

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

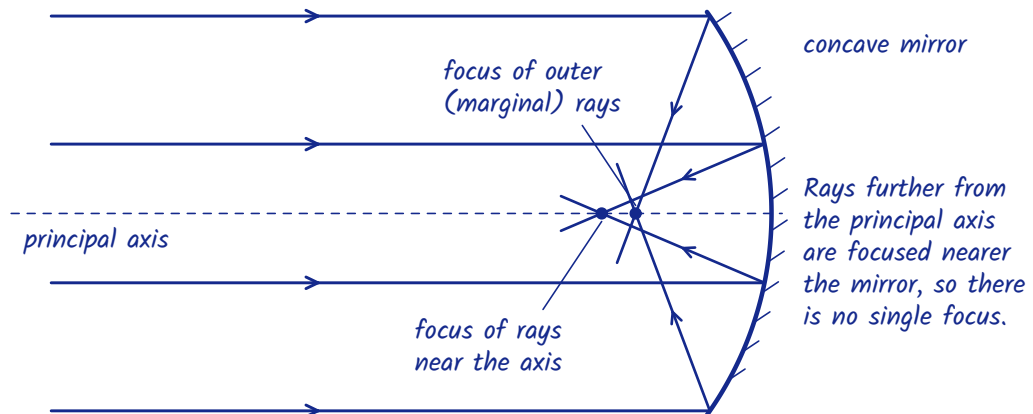
The concave mirrors used in some reflecting telescopes can suffer from spherical aberration.

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

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: the GTC is on the Earth's surface, so light must travel

through some of the atmosphere to reach it. The atmosphere absorbs

some of the light, reducing the amount arriving, and turbulence makes the image blur, which affects resolution. Being 2300 m above sea level reduces this, as there is less atmosphere above it, but cannot remove it. Ultraviolet is absorbed by the atmosphere, which is why the IUE has to be in orbit.

The IUE in geosynchronous orbit is above the atmosphere, but it needs its own power source (solar panels) and its information has to be sent (transmitted) to the ground for analysis. Its position is inconvenient: if something goes wrong it is very difficult and expensive to service or repair an orbiting satellite, whereas the GTC can easily be maintained. Collecting power: collecting power is proportional to D^2 , so ratio GTC : IUE = $10.4^2 \div 0.45^2 = 530$. The GTC has about 530 times the collecting power of the IUE, so the GTC is better, as the bigger diameter telescope makes brighter images and can detect fainter objects. Minimum angular resolution: $\theta \approx \lambda/D$, so it is proportional to $1/D$ (and to λ).

$$\text{IUE: } \theta = 2.0 \times 10^{-7} \div 0.45 = 4.4 \times 10^{-7} \text{ rad}$$

$$\text{GTC: } \theta = 1.0 \times 10^{-6} \div 10.4 = 9.6 \times 10^{-8} \text{ rad}$$

Ratio GTC $\div$ IUE = $(1.0 \times 10^{-6}/10.4) \div (2.0 \times 10^{-7}/0.45) = 0.2$, so the GTC is about 5 times better at resolving, even though it detects longer wavelengths. The bigger diameter telescope makes clearer, more detailed images.

Overall the GTC has the greater collecting power and the better resolution, but the IUE can observe ultraviolet radiation that cannot reach the ground.

- 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]

*$QE = \text{number of photons detected} \div \text{total number of photons arriving}$
at the detector (as a %).*

CCD: QE above 80%, eye: QE only about 1%.

Turn to page 6 for the next question

Turn over for the next question

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ANSWER IN THE SPACES PROVIDED**

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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**.

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 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.

Their temperatures (7700 K to 9600 K) are all in the range for class

A, which is 7500 K to 11 000 K.

0 2

. 2 Deduce which of the three stars appears brightest.

[2 marks]

The lower the apparent magnitude, the brighter the star appears.

Vega has the lowest apparent magnitude (0.03), so Vega appears

brightest.

0 2

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

[3 marks]

$m - M = 5 \log(d/10)$: smallest $m - M$ means closest

Altair: $0.77 - 2.21 = -1.44$ (Vega -0.57 , Deneb 9.63)

so Altair is the closest: $-1.44 = 5 \log(d/10)$

$\log(d/10) = -0.288$ $d = 10 \times 10^{-0.288} = 5.15$ pc

distance = 5.2 pc

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

[3 marks]

Deneb is the largest.

All three stars have approximately the same surface temperature (7700 K to 9600 K), but Deneb has a much brighter (more negative) absolute magnitude of -8.38 , so it has a much greater power output (luminosity).

As $P = \sigma AT^4$, to have a much greater power output for a similar temperature, Deneb must have a much greater surface area, so it is the largest. (On the HR diagram Altair and Vega are main sequence stars and Deneb is a giant.)

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

[2 marks]

$$\text{Wien's law: } \lambda_{\max} T = 2.9 \times 10^{-3} \text{ m K}$$

$$\lambda_{\max} = 2.9 \times 10^{-3} \div 7700$$

$$\lambda_{\max} = 3.77 \times 10^{-7} \text{ m}$$

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

Turn over for the next question

Turn over ►

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 (exploding star) that produces a rapid, enormous increase in brightness, i.e. its absolute magnitude falls sharply.

0 3

. 2 State the defining properties of a neutron star.

[2 marks]

*Extremely dense (similar to the density of a nucleus).
Made up (almost entirely) of neutrons.*

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.

[2 marks]

$$R_s = 2GM / c^2$$

$$R_s = 2 \times 6.67 \times 10^{-11} \times 2 \times 2.0 \times 10^{30} \div (3.0 \times 10^8)^2$$

$$R_s = 5.93 \times 10^3 \text{ m}$$

radius = 5.9×10^3 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]

A collapsing star can produce a gamma ray burst, releasing in seconds energy similar to the total output of the Sun over its lifetime.

The beams are highly collimated; if directed towards the Earth, it could destroy the ozone layer and cause a mass extinction event.

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]

The star is much brighter than the light reflected from the planet, so the planet is lost in the star's glare.

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]

The planet and star orbit around their common centre of mass, so the star moves towards and then away from the Earth as the planet orbits. This causes a periodic shift in the wavelength of the light received from the star (blue shift, then red shift of its spectral lines).

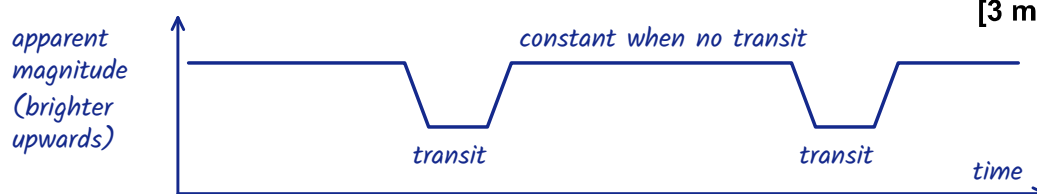
0 4

. 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 passes in front of the star (a transit, as seen from Earth), it blocks (absorbs) some of the light from the star, so the amount of light reaching Earth is reduced.

Apparent magnitude is a measure of the amount of light reaching Earth from the star, so during each transit the star appears dimmer (its apparent magnitude increases) and then returns to its constant value.

The dip repeats once every orbital period.

END OF QUESTIONS

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There are no questions printed on this page.