

INSTRUCTIONS

- You are given an envelope marked **B**. Please verify the Contestant Code printed on it. Inside you will find:
 - This Instruction Sheet in English and/or your native language (if applicable)
 - Data Sheet in English and/or your native language (if applicable)
 - A set of Working Sheets
 - One envelope marked **S** (please verify the Contestant Code marked on it).
- You are allowed to open the envelope **S** only when the whistle is blown to signal the start of examination.** The exam time (55 minutes) starts from this point.
- Inside the envelope **S** you will find the following:
 - Question Paper in English and/or your native language (if applicable)
 - A Star Atlas
 - A set of Summary Answer Sheets (please verify the Contestant Code marked on them).
- This examination consists of the following questions:

OT01	40 points
OT02	15 points
OT03	20 points
Total:	75 points

- Setup:**
 - You are assigned one telescope station, where you will find a six-inch Newtonian telescope with an equatorial (EQ3) mount. You must always remain in the vicinity of your telescope during the observation.
 - An Examiner is assigned to your telescope station. Please provide your Contestant Code to the Examiner for verification.
 - The telescope is NOT polar-aligned, and the finder scope is NOT attached.
 - At the station, there is an Equipment Box placed under the telescope, containing the following items:
 - Two eyepieces: 25 mm and 10 mm
 - A finder scope
 - A head torch
 - A green pen

- 5. A stopwatch
- 6. A clock

You should leave these items at the station after use.

- **During the examination:**

- The flow of the exam will be as follows:

15 min	Question reading and planning observations
30 min	Observations
10 min	Calculations and finalization

- At the start of the exam, you will have 10 minutes in the gymnasium to read the question paper and make any preliminary plans for your observation. At the end of this time, a whistle will be blown, and you must leave the gymnasium and approach the telescope in the stadium.
- For the next 5 minutes, you are expected to familiarize yourself with the contents of the Equipment Box, and the telescope, **but you are not allowed to change its orientation.**
- At the 15th minute, the whistle will blow again. You will then have 30 minutes to conduct your observations using the telescope.
- The students can work on ANY task during the 30 minutes of observation.
- For the last 10 minutes, you should finalize your calculations.

- **At the end of the examination:**

- Ensure your Contestant Code and sheet numbers are correctly written on all used Working Sheets.
- Arrange your sheets in the following way:

Arrange the Summary Answer Sheets in numerical order from OT01 to OT03. All Summary Answer Sheets must be submitted, whether used or unused.

Arrange the Working Sheets in sequential order of the question numbers. Only include the Working Sheets that you actually used.

Place the bundle of Summary Answer Sheets on top of the bundle of Working Sheets.

- Place all the sheets arranged in the above manner inside the envelope **S**.
- **Only the contents of the envelope **S** will be evaluated. Any sheet that is not placed inside this envelope will not be evaluated.**
- Place the envelope **S** inside the envelope **B**.
- All other sheets, namely, Instruction Sheet(s), Data Sheet(s), Question Paper(s), unused Working Sheet(s), and Star Atlas should be placed directly inside the

envelope B.

- Tie the thread seal on the envelope B.
- Hand over the envelope B to the examiner. Make sure that no sheet is left on the table.

UNIVERSAL CONSTANTS

Avogadro constant	$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$
Boltzmann constant	$k_B = 1.381 \times 10^{-23} \text{ J K}^{-1}$
Electron charge magnitude	$e = 1.602 \times 10^{-19} \text{ C}$
Speed of light in vacuum	$c = 2.998 \times 10^8 \text{ m s}^{-1}$
Universal gravitational constant	$G = 6.674 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Stefan-Boltzmann constant	$\sigma = 5.670 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Permittivity of free space	$\epsilon_0 = 8.854 \times 10^{-12} \text{ m}^{-3} \text{ kg}^{-1} \text{ s}^4 \text{ A}^2$
Mass of electron	$m_e = 9.109 \times 10^{-31} \text{ kg} = 0.511 \text{ MeV}/c^2$
Mass of proton	$m_p = 1.673 \times 10^{-27} \text{ kg} = 938.272 \text{ MeV}/c^2$
Mass of He nucleus	$m_{\text{He}} = 6.645 \times 10^{-27} \text{ kg} = 3727.181 \text{ MeV}/c^2$

ASTRONOMICAL DATA

Mass of Sun	$M_{\odot} = 1.988 \times 10^{30} \text{ kg}$
Radius of Sun	$R_{\odot} = 6.957 \times 10^8 \text{ m}$
Luminosity of Sun	$L_{\odot} = 3.828 \times 10^{26} \text{ W}$
Distance from Earth to Sun	$d_{\odot} = 1.496 \times 10^{11} \text{ m}$
Solar constant on Earth	$F_{\odot} = 1361 \text{ W m}^{-2}$
Hubble constant	$H_0 = 67.7 \text{ km s}^{-1} \text{ Mpc}^{-1}$
Age of the Universe today	$t_0 = 13.8 \text{ Gyr}$
Astronomical Unit	$1 \text{ au} = 1.496 \times 10^{11} \text{ m}$
parsec	$1 \text{ pc} = 3.086 \times 10^{16} \text{ m}$
light-year	$1 \text{ ly} = 9.461 \times 10^{15} \text{ m}$
Geographical coordinates of Hanoi	Latitude: $20^\circ 58' \text{ N}$, Longitude: $105^\circ 45' \text{ E}$

MATHEMATICAL FORMULAS

Derivatives	$y' = \frac{dy}{dx}$ and $y'' = \frac{d^2y}{dx^2} = \frac{d}{dx} \left(\frac{dy}{dx} \right)$
Integrals	$\int y dx = f$ so that $\frac{df}{dx} = y$ and $\int_a^b y dx = f(b) - f(a)$
Chain rule	$\frac{dy}{dx} = \frac{dy}{du} \frac{du}{dx}$
Product rule	$\frac{d}{dx}(uv) = \frac{du}{dx}v + u\frac{dv}{dx}$
Quotient rule	$\frac{d}{dx}\left(\frac{u}{v}\right) = \frac{1}{v^2} \left(\frac{du}{dx}v - u\frac{dv}{dx} \right)$
Powers	$\frac{d}{dx}x^\alpha = \alpha x^{\alpha-1}$ and $\int x^\alpha dx = \frac{x^{\alpha+1}}{\alpha+1} + \text{constant}$ ($\alpha \neq -1$)
Exponents	$\frac{d}{dx}e^x = e^x$ and $\int e^x dx = e^x + \text{constant}$
Logarithms	$\frac{d}{dx} \ln x = \frac{1}{x}$ and $\int \frac{1}{x} dx = \ln x + \text{constant}$
Sines	$\frac{d}{dx}(\sin x) = \cos x$, $\int \sin x dx = -\cos x + \text{constant}$
Cosines	$\frac{d}{dx}(\cos x) = -\sin x$, $\int \cos x dx = \sin x + \text{constant}$
Taylor expansions up to first orders	$(1+x)^\alpha = 1 + \alpha x$ for $ x \ll 1$, $(1+x_1)(1+x_2) = 1 + x_1 + x_2$ for $ x_1 , x_2 \ll 1$
Taylor expansion up to second orders	$y = y_0 + y'_0(x - x_0) + \frac{1}{2}y''_0(x - x_0)^2$ for $x \approx x_0$

OT01 (40 points)

- a) (10 points) Point the telescope at Saturn, then call your examiner for confirmation and marking after using the highest magnification available. If you are unable to point at the target, the examiner will do it for you, but you will get no points.
- b) (5 points) Write down your observing time and estimate the zenith distance z of Saturn.
- c) (11 points) Write down your observing time and estimate the acute angle of the rotation axis of Saturn relative to the horizon of the observing site.
- d) (14 points) The declination of Saturn is $+2^\circ$, assume that its diurnal circle is great circle, determine its hour angle HA at your observing time.

OT02 (15 points)

Using the attached sky atlas page, point the telescope at Messier 29, then call your examiner for confirmation and marking after using the highest magnification available.

OT03 (20 points)

Reverberation mapping (or echo mapping) is a technique used to estimate the mass of a black hole at the center of an Active Galactic Nucleus by observing the variations in light emitted from the system. In this setup, a repeating dot flash represents a sudden flare from the accretion disk, and a stationary concentric ring appearing after a while represents the light echoing through the gas region around the central black hole.

- a) (5 points) Target Acquisition: Point your telescope toward the top floor of the Phenikaa Tower (the highest building on the Phenikaa campus), where the central dot and ring flashes will appear. Call your examiner for confirmation and marking. (If you cannot find the target, you may ask your examiner to point the telescope for you for 0 points in this part.)
- b) (10 points) Measure the time delay (τ) between the dot flash and the subsequent ring at least 3 times (up to 5 times). Record all individual readings, and calculate the mean time delay and its uncertainty.
- c) (5 points) Assume the gas orbiting the black hole with velocity of 3000 km s^{-1} and one measured second corresponding to one day. Calculate the black hole's mass M (in $M_\odot$).