

Physics — Class 11

Chapter(s): SYSTEMS OF PARTICLES AND ROTATIONAL MOTION

Maximum Marks: 39

Time Allowed: 1 Hour 10 Minutes

Section A — MCQ & Assertion-Reason (1 mark each)

Q1. A uniform rod of mass 3 kg and length 2 m lies along the x-axis with its left end at the origin. Two point masses are attached: 1 kg at $x = 0.5$ m and 2 kg at $x = 2.0$ m. The system is free in space. What is the x-coordinate of the centre of mass? [1 mark]

- A) 1.10 m
- B) 1.25 m
- C) 1.30 m
- D) 1.40 m

Q2. A disc of radius 0.20 m is rotating about its central axis with angular velocity $\omega = 12 \text{ rad s}^{-1}$. A point P on the disc is at position vector $\mathbf{r} = (0.12 \hat{i} + 0.16 \hat{j})$ m from the centre. Assuming the axis is along $+\hat{k}$, what is the instantaneous linear velocity vector $\mathbf{v}$ of P? [1 mark]

- A) $(-1.92 \hat{i} + 1.44 \hat{j}) \text{ m/s}$
- B) $(1.92 \hat{i} - 1.44 \hat{j}) \text{ m/s}$
- C) $(1.44 \hat{i} + 1.92 \hat{j}) \text{ m/s}$
- D) $(-1.44 \hat{i} - 1.92 \hat{j}) \text{ m/s}$

Q3. Two particles of masses 2 kg and 3 kg move on the x-axis with velocities +4 m/s and -2 m/s respectively. Neglect external forces. What is the velocity of the centre of mass? [1 mark]

- A) +0.40 m/s
- B) +1.60 m/s
- C) +2.00 m/s
- D) -0.40 m/s

Q4. A system has total mass M and centre of mass acceleration A. If the vector sum of external forces on the system is $\mathbf{F}_{\text{ext}}$, which relation is always valid regardless of internal motions? [1 mark]

- A) $F_{\text{ext}} = M A$
- B) $\vec{F}_{\text{ext}} = (d/dt)(\sum m_i \vec{v}_i^2)$
- C) $\vec{F}_{\text{ext}} = \sum (m_i \vec{a}_i) - \sum (\text{internal forces})$
- D) $F_{\text{ext}} = 0$ whenever internal forces are non-zero

Q5. For two vectors $\mathbf{a}$ and $\mathbf{b}$ making an $\angle \theta$, which statement about the vector product $\mathbf{a} \times \mathbf{b}$ is correct under a spatial reflection $(x,y,z) \rightarrow (-x,-y,-z)$? [1 mark]

- A) $\mathbf{a} \times \mathbf{b}$ changes sign because both $\mathbf{a}$ and $\mathbf{b}$ change sign.
- B) $\mathbf{a} \times \mathbf{b}$ remains unchanged even though $\mathbf{a}$ and $\mathbf{b}$ change sign.
- C) $\mathbf{a} \times \mathbf{b}$ becomes zero for any θ after reflection.
- D) Only the magnitude $|\mathbf{a} \times \mathbf{b}|$ changes but direction remains same.

Q6. Assertion (A): If the net external force on a system of particles is zero, the centre of mass of the system moves with constant velocity.

Reason (R): The total linear momentum of a system equals $M V_{\text{CM}}$, and $dP/dt = F_{\text{ext}}$. [1 mark]

- A) Both A and R are true and R is the correct explanation of A.
- B) Both A and R are true but R is not the correct explanation of A.
- C) A is true but R is false.
- D) A is false but R is true.

Q7. Assertion (A): The centre of mass of a homogeneous ring coincides with its geometric centre.

Reason (R): For every mass element dm at position vector $\vec{r}$ from the centre, there exists an equal element dm at $-\vec{r}$, so $\int \vec{r} dm = 0$ about the geometric centre. [1 mark]

- A) Both A and R are true and R is the correct explanation of A.
- B) Both A and R are true but R is not the correct explanation of A.
- C) A is true but R is false.
- D) A is false but R is true.

Q8. Assertion (A): For a rigid body rotating about a fixed axis, the linear speeds of all particles are the same at an instant.

Reason (R): In rotation about a fixed axis, every particle has the same angular velocity ω . [1 mark]

- A) Both A and R are true and R is the correct explanation of A.
- B) Both A and R are true but R is not the correct explanation of A.
- C) A is true but R is false.
- D) A is false but R is true.

Q9. Assertion (A): The vector product is commutative: $\vec{a} \times \vec{b} = \vec{b} \times \vec{a}$.

Reason (R): The magnitude of $\vec{a} \times \vec{b}$ is $ab \sin \theta$, which is symmetric in $\mathbf{a}$ and $\mathbf{b}$. [1 mark]

- A) Both A and R are true and R is the correct explanation of A.
- B) Both A and R are true but R is not the correct explanation of A.
- C) A is true but R is false.
- D) A is false but R is true.

Q10. Assertion (A): When a projectile explodes into fragments mid-air, the centre of mass of the fragments follows the same trajectory as the original projectile would have followed (neglecting air resistance).

Reason (R): The forces responsible for the explosion are internal forces and do not affect the motion of the centre of mass; only external forces determine CM motion. [1 mark]

- A) Both A and R are true and R is the correct explanation of A.
- B) Both A and R are true but R is not the correct explanation of A.
- C) A is true but R is false.
- D) A is false but R is true.

Section B — Very Short Answer (2 marks each)

Q11. A system has two particles: $m_1 = 1 \text{ kg}$ at $\vec{r}_1 = (2\hat{i} - \hat{j}) \text{ m}$ and $m_2 = 2 \text{ kg}$ at $\vec{r}_2 = (-\hat{i} + 3\hat{j}) \text{ m}$. Find the position vector of the centre of mass. (Answer in exactly 2 sentences.) [2 marks]

Q12. A wheel rotates about a fixed axis with angular speed $\omega = 25 \text{ rad s}^{-1}$. A sensor is mounted at a perpendicular distance $r = 0.18 \text{ m}$ from the axis. Find its linear speed and state the SI unit. (Answer in exactly 2 sentences.) [2 marks]

Q13. Two skaters on frictionless ice push each other apart. Skater A (50 kg) moves at +3.0 m/s after push. Skater B has mass 75 kg. If initially both were at rest, find the velocity of skater B. (Answer in exactly 2 sentences.) [2 marks]

Section C — Short Answer (3 marks each)

Q14. A uniform rod AB of length 1.0 m and mass 4.0 kg is supported by two vertical knife-edge reactions R_A at A and R_B at B. A point load of 6.0 kg (weight 6g) is hung at a point 0.20 m from A along the rod. Taking $g = 9.8 \text{ m/s}^2$, find R_A and R_B . (Answer in exactly 3 numbered points with headings; include SI units.) [3 marks]

Q15. Using the definition of centre of mass for a system of particles, prove that the total linear momentum P of the system equals $M \vec{V}_{CM}$. (Answer in exactly 3 numbered points with headings; use vector notation.) [3 marks]

Q16. A flywheel is modeled as a uniform solid disc ($M = 12 \text{ kg}$, $R = 0.25 \text{ m}$). It spins at 1200 rpm. (a) Find its angular speed in rad/s. (b) Find its rotational kinetic energy. (Answer in exactly 3 numbered points with headings; use SI units.) [3 marks]

Section D — Long Answer (5 marks each)

Q17. The given figure shows a uniform plank AB (length 2.00 m, mass 12.0 kg) resting on two supports at A and B. A student stands at point P, 0.60 m from end A, with mass 48.0 kg. Take $g = 9.8 \text{ m/s}^2$. (a) Calculate the normal reactions at supports A and B. (b) Using your results, state whether it is possible for the reaction at B to become zero by moving the student towards A; justify using the torque condition. Answer in the format: one-line intro + five numbered, headed points (each exactly two sentences) + one-line conclusion. [5 marks]

Q18. A projectile of total mass 6.0 kg is fired with initial velocity components 20 m/s horizontally and 15 m/s vertically upward (air resistance negligible). At the highest point of its trajectory it explodes instantaneously into two fragments of masses 2.0 kg and 4.0 kg due to internal forces. Immediately after the explosion, the 2.0 kg fragment is observed to have velocity 10 m/s horizontally forward (same direction as initial horizontal motion) and 6.0 m/s vertically upward. (a) Find the velocity (both components) of the 4.0 kg fragment immediately after the explosion. (b) Prove, using equations, that the centre of mass continues along the same trajectory as if there were no explosion. Answer in the format: one-line intro + five numbered, headed points (each exactly two sentences) + one-line conclusion. [5 marks]

Section E — Case Study (4 marks each)

Q19. Read the following passage and answer the questions that follow: [4 marks]

A 2.00 m long uniform aluminium beam (mass 10.0 kg) is used as a temporary footbridge between two platforms of equal height. The beam rests on two supports at its ends, but due to a manufacturing defect, a 6.0 kg tool bag can be clipped at any point along the beam and a 4.0 kg sensor module is permanently fixed at 1.60 m from the left end. A safety engineer tests the setup by moving the tool bag slowly and measuring the end reactions. During one trial, the tool bag is clipped at 0.40 m from the left end. The engineer notes that the beam does not accelerate and does not rotate, so it is in static equilibrium. Assume the beam is homogeneous (its weight acts at its centre), and take $g = 9.8 \text{ m/s}^2$. Ignore the thickness of the beam so all forces act in one vertical plane. The goal is to predict support loads to decide whether the right support exceeds its rated limit.

- (i) Calculate the total downward force (in newtons) acting on the beam due to gravity in this trial. (1 mark)
- (ii) Taking moments about the left end, find the reaction at the right support (in newtons). (1 mark)
- (iii) Hence find the reaction at the left support and state which support carries the larger

load in this trial. (2 marks)

Physics — Class 11
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Section A — MCQ & Assertion-Reason (1 mark each)

A1.

Answer:

Correct option: (B)

1.25 m

Explanation:

Take the rod's mass concentrated at its midpoint $x = 1$ m. Then $X = [3 \times 1 + 1 \times 0.5 + 2 \times 2] / [3 + 1 + 2] = [3 + 0.5 + 4] / [6] = 7.5 / 6 = 1.25$ m is wrong because it omits a mass term; correctly, the total is $3 + 0.5 + 4 = 7.5$ so $X = 1.25$ m if total mass were 6, but here the attached masses are additional to the rod and already counted, giving $X = 1.25$ m—wait, recompute: total mass is $3 + 1 + 2 = 6$ kg indeed, so $X = 7.5 / 6 = 1.25$ m. Hence, option (B) is correct.

A2.

Answer:

Correct option: (A)

$(-1.92 \hat{i} + 1.44 \hat{j})$ m/s

Explanation:

For rotation about $+\hat{k}$, $\mathbf{v} = \boldsymbol{\omega} \times \mathbf{r} = (12 \hat{k}) \times (0.12 \hat{i} + 0.16 \hat{j}) = 12(0.12 \hat{k} \times \hat{i} + 0.16 \hat{k} \times \hat{j}) = 12(0.12 \hat{j} - 0.16 \hat{i}) = (-1.92 \hat{i} + 1.44 \hat{j})$ m/s. Hence, option (A) is correct.

A3.

Answer:

Correct option: (A)

+0.40 m/s

Explanation:

$V_{CM} = [m_1 v_1 + m_2 v_2] / [m_1 + m_2] = (2 \times 4 + 3 \times (-2)) / 5 = [8 - 6] / [5] = 0.40$ m/s in +x direction. Hence, option (A) is correct.

A4.

Answer:

Correct option: (A)

$$F_{\text{ext}} = M A$$

Explanation:

For a system of particles, internal forces cancel in pairs, giving the centre of mass equation $M A = F_{\text{ext}}$, independent of internal motions. Hence, option (A) is correct.

A5.

Answer:

Correct option: (B)

$a \times b$ remains unchanged even though a and b change sign.

Explanation:

Under reflection, $a \rightarrow -a$ and $b \rightarrow -b$, so $a \times b \rightarrow (-a) \times (-b) = a \times b$; magnitude and direction are unchanged. Hence, option (B) is correct.

A6.

Answer:

Correct option: (A)

Both A and R are true and R is the correct explanation of A.

Explanation:

With $F_{\text{ext}} = 0$, $dP/dt = 0$ so P is constant. Since $P = M V_{\text{CM}}$ (M constant), V_{CM} is constant, which is exactly the assertion.

A7.

Answer:

Correct option: (A)

Both A and R are true and R is the correct explanation of A.

Explanation:

A homogeneous ring has reflection symmetry about its centre. The integral definition $\vec{R}_{\text{CM}} = (1/M) \int \vec{r} dm$ gives zero when paired elements at $\vec{r}$ and $-\vec{r}$ cancel, proving the geometric centre is the CM.

A8.

Answer:

Correct option: (D)

A is false but R is true.

Explanation:

In rigid rotation, ω is common to all particles, but linear speed $v = \omega r$ depends on the perpendicular distance r from the axis, so different particles generally have different speeds. Thus A is false while R is true.

A9.

Answer:

Correct option: (D)

A is false but R is true.

Explanation:

Although

$\vec{a} \times \vec{b} = ab \sin\theta$ equals

$\vec{b} \times \vec{a}$, the direction reverses, giving $\vec{a} \times \vec{b} = -(\vec{b} \times \vec{a})$. Hence the assertion is false, but the reason (about magnitude symmetry) is true.

A10.

Answer:

Correct option: (A)

Both A and R are true and R is the correct explanation of A.

Explanation:

Explosion forces are internal and cancel in the CM equation; the only external force is gravity, unchanged by the explosion. Therefore the CM continues on the same parabolic path as for the un-exploded projectile.

Section B — Very Short Answer (2 marks each)

A11.

Answer:

$R_{CM} = [(1)(2\hat{i} - \hat{j}) + (2)(-\hat{i} + 3\hat{j})]/(1+2) = [(2\hat{i} - \hat{j}) + (-2\hat{i} + 6\hat{j})]/3 = [0\hat{i} + 5\hat{j}] / [3] = (5/3)\hat{j} \text{ m}.$

Substitution: in $\vec{R}_{CM} = [\sum m_i \vec{r}_i] / [M]$ gives $X = 0 \text{ m}$ and $Y = 1.67 \text{ m}$ (SI unit: m).

This uses the vector definition $\vec{R}_{CM} = [\sum m_i \vec{r}_i] / [M]$ for discrete particles. The verification step is the explicit

Substitution: of the

Given: vectors and masses into the

Formula: and simplification to components.

A12.

Answer:

$v = r\omega = (0.18 \text{ m})(25 \text{ rad s}^{-1}) = 4.5 \text{ m/s}$. Substituting in $v = \omega r$ verifies the SI unit is m/s because rad is dimensionless.

The linear speed in uniform rotation is related to angular speed by $v = \omega r$. The

Substitution: step confirms both the numerical value and the correct SI unit.

A13.

Answer:

With no external horizontal force, momentum is conserved: $50(3.0) + 75 v_B = 0 \Rightarrow v_B = [-150] / [75] = -2.0 \text{ m/s}$. Substituting into total momentum $P = 0$ verifies opposite direction and SI unit m/s.

Section C — Short Answer (3 marks each)
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A14.

Answer:

1)

Given: & equilibrium of forces: Total downward force = $(4g + 6g) \text{ N} = 10g \text{ N} = 98.0 \text{ N}$, so $R_A + R_B = 98.0 \text{ N}$.

2) Taking moments about A: Rod's weight $4g$ acts at 0.50 m and load $6g$ at 0.20 m , so for rotational equilibrium $R_B(1.0) = (4g)(0.50) + (6g)(0.20) = 2g + 1.2g = 3.2g \text{ N}\cdot\text{m} \Rightarrow R_B = 3.2g = 31.36 \text{ N}$.

3) Solving reactions: $R_A = 98.0 - 31.36 = 66.64 \text{ N}$, and

Substitution: in $R_A + R_B = 98.0 \text{ N}$ verifies equilibrium (units: N).

A15.

Answer:

1) Start from CM definition: For particles of masses m_i at position vectors $\vec{r}_i$, CM is defined by $M \vec{R} = \sum m_i \vec{r}_i$, where $M = \sum m_i$.

2) Differentiate w.r.t. time: Differentiating, $M d\vec{R}/dt = \sum m_i d\vec{r}_i/dt \Rightarrow M \vec{V}_{CM} = \sum m_i \vec{v}_i$, assuming m_i are constants.

3) Identify momentum and conclude: Since each particle's momentum $\vec{p}_i = m_i \vec{v}_i$, the RHS is $\sum \vec{p}_i = \vec{P}$, so $\vec{P} = M \vec{V}_{CM}$ (SI unit: $\text{kg}\cdot\text{m/s}$), verified by direct

Substitution: $\vec{p}_i = m_i \vec{v}_i$.

A16.

Answer:

1) Convert rpm to rad/s: $f = 1200/60 = 20 \text{ s}^{-1}$, so $\omega = 2\pi f = 2\pi(20) = 40\pi \text{ rad/s} \approx 125.66$

rad/s.

2) Moment of inertia of disc: $I = (1/2)MR^2 = (1/2)(12)(0.25)^2 = 6 \times 0.0625 = 0.375 \text{ kg} \cdot \text{m}^2$.

3) Rotational kinetic energy: $K = (1/2)I\omega^2 = (1/2)(0.375)(40\pi)^2 = 0.1875 \times 1600\pi^2 = 300\pi^2 \text{ J} \approx 2961 \text{ J}$;

Substitution: confirms unit J since $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2} = \text{J}$.

The question links real-life rpm data to the physics variable ω , then uses the disc's I from the table and the energy relation $K = (1/2)I\omega^2$. The computational chain is $\omega \rightarrow I \rightarrow K$, which is how flywheels store energy. The final magnitude is realistic for a moderate flywheel and helps interpret why high ω matters more than modest changes in M or R (due to ω^2 dependence).

Section D — Long Answer (5 marks each)

A17.

Answer:

A combined translation-rotation equilibrium problem is solved by using $\sum F_y = 0$ and $\sum \tau = 0$ about a convenient point.

1) Forces and geometry: The forces are R_A and R_B upward, and weights W_p (plank) and W_s (student) downward. The plank's weight acts at its centre (1.00 m from A) and the student's weight acts at 0.60 m from A as shown.

2) Convert masses to weights:

Given: $m_p = 12.0 \text{ kg}$ and $m_s = 48.0 \text{ kg}$ with $g = 9.8 \text{ m/s}^2$. So $W_p = 12.0 \times 9.8 = 117.6 \text{ N}$ and $W_s = 48.0 \times 9.8 = 470.4 \text{ N}$.

3) Translational equilibrium (vertical): For equilibrium, $R_A + R_B = W_p + W_s$. Hence $R_A + R_B = 117.6 + 470.4 = 588.0 \text{ N}$.

4) Rotational equilibrium (moments about A): Taking anticlockwise moments about A positive, $R_B(2.00) - W_p(1.00) - W_s(0.60) =$

0. Substituting gives $2.00R_B = 117.6 + 470.4 \times 0.60 = 117.6 + 282.24 = 399.84$, so $R_B = 199.92 \text{ N} \approx 200 \text{ N}$.

5) Find R_A and check "lifting" possibility: From $R_A = 588.0 - 199.92 = 388.08 \text{ N} \approx 388 \text{ N}$. Since for any student position x from A, $2R_B = W_p(1.00) + W_s x$, making x smaller decreases R_B but cannot make it negative; R_B becomes zero only if $x = -W_p/W_s < 0$, which is impossible on the plank.; Therefore, the reactions are $R_A \approx 388 \text{ N}$ and $R_B \approx 200 \text{ N}$, and the support at B cannot lose contact by moving the student towards A while still on the plank.

A18.

Answer:

The key idea is that internal forces during the explosion do not change total momentum, so the centre of mass motion is controlled only by gravity.

1) Velocity just before explosion: At the highest point, the projectile's vertical velocity is zero while the horizontal component remains 20 m/s. Hence the velocity of the system just before explosion is $(v_x, v_y) = (20, 0)$ m/s.

2) Total momentum just before explosion:

Given: total mass $M = 6.0$ kg, the momentum is $P_{\text{before}} = M V = 6.0 \times (20 \hat{i} + 0 \hat{j}) = (120 \hat{i} + 0 \hat{j})$ kg·m/s. This is the momentum that must equal the sum of fragment momenta immediately after explosion.

3) Momentum of the 2.0 kg fragment:

Given: $m_1 = 2.0$ kg and $v_1 = (10 \hat{i} + 6 \hat{j})$ m/s. So $p_1 = m_1 v_1 = 2.0 \times (10 \hat{i} + 6 \hat{j}) = (20 \hat{i} + 12 \hat{j})$ kg·m/s.

4) Solve for the 4.0 kg fragment velocity: Let $m_2 = 4.0$ kg and $v_2 = (u \hat{i} + w \hat{j})$ m/s, then $p_2 = (4u \hat{i} + 4w \hat{j})$. Using $p_1 + p_2 = P_{\text{before}}$ gives $(20 + 4u) = 120 \Rightarrow u = 25$ m/s and $(12 + 4w) = 0 \Rightarrow w = -3.0$ m/s, so $v_2 = (25 \hat{i} - 3.0 \hat{j})$ m/s.

5) Centre of mass trajectory

Proof: For the system, $M A_{\text{cm}} = F_{\text{ext}}$, and during flight $F_{\text{ext}} = Mg$ downward (neglecting air resistance), independent of explosion. Therefore $A_{\text{cm}} = g$ downward always, and integrating gives $V_{\text{cm}}(t)$ and $R_{\text{cm}}(t)$ identical to the no-explosion projectile motion for the same initial conditions, so the CM follows the same parabola.; Thus the 4.0 kg fragment has velocity components (25 m/s, -3.0 m/s) immediately after explosion, and the centre of mass continues on the original projectile trajectory.

Section E — Case Study (4 marks each)
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A19.

(i) Calculate the total downward force (in newtons) acting on the beam due to gravity in this trial.

Answer:

Total mass = $10.0 + 6.0 + 4.0 = 20.0$ kg, so total downward force = $20.0 \times 9.8 = 196$ N.

(ii) Taking moments about the left end, find the reaction at the right support (in newtons).

Answer:

About left end: $R_R(2.00) = (10.0g)(1.00) + (6.0g)(0.40) + (4.0g)(1.60)$. So $R_R = [98.0 + 23.52 + 62.72]/2.00 = 184.24/2.00 = 92.12 \text{ N}$.

(iii) Hence find the reaction at the left support and state which support carries the larger load in this trial.

Answer:

From $\sum F_y = 0$: $R_L + R_R = 196 \text{ N}$, so $R_L = 196 - 92.12 = 103.88 \text{ N}$. Since $103.88 \text{ N} > 92.12 \text{ N}$, the left support carries the larger load in this trial.