# Class Test (M.Tech) — 30 Objective Questions

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## How to use these questions

There are 30 questions drawn from the four topics of the study plan — the $n$-body problem, the two-body problem, orbital elements, and orbital maneuvers. Every question has exactly one correct option. Choose it before opening the **Answer**, which gives the reason and, for a number, the calculation. All the answers are listed together in the answer key at the end.

**Data**, unless a question says otherwise. $\mu_\oplus = 398\,600\ \mathrm{km^3/s^2}$, $R_\oplus = 6378\ \mathrm{km}$, $g_0 = 9.80665\ \mathrm{m/s^2}$, $G = 6.674 \times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$, $\mu_\odot = 1.327{\times}10^{11}\ \mathrm{km^3/s^2}$, $1\ \mathrm{AU} = 1.496{\times}10^{8}\ \mathrm{km}$, $M_\odot/m_{\mathrm{Jupiter}} = 1047.6$, $J_2 = 1.08263{\times}10^{-3}$. Burns are impulsive and orbits are two-body, unless a question says otherwise. Angles in Kepler's equation are in radians.

Symbols and constants shared by all the notes are collected on the notation page; the study plan gives the order in which to read the notes.

**1.** How many classical integrals (constants of the motion) does the $n$-body problem have?

(A) 6
(B) 9
(C) 10
(D) 12

**Answer.** **(C)** Three for the velocity of the centre of mass, three for its initial position, three for the total angular momentum, and one for the total energy: $3 + 3 + 3 + 1 = 10$.

**2.** The total potential energy of the Sun and eight planets is a sum over pairs. How many terms does it have?

(A) 81
(B) 72
(C) 36
(D) 9

**Answer.** **(C)** The number of pairs among $n = 9$ bodies is $n(n-1)/2 = 9 \cdot 8/2 = 36$. Summing over $i$ and $j$ separately would count each pair twice, which is where the factor $\frac{1}{2}$ in $V$ comes from.

**3.** Kepler's three laws were obtained

(A) from Newton's law of gravitation
(B) from the shape of the Moon's orbit
(C) from the conservation of angular momentum
(D) by fitting Tycho Brahe's observations, not by deduction from a law of force

**Answer.** **(D)** Kepler fitted Tycho's observations of Mars (1609, 1619). He did speculate about a moving force from the Sun (his *anima motrix*), but the laws came from the data, not from it. Newton later derived them from his law of gravitation.

**4.** At new moon, compare the Sun's pull on the Moon with the Earth's pull on the Moon ($M_\odot/M_\oplus = 3.33\times10^5$, $r_{\mathrm{EM}} = 384\,400$ km, $r_{\mathrm{SM}} \approx 1$ AU). The ratio is about

(A) 0.01
(B) 0.5
(C) 2.2
(D) 180

**Answer.** **(C)** $(M_\odot/M_\oplus)(r_{\mathrm{EM}}/r_{\mathrm{SM}})^2 = 3.33\times10^5 \times (384\,400/1.496\times10^8)^2 = 2.2$. Yet the Earth–Moon *relative* motion is well modelled as two-body, because the Sun pulls the Earth almost equally.

**5.** The solar system as a whole accelerates towards the galactic centre at about $2\times10^{-10}$ m/s$^2$. Why can this be ignored in planetary dynamics?

(A) Because the barycentre does not move
(B) Because it is too small ever to have been measured
(C) Because the galactic centre is too far for gravity to act
(D) Because it is almost the same for every body, so it cancels from their relative motion

**Answer.** **(D)** A uniform acceleration shifts every body equally and drops out of the relative equations of motion. Only its *difference* across the solar system, a tidal term, could matter, and that is utterly negligible. Option (B) is false: Gaia measured the acceleration in 2020.

**6.** The conservation of the total angular momentum of $n$ bodies requires that the mutual forces

(A) are equal and opposite and act along the line joining each pair
(B) are equal and opposite only
(C) are attractive
(D) fall off as $1/r^2$

**Answer.** **(A)** Equal and opposite forces cancel in the sum of forces, but their torques cancel only if they also act along $\mathrm{r}_{ij}$ (the "strong" form of the third law). Gravity satisfies both; the $1/r^2$ law itself is not needed.

**7.** An isolated three-body system has total energy $E < 0$. Which statement is correct?

(A) The centre of mass must be at rest
(B) The motion must be periodic
(C) All three bodies must stay within a bounded region forever
(D) One body may still be ejected to infinity, leaving the other two more tightly bound

**Answer.** **(D)** $E < 0$ means the system as a whole cannot fly apart completely, but one body can carry away positive energy while the remaining pair sinks deeper. Ejections of this kind are common in numerical three-body runs.

**8.** In a numerical $n$-body integration, the most common check of accuracy is

(A) that every body stays on its initial Kepler ellipse
(B) that the total energy and angular momentum stay constant
(C) that the bodies keep their initial order of distance from the barycentre
(D) that the time step stays constant

**Answer.** **(B)** The ten classical integrals are exact properties of the true solution, so their drift in the computed solution measures the numerical error.

**9.** Two planets have orbital angular momenta $L_1$ and $L_2 = L_1/2$, and their orbit planes are inclined at 6° to each other. The invariable plane is inclined to the plane of planet 1 by about

(A) 2.0°
(B) 0.5°
(C) 3.0°
(D) 4.0°

**Answer.** **(A)** $\mathrm{H} = \mathrm{L}_1 + \mathrm{L}_2$. Its angle from $\mathrm{L}_1$ is $\arctan\dfrac{L_2\sin 6^\circ}{L_1 + L_2\cos 6^\circ} = \arctan\dfrac{0.0523}{1.497} = 2.0^\circ$: the larger angular momentum keeps the invariable plane closer to its own plane.

**10.** Every mass in an $n$-body system is multiplied by 4, and the initial positions are kept. To retrace exactly the same paths, the initial velocities must be multiplied by

(A) 1/2, and the motion takes twice as long
(B) 16, and the timing is unchanged
(C) 4, and the motion takes a quarter of the time
(D) 2, and the motion takes half as long

**Answer.** **(D)** At the same positions every acceleration is 4 times larger. Putting $t' = t/2$ keeps $d^2\mathrm{R}/dt'^2$ matched, so the same paths are followed twice as fast, with velocities doubled.

**11.** Kepler's second law (equal areas in equal times) is equivalent to the conservation of

(A) the eccentricity vector
(B) angular momentum
(C) linear momentum
(D) energy

**Answer.** **(B)** The areal velocity is $\frac{1}{2}|\mathrm{r}\times\dot{\mathrm{r}}| = h/2$. It is constant for any central force.

**12.** Kepler's equation, relating the mean anomaly $M$ to the eccentric anomaly $E$, is

(A) $M = E - e\sin E$
(B) $\tan\frac{M}{2} = \sqrt{\frac{1-e}{1+e}}\tan\frac{E}{2}$
(C) $M = E - e\cos E$
(D) $M = E + e\sin E$

**Answer.** **(A)** $M = n(t-t_p) = E - e\sin E$. Option (B) is the half-angle relation between $E$ and the *true* anomaly, with $f$ replaced by $M$.

**13.** The geostationary orbit has period one sidereal day, 23.9345 h. Its radius is about

(A) 42 164 km
(B) 35 786 km
(C) 42 241 km
(D) 384 400 km

**Answer.** **(A)** $r = (\mu T^2/4\pi^2)^{1/3} = (398\,600\times 86\,164^2/4\pi^2)^{1/3} = 42\,164$ km. (35 786 km is the *altitude*; using 24 h instead of the sidereal day gives 42 241 km.)

**14.** An orbit has $e = 0.5$. The ratio of periapsis speed to apoapsis speed is

(A) 4
(B) 2
(C) 3
(D) 1.5

**Answer.** **(C)** $h = r_p v_p = r_a v_a$, so $v_p/v_a = r_a/r_p = (1+e)/(1-e) = 1.5/0.5 = 3$.

**15.** On an ellipse, the body is at $r = a$ when

(A) $\sin f = e$
(B) $\cos f = -e$
(C) $f = 90°$
(D) $\cos f = e$

**Answer.** **(B)** $a(1-e^2)/(1+e\cos f) = a$ gives $1 + e\cos f = 1 - e^2$, i.e. $\cos f = -e$. This is the end of the minor axis, which lies on the apoapsis side of the focus.

**16.** A hyperbolic flyby has $e = 2$. The velocity is turned through

(A) 120°
(B) 90°
(C) 60°
(D) 30°

**Answer.** **(C)** $\delta = 2\arcsin(1/e) = 2\arcsin\frac{1}{2} = 60^\circ$. ($120^\circ$ is the true anomaly of the asymptote, $f_\infty = \arccos(-1/e)$; the turn is $2f_\infty - 180^\circ$.)

**17.** Kepler's third law with $\mu = GM_\oplus$ predicts the Moon's period for its observed $a$. Including the Moon's mass ($M_\oplus/M_{\text{Moon}} = 81.3$) changes the predicted period by

(A) about $-1.2\%$
(B) about $-0.6\%$
(C) about $+0.6\%$
(D) nothing

**Answer.** **(B)** $T \propto 1/\sqrt{G(M+m)}$, so the period is multiplied by $1/\sqrt{1+1/81.3} = 0.9939$: about 0.6% shorter.

**18.** A hyperbolic flyby has $r_p = 7000$ km and $v_\infty = 3$ km/s. Its eccentricity is about

(A) 2.16
(B) 1.58
(C) 1.16
(D) 1.02

**Answer.** **(C)** $|a| = \mu/v_\infty^2 = 44\,289$ km, and $r_p = |a|(e-1)$, so $e = 1 + r_p v_\infty^2/\mu = 1 + 63\,000/398\,600 = 1.158$.

**19.** Why are exactly six classical orbital elements needed?

(A) Because the two-body equations of motion need six initial conditions
(B) Because the orbit lies in a plane
(C) Because the ellipse has six symmetries
(D) Because Kepler stated three laws, each fixing two numbers

**Answer.** **(A)** The relative motion is three second-order ODEs, i.e. six first-order ones, so a state needs six numbers; the elements are just a more meaningful choice of those six.

**20.** The node vector $\mathbf{n} = \hat{\mathbf{K}} \times \mathbf{h}$ points towards

(A) the descending node
(B) periapsis
(C) the vernal equinox
(D) the ascending node

**Answer.** **(D)** At the ascending node the body crosses the equator going north. Check with a polar orbit that crosses $\hat{\mathbf{I}}$ going north: $\mathbf{h} \propto \hat{\mathbf{I}} \times \hat{\mathbf{K}} = -\hat{\mathbf{J}}$, and $\hat{\mathbf{K}} \times (-\hat{\mathbf{J}}) = \hat{\mathbf{I}}$, the ascending node.

**21.** The argument of latitude $u$ is

(A) $\Omega + \omega + f$
(B) $\Omega + \omega$
(C) $\omega + f$
(D) $f - \omega$

**Answer.** **(C)** $u$ is the angle in the orbit plane from the ascending node to the body. $\Omega + \omega$ is the longitude of periapsis, and $\Omega + \omega + f$ the true longitude.

**22.** A sun-synchronous orbit is one whose

(A) apse line points at the Sun
(B) period is one solar day
(C) plane always contains the Sun
(D) node moves east at the Sun's mean rate, about $0.986^\circ$ per day

**Answer.** **(D)** $\dot{\Omega} = 360^\circ/365.2422\ \text{d} = 0.9856^\circ$/day keeps the orbit plane at a fixed angle to the Sun, so the local solar time of each pass is fixed.

**23.** Sriharikota is at latitude $13.7^\circ$ N. Ignoring range-safety limits on the launch azimuth, the smallest inclination reachable by a direct launch from there is

(A) $76.3^\circ$

(B) 13.7°
(C) 6.9°
(D) 0°

**Answer.** **(B)** $\cos i = \cos\phi \sin\beta \le \cos\phi$, so $i \ge \phi$, with equality for a launch due east. Lower inclinations need a plane change later.

**24.** The ISS orbit has $i = 51.6°$. When its argument of latitude is $u = 30°$, its latitude is about

(A) 23.1°
(B) 15.0°
(C) 25.8°
(D) 30.0°

**Answer.** **(A)** $\sin\delta = \sin i \sin u = 0.7837 \times 0.5 = 0.392$, so $\delta = 23.1°$. (Halving $i$, 25.8°, is the common mistake.)

**25.** An orbit has $e = 10^{-4}$. A small error $\delta e = 10^{-5}$ in the eccentricity vector, perpendicular to it, changes $\omega$ by about

(A) 57°
(B) 5.7°
(C) 0.06°
(D) 0.0006°

**Answer.** **(B)** $\delta\omega = |\delta \mathrm{e}|/e = 0.1$ rad $= 5.7°$. For a nearly circular orbit $\omega$ is ill-conditioned, although the position barely changes; $(e\cos\omega, e\sin\omega)$ are well behaved.

**26.** A spacecraft moving at 7.5 km/s turns its orbit plane by 60° without changing speed. The cost is

(A) 15.0 km/s
(B) 6.50 km/s
(C) 7.50 km/s
(D) 3.75 km/s

**Answer.** **(C)** $\Delta v = 2v\sin(\Delta i/2) = 2 \times 7.5 \times \sin 30° = 7.5$ km/s: a 60° turn costs as much as the whole orbital speed.

**27.** A chaser on the same circular orbit as its target is 20° *behind* it. To catch up with a phasing manoeuvre, it should enter a phasing orbit that is

(A) larger, with a longer period
(B) circular and higher
(C) the same size, but inclined
(D) smaller, with a shorter period

**Answer.** **(D)** In the time the target needs to cover $2\pi k - \Delta\theta$, which is less than $k$ target periods, the chaser must complete exactly $k$ revolutions. A shorter period needs a smaller $a$, so it slows down (retrograde burn) to drop into a lower ellipse.

**28.** To add a given amount of orbital energy with the least $\Delta v$, a tangential burn should be made

(A) at the end of the minor axis
(B) anywhere, because energy is path-independent
(C) where the speed is least, at apoapsis
(D) where the speed is greatest, at periapsis

**Answer.** **(D)** $\Delta\varepsilon \approx v\,\Delta v$, so each m/s buys most energy where $v$ is largest: the Oberth effect.

**29.** The $\Delta v$ to escape from a circular orbit of radius 6678 km is about

(A) 3.20 km/s
(B) 2.26 km/s
(C) 7.73 km/s
(D) 10.93 km/s

**Answer.** **(A)** $\Delta v = (\sqrt{2} - 1)v_c = 0.4142 \times 7.726 = 3.200$ km/s. (10.93 km/s is the escape speed itself.)

**30.** A Hohmann transfer from the Earth's orbit (1 AU) to Mars's orbit (1.524 AU), both taken circular and coplanar, takes about

(A) 146 d
(B) 259 d
(C) 343 d
(D) 517 d

**Answer.** (**B**) $a_t = 1.262$ AU, and half its period is $\frac{1}{2}(1.262)^{3/2}$ yr $= 0.709$ yr $= 259$ d.

## Answer key

All 30 answers, in order.

**Answer.**

| Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | C | 2 | C | 3 | D | 4 | C | 5 | D | 6 | A | 7 | D | 8 | B | 9 | A | 10 | D |
| 11 | B | 12 | A | 13 | A | 14 | C | 15 | B | 16 | C | 17 | B | 18 | C | 19 | A | 20 | D |
| 21 | C | 22 | D | 23 | B | 24 | A | 25 | B | 26 | C | 27 | D | 28 | D | 29 | A | 30 | B |