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Candidate number

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Surname

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Forename(s)

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Astrophysics

Friday 5 June 2020

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.
- 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	



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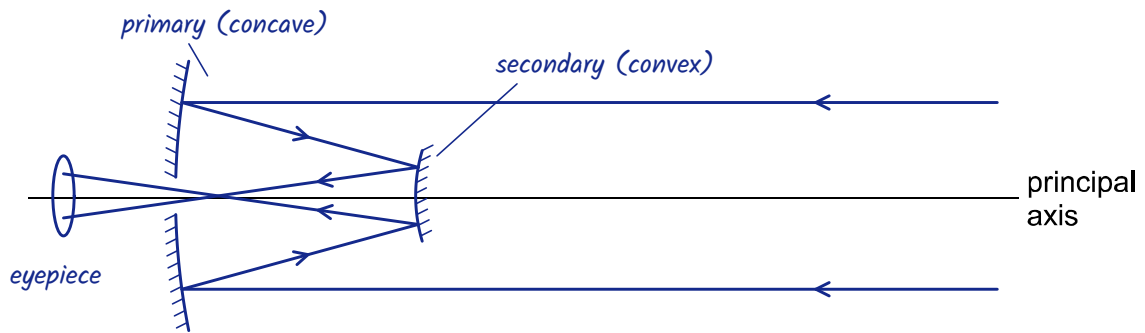
Section B

Answer **all** questions in this section.

0 1 . 1

Draw a ray diagram for a Cassegrain telescope.
Your diagram should show the paths of **two** rays up to the eyepiece lens.
The rays should initially be parallel to the principal axis.

[2 marks]



0 1 . 2

A spacecraft passes Pluto at a distance of 12 500 km. The telescope on board has an aperture of diameter 0.21 m and operates at a wavelength of 450 nm.

Discuss whether this telescope is suitable for studying a crater with a diameter of approximately 1 km on Pluto.

[3 marks]

$$\theta \approx \lambda/D = 450 \times 10^{-9} / 0.21 = 2.14 \times 10^{-6} \text{ rad}$$

$$\text{smallest detail} = \theta \times \text{distance} = 2.14 \times 10^{-6} \times 12.5 \times 10^6 \text{ m}$$

$$\text{smallest detail resolved} \approx 27 \text{ m}$$

The telescope can resolve detail about 27 m across on Pluto, which is much smaller than the 1 km crater (the crater is about 40 times bigger, it subtends about 8.0×10^{-5} rad, much more than 2.1×10^{-6} rad).

So the telescope is suitable for studying the crater.



0 1 . 3

The Hubble telescope has an aperture of diameter 2.4 m.

Compare the collecting power of the Hubble telescope with the telescope on the spacecraft in Question 01.2.

[2 marks]

$$\text{collecting power} \propto \text{area} \propto D^2$$

$$\text{ratio} = 2.4^2 / 0.21^2 = 5.76 / 0.0441 = 130$$

Collecting power is proportional to the area of the aperture (objective),
so to diameter squared.

Hubble's collecting power is about 130 times greater than that of the
spacecraft telescope, so it collects much more light and can see much
fainter objects.

0 1 . 4

An astrophysicist had to decide whether to use a reflecting telescope or a refracting telescope on the spacecraft in Question 01.2.

Discuss which type of telescope to use.

[3 marks]

Lenses in refractors suffer from chromatic aberration (and spherical
aberration), but mirrors do not suffer chromatic aberration.

Reflectors are lighter and shorter than refractors of the same aperture,
which matters on a spacecraft.

But in a reflector the secondary mirror and its support block some light,
reducing image brightness and causing diffraction effects.

I would use a reflecting telescope: with no chromatic aberration the
image of the crater is sharper with no coloured fringes.

10

Turn over ►



0 2

Table 1 summarises some information about four stars in the constellation Cassiopeia.

Table 1

Name	Colour	Apparent magnitude	Distance / ly
Caph	white	2.3	55
Ruchbah	blue/white	2.7	99
Schedar	orange	2.2	228
Tsih	blue	2.2	610

0 2

. 1

Which star has the highest surface temperature?
Tick (✓) **one** box.

[1 mark]

Caph

☐

Ruchbah

☐

Schedar

☐

Tsih

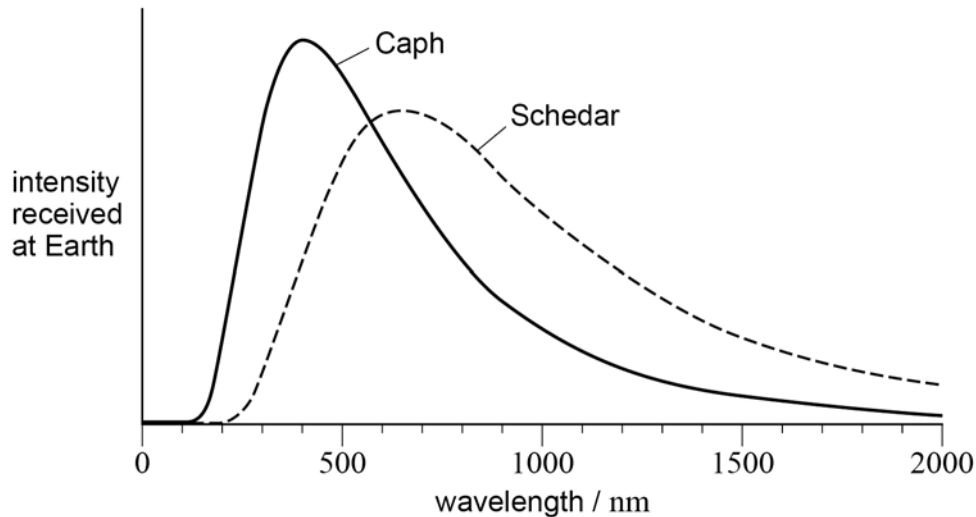
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0 2 . 2

Figure 1 shows the intensity received at Earth from two of the stars, plotted against wavelength.

The effect of absorption by the Earth's atmosphere is not shown.

Figure 1



Discuss what information can be found from **Figure 1** about the temperature and colour of these stars.

Support your answer with suitable calculations.

[4 marks]

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

Caph: $\lambda_{\max} \approx 400 \text{ nm}$, $T = 2.9 \times 10^{-3} / 400 \times 10^{-9} = 7250 \text{ K}$

Schedar: $\lambda_{\max} \approx 660 \text{ nm}$, $T = 2.9 \times 10^{-3} / 660 \times 10^{-9} = 4400 \text{ K}$

so Caph is much hotter than Schedar

The colour depends on the wavelengths produced (emitted) across the visible spectrum.

Schedar's peak is at a longer wavelength and it emits relatively more long wavelength (red) light, so it is redder (orange) than Caph. Caph peaks near the blue end but emits across all the visible spectrum, so it looks white.

This agrees with spectral class: 7250 K is class F (white) and 4400 K is class K (orange).

Question 2 continues on the next page

Turn over ►



0 2 . 3

State which star in **Table 1** is dimmest on the absolute magnitude scale.

[1 mark]

Caph

0 2 . 4

Calculate the absolute magnitude of Schedar.

[3 marks]

$$d = 228 \text{ ly} \div 3.26 = 70 \text{ pc}$$

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

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

$$M = 2.2 - 5 \log(70/10) = 2.2 - 4.2$$

$$M = -2.0$$

absolute magnitude = -2.0

0 2 . 5

Tsih has a mass over 15 times the mass of the Sun.
Tsih may eventually collapse to form a black hole.

Calculate the radius of the event horizon for a black hole with a mass 15 times that of the Sun.

[2 marks]

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

$$M = 15 \times 1.99 \times 10^{30} = 2.99 \times 10^{31} \text{ kg}$$

$$R_s = 2 \times 6.67 \times 10^{-11} \times 15 \times 1.99 \times 10^{30} / (3.00 \times 10^8)^2$$

$$R_s = 4.4 \times 10^4 \text{ m}$$

radius = 4.4 × 10⁴ m

11



0 3

Type Ia supernovae can be used as standard candles.

0 3 . 1

State what is meant by a standard candle.

[1 mark]

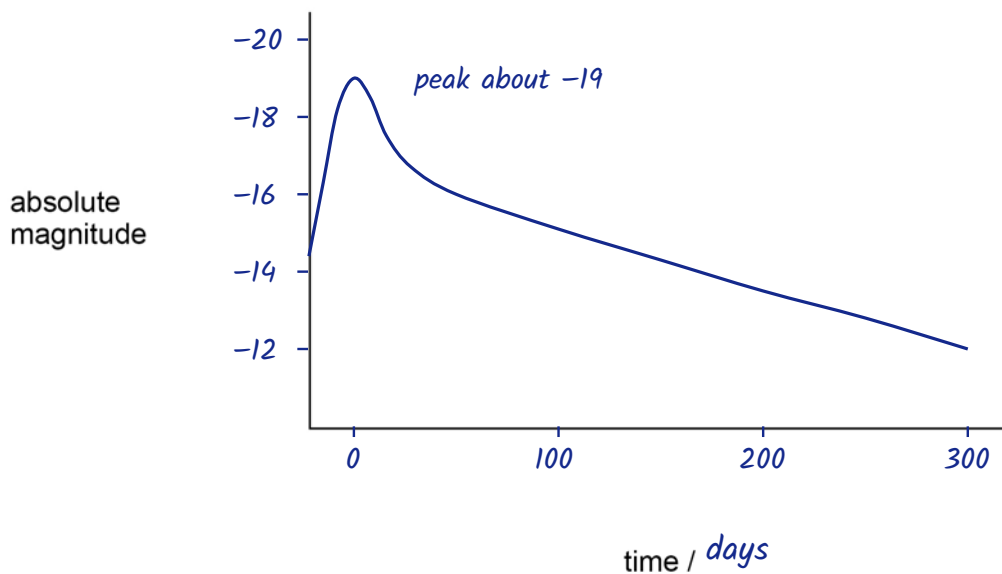
An object (e.g. a type Ia supernova) of known absolute magnitude, so its luminosity (intrinsic power output) is known.

0 3 . 2

Sketch on **Figure 2** the light curve for a type Ia supernova. Annotate your graph with suitable scales and a unit for time.

[3 marks]

Figure 2



Question 3 continues on the next page

Turn over ►



0 3 3

Measurements of type 1a supernovae are used to find a value for the Hubble constant.

The distance from Earth is known for many type 1a supernovae.

Describe how these values of distance are used, with other data, to find the Hubble constant.

Your answer should include:

- the other data needed and how these data are used
- the graph plotted, including appropriate units for the axes
- how the Hubble constant is obtained and any limitations on the result.

[6 marks]

Data needed: the distance d of each supernova is found from its known absolute magnitude M and its measured apparent magnitude m , using

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

We also need the red shift z of the galaxy containing each supernova.

The spectrum of the light is recorded and the wavelength of known spectral (absorption) lines, e.g. hydrogen lines, is measured and compared with the wavelength of the same line from a source at rest in the laboratory: $z = \Delta\lambda/\lambda$.

The recessional velocity of each galaxy is then found from $v = zc$ (valid as z is much less than 1).

Graph: plot recessional velocity v (in km s^{-1}) on the y-axis against distance d (in Mpc) on the x-axis. The points lie close to a straight line through the origin, showing $v = H_0 d$.

The Hubble constant H_0 is the gradient of the line of best fit, in $\text{km s}^{-1} \text{Mpc}^{-1}$ (it can be converted to s^{-1} by changing Mpc to km).

Limitations: there is a lot of scatter in the data, because galaxies have their own (peculiar) motions as well as the expansion, and because of random errors in measuring m and λ , so data from lots of supernovae are needed.



The apparent magnitude may be affected by dust and gas that the light passes through (absorption), which makes the distance too large.

At large distances the accelerating expansion of the universe affects the graph, so it is no longer a straight line and the value of H_0 depends on which data are used.

Turn over for the next question

10

Turn over ►



0 4

Table 2 gives data about the supergiant star Melnick 34 and the Sun.

Table 2

Name	Radius / m	Surface temperature / K
Melnick 34	1.4×10^{10}	53 000
Sun	7.0×10^8	5 700

0 4

1

Calculate $\frac{\text{power output of Melnick 34}}{\text{power output of the Sun}}$.

[2 marks]

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

$$\text{ratio} = \sigma 4\pi r_M^2 T_M^4 / \sigma 4\pi r_S^2 T_S^4 = (r_M/r_S)^2 \times (T_M/T_S)^4$$

$$= (1.4 \times 10^{10})^2 \times 53000^4 / ((7.0 \times 10^8)^2 \times 5700^4)$$

$$= 400 \times 7.47 \times 10^3 = 3.0 \times 10^6$$

answer = 3.0×10^6

0 4

2

Discuss why the evolution of a supergiant star in the local part of our galaxy could be dangerous for life on Earth.

[2 marks]

A supergiant will undergo a supernova, collapsing to form a neutron star or black hole.

This can produce a gamma ray burst: a highly collimated, very intense beam of gamma rays. If it is directed at Earth it could damage DNA and kill cells (and destroy the ozone layer), so it could wipe out life.

4

END OF QUESTIONS



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1 6



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