AQA

Please write clearly in block capitals.

Centre number | 1 | 3 | 5 | 2 | 6 | Candidate number | 6 | 2 | 4 | 9 |

Surname Matheson

Forename(s) Lewis

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3
Section B Astrophysics

ALevelPhysicsOnline.com

Thursday 15 June 2023 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.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
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.

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Section B

Answer **all** questions in this section.

0 1 . 1 Draw a labelled diagram to define the parsec (pc).

[1 mark]

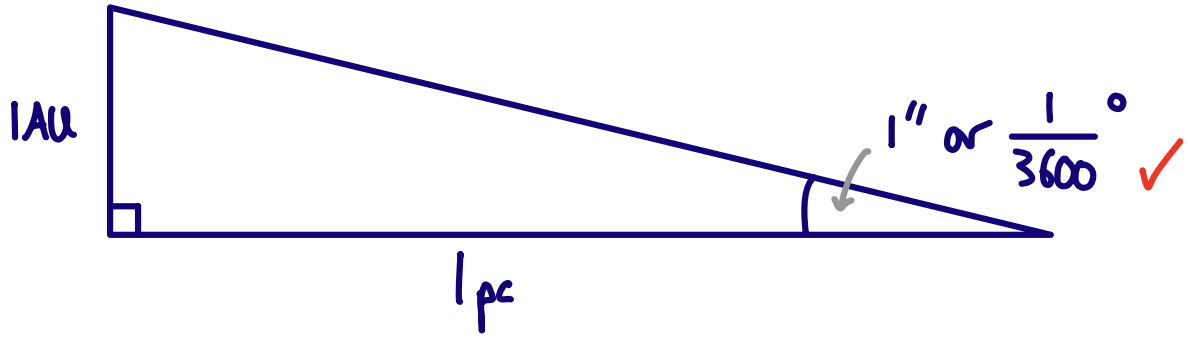

Table 1 shows data for two stars: Rigel and the Sun.

Table 1

Star	Surface temperature / K	Absolute magnitude	Mass / kg
Rigel	12 000	−7.84	3.6×10^{31}
Sun	5700	4.83	2.0×10^{30}

0 1 . 2 State the spectral class of Rigel.

[1 mark]

B ✓ (As temperature between 11,000 and 25,000 K)

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0 1 . 3 The apparent magnitude of Rigel is 0.11

Calculate, in pc, the distance from Rigel to the Earth.

[2 marks]

$$m - M = 5 \log\left(\frac{d}{10}\right)$$

$$\frac{m-M}{5} = \log\left(\frac{d}{10}\right)$$

$$\frac{m-M}{5} = \log d - \log 10$$

$$\log d = \frac{m-M}{5} + 1$$

$$d = 10^{\left(\frac{m-M}{5}+1\right)}$$

$$d = 10^{\left(\frac{0.11-(-)7.84}{5}+1\right)}$$

$$d = 389$$

distance = 390 ✓ pc

Question 1 continues on the next page

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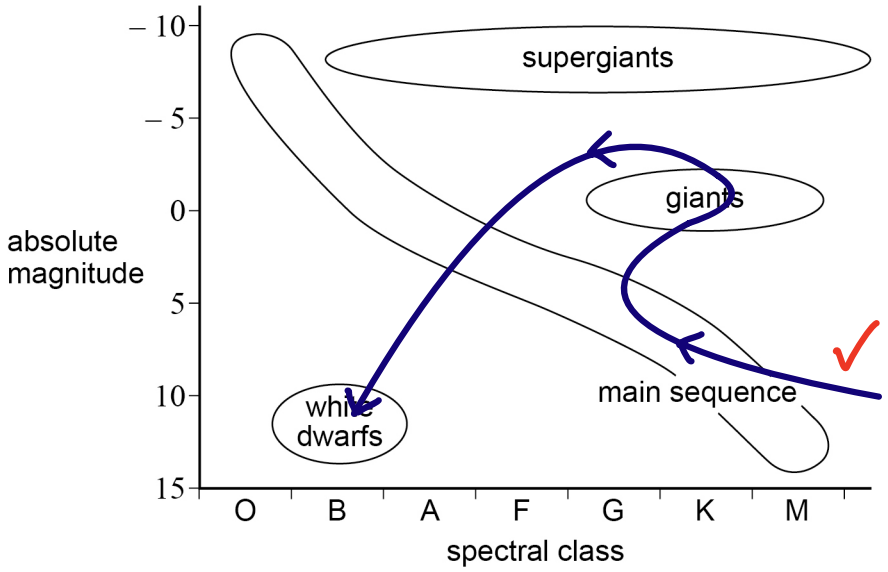
0 1 . 4 **Figure 1** shows a Hertzsprung–Russell (HR) diagram.

Figure 1



Draw a line on **Figure 1** to show the evolution of the Sun from formation to white dwarf.

[1 mark]

0 1 . 5 One stage in the evolution of Rigel includes the emission of a gamma ray burst.

Outline the circumstances during which a gamma ray burst will be emitted by Rigel.

[2 marks]

When a red supergiant collapses ✓ and forms either a neutron star of a black hole. ✓

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0 2 . 1 State what is meant by normal adjustment when applied to an astronomical refracting telescope.

[1 mark]

The final image is at infinity. ✓

0 2 . 2 Which combination of lenses gives the largest angular magnification when used as an astronomical telescope in normal adjustment?

Tick (✓) **one** box.

Both must be converging and $f_o > f_e$

[1 mark]

Objective lens		Eyepiece lens		
Focal length / cm	**Type**	**Focal length / cm**	**Type**	
~~5~~	~~diverging~~	~~100~~	converging	
~~5~~	converging	~~100~~	converging	
100	~~diverging~~	5	converging	
100	converging	5	converging	✓ ✓

V1031 and WASP-82 are two stars in the constellation Orion.
V1031 appears 40 times brighter than WASP-82 when viewed from Earth.
The apparent magnitude of V1031 is 6.0

0 2 . 3 Calculate the apparent magnitude of WASP-82.

[2 marks]

$2.51^x = 40$

Difference in apparent magnitudes

$x = \log_{2.51}(40) = 4.01$

$4.01 + 6.0 = 10.01$ ✓

apparent magnitude = 10 ✓

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0 2 . 4 V1031 is just visible to the naked eye of an astronomer when her pupil diameter is 7 mm.

Suggest whether she can observe WASP-82 using a telescope with an objective diameter of 60 mm.
Support your answer with a calculation.

[2 marks]

$P \propto A \therefore P \propto d^2 \therefore P/d^2 = k$

$\frac{P_{eye}}{d^2_{eye}} = \frac{P_{tele}}{d^2_{tele}} \quad \frac{P_{tele}}{P_{eye}} = \frac{d^2_{tele}}{d^2_{eye}} = \left(\frac{60}{7}\right)^2 = 73.5$ ✓

The telescope is 73 times more powerful than the eye, $73 > 40$ ∴ WASP-82 can be observed. ✓

0 2 . 5 CCDs are often connected to telescopes.

Explain **two** reasons why this improves the ability of astronomers to observe dim stars.

[3 marks]

1 CCDs have a better quantum efficiency ✓ because a greater proportion of incident photons are detected. ✓

2 It can be exposed for long periods so more light is collected. ✓

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0 3 . 1 State the defining property of a black hole.

[1 mark]

An object that has an escape velocity greater than the speed of light. ✓

0 3 . 2 In 2019, astronomers linked several radio telescopes to produce a single telescope called the EHT. The resolution of the EHT is the same as the resolution that a telescope with an aperture equal to the diameter of the Earth could achieve.

Table 2 shows data about the EHT and the Hubble telescope.

Event Horizon Telescope ↗ **Table 2**

	Aperture	Operating wavelength
EHT	1.3×10^7 m	1.3 mm
Hubble	2.4 m	410 nm

Galaxy M87 is 5.3×10^7 light years from Earth. The supermassive black hole at the centre of M87 has a mass 6.5×10^9 times the mass of the Sun.

The radius of the event horizon is R.

The astronomers propose to use either the EHT or the Hubble telescope to observe stars whose distance from the centre of the black hole is less than $1000R$.

Discuss, with calculations, which telescope is more suitable for this observation.

[4 marks]

$$R_s = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 6.5 \times 10^9 \times 1.99 \times 10^{30}}{9.00 \times 10^{16}}$$

$R_s = 1.917 \times 10^{13}$ m ✓

Angle subtended by stars either side of the black hole

$$\theta = \frac{2R}{d} = \frac{2 \times 1000 \times 1.917 \times 10^{13}}{5.3 \times 10^7 \times 9.46 \times 10^{15}} = 7.64 \times 10^{-8} \text{ rad}$$ ✓

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Resolution of telescopes

EHT: $\theta = \frac{\lambda}{D} = \frac{1.3\times10^{-3}}{1.3\times10^{7}} = 1.0\times10^{-10}$ rad ✓

Hubble: $\theta = \frac{\lambda}{D} = \frac{410\times10^{-9}}{2.4} = 1.71\times10^{-7}$ rad

EHT is the most suitable as it can resolve region around the event horizon ($1.0\times10^{-10} < 7.64\times10^{-8}$) ✓

0 3 . 3 A star is orbiting the black hole in M87. The star is observed in the plane of its orbit. The wavelength of a spectral line observed in the light emitted from the star varies between a maximum and a minimum value.

maximum value observed = 374.96 nm
minimum value observed = 373.53 nm

Calculate the orbital speed of the star.

[3 marks]

$\Delta\lambda = \frac{374.96 - 373.53}{2} = 0.715$ nm ✓

$\lambda_{average} = \frac{374.96 + 373.53}{2} = 374.245$ nm ✓

$z = \frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ $\quad v = \frac{\Delta\lambda\, c}{\lambda} = \frac{0.715 \times 3.00\times10^{8}}{374.245}$

orbital speed = 5.73×10^{5} ✓ m s^{-1}

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0 4 M40 A and M40 B are two stars that appear very close to each other when viewed from Earth.
There are two possible reasons for this:

- they are an orbiting binary system
- they are distant from each other and only appear in the same line of sight.

In an orbiting binary system, the difference between the apparent magnitude and the absolute magnitude for each star is similar.

Table 3 shows data about these two stars.

Table 3

	Temperature / K	**Radius of star / m**	**Apparent magnitude**
M40 A	6000	6.3×10^{9}	9.7
M40 B	4700	1.1×10^{10}	10.1

Discuss the appearance of the two stars to an astronomer on the Earth.
In your answer you should:

- compare the colour of the stars
- compare the brightness of the stars
- deduce, with a calculation, whether the stars form an orbiting binary system.

[6 marks]

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Colour: B is cooler than A ✓

A is a F/G star ∴ White/yellow-white

B is a K star ∴ Orange ✓

(The class is related to temperature)

Brightness: $2.51^{10.1-9.7} = 2.51^{0.4} = 1.5$ ✓

A appears 1.5 times brighter than B as difference in apparent magnitude is 0.4.

Distance: A: $P = \sigma A T^4$

$P = 5.67\times10^{-8} \times \pi \times (6.3\times10^{9})^2 \times 6000^4$

$P_A = 3.66\times10^{28}$ W ✓

B: $P = \sigma A T^4$

$P = 5.67\times10^{-8} \times \pi \times (1.1\times10^{10})^2 \times 4700^4$

$P_B = 4.22\times10^{28}$ W ✓

The power output of A is less than B, but it appears brighter in the sky.

∴ A must be closer than B and they are not part of a binary system. ✓

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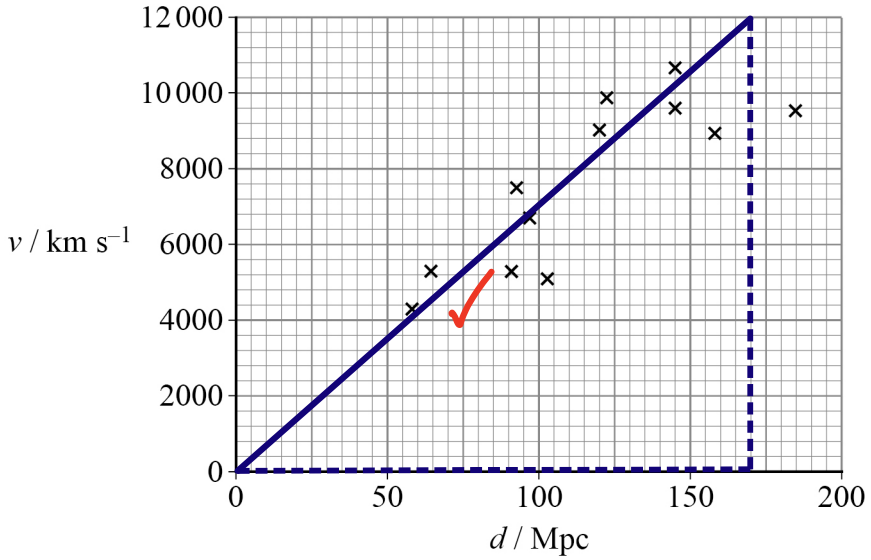
0 5 **Figure 2** shows, for some galaxies, how their recession speed v varies with distance d from the Earth.

Figure 2



0 5 . 1 Estimate, using **Figure 2**, the age in seconds of the Universe.

[3 marks]

$v = H_0 d$ $\quad H_0 = \frac{\Delta v}{\Delta d} = \frac{12\,000}{170}$ km s^{-1} Mpc ✓

$H_0 = \frac{12\,000 \times 1000}{170 \times 3.09 \times 10^{22}} = 2.28 \times 10^{-18}$ s^{-1}

$t = \frac{1}{H_0} = \frac{1}{2.28 \times 10^{-18}}$

age of Universe = 4.38×10^{17} ✓ s

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0 5 . 2 The estimate in Question **05.1** assumes that the Universe has expanded at a constant rate. Measurements involving type 1a supernovae that are at large distances from Earth caused astronomers to make a modification to this assumption.

State:

- the modification
- the explanation that was proposed to account for this modification.

[2 marks]

The rate of expansion of the Universe is increasing ✓, due to dark energy. ✓

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END OF QUESTIONS

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