BPhO
British Physics Olympiad

British Olympiad in Astronomy and Astrophysics

Competition Paper

Name	
School	

Total Mark/50

24th April 2015

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 the first competition paper of the British Olympiad in Astronomy and Astrophysics.

To solve some of the questions, you will need to write equations, draw diagrams and, in general, show your working.

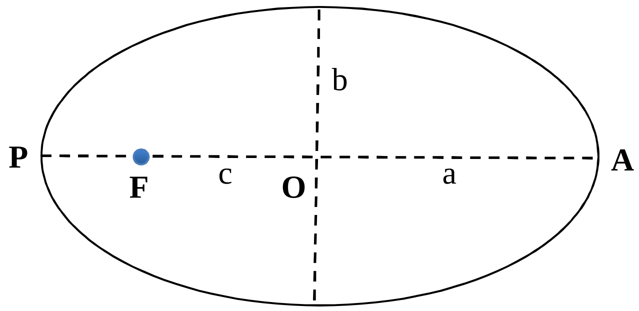
This paper has real problems and is not like an A level paper. The questions are more difficult because you are not told how to proceed. If you cannot do many, do not be disheartened. If you can do some then you should be delighted. A good mark is from a few questions solved.

There are two optional parts that you may attempt after the exam. These are more difficult questions that follow up on the questions to indicate how much information can be deduced from the data by a keen astrophysicist.

Useful constants

Speed of light	c	3.00×10^{8}	$\mathrm{m\ s^{-1}}$
Gravitational constant	G	6.67×10^{-11}	$\mathrm{N\ m^{2}\ kg^{-2}}$
Solar mass	M_{solar}	1.99×10^{30}	kg
Astronomical Unit	AU	1.496×10^{11}	m
Parsec	pc	3.086×10^{16}	m
Earth's orbit semi-major axis		1	AU
Earth's rotation period	1 day	24	hours
Earth's mass	M_{Earth}	5.97×10^{24}	kg
Earth's axial tilt		23.4	°

You might find the diagram of an elliptical orbit below useful in solving some of the questions:



Elements of an elliptic orbit:

a – semi-major axis
b – semi-minor axis
$e = \frac{c}{a}$ –eccentricity, where $c = FO$
F – Sun/Earth - focus
P – perihelion/perigee (point nearest to F)
A – aphelion/apogee (point furthest from F)

Kepler's Third Law:

For an elliptical orbit, the square of the period of orbit of a planet about the Sun is proportional to the cube of the semi-major axis (a) (the average of the minimum and maximum distances from the Sun).

List of symbols used in the paper:

φ - geographic latitude
L – geographic longitude
UT – Universal Time

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. Why is the Moon heavily cratered, but not the Earth?

   A. The Moon has stronger gravity, so it attracts more space debris
   B. The Moon formed earlier than the Earth, so it had more time to be bombarded by asteroids
   C. The craters on Earth were eroded by the oceans and atmosphere over a long period of time
   D. The Moon orbits around the Earth in addition to orbiting around the Sun, so it collects more space debris

2. We do not expect to find life on planets orbiting around high-mass stars because:

   A. High-mass stars are far too luminous
   B. The lifetime of a high-mass star is too short
   C. High-mass stars are too hot to allow for life to form
   D. Planets cannot have stable orbits around high-mass stars

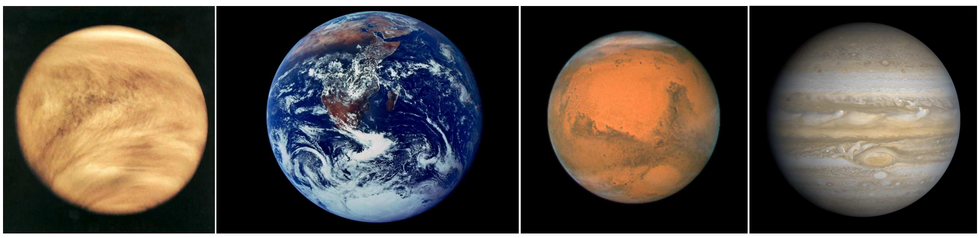
3. What would happen to the Earth's orbit if the Sun suddenly became a black hole with the same mass?

   A. It would spiral inwards because of the strong gravitational forces
   B. It would fall on a straight line into the black hole
   C. It would become an open orbit and the Earth would escape from the Solar System
   D. Nothing

4. A 10-inch refracting telescope with focal ratio (defined as the ratio of the focal length and aperture) of 10 is used with a 25 mm focal length eyepiece. What is the magnifying power of the telescope? (1 inch = 2.54 cm)

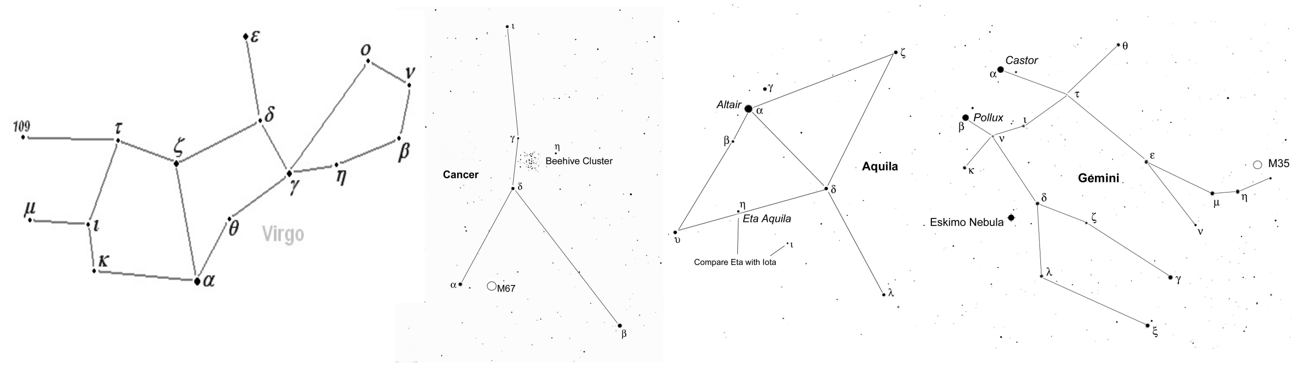
   A. 10x
   B. 50x
   C. 100x
   D. 200x

5. Which of the following planets has the longest day, defined as the period of a complete rotation about its axis?



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

6. Which of the following is not a zodiacal constellation?



A. Virgo B. Cancer C. Aquila D. Gemini

7. The Sun is seen setting from London ($\varphi = 51°30'\mathrm{N}, L = 0°8'$ W) at 21:00 UT. At what time UT will it be seen setting in Cardiff ($\varphi = 51°30'\mathrm{N}, L = 3°11'$ W) on the same day?

A. 21:12
B. 21:00
C. 20:48
D. 20:58

8. How far away must your friend be standing from you such that the attractive force exerted on you is similar to the maximum gravitational force exerted on you by Mars? Assume that your friend's mass is 65 kg. The mass of Mars is 6.4 x 10^{23} kg and the minimum distance from Earth to Mars is 0.52 AU.

A. 2.3 m
B. 0.8 mm
C. 0.8 m
D. 2.3 mm

9. A comet follows an elliptical orbit that is 31.5 AU at aphelion and 0.5 AU at perihelion. What is the period of the comet?

A. 181 years
B. 16 years
C. 64 years
D. 6.3 years

10. In which of the following places is the length of the shortest day of the year equal to half the length of the longest night?

A. Dubai ($\varphi = 25°$N)
B. London ($\varphi = 52°$N)
C. Rio de Janeiro ($\varphi = 23°$S)
D. Tromsø ($\varphi = 70°$N)

[HINT: Do not attempt to calculate the latitude, but rather look at the answers and consider how the length of the day varies with latitude and time of year.]

/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

A geostationary satellite is one that orbits in the equatorial plane of the Earth with the same period and in the same direction as the Earth's rotation. These orbits are important for communication and weather observation because the satellite always remains above the same point on Earth. The orbits of geostationary satellites are circular.

a) Calculate the radius of the orbit of a geostationary satellite. **Ans:_____________[3]**

____

____

____

____

____

____

b) Imagine now that the satellite was orbiting the Earth at the same orbital radius and same period, but in the opposite direction. For approximately how many hours a day would a satellite be above the horizon for an observer at ground level, situated on the Equator? Assume that the radius of the Earth can be neglected. **Ans:____________[2]**

____

____

____

____

____

____

____

/5

Question 12

The light from distant galaxies has distinct spectral features characteristic of the gas which makes them up. The astronomer Edwin Hubble noticed that the lines in the spectra of most galaxies are shifted towards the red end of the spectrum. This lead to his famous discovery that the recessional velocity of a galaxy is proportional to the distance to the galaxy, the constant of proportionality being H_0, implying that the Universe is expanding.

To measure the redshift of a galaxy, astronomers usually use the z parameter. Suppose that we observe a galaxy with a redshift of $z = 0.30$ and find that one of the lines in the hydrogen spectrum has been redshifted, compared to its rest wavelength of 486.1 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) Assuming that the classical Doppler effect $\left(z \approx \frac{v}{c}\right)$ is a reasonable approximation, what is the redshifted wavelength λ of the receding galaxy, in nm?

Ans:_________ [3]

b) When we observe the galaxy, how far into its past are we looking? **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. Total: **20 marks**.*

Question 13 Solar Eclipse

A major astronomical event happened on the morning of Friday 20th March 2015: a partial solar eclipse visible from the whole of the UK (at least from the parts not fully covered by clouds). The next partial solar eclipse of the same totality will happen in 2026 and the next total solar eclipse visible from the UK will be in 2090. In the image below you can see a time lapse of the eclipse, as seen from Sheffield, UK.

Figure 1 The partial solar eclipse visibility as seen from Sheffield, UK.

a) From the images in Figure 1 identify the time corresponding to the maximum of the partial solar eclipse.

____

____ [1]

b) The apparent magnitude of an object is a measure of its brightness as seen by an observer on Earth. Note that the brighter the object appears, the lower its magnitude. From Figure 1, the maximum coverage of the solar eclipse, as seen from Sheffield, was 90%. Using the relation between the difference in apparent magnitudes m and the variation in brightness, F, also known as Pogson's formula, $F_2/F_1 \approx 2.512^{-(m_2-m_1)}$, estimate the magnitude of the Sun at the maximum of the eclipse, if the apparent magnitude of the Sun is -26.74. Assume that the brightness of the solar disc is uniform, therefore being proportional to the surface area.

____

____

____

[3]

c) The only two populated places where the totality could be seen were the Faroe and Svalbard Islands. Explain if it would ever be possible to see a total solar eclipse from the Capital of Svalbard, Longyearbyen ($\varphi = 78°13'$N $15°33'$E) during December.

[1]

d) The tidal interaction between the Earth and the Moon causes the Moon to move away from the Earth (increase its semi-major axis) by 3.82 cm/year, and the Earth to spin down very slowly. Considering the most favourable case and using the data below estimate in how many years a total solar eclipse will not be visible from anywhere on Earth. Assume that the eccentricity of the Moon's orbit does not change.

The radius of the Moon is $R_M = 1737.5$ km, the mean distance to the Moon is $a_M = 385{,}000$ km and the eccentricity of the Moon's orbit is $e_M = 0.055$. The radius of the Sun is $R_S = 695{,}800$ km, the mean distance to the Sun is $a_E = 149.6 \times 10^6$ km and the eccentricity of Earth's orbit is $e_E = 0.0167$.
[HINT: Make use of the ellipse on page 1 and identify where the most favourable case lies, considering the angular diameters of the Sun and of the Moon, respectively]

____ [7]

/12

Question 14 Transiting extrasolar planet

One method of detecting extrasolar planets is to observe their transit across the disc of their host star. During the transit, the observed brightness of the star drops by a small amount, depending on the size of the planet. In 1999, following the spectroscopic detection of a planet around star HD 209458, astronomers David Charbonneau and Gregory Henry were able to observe a transit of the planet across the disc of the star, making it the first detection of a transiting extrasolar planet. The planet, named HD 209458b was found to be orbiting the star with a mass of 1.15 M_{solar} on a circular orbit every 3.525 days, much faster than the Earth is orbiting the Sun. Hundreds of extrasolar planets have since been detected using the transit method by the Kepler mission. However, the main disadvantage of this method is that the orbit of the planet has to be very close to edge-on, for the transit to occur from our vantage point. In this question, assume that the planet's orbit is perfectly edge-on, such that the transit is central. The figures below are the plot of the light curve of star HD 209458, showing the drop in brightness during the transit, and a schematic of the transit. Because the surface brightness of the star's disc is not uniform (an effect called limb darkening), the real light curve in Figure 2 does not fully resemble the idealised case in Figure 3.

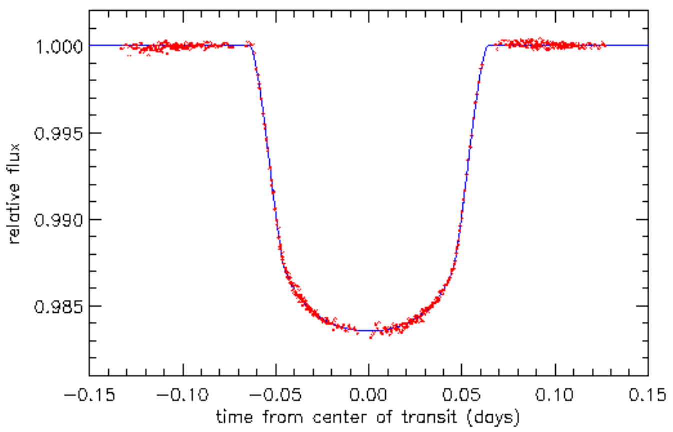


Figure 2. The light curve of the star HD 209458.

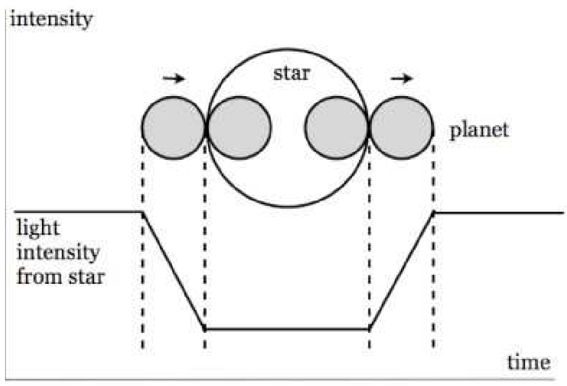


Figure 3. Schematic of the transit.

a) From Figure 2, what percentage of the star's disc is covered by the planet in the middle of the transit? Estimate an error in your determination.

____ [1]

b) From your answer in a) determine the ratio of the radius of the planet and the radius of the star.

____

____

____ [2]

c) Estimate the radius of the planet's orbit in AU, assuming that the mass of the planet is much smaller than the mass of the star.

____

____

____

____

____[2]

d) From Figure 2 estimate the total transit time, from first to last contact (as shown in the Figure 3). Assuming that the speed at which the transit occurs is equal to the circular speed of the planet around the star, calculate the radii of the star and of the planet. Express them in units of solar radii and Jupiter radii, respectively ($R_{\mathrm{Sun}} = 6.96 \times 10^5$ km, $R_{\mathrm{Jupiter}} = 7.0 \times 10^4$ km).

____

____

____

____

____

____

____

____

____

____[3]

/8

END OF PAPER