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I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Astrophysics

Monday 17 June 2024

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	
TOTAL	



J U N 2 4 7 4 0 8 3 B A 0 1

Section B

Answer **all** questions in this section.

0 1

A student uses a refracting telescope in normal adjustment to make observations of Jupiter.

The telescope has an angular magnification of 75

0 1 . 1

The eyepiece has a focal length of 22 mm.

Determine the distance between the eyepiece and the objective lens.

[2 marks]

$$M = f_o \div f_e \text{ so } f_o = M \times f_e = 75 \times 0.022 = 1.65 \text{ m}$$

$$\text{In normal adjustment, distance} = f_o + f_e$$

$$\text{distance} = 1.65 + 0.022 = 1.672 \text{ m}$$

$$\text{distance} = \underline{1.67} \text{ m}$$

0 1 . 2

When viewed through the telescope, the image of Jupiter subtends an angle of 1.7×10^{-2} rad.

Calculate, in km, the distance between the Earth and Jupiter.

$$\text{mean radius of Jupiter} = 7.0 \times 10^4 \text{ km}$$

[2 marks]

$$\text{Angle subtended at unaided eye: } \alpha = \beta \div M = 1.7 \times 10^{-2} \div 75$$

$$\alpha = 2.27 \times 10^{-4} \text{ rad}$$

$$\text{diameter of Jupiter} = 2 \times 7.0 \times 10^4 = 1.4 \times 10^5 \text{ km}$$

$$\text{distance} = \text{diameter} \div \alpha = 1.4 \times 10^5 \div 2.27 \times 10^{-4}$$

$$\text{distance} = 6.2 \times 10^8 \text{ km}$$

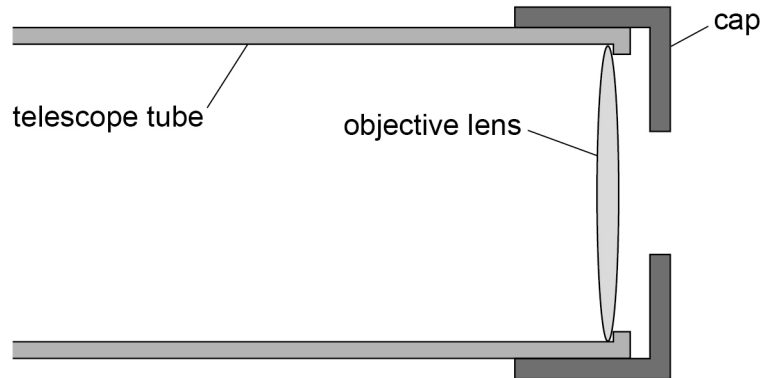
$$\text{distance} = \underline{6.2 \times 10^8} \text{ km}$$



The student places a cap over one end of the telescope. The cap has a circular hole in its centre.

Figure 1 shows the end of the telescope, the objective lens and the cap.

Figure 1



0 1 . 3

State and explain the effect that the addition of the cap has on the chromatic aberration caused by the lens.

[3 marks]

Caused by dispersion: different wavelengths are refracted by different amounts, so focus at different points.

This is greatest at the edge of the lens (most curved). The cap blocks the edge, so light only passes through the centre, where curvature is small, so chromatic aberration is reduced.

0 1 . 4

Explain **two** other effects that the addition of the cap has on the image of Jupiter.

[4 marks]

1 *The image is dimmer: the cap reduces the effective diameter d of the objective, and collecting power is proportional to the area, i.e. to d^2 , so less light is collected.*

2 *The image is less clear (less detail): the minimum angular resolution $\theta \approx \lambda/d$ is proportional to $1/d$, so with a smaller d the minimum resolvable angle is larger.*

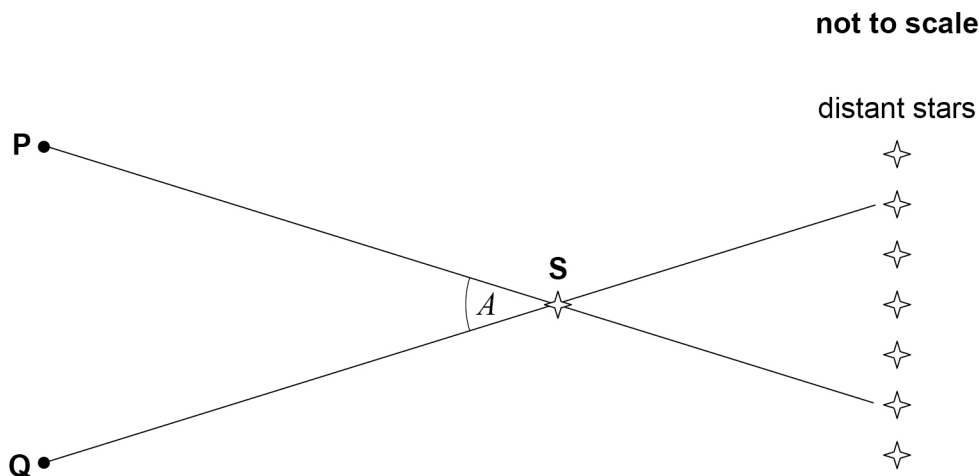


0 2

The apparent change in position of a nearby star relative to distant stars is due to an effect known as parallax.

Figure 2 shows how parallax arises. As the Earth moves from point **P** to point **Q**, an observer on the Earth sees the position of a nearby star **S** change in relation to distant stars.

Figure 2



Angle A is the parallax angle. This angle can be used to determine the distance to a nearby star, provided that the relative motion between the star and the Sun is negligible between observations.

0 2 . 1

The distance from the Sun to **S** is 79 ly.

The Earth takes 6 months to move from point **P** to point **Q**.

Calculate, in degrees, angle A .

[2 marks]

$$s = PQ = 2 \times 1.5 \times 10^{11} = 3.0 \times 10^{11} \text{ m}$$

$$r = 79 \times 9.46 \times 10^{15} = 7.47 \times 10^{17} \text{ m}$$

$$A \approx s \div r = 3.0 \times 10^{11} \div 7.47 \times 10^{17} = 4.0 \times 10^{-7} \text{ rad}$$

$$A = 4.0 \times 10^{-7} \times 180 \div \pi = 2.3 \times 10^{-5} ^\circ$$

$$A = \underline{2.3 \times 10^{-5}} ^\circ$$



0 2 . 2

Parallax is used to determine the distance to a different star. Observations of the star produce the following data:

distance determined using parallax = 0.40 pc

apparent magnitude = 13.5

absolute magnitude = 16.7

An astronomer suggests that the star moved significantly relative to the Sun between the two parallax observations.

Discuss whether this suggestion is valid.

[4 marks]

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

$$13.5 - 16.7 = -3.2 = 5 \log (d/10)$$

$$\log (d/10) = -0.64, \text{ so } d = 10 \times 10^{-0.64} = 2.3 \text{ pc}$$

Check with $d = 0.40$ pc: $5 \log (0.40/10) = -7.0$, which is not -3.2

The distance from the magnitudes (2.3 pc) is about 6 times greater than the parallax distance of 0.40 pc, a very large difference. Also 0.40 pc is much closer than the nearest known star (about 1.3 pc).

So the parallax distance must be wrong: the star's own motion between the observations made the measured parallax angle far too large.

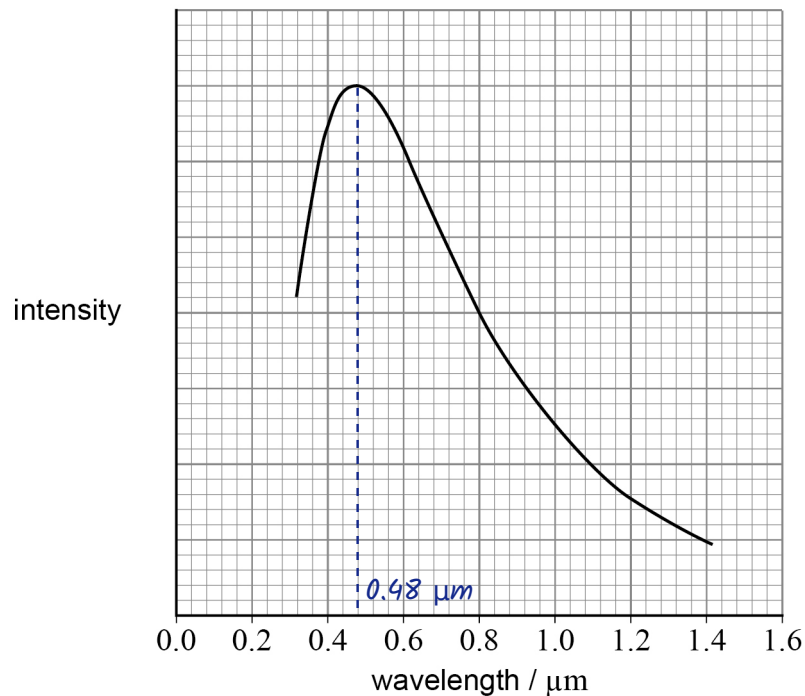
So the astronomer's suggestion is valid: the star did move significantly relative to the Sun between the two observations.



0 3 . 1

Figure 3 shows the variation of intensity with wavelength for a star.

Figure 3



Show that **Figure 3** is consistent with a black-body temperature of about 6.0×10^3 K.

[2 marks]

From the graph the peak is at $\lambda_{\max} = 0.48 \mu\text{m} = 0.48 \times 10^{-6} \text{ m}$

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

$$T = 2.9 \times 10^{-3} \div 0.48 \times 10^{-6} = 6.04 \times 10^3 \text{ K}$$

This is about 6.0×10^3 K, so Figure 3 is consistent.

0 3 . 2

The radius of the star is $9.6 \times 10^6 \text{ m}$.

Calculate the power output of the star.

[2 marks]

$$P = \sigma AT^4 = \sigma \times 4\pi r^2 \times T^4$$

$$P = 5.67 \times 10^{-8} \times 4\pi \times (9.6 \times 10^6)^2 \times 6000^4$$

$$P = 8.5 \times 10^{22} \text{ W}$$

power output = 8.5×10^{22} W



0 3 . 3 Which row gives the type and spectral class of the star?

Tick (✓) **one** box.

[1 mark]

Type of star	Spectral class	
white dwarf	F	✓
main sequence	G	
red giant	K	
main sequence	F	
red giant	G	
white dwarf	K	

0 3 . 4 The light from the star passes through an interstellar dust cloud before reaching Earth. The reduction in intensity when light passes through a dust cloud is assumed to be inversely proportional to the wavelength of the light.

An astronomer on the Earth estimates the black-body temperature of the star.

Discuss the effect that the dust cloud has on this estimate.

[2 marks]

The dust reduces the intensity more at shorter wavelengths (reduction $\propto 1/\lambda$), so more of the short-wavelength light is removed and the observed spectrum has lower intensity at short wavelengths.

So the observed peak of the black-body curve is shifted to a longer wavelength (to the right) than in Figure 3.

Since $\lambda_{\max} T = \text{constant}$, a larger $\lambda_{\max}$ gives a lower value of T , so the astronomer's estimate of the temperature is lower than the actual temperature of the star.

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0 4

The Earth is in the galaxy known as the Milky Way. The Andromeda Galaxy is one of the closest galaxies to the Milky Way.

0 4 . 1

The Andromeda Galaxy approaches the Milky Way at a speed of 110 km s^{-1} . The distance between the galaxies is 770 kpc .

Discuss whether these data can be used to estimate an age for the Universe.

[2 marks]

The age of the Universe is estimated using Hubble's law, $v = H_0 d$, with $\text{age} \approx 1/H_0$ (the gradient of a v against d graph for receding galaxies).

These data give $d/v = 2.4 \times 10^{22} \text{ m} \div 1.1 \times 10^5 \text{ m s}^{-1} \approx 2 \times 10^{17} \text{ s}$, but this is not valid: Andromeda is approaching us (blue-shifted), not receding, so Hubble's law does not apply. So no, the data cannot be used.

0 4 . 2

There is a supermassive black hole at the centre of the Andromeda Galaxy. The mass of this black hole is 1.60×10^8 solar masses.

Calculate the radius of the event horizon of this black hole.
State an appropriate unit for your answer.

[3 marks]

$$M = 1.60 \times 10^8 \times 1.99 \times 10^{30} = 3.18 \times 10^{38} \text{ kg}$$

$$R_s = 2GM \div c^2$$

$$R_s = 2 \times 6.67 \times 10^{-11} \times 3.18 \times 10^{38} \div (3.0 \times 10^8)^2$$

$$R_s = 4.7 \times 10^{11} \text{ m}$$

radius = 4.7×10^{11}

unit = m

Question 4 continues on the next page

Turn over ►



0 4 . 3

Scientists predict that a quasar will be produced as the Milky Way and the Andromeda Galaxy merge.

Explain what is meant by a quasar.

Go on to suggest why a quasar may be produced as galaxies merge.

In your answer you should:

- describe the typical properties of a quasar
- explain how observations of quasars provide evidence for these properties
- suggest the process of quasar formation that is likely when two galaxies merge.

[6 marks]

A quasar is a very distant, extremely luminous object at the centre of an active galaxy. It is powered by a supermassive black hole in the galaxy's centre.

Properties: a quasar has a huge power output, about 10^{39} to 10^{42} W, far more than a whole galaxy, but it is very small, only about the size of the solar system. Quasars are very distant (billions of light years away).

Evidence: quasars are seen at the centres of active galaxies, often producing jets. They were discovered as very bright radio sources and are far brighter than their host galaxy. Their spectra have very large red-shifts, which by Hubble's law shows they are very distant, so their power output must be enormous to be seen. Their brightness fluctuates rapidly (over hours or days), so they must be small, since the size can be no more than the distance light travels in that time.

Formation on merging: when the Milky Way and Andromeda merge, gravitational interactions disturb the orbits of gas, dust and stars, so large amounts of material move towards the supermassive black hole(s) at the centre. The black hole becomes active, 'consuming' this material, which forms a hot accretion disc that emits huge amounts of radiation, so a quasar is produced.



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