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A-level PHYSICS

Paper 3

Section B Astrophysics

Thursday 14 June 2018

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.

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.
- 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 1 8 7 4 0 8 3 B A 0 1

Section B

Answer **all** questions in this section.

0 1

The Griffith Observatory in Los Angeles includes an astronomical refracting telescope (Griffith telescope) with an objective lens of diameter 305 mm and focal length 5.03 m

0 1 . 1

Calculate the wavelength of light for which the Griffith telescope has a minimum angular resolution of 1.8×10^{-6} rad

[2 marks]

$$D = 305 \text{ mm} = 0.305 \text{ m}$$

$$\theta = \lambda / D \quad \text{so} \quad \lambda = \theta D$$

$$\lambda = 1.8 \times 10^{-6} \times 0.305 = 5.49 \times 10^{-7} \text{ m}$$

wavelength = 5.5×10^{-7} m

0 1 . 2

The Griffith telescope is used to observe two point objects which subtend an angle of 1.8×10^{-6} rad at the unaided eye.

The typical human eye has a minimum angular resolution of approximately 3.2×10^{-4} rad

Calculate the focal length of the eyepiece lens so that an observer can just resolve the two objects when observing them through the Griffith telescope.

[3 marks]

$$\text{Angular magnification } M = \text{angle at eye} / \text{angle at telescope}$$

$$M = 3.2 \times 10^{-4} / 1.8 \times 10^{-6} = 178$$

$$M = f_o / f_e \quad \text{so} \quad f_e = f_o / M$$

$$f_e = 5.03 / 178 = 0.0283 \text{ m}$$

focal length = 0.028 m



0 1 . 3

The asteroid Apophis has a diameter of 325 m

It has been calculated that, in 2029, its distance of closest approach to the Earth's surface will be 3.0×10^4 km

The Griffith telescope may be used to view Apophis using the eyepiece calculated in question 01.2

Deduce whether this telescope is suitable to obtain a detailed view of Apophis. Support your answer with a calculation.

[3 marks]

The telescope can resolve objects down to an angle of 1.8×10^{-6} rad.

At 3.0×10^4 km = 3.0×10^7 m, this angle is subtended by an object

of size $3.0 \times 10^7 \times 1.8 \times 10^{-6} = 54$ m.

This is only $54/325 \approx 1/6$ of the diameter of Apophis (equivalently,

angular size of Apophis = $325 / 3.0 \times 10^7 = 1.1 \times 10^{-5}$ rad, only about 6 times the minimum angular resolution).

So Apophis would only be about 6 resolved points across: it can be seen,

but it is too small for detail to be seen. The telescope is not suitable for a detailed view.



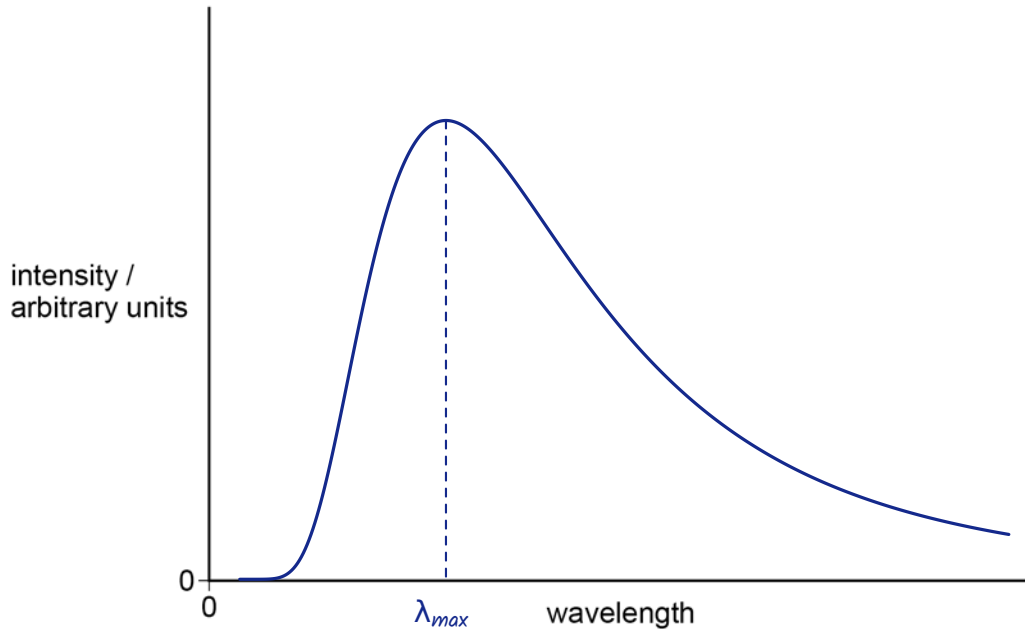
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0 2 . 1

Sketch, on the axes in **Figure 1**, the black-body radiation curve for a typical star.**[2 marks]****Figure 1**

0 2 . 2

Explain, with reference to the SI units involved, how the curve you have drawn can be used to determine the black-body temperature of the star.

[3 marks]

Read off the peak wavelength λ_{max} (the wavelength at which the intensity is a maximum) from the curve, as marked on the wavelength axis.

Use Wien's displacement law: $\lambda_{max}T = 2.9 \times 10^{-3} \text{ m K}$ (0.0029 metre kelvin).

λ_{max} must be in metres (the SI unit of length), so $T = 2.9 \times 10^{-3} / \lambda_{max}$ gives the black-body temperature of the star in kelvin (K, the SI unit of temperature).

Question 2 continues on the next page**Turn over ►**

0 2 . 3

Two stars, 61 Cygnus A and 61 Cygnus B, can be seen very close together in the constellation Cygnus. Early astronomers were unsure whether the two stars form a binary system, or simply appear in the same line of sight.

Table 1 shows some of the properties of the two stars.

Table 1

	Temperature / K	Radius / km	Apparent magnitude
61 Cygnus A	4500	4.7×10^5	5.2
61 Cygnus B	4100	4.1×10^5	6.1

Evaluate whether the data support the suggestion that the two stars form a binary system.

In your answer you should

- compare the two stars as seen by an observer on Earth
- support your evaluation with suitable calculations.

[6 marks]

Colour: both stars have surface temperatures of about 4000 to 4500 K, so both appear orange. 61 Cygnus B is cooler (4100 K), so it appears slightly redder than 61 Cygnus A.

Brightness: A has the smaller apparent magnitude, so A appears brighter. Difference in apparent magnitude = $6.1 - 5.2 = 0.9$, so brightness ratio = $2.51^{0.9} \approx 2.3$, i.e. A appears about 2.3 times (about twice) as bright as B.

Power output: using Stefan's law $P = \sigma AT^4 = \sigma \times 4\pi r^2 \times T^4$, with r in metres:

$$P_A = 5.67 \times 10^{-8} \times 4\pi \times (4.7 \times 10^8)^2 \times 4500^4 = 6.45 \times 10^{25} \text{ W}$$

$$P_B = 5.67 \times 10^{-8} \times 4\pi \times (4.1 \times 10^8)^2 \times 4100^4 = 3.38 \times 10^{25} \text{ W}$$

So $P_A / P_B = 6.45 / 3.38 \approx 1.9$, i.e. A has about twice the power output of B.

Distance: the intensity received at Earth is $I = P / 4\pi d^2$. If both stars were at the same distance, the brightness ratio would equal the power



ratio, about 1.9. The observed ratio is about 2.3, which is very similar

(it gives $d_B/d_A = \sqrt{2.3/1.9} \approx 1.1$).

Evaluation: as A has about twice the power output of B and A appears about twice as bright, the two stars must be at about the same

distance from Earth. This is consistent with (supports) the idea that they form a binary system rather than simply lying in the same line of sight.

However, being the same distance away does not prove they are a binary; this could be confirmed by observing their orbital motion (e.g. periodic Doppler shifts or changing positions).

0 2 . 4

What is the spectral class of 61 Cygnus A?
Tick (✓) the correct box.

[1 mark]

- | | |
|---|-------------------------------------|
| A | ☐ |
| F | ☐ |
| G | ☐ |
| K | ☒ |

12

Turn over ►



0 3 . 1

Describe the links between galaxies, black holes and quasars.

[2 marks]

*Quasars are produced by (powered by) supermassive black holes.**These supermassive black holes are at the centres of (active) galaxies: a quasar is an active galactic nucleus, where matter falling towards the black hole emits huge amounts of radiation.*

0 3 . 2

At a distance of 5.81×10^8 light year, Markarian-231 is the closest known quasar to the Earth. The red shift z of Markarian-231 is 0.0415

Use these data to estimate an age, in seconds, of the Universe.

[4 marks]

$$v = cz = 3.0 \times 10^8 \times 0.0415 = 1.25 \times 10^7 \text{ m s}^{-1} (= 1.25 \times 10^4 \text{ km s}^{-1})$$

$$d = 5.81 \times 10^8 \text{ ly} = 5.81 \times 10^8 / 3.26 = 1.78 \times 10^8 \text{ pc} = 178 \text{ Mpc}$$

$$(d = 5.81 \times 10^8 \times 9.46 \times 10^{15} = 5.50 \times 10^{24} \text{ m})$$

$$v = Hd \quad \text{so} \quad H = v/d = 1.25 \times 10^4 / 178 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$\text{Age of Universe} \approx 1/H = d/v$$

$$= 5.50 \times 10^{24} / 1.25 \times 10^7 = 4.4 \times 10^{17} \text{ s}$$

$$\text{age} = \underline{4.4 \times 10^{17}} \text{ s}$$



0 3 . 3

A typical quasar is believed to be approximately the size of the solar system, with a power output similar to that of a thousand galaxies.

Estimate, with reference to the inverse-square law, how much further the most distant visible quasar is likely to be compared to the most distant visible galaxy.

[3 marks]

The most distant visible quasar and the most distant visible galaxy must have the same (minimum detectable) brightness, i.e. the same received intensity at Earth.

Inverse-square law: $I = P / 4\pi d^2$, so $P_{\text{quasar}} / d_{\text{quasar}}^2 = P_{\text{galaxy}} / d_{\text{galaxy}}^2$

With $P_{\text{quasar}} = 1000 P_{\text{galaxy}}$: $1000 / d^2 = 1/1$, so $(d_{\text{quasar}} / d_{\text{galaxy}})^2 = 1000$, giving $d_{\text{quasar}} / d_{\text{galaxy}} = (1000)^{1/2} \approx 32$.

So the most distant visible quasar is about 30 times further away than the most distant visible galaxy.

9

Turn over for the next question

Turn over ►



0 4

Evidence to support the Big Bang theory comes from cosmological microwave background radiation and the relative abundance of hydrogen and helium in the Universe.

0 4 . 1

Explain what is meant by cosmological microwave background radiation and how its existence supports the Big Bang theory.

[3 marks]

CMBR is electromagnetic radiation coming from all parts of the Universe (from all directions), with almost the same intensity in every direction (isotropic).

Its spectrum is a black-body curve with a peak in the microwave region, corresponding to a temperature of about 2.7 K.

It was emitted when the Universe had cooled sufficiently for matter and radiation to decouple: protons and electrons combined to form neutral atoms, so the photons could then travel freely.

As the Universe has expanded, this radiation has been red-shifted (stretched to longer wavelengths and lower energies) into the microwave region.

It is interpreted as the radiation left over from the hot, dense early Universe, as predicted by the Big Bang theory, so its existence supports the theory.



0 4 . 2

Explain how the relative abundance of hydrogen and helium supports the Big Bang theory.

[3 marks]

The Big Bang theory suggests that, when the Universe was very young, it was hot and dense enough for a very brief period of nuclear fusion, producing helium from fusing hydrogen (protons and neutrons).

Protons and neutrons were created in a ratio of about 7:1. Fusion stopped as the Universe then expanded and cooled, too rapidly for larger nuclei to be created.

This results in a relative abundance of hydrogen to helium (by mass) of about 3:1, which matches what is observed in the Universe, supporting the Big Bang theory.

6

END OF QUESTIONS



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