Diploma Programme
Programme du diplôme
Programa del Diploma

Astronomy
Standard level
Paper 2

Specimen paper

Candidate session number

1 hour 30 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer all questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the astronomy data booklet is required for this examination paper.
- The maximum mark for this examination paper is **[60 marks]**.

18 pages

Section A

Answer **all** questions. Write your answers in the boxes provided.

1. This question is about Kepler's third law of planetary motion.

Johannes Kepler (1571–1630) proposed three laws for planetary motion. The third law gives the relationship between a planet's orbital period (T) and its orbital distance (R) as

Equation 1: $$T^2 = \text{constant} \times R^3$$

Isaac Newton (1642–1727) explained this variation by considering his Law of Gravitation applied to circular motion, giving

Equation 2: $$T^2 = \frac{4\pi R^3}{GM}$$

(a) Using data for the orbit of the Earth, show that the value of the constant in Equation 1 is approximately 3×10^{-19}. Your answer should be given to 3 significant figures. [3]

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(b) Identify the SI units for the constant in Equation 1. [1]

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(Question 1 continued)

(c) The orbital distance of Jupiter is 7.78×10^{11} m. Calculate Jupiter's orbital period in seconds. [2]

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(d) Use the value of the constant in Equation 1 to calculate the mass of the Sun. [3]

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(e) Over time, the Sun loses mass in the form of a solar wind. On the assumption that given a long enough time, this would not be insignificant, briefly describe the effect you would expect this to have on Jupiter's orbital distance. [1]

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2. This question is about the search for extra-terrestrial intelligent life.

The search for intelligent life in the universe is presently limited to our own galaxy. One of the favoured ways of doing this is to use radio signals.

(a) Explain why we do not send out probes or spaceships to search for life outside the solar system. [2]

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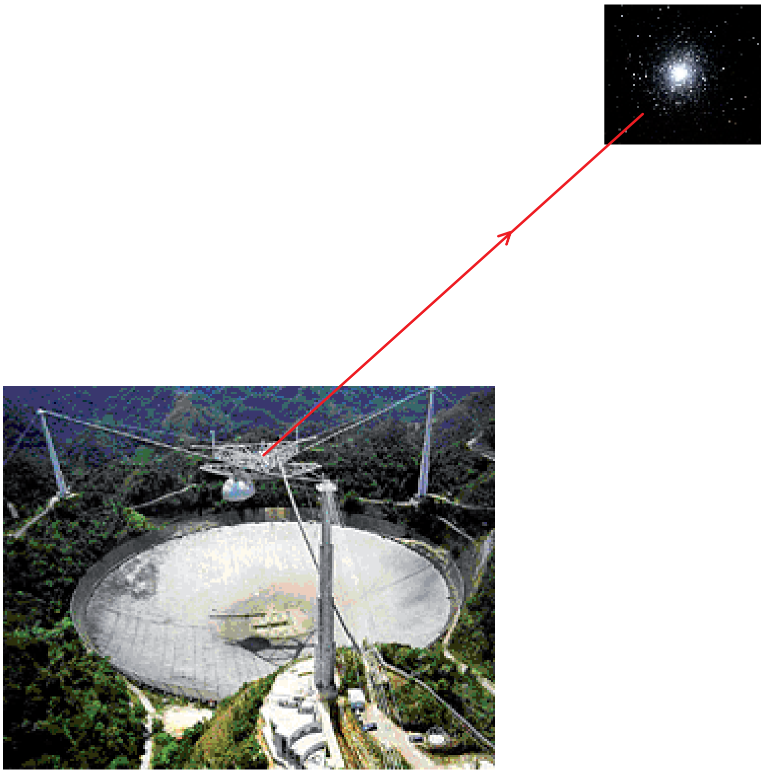
(Question 2 continued)

(b) Radio signals travel at the speed of light and in 1974 a signal was sent from the Arecibo telescope in Puerto Rico. The signal was sent in the direction of the globular cluster known as M13, about 25 100 light-years away (**Figure 1**).

Figure 1: Arecibo radio signal sent to M13



Considering the same point in the year 2007, calculate how far the signal had travelled towards M13. Express your answer in both light years **and** metres. [3]

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(Question 2 continued)

(c) The message sent towards M13 was coded information in the form of 1679 “bits” of data. Each bit can be considered as an individual dot making up an image. This produces an image made of 1679 dots.

The data was in a form such that each bit was either a “1” or “0” *ie*, the signal was a collection of “1”s and “0”s – a “1” indicating that the dot was black and a “0” indicating that the dot was white (or blank).

1679 is the product of the two prime numbers 23 and 73 *ie*, $23 \times 73 = 1679$.

Define what is meant by prime numbers. [1]

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(d) Explain how this fact would allow intelligent life to take the 1679 sequence of dots and reform an image that would make sense. [2]

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(Question 2 continued)

(e) If the message successfully reached M13, was seen by intelligent life, and then a message was sent back to us, calculate, in seconds, how much time the total trip there and back would have taken. [2]

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3. This question is about the Milky Way galaxy.

(a) The Milky Way is known as a spiral galaxy (**Figure 5**).

Figure 5: An impression of the Milky Way galaxy

Spiral galaxies are noted for having three basic parts. One is called the *disc* (which contains the spiral arms). State the other two parts of a spiral galaxy. [2]

1: . . . .

2: . . . .

(b) The spiral arms of the Milky Way were once incorrectly thought to be the regions where stars were concentrated. This is now known to be false.

Explain what produces the spiral arms. [2]

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(Question 3 continued)

(c) Most of the young (newly formed) stars of the Milky Way lie in the disc. Explain this fact. [2]

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(d) It is thought that the spiral arms of the Milky Way are not due to the light output from a fixed set of stars. If this were so, then they would be expected to wind up around the rotating galaxy – a problem known as the winding dilemma.

Explain the generally fixed shape of the spiral arms, hence showing how this dilemma can be explained. [2]

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(e) If other stars in the Milky Way are observed, it is seen that those stars which are both behind us and further out from the galactic centre show red-shift. Explain why this observation does **not** mean that the galaxy is expanding. [2]

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4. This question is about the density of the universe.

There is a theory which suggests that the ultimate fate of the universe will be determined by how strong the gravitational forces are within it. To try to quantify this, it has been found useful to consider the density ρ of the universe compared with the so-called critical density ρ_o.

The critical density is estimated to be approximately $1 \times 10^{-26}\,\text{kg m}^{-3}$. If the universe has an overall average density greater than this, then it is thought that the universe will stop expanding and contract. If the density of the universe is less than this, then the universe will expand forever.

(a) The age of the universe is thought to be 13.8×10^{9} years. Show that this time is approximately equal to 4.4×10^{17} s. Your answer should be expressed to at least 3 significant figures. [1]

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(b) From the moment of the Big Bang, the size of the observable universe has expanded at the speed of light. Using your answer to (a), what would be the radius of the observable universe? Express your answer in metres. [2]

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(Question 4 continued)

(c) Assuming that the observable universe has expanded since the Big Bang, equally in all directions, calculate the volume of the visible observable universe.

(It may be useful to recall that the volume of a sphere is given by $V = \frac{4}{3}\pi r^3$) [2]

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(d) The number of stars in the observable universe is suggested to be 3×10^{22}. If it is assumed that there is no other significant mass in the universe and if the stars are assumed to have an average mass of $1\,M_{\odot}$, calculate the total mass of the observable universe in kg. Express your answer to the appropriate number of significant figures. [1]

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(e) Calculate the density of the observable universe. Express your answer to the appropriate number of significant figures.

(It may be useful to recall that $\text{Density} = \frac{\text{Mass}}{\text{Volume}}$) [2]

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(Question 4 continued)

(f) By considering how your answer to (e) compares with the critical density of the universe, comment on the ultimate fate of the universe. [2]

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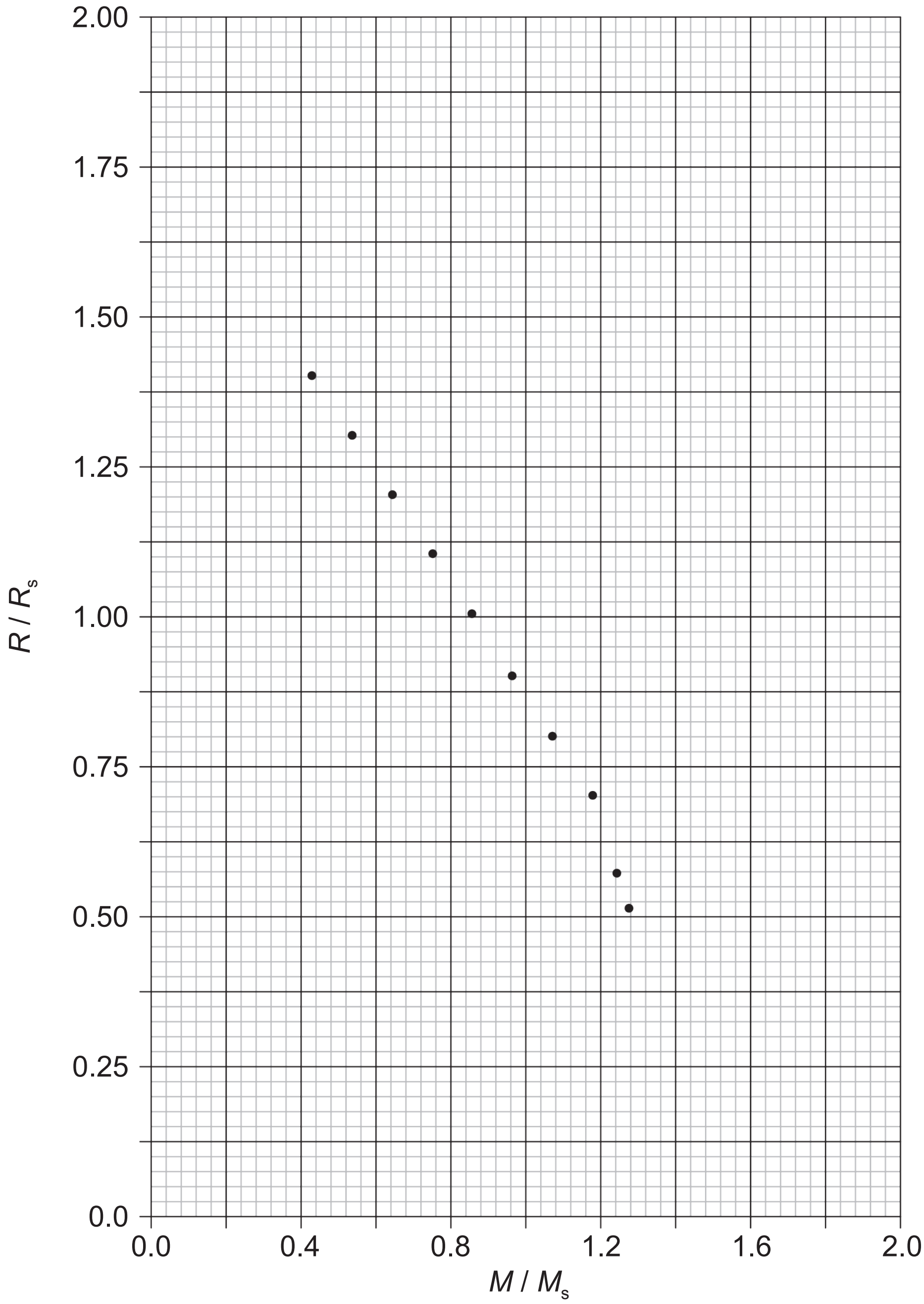
Section B

Answer **all** questions. Write your answers in the boxes provided.

5. This question is about the mass-radius relation for a certain type of star. Please note that in this question, solar values are designated by the subscript '$_s$', not the more usual 'Θ'.

The radius R and mass M of ten different stars were measured and the results are shown plotted below.



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(Question 5 continued)

The radius is expressed in terms of the Sun's radius R_s and the mass in terms of the Sun's mass M_s.

The uncertainty in the measurement of the mass is negligible. The uncertainty in the measurement of the radius is $\pm 0.05\ R_s$.

(a) The first data point is for a star with a mass of 0.32 times the mass of the Sun.

(i) Determine the fractional uncertainty in the value of its radius. [3]

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(ii) Without additional calculation, explain how the percentage uncertainty in the value of radius of the stars, changes as the mass of the star increases. [3]

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(b) Draw error bars for the first and the last data points.

(c) Using your answer to (b):

(i) suggest why there might be a linear relationship between R and M for these stars. [2]

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(Question 5 continued)

(ii) determine the equation for this linear relationship. [3]

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(iii) estimate the maximum value for the mass of this type of star. [1]

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(d) Suggest why no star of this type can in fact have a mass equal to your answer to (b)(iii). [1]

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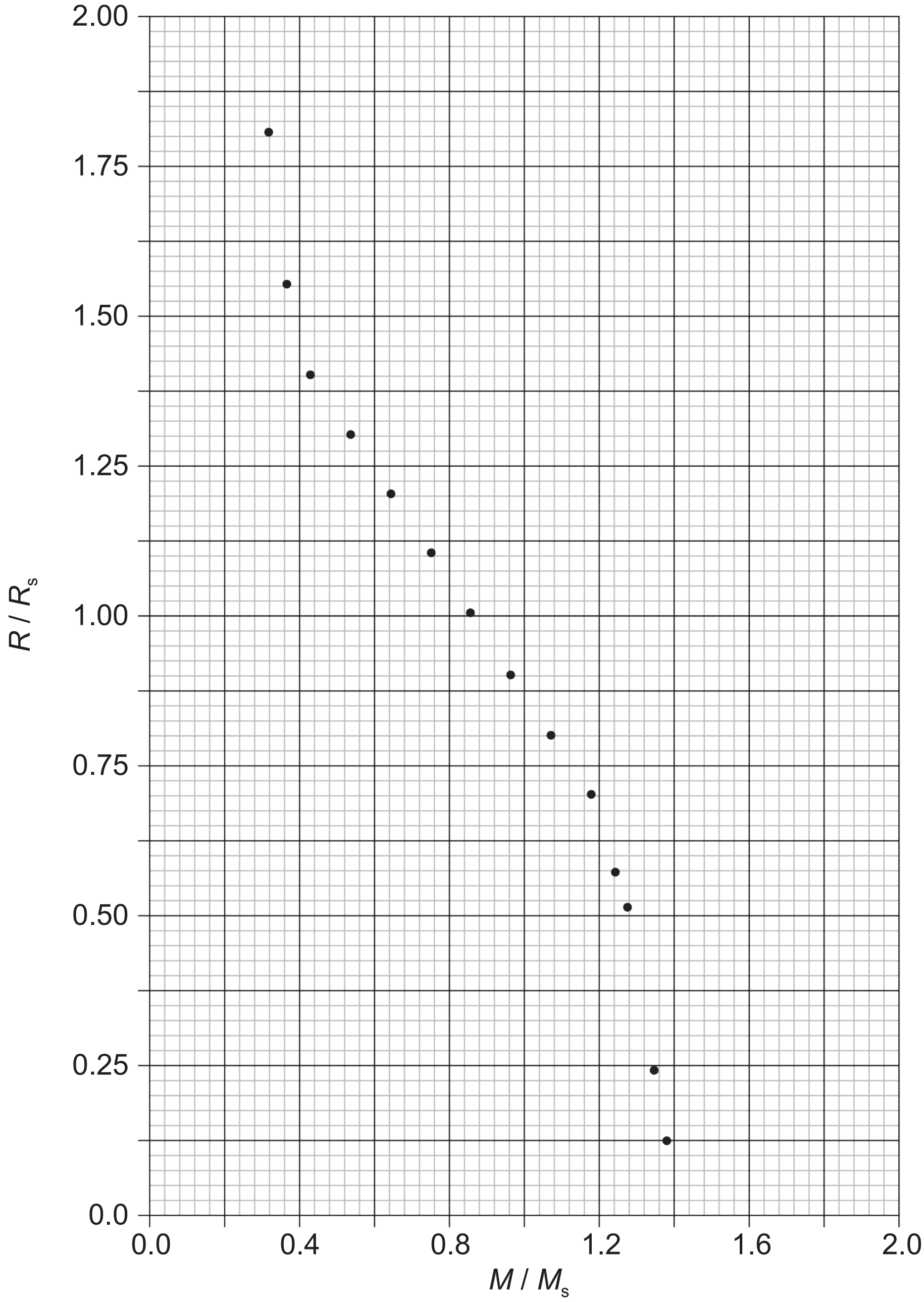
(Question 5 continued)

(e) Additional data show that the relation between *R* and *M* is in fact not linear, as suggested by the graph below.



Uncertainties in the data are not shown.

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(Question 5 continued)

(i) Draw a line of best-fit for the data. [1]

(ii) The new data suggests that the maximum value for the mass of this type of star is different from your answer in (b)(iii). Estimate this new value. [1]

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(iii) Suggest why your answer to (d)(ii) is only an estimate. [1]

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(f) It is hypothesized that the mass-radius relation for a different type of star is $R = kM^n$ where k and n are constants.

Explain how a graph may be used to:

(i) verify this hypothesis. [2]

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(ii) determine the constant n. [1]

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