger surface area (and therefore be larger) ✓ (or similar)
- Deneb is the largest ✓

0 2 . 5 Calculate the wavelength of the peak in the black body radiation curve of Altair.

[2 marks]

$\lambda_{max} T = 0.0029$



$\lambda_{max} = \frac{0.0029}{T} = \frac{0.0029}{7700}$ ✓

$= 3.8 \times 10^{-7}$ m

wavelength = 3.8×10^{-7} ✓ m

0 3 Antares is a red supergiant star in the constellation of Scorpio. It has a mass about 18 times that of the Sun.
Eventually the star will become a supernova, leaving behind a core that could form a neutron star or a black hole.

0 3 . 1 State what is meant by a supernova.

[1 mark]

An object that produces a rapid increase in brightness

0 3 . 2 State the defining properties of a neutron star.

[2 marks]

- Consists entirely of neutrons ✓
- They have a very high density ✓

0 3 . 3 To become a black hole it is likely that the core would have to have a mass at least twice that of the Sun.

Calculate the Schwarzschild radius of a black hole with a mass twice that of the Sun. (1.99×10^{30} kg)

[2 marks]

$R_s = \frac{2GM}{c^2}$ — G: Gravitational constant; M: mass of black hole; c: speed of light

$\frac{2\times6.67\times10^{-11}\times2\times1.99\times10^{30}}{(3.00\times10^{8})^2}$ ✓ $= 5899.2\text{m}$

$\simeq 5900\text{m}$

radius = 5900 ✓ m

0 3 . 4 Some scientists are concerned about the consequences for the Earth of a supernova occurring in a nearby part of the galaxy.

Explain the cause of this concern.

[2 marks]

- Gamma ray bursts with energy similar to the Sun's total output ✓
- Bursts are highly collimated, so could cause a mass extinction event if pointed in Earth's direction ✓

0 4 In 1999 a planet was discovered orbiting a star in the constellation of Pegasus.

0 4 . 1 State **one** reason why it is difficult to make a direct observation of this planet.

[1 mark]

- Planet is small and far away; not big enough for resolution of telescopes ✓ Reflected light from planet is negligible compared to star itself ✓

0 4 . 2 The initial discovery of the planet was made using the radial velocity method which involved measuring a Doppler shift in the spectrum of the star.

Explain how an orbiting planet causes a Doppler shift in the spectrum of a star.

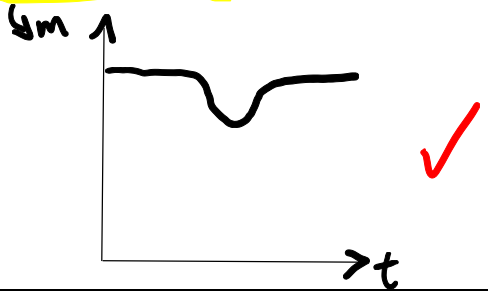
[2 marks]

- Planet and star orbit a common centre of mass, so star moves closer to and further from us ✓
- Wavelength of light from the star is shifted ✓

0 4 . 3 The discovery was confirmed by measuring the variation in the apparent magnitude of the star over a period of time.

Explain how an orbiting planet causes a change in the apparent magnitude of a star. Sketch a graph of apparent magnitude against time (a light curve) as part of your answer.

[3 marks]



✓

- When the planet moves in front of the star, it absorbs some of the star's light, so less light reaches the observer on Earth ✓
- Apparent magnitude is determined from the amount of light received at Earth ✓

END OF QUESTIONS

There are no questions printed on this page.

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