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Centre number

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Candidate number

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Candidate signature

A-level PHYSICS

Paper 3

Section B Astrophysics

Monday 3 June 2019

Afternoon

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.

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.
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- 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).
- Show **all** your working.

For Examiner's Use

Question	Mark
1	
2	
3	
4	
TOTAL	

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.

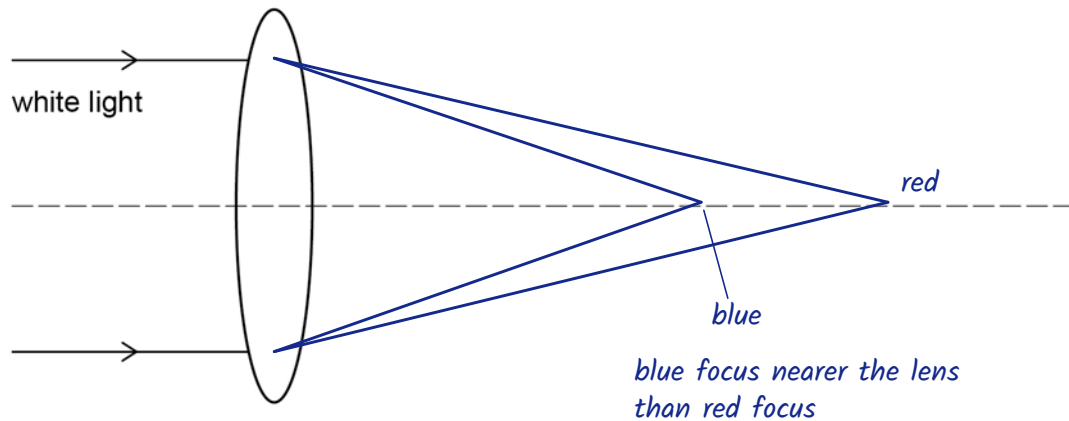


J U N 1 9 7 4 0 8 3 B A 0 1

Section BAnswer **all** questions in this section.

0 1 . 1 The lenses used in refracting telescopes can cause chromatic aberration.

Complete **Figure 1** to show how a lens produces chromatic aberration.

[1 mark]**Figure 1**

0 1 . 2 A Cassegrain telescope uses mirrors.

What are the shapes of the primary and secondary mirrors in a Cassegrain telescope?

Tick (✓) **one** box.

[1 mark]

Primary mirror	Secondary mirror	
concave	concave	
concave	convex	✓
convex	concave	
convex	convex	



0 1 . 3

Table 1 contains information about two telescopes, **A** and **B**. Each telescope is planned to be the biggest of its type in the world.

Table 1

Telescope	A	B
Type	Optical reflecting telescope	Radio telescope
Diameter / m	39.3	110
Range of wavelengths detected	350 nm to 1800 nm	2.5 mm to 1000 mm

Discuss the similarities and differences between optical reflecting telescopes and radio telescopes. Your answer should include references to:

- structure
- positioning
- collecting power.

Go on to discuss which telescope, **A** or **B**, will give a more detailed image of an astronomical object that emits both radio waves and visible light.

[6 marks]

Structure: both use a large reflecting surface (dish or mirror) which is parabolic, to bring the radiation to a focus. In an optical reflector a concave primary mirror reflects light onto a secondary mirror and then to an eyepiece or CCD. In a radio telescope there is no secondary reflector: the detector (aerial) is placed at the focal point of the primary dish. The radio dish can be made of wire mesh, as the mesh spacing only has to be small compared with the long radio wavelengths, whereas the optical mirror must be smooth to within a fraction of a wavelength.

Positioning: both visible light and radio waves pass through the atmosphere with little absorption, so both can be used on the Earth's

Question 1 continues on the next page

Turn over ►



surface. However, optical telescopes must be away from light pollution in cities, and are placed high up on mountains in dry places to be above clouds and atmospheric distortion (turbulence). Radio telescopes can be at low altitude, even in cloudy places, but must be in quiet areas away from radio interference (mobile phones, TV transmitters). Collecting power: collecting power $\propto D^2$, so B collects $(110 / 39.3)^2 = 7.8$ times as much power as A. However, radio sources tend to be very weak compared with optical sources, so the radio telescope needs the bigger dish.

Resolving power: minimum angular resolution $\theta \approx \lambda / D$ (smaller θ means more detail).

$$A: \theta = 350 \times 10^{-9} / 39.3 = 8.9 \times 10^{-9} \text{ rad (up to } 1800 \times 10^{-9} / 39.3 = 4.6 \times 10^{-8} \text{ rad)}$$

$$B: \theta = 2.5 \times 10^{-3} / 110 = 2.3 \times 10^{-5} \text{ rad (up to } 1.0 / 110 = 9.1 \times 10^{-3} \text{ rad)}$$

Even though B has the larger diameter, the radio wavelengths are so much longer that B's minimum angle is about 2600 times bigger than A's. So A has a much higher resolving power, and A will give the more detailed image of the object.



0 2

Table 2 shows some properties of the four brightest stars in the constellation Canis Minor.

Table 2

Name	Apparent magnitude	Absolute magnitude	Spectral class
Gamma A	4.46	−0.50	K
Gomeisa	2.89	−0.70	B
HD 66141	4.39	−0.13	K
Procyon	0.34	2.65	F

0 2 . 1

Discuss, with reference to the Hipparcos scale, why many star maps show only two stars in the constellation Canis Minor.

[3 marks]

Hipparcos scale: the brightest stars are magnitude 1, down to magnitude 6 for the dimmest visible to the naked eye (in good conditions).

Gamma A (4.46) and HD 66141 (4.39) are much dimmer than Gomeisa (2.89) and Procyon (0.34), nearer to magnitude 6, so only Gomeisa and Procyon are likely to be seen (unless conditions are good).

0 2 . 2

State and explain which star in **Table 2** has the most prominent Hydrogen Balmer absorption lines.

[2 marks]

Gomeisa, as it is a B class star.

B class stars are hot enough (about 10 000 to 30 000 K) to have many hydrogen atoms with electrons in the $n = 2$ state, which absorb the Balmer wavelengths.

Question 2 continues on the next page

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0 2 . 3

Deduce which star, Gamma A or HD 66141, has the larger diameter.

[3 marks]

Both stars are spectral class K, so they have the same (similar) surface temperature.

Gamma A has the more negative absolute magnitude (-0.50 compared with -0.13), so Gamma A is brighter than HD 66141 at the same distance, so Gamma A has the greater power output.

Stefan's law: $P = \sigma AT^4$. With the same T , $P \propto A$, so Gamma A has the larger surface area and therefore Gamma A has the larger diameter.

0 2 . 4

Astronomers recently used the radial velocity method to discover an exoplanet orbiting HD 66141.

Describe the main features of the radial velocity method in the detection of planets.

[2 marks]

The planet and the star both orbit their common centre of mass, so the star moves alternately towards and away from the Earth.

This causes a periodic Doppler shift in the light received from the star: its spectral lines are alternately red shifted and blue shifted, with the period of the planet's orbit.



0 2 . 5

Calculate the distance from the Earth to Procyon.
Give an appropriate unit for your answer.

[3 marks]

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

$$0.34 - 2.65 = 5 \log (d / 10)$$

$$\log (d / 10) = -2.31 / 5 = -0.462$$

$$d = 10 \times 10^{-0.462}$$

$$d = 3.45 \text{ pc}$$

distance = 3.45 unit pc

13

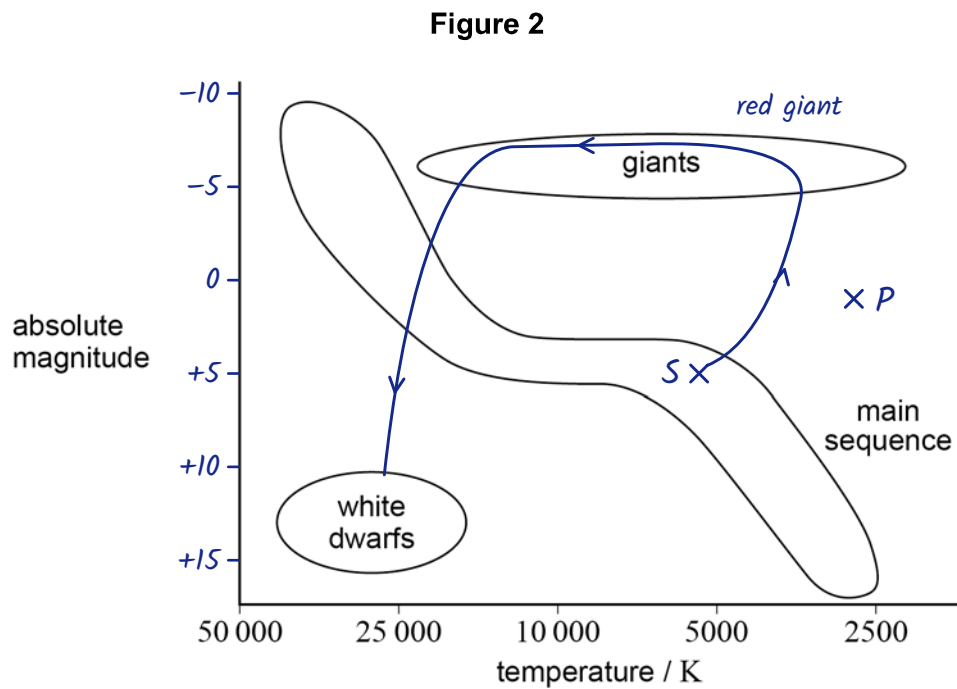
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0 3

Figure 2 is a Hertzsprung-Russell (HR) diagram.



0 3 . 1

Label the absolute magnitude axis with a suitable scale.

[1 mark]

0 3 . 2

Label with an **S** the position of the Sun on the HR diagram.

[2 marks]

0 3 . 3

Draw a line on the HR diagram to show the evolution of a star similar to the Sun from formation to white dwarf.

[2 marks]

0 3 . 4

Label with a **P** the position on the HR diagram of a star much redder, and with a greater power output, than the Sun.

[1 mark]



0 3 . 5

A star much more massive than the Sun may become a supernova and then a black hole.

Discuss whether supernovae and black holes can be placed on the HR diagram in **Figure 2**.

[3 marks]

A supernova is extremely bright: its absolute magnitude is about -20 , which is beyond (off) the scale of the HR diagram. Also it is short-lived and its brightness varies, so it cannot be assigned a fixed position.

A black hole has an escape velocity greater than c , so no light is emitted from it: its absolute magnitude would be too dim to fit on the scale, and its temperature would be far too low (less than 2500 K).

So neither supernovae nor black holes can be placed on the HR diagram.

9

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0 4 . 1 Table 3 contains information about two galaxies.

Table 3

Galaxy	Red shift, z	Distance from Earth / ly
NGC 936	4.8×10^{-3}	6.8×10^7
NGC 3379	3.0×10^{-3}	3.2×10^7

Discuss whether these data are consistent with Hubble's Law.

[3 marks]

$$z = v / c \text{ so } v = zc$$

$$\text{NGC 936: } v = 4.8 \times 10^{-3} \times 3.0 \times 10^5 = 1440 \text{ km s}^{-1}$$

$$d = 6.8 \times 10^7 / 3.26 = 2.09 \times 10^7 \text{ pc} = 20.9 \text{ Mpc}$$

$$H = v / d = 1440 / 20.9 = 69 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$\text{NGC 3379: } v = 3.0 \times 10^{-3} \times 3.0 \times 10^5 = 900 \text{ km s}^{-1}$$

$$d = 3.2 \times 10^7 / 3.26 = 9.82 \times 10^6 \text{ pc} = 9.82 \text{ Mpc}$$

$$H = v / d = 900 / 9.82 = 92 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

(Hubble's law $v = Hd$, data booklet $H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$)

NGC 936 ($H = 69$) is consistent with Hubble's law, but NGC 3379 ($H = 92$) is not, so the data are not fully consistent, unless other factors (e.g. the galaxy's own motion in its cluster) affect the velocity or distance.



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Quasars are the most distant measurable objects.

Discuss **one** problem associated with the determination of the distance from the Earth to a quasar.

[2 marks]

Distant quasars are very faint, so a standard candle (e.g. a type Ia supernova) in the associated galaxy would be too faint to observe, and the inverse square law cannot be used.

So Hubble's law must be used, but this is not reliable over such large distances due to dark energy (the accelerating universe).

5

END OF QUESTIONS



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