# BPhO
## British Physics Olympiad

# British Olympiad in Astronomy and Astrophysics

# **Trial Paper**

| Name | |
|------|--|
| School | |

# **March 2015**

**Total Mark/50**

*Time Allowed: **One hour***

*Attempt as many questions as you can.*

*Write your answers on this question paper.*

*Marks allocated for each question are shown in brackets on the right.*

*You may use any calculator.*

*You may use any standard formula sheet.*

*This is a trial paper for the British Olympiad in Astronomy and Astrophysics. The first competition paper of the British Olympiad in Astronomy and Astrophysics will take place in April 2015 and will have a similar format and questions to this trial paper.*

*To solve some of the questions, you will need to write equations, draw diagrams and, in general, show your working. There are two optional parts that you should attempt in extra time. These are more difficult questions that will not be marked, but they are useful for your training.*

# Useful constants

| Speed of light | $c$ | $3.00 \times 10^8$ | m s$^{-1}$ |
|---|---|---|---|
| Gravitational constant | $G$ | $6.67 \times 10^{-11}$ | N m$^2$ kg$^{-2}$ |
| Solar mass | $M_{\text{solar}}$ | $1.99 \times 10^{30}$ | kg |
| Astronomical Unit | AU | $1.496 \times 10^{11}$ | m |
| Earth's orbit semi-major axis | | 1 | AU |
| Earth's orbital period | 1 year | 365.25 | days |

# Section A: Multiple Choice

*Circle the correct answer to each question. Each question is worth 2 marks. There is only one correct answer to each question. Total: **20 marks**.*

1. Which of the following types of stars is the hottest?

        A. Red giant
        B. Brown dwarf
        C. O-type blue giant
        D. Yellow main sequence star

2. The majority of the mass in the Universe is contained in:

        A. The most massive stars
        B. Gas and dust
        C. Dark matter
        D. Supermassive black holes

3. How much more or less light can an 8-metre aperture telescope collect compared to a 4-metre aperture telescope (in the same amount of time)?

        A. Half the amount
        B. The same amount
        C. Twice as much
        D. Four times as much

4. Why aren't solar/lunar eclipses observed at every new and full moon?

        A. Because the orbital plane of the Moon is tilted compared to the Earth's orbit around the Sun
        B. Eclipses happen every month, but they can be seen from different places on Earth
        C. Most eclipses happen during the day, so they are not visible
        D. Because the Earth-Moon distance changes in time

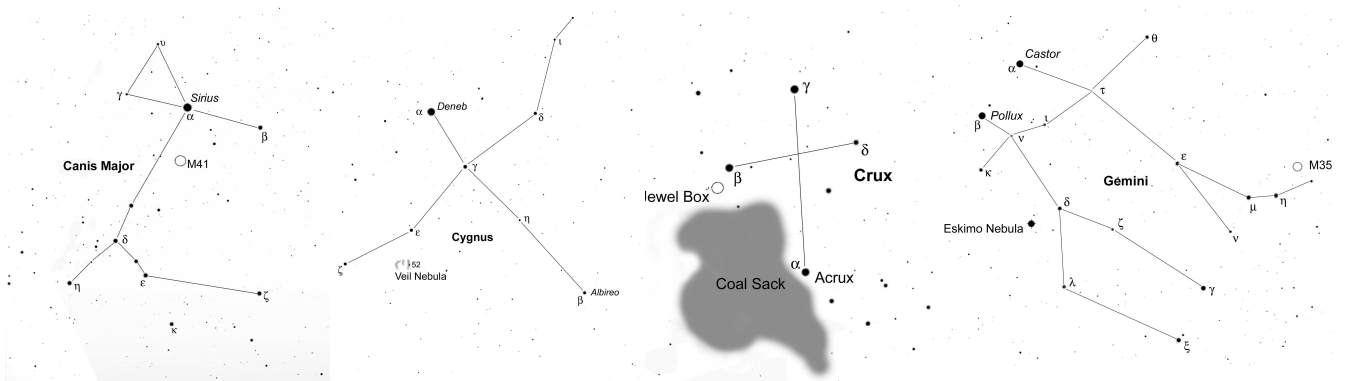5. Which planet would you not be able to see on the night sky at midnight from the UK?



    A. Jupiter          B. Venus          C. Mars          D. Saturn

6. Which of the following constellations is not visible from the UK?



| A. Canis Major | B. Cygnus | C. Crux | D. Gemini |

7. What is Earth's mean orbital speed around the Sun?

     A. $150 \text{ km s}^{-1}$
     B. $30 \text{ km s}^{-1}$
     C. $15 \text{ km s}^{-1}$
     D. $0.3 \text{ km s}^{-1}$

8. If your mass is 65 kg, what is the maximum value of the attractive force exerted on you by Jupiter? The mass of Jupiter is $1.9 \times 10^{27}$ kg and its semi-major axis is 5.2 AU.

     A. $1.4 \times 10^{-5}$ N
     B. $2.1 \times 10^{-11}$ N
     C. $9.6 \times 10^{-6}$ N
     D. $2.1 \times 10^{-5}$ N

9. The famous comet, Halley's comet, appeared in the night sky in 1986. The semi-major axis of its orbit is 17.8 AU. When is it going to return next?

     A. 2023
     B. 2061
     C. 2064
     D. 2093

10. Suppose a colony is established on Mars. How long would it take for a Martian doctor to send a question to a colleague on Earth and receive a response, when Mars is closest to Earth? Assume that the colleague replies instantly. The radius of Mars's orbit is 1.524 AU.

     A. 8.7 minutes
     B. 25.3 minutes
     C. 4.3 minutes
     D. 12.7 minutes

/20

## Section B: Short Answer

*Write your answers to the following questions. Each question is worth 5 marks. You should show your working in the spaces provided.* *Total:* **10 marks**.

### Question 11

In the image below you can see the projection of the shadow of a child onto the wall he faces. The height of the child from head to toes is 1.8 m, the length of the shadow on the wall is 0.8 m and on the ground is 1.6 m.



[*HINT:* It is useful to draw a diagram of the child, the wall and the position of the Sun]

**a)** What is the altitude of the Sun above the horizon?    **Ans:** _____ **[3]**

b) What would be the length of the shadow in the absence of the wall? **Ans:** _____ **[2]**

/5

# Question 12

An astronomer observes a galaxy and finds that one of the lines in the hydrogen spectrum has been redshifted to 669.4 nm, compared to the rest wavelength of 656.3 nm. Assume that the Universe is undergoing a uniform expansion, with the rate given by the Hubble constant, $H_0 = 72 \text{ km s}^{-1}\text{Mpc}^{-1}$.

a) The shift of the line is due to the Doppler effect. What is the velocity $v$ of the receding galaxy, in km s$^{-1}$?                                   **Ans:** _____[3]

b) Edwin Hubble discovered his famous law that the recession velocity of a galaxy is proportional to the distance to the galaxy, the constant of proportionality being $H_0$. What is the distance $r$ to the galaxy in Mpc?                         **Ans:** _____[2]

[A Mpc (abbreviation for megaparsec) is one million parsecs. It is a useful unit used by astronomers to measure the large distances to galaxies]

/5

# Section C: Long Answer

*Write complete answers to the following questions. Each question is worth 10 marks. The last point of each question is optional – for your training only. Total: **20 marks**.*

### Question 13    Solar Eclipse

On the morning of Friday 20th March 2015 a partial solar eclipse will be visible from the whole of the UK. Solar eclipses are quite rare and this will be a major event, with the Moon passing in front of the Sun and covering a large portion of the solar disc. This will be an event you will remember for the rest of your life, but *remember you shouldn't watch the Sun without a suitable filter!*

The radius of the Moon is 1737.5 km and the distance to the Moon will be 365,100 km on that day. The radius of the Sun is 695,800 km and the distance to the Sun is 149.6 million km. The Moon orbits the Earth, in an anticlockwise direction (viewed from the above the North Pole), the same direction as the Earth rotates about its axis. The period of the Moon's orbit around the Earth, relative to the Sun (the synodic period – the period between when the Sun, Moon and Earth are in line), is 29.5 days. Using this information:

a)  Calculate the angular diameters in degrees (how large they appear) of the Sun and of the Moon, respectively, as they will be seen in the sky on that day.

[3]

b)  To observe the eclipse you will be using a telescope with a focal length of 200 cm and an eyepiece with a focal length of 25 mm and field of view (FOV) of 52°. Is it possible to see the entire image of the solar disc in the eyepiece of this telescope?

[2]

c) Suppose that you are observing the eclipse from a place near the North Pole where the Earth's spin can be neglected. Calculate the duration of the eclipse from the first to last contact, assuming that the eclipse is central.

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_____ [3]

d) Explain if the image below (Figure 1) shows the beginning or end of the solar eclipse.



**Figure 1. Binocular view of the solar eclipse. The N and E directions for the observer are shown.**

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_____ [2]

/10

e) *Optional*

Estimate the duration of the eclipse from the first to last contact, assuming that the eclipse is central, for an observer situated in London (latitude $\varphi = 52.5°$). In this case, Earth's spin cannot be neglected. The radius of the Earth is $R_{\text{Earth}} = 6370$ km and the spin period is $T_{\text{Earth}} = 24$ hours. (the distance to the Moon can be taken to be the same).

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# Question 14    Extrasolar planet discovery

In 1995 a team of Swiss astronomers from the Geneva Observatory announced that they had discovered the first planet outside our solar system around the star 51 Pegasi.  They found it by looking at the spectrum of the star and observing the slight change in its velocity, as the star and planet move around their common centre of mass. The planet was found to be orbiting the star on a near circular orbit every 4.23 days, much faster than the Earth is orbiting the Sun. Since then, the radial velocity method that relies on the Doppler effect has been used to discover hundreds of extrasolar planets. The figure below is the original plot of the radial velocity of star 51 Pegasi as it varies with the time.
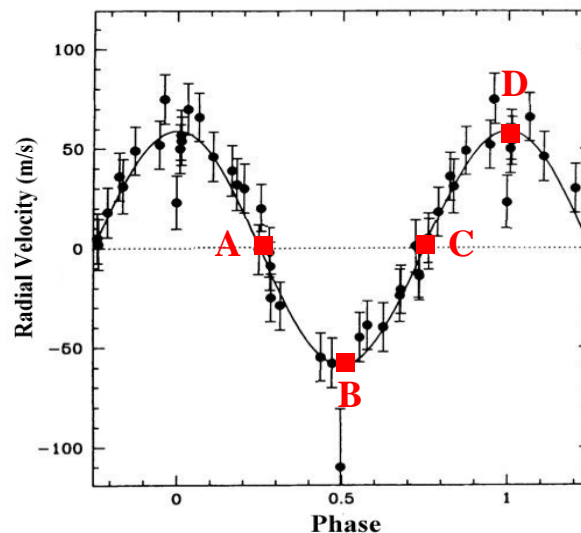


Figure 2. The radial velocity curve of the star 51 Pegasi. The phase of 1 is equivalent to one full period of the planet around the star.

a)  In the figure below (Figure 3), mark in the boxes the letters (A, B, C and D) corresponding to the positions of the star 51 Pegasi around the star-planet centre of mass, as inferred from the radial velocities in Figure 1. Assume that the star is orbiting in a clockwise direction. The figure is not drawn to scale.
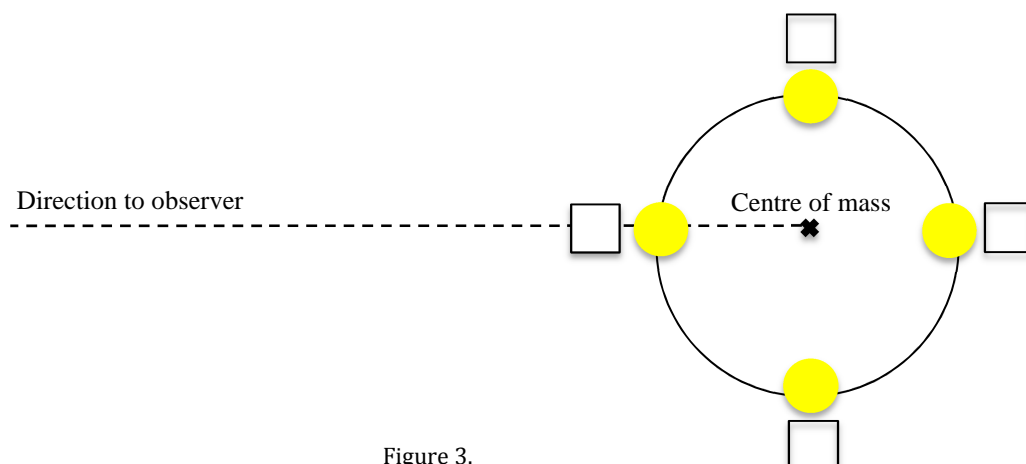


Figure 3.

[2]

9

b) From Figure 2, determine the velocity of the star around the star-planet centre of mass and estimate an error in your determination.

_____

_____ [1]


c) The star 51 Pegasi has a similar mass to the Sun. Estimate the distance from the planet to the star in AU, assuming that the mass of the planet is much less than that of the star.

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_____ [3]


d) Estimate the mass of the planet and express it in terms of Jupiter masses, $M_{\text{Jupiter}} = 1.9 \times 10^{27}$ kg. Why is this a lower limit for the real mass of the planet?

[*HINT:* For a binary system $m_1 r_1 = m_2 r_2$, where $r$ is the distance from the object with mass $m$ to the centre of mass of the system]

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_____ [4]

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e) *Optional*

Without making the approximation that the mass of the planet is much less than the mass of 51 Pegasi, calculate the mass of the planet (expressed in terms of Jupiter masses $M_{\text{Jupiter}} = 1.9 \times 10^{27}$ kg) by obtaining an expression involving the ratio $\frac{r_{planet}}{r_{star}}$.

**END OF PAPER**