	Question	Answer
1	How much brighter is a magnitude 1 star than a magnitude 3 star? A. 6.31 times brighter B. 4 times brighter C. 2 times brighter D. 0.50 times brighter E. 0.16 times brighter	Answer: A. Repurpose the Luminosity-Absolute magnitude relationship in the Formula Book, and we get that the magnitude 1 star is 10^(2/2.5)=6.31 times brighter.
2	For a stargazer who is interested in looking at celestial objects other than the Moon, the best time to stargaze is during New Moon compared to the Full Moon. Why? A. The glare of the moon washes out the fainter objects in the sky B. The Moon will pass in front of several objects in the sky C. The objects only align in place with star charts during New Moon D. Telescopes can only function during New Moon but not Full Moon E. All celestial objects are only visible in the sky during New Moon	Answer: A The glare of the moon interferes with telescopic views of deep sky objects
3	During an astronomy outreach event, a member of the public asked "How do you visually tell a star apart from a planet?" What could be an accurate response? A. Planets always appear brighter than stars B. Stars "twinkle" but not planets C. Planets appear significantly bigger than stars to the naked eye D. Stars are of a different colour from the planets E. Planets are only visible through a telescope	Answer: B. Although stars are enormous, they are very far away from the Earth as compared to planets, and hence appear very small. Light from stars gets refracted as it passes through the atmosphere of the Earth, causing them to twinkle. The planets are much closer to Earth, hence appearing larger to us. Thus, the displacement due to refraction is much smaller relative to their apparent size and therefore there is no twinkle.
4	What is the ratio of a man's weight on Earth to his weight on Saturn? A. 1:1 B. 2:1 C. 3:1 D. 5:1	Answer: A. Compute the gravitational acceleration on both planets.

<table>
<tr><td></td><td>E. 6:1</td><td></td></tr>
<tr><td>5</td><td>Which of the following stellar spectral classes have the highest surface temperature?
A. A
B. B
C. F
D. G
E. K</td><td>Answer: B.

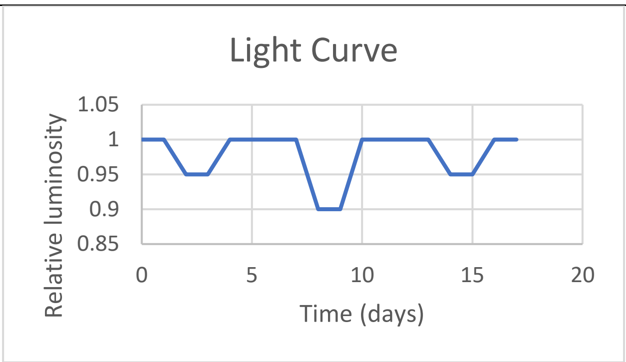
In order from hottest to coolest: O, B, A, F, G, K, M</td></tr>
<tr><td>6</td><td>While Clarence was reading a book on telescopes, he came across an equation which seems interesting. The equation suggested that for a night sky object with a declination of δ, if we want an object to stay within the field of view (FOV) for a certain amount of time t, the required FOV would be given by the equation:
$$FOV = k\,t\cos\delta$$
This is provided that we position the object to one side of the eyepiece (along the edge of the field of view) and turn off the telescope drive.
Which of the following could be a possible value of the constant k?

A. 1.04×10^{-3}
B. 2.09×10^{-3}
C. 4.18×10^{-3}
D. 6.25×10^{-3}
E. 8.33×10^{-3}</td><td>Answer: C

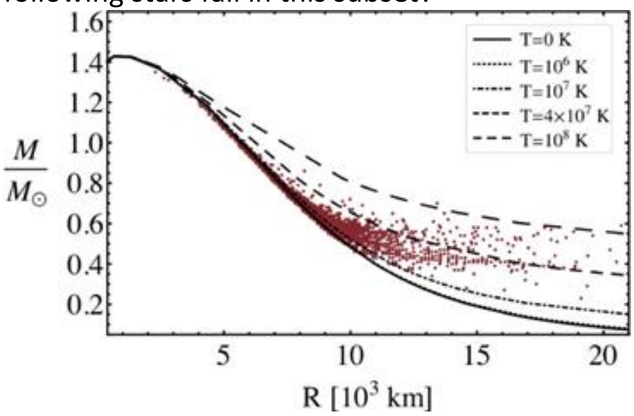
Since this equation must work for all declination values, we can easily set it to be at $\delta = 0^o$. Hence, these objects will tend to drift across the diameter in the field of view. Thus, to determine the FOV, ie angular displacement, we know that the angle travelled (ie. "FOV") of 360^o is done through 24 hours (well, that's because that is the total angle rotated by the Earth about its own axis).
Hence, $FOV = 360^o$, $t = 86164\ s$, $\delta = 0^o$ gives $k = 4.18 \times 10^{-3}$ (Note that it does not matter if we use a sidereal day or a solar day. The answers will round off to be around this value)</td></tr>
<tr><td>7</td><td><table>
<tr><td>Star</td><td>Vega</td><td>Aldebaran</td><td>10 Lacertae</td></tr>
<tr><td>Spectral type</td><td>A0V</td><td>K5III</td><td>O9V</td></tr>
<tr><td>Declination</td><td>− 38° 47′ 01″</td><td>+ 16° 30′ 33″</td><td>−39° 03′ 00″</td></tr>
<tr><td>Apparent magnitude</td><td>+0.026</td><td>+0.86</td><td>+4.88</td></tr>
<tr><td>Distance from Earth</td><td>25.04 ly</td><td>65.3 ly</td><td>2,330.9 ly</td></tr>
<tr><td>Colour index (B–V)</td><td>+0.00</td><td>+1.44</td><td>-0.21</td></tr>
</table>
Given the information above, which of the following statement is incorrect?
A. 10 Lacertae is the hottest star</td><td>Answer: D.

While Aldebaran lies in the northern half of the celestial sphere, that does not imply that its invisible to all southern hemisphere observers</td></tr>
</table>

	B. All three stars are in the Milky Way C. Only two of the three stars are in their main sequence stage D. Aldebaran cannot be seen in the southern hemisphere E. Vega is the dimmest in terms of absolute magnitude	
8	Contrary to what one might expect, the latest sunrise of the year does not occur during the respective hemisphere's winter solstice. Why is this so? You may assume this location does not lie within equatorial latitudes without loss of generality. A. The Earth is significantly oblate and this leads to variations in the time of sunrise due to horizon effects. B. The Sun is significantly oblate, and this leads to variations in the time of sunrise as our perspective of the Sun's shape changes across time C. As Earth's orbit is elliptical, the Sun appears to drift across the night sky at different rates across the year. D. Milankovitch cycles affect the Earth's axial tilt, causing a large constant drift in sunrise timing. E. The question statement is false.	Answer: C. A and B are clearly false, and while Milankovitch cycles do affect Earth's axial tilt, it takes place over long timescales and thus is too small to be easily noticeable.
9	What does it mean for an object to have a redshift of z=1.2? A. The object has a luminosity distance of 1.2 megaparsecs B. The object has a co-moving distance of 1.2 megaparsecs C. The object emits 1.2 times more red light (600nm) as a proportion of its total emission than our reference star, the Sun D. The wavelengths of the object's emitted light are all increased by 1.2 times compared to the original wavelength E. The object's observed velocity is 1.2 times greater than the velocity generated by the Hubble Flow at that distance	Answer: D. The formula for z in the Formula Book is given: simply translate the math.
10	The following chart is a hypothetical light curve for a star and associated bodies.	Answer: A.

	 Which of the following statements are plausible explanations for this observation? I. The star is part of a binary-star system, and this curve is a result of eclipses. II. The star is likely a small red dwarf with at least two massive exoplanets. III. The star is a classical Cepheid variable. IV. The star is a RR Lyrae variable. A. I. and II. B. II. only. C. III. and IV. D. III. only. E. I., II., III., and IV. (All of the above) .	I. and II. are correct. Cepheids and RR Lyrae show very different light curves. <if there is space, insert the charts for their respective light curves – see original in Qi En's draft>
11	One fine day, Brian noticed two satellites that are passing directly overhead in opposite directions. He decided to label the satellite moving from west to east A, and the satellite moving from east to west C. Turns out, he noticed the same two satellites passing directly over his head again exactly 8 hours later! Suppose the satellites are in circular orbit and assume that Brian is on the equator (well, close enough since he stays in Singapore). What is the ratio of the orbital radius of satellite A to that of satellite B? A. 0.481 B. 0.630 C. 1 D. 1.587 E. 2.080	Answer: B Note - Direction of rotation of the Earth: West to East Notice that for satellite **A**, since it is orbiting in the same direction as the direction of rotation of the Earth, he must have covered an angle equivalent to one entire round, and the angle rotated by the Earth during these 8 hours. Hence, $\theta_A = 360^o + 120^o = 480^o$ (8 hours amount to 120^o) A similar logic can be applied to satellite **C**. However, since it is orbiting in the **opposite** direction, the total angle covered is one entire round, but with the angle rotated by the

		Earth during these 8 hours being subtracted off. Hence, $\theta_B = 360^o - 120^o = 240^o$. Now, these angles are covered in the same amount of time, 8 hours. Hence, we can deduce that the angular velocity of **A** is twice of **C**, i.e, $\frac{\omega_C}{\omega_A} = \frac{1}{2}$. This is equivalent to saying that the orbital period of A is half that of C. From Kepler's 3rd Law of Orbital Motion, we can obtain the following equation: $\omega^2 = \frac{GM}{r^3}$ Hence, $$\frac{r_A}{r_C} = \left(\frac{\omega_C}{\omega_A}\right)^{\frac{2}{3}}$$ Therefore, the required ratio is $(0.5)^{\frac{2}{3}} = 0.630$
12	Sharadh's Q6	
13	Which of these sentences about the celestial sphere is false? A. The angle between the ecliptic and the celestial equator is the axial tilt of the Earth B. An observer stationed at a location would observe the exact same night sky every year at the same date and time C. The rotational axis of the Earth always points at the celestial North and South poles. D. Most of the planets of the solar system lie close to the ecliptic plane E. The equatorial coordinate system uses declination and right ascension, the latter being the "longitude" of the object from the March equinox.	Answer: B. 1) the visible planets all have synodic periods that are significantly different from 1 year. 2) Due to axial precession, the rotational axis of the Earth changes its orientation, so the night sky changes slowly with a period of 26000 years. The rest of the options are self-explanatory.
14	Sharadh's Q7	
15	Ceres has an eccentricity of 0.0758. What is the ratio of angular velocity at perihelion to aphelion? (recall linear velocity = angular velocity * distance from focus) A. 0.28 B. 1	Answer: D It can be determined from Kepler 2nd law that LINEAR velocity ratio at perihelion to

<table>
<tr><td></td><td>C. 1.16
D. 1.35
E. 3.63</td><td>aphelion is inversely proportional to distance. (angular momentum is conserved) ANGULAR velocity is inversely proportional to distance^2. The ratio of distance is (1+e)/(1-e). (b) is a red herring for those who confuse angular momentum with angular velocity</td></tr>
<tr><td>16</td><td>The graph shows an empirically derived relationship between mass and radius for a particular subset of stars, given a certain surface temperature. Which of the following stars fall in this subset?


A. **Sirius B, A1 white dwarf**
B. Beta Tauri, B7 giant
C. Rigel, B8 supergiant
D. Alpha Herculis, M5 red giant
E. Sigma Orionis, O9 main sequence</td><td>Answer: A

The major challenge in this question is to identify that the subset is that of white dwarves. There are 3 clues to point at that. (1) The occurrence of the stars sharply falls at Chandrasekhar limit (2) A radius comparable to planets (3) Extremely high surface temperature

Sirius B is the nearest white dwarf to Earth and participants are expected to know this.</td></tr>
<tr><td>17</td><td>The following is a selected list of solar system objects and their respective deity according to an ancient Vedic (Indian) astrology text dated ~700 BCE
<table><tr><th>Object</th><th>Deity</th></tr><tr><td>Sun</td><td>Surya</td></tr><tr><td>Mars</td><td>Mangala</td></tr><tr><td>Mercury</td><td>Budha</td></tr><tr><td>Saturn</td><td>Shani</td></tr><tr><td>Neptune</td><td>Rahu</td></tr></table>
Which of the five pairs cannot possibly be correct?
A. Neptune-Rahu
B. Saturn-Shani
C. Mars-Mangala
D. Mercury-Budha
E. Sun-Surya</td><td>Answer: A.

As Neptune is not visible to the naked eye, ancient Indians do not have any known means to observe Neptune and thus did not know of its existence.</td></tr>
</table>

18	A region of the Eagle Nebula has a thickness of 50 pc. From Earth, the closer edge of the nebula has a distance of 6900 light years. An A1 subgiant was observed along the line of sight of the nebula, and spectroscopic analysis shows that the star has an absolute magnitude of -0.01. What is the difference in apparent magnitude if the star was behind the nebula compared to in front of it? You may assume a fixed interstellar extinction of 0.8 magnitudes due to the nebula. a. 0.77 b. 0.80 c. 0.83 d. 0.85 e. 0.87	Answer: D Using the distance modulus equation (found in formula booklet), the difference between the apparent magnitudes in the 2 positions purely due to distance is: *Convert 6900ly to 2116pc* log((2116+50)/10)*5-log((2116/10)*5 = 0.05 Add this to the interstellar extinction to get 0.85.
19	The van Allen belts are zones of energetically charged particles that originate from the Sun that have been trapped in a planet's magnetic field. Jupiter's van Allen belts are particularly intense, posing a major radiation hazard to any orbiting spacecraft or human. Which of the following is the most ineffective method to of reducing radiation damage caused by charged particles? A. Orbiting the planet in an highly elliptical polar orbit. B. Storing food and water in the walls of the spacecraft. C. Build a Faraday cage of metal wire mesh around the essential parts of the spacecraft D. Build a lead box around essential parts of the spacecraft. E. All of the above methods are feasible.	Answer: C A Faraday cage would stop electric fields from penetrating the interior, but would not actually stop charged particles, which were already accelerated beforehand by the external field. Thus these particles would not be effectively stopped by a Faraday Cage – shielding is required to slow these particles down to a stop.
20	Which of the following statements about large telescopes are correct? I. For large observatory-class telescopes, perfectly spherical optical elements are recommended to minimize aberrations. II. Space telescopes all follow a Cassegrain-Nasmyth design III. In recent decades, refractors are generally not seen among large telescopes. Instead, reflectors are more popular. A. I only B. I and II	Answer: D. I is untrue, using spherical optical elements will introduce spherical aberration in images. In fact, aspheric optical elements are used instead. II is untrue: On Earth, a Nasmyth focus is usually used for observatories as light is directed outwards along the altitude axis. This allows heavy instruments (e.g. spectrometers) to be used without moving along with the telescope and straining the

	C. II only D. III only E. I, II and III	bearings of the observatory. In space however, the scope can move freely in zero-gravity, allowing heavy equipment to be installed directly at the Cassegrain focus and hence Cassegrain design is more commonly used. III is true: Reflectors are indeed more popular in the recent century as it grants longer focal length, less glass to grind perfectly (1 mirror surface compared to 2 on refractors), relatively cheaper as aperture size increases.
21	Bob is trying to measure the distance of the Large Magellanic Cloud using both a Type Ia supernova and Cepheid Variables. He discovered that the result he got using Cepheid Variables is much further than the result from using a Type Ia supernova. Which of the following is not a possible reason for the discrepancy in his results? A. He misidentified Type 1b/1c Supernova as a Type 1a Supernova B. He underestimated the interstellar extinction when measuring the brightness of Cepheids. C. He misidentified RR Lyrae variables as classical Cepheids D. He failed to account for the atmospheric disturbances on the days of his observation. E. All of the above are possible reasons for the observed discrepancy in results.	Answer: D Any brightness variation due to atmospheric disturbances would be averaged out over the duration of observation.
22	'Oumuamua was discovered using the Pan-STARRS telescope at Haleakala Observatory, Hawaii, on 19 October 2017, 40 days after it passed its closest point to the Sun. At this point, 'Oumuamua was 0.22 AU away from Earth. The focal length of the Pan-STARRS telescope at 6.11 m with the diameter of the image sensor at 32 cm. It also has an aperture diameter of 1.8 m. Determine the size of an object that the telescope can resolve at the distance between the Earth and	Answer: A Resolvable diameter can be calculated using Rayleigh's Criterion $\frac{Diameter}{Dist} = 1.22\frac{\lambda}{d}$. Distance is mentioned to be at 0.22 AU. Hence, the value of diameter calculated would be 13900 m. For the calculation of the TFOV of a telescope, along the two

<table>
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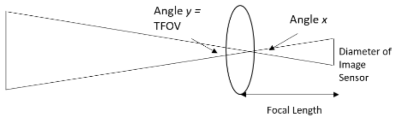
<td></td>
<td>‘Oumuamua on 19 October 2017 through a red filter (623 nm), and the actual field of view (TFOV) of the telescope.

<table>
<tr><td></td><td>Resolvable Diameter (m)</td><td>TFOV (°)</td></tr>
<tr><td>A.</td><td>1.4×10^4</td><td>3.0</td></tr>
<tr><td>B.</td><td>2.8×10^4</td><td>1.5</td></tr>
<tr><td>C.</td><td>1.4×10^4</td><td>1.5</td></tr>
<tr><td>D.</td><td>2.8×10^4</td><td>6.0</td></tr>
<tr><td>E.</td><td>5.6×10^4</td><td>3.0</td></tr>
</table>
</td>
<td>ends of the TFOV of the sky, it will converge at focal length of the telescope after passing through the lens. The simplified lens diagram is shown below.


Hence, TFOV will be equals to angle x, by simple trigonometry, $\tan x = \frac{32\ cm}{6.11\ m}$ => angle x = 3.0°</td>
</tr>
<tr>
<td>23</td>
<td>Which of the following
are major factors contributing to the equation of time?

I. Diameter of the Earth
II. Orbital eccentricity of Earth’s orbit
III. Axial tilt of the Earth’s rotation
IV. Sidereal rotation period of Earth

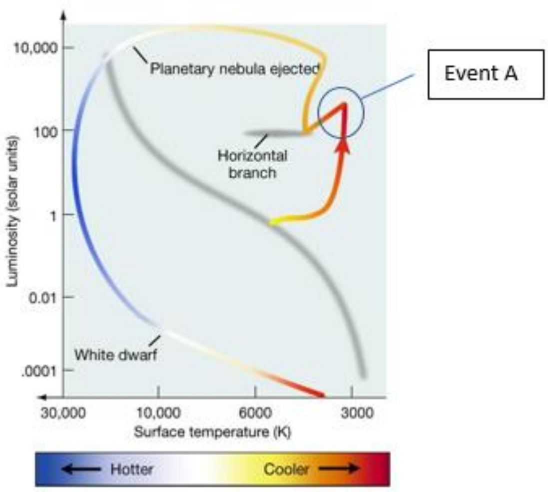
A. I and II
B. I and III
C. II and III
D. III and IV
E. II, III, IV</td>
<td>Answer: E?

Keven will supply a proper written explanation</td>
</tr>
<tr>
<td>24</td>
<td>Which of the following statements are TRUE?

I. The complete analemma may be photographed anywhere on Earth.
II. If the analemma is photographed exactly at local apparent noon, the long axis of the analemma is perpendicular to the local horizon.
III. The Sun spends equal fractions of the year tracing out each lobe of the analemma.
IV. The analemma as photographed at two different locations with the same longitude but differing latitudes θ and −θ are mirror reflections of each other along the x-axis.

A. I only
B. I and II
C. II and III
D. II and IV
E. None of the above options are correct.</td>
<td>Answer: D?

Keven will supply a proper written explanation</td>
</tr>
<tr>
<td>25</td>
<td>The hyperbolic excess velocity, v_∞, is defined by the velocity attained by the spacecraft as the spacecraft reaches infinity.</td>
<td>Answer: C</td>
</tr>
</table>

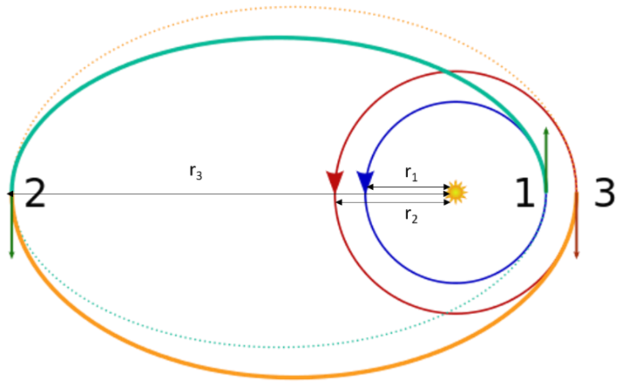
	The velocity at a given distance from the gravitating body is given by v and the escape velocity from the gravitating body is given by v_e. Which of the following expression used to calculate the escape velocity of a gravitating body v_e is correct? A. $v_\infty = v + v_e$ B. $v_\infty{}^2 = v^2 + v_e{}^2$ C. $v_\infty = \sqrt{(v - v_e)(v + v_e)}$ D. $v_\infty{}^2 = v^2 + \frac{v_e{}^2}{4}$ E. $v_\infty = \sqrt{(v - \frac{v_e}{2})(v + \frac{v_e}{2})}$	We can solve this by looking at the definitions involved TE = KE(excess) TE= KE(excess) + escape velocity KE – GPE at the point By definition, a body at escape velocity has enough KE to overcome gravity, thus both terms sum to 0. We now recall that by energy conservation, TE is also given by current KE-current GPE, yielding: Current KE – GPE at the point = KE(excess) + escape velocity KE – GPE at the point Current KE = KE(excess) + escape velocity KE Dividing throughout yields: $v^2 = v_e{}^2 + v_\infty{}^2$ $v_\infty{}^2 = v^2 - v_e{}^2$ $= (v_e + v)(v - v_e)$ Square-rooting yields the desired answer
26	 The HR diagram shows the stellar evolution of a low-mass main sequence star such as our Sun. Which of the following best describes the dominant source of energy production during Event A? A. Nuclear fusion of 3 helium-4 nuclei into carbon-12	Answer: A Event A is the helium flash, during which 3 helium nuclei fuse to form carbon.

	B. Nuclear fusion of 2 hydrogen-1 nuclei into hydrogen-2 (deuterium) C. Nuclear fusion of 4 hydrogen-1 nuclei into helium-4 D. Nuclear fusion of 1 carbon-12 and 1 hydrogen-1 nuclei into nitrogen-13 E. Nuclear fusion of 1 nitrogen-15 and 1 hydrogen-1 nuclei into oxygen-16	
27	Manhattanhenge is an event during which the setting sun or the rising sun is aligned with the main street grid of Manhattan, New York City. It is known that Manhattanhenge sunsets occur in pairs. Given that a Manhattanhenge sunset occured on 30 May 2019. On what date does the other Manhattanhenge sunset occur in 2019? A. 11 June B. 12 July C. 30 August D. 30 September E. 11 October	Answer: B Why does a Manhattanhenge sunset occur twice a year? This happen because on those dates, the sunset's azimuth aligns with the direction of the street. This implies that Manhattenhenge sunsets are equally spaced around the summer solstice, and that the other Manhattenhenge sunset must happen AFTER the summer solstice. Given that summer solstice happens around 21st June and 30 May is about 20 days apart from summer solstice, we then find the date that is approximately 20 days after 21^{st} June, which is 12th July.
28	Being an inquisitive astronomer, Keven wants to know how to go about determining the **speed** of a star that is moving away from Earth, with respect to an observer from the Earth (i.e himself). The following information are provided to him: • The spectral line of iron from the star at λ_{rest} (wavelength recorded with respect to the frame of the star) is redshifted by a magnitude given by the quantity $\Delta\lambda$. We can assume that $\Delta\lambda \ll \lambda_{rest}$. The wavelengths are all recorded in metres. • The proper motion is given by μ, recorded in arc seconds per year. • The parallax of the star is given by p, recorded in arc seconds. We can assume that p is small enough such that $\sin p \approx p$	Answer: D Recall that for relativistic redshift, $z = \frac{\Delta\lambda}{\lambda_{rest}} = \frac{v_r}{c}$, where v_r represents radial velocity. Hence, we can see that $v_r = \frac{c\Delta\lambda}{\lambda_{rest}} \frac{m}{s} = \frac{c\Delta\lambda}{1000\ \lambda_{rest}} \frac{km}{s}$ for the radial component of the velocity of the star. Next, for a given parallax angle, we know that $\tan p \approx p = 1\ AU/r$, hence, $r = 1\ AU/p$ Furthermore, since the tangential velocity is given by $v_\theta = r\mu = 1\ AU * \frac{p}{\mu} = \frac{4.74\ p}{\mu} \frac{km}{s}$

	Which of the following expression best represents the expression that Keven should use to determine the speed of the star relative to him, in km/s? Hint: To ease your calculation, note that $\frac{1\ AU}{1\ year}$ is approximately $4.74\frac{km}{s}$. A. $\sqrt{\left(\frac{c\Delta\lambda}{\lambda_{rest}+\Delta\lambda}\right)^2+\left(\frac{4740\ p}{\mu}\right)^2}$ B. $\sqrt{\left(\frac{c\Delta\lambda}{1000\ \lambda_{rest}}\right)^2+\left(\frac{4.74\ \mu}{p}\right)^2}$ C. $\sqrt{\left(\frac{c\Delta\lambda}{\lambda_{rest}}\right)^2+\left(\frac{4.74\ p}{\mu}\right)^2}$ D. $\sqrt{\left(\frac{c\Delta\lambda}{1000\ \lambda_{rest}}\right)^2+\left(\frac{4.74\ p}{\mu}\right)^2}$ E. $\sqrt{\left(\frac{c\Delta\lambda}{1000(\lambda_{rest}+\Delta\lambda)}\right)^2+\left(\frac{4740\ \mu}{p}\right)^2}$	Hence, the speed is given by $v = \sqrt{v_r^2+v_\theta^2} = \sqrt{\left(\frac{c\Delta\lambda}{1000\ \lambda_{rest}}\right)^2+\left(\frac{4.74\ p}{\mu}\right)^2}$
29	Some astronomers suggest that the search for extra-terrestrial life should include planets and moons outside of the Habitable Zone. A possible reason is: A. Liquid water is the only possible solvent for biochemical reactions to occur in. B. Many other celestial bodies are well-known sources of radio emissions. C. Besides radiation from a star, other mechanisms could generate heat on a celestial body. D. All of the above. E. None of the above; They simply have too much free time.	Answer: C This question is testing the student's attention to details based on how the statements are worded. A. Methane (e.g. on Titan) is another likely solvent, and if A was true, it would only be detrimental to the case. B. Missing the point; giving out radio does not equate to life or intelligent life, e.g. if the source is a pulsar. C. True; Radioactive heating and tectonics due to gravitational forces are two such mechanisms.
30	Suppose that scientists are about to put a spherical rock of a uniform mass of 5×10^{11}kg and radius 1km on a hypothetical planet with the same mass and radius as Jupiter (on the Formula Booklet), except this planet is perfectly spherical. However, they would prefer it if the rock is as close as possible to the planet's surface. (Assume the rock is held together by only gravity) Which of the following recommended distances (from planet surface to this rock) is the most ideal? A. 126,000,000 km B. 12,600,000 km C. 1,260,000 km	Answer: D Density of body: $\rho_b = \frac{5\times10^{11}}{\frac{4}{3}\pi1000^3}$ $= 500\times\frac{3}{4\pi}$ Density of planet: $\rho_p = \frac{1.899\times10^{27}}{\frac{4}{3}\pi(7.149\times10^7)^3}$

	D. 126,000 km E. It does not matter where the satellite is placed if it is not going to crash.	$= 5197.43 * \frac{3}{4\pi}$ $= 1240\ kg\ m^{-3}$ Density ratio: $\frac{\rho_p}{\rho_b} = 10.395$ Roche limit $= 1.26R_J \times (10.395)^{\frac{1}{3}}$ $= 2.75\ R_J$ Since we want distance from surface, we find $1.75\ R_J\ \approx 125{,}000\ km$. Thus we can go as low as option D.
31	One reason that intelligent life is rare or even simply an exception for humanity is because of factors that prevent its development or prematurely ends them. This is known as the Great Filter Hypothesis. Which of the following are examples of such a 'Great Filter'? i. Most, if not all other planets, are missing necessary requirement(s) to support life in the first place (Rare Earth Hypothesis). ii. It is highly improbable for inorganic molecules to develop into living cells. iii. Rational intelligent life is unwilling to communicate or transmit signals to space that indicate its existence, over fears of elimination by a more advanced alien civilisation. iv. Many catastrophes result in large or even full-scale extinction events before intelligent life can develop, or engineer technology to prevent its demise. v. Intelligent life tends to be self-destructive in nature, whether intentional (e.g. wiping itself out by nuclear warfare) or unintentional (e.g. causing irreversible ecological collapse). A. i., ii. and iii. B. iv. and v. C. iii., iv. and v. D. i., ii., iv. and v. E. All of the above.	Answer: D i. is true, and Earth is the only planet we know that passed this filter. Planets in the habitable zone are candidates, but there could likely be some unknown factor (e.g. lack of water in the first place, hostile chemistry in its environment, etc.) that prevents life from forming. ii. is true, and again we only know Earth to be the only planet with such a development. iii. is tricky and false; Elimination by an advanced alien civilisation is a 'Great Filter' event, but being unwilling to communicate over this hypothetical fear doesn't result in a filter per se. iv. is true, and Earth is one of the lucky few (or the only one) which hasn't experienced a full-scale extinction event while having recovered from many large-scale ones. v. is true, and some argue that humans are very close to ending our species.
32	Which of the following statements is false?	Answer: E.

	A. A Dark Nebula that consists of mostly unionised Hydrogen is likely designated as a HI Region. B. A Nebula with a large HII Region is highly likely to be a star-forming region. C. There is no such thing as a HIII region, because Hydrogen only has one valence electron. D. High levels of OIII is responsible for Green-cyan spectral colours in Planetary Nebulae. E. None of the above.	I, II, III refer to that element's ionisation state. All of them are true statements, including D. That surprised many astronomers when it was initially discovered as ionised oxygen rarely occurs on Earth.
33	A physics student derived the following formula from the Stefan-Boltzmann law to estimate the radius, surface temperature or luminosity of a given star, if two of the three other values are known, in comparison to the Sun: $$\frac{R}{R_\odot} \approx \left(\frac{T_\odot}{T}\right)^2 \cdot \sqrt{\frac{L}{L_\odot}}$$ Where R is the radius of the star, $R_\odot$ is the radius of the sun, T is the surface temperature of the star, $T_\odot$ is the surface temperature of the sun, L is the luminosity of the star, and $L_\odot$ is the luminosity of the sun. He then investigated two different stars, X and Y. Both stars have a surface temperature of about 8,000 K, but X is 1000 times less luminous than the sun, while Y is 100,000 times more luminous. Suggest identities for X and Y, given that their estimated radius is of the correct order of magnitude from this estimation formulae. A. X: White dwarf; Y: White supergiant B. X: White dwarf; Y: Main sequence C. X: Main sequence; Y: White supergiant D. X: Small main sequence; Y: Large main sequence E. None of the above	Answer: A X is about 0.01 of the solar radius while Y is about 165 times larger; A. is the correct option. Refer to Procyon B and Deneb for approximate real-life counterparts. Math isn't actually needed to solve this question. Recall that for main sequence stars, luminosity steadily increases with temperature. Thus we can straightaway rule out that X is a main sequence star: no main sequence star can be both hotter yet less luminous than our sun. Similarly, the extreme luminosity for Y suggest it must either be a massive OB main sequence star, or a supergiant. OB stars have much higher surface temperatures than 8000K, ruling them out as a possibility.
34	Which of the following claim about the solar system is false? A. Io, a moon of Jupiter, is subjected to extreme tidal heating and as such is the most volcanically active object in our Solar system, with several of its volcanoes being taller than Mount Everest on Earth. B. Mercury has a very thin atmosphere (approximately 1 nanopascal), but due to its extreme proximity to the sun, most of it is constantly lost from the solar wind, and it is shaped like a comet's tail behind the planet. C. Uranus, due to its axial tilt of about 98°, ends up having its poles face the Sun during a solstice. Yet strangely, the temperature of its equator is higher than that of its poles. D. 50 km above the deadly sulfuric acid clouds of Venus, there exists a zone at 1 atmospheric pressure with an average temperature of 25°C, theoretically making it possible for	Answer: E E. is false; Ganymede is the largest moon in both mass and radius (Titan is second in both metrics), and the gas giants experience precipitation as well (e.g. metallic hydrogen rain in Jupiter, diamond rain on all four gas giants, etc).

	humans to stay in floating cities on this otherwise inhospitable planet. E. Titan, a moon of Saturn, is the largest moon by radius in the Solar System. It is also the only other place in the solar system, other than Earth and Venus, to experience precipitation.	
35	Consider the effects of axial tilt and axial precession on the position of the celestial poles. Earth's axial tilt varies from 22.1° to 24.5° over a period of 41,000 years. The current tilt is 23.44° and decreasing. Axial precession has a period of around 25,800 years. By 20350, the North Celestial Pole will be very near Thuban (14h04m; +64°22', J2000.0) Using the RA and Dec system of that date, what is the declination of the sun during the northern vernal equinox at 20350? A. 1° B. 25° C. 0° D. 22° E. 24°	ANS: C. Given that we are using the RA/Dec of that date, none of the information matters. By definition of the equinox, the Sun lies on the celestial equator at the equinox of that date, thus declination of the Sun at then must be 0 degrees.
36	*Refer to the information below and answer questions 36 and 37.* Let us consider a bi-ellptic transfer, a more general case of the Hoffmann Transfer. The diagram below illustrates this process.  • Starting from an initial circular orbit of radius r_1, at position indicated "1", a prograde burn puts the spacecraft on the first elliptical transfer. • Next, at the position indicated "2", a second prograde burn puts the spacecraft on its second elliptical transfer. • Lastly, at the position indicated "3" when the final desired circular orbital radius of r_2 is reached, a retrograde burn circularizes the trajectory.	Answer: E Recall from Kepler's 3rd Law of Planetary Motion that $T = 2\pi\sqrt{\frac{a^3}{GM}}$. Thus, the total time taken can be split into two components, time taken to go from position "1" to "2", labelled as t_1, and time taken to go from position "2" to "3", labelled as t_2. These are also half of the period of orbit for each of the ellipses. Hence, $t = \pi\sqrt{\frac{a^3}{GM}}$ Now, what is left is to determine what exactly is the semimajor axis in each ellipse. I. Notice that from 1 to 2, the total distance is $r_1 + r_3$. Hence, the semimajor axis for the first ellipse is $\frac{r_1 + r_3}{2}$

	Which of the following expression represents the total transfer time of the entire bi-ellptic transfer process? (NB: Total time refers to the time taken to travel from position "1" to "3".) A. $\frac{\pi}{2\sqrt{2GM}}\left((r_3-r_1)^{\frac{3}{2}}+(r_3-r_2)^{\frac{3}{2}}\right)$ B. $\frac{\pi}{2\sqrt{GM}}\left((r_3-r_1)^{\frac{3}{2}}+(r_3-r_2)^{\frac{3}{2}}\right)$ C. $\frac{\pi}{\sqrt{2GM}}(r_3)^{\frac{3}{2}}$ D. $\frac{\pi}{2\sqrt{GM}}\left((r_1+r_2)^{\frac{3}{2}}+(r_2+r_3)^{\frac{3}{2}}\right)$ E. $\frac{\pi}{2\sqrt{2GM}}\left((r_1+r_2)^{\frac{3}{2}}+(r_2+r_3)^{\frac{3}{2}}\right)$	Hence, $$t_1=\pi\sqrt{\frac{(r_1+r_3)^3}{8GM}}$$ II. Similarly, from 2 to 3, the total distance is r_2+r_3. Hence, the semimajor axis for the second ellipse is $$\frac{r_2+r_3}{2}$$ Hence, $$t_2=\pi\sqrt{\frac{(r_2+r_3)^3}{8GM}}$$ Thus, the required expression is $t=t_1+t_2=$ $$\frac{\pi}{2\sqrt{2GM}}\left((r_1+r_2)^{\frac{3}{2}}+(r_2+r_3)^{\frac{3}{2}}\right)$$
37	To measure the efficiency of fuel being used, it is always good to consider the quantity known as the *delta-v*. Simply put, it is the magnitude of the difference between the velocity before and after a burn occurs. Which of the following expression correctly represents the delta-v quantity associated with the second burn? A. $\sqrt{\frac{2GM(r_2-r_1)}{r_3(r_1+r_3)}}$ B. $\sqrt{\frac{2GM(r_3-r_1)}{r_3(r_2+r_3)}}$ C. 0 D. $\sqrt{\frac{2GM}{r_3}}\left(\sqrt{\frac{r_1}{r_1+r_3}}-\sqrt{\frac{r_2}{r_2+r_3}}\right)$ E. $\sqrt{\frac{2GM}{r_3}}\left(\sqrt{\frac{r_2}{r_1+r_3}}-\sqrt{\frac{r_1}{r_2+r_3}}\right)$	Answer: E Recall from the vis-viva equation that $v^2=GM(\frac{2}{r}-\frac{1}{a})$ Hence, what we need to determine is the velocity before and after the 2nd retrograde burn. Note that such a quantity is non-zero (since it is a burn). Despite the spacecraft being at the same position r, the orbital semimajor axis is now different, hence causing a difference in the *delta-v* quantity. Note that a_i and a_f which refers to the semimajor axes of the initial and final ellipse are already calculated in 3. $$v_i=\sqrt{GM\left(\frac{2}{r_3}-\frac{1}{a_i}\right)}$$ $$=\sqrt{GM\left(\frac{2}{r_3}-\frac{2}{r_1+r_3}\right)}$$ $$=\sqrt{\frac{2GM(r_1)}{r_3(r_1+r_3)}}$$ and

		$v_f = \sqrt{GM\left(\frac{2}{r_3} - \frac{1}{a_f}\right)}$ $= \sqrt{GM\left(\frac{2}{r_3} - \frac{2}{r_2 + r_3}\right)}$ $= \sqrt{\frac{2GM(r_2)}{r_3(r_2 + r_3)}}$ Henceforth, Δv $= \sqrt{\frac{2GM(r_2)}{r_3(r_2 + r_3)}} - \sqrt{\frac{2GM(r_1)}{r_3(r_1 + r_3)}}$ $= \sqrt{\frac{2GM}{r_3}}\left(\sqrt{\frac{r_2}{r_2 + r_3}} - \sqrt{\frac{r_1}{r_1 + r_3}}\right)$ Note that $\sqrt{\frac{r_2}{r_2+r_3}} - \sqrt{\frac{r_1}{r_1+r_3}} > 0$ since $r_2 > r_1$ and we already demanded that Δv is a non-negative quantity (since it is the **difference** between two quantities)
38	With respect to a hypothetical observer on the Sun, the phases of the Moon as seen by the observer repeat once and only once approximately every ....? (Exclude eclipses/occultations from consideration) A. 24 hours B. 27.3 days C. 29.5 days D. 365.25 days E. None of the above	Answer: E. As seen from the Sun, the phase of the Moon is always full.
39	According to the formula booklet, we realise that the formula for Jeans Length given is $R_J = \sqrt{\frac{15k_BT}{4\pi G < m >< \rho >}}$ Here, the formula assumes that we are dealing with the collapse of a spherical nebula **of uniform density**. Which of the following statement about the Jeans Length, R_J', is true if instead, the mass of the nebula is **concentrated on the surface of the spherical nebula** (or what we call a spherical shell nebula)?	Answer: C To answer this question, we first consider the main criterion for the formation of a star from the collapse of a nebula – gravitational pressure predominates thermal pressure. Instead of looking at the individual pressure terms, we can instead consider the total

	(NB: Assume that in both cases, the quantity $< m >$, the average mass per atom, remains unchanged.) A. $R_J' > R_J$ B. $R_J' = R_J$ C. $R_J' < R_J$ D. There is no valid expression for $R_J{}'$, since the quantity representing average density, $< \rho >$, is ill-defined. E. The expressions from options A to C are all possible, depending on the dominant element in the nebula.	energy of the system $E = U + \Omega$, where U refers to the kinetic energy of the particles in the nebula, and Ω refers to the (gravitational) potential energy of the particles in the nebula. $E < 0$ <=> Gravitationally bound <=> Collapse. Hence, what we are comparing is just Ω needed to balance U. For which the mass is concentrated on the surface, the gravitational potential energy is "higher" (more negative), $\Omega' < \Omega$. Hence, $U' > U$. Physically, we need the nebula to contract more to create a stronger thermal pressure to work against this higher gravitational potential energy (ie for U to be higher, the radius of the nebula at equilibrium would have to be smaller). This means that $\boldsymbol{R_J' < R_J}$. • D: An ill-defined ρ does not mean that the equation loses its meaning, especially since we are looking at $< \rho >$ (average density) instead of ρ. Here, we are just looking at the total mass divided by its total volume, which is obviously well-defined. • E: The main element in a nebula is probably the same (Hydrogen). Even if two nebulae have different dominant element, we are asking for the expression of Jeans Length for which $< m >$ is kept constant. FYI: For a spherical shell nebula, the expression for Jeans Length is $R_J' =$

		$\sqrt{\frac{9k_BT}{8\pi G<m><\rho>}} < \sqrt{\frac{15k_BT}{4\pi G<m><\rho>}} = R_J$
40	Which following celestial object is NOT fictional? A. Tachyon Ring – A stream of relativistic particles travelling faster than the speed of light due to its high-speed orbit (>0.95c) around a high velocity (>0.95c) neutron star. B. Tired Star – A special type of redshifted star discovered by Fritz Zwicky, its high surface gravity cause photons to lose energy over time, resulting in redshift of its emission spectra. C. The Blazar – An active galactic nucleus from another galaxy that is emitting a relativistic jet of ionised particles at nearly the speed of light (>0.95c), facing the Earth. D. Type X Supernova – A supernova resulting from a neutron star crossing the Chandrasekar Limit and exploding into a burst of high energy X-rays and gamma rays. E. Poison Nebula – A HII region in space consisting of ionised formaldehyde and cyanide and its derivatives, detectable by shifts in its Hydrogen emission spectra as a result.	Answer: C A. Yes, Tachyons are hypothetical for travelling faster than the speed of light – but they have yet to be observed. Also, you can't simply sum up the speed of objects this way to obtain a speed greater than c. B. Tired light. C. Real. D. Chandrasekar limit applies to white dwarfs for Type Ia; Type X doesn't exist. E. While Formaldehyde and Cyanide are indeed found in space, they are likely trace compounds compared to Hydrogen – and would not be responsible for changing the Hydrogen emission spectra.
41	The upcoming James Webb Space Telescope (JWST) observes primarily in infrared (1.3µm), while the Hubble Space Telescope (HST) observes primarily in visible light (0.5µm). Given that JWST has the same angular resolution as HST, approximately how much larger must the surface area of the aperture of JWST be compared to HST (assume both mirrors to be perfect circles)? A. 2.6x B. 6.8x C. 3.2x D. 8.4x E. None of the Above	Answer: B Rayleigh Criterion + small angle approximation yield: $\Delta\theta_{min} = 1.22\frac{\lambda}{D}$ Clearly, for both telescopes to have the same angular resolution, JWST needs to have a diameter that is 1.3/0.5 = 2.6 times larger. Since we want the surface area ratio, squaring 2.6 yields the answer
42	Which optical phenomenon is not caused by interplanetary dust?	Answer: C False dawn and zodiacal light

	A. Zodiacal light B. Gegenschein C. Airglow D. False Dawn E. None of the above	are the same phenomenon, and are caused by scattering of sunlight by interplanetary dust. Gegenschein is caused by direct backscatter of light by interplanetary dust towards the antisolar point, which causes Gegenschein. Airglow is caused by recombination of ionized air molecules and cosmic ray ionization
43	Using the table given below, please answer questions 43-45 <insert table> The Island of Coll in Scotland is a designated dark sky site with coordinates 56°37’N,06°32’W. On local midnight of the Autumnal Equinox, which of the above objects can be seen? Assume that the current sky follows J2000.0 Epoch. A. IC1805, IC1848 and NGC7789 only B. IC1805, IC1848, NGC7789 and B68 only C. IC1805, IC1848, NGC362 and B68 only D. NGC3918 and NGC362 only E. NGC362, NGC3918, NGC7789 and B68 only	Answer: A At autumnal equinox, the Sun has RA=12h. Thus at local midnight of the autumnal equinox, the local sidereal time is 00h. Thus pick objects that have similar RA, bearing in mind declination considerations.
44	Great Barrier Island in New Zealand is another such offshore island which is excellent for stargazing. Its coordinates are 36°13’50,3” S 175°28’30,9”W. Given that at this location, NGC 362 is currently crossing the local meridian, which objects will NOT be seen by an observer to cross the local meridian within the next 6 hours? A. NGC 3918 and B68 only B. IC 1805, IC 1848 and NGC 7789 only C. IC 1805, IC 1848 and B68 only D. IC 1805, IC 1848, NGC 7789 and NGC 3918 only E. IC 1805, IC 1848, NGC 7789, NGC 3918 and B68 only	Answer: E Given the RA of NGC 362 is 01h 03m, objects that have an RA of up to 07h 03m will cross the local meridian within the next 6 hours. The only two objects that have an RA within this range are totally invisible from this location, thus yielding E as the answer
45	From a certain location, NGC7789 is observed to be circumpolar. On New Year’s Day, NGC7789’s altitude with the ground was measured. The object reaches its highest altitude at around 1801 hours local time at 80.4 degrees and its lowest at around 0600 hours local time at 14.1 degrees. What is the latitude of the location?	Answer: B Average the largest and lowest altitude to get the altitude of the north celestial pole. From

	A. 43°N B. 47°N C. 43°S D. 47°S E. 47°E	there calculate the latitude accordingly.
46	Given the equation for hydrostatic equilibrium as given in the Formula Book, which of the following statements are FALSE? A. The pressure within a star always decreases as we move outwards from the core B. For a body in hydrostatic equilibrium, $P = \rho_r \times \frac{GM_r}{r}$ at all points in the star C. Outside of the star where $\rho \approx 0, \frac{dP}{dr} \approx 0$ D. For a star to be in hydrostatic equilibrium, the local pressure gradient must equal the local gravitational acceleration multiplied by the local density at all points in the star. E. An object does not need to be undergoing fusion in order to be in hydrostatic equilibrium	Ans: B. A: observe that density, radius and mass are all positive: thus dP/dR is always negative C: Outside of the star, density is 0 by definition. Thus $\frac{dP}{dr}$ becomes 0. D: Note that $\frac{GM_r}{r^2}$ is the local gravitational acceleration g E: No terms involving nuclear fusion does not appear at all. This makes sense: Earth and the planets are in hydrostatic equilibrium too! B is false as density and mass are functions of R, thus solving this differential equation is far more complicated than it seems...
47	While camping in a secluded island on 25th May 2019, Ryan noticed a meteor in the night sky. We thus know that the meteor is definitely associated with the... A. Eta Aquariids B. Orionids C. Geminids D. Antihelion Source E. Insufficient information to answer the question	Answer: E While it is likely that the meteor is associated with the Eta Aquariids, it is also possible that the meteor is a sporadic (not associated with any meteor shower). Thus, to confirm the identity of a meteor, we need to track its trajectory and see if it matches the associated radiant of the shower. This information is not given to us.
48	Compared to the Sun, Betelgeuse has nearly no hydrogen absorption lines. Instead, Betelgeuse displays numerous oxide absorption lines like TiO. Why is this the case?	Answer: A Ans: Betelgeuse is not a planetary nebula and is too massive

	A. Due to the lower surface temperature of Betelgeuse, most hydrogen atoms do not have electrons in the right energy level to absorb/re-emit photons. B. As Betelgeuse is a highly evolved star, its hydrogen shell has been ejected in the surrounding planetary nebula C. Oxide molecules preferentially absorb radiation, thus suppressing the hydrogen absorption line D. All hydrogen in Betelguese has been used up in the s-process, creating the raw elements for heavy metal oxides like TiO. E. Due to the high velocity of Betelgeuse, the hydrogen absorption lines are all Doppler-shifted onto oxide absorption lines	to form one, so B is false. C is false as each compound/atom has its own unique set of absorption lines. For similar reasons E is false. D is false: the outer envelope does not undergo nuclear fusion at all.
49	What can we learn by observing a light curve of the associated object? I. The rotation period of a comet II. Whether it is an intrinsic variable star or an extrinsic variable star III. The age of a star IV. What type of supernova occurred Which of the statements above are correct? a. I, II, III b. I, II, IV c. I, III, IV d. II, III, IV e. All of the above	Answer: B III is false: generally more information is required (e.g. main sequence fitting of an associated star cluster)
50	Sharadh's Q13 (as of Box Version Jan 27)	

Q43 table

Object Name	Type	Angular Size/'	RA	DEC	Apparent magnitude
IC1805	Bright Nebula	212	02h34m	+61°31'	6.50
IC1848	Bright Nebula	168	02h52m	+60°29'	6.50
NGC7789	Open Cluster	16.0	23h58m	+56°48'	6.70
NGC3918	Planetary Nebula	0.15	11h51m	-57°17'	8.50
NGC362	Globular Cluster	12.9	01h03m	-70°44'	6.58
B68	Dark Nebula	3.50	17h23m	-23°50'	NA