



**2nd International Olympiad on Astronomy and Astrophysics Junior**  
**Greece, Volos**  
**24 – 30 September 2023**  
**Theory**

**Instructions:**

- A) Do not touch envelopes until the start of the examination.
- B) The theoretical examination lasts for 3.5 hours, has 12 questions in total and a total of 180 points.
- C) Questions 1 to 10 are worth 10 points each.
- D) Questions 11 and 12 are worth 40 points each.
- E) For questions 9 and 10, you may only write the correct answer. No explanation is necessary. For all other questions detailed solution is necessary.
- F) There are Answer Sheets for carrying out detailed work/rough work. On each Answer Sheet page, please fill in:
  - a. Student Code (Country Code and student's number, example: GEO-3)
  - b. Question Number
- G) If you have written something on any sheet which you do not want to be evaluated, cross it out.
- H) Use as many mathematical expressions as you think may help the evaluator to better understand your solutions. The evaluator may not understand your language. If it is necessary to explain something in words, please use short phrases (if possible, in English).
- I) You are not allowed to leave your work desk without permission. If you need any assistance (malfunctioning calculator, need to visit a restroom, need more Answer Sheets, etc.), please draw the attention of the proctor.
- J) The beginning and end of the examination will be indicated by the proctor. Additionally, the proctor will announce the remaining time every hour and also fifteen minutes before the end of the examination.
- K) At the end of the examination, you must stop writing immediately. Sort your Answer Sheets according to Question numbering and put everything back in the envelope.
- L) Wait at your table until your envelope is collected. Once all envelopes are collected, your student guide will escort you out of the examination room.
- M) A list of constants and useful relations are given on the next pages.



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**Useful Constants:**

**Fundamental constants**

Speed of light in vacuum	$c$	=	$2.998 \times 10^8 \text{ m s}^{-1}$
Stefan-Boltzmann constant	$\sigma$	=	$5.670 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Universal gravitational constant	$G$	=	$6.674 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Universal gas constant	$R$	=	$8.315 \text{ J mol}^{-1} \text{ K}^{-1}$
Avogadro constant	$N_A$	=	$6.022 \times 10^{23} \text{ mol}^{-1}$
Wien's displacement law	$\lambda_m T$	=	$2.898 \times 10^{-3} \text{ m K}$

**Astronomical data**

1 parsec	1 pc	=	$3.086 \times 10^{16} \text{ m}$
		=	206 265 au
		=	3.262 ly
1 astronomical unit (au)	1 au	=	$1.496 \times 10^{11} \text{ m}$
Hubble constant	$H_0$	=	$70 \text{ km s}^{-1} \text{ Mpc}^{-1}$
Solar luminosity	$L_\odot$	=	$3.826 \times 10^{26} \text{ W}$
Effective temperature of Sun	$T_{\text{eff}, \odot}$	=	5778 K
Obliquity of the ecliptic (Earth)	$\varepsilon$	=	$23.5^\circ$
Inclination of the lunar orbit w.r.t. ecliptic		=	$05^\circ 08' 43''$
Apparent visual magnitude of full moon		=	-12.74
1 sidereal day		=	$23^{\text{h}} 56^{\text{m}} 04^{\text{s}}$
1 tropical year		=	365.2422 solar days
1 sidereal year		=	365.2564 solar days
<b>Solar magnitudes</b>			
Apparent visual		=	-26.75
Absolute visual		=	+4.82
Apparent bolometric		=	-26.83
Absolute bolometric		=	+4.74



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**Solar System**

<b>Object</b>	<b>Mean radius (km)</b>	<b>Mass (kg)</b>	<b>Orbital Radius (au)</b>
Sun	695 500	$1.988 \times 10^{30}$	---
Mercury	2 440	$3.301 \times 10^{23}$	0.387
Venus	6 052	$4.867 \times 10^{24}$	0.723
Earth	6 378	$5.972 \times 10^{24}$	1.000 000
Moon	1 737	$7.346 \times 10^{22}$	0.002 572
Mars	3 390	$6.417 \times 10^{23}$	1.524
Jupiter	69 911	$1.898 \times 10^{27}$	5.203
Saturn	58 232	$5.683 \times 10^{26}$	9.537
Uranus	25 362	$8.681 \times 10^{25}$	19.189
Neptune	24 622	$1.024 \times 10^{26}$	30.070

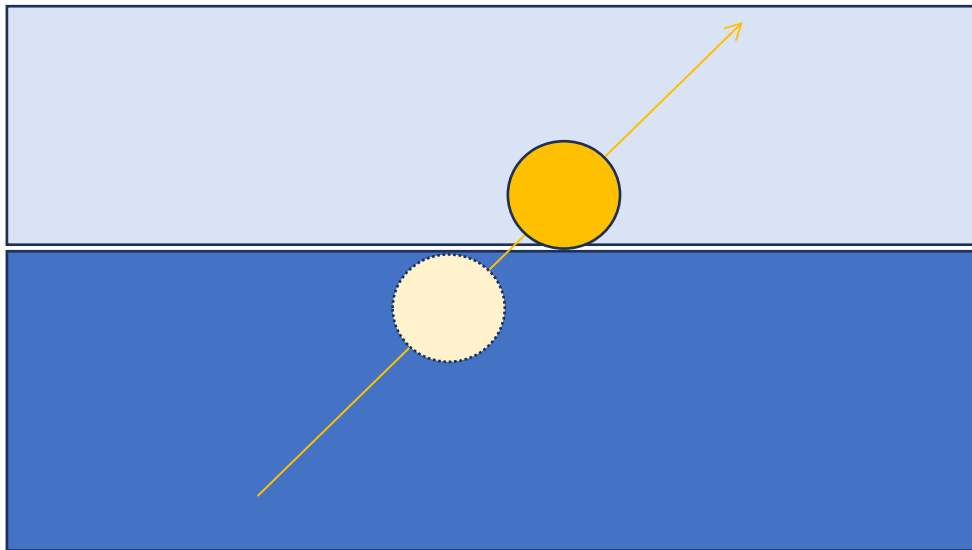


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**Question 1: Horizon crossing.**

The Sun, at some location, crosses the horizon at sunrise on autumnal equinox day at an angle of  $45^\circ$ . The angular diameter of the Sun is 32 arcminutes. How long does it approximately take for the entire solar disk to cross the horizon?

You may neglect atmospheric effects.



**Question 2: Planet orbits**

Two planets, A and B, orbit a star S in circular, coplanar orbits, in the same direction. The orbital radius of planet A is 9 times smaller than the orbital radius of planet B. The orbital period of planet A is 10 Earth days. An astronomer on Earth realizes that at 10:00 am on 26/9/2023, an observer on planet B would observe a transit of planet A in front of star S. When is the next transit due to planet A to be seen by an observer on planet B?

(All dates/times are given on Earth times).

The masses of planets A and B are very small compared to the mass of star S.

**Question 3: Unresolved binary star**

An unresolved binary star consists of two members whose apparent magnitudes are  $m_1=2.0$  mag and  $m_2=4.5$  mag. What is the combined apparent magnitude of this binary system?

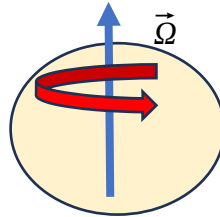




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**Question 4: Rapidly spinning neutron star.**

A neutron star is a rapidly spinning compact star. A particular neutron star has a mass of  $1.40 M_{\odot}$  and its radius is 10.0 km. What is the shortest possible spin period for it, before it starts shedding its mass away?



**Question 5: Moon phases**

The first full moon for 2024 in Volos is on the 25<sup>th</sup> of January at 19:54. At what date and time will the last full moon for 2024 (visible from Volos) occur?

**Question 6: Solar Eclipse.**

Assume that one day the Moon's apogee coincides with the Earth's perihelion. An observer, at an appropriate location on the Earth, observes the eclipse at zenith at its maximum. What fraction of the solar disk area is covered?

The maximum distance between the centers of the Earth and the Moon is 405,000 km, while the minimum distance between the Earth and the Sun is 147,100,000 km.

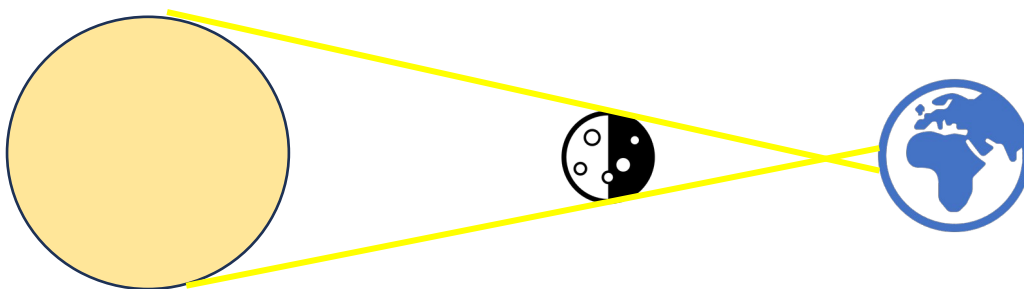
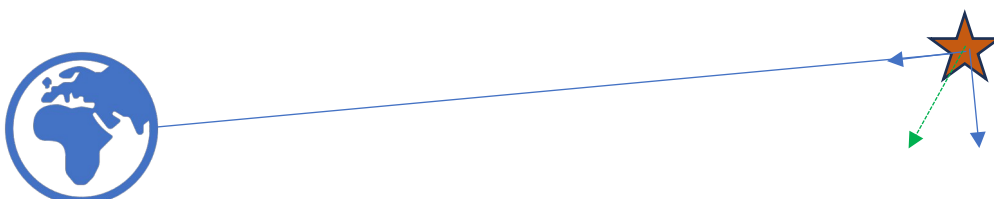


Figure not to scale.

**Question 7: Parallax and proper motion**

The parallax of Barnard's star is 0.552 arcseconds and its proper motion is  $\mu=10.31$  arcseconds/year. From its spectrum, an observer noticed that the absorption line  $H_{\alpha}$  is seen at 656.044 nm instead of 656.281 nm. What is the total speed of the Barnard's star relative to this observer?





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**Question 8: Telescope.**

The focal length of a telescope is 900 mm and its aperture is 4 inches. We use an eyepiece whose focal length is 25 mm. What is the magnification  $m$  of this telescope and what is its focal ratio  $f$ ?

1 inch is 2.54 cm.

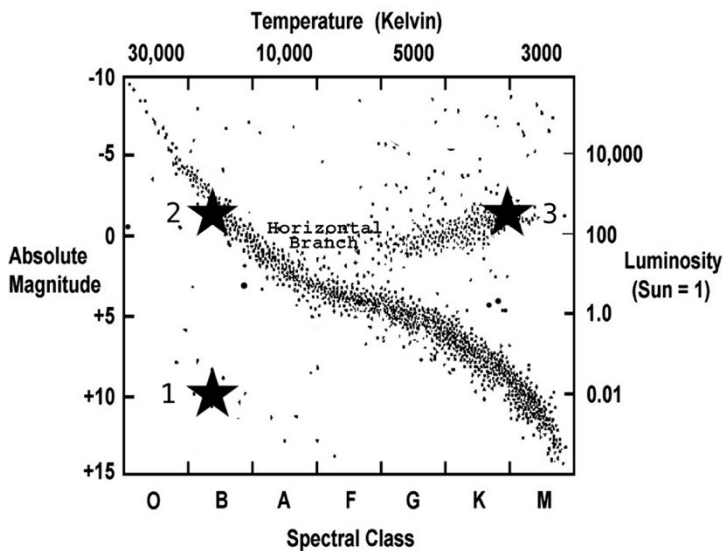
**Question 9: Cosmology**

Arrange the following events in the order in which they occurred (from earliest to the most recent).

- A) Formation of the first stars.
- B) Inflationary era of the universe
- C) Formation of helium nuclei
- D) Formation of neutral hydrogen
- E) Formation of oxygen atoms

**Question 10: H-R diagram.**

The image below shows the H-R diagram and three stars: 1, 2 and 3. For each statement below write “TRUE” if the statement is definitely true. Write “FALSE” if the statement is definitely false. Write “MAYBE” if the information is insufficient to draw a conclusion.



- A) Star 1 is a main sequence star.
- B) The radius of star 2 is larger than that of star 3.
- C) Star 2 is younger than the current age of the Sun.
- D) Star 3 is more massive than the Sun.
- E) Star 3 is colder than the other two stars.



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**Question 11: SIRIUS A and B**

Sirius is the brightest star of the night sky during the winter of the northern hemisphere and the summer of the southern hemisphere. It has an apparent visual magnitude  $m_v = -1.47$  mag. Sirius B is the binary companion of Sirius A and its magnitude is  $m_v = 8.5$  mag. Their orbital period is 50 years and the parallax of the system is 350 milliarcseconds, while their angular separation is 7 arcseconds.

You can assume that Sirius A has a surface temperature of  $T = 10,000$  K. The temperature of Sirius B is estimated to be 25,000 K. Both stars have a bolometric correction equal to -0.4. An absolute bolometric magnitude of zero corresponds to a luminosity of  $3 \times 10^{28}$  W. The orbit is assumed to be circular, and the line of sight is perpendicular to the orbital plane of the system.

- A) Calculate the luminosity and radius of Sirius A and B. **[12 Points]**
- B) What is the orbital separation of the system in meters? **[8 Points]**
- C) What is the total mass of the system? **[8 Points]**
- D) Assuming that the mass of Sirius A is twice the mass of Sirius B, what is the mean density of Sirius B? **[6 Points]**
- E) In the H-R diagram shown in question 10, which star number (1 / 2 / 3) will be the closest to the star Sirius B? **[6 Points]**

**Question 12: SATELLITES**

The term geostationary (GEO) refers to a satellite whose orbit is on the equatorial plane, its orbit is circular, and its orbital period is equal to Earth's period of revolution around its axis.

For this problem, all orbits around Earth are considered circular. An important characteristic of the orbit of a satellite is the elevation angle of the satellite, which is defined as the angle at which the satellite is visible above the local horizon for an observer on Earth.

- A) What is the maximum latitude the geostationary satellite is visible at? **[12 Points]**

Geostationary satellites, because of their distance from the center of the Earth, observe only a fraction of the Earth's surface. If a satellite needs to view a larger fraction of the Earth, it must change its orbit using rockets.

- B) The satellite moves from its location and observes the Earth having an angular diameter of  $10^\circ$ . What is the distance of the satellite from the center of the Earth? **[10 Points]**
- C) How much does the total (kinetic and potential) energy of the satellite need to change to move from the geostationary orbit to the one described in question (B)? The satellite has a mass of 1000 kg. **[10 Points]**



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- D) What is the ratio of the gravitational acceleration  $g$  on the Earth's surface compared to the gravitational acceleration at the location described in question (B). **[8 Points]**