AstroChallenge 2021
Senior MCQ Round

SOLUTIONS

Monday 7th June 2021

PLEASE READ THESE INSTRUCTIONS CAREFULLY.

1. This paper consists of **34** printed pages, including this cover page.
2. You are required to keep your microphone and camera on at all times throughout the round.
3. You are not allowed to use your keyboard at all times, but you may use your mouse to scroll through the question paper as well as switch to the formula booklet.
4. Any materials other than the Question Paper and Formula Booklet are strictly prohibited.
5. You have **2 hours** to attempt **ALL** questions in this paper. If you think there is more than one correct answer, choose the *most* correct answer.
6. Write your answers on a piece of A4 paper. Write your **Name**, **School**, and **Team Number** at the **bottom right corner** before taking a photo to submit. Failure to conform to this may result in us being unable to find the owner of the script.
7. It is *your* responsibility to ensure that your answer script has been submitted.

1. Venus completes 13 full orbits around the Sun every 8 years. Venus last made a conjunction with the Pleiades star cluster in April 2020. When will Venus next undergo a conjunction with the Pleiades?

   (A) Nov 2022

   (B) Nov 2020

   (C) Apr 2028

   (D) Apr 2023

   (E) Aug 2022

   Solution:

   The Pleiades is assumed to be stationary in this case as it is part of the background stars against the motion of Earth and Venus. The 2 planets will therefore line up together against the background in the same position very interval which is equivalent to the regularity of the planet that is slower, that is Earth. Hence, their next conjunction occurs exactly 8 years later.

2. Which of the statements below is generally true?

   (A) Epicycles cannot explain the retrograde motion of superior planets.

   (B) The cube of a body's orbital period is directly proportional to the square of the semi-major axis of its orbit.

   (C) The gravitational force between two objects is proportional to both the product of the masses of the two objects as well as the square of the distance between them.

   (D) The geocentric model cannot explain seasons on Earth.

   (E) None of the above statements are generally true.

   Solution:

   A False. Epicycles were invented to explain the observation of retrograde motion, thus they certainly can explain it.

   B False. Kepler's Third Law tells us that the square of the orbital period is proportional to the cube of the semi-major axis of the orbit.

   C False. The gravitational force is inversely proportional to the square of the distance between them, not proportional.

   D False. Seasons are caused by axial tilt which can still be explained in a geocenteric model.

3. During the quarter moon, what kind of tides are generally expected on Earth? Where is the Moon approximately located?

(A) Spring tides. The Moon is between the Earth and the Sun.

(B) Spring tides. The Moon is on the opposite side of the Sun.

(C) Neap tides. The Moon is on the opposite side of the Sun.

(D) Trick question. Tides occur every day and are of the same magnitude regardless of the Moon's position, hence there is no differentiation.

(E) None of the above.

Solution:

The moon is neither between the Earth and the Sun nor is the moon on the opposite side as the Sun. The moon must be "beside" the Earth relative to the Sun so as to observe a Quarter-Moon. The tides are known as Neap Tides.

4. Which of the following stars make up the Summer Triangle?

(A) Vega, Shaula, and Mizar

(B) Albeiro, Altair, and Vega

(C) Vega, Albeiro, and Deneb

(D) Altair, Denebola, and Vega

(E) None of the above

Solution:

None of the above is correct. The Summer Triangle consists of the stars of Vega in Lyra, Altair in Aquila and Deneb in Cygnus.

5. Billy was visiting his alien friend Timmy who had set up base at Mercury to observe our Sun. While there, Billy saw the Sun rising from the east, only to backtrack in the opposite direction and then set below the horizon again two Earth days later! Billy was bewildered. How can Timmy best explain what was observed?

(A) Mercury is at perihelion and its angular rotational velocity has exceeded its angular orbital speed.

(B) Mercury is at aphelion and its angular orbital speed has exceeded its angular rotational velocity.

(C) Mercury is tidally locked to the Sun but wobbles just enough for the solar terminator to shift.

(D) Atmospheric distortion creates this optical illusion.

(E) None of the above explains the phenomenon.

Solution:

This question requires knowledge of apparent retrograde motion and Kepler's second law. Mercury's orbit is quite elliptical; when it is at its nearest approach to the Sun (at perihelion), it experiences a stronger gravitational pull from the Sun and moves faster. You can think of the Sun's gravity acting like a slingshot, and Mercury is accelerating before getting catapulted away. Given how slowly Mercury already rotates around its own axis (one Mercury day = 58 Earth days), and that it rotates very quickly around the Sun (one Mercury year = 88 Earth days), the extra speed boost it gets at perihelion increases its orbital speed beyond its angular rotational velocity. With a little visualisation, we can imagine how the Sun can go through apparent retrograde motion in the Mercurian sky.

A This comes close but inaccurately describes the mechanism behind the phenomenon.

B This comes close but inaccurately describes the mechanism behind the phenomenon.

C This is wrong because Mercury is not tidally locked to the Sun.

D This is dubious and unlikely.

6. A distant planet has been discovered to have an orbital period of 800 days with a rotational period of 40 Earth hours per day. Assuming that the planet's rotational axis is aligned with its orbital plane, how many minutes do the stars rise earlier between successive days?

(A) 5 hours

(B) **3 minutes**

(C) 0.5 days

(D) 3.2 hours

(E) 6.4 hours

Solution:

Distributing 40 hours across 800 days gives us a progression of 0.05 hours per day, which is equivalent to 3 minutes.

7. Every second, the sun converts roughly 600 million tons of hydrogen into 596 million tons of helium. Which statement correctly describes what happens to the remaining 4 tons?

(A) Ejected into space

(B) Reabsorbed by molecular hydrogen

(C) Converted into other elements

(D) **Converted into light**

(E) Trick question. This is not possible.

Solution:

The proton-proton chain does produce energy in the form of light.

8. Suppose that a civilisation that has developed in the northern hemisphere of Mars is currently at a developmental stage roughly similar to that of the Ming Dynasty (14^{th} century to 17^{th} century) on Earth. Which of the following myths is most unlikely to have appeared and prevailed in the civilisation?

(A) **Sun God Ram and his twin sister the Moon God Kham.**

(B) A Hunter killed by a Giant Scorpion.

(C) The Sun God Ram struck a deal with The God of the Underworld Bam to create the four seasons.

(D) The Sky Dogs Puppis and Doggis cannot devour the Sun God Ram as a whole.

(E) None of the above is possible.

Solution:

Mars has two moons. The constellations would be similar on Earth as on Mars. As such, it is entirely possible that they would have come up with some sort of variation of the Orion Scorpius story. There are four seasons on Mars. The moons of Mars, both Phobos and Deimos, are too small to create a total eclipse of the Sun when they transit across the latter.

9. What is one possible reason why Galileo Galilei come to realise that the Earth was not, as was commonly believed at that time in the West, the centre of the Solar System?

(A) He observed the solar analemma.

(B) He observed the Milky Way.

(C) He read astronomy books written by the Chinese brought back by Marco Polo.

(D) **He observed the phases of Venus.**

(E) Trick question. Galileo had in fact thought that the Earth was in fact at the centre of the Solar System all along.

Solution:

A It is not possible to tell the centre of the solar system by merely observing t he solar analemma.

B Observing the Milky Way would not help in this matter.

C Chinese books are unlikely to have made their way into Europe in large quantities at that time. Even if they had, it is unlikely that he was able to read or understand them.

D Galileo concluded that Venus must travel around the Sun, passing at times behind and beyond it, rather than revolving directly around the Earth. His observations of the phases of Venus virtually proved that the Earth was not the centre of the universe.

10. Which of the following statements is generally true?

(A) Omega Centauri was not listed in the Messier catalogue because it had not formed yet at the time of the catalogue's publication.

(B) Uranus was first discovered and recognised by Galileo Galilei using a telescope in 1640.

(C) The ancient Chinese came up with 25 solar terms in a year to track the progress of the Sun every 15 degrees as it moves across the celestial sphere.

(D) The Newtonian telescope using mirrors was invented before refractors due to the complexity of glass-making at that time.

(E) None of the above statements are generally true.

Solution:

A Omega Centauri was not listed because it was located too far south.

B Uranus was first discovered and recognized by William Herschel.

C There were 24 solar terms, a full circle is 360 degrees and hence only has space for 24 divisions at 15 degrees each.

D The refractor was invented before the reflector.

11. Jerry has bought a new Dobsonian telescope with the specifications below. Which of the following eyepiece and Barlow combinations should he use if he wants to observe the Ring Nebula (M57) in Lyra, knowing that the angular diameter of M57 is 1.5 arcminutes? Assume that all the eyepieces have an apparent field of view of 52 degrees.

Aperture	305 mm
Focal Length	1500 mm
Focal Ratio	$f/4.9$
Tube Length	1400 mm

(A) 32mm with 2x Barlow

(B) 25mm with no Barlow

(C) 25mm with 3x Barlow

(D) 20mm with 2x Barlow

(E) 16mm with 3x Barlow

Solution:

We need to first understand how to best view planetary nebulas. Ring Nebula is a planetary nebula that is only $1.5'$ in angular diameter. We would therefore require a high magnification. However, we should also keep in mind that there is an upper limit after which any higher magnificaction might compromise on viewing quality and this limit varies from telescope to telescope.

In general, it is set at twice its aperture in millimeters. This leaves option E as the most reasonable answer since it offers the highest magnification of $281.25\times$ among all the options, while at the same time still steering clear of the upper limit (which is around $610\times$ for this telescope).

12. If you stand on the Moon and Earth gaze, what would you observe?

(A) The Earth rises and sets every 12 hours.

(B) The Earth looks as big from the Moon as the Moon looks from the Earth.

(C) Total solar eclipses on the moon make the Earth appear red, just like the Moon does during total lunar eclipses on Earth.

(D) The Earth's geographical features will change over the course of a lunar day.

(E) None of the above are correct.

Solution:

A The Earth rotates on its axis faster than the moon does. Hence, it would not rise or set but will move around the sky slightly.

B The Earth would look bigger.

C The frequency of solar eclipses as seen on the Moon is roughly equivalent to the frequency of lunar eclipses as seen on Earth.

D The Earth rotates its axis faster than the moon does. Hence, there is no "dark-side" of the earth as the moon has.

13. Which of the following statements about the (solar) analemma is false?

(A) The complete analemma cannot be seen inside both the Arctic and Antarctic Circles.

(B) The smaller loop of the analemma always points towards the north.

(C) The analemma is created by taking a photo of the position of the Sun at the same mean solar time between regular days.

(D) The image of the Sun at the intersection in the middle of the figure-eight shape is taken on the day of vernal equinox.

(E) Both Earth's eccentricity and obliquity result in the figure-8 shape. with a big lobe and a small lobe.

Solution:

A This is true because the analemma stretches from $+23.5°$N to $-23.5°$S.

B This is true because the last point on the smaller loop is the position of the Sun during summer solstice, which is when the sun appears highest in the sky.

C This is true because it is how an analemma is created. The Sun changes its declination every day at the same mean solar day.(**Note:** This is not the apparent solar time, which is the time reflected on the sundial).

D This is false as the equinoxes correspond to the analemma middle points, not the intersection points. The intersection point has no special event.

E This is true. The combined effect of the eccentricity of Earth's orbit and the obliquity of Earth's tilt gives the resulting shape in the graph of the solar declination against the equation of time.

14. Which of the following statements regarding Hubble's law is correct?

(A) It is a set of laws to regulate the operation and use of the Hubble Space Telescope.

(B) It is a set of laws to regulate the Hubble tuning fork.

(C) **It is used to show that galaxies move away from us at a rate proportional to their distance from us.**

(D) It is used to show that the Universe is flat.

(E) None of the above statements are correct.

Solution:

A This is a troll option.

B This is also a troll option.

C Hubble's law is indeed used to calculate the distance to far flung galaxies with measurable data. The measurable data in this case is redshift, which can then use to derive the velocity it is moving away from us.

D Whehter a universe is flat is not has no relation to Hubble's law.

15. Consider a binary star system where the semi-major axis between the stars is 0.97AU and the period is 0.38 years. What is the total mass of the combined system?

(A) 2.40×10^{11}kg

(B) 5.57×10^{16}kg

(C) **1.26×10^{31}kg**

(D) 2.91×10^{31}kg

(E) 1.67×10^{34}kg

Solution:

This is given directly by Kepler's third law:

$$T^2 = \frac{4\pi^2}{G(m_1 + m_2)} a^3$$

Substituting in the values gives $m_1 + m_2$ directly.

16. Omega Centauri is a globular cluster that is commonly seen in the night sky with an apparent magnitude of 5.33 at a distance of 4.84kpc from Earth. What is the luminosity of Omega Centauri as a ratio of the Sun's luminosity? Take the absolute magnitude of the Sun to be 4.83.

(A) 1.12×10^{-1}

(B) **1.48×10^{5}**

(C) 1.35×10^{9}

(D) 1.94×10^{13}

(E) 1.24×10^{17}

Solution:

We can first use the distance modulus to get the absolute magnitude of Omega Centauri

$$m - M = 5\text{lg}\frac{d}{10\text{pc}}$$

With the absolute magnitudes of both the Sun and Omega Centauri, we can use the relationship between luminosity and absolute magnitude

$$\frac{L_1}{L_\odot} = 10^{\frac{M_\odot - M_1}{2.5}}$$

to obtain the required luminosity ratio.

17. Which of the following statements about relativity is generally true?

(A) Generally, with respect to the observer, objects moving forward at speed v affected by length contraction can counteract the effect of the contraction by moving backwards at the same speed v.

(B) Generally, with respect to the observer and with all other factors kept constant, a clock located in a weaker magnetic field will tick slower. However, a clock located in a stronger magnetic field will tick faster.

(C) Generally, with respect to the observer, a clock located on an object moving forwards will tick slower. However, a clock located on an object moving backwards will tick faster.

(D) **Generally, with respect to the observer, a clock located in a weaker gravitational field will tick faster. However, a clock located in a stronger gravitational field will tick slower.**

(E) None of the above statements are generally true.

Solution:

The effects are the same whether one is moving forwards or backwards, thus options A and C are false. Magnetic fields do not affect time dilation. This leaves us with option D, which describes gravitational time dilation.

18. Imagine that you are in a post-COVID world without travel restrictions and are currently on a stargazing trip in a remote location at a latitude of 35°N. Capella (RA/DE: 5h 18m / +46deg 01min) is currently 3 degrees above the western horizon. The following table shows a list of DSOs you have decided to try to observe for tonight.

Object Name	RA	DEC
Heart Nebula	2h 34m	+61deg 32min
Omega Centauri	13h 28m	−47deg 35min
Black-Eye Galaxy	12h 57m	+21deg 34min
Dumbbell Nebula	20h 00m	+22deg 46min

In what order, from highest to lowest priority, should you arrange your observations so as to maximise your chances of seeing every one of the DSOs on your list?

(A) **Omega Centauri, Black Eye Galaxy, Dumbbell Nebula, Heart Nebula**

(B) Heart Nebula, Black Eye Galaxy, Omega Centauri, Dumbbell Nebula

(C) Black Eye Galaxy, Omega Centauri, Heart Nebula, Dumbbell Nebula

(D) Dumbbell Nebula, Omega Centauri, Black Eye Galaxy, Heart Nebula

(E) Dumbbell Nebula, Heart Nebula, Omega Centauri, Black Eye Galaxy

Solution:

A quick calculation ($90° - 61° = 29°$) shows us that the Heart Nebula is circumpolar and thus has lower priority. Ideally, one would want to view it when it is near the meridian, and judging by the RA (which is earlier than Capella), it is around its lower culmination.

The Dumbbell Nebula has a RA of 20h, indicating that it is on the eastern side of the sky and thus would have lower priority.

Between Omega Centauri and the Black Eye Galaxy, the latter has a slightly earlier RA and thus is normally prioritized if we are near the equator. However, at northern latitudes, objects with more southern declinations spend less time above the horizon and thus set faster.

While we normally need spherical trigonometry to ascertain which objects set earlier, there is a very small difference in RA between Omega Centauri and Black Eye Galaxy (31 minutes). Omega Centauri will set earlier and thus should be prioritized. (**Note:** Omega Centauri is very barely visible.)

19. Which of the following statements about stellar evolution is true?

(A) Pair-instability supernovae are hypothesised to be one of the causes of gamma-ray bursts.

(B) Electron-degeneracy pressure is the main support against gravity when Sun-like stars turn into white dwarfs.

(C) It is not possible for a star with 1 solar mass to eventually undergo a supernova.

(D) The Sun will turn into a red supergiant as it begins fusing hydrogen to helium in shells around the helium core.

(E) None of the above.

Solution:

A This is not usually considered a cause. Supernovae usually end up with nothing.

B This is true.

C It is possible if it is a type 1A supernova.

D This is not true. The Sun will never turn into a red supergiant.

20. Justin is using an apochromatic refractor, a polar-aligned motorised equatorial mount, and a standard DSLR with T-Ring adapter for astrophotography. The refractor has a focal length of 600mm and an aperture of 102mm. After reviewing a 60s exposure shot, he found that the image contained unwanted star trails.

Which of the following mistakes would be least significant in contributing to the star trails?

(A) Not using a guide scope and autoguiding camera.

(B) Setting up the equatorial mount in an open field that is prone to wind.

(C) Centring a wrong star in the telescope during the polar alignment of the equatorial mount.

(D) Not balancing the set-up with enough counterweights.

(E) Setting up the equatorial mount on soft ground that is prone to vibrations.

Solution:

A Not using a guide scope and autoguider is almost inconsequential for short exposures like 60s.

B Wind can cause the set-up to shake and result in star trails.

C Centering the wrong star would throw the polar alignment off completely.

D Not balancing the telescope using counterweights can lead to backlash in the gears of the mount.

E Vibrations can cause the set-up to shake and result in star trails.

21. The study of how life originated on Earth plays a significant role in determining if extra-terrestrial life exists beyond the Solar System. By studying how life originates from non-living, simple organic compounds, we develop an appreciation of how life can form elsewhere in the universe. Which of the following astrobiological statements is true?

(A) Water is the only solvent in which biochemical reactions can take place.

(B) The abiogenesis hypothesis suggests that life exists as simple micro-organisms lying dormant in bodies such as asteroids and comets, and are distributed when these bodies collide.

(C) Panspermia is the hypothesis that life came about from the reaction of non-living matter, such as simple organic compounds.

(D) The Rare Earth hypothesis suggests that the probability of finding extra-terrestrial life is high.

(E) The Drake equation is a way to compute the probability of existing civilisations capable of communicating with us.

Solution:

A False. Ammonia and various other hydrocarobs can serve as biological solvents.

B False. The abiogenesis hypothesis suggests that life came about from the reaction of non-living matter, such as simple organic compounds.

C False. The panspermia hypothesis suggests that life exists as simple micro-organisms lying dormant in bodies such as asteroids and comets and are distributed when these bodies collide.

D False. The Rare Earth hypothesis suggests that life on Earth was highly improbable and it is unlikely that we find extra-terrestrial life.

E True. The Drake equation is a formula to compute the probability of finding intelligent life.

22. Under what circumstances in Beijing (39.9042°N, 116.4074°E) will the tip of a shadow of a stick over the period of a day draw a straight line on the ground?

(A) At the winter solstice.

(B) At the vernal equinox.

(C) When the Sun is directly above Beijing.

(D) Trick question. It is impossible.

(E) It is possible, but none of the above circumstances are correct.

Solution:

This question has been **VOIDED**. The shadow of a gnomon/sundial traces out a straight line at equinox regardless of latitude or sundial positioning. There is effectively no tilt of the Earth during the equinoxes.[1]

[1]More information is linked here.

For Questions 23 to 25, please refer to the following passage.

The sky is dark and the night is chilly. A constant wind blows as you consider if you want to stargaze. You know that the W of Cassiopeia can be seen all night and so can Draco. But barely so. You observe that the Sun will set around 1700 and you have to plan for a long night ahead.

With this in mind, you obtain the following information from the local observatory.

If you are willing to get up early this morning, you will enjoy one of the finest sights in the northern hemisphere sky, the great globular cluster in Hercules, cataloged as M13. Hercules rises in the east about three hours before sunrise; give it another hour and M13 will sit a respectable 15° (and climbing) above the horizon. You can find it about one-third of the way between Eta (η) and Zeta (ζ) Herculis.

Shining at magnitude 5.3, this ancient star cluster spans 16.6′ and is easily visible in binoculars. A telescope will bring out even more of its over 100,000 members. Embedded within the cluster's core are three dark lanes, often called the propeller. Spanning 3′, this feature sits just southeast of the central region of the core. It is best viewed under higher magnification (200× to 300×) in larger (8-inch or so) scopes, but good observing conditions will afford those with smaller instruments a better chance. Some observers find that using averted vision, or looking slightly away from the region you want to focus on, makes the propeller appear more easily.

Even if you can't find this feature, the Hercules Cluster is still a sparkling wonderland you can enjoy through the eyepiece until dawn. It's arguably the best northern hemisphere globular and will rise earlier each morning as the month goes on, affording even better views with time. There are a few hours between sunset and moonrise to enjoy dark skies tonight. Once darkness falls, consider trying for the Andromeda Galaxy (M31), located high in the east in its namesake constellation. From a particularly dark location, you may be able to see a dim, gray smudge without any optical aid at all. It is the farthest object visible to the naked eye. Look for it about 1.3° west of Nu (ν) Andromedae. Pull out binoculars or a telescope for an even better view of the galaxy's bright centre and dimmer outskirts.

Source

23. Based on the passage above, which northern hemisphere astronomical season is most likely referenced above?

(A) **Between Autumn and Winter**

(B) Between Winter and Spring

(C) Between Spring and Summer

(D) Between Summer and Autumn

(E) Not enough information to determine

Solution:

Andromeda cannot rise in Spring / Summer, hence it is likely to be between Autumn and Winter.

24. Based on the passage above, which phase is the moon most likely to be in?

(A) Full

(B) New

(C) Waxing crescent

(D) Waning gibbous

(E) Not enough information to determine

Solution:

The moon will rise just after sunset. As such, the moon is part full but only just.

25. Based on the passage above, which of the following constellations is likely to be at the zenith at local midnight?

(A) Auriga

(B) Andromeda

(C) Hercules

(D) Crux

(E) Ursa Minor

Solution:

This can be done by elimination. You are in the northern hemisphere so Crux is out. Ursa Minor is unlikely because to be at the zenith especially in this season where Andromeda is visible, you would have to be almost at the North pole. However, it was stated that many constellations still rise and set. Most importantly, Draco is circumpolar but barely so. It is possible to see Andromeda but it has been stated in the passage that when darkness fell, it was already high in the east. Hence, when local midnight comes, it would be almost setting. Hercules is not visible at that time, since it has been stated in the passage that Hercules rises in the east 3 hours before sunrise.

26. Some random person thought that it would be a good idea to adapt a sundial to keep time at night using the Moon instead of the Sun. Which of the following issues is/are unlikely to arise?

(A) The time measured may vary significantly one night to another night.

(B) It would not work for at least one entire night a month and at least part of the night on most of the month.

(C) The shadow may be affected by artificial light sources and as such may not be readily visible.

(D) All of the above are possible issues.

(E) None of the above are possible issues.

Solution:

A The moon rises and sets at different times each day.

B This has the same issue as A.

C There might be heavy light pollution which would make the moon shadow not readily visible.

27. How much time elapses in the frame of a photon that has travelled for 0.03s in the perspective of a non-relativistic observer?

(A) 0.015s

(B) 0.02s

(C) 0.03s

(D) 0.04s

(E) No time passes for the photon

Solution:

In the case of a photon, no time would have passed due to relativity.

28. Order the following time periods of the universe from the earliest to the latest.

I The Big Bang

II Age of reionisation

III Inflationary epoch

IV Quark epoch

V Planck epoch

VI Photon epoch

(A) I, II, III, IV, V, VI

(B) I, IV, V, VI, III, II

(C) **I, V, III, IV, VI, II**

(D) I, V, IV, VI, III, II

(E) None of the above orders are correct

Solution:

This question requires an understanding of cosmology, specifically the chronology of the Universe and its stages.

29. Celestial navigation has a rich and interesting history. The navigator would use 'sights', or angular measurements taken between a celestial body (e.g., the Sun, the Moon, Polaris, or one of 57 other navigational stars and planets) and the visible horizon to locate one's position in the world, on land as well as at sea.

    Let us explore a simple application of Celestial Navigation using our wrist watch.

    To use our watch as a compass in the northern hemisphere, hold the watch horizontal and point the hour hand at the Sun. The halfway mark between the hour hand and the twelve o'clock mark is south.

    For example, if it is 8 o'clock, point the 8 on the watch face at the Sun. South would then be at the 10 o'clock position. If it is 4 o'clock, point the 4 on the watch face at the Sun. South would be in the 2 o'clock position.

    What assumptions were used in the passage above?

    I Your wristwatch is correctly synced to local time.

    II Your wristwatch is correctly synced to local solar time.

    III You are located not in the tropics at a latitude below the Tropic of Cancer.

    IV The season is not winter.

    V The time is not noon.

    (A) I and III only

    (B) II and III only

    (C) III and IV only

    (D) II, III, and V only

    (E) I, III, and V only

    Solution:

    II and III must be correct because you are trying to tell the direction of north. If your clock is not synced with the local solar time, your watch is effectively not telling the correct time. If you are located i the tropics, then sometimes the Sun will be north of you and sometimes it will be south of you. IV and V do not matter.

For Questions 30 and 31, please refer to the following table.

Object Name	Apparent Magnitude	Apparent Size (arcminutes)
Triangulum Galaxy	5.72	70.8×41.7
Andromeda Galaxy	3.44	190.2×60.0
Orion Nebula	4.0	65.0×60.0
Dumbbell Nebula	7,5	8.0×6.0
Eskimo Nebula	10.1	0.8×0.8

30. Calculate the surface brightness of each DSO in mag/arcsec^2, and hence arrange them in order of increasing surface brightness.

(A) Eskimo Nebula, Dumbbell Nebula, Orion Nebula, Andromeda Galaxy, Triangulum Galaxy

(B) Andromeda Galaxy, Orion Nebula, Triangulum Galaxy, Dumbbell Nebula, Eskimo Nebula

(C) **Triangulum Galaxy, Andromeda Galaxy, Orion Nebula, Dumbbell nebula, Eskimo Nebula**

(D) Triangulum galaxy, Dumbbell Nebula, Eskimo Nebula, Andromeda Galaxy, Orion Nebula

(E) Eskimo Nebula, Dumbbell Nebula, Triangulum Galaxy, Orion Nebula, Andromeda Galaxy

Solution:

Surface brightness is given by

$$2.5\log(A) + m$$

where m is the apparent magnitude and A is the angular area. This is derived from the relationship between magnitude and luminosity as well as the fact that the apparent magnitude is proportional to $2.5\log\frac{L}{A}$ where L is the luminosity. The calculated surface brightness of the objects are

- Triangulum: 23.3
- Andromeda: 22.5
- Orion: 21.87
- Dumbbell: 20.6
- Eskimo: 18.5

31. In a mildly light-polluted night sky with a surface brightness of 19.4mag/arcsec^2, which of the above objects are visible with the naked eye.

(A) Eskimo Nebula only

(B) Dumbbell Nebula and Eskimo Nebula

(C) Orion Nebula and Andromeda Galaxy

(D) Orion Nebula, Andromeda Galaxy, Dumbbell Nebula, and Eskimo Nebula

(E) Triangulum Galaxy, Orion Nebula, and Andromeda Galaxy

Solution:

Dumbbell Nebula and Eskimo Nebula are too small to be seen with the naked eye. Triangulum Galaxy requires very dark skies (around Bortle 2 and below, which is around a surface brightness of 21and above). Surface brightness is not a completely reliable predictor of visibility. Other factor like the actual luminosity distribution of the object are more important in affecting visibility. For instance, both the Orion Nebula and Andromeda Galaxy have extremely bright central cores.

Note: This question would beenfit those who have actually burnt midnight oil to go stargazing.

32. The James Webb Space Telescope (JWST) will be deployed at the second Lagrange point (L2) of the Earth-Sun system, unlike the upcoming Chinese Space Telescope Xuntian, which orbits the Earth at low Earth orbit. The JWST observes in the visible light through mid-infrared region of the electromagnetic spectrum, whereas the Xuntian observes in the ultraviolet, visible light, and near-infrared regions.

With reference to the above information, which of the following statements is/are true?

I It is necessary for the JWST to employ a sunshield to shield its observing instruments from significant heat sources such as the Sun.

II The JWST is positioned at L2 such that the Earth, Sun, and Moon are in the same general direction, reducing instrumental interference due to radio waves emitted by these bodies.

III The JWST is positioned at L2 because it is a point of stable equilibrium and no fuel will be required to keep it on its intended orbital path.

IV The JWST is not positioned at L4 or L5 because they are relatively far away from the Earth. At 0.5AUs from Earth, light takes a longer time to travel to L4 or L5, limiting the ability to perform real-time commands.

(A) **I only**

(B) I and III only

(C) I and IV only

(D) I, II, and III only

(E) I, III, and IV only

Solution:

I The JWST observes in infrared so it is necessary to shield its instruments from significant heat sources, which may otherwise interfere with observations.

II The JWST observes in infrared so radio waves will not affect observations.

III L2 is metastable and thus, objects there still require a small amount of fuel to maintain orbit.

IV L4/L5 form an equilateral triangle with the Sun and Earth, thus they are at 1AU distance.

33. The Hubble Space Telescope (HST) has a Cassegrain reflector design and employs a hyperbolic primary and secondary mirror. When the HST was first deployed, it was found that the outer perimeter of the primary mirror was polished to be too flat, a serious problem that caused its images to be flawed. What was the type and cause of the main optical aberration that was introduced?

(A) Chromatic aberration due to different wavelengths of light being reflected at different angles.

(B) Coma aberration where light reflected from the edges of the primary mirror is focused at the image plane closer to the optical axis compared to light reflected nearer to the centre.

(C) Coma aberration where light reflected from the edges of the primary mirror is focused at the image plane further from the optical axis compared to light reflected nearer to the centre.

(D) Spherical aberration where light reflected from the edges of the primary mirror are focused to a plane closer to the mirror compared to light reflected nearer to the centre.

(E) Spherical aberration where light reflected from the edges of the primary mirror are focused at a plane further from the mirror compared to light reflected nearer to the centre.

Solution:

For A/B/C, the HST mirror is supposed to be hyperbolic / parabolic. When it is polished too flat, the mirror becomes more spherical and hence, spherical aberration is introduced. This has nothing to do with chromatic aberration and coma aberration. For D and E, there will be negative spherical aberration since the mirror is too flat. This means the light rays are insufficiently bent, and light further from the optical axis will be focused to a longer focal distance compared to light closer to the optical axis.

34. Olbers' paradox describes how every point in the night sky should be bright on the assumption that the Universe is endless and uniformly populated with stars, contrary to observation. Which of the following is not a possible solution to Olbers' paradox?

(A) The Universe is finitely old and ends at some point.

(B) The speed of light is finite.

(C) The age of stars is finite.

(D) Light from distant stars get scattered too much and is hence too dim to detect.

(E) The number of stars in the Universe is finite.

Solution:

C is the preferred answer because stars are born continually and die continually as well. As long as the universe maintains a constant density of stars, there will be an infinite number of stars in the same line of sight. This does not answer the paradox.

D is also an acceptable solution. If there is an infinite number of stars, no matter how much light is scattered, it will still be bright everywhere. Hence, this does not explain why we have dark skies and hence does not answer the paradox.

35. A deep-sky object located directly at the celestial equator with an angular diameter of $10'$ is viewed from the eyepiece of a telescope with a true field of view of $0.8°$. Object tracking on the telescope is disabled and the object is aligned at the edge of the field of view. Assuming the object moves along the diameter of the eyepiece before disappearing, calculate the time it takes for the object to drift out of view of the eyepiece.

(A) 13 seconds

(B) 19 seconds

(C) **3.2 minutes**

(D) 4.8 minutes

(E) There is not enough information to determine the time.

Solution:

Objects on the Celestial Equator in the sky rotate once every sidereal day, that is, $360°$ in 23h56m4.1s. This gives $0.251°/\text{min}$. THe time it takes to drift out of the eyepiece is thus

$$\frac{0.8°}{0.251°/\text{min}} = 3.19\text{min}$$

36. Gravity assists are commonly used to slingshot spacecraft by utilising the gravitational pull of astronomical bodies. Which of the following statements is/are true?

I A gravity assist can be used to increase or decrease the speed of a spacecraft, as well as redirect its path.

II A practical limitation of gravitational assists using planets is atmospheric drag, where the energy lost due to drag is greater than the energy gained from the planet's gravity.

III Assuming no atmospheric drag, the total sum of kinetic energy of the spacecraft and astronomical body remains constant.

IV Gravitational assists using the Sun are feasible but depend solely on the spacecraft's ability to resist the Sun's heat.

(A) I only

(B) I and III only

(C) **I, II, and III only**

(D) I, III, and IV only

(E) I, II, III, and IV

Solution:

I True.

II True. Kinetic energy will be lost through friction with the atmosphere.

III True.

IV False. Gravitational assists using the Sun is not possible because the Sun is stationary relative to the solar system and gravitational assists involve using the relative motions of astronomical bodies. The mechanism involved here is the Oberth Maneuver.

37. Which of the following lines of evidence could possibly support the existence of dark matter?

(A) The Universe is dark.

(B) Dark nebulae have been detected.

(C) Black holes have been recently photographed.

(D) The galactic rotation curve of most galaxies does not make sense.

(E) The rate of expansion of the universe is speeding up, not slowing down.

Solution:

Only D explains dark matter. A,B and C clearly do not relate to dark matter. E is a possible explanation of dark energy, not dark matter.

38. Your classmate Donovan has been an avid amateur astronomer for three years and owns a $6''$ Newtonian reflector ($f/5$) with a manual equatorial mount. He wishes to do astrophotography and has sought your advice on what equipment to buy. Based on his current equipment, which of the following statements can you offer him as advice?

I He should get a light pollution filter to sieve out unwanted stray light entering his telescope.

II He should purchase an auto-guider to help him automatically track objects that his telescope is pointed at.

III A high-speed video camera and Barlow lens can be purchased for capturing detailed images of planets by utilising the large aperture of his telescope.

IV Since he possesses an equatorial mount and a fast Newtonian reflector, he can use a DSLR or purchase a dedicated astronomy imaging camera to take pictures of deep-sky objects like the Orion Nebula and the Andromeda Galaxy.

(A) I only

(B) III only

(C) II and III only

(D) I, II, and III only

(E) II, III, and IV only

Solution:

I Although light pollution is also a consideration, the more significan t problem would be the lack of an automated mount. We can also deduce that option III is correct and since there

is no MCQ option which allows for both options I and III to be selected, we rule out this option.

II Auto-guiders only work with tracking mounts.

III Planets are large and bright enough such that the high-speed video camera would still be able to capture detailed frames of them, in spite of minor inaccuracies due to manual trackcing.

IV Deep-sky objects such as the Orion Nebula and the Andromeda Galaxy are relatively dim and require long-exposure photography, which manual tracking is unable to accomplish without resulting in unwanted star trails.

39. Collimation is the process of aligning all components in a telescope to bring light to its best focus. Generally, which of the following telescopes require frequent collimation?

I Newtonian reflector

II Schmidt-Newtonian

III Schmidt-Cassegrain

IV Keplerian refractor

V Galilean refractor

VI Ritchey–Chrétien

(A) I only

(B) I and II only

(C) I, II, III and V only

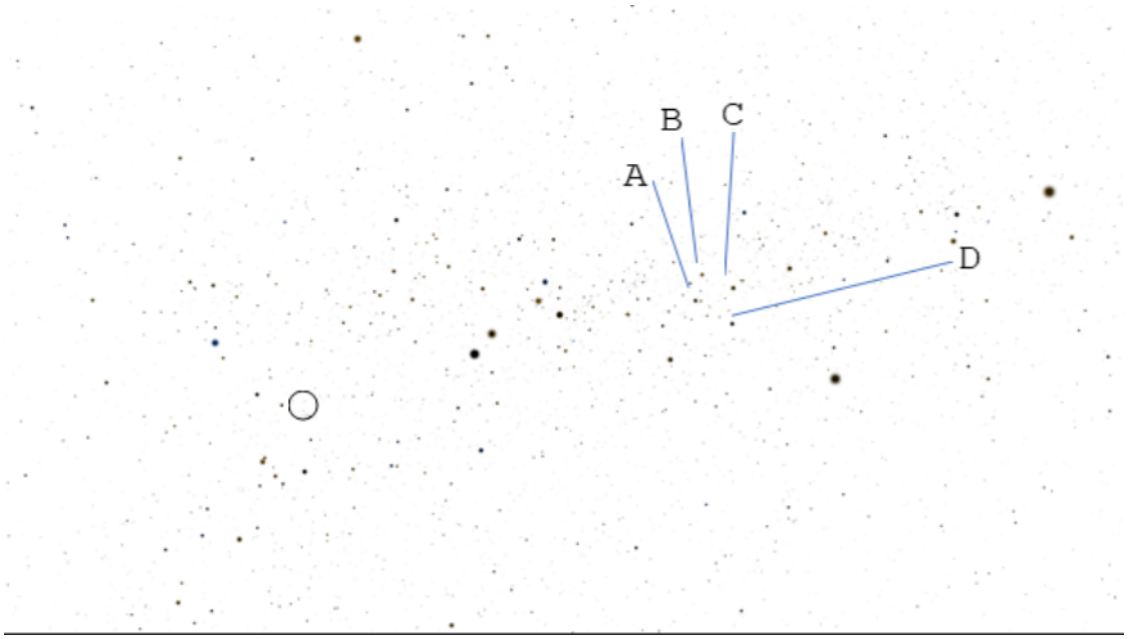
(D) I, III, and VI only

(E) None of the above combinations are correct

Solution:

I, II, III and VI all require collimation of some sort before use. Generally, all telescopes do need to be collimated. However, refractors usually have their lens locked in. As such, it is hard to go out of collimation. Alternatively, it is very hard to do so even if it is because you would have to open it to do it. All telescoes listed are real telescope types. Ritchey-Chrétien is in the telescope type used in the HST.

For Questions 40 and 41, please refer to the following image.



40. Which DSO would one expect to see in the circled region?

(A) **False Comet**

(B) False Cross

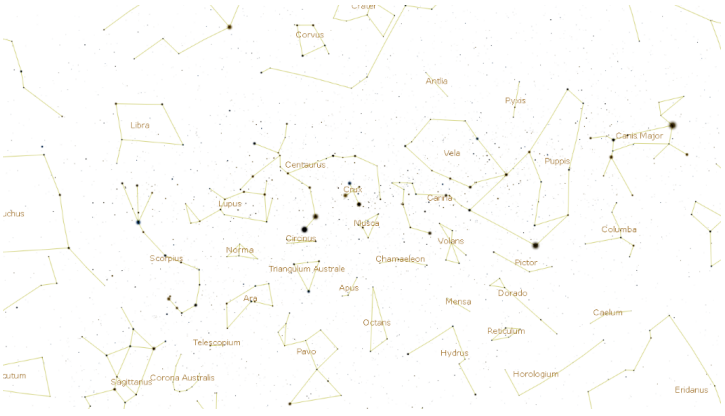
(C) False Eskimo

(D) Jewel Box

(E) Southern Pleiades

Solution:

It is located in Scorpius.



The False Cross is not a DSO but an asterism (ABCD). The False Eskimo does not exist. Jewel Box and the Southern Pleiades are in the wrong place.

41. The stars A, B, C, and D form part of a constellation. What is that constellation?

(A) Crux

(B) Argo Navis

(C) Carina

(D) Scorpius

(E) Trick question. This is an asterism formed from at least two different constellations.

Solution:

See the above. ABCD is actually the false cross located with stars from both Carina and Vela.

For Questions 42 to 44, please refer to the following table.

Star	A	B	C
Spectral Type	B0IV	B3III	A5IV
Right Ascension	0h 58m 00s	1h 55m 56s	1h 27m 12s
Declination	60°49′50″	63°46′23″	60°20′39″
Apparent Magnitude	1.6–3.0	3.3	2.7
Distance from Earth	615ly	448ly	99.5ly
Color Index (B–V)	−0.05	−0.15	0.16

42. Which of the following statements is/are correct?

I Star C is a white dwarf.

II Star B is definitely more massive than the Sun.

III Stars A and C are located on the main sequence.

IV Star A is the hottest among them all.

V All three stars are very much likely gravitationally bound.

(A) I and II only

(B) II and III only

(C) **II and IV only**

(D) II, IV and V only

(E) None of the above options are correct

Solution:

I Star C has a spectral type of IV meaning it is a sub giant (above main sequence) and is thus not a white dwarf.

II This is true.

III None of the stars are located on the main sequence (V).

IV Star A has a spectral class of B0, meaning it is the hottest within B. Star C, being an A class star is less hot than either star A or star B.

V The stars are located some many degrees apart, thus they cannot be gravitationally bound.

43. Rank the following in increasing order of luminosity. You are given that the Sun is located 8 light minutes away and that its apparent magnitude is -26.7.

I The Sun

II Type 1a supernova

III Star A

IV Star B

V Star C

(A) I, II, III, IV, V

(B) I, IV, V, II, III

(C) II, III, IV, V, I

(D) IV, V, III, II, I

(E) None of the above orders are correct

Solution:

We can use the distance modulus

$$m - M = 5\lg\frac{d}{10\text{pc}}$$

to calculate the absolute magnitudes of the objects, which correspond to their luminosity. We are also given that the absolute magnitude of a type 1a supernova from the formula book. This gives the following calculated values

- Sun: 4.9
- Type 1a supernova: -19.3
- Star A: -4.1
- Star B: -2.4
- Star C: 0.28

This gives the correct order as I, V, IV, III, II.

Note: The value for star A is calculated using the median of the two values given. Using any other value within the range would not change your answer.

44. It is further given that the radial velocities of Star B and Star C is -8.1kms^{-1} and -6.7kms^{-1} respectively. Assuming a fixed and constant rate of motion, roughly how long will it take for the apparent magnitude of Star B to be dimmer than that of Star C?

(A) 2000 years

(B) 20000 years

(C) 200000 years

(D) 2 million years

(E) 20 million years

Solution:

This question has been **VOIDED**.

45. Which of the following statements about the midnight sun is false?

(A) The midnight sun lasts for 6 months for locations near the celestial poles.

(B) The midnight sun can be seen outside the Arctic Circle and the Antarctic Circle, due to atmospheric refraction of the sun below the horizon.

(C) At the north and south celestial poles, the Sun only rises and sets once a year on the equinoxes.

(D) On the winter solstice at the north celestial pole, the Sun will stop moving north, change direction, and start to move south.

(E) At the south celestial pole, the midnight sun can be seen longer than September 23 to March 21 due to atmospheric refraction of the Sun below the horizon.

Solution:

A True.

B True.

C True.

D False. The Sun cannot be seen on the winter solstice. It will also stop moving south, not north on that date.

E True.

46. Which of the below practical astronomy tips for use in Singapore is correct?

(A) You should proceed to stargaze when the Moon is full.

(B) You should align your mount to the north by using a polar scope and finding Polaris.

(C) You should balance the mount before you mount the telescope.

(D) You should load the counterweight before loading anything else onto the mount.

(E) None of the above tips make sense.

Solution:

A False. The full moon will make it too bright to observe many dimmer objects.

B False. You are likely unable to see Polaris in Singapore because we are very near the celestial equator. A compass would do.

C False. You should only balance the mount after you have mounted the telescope as well as the telescope accessories.

D True.

47. Which of the following factors are not considered when calculating the orbital speed of a satellite?

(A) Gravitational constant

(B) Mass of the parent body

(C) Mass of the satellite

(D) Orbital radius/semi-major axis of the satellite around the parent body

(E) All of the above are considered

Solution:

The orbital speed is given by

$$v = \sqrt{\frac{GM}{r}}$$

where G is the gravitational constant, M is the mass of the parent body and r is the orbital radius / semi-major axis of the satellite around the parent body.

48. Europa is the second inner-most Galilean moon of Jupiter. It is seen as a possible candidate for extra-terrestrial life due to the conditions it experiences. Which of the following observations of Europa is/are significant in determining if it can possibly host life?

I A subsurface ocean is hypothesised to exist below Europa's surface.

II Europa is located outside the circumstellar habitable zone of the solar system.

III Tidal heating exists due to the gravitational interaction between Jupiter and Europa.

(A) I only

(B) I and II only

(C) I and III only

(D) I, II, and III

(E) None of the above

Solution:

I Significant. Liquid water is an ideal solvent for cells.

II Insignificant. Extremophiles can still exist in hostile conditions evn if the celestial body is not within the habitable zone.

III Significant. The tidal heateing is dissipated as heat in the core, subsurface ocean and icy crust. This source of heat is suggested to be the principal heat source to maintain Europa's liquid oceans.

49. In 1964, a weak radio signal was detected using a supersensitive horn antenna after attempting to eliminate all sources of interference. The radio waves detected were evenly spread across all parts of the sky and were subsequently attributed to the Cosmic Microwave Background Radiation (CMBR). Which of the following statements is/are true?

I The expansion of the universe causes the temperature of the CMBR to decrease over time.

II The discovery of the CMBR supports the steady-state model, where the density of matter in the expanding universe is constant due to the continuous creation of matter.

III As the universe expands, the CMBR is redshifted, decreasing the wavelength of the radiation over time.

(A) I only

(B) I and II only

(C) I and III only

(D) I, II, and III

(E) None of the above

Solution:

I True. As the universe expands, the CMBR photons are redshifted and their energy decreases, causing the temperature to decrease.

II False. The CMBR refutes the steady-state model since the observed spectrum of the CMBR was a thermal, black body spectrum, a result that the steady state model was unable to reproduce.

III False. As the universe expands, the CMBR is redshifted. However, a redshift corresponds to an increase in the wavelength of radiation, not a decrease.

50. When studying the stellar spectrum of the binary Delta Orionis, Johannes Hartman realised the calcium absorption lines did not share the same periodic displacements as absorption lines of other similar stars. What did this observation lend evidence to?

(A) Presence of a third component in the Delta Orionis star system.

(B) The presence of atmospheric calcium in Earth's upper atmosphere.

(C) **The presence of interstellar gas.**

(D) The use of calcium fluoride in coating mirrors was not suitable for spectroscopy.

(E) Hartman made a mistake somewhere somehow.

Solution:

A This would not result in the effect.

B This is too negligble.

C Interstellar gas causes this to happen.

D This is too negligble.