AstroChallenge 2023
Junior MCQ Round

SOLUTIONS

Monday 29th May 2023

PLEASE READ THESE INSTRUCTIONS CAREFULLY.

1. This paper consists of **29** printed pages, including this cover page.
2. Do **NOT** turn over this page until instructed to do so.
3. 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.
4. At the end of the paper, submit this booklet together with your answer script.
5. Your answer script should clearly indicate your name, school, and team.
6. It is *your* responsibility to ensure that your answer script has been submitted.

1. Given that a planet's orbit has an eccentricity of 0.65 and the distance of the planet to its star at the furthest point is 3×10^{11} meters. find the length of the semi-major axis.

   (A) 8.57×10^{11} m

   (B) 1.82×10^{11} m

   (C) 5.19×10^{11} m

   (D) 1.05×10^{11} m

   (E) 4.95×10^{11} m

   Solution:

   We can find the semi-major axis from the apoapsis distance using the following formula:

   $$r_{apoapsis} = a(1 + e)$$

   $$3 \times 10^{11} = a \times 1.65$$

   $$a \approx 1.82 \times 10^{11} m$$

2. Which of the following statements about lunar and solar eclipses is/are false?

   (A) Lunar eclipse can only occur during a full moon

   (B) Eclipses can only happen when the Sun, Earth, and Moon are in syzygy

   (C) The totality of solar eclipse can last as long as the totality of lunar eclipse

   (D) All of the above

   (E) None of the above

   Solution:

   A and B are true. The totality of a solar eclipse can only last 7 minutes at most, but the totality of a lunar eclipse can last up to 2 hours.

3. Assuming both planets have circular orbits with radii of their semi-major axes, what is the maximum elongation of Mercury as observed from Earth?

(A) **22.8°**

(B) 28.3°

(C) 34.2°

(D) 37.8 °

(E) 42.8 °

Solution:

Maximum elongation is achieved when the Mercury-Earth-Sun system creates a right triangle with the right angle at Mercury. Using the semi-major length of both planets' orbits. We can get the maximum elongation to be:

$$\sin\theta = \frac{a_{mercury}}{a_{earth}}$$

$$\sin\theta = \frac{5.791}{14.96}$$

$$\sin\theta = \sin^{-1}(0.3871) = 22.8°$$

4. Which of the following optical aberrations do not match the possible method to resolve or minimise it?

1	Chromatic Aberration	Adding additional lenses of corresponding refractive index to focus light of different wavelengths to the same point.
2	Coma	Increase objective lens' size to increase magnification.
3	Spherical Aberration	Increase focal ratio to decrease angle of aberration.
4	Field Curvature	Using a field flattener.

(A) 1

(B) **2**

(C) 3

(D) 4

(E) All the optical aberrations and their methods of resolving them match

Solution:

Chromatic aberration is an off-axis aberration (the effect worsens with the angle from the optical

axis) and is thus mitigated by implementing higher focal ratio. For comas, you should instead increase the focal ratio to decrease the aberration.

5. Jeanne was stargazing when she noticed the following:

   - Two planets Jupiter and Saturn could be seen. Jupiter was seen in Scorpius and Saturn was seen in Sagittarius
   - A half moon is seen on the meridian. A quick check of her watch showed that it was coincidentally now near midnight
   - The 7 stars of the Big Dipper shine brightly in the sky. Extending a line connecting 2 stars of the Big Dipper, she could locate Polaris

   She then immediately concluded she must be dreaming. What did she realize?

   (A) Jupiter and Saturn cannot be seen together in the sky.

   (B) Jupiter and Saturn will never be in the constellations Scorpius and Sagittarius respectively.

   (C) If a moon is seen on the meridian at midnight, it cannot be a half moon.

   (D) If Scorpius and Sagittarius are in the night sky, then the Big Dipper cannot be seen in the same night sky as the former two are summer constellations while the latter is part of Ursa Major which is a spring constellation.

   (E) There is no way to use the Big Dipper to locate Polaris as they are too far apart in the night sky to estimate accurately.

Solution:

Jupiter and Saturn can be seen together as long as they are within the ecliptic (i.e., zodiac line). Ursa Major is not far enough from Scorpio and Sagittarius to justify Jeanne to dream, while the method in Statement (iii) is a common way to locate Polaris. Meanwhile, the only time the Moon can be seen on the Meridian at local midnight is when it is Full Moon.

6. You look at the clock and it is now 12 am, 25^{th} December 2023. You look up in the sky and see a bright red star. What can this star be? Your location on Earth is unknown.

i Sirius

ii Aldebaran

iii Castor

iv Arcturus

(A) i or ii

(B) **ii or iv**

(C) iii or iv

(D) i or iii

(E) None of the above

Solution:

Even though the time of observation is known, the information on the location is not given. It is therefore impossible to infer what the night sky is for the observer. Hence, any red star is a plausible answer. Among the options, Aldebaran and Arcturus are red stars.

7. Which of the following statements are true about elliptical galaxies?

i Stars in elliptical galaxies tend to be older

ii Elliptical galaxies tend to have lower rates of star formation than spiral galaxies

iii Elliptical galaxies do not have active galactic nuclei

iv Orbits of stars in elliptical galaxies are randomly distributed

v Elliptical galaxies are largely stripped of interstellar gas and dust

(A) i, ii, and v

(B) ii, iii, and v

(C) **i, ii, iv, and v**

(D) i, ii, iii, and v

(E) All of the above

Solution:

Option (iii) is incorrect with a popular counterexample being Messier 87.

8. On December 8^{th} 2022, Mars was occulted by the Moon just as it reached opposition to Earth. What was the Moon's phase that night?

   (A) New Moon

   (B) First Quarter

   (C) Full Moon

   (D) Third Quarter

   (E) Impossible to tell from the given information

   Solution:

   For the Moon to occult Mars during opposition (where it is directly opposite the Sun), the Moon itself has to be in opposition as well, which means that it is in the Full Moon phase.

9. Suppose that werewolves transformed whenever the Full Moon was above the horizon. Which of these nights with the Full Moon would force a werewolf in Bern (46°56′ N, 7°26′ E) to transform for the longest amount of time? None of these nights feature a total lunar eclipse.

   (A) The night of January 6, 2023

   (B) The night of April 6, 2023

   (C) The night of July 3, 2023

   (D) The night of September 30, 2023

   (E) The Full Moon is above Bern's horizon for the same duration on all 4 nights

   Solution:

   At full moon, the Moon is diametrically opposite of the Sun. The Moon will be above the horizon the longest on days where the Sun will be above the horizon the shortest. Since Bern is significantly north of the Equator, the best answer will be the time closest to the Winter Solstice (23 December).

10. Which of the following does **not** describe the characteristics of a planet.

(A) A planet moves in an ellipse with the Sun at one of the foci

(B) Planets are able to clear the neighborhood around its orbit

(C) The period of revolution of a planet about the Sun is directly proportional to the semi-major axis of the ellipse of the orbit

(D) All of the above

(E) None of the above

Solution:

Options A and B are two of the official characteristics of a planet set by the IAU. Option C directly contradicts Kepler's third law.

11. One tropical year is the time the Sun takes to return to the same solstices or equinoxes, while the sidereal year is the time the Sun to return to the same position relative to distant stars.

Given that a sidereal year is longer than a tropical year, looking from the north ecliptic pole to the south ecliptic pole, which of the following describes the rotation of the **first point of Aries** and the **first point of Libra** on the ecliptic plane compared to distant stars?

(A) Counter-clockwise,clockwise

(B) Clockwise, clockwise

(C) Counter-clockwise, counter-clockwise

(D) Clockwise, counter-clockwise

(E) Both points do not move compared to distant stars

Solution:

Since the tropical year is shorter than a sidereal year, the Sun will reach solstices and equinoxes at a progressively earlier Right Ascension (RA) over many years. This is the cause of the precession of equinoxes. Note that RA is defined by the celestial sphere.

When viewed from the North Ecliptic Pole centered at Earth, the Sun appears to move around the Earth in a counter-clockwise motion. At each subsequent tropical year, the Sun makes less than one full revolution relative to the celestial sphere. Therefore, the position of the equinoxes and solstices appear "backwards" (i.e., clockwise).

12. The cosmological principle states that:

(A) The observable universe is finite and the universe is expanding

(B) The universe is dominated by dark matter and dark energy which we cannot detect on the electro-magnetic spectrum

(C) The universe appears the same in all directions for observers anywhere at a large enough scale

(D) The universe expanded from a singularity and is currently expanding at an increasing rate

(E) The total entropy of the universe will continue to increase until it reaches a maximum

Solution:

The cosmological principle states that the universe is isotropic and homogenous at large enough scales.

Isotropy means that the Universe seems to be uniform regardless of direction we are observing from Earth.

Homogeneity means that the Universe seems to be uniform at every point in space.

13. For any object to become a black hole, it must cross what is known as the Schwarzchild radius, given by the formula below.

$$R_g = \frac{2GM}{c^2}$$

Calculate the Schwarzchild radius for Earth to become a black hole.

(A) 8.8×10^3 m

(B) 8.8 m

(C) 8.8×10^{-3} m

(D) 8.8×10^{-5} m

(E) 8.8×10^{-8} m

Solution:

$$R_g = \frac{2 \times (6.674 \times 10^{-11})(5.972 \times 10^{24})}{9 \times 10^{16}}$$

$$R_g \approx 8.8 \times 10^{-3} m$$

14. Assuming that you can see Cassiopeia in its lower culmination at local midnight, which of the following is **not** correct?

(A) You are in the Northern Hemisphere

(B) You are not located in the tropics

(C) **You are observing it in autumn**

(D) You are observing it in spring

(E) More than one options are incorrect

Solution:

Cassiopeia's declination in the far North makes it likely for the observer to be in the Northern Hemisphere. Its location near the First Point of Aries (23h to 4h) means it should have been near its upper culmination at local midnight instead. Hence, the statement in option C is incorrect.

15. What is the line that the Sun traces out on the celestial sphere over the course of a year called?

(A) Celestial equator

(B) **Ecliptic**

(C) Analemma

(D) Prime Meridian

(E) None of the above

Solution:

This is by definition of the ecliptic

16. The Hawking Temperature is the theoretical black-body equivalent temperature of a black hole radiating Hawking radiation. It is given by:

$$T_H = \frac{hc^3}{16\pi^2 GMk_B}$$

where h, c, G, k_B ,and M are the Planck's constant, speed of light, the gravitational constant, Boltzmann's constant, and the mass of the black hole, respectively.

What is the ratio of the power of black body radiation (in Watts) between two black holes if the second one had half the mass of the first?

(A) 2 : 1

(B) 1 : 2

(C) 1 : 4

(D) 1 : 8

(E) **1 : 16**

Solution:

A perfect black-body have the power correlated to its effective temperature as:

$$P \propto T^4$$

From the formula given in the question, we can calculate the ratio of the Hawking Temperature as:

$$T_{H,1} : T_{H,2} = m_2 : m_1 = 1 : 2$$

and then the power radiated:

$$P_1 : P_2 = T_1^4 : T_2^4 = m_1^4 : m_2^4$$

$$P_1 : P_2 = 1^4 : 2^4$$

$$P_1 : P_2 = 1 : 16$$

17. The Sun's equatorial rotational period is 24.47 Earth days. What would be the orbital radius of a helio-synchronous orbit in Astronomical Units (AU)?

(A) 1.22×10^{-4}

(B) 2.45×10^{-4}

(C) 2.56×10^{-4}

(D) 1.28×10^{-4}

(E) **0.16**

Solution:

A helio-synchronous orbit means the revolution of an object within the orbit is equal to the rotational orbit of the Sun. We use Kepler's third law against Earth's orbit to find the orbit with

the revolution period equal to 24.47 Earth days.

$$T^2_{earth} : T^2_{hsync} = a^3_{earth} : a^3_{hsync}$$

$$a^3_{hsync} = \left(\frac{24.47}{365.2425}\right)^2$$

$$a_{hsync} = 0.067^{2/3} \approx 0.16AU$$

18. Which of the following statements is/are false?

i Only inferior planets can be at inferior conjunction

ii Only inferior planets can be at quadrature

iii Both inferior and superior planets can be at conjunction

iv Inferior planets can be at opposition

(A) i only

(B) i and ii

(C) i, iii, and iv

(D) ii and iv

(E) All options are correct

Solution:

Inferior planets can be at conjunctions (inferior and superior) with Earth. However, unlike superior planets, it cannot be in opposition and quadratures. Hence, options (ii) and (iv) are false.

19. Star A and Star B have the same absolute magnitude. Star A has an apparent magnitude of +3.6. Star B is twice as far from Earth as Star A. What is the apparent magnitude of Star B?

(A) +1.8

(B) +2.1

(C) +4.6

(D) +5.1

(E) +7.2

Solution:

Since the absolute magnitude is the same, we can directly compare the apparent magnitude of

Star B using the distance modulus:

$$m - 3.6 = 5log(2)$$

$$m = 3.6 + 1.5 = 5.1$$

20. Which of the following is true?

(A) The Caldwell Catalogue is organized by declination from South to North

(B) **The Messier Catalogue cuts off around declination 30 degrees South since Messier could not see things further south of that**

(C) The New General Catalogue is a work of Edwin Hubble

(D) The Messier Catalogue contains a few comets

(E) None of the above

Solution:

I: The Caldwell Catalogue is organized from North to South.

III: The NGC is instead compiled by the Danish astronomer John Louis Emil Dreyer

IV: The Messier Catalogue is written specifically to help astronomers differentiate comets against non-comet objects (i.e., DSOs)

This leaves us with statement (ii) which is correct considering his residence in the Northern Hemisphere (France)

Read this passage to answer question 21 and 22

You are the captain of the research vessel RV AstroChallenge on a hydrographic survey mission. Unexpectedly, a coronal mass ejection has knocked all communications and GPS satellites offline. The only way for you to pinpoint your coordinates and find a way back home is to use the Sun, the stars, and a clock synchronised to GMT. The coordinate of Greenwich is 51.48°N, 0°E and the current date is 21 June.

21. You sighted the Sun with a sextant just as it crosses the local noon and found that it has an altitude of 30 degrees due North. What is your local latitude?

(A) 36.5 °N

(B) 36.5 °S

(C) 6.5 °N

(D) 6.5 °S

(E) 53.5 °S

Solution:

At Summer solstice, the Sun has a declination of +23.5° and hence a polar angle of 66.5°. The Sun's altitude is 30°N implies that the North Celestial Pole should be below the horizon at the latitude:

$$\alpha = 30 - 66.5 = -36.5$$

Hence, you should be located 36.5° South of the equator.

22. You checked the ship's clock at local noon and found that the current Greenwich Mean Time is 0630hrs (24-hr time). What is your local longitude?

(A) 82.5 °E

(B) 82.5 °W

(C) 97.5 °E

(D) 97.5 °W

(E) 42 °W

Solution:

The local solar time is 5.5hrs later than Greenwich's solar time, which implies the location is in the Eastern Hemisphere. The longitude can be calculated from time difference:

$$\theta = 360° \times \left(\frac{5.5}{24}\right)$$

$$\theta = 82.5°$$

Hence, you should be located 82.5° East of Greenwich.

23. You visited Melbourne, Australia (37.82°S, 144.97°E) last December for a stargazing trip. You wrote down some of the stars that you saw in a notebook. However, your friend told you that there are some mistakes in the recording as these stars shouldn't be visible during your trip.

Stars Seen	Right Ascension	Declination
Canopus (α Carinae)	06h 24m 27s	-53°42' 25.4"
Polaris (α Ursae Minoris)	03h 00m 34s	+89°21' 37.3"
Navi (γ Cassiopeae)	00h 58m 05.2s	+60°50' 23.7"
Rigel (β Orionis)	05h 15m 38s	-08°10' 30.9"
Adhara (ϵ Canis Majoris)	06h 59m 31s	-29°00' 09.4"
Dubhe (α Ursae Majoris)	11h 05m 07.6s	+61°37' 46.2"

How many of the above stars are incorrectly recorded? You may assume the RA and declination are recorded correctly.

(A) 1

(B) 2

(C) 3

(D) 4

(E) 5

Solution:

Melbourne is in the Southern Hemisphere and thus some northern stars are never visible from the city. The northernmost declination visible from Melbourne are given by:

$$\delta_{max} = 90 + (-37.82) = +52.16$$

Thus, any stars with $\delta > +52.16°$ are not visible. In this case, this includes Polaris, Navi, and Dubhe.

24. Two stars are the same distance from the observer. Star A has a surface temperature of 4000K and Star B has a surface temperature of 16000K. Star A's radius is 4 times that of Star B. How much more luminous is star B compared to Star A?

(A) Same luminosity

(B) 2 times

(C) 8 times

(D) 16 times

(E) 256 times

Solution:

Note the Stefan-Boltzmann law of black body radiation:

$$P = A\epsilon\sigma T^4$$

Assuming the stars in question can be approximated to black bodies and perfect spheres, the following relation applies.

$$P \propto AT^4 \propto r^2T^4$$

$$\frac{P_B}{P_A} = \frac{r_B^2 T_B^4}{r_A^2 T_A^4}$$

$$\frac{P_B}{P_A} = \frac{1 \times 16000^4}{4^2 \times 4000^4}$$

$$\frac{P_B}{P_A} = 16$$

25. Given our current understanding about the early universe, sort the following events chronologically.
    1. Big Bang Nucleosynthesis
    2. Reionization
    3. Cosmological Inflation
    4. Formation of protons and neutrons
    5. Recombination

(A) 1, 4, 3, 2, 5

(B) 2, 5, 3, 1, 4

(C) **3, 4, 1, 5, 2**

(D) 4, 1, 3, 5, 2

(E) 5, 2, 3, 4, 1

Solution:

Out of all these events, cosmological inflation (3) occurs first. After that, protons and neutrons must form (4) before Big Bang Nucleosynthesis (1) can occur. Then, the recombination of positive nuclei and negative electrons occurs (5) which allows reionization (2) after the universe has cooled down more.

You are provided with 3 telescopes with the following specifications. Answer question 25 and 26 based on the information given.

Name:	Telescope A	Telescope B	Telescope C
Type:	Newtonian Reflector	Schmidt Cassegrain	APO Triplet Refractor
Aperture:	203mm	127mm	107mm
Focal Ratio:	F3.9	F10	F7
Weight:	7.94kg	2.72kg	6.9kg

26. Which of the following statements is/are true given no accessories are used?

i Telescope A contains 2 mirrors

ii Telescope B is best for observing large Deep Sky Objects (DSO) as it has a long focal length

iii Telescope C contains a mirror and a few lenses

iv Telescope A has the shortest focal length

(A) **i only**

(B) i and ii

(C) i, ii, and iv

(D) ii and iv

(E) All of the above

Solution:

I: Newtonian telescopes contain 2 mirrors.

II: Schmidt Cassegrain telescopes' focal length are much more suitable for planets.

III: Refractors, as the name suggests, do not have mirrors. Telescope C has the shortest focal length.

27. Which of the above telescopes will allow you to resolve the Tycho Crater (diameter = 85km) on the Moon?

(A) Telescope A

(B) Telescope B

(C) Telescope C

(D) **All of the above**

(E) None of the above

Solution:

We use $\lambda = 550nm$ to prove that the telescopes are all too small to resolve the Tycho Crater. Using small-angle approximation:

$$\theta \approx \frac{1.22\lambda}{D}$$

$$\frac{85 \times 10^3}{3.843 \times 10^8} = \frac{1.22(550 \times 10^{-9})}{D}$$

$$D \approx 3.034mm$$

For any wavelength within the order of visible light, the telescope aperture size must be at least 3mm to be able to resolve the crater. Our telescopes with their hundred-milimeters will be more than enough to resolve them.

28. Why does Mars appear red to the naked eye?

(A) **The Martian surface is rich in iron oxides, which appear red**

(B) Mars is a black body and thus emit red light by Wien's Law

(C) Widespread volcanic activity in the Tharsis Montes region emits significant amount of red light

(D) Raging wildfires on its surface emit red light

(E) Mars is not red, it only appears red due to post-processing

Solution:

A is correct. Mars' surface is abundant in iron oxides, which has a characteristically red colour.

B is incorrect because Mars' surface temperature is too cool to radiate significant visible light.

C is incorrect because Mars has no recent volcanic activity significant enough to render the planet red.

D is incorrect because the lack of oxygen on Mars make widespread wildfires impossible.

E is incorrect as Mars also appear red even in naked-eye observations.

29. Polaris (α Ursae Minoris) is an observable star close to the North Celestial Pole – hence we call it the North Star. However, due to axial precession, there have been several bright stars close enough to the Celestial Pole to deem themselves worthy of being named one in foretime. Thuban (α Draconis) was one during 3000 BC. Estimate the current declination of Thuban, given the axial precession period of Earth is 26,000 years.

(A) $-47\,^\circ$

(B) $+24\,^\circ$

(C) $+26\,^\circ$

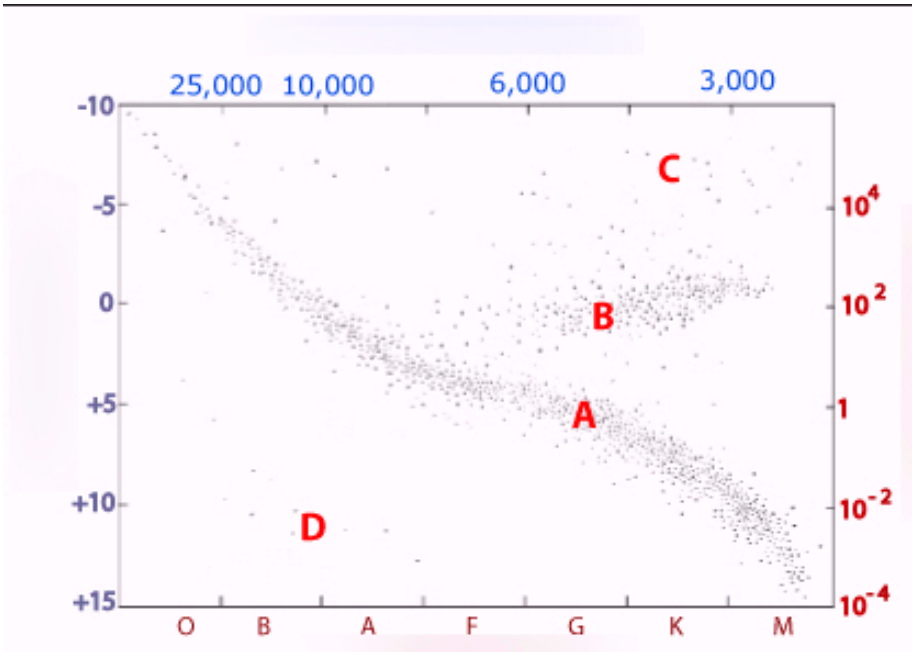
(D) **$+64\,^\circ$**

(E) $+90\,^\circ$

Solution:

The axial tilt of the Earth is 23.5° from the normal of the orbital plane. Without calculations, we can infer that the polar angle of any potential polar stars cannot be more than twice the axial tilt. This leaves us with a star with the declination of +64°.

30. Below is a standard Hertzsprung-Russel diagram. The bottom and left axes labels represent spectral class and absolute magnitude respectively.



Which region labelled on the HR Diagram could you find Betelgeuse (α Orionis)?

(A) A

(B) B

(C) **C**

(D) D

(E) E

Solution:

Regions labelled A, B, C, and D are main-sequence stars, giants, supergiants, and white dwarves, respectively.

31. The image below is a negative image of the Milky Way. Identify the labelled asterism.

(A) Spring Triangle

(B) Summer Triangle

(C) Winter Triangle

(D) The Great Triangle of Pegasus

(E) None of the above

Solution:

The image shown above shows the patch of the sky near Sagittarius and Scorpius. The triangle shown in the image does not correspond to any asterisms listed.

32. Which of the following statements incorrectly describe sunspots?

(A) Sunspots are regions with locally strong magnetic fields on the surface of the Sun

(B) Sunspots are regions with higher-than-average temperatures on the surface of the Sun

(C) The number of sunspots varies in a cycle with a period of approximately 11 years

(D) Higher number of sunspots observed during solar maximum generally coincide with greater frequency of aurorae seen on Earth

(E) None of the above

Solution:

Sunspots are points in the solar surface with concentrated magnetic flux and its numbers varies cyclically every 11 years. Due to their magnetic nature, they are related to the aurora activity on

Earth. The magnetic flux inhibit convention near the sunspots which decreases local temperature and thus appear as dark spots to us.

33. Estimate the distance of ACGC 2214 (AstroChallenge General Catalogue 2214) from the Sun given that it has an annual parallax of 1.3 arcseconds

(A) 0.77 ly

(B) 1.3 ly

(C) **2.5 ly**

(D) 4.2 ly

(E) 12.7 ly

Solution:

By the definition of a parsec, we use the following approximation:

$$d = \frac{1}{1.3} pc$$

$$d = \frac{3.261}{1.3} ly$$

$$d \approx 2.51 ly$$

34. Which of these statements about white dwarves are true?

(A) They are formed when brown dwarves contract and commence hydrogen fusion

(B) **The Sun will eventually evolve into a white dwarf**

(C) They are almost entirely composed of neutrons

(D) A white dwarf must have a mass smaller than the Sun

(E) None of the options are correct

Solution:

A white dwarf is the stellar remnant of stars with masses from 0.6 to 10 solar masses, which means the Sun will evolve into one eventually. Their mass ranges from 0.17 to 1.33 solar mass which means they are not strictly less massive than the Sun. They are not dense enough to undergo neutron degeneracy akin to neutron stars and hence are mostly composed of hydrogen and helium.

35. Listed below are three calendars used in Persia (modern-day Iran) throughout different periods in history and the number of days in each month.

Name	Days in Months
Xorsidi	31, 31, 31, 31, 31, 31, 30, 30, 30, 30, 30, 29
Jalali	30, 31, 32, 31, 32, 30, 31, 30, 29, 30, 29, 30
Hijri	29, 30, 30, 29, 30, 29, 29, 30, 29, 30, 29, 29

Which of the mentioned calendars are solar calendars?

(A) Xorsidi

(B) **Xorsidi and Jalali**

(C) Xorsidi and Hijri

(D) Jalali and Hijri

(E) All of the above

Solution:

Common characteristics of solar calendars are that their cumulative days totaled up to approximately 365 days. Both the Xorsidi and Jalali calendars have a total of 365 days. Hijri is a lunar calendar as the total days does not correspond to Earth's revolution while adhering to lunar synodic period (29.5 days).

36. Which of the following is **not** a source for internal heating mechanisms present within the planets of the Solar System?

(A) Tidal heating

(B) Gravitational contraction

(C) Radioactivity

(D) **Thermal ionization**

(E) None of the above

Solution:

A: Tidal heating occurs in planets with natural satellites from energy dissipated from tidal deformations caused by the satellite's gravitational pull.

B: Gravitational contraction produces heat from the inwards pressure of the planet.

C: Some terrestial planets also have radioactive isotopes that heats up the internal parts of the planet

D: Thermal ionization is the process of a molecule being ionized due to high temperature. This is a reaction that consumes thermal energy (instead of radiating them), thus it is not possible for it to be a heating mechanisms for planets.

37. Suppose you launch a projectile at 12 km/s directly upwards from Earth's surface. Assuming a one-body problem, what will happen?

(A) The projectile will travel a long distance and eventually fall back down to Earth

(B) The projectile will reach orbit and orbit around the Earth indefinitely

(C) **The projectile will never return to Earth again**

(D) The projectile will be travelling faster than the universe is expanding and hence reach the end of the universe given enough time

(E) None of the above statements will happen

Solution:

The escape velocity on Earth's surface is:

$$v_{esc} = \sqrt{\frac{2GM}{R}}$$

$$v_{esc} = \sqrt{\frac{2(6.674 \times 10^{11})(5.972 \times 10^{24})}{6.37 \times 10^{6}}}$$

$$v_{esc} \approx 11.2 km/s$$

Since 12 km/s $> v_{esc}$, the projectile will escape Earth's gravity and not return back to Earth, even when shot directly upwards.

38. Planets are deemed as wanderers across the night sky whereas stars are not. However, some stars still move across the night sky relative to each other. What is one of the reasons for such an observation.

(A) The difference between a solar day and a sidereal day is about 4 minutes, causing stars to rise four minutes earlier each day

(B) The precession of the equinoxes cause the stars to rise and fall at different times over a long period of time

(C) **Stars may drift apart or closer together over time due to their own peculiar velocities**

(D) Tectonic plates moving causes stars to appear out of place

(E) Trick question: Stars do not move relative to each other like planets do

Solution:

Due to their own intrinsic velocities in space, the position of stars relative to each other will change.

Both A and B refer to the apparent motions of the stars due to the rotational effects of the Earth. The stars will move together on a similar manner together and are hence not the correct answers. Tectonic plates do not have any effect in our observation of the stars.

39. Which part of the electromagnetic spectrum would likely be the most suitable for detecting a hypothetical nearby alien civilization at a similar developmental stage as mankind in the 1900s?

(A) Ultraviolet

(B) Infrared

(C) Cosmic rays

(D) Radio

(E) Microwave

Solution:

Besides visible light, human civilization in 1900s mostly emit radio waves for navigation and communication. Cosmic rays are not part of the electromagnetic spectrum.

40. From the point of view of someone on Mars, which of the following appear to be *incorrect*? The planets are in opposition from an Earth observer.

(A) Jupiter will appear larger in the night sky than on Earth due to its closer distance

(B) Earth's apparent size from Mars is larger than Mars' apparent size from Earth

(C) The Sun will appear brighter to an observer on Mars than on Earth due to Mars having less atmosphere

(D) Stars will appear dimmer in general to an observer on Mars

(E) More than one of the above statements are incorrect

Solution:

A: Jupiter will indeed be closer to Mars in opposition than on Earth.

B: Earth's larger size means that the apparent size will be larger than Mars' apparent size given equal distance.

C and D: Since the Sun is farther away from Mars, it will generally appear dimmer as observed from there.

41. It is November 2022 at 3 am and Mars just crosses the meridian a few minutes ago. At the same time and date in 2023, will Mars still be visible in the night sky?

(A) Yes, Mars is around inferior conjunction

(B) Yes, Mars is around superior conjunction

(C) No, Mars is around inferior conjunction

(D) No, Mars is around superior conjunction

(E) Not enough information to tell

Solution:

Since Mars crossed the meridian at 3am at the 2022 observation, Mars has passed Eastern Quadrature and is approaching opposition. Taking into account Mars' synodic period at 687 days, we can estimate that Mars should be roughly behind the Sun at the same time and date next year (365 days later). Since, Mars is an superior planet, we call the configuration a superior conjunction.

The following table contains information regarding a Cube-Satellite in Low Earth Orbit. Answer questions 32-34 with the information provided in the table.

Name	Eclipse-SAT
Mass	22.15 kg
Orbital Height	800 km
Orbital Type	Circular Sun-synchronous
Orbital Inclination	98.67°

42. Calculate the orbital period of the Eclipse-SAT satellite.

(A) 89 minutes

(B) 95 minutes

(C) 101 minutes

(D) 109 minutes

(E) 120 minutes

Solution:

We use Kepler's third law and calculate its orbit against Moon's orbit.

$$T_{SAT}^2 : T_{moon}^2 = (h_{SAT} + R_{earth})^3 : a_{moon}^3$$

$$T_{SAT} = (27.322 days)\sqrt{\left(\frac{6370 + 800}{3.843 \times 10^5}\right)^3}$$

$$T_{SAT} = 0.06963 days \approx 101 minutes$$

You may also calculate the orbit velocity using $\sqrt{\frac{GM}{R+h}}$ to calculate the orbital period.

43. Calculate the orbital speed of the Eclipse-SAT satellite.

(A) 6.34 km/s

(B) **7.46 km/s**

(C) 8.98 km/s

(D) 9.49 km/s

(E) 11.2 km/s

Solution:

Using your answer from the previous question,

$$v = \frac{2\pi(R_{earth} + h_{SAT})}{T_{SAT}}$$

$$v = \frac{2\pi \times 7170}{101 \times 60}$$

$$v \approx 7.46 km/s$$

Similar to Q42, you may also calculate the orbit velocity using $\sqrt{\frac{GM}{R+h}}$ instead.

44. A communication center on ground last communicated with the Eclipse-SAT satellite directly overhead at midnight (0000 hrs) of 21 June 2023. If the satellite orbits in the equatorial plane on a prograde motion (i.e., same as Earth rotation's direction), when would the satellite be directly overhead the center again? Take the length of one sidereal day to be 86164 seconds.

(A) 0014 hrs

(B) 0029 hrs

(C) 0142 hrs

(D) 0145 hrs

(E) **0149 hrs**

Solution:

The question implicitly asked us to find the synodic period from Earth's rotation and the satellite's orbit revolution.

$$\frac{1}{T_{syn}} = \frac{1}{T_{SAT}} - \frac{1}{T_E}$$

where T_{SAT} is the satellite's orbital period (as found in Question 42) and T_E is Earth's sidereal

day.

$$\frac{1}{T_{syn}} = \frac{1}{6060} - \frac{1}{86164}$$
$$T_{syn} \approx 6518s \approx 1h49m$$

45. An alien civilization is more technologically advanced than the human civilization. An alien astrologer (*yes, astrology is a science for them*) observed the time evolution of the solar system and tabulated the distance between the aphelion and perihelion of each planet and the time each planet takes to orbit the Sun.

    What can the alien astrologer know from the gradient of the straight line with the highest accuracy? Assume their line of sight aligns with our ecliptic.

    (A) Sun's radius

    (B) Sun's luminosity

    (C) **Sun's mass**

    (D) Earth's radius

    (E) Earth's mass

Solution:

Assuming the Earth's mass is negligible relative to the Sun, one can calculate the orbital velocity from the information given. Since $v = \sqrt{\frac{GM}{r}}$ and r is known, one can calculate Sun's mass directly. Since its mass is obtained directly, no intermediate variables are required which results in highest accuracy.

46. Recently, astronomers discovered that the dwarf planet Quaoar possesses a ring system outside of its Roche limit. Why is this unusual?

    (A) Dwarf planets are too small to support a ring system

    (B) **Given enough time, this ring would coalesce into moons**

    (C) A ring system requires multiple moons in order to be stable, which Quaoar does not possess.

    (D) Due to the presence of numerous other bodies in the Kuiper belt, these rings would be easily destabilized by the gravitational influence of other bodies

    (E) This situation is not unusual at all

Solution:

Roche limit is defined as the smallest orbit where a smaller celestial body would be able to sustain itself from a larger celestial body (i.e., planets or dwarf planets) before being disintegrated

through the latter's tidal force. Rings usually form from the disintegrated materials of the broken celestial body.

Otherwise, ring-like materials outside the Roche limit would instead coalesce into a singular celestial body (i.e., a moon). Quaoar's case, therefore, is peculiar since the ring system should have coalesced into moons.

47. The James Webb Space Telescope is one of the most anticipated space telescopes with an immense budget. Because it is primarily designed for near-infrared astronomy, it must be positioned at the L2 Lagrange point of the Earth-Sun system. Which of the following statement(s) is/are true?

i At $L2$, its instruments can be kept cold and thermally stable

ii It can only observe objects in certain angles at any instance of time due to its sunshield

iii It orbits around the Earth with the same period as the Moon

(A) i only

(B) i and ii

(C) ii and iii

(D) All of the above

(E) None of the above

Solution:

Note that Earth's L2 is located behind the Earth as seen from the Sun. At L2, the largest sources of infrared radiation (i.e., Sun, Earth, and Moon) are all in the same direction and thus can be easily blocked by a sunshield. Note that the infrared radiation from these objects can severely impair the telescope's optical capability in Infrared.

48. The Arecibo Telescope was a large radio telescope built in the mountains of Puerto Rico, US. Unlike conventional radio telescopes which have parabolic reflectors, the Arecibo Telescope had a spherical primary reflector. Which of the following reasons best explains why?

(A) A spherical shape matched best the natural sinkhole it was built on

(B) A spherical reflector allowed the telescope to collect more light given the same area

(C) A spherical reflector allowed the telescope to only focus on very specific radio wavelengths

(D) A spherical shape allowed the detector to re-orientate and focus on any part of the primary reflector to look at different parts of the sky

(E) A spherical reflector does not suffer from chromatic aberration

Solution:

The spherical shape means that the receiver can be oriented at any part of the dish, hence

processing images of different parts of the night sky.

49. Unlike planets like Earth and Uranus, Jupiter does not experience significant seasonal changes. This is primarily because

(A) Jupiter is tidally locked to the Sun

(B) Jupiter moves too slowly along its orbit

(C) **The axial tilt of Jupiter is negligible**

(D) The weather on Jupiter is driven by tidal forces exerted by the Galilean moons

(E) The weather on Jupiter is driven by deuterium fusion within its core

Solution:

Seasonal changes as seen on Earth and Uranus are direct consequences of the planet's axial tilt as different hemispheres faces the Sun for different periods of time at any instance. With its 3° tilt against the normal of the orbital plane, seasonal changes in Jupiter is barely noticeable.

50. In the RA-Dec coordinate system, the 0000hrs RA meridian is defined to be at the First Point of Aries, with RA increasing in the west-to-east direction. Which of the following statements are true about RA-Dec coordinates? Note that the start of the tropical year is defined by the First Point of Aries.

i The RA of the Sun increases throughout a tropical year

ii The RA of stars increase throughout a sidereal year

iii Celestial objects with a later RA rise later in the night

iv Stars with the same RA always rise and set at the same solar time

(A) i only

(B) i and ii

(C) **i and iii**

(D) i, iii, and iv

(E) All of the above

Solution:

I is true as the Sun moves from West to East along the ecliptic over the course of a year.

II is false as the Right Ascension of stars is fixed and does not change without any peculiar motions.

III is true as the sky rotates from East to West, thus stars rising in the East have a later RA than stars setting in the West

IV is false as the statement is only true at the equator

[End of paper]