INAO-2026

PAPER SOLUTION

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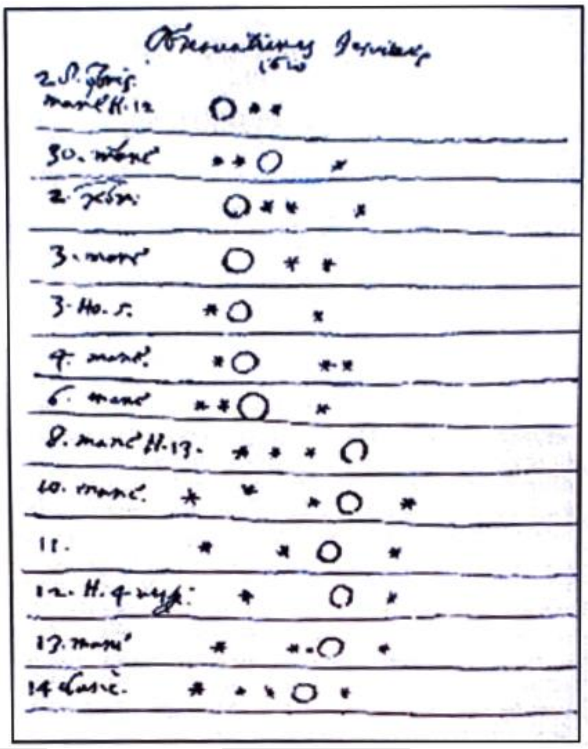
Indian National Astronomy Olympiad (INAO) 2026

DATE : 31-January-2026

1. (a) One of Galileo's discoveries was the satellites of Jupiter and in his notebook he drew sketches showing the position of the satellites every night. In this picture of his original hand-written notes, the big circle denotes Jupiter and small stars represent the positions of four satellites. The writing on the left is the date.



(b) (10 marks) The following table gives recent measurements of the position of one of the satellites, Europa, with respect to Jupiter at various times. Here, x represents the magnitude of distance between Jupiter and Europa, as measured in a similar image / sketch. Obtain the time period (T) of Europa through a suitable linear plot. (You may assume that the maximum magnitude of x is 3 cm).

T (in hour)	x (in cm)
0	not seen
1	0.49
2	0.65
3	0.84
4	1.06
5	1.26
6	1.45
7	1.65
8	1.82

T (in hour)	x (in cm)
9	2.02
10	2.18
11	2.32
12	2.45
13	2.56
14	2.67
15	2.78
16	2.84
17	2.91

(b) (2 marks) Draw a rough sketch of the same plot as in part (a), for a full period of Europa.

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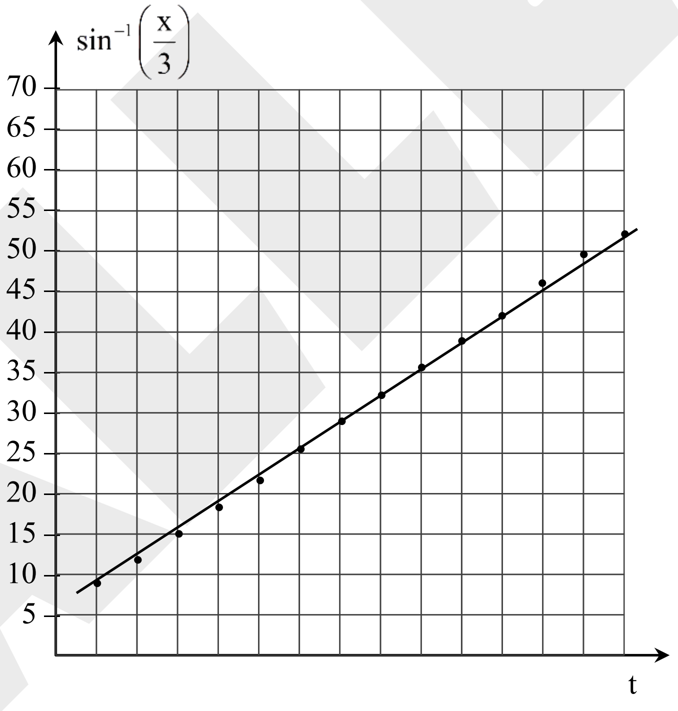
Sol. (a) Since europa will be revolving around Jupiter in almost circular orbit so we can write

$x = 3\sin(\omega t + \phi)$

So to plot linear graph between t and x

we should plot graph between t & $\sin^{-1}\left(\frac{x}{3}\right)$

T	x	$\sin^{-1}\left(\frac{x}{3}\right)$	T	x	$\sin^{-1}\left(\frac{x}{3}\right)$
0	x	x	9	2.02	42.3248
1	0.49	9.4	10	2.18	46.607
2	0.65	12.51	11	2.32	50.65
3	0.84	16.26	12	2.45	54.7525
4	1.06	20.69	13	2.56	58.576
5	1.26	24.83	14	2.67	62.8732
6	1.45	28.9	15	2.78	67.92
7	1.65	33.367	16	2.84	71.2031
8	1.82	37.35	17	2.91	75.93



$\sin^{-1}\left(\frac{x}{3}\right) = \omega t + \phi$

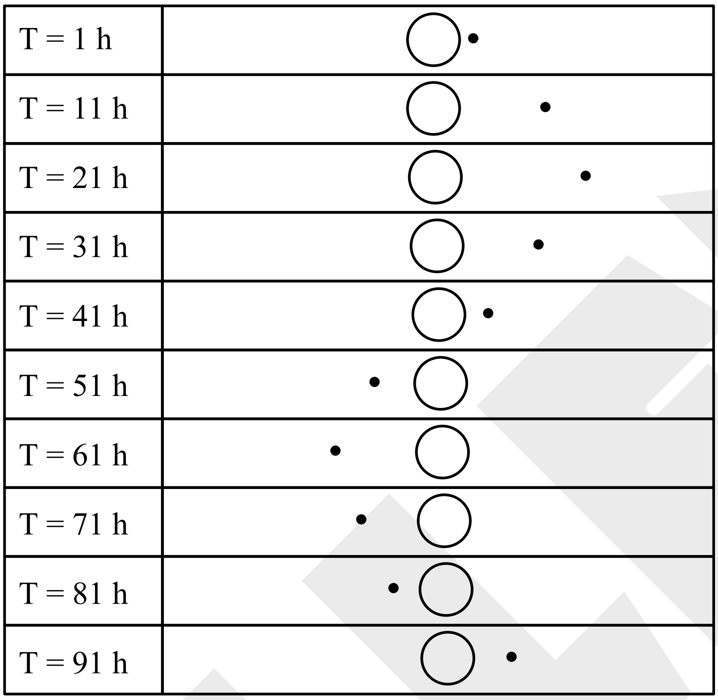
$\therefore$ slope represents $= \omega$

From graph slope $\approx 4.22°$ per hour

$\therefore$ Time period $= \dfrac{360°}{\omega} \approx 85.22$ hours

$T \approx 3.55$ days.

(b) Rough sketch



2. (a) (6 marks) An observer is located in the city of Nashik (latitude ≈ 20°N and longitude ≈ 73°E). She observes the rising of the Sun on different days of the year.

The figure in the answersheet depicts the eastern horizon (approximated as a straight line) for the city of Nashik with East cardinal point marked as E. The azimuth range is given to be 60° to 120° with markings at every 10°. In the table below, you are given certain dates alongside alphabets. Mark the approximate rising points of the Sun as seen by the observer for these dates on the image of the horizon given in the answersheet and label them with the corresponding alphabets. Precise calculations are not expected. Note: For definition of Azimuth refer Appendix.

Letter	Date
A	01 Jan 2025
B	01 Apr 2025
C	15 May 2025
D	01 Jun 2025
E	01 Jul 2025
F	01 Oct 2025

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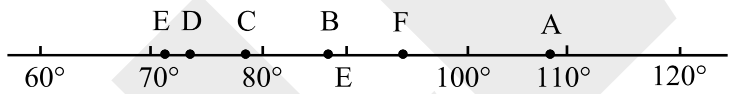
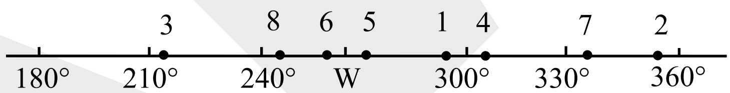
(b) (4 marks) Now consider an observer who is located in a city which lies on the equator of Earth. The figure given in the answersheet is of the horizon (approximated as a straight line) as seen from the equator in the azimuth range 180° to 360°. The cardinal west point is marked with letter W. The azimuths are marked at a separation of 30°. Mark the approximate setting points of the following stars (by writing their corresponding Sr. No.), if applicable, on the figure of horizon given in your answersheet.

Sr. No.	Star Common Name	Bayer Name
1	Pollux	α Gem
2	Polaris	α UMi
3	Canopus	α Car
4	Vega	α Lyr
5	Revati	ζ Psc
6	Rigel	β Ori
7	Dubhe	α UMa
8	Kaus Borealis	λ Sgr

Sol. (a)



(b)



δ – Pollux $\approx$ 28° $\rightarrow$ (1)

δ – Polaris $\approx$ 90° $\rightarrow$ (2)

δ – Canopus $\approx$ –52° $\rightarrow$ (3)

δ – Vega $\approx$ 38° $\rightarrow$ (4)

δ – Revati $\approx$ 7° $\rightarrow$ (5)

δ – Rigel $\approx$ –8° $\rightarrow$ (6)

δ – Dubhe $\approx$ 61° $\rightarrow$ (7)

δ – Kaus Borealis $\approx$ –25° $\rightarrow$ (8)

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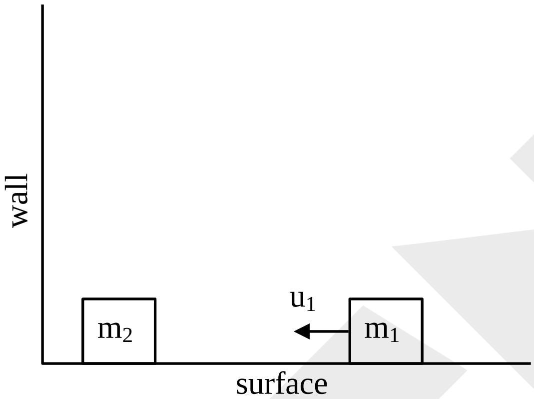
3. Two blocks, m_1 and m_2 are placed on a frictionless horizontal surface next to a fixed rigid wall. Block m_2 is at rest close to the wall and block m_1 moves towards it with velocity $u_1 = -1 ms^{-1}$. All collisions (between the blocks and with the wall) are perfectly elastic.



(a) (5 marks) In the first case, we consider two identical blocks, each of mass 1 kg. Calculate total number of collisions (block-block or block-wall), n_1, that will occur in this system

(b) (2 marks) Now, we will attempt to describe this motion in velocity space by drawing an appropriate figure but for a more general problem.

In the coordinate grid given in the answersheet, we redefine the two axes as, $\alpha = v_1\sqrt{m_1}$ and $\beta = v_2\sqrt{m_2}$.

Plot the values of α and β that depict the velocities between successive collisions during each phase and connect them with straight line arrows depicting the transition at the instance of each collision.

(c) (3 marks) On this phase diagram, we can plot several constant energy contours. Draw the constant energy contour, on the same grid given in part (b), that passes through the phase points that you have plotted

(d) (6 marks) Consider a general case with arbitrary values of m_1 and m_2. In the phase diagram for this general case, let points a, b, c be the first three phase points. Let $\angle abc = \theta$. Find expression for θ in terms of m_1 and m_2.

(e) (3 marks) Using this information form part (d) draw a complete phase diagram for $m_1 = 4m_2$.

(f) (3 marks) You may have realised, in a general case, i.e. for an arbitrary ratio m_1/m_2, you will be able to define a region of this curve in which the last phase point must lie. If p and q are the end points of that region on the curve and o is the origin, find equations of lines op and oq.

Draw these lines for $m_1/m_2 = 4$ case in the diagram of part (e).

Hint : In one of the two equations, you will be using the ratio $\frac{m_2}{m_1}$.

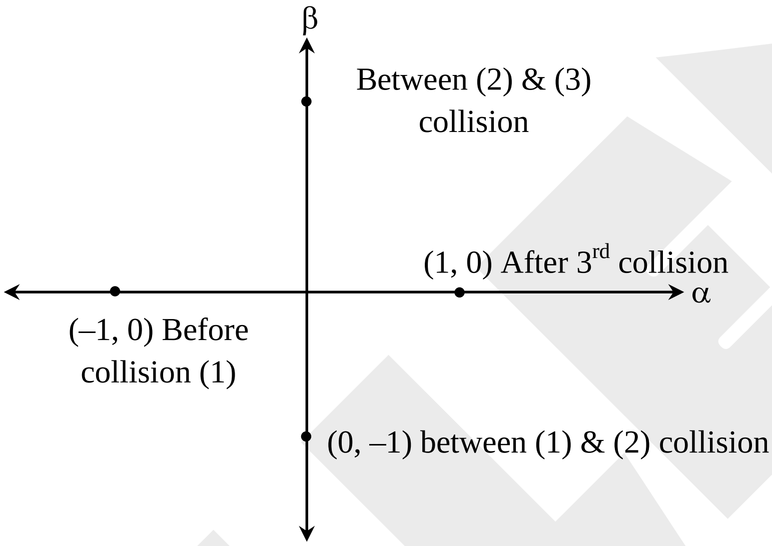
(g) (5 marks) Write an inequality showing bounds on n, where n is the total number of collisions, in terms of m_1 and m_2.

Hint : Find an inequality between θ and n.

(h) (3 marks) Lastly, use the information above to estimate the total number of collisions, n_{total}, for the case $m_1 = 10^{10} m_2$.

Sol. (a) For equal masses it is very easy to conclude that there will be 3 collisions.

(b)



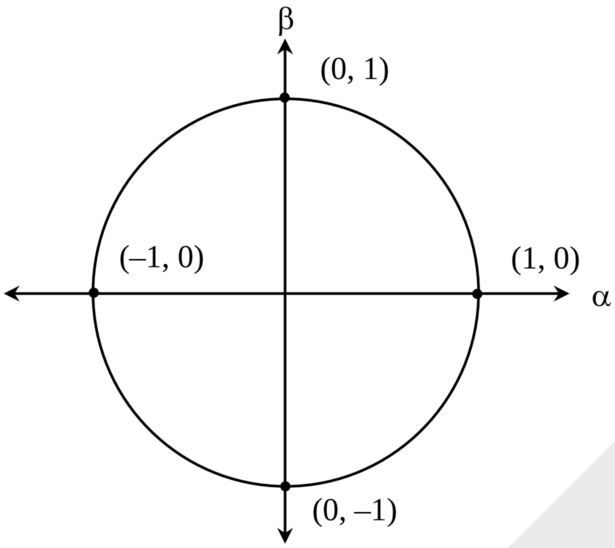
Before collision 1	$v_1 = -1$ m/s	$v_2 = 0$
	$\alpha = -1$	$\beta = 0$
Between collision 1 & 2	$v_1 = 0$	$v_2 = -1$
	$\alpha = 0$	$\beta = -1$
Between collision 2 & 3	$v_1 = 0$	$v_2 = +1$
	$\alpha = 0$	$\beta = +1$
After 3 collision	$v_1 = 1$	$v_2 = 0$
	$\alpha = 1$	$\beta = 0$

(c) $\alpha = v_1\sqrt{m_1} \Rightarrow \frac{\alpha^2}{2} = KE_1$

$\beta = v_2\sqrt{M_2} \Rightarrow \frac{\beta^2}{2} = KE_2$

Now, $KE_1 + KE_2$ = constant during elastic collision

$\therefore \frac{\alpha^2}{2} + \frac{\beta^2}{2}$ = constant will represent a circle.



(d) At a $\alpha_a = -v_1\sqrt{M_1}$ $\beta_a = 0$

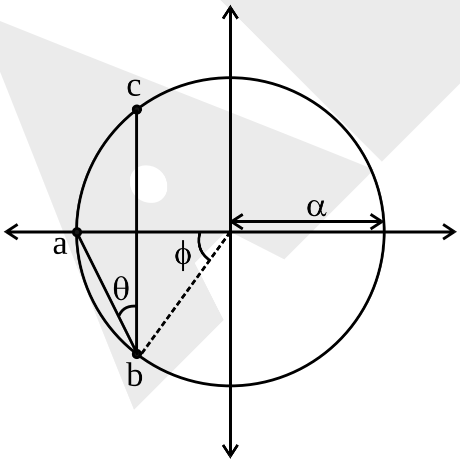
After collision at b

$$v_1^1 = -\frac{(M_1 - M_2)v_1}{(M_1 + M_2)} \qquad v_2^1 = -\frac{2M_1V_1}{M_1 + M_2}$$

$$\alpha_b = -\frac{(M_1 - M_2)v_1}{M_1 + M_2}\sqrt{M_1} \qquad \beta_b = \frac{2M_1v_1}{M_1 + M_2}\sqrt{M_2}$$

After collision at c

$$\alpha_c = -\frac{(M_1 - M_2)v_1}{(M_1 + M_2)}\sqrt{M_1} \qquad \beta_c = \frac{2M_1v_1\sqrt{M_2}}{M_1 + M_2} \qquad \alpha = M_1\sqrt{v_1}$$



$$\tan\theta = \frac{\alpha(1 - \cos\phi)}{\alpha\sin\phi}$$

$$\alpha \sin\phi = \frac{2m_1v_1}{m_1+m_2}\sqrt{m_2}$$

$$\alpha \cos\phi = \frac{(m_1-m_2)v_1}{(m_1+m_2)}\sqrt{m_1}$$

$$\tan\theta = \frac{v_1\sqrt{m_1} - v_1\sqrt{m_1}\left(\frac{m_1-m_2}{m_1+m_2}\right)}{\frac{2m_1v_1}{m_1+m_2}\sqrt{m_2}}$$

$$\tan\theta = \frac{v_1\sqrt{m_1}(m_1+m_2-m_1+m_2)}{2m_1v_1\sqrt{m_2}}$$

$$\tan\theta = \frac{2m_2\sqrt{m_1}}{2m_1\sqrt{m_2}} = \sqrt{\frac{m_2}{m_1}}$$

$$\therefore \quad \theta = \tan^{-1}\sqrt{\frac{m_2}{m_1}}$$

(e) Here $\tan\theta = \sqrt{\frac{M_2}{4M_2}} = \frac{1}{2}$

Now, we can notice that $\alpha^2 + \beta^2 = \text{const}^n$ ....(1)

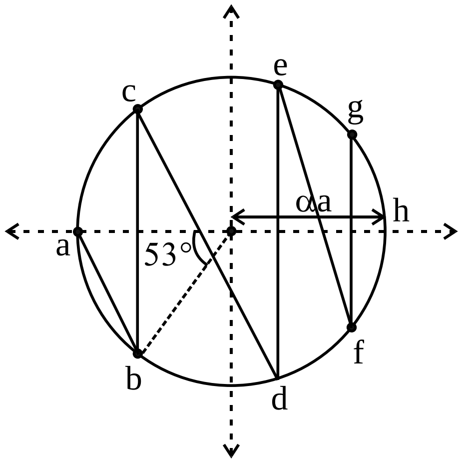
We can also note that linear momentum is conserved therefore

$$\sqrt{M_1}\ \alpha + \sqrt{M_2}\ \beta = \text{const}^n.$$

$$\beta = -\sqrt{\frac{M_1}{M_2}}\ \alpha + \text{const}^n \text{ ....(2)}$$

$\therefore$ Any phase point will always lie on intersection of eq^n. (1) & eq^n. (2)

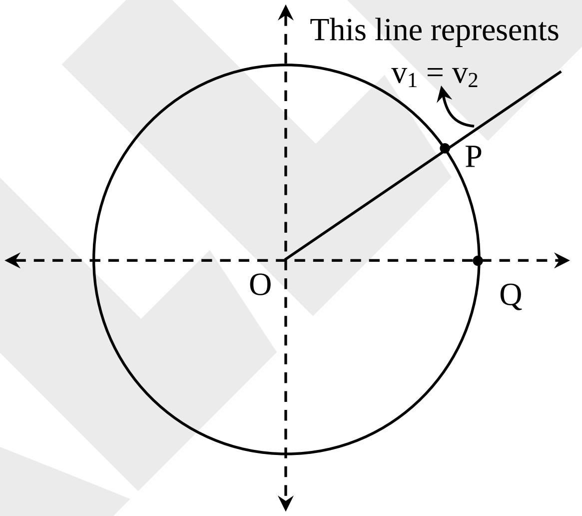
$\therefore$ Slope of (2) is $-\sqrt{\frac{M_1}{M_2}} = -2$



Complete phase diagram

$\alpha_b = -\frac{3}{5}\alpha_a \qquad \beta_b = \frac{4}{5}\alpha_a$

(f) Now, last phase point must lie in a region such that final speed of m_1 should be greater than final speed of m_2

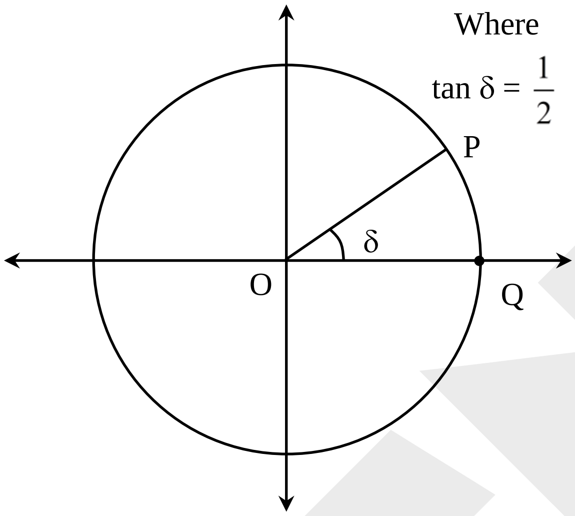


$\alpha = v_1\sqrt{m_1} \qquad \beta = v_2\sqrt{m_2}$

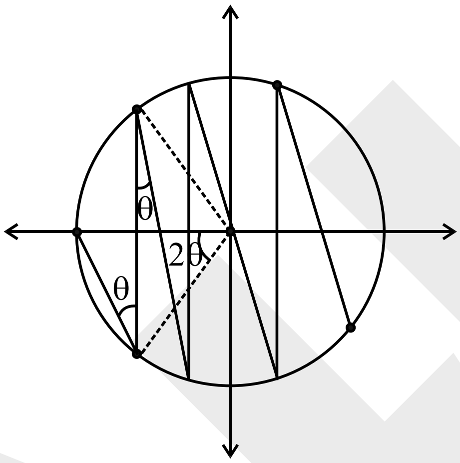
$\therefore \quad v_2 = v_1 \quad \Rightarrow \quad \frac{\alpha}{\sqrt{m_1}} = \frac{\beta}{\sqrt{m_2}}$

$\therefore \quad \beta = \sqrt{\frac{m_2}{m_1}}\,\alpha$ represent equation of line OP and $\beta = 0$ represents equation of line OQ

for $\frac{m_1}{m_2} = 4 \Rightarrow \beta = \frac{\alpha}{2}$



(g)



We can notice that two consecutive phase points subtends an angle 2θ at centre of circle

where $\tan\theta = \sqrt{\frac{M_2}{M_1}}$

Now, addition of all these 2θ segments should be less than 2π.

$\therefore$ If we have n phase points then

$$2n\theta < 2\pi$$

$$n\theta < \pi$$

$$n\tan^{-1}\left(\sqrt{\frac{M_2}{M_1}}\right) < \pi$$

(h) Now when $M_1 = 10^{10} M_2$

then $\sqrt{\frac{M_2}{M_1}} = 10^{-5}$

$\tan^{-1}\sqrt{\frac{M_2}{M_1}} \approx 10^{-5}$

$\therefore\ n < 10^5\ \pi$

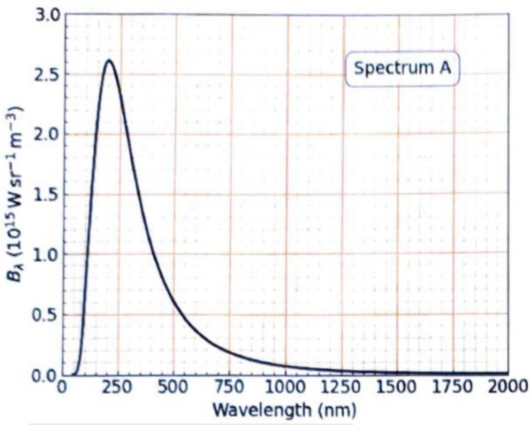
$n < 314159.26$

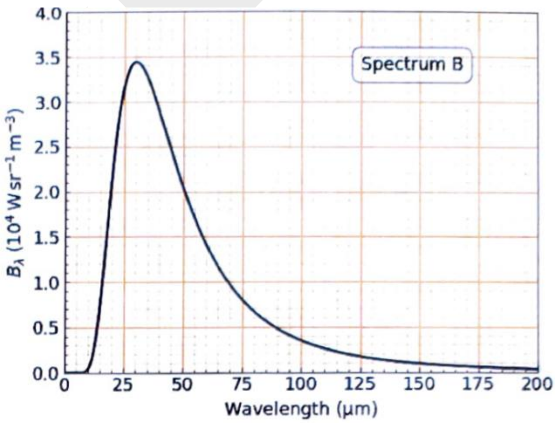
$\therefore\ n = 314159$

4. Blackbody Radiation

(a) (4 marks) Consider a star of radius $R_s = 3R_\odot$ and a gas cloud of radius R_g at a distance d from the star. Assume that the gas cloud doesn't contain any source of radiation and there are no other stars in the vicinity of this system. Both the star and the gas cloud can be assumed to be blackbodies.

You are given two spectra (A and B) below. Determine which spectra corresponds to the star and which corresponds to the gas cloud. Justify your answer. Also, calculate the effective temperature for the star, T_s, and for the gas cloud, T_g.





(b) (4 marks) Calculate the distance, d, of the gas cloud from the star.

Sol. (a) Spectrum A corresponds to the spectrum of a star because its peak appears at a lower wavelength and hence it is spectrum of a higher temperature objects.

Now according to wein's law

$\lambda T = \text{constant} = 2.89 \times 10^{-3}$

$$T = \frac{2.89 \times 10^{-3}}{\lambda}$$

$$T_s = \frac{2.89 \times 10^{-3}}{\lambda_s} \approx \frac{2.89 \times 10^{-3}}{200 \times 10^{-9}}$$

$T_s \approx 14450$ K (star temperature)

$$T_g = \frac{2.89\times10^{-3}}{\lambda_s} \approx \frac{2.89\times10^{-3}}{30\times10^{-6}}$$

$T_g \approx 96.33$ K (gas cloud temperature)

(b) For thermal equilibrium of gas cloud

$$\sigma 4\pi R_g^2 T_g^4 = \frac{\sigma 4\pi R_s^2 T_s^4}{4\pi d^2}\pi R_g^2$$

$$T_g^4 = \frac{R_s^2 T_s^4}{4d^2}$$

$$\Rightarrow d^2 = \frac{R_s^2 T_s^4}{4T_g^4} = \frac{9R_\odot^2 T_s^4}{4T_g^4} = \frac{9\times(6.957\times10^8)^2\times(14450)^4}{4\times(96.33)^4}$$

$$d^2 = 55138084224.2\times10^{16}\ \text{m}^2$$

$$\Rightarrow \boxed{d = 2.34814\times10^{13}\ \text{m}}$$

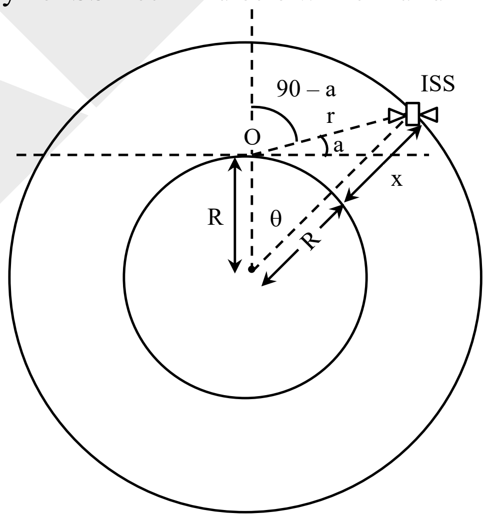
5. (10 marks) **Observing the ISS**

The International Space Station (ISS) is sometimes visible in the sky, during the morning and evening twilight, as a bright moving object. One day, Kundan sees the ISS rising at the horizon, then passing near the zenith, and then setting in the opposite direction.

Consider the ISS to be ω metre across and orbiting the Earth in a circular orbit at a height x metre above the Earth's surface.

Derive an expression for its apparent angular size, ϕ, measured by Kundan as a function of its altitude from Kundan's location.

Sol. Orbital period of ISS around earth is roughly 90 minutes. Due to this we can assume that earth does not rotate significantly as ISS risen and sets while Kundan is observing.



R ⟶ radius of earth

Angular size of ISS will be $\phi \approx \frac{\omega}{r}$

Now, using cosine rule we get

$(R + x)^2 = R^2 + r^2 - 2Rr \cos(90 + a)$

$(R + x)^2 = R^2 + r^2 + 2Rr \sin a$

$r^2 + 2Rr \sin a + R^2 - (R + x)^2 = 0$

$$r = \frac{-2R\sin a \pm \sqrt{4R^2 \sin^2 a - 4(R^2 - (R+x)^2)}}{2}$$

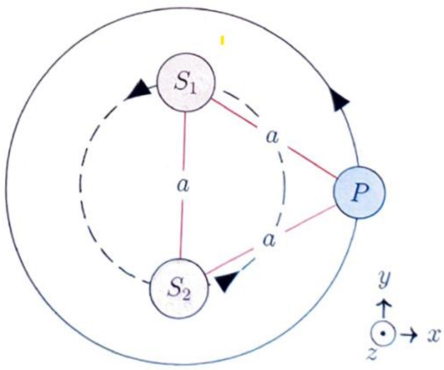
$$r = \frac{-2R \sin a + \sqrt{4R^2 \sin^2 a + 4(R+x)^2 - 4R^2}}{2}$$

$$r = -R \sin a + \sqrt{(R+x)^2 - R^2 \cos^2 a}$$

$$\phi = \frac{\omega}{\sqrt{(R+x)^2 - R^2 \cos^2 a} - R\sin a}$$

6. Planet's Orbit around a Binary Star System:

Dhananjay, an exoplanet researcher, wanted to explore the prospects of life on an Earth like planet in a binary star system. More specifically he wanted to look into the following configuration: two identical stars S_1, S_2 and a planet P have circular orbits about the center of mass of the system and at every point in time, the three bodies form a equilateral triangle with side of length a = 2 au as shown in the figure below.



(Note that at the instance shown in this figure, the radius vector from the centre of mass of the system to P is exactly along the x-axis).

The period t_p of such a system is known to be:

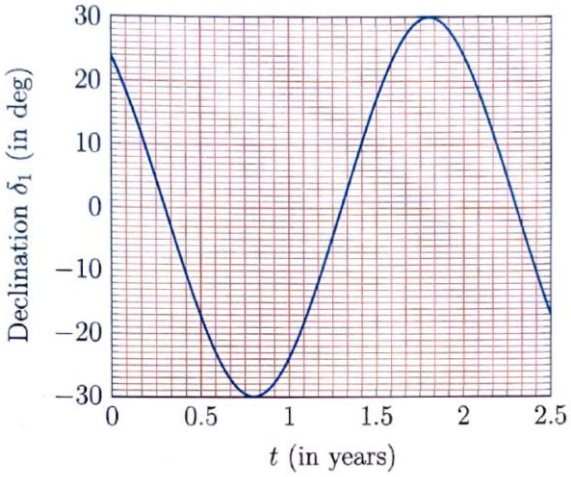
$$t_p = \sqrt{\frac{4\pi^2 a^3}{G(m_1 + m_2 + m_3)}}$$

You can take the mass and radius of the planet P to be exactly that of Earth and the two stars are Sun like. The sidereal period of rotation of P is 1d and the angle made by the P's axis of rotation with the z-axis in the diagram above, called the axial tilt, is $\in = 30°$.

Help Dhananjay answer the following questions about the planet:

(a) (3 marks) Taking the albedo of the planet P to be A = 0.15, estimate its average surface temperature (T_p).

Dhananjay calculated the variation of declination, δ_1, of star 1 with time as seen from the planet. This variation is plotted in the figure below.



Note that declination is defined in the usual sense - the angle made by the object with the celestial equator of the planet.

(b) (4 marks) Plot the declination, δ_2, of star S_2 vs time in the plot provided in answersheet.

(c) (6 marks) The configuration of the two stars and planet system shown in the figure given in the preamble of the question is the orientation of the system corresponding to time t = 0 in the declination vs time plot.

In the figure given in the answersheet, mark the direction of the equinoxes, as seen from the planet, with respect to the x-axis on the orbit of planet. Mark the equinox after which the days get longer, in the northern hemisphere of the planet, with a × and write VE beside it and the other one with Δ and write AE beside it.

Note that the equinox is the day corresponding to the median day length.

(d) (10 marks) We define the effective flux at a point on the planet as the energy per unit area per unit time falling on a tangential plane at that point. Plot the effective flux on the planet's North Pole from t = 0 yr to t = 2.5 yr.

(e) (4 marks) What will be the typical day length at the equator, $t_{day,\ eq}$, and the pole, $t_{day,\ pole}$? Explain your answer.

(f) (3 marks) What is/are the number, of zero shadow days, N_{ZSD} for an observer on the planet in one period of the system for the following two cases -

Case 1: Latitude > 30°

Case 2: Latitude < 30°

Explain your answer in brief.

Sol. (a) $\sigma 4\pi R_p^2 T_p^4 = (1-A)\times 2\times \frac{S}{4}\times \pi R_p^2$

We use solar constant from stars as $\frac{S}{4}$

$\because$ they are sun like and a distance twice that of earth

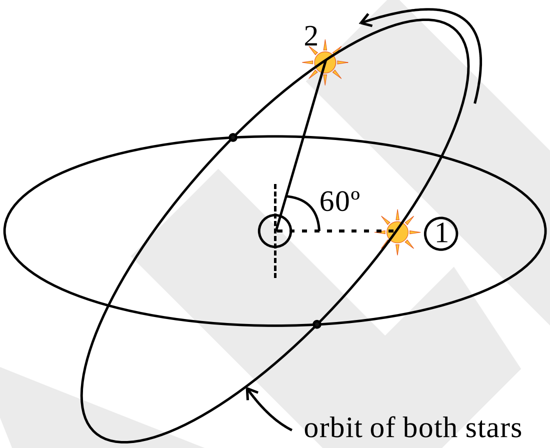
$\sigma 4T_p^4 = (1-A)\frac{S}{2}$

$T_p^4 = (1-A)\frac{S}{8\sigma}$

$T_p^4 = (1-0.15)\times \frac{1361}{8\times 5.67\times 10^{-8}}$

$T_P = 224.725$ K

(b) In planets frame



We can see that w.r.t. planet both stars orbit in same plane and maintain an angular separation of 60º.

From diagram we can interpret that star (2) is ahead in orbit by from star (1).

Therefore the δ_2 of star v/s t graph will be identical to δ_1 v/s t only difference will be that graph of star (2) will lead graph of star (1) by a time.

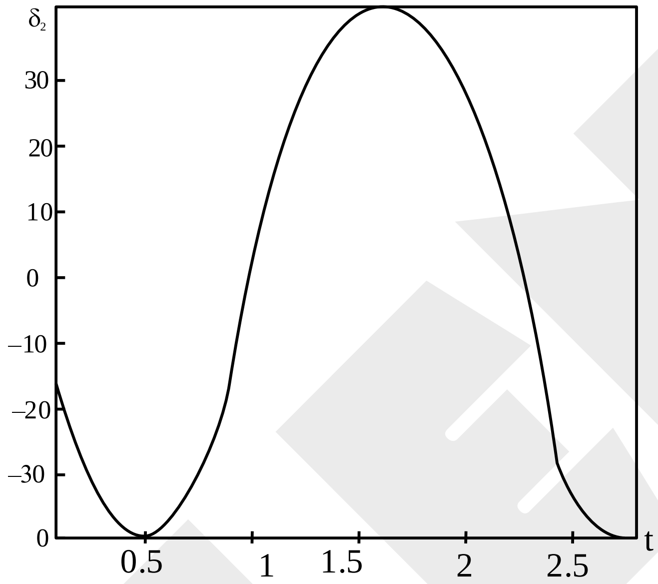
$\Delta t = \frac{\pi}{3\omega} = \frac{\pi T}{32\pi}$

$\Delta t = \frac{T}{6}$

Now, using $T = \sqrt{\frac{4\pi^2 a^3}{a(M_1+M_2+M_3)}}$

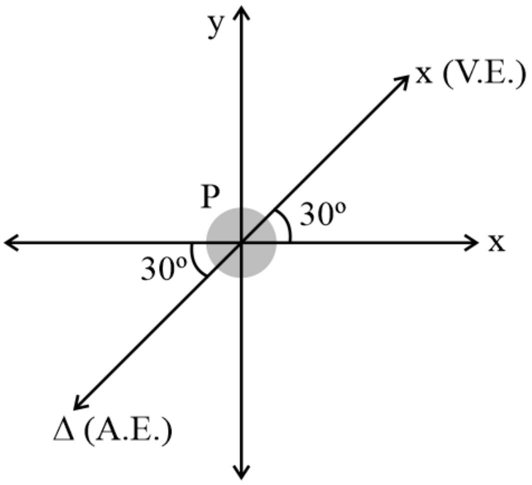
We can conclude that T = 2 years

$\therefore \Delta t = \frac{1}{3}$ years.



(c) From the situation of the two stars we can interpret that median day length will occur when $\delta_1 = -\delta_2$

Now, this will occur when star (2) has revolved 30º further after the zero declination points. Assuring from graph of δ_2 v/s t we can say that $\delta_2 \approx 0$ at t = 0 then we can say that A.E occurs at $t \approx \frac{T}{12} \approx \frac{1}{6}$ years and V.E occurs at $t = \frac{T}{12} + \frac{T}{2} = \frac{7}{6}$ years.

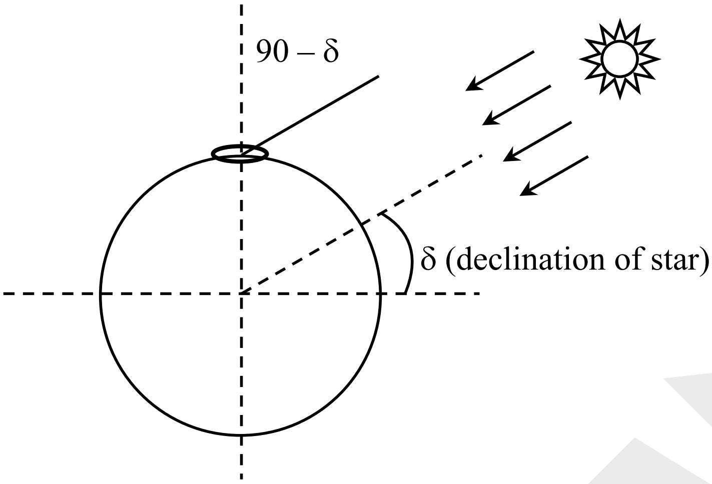


SOLUTION

Indian National Astronomy Olympiad (INAO) 2026

DATE : 31-January-2026

(d)



When a star has declination δ, the effective flux falling on North pole will be proportional to cos (90 – δ) which is sin δ

$\therefore$ Effective flux $\propto \sin\delta_1 + \sin\delta_2$

Here we keep in mind that if

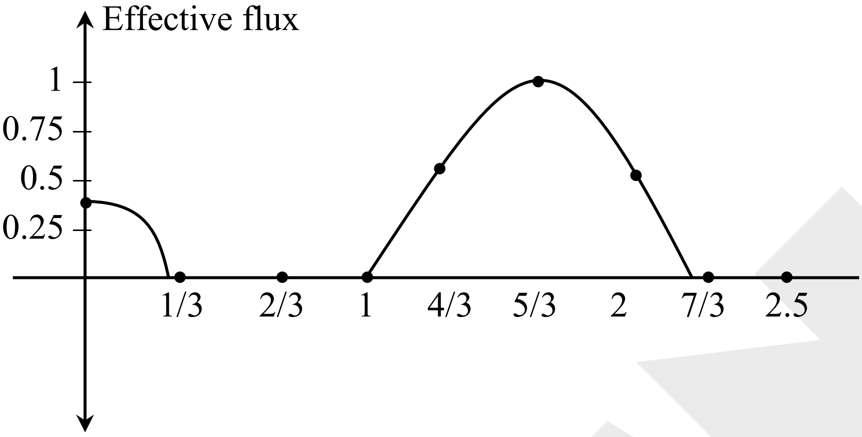
$\delta_1 < 0$ then effective flux $\propto \sin\delta_2$

$\delta_2 < 0$ then effective flux $\propto \sin\delta_2$

If $\delta_1 < 0$ and $\delta_2 < 0$ then effective flux = 0

From graph we can make a table

t (years)	δ_1	δ_2	$\sin\delta_1 + \sin\delta_2$
0	24°	–3°	0.41
0.33	–3°	–27°	0
0.67	–27°	–24°	0
1	–24°	+2°	0.035
1.33	+2°	+27°	0.489
1.67	+27°	+24°	0.861
2	+24°	-3°	0.41
2.33	–3°	–27°	0
2.5	–16°	–30°	0



(e) At equator after the first star rises the other star effectively rises after earth has rotated through 60° and after the setting of first star the second star will effectively set after earth has rotated by 60°

So, $\Delta t = \frac{240°}{\omega} = \frac{240°}{360°}T$

$= \frac{2}{3}T = \frac{2}{3} \times 24 = 18h$

Going through similar analysis at north pole the duration of day will be

$\Delta t = \frac{2}{3} \times T_{\text{orbital period}}$

$\Delta t = \frac{2}{3} \times 2 = \frac{4}{3}$ years

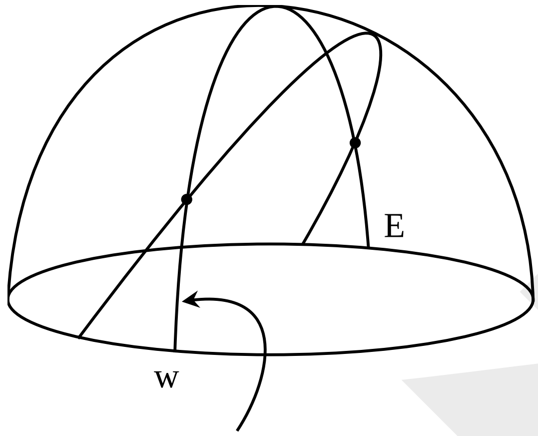
By definition of day we assumed here duration of day light.

(f) For case 1: latitude > 30°

Zero shadow will occur when both stars lie on prime vertical and have same altitude. However this can occur for latitudes > 30° and it will occur twice a year however for certain latitude $\phi > \phi_0$ No zero shadow day can occur however here $\phi_0 > 30°$

Exact calculation of ϕ_0 requires detailed analysis.

For case 2 : Zero shadow will occur when both stars lie on prime vertical plane and altitude of both stars is also equal.

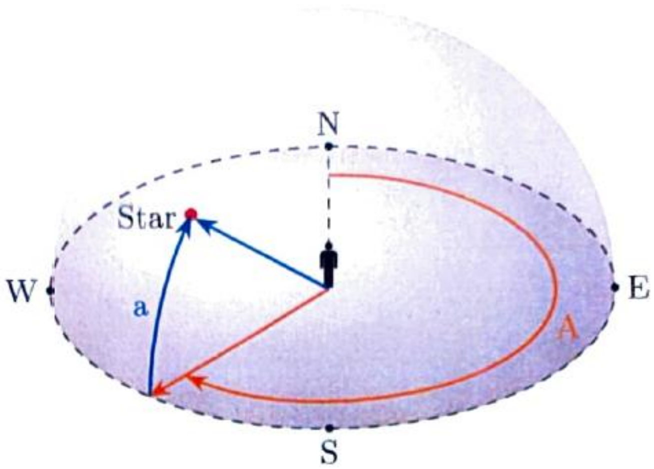


Prime vertical

Now, this can occur only twice a year. Hence No of zero shadow days for latitudes < 30° will be two.

Appendix

Altitude – Azimuth System



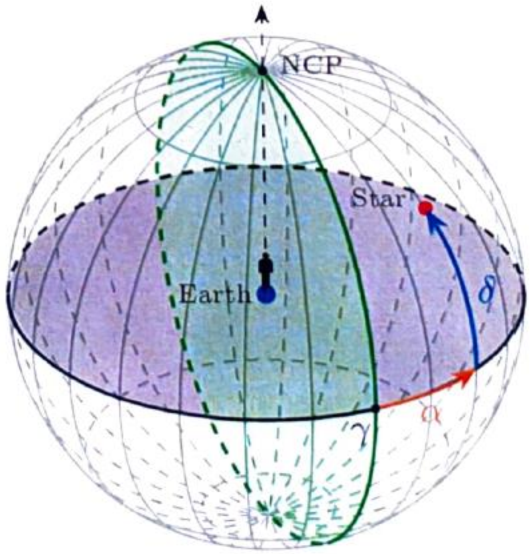
Azimuth (A):

Azimuth is the angle measured along the horizon to indicate the position of a given star. It is measured from the north (0°), towards East (90°). The south will correspond to 180°, and the west will correspond to 270°. The angle of elevation of the star does not matter; e.g. all objects exactly due east will have same 90° azimuth, irrespective of elevation.

Altitude (a):

Altitude is the angle of elevation of the star measured from the horizon (0°). A star exactly overhead, i.e. at Zenith, will have the highest altitude (90°).

Right Ascension - Declination System



Right Ascension (α):

Right Ascension (RA) is the celestial analogue of the terrestrial longitude. The zero of RA passes through the Vernal Equinox point (γ), which marks the position of the Sun when it crosses the Celestial Equator into the northern part of the sky around 21 March every year.

RA, measured in hours-minutes-seconds along the celestial equator, increases as the Sun moves ahead from γ for the full year.

Declination (δ):

Declination is the celestial counterpart of the terrestrial latitude. It is the angular distance in degrees of the star from the celestial equator along the meridian (i.e. given line of RA).

It is measured from the celestial equator (0°) to the poles (±90°).

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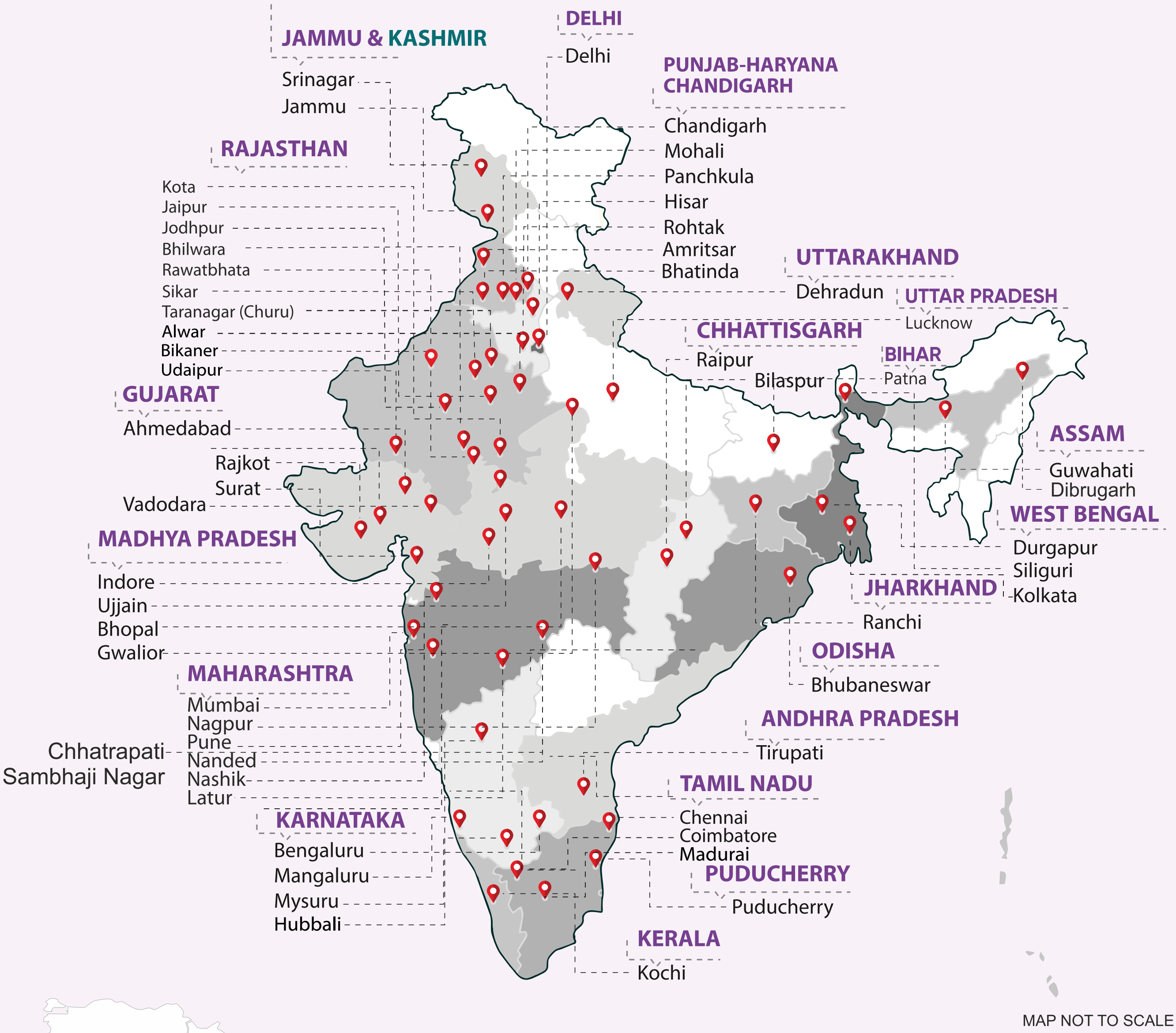

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