Precise

SAMPLE CONTENT

PHYSICS

Vol. I

BASED ON LATEST BOARD PAPER PATTERN

Std. XII
Science

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Precise

PHYSICS (Vol. I)

Std. XII Sci.

Salient Features

- Written as per **Latest Board Paper Pattern**
- Subtopic-wise segregation for powerful concept building
- Complete coverage of Textual Exercise Questions, Intext Questions and Numericals
- Marks provided to the Questions as per relevant weightage as deemed necessary
- Relevant Previous Years' Board Questions:
  - **March 2013 to July 2023**
- Each chapter contains:
  - 'Quick Review' of the chapter for quick revision
  - 'Important Formulae' and 'Solved Examples' to cover numerical aspect in detail
  - 'Exercise' to provide Theory questions, Numericals and MCQs for practice
  - Selective questions from NCERT textbook for practice
- Includes Important Feature to elucidate concept: ***Reading Between the Lines***
- Q.R. codes provide:
  - The Video/pdf links boosting conceptual retention
- Includes Board Question Paper of February 2024 (Solution in pdf format through QR code)

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PREFACE

Precise Physics Vol. I, Std. XII Sci. is intended for every Maharashtra State Board aspirant of Std. XII, Science. The scope, sequence, and level of the book are consistent with the latest textbook released by Maharashtra State board.

We believe that the study of Physics needs driving desire to learn and willingness to work hard. The earnestness to dive into the subject eventuates naturally when students are presented with meaningful content that is easy to read and understand rather than being mired down with facts and information. Students do much better when they grasp the nub of the subject.

While beginning with a chapter in Physics, students should study to understand the content and not merely read point blankly. They can go slowly, knowing Physics can't be read like a novel, choosing their own pace. But it is essential for students to comprehend the concepts involved, ruminate and reproduce their own versions of the same.

To quote Albert Einstein, **"If you can't explain it simply, you don't understand it yourself."**

Students should then attempt theoretical questions based on these concepts to gauge the level of understanding achieved.

Next advance after gaining command over theory would be numericals. Though Physics is communicated in English, it is expressed in Mathematics. Hence, it is essential to befriend formulae and derivations. These should be learnt and memorized. Once physical mathematics of concept is ingrained, solved numericals should be studied, starting from simple problems to difficult by escalating level of complexity gradually. Students are required to practise numericals and ascertain their command on problem solving. Calculations at this stage must be done using log table keeping in mind that calculators are not allowed in Board Exams. **When it comes to problems in Physics nothing makes students perfect like practice!**

Amongst building concepts, advancing into numbers and equations, it is essential to ponder underlying implications of subject. Students should read from references, visit authentic websites and watch relevant fascinating links.

Such a holistic preparation of subject is the key to succeed in the board examination.

After all, **"Success is no accident. It is hard work, perseverance, learning, studying, sacrifice and most of all, love of what you are doing or learning to do,"** as said by legendary football player Pele and students should bear it in mind!

Our **Precise Physics Vol. I, Std. XII Sci.** adheres to our vision and achieves several goals: **building concepts**, **developing competence to solve numericals, recapitulation and self-study** —all while encouraging students toward cognitive thinking.

Features of the book presented below will explicate more about the same!

We hope the book benefits the learner as we have envisioned.

Publisher

Edition: Sixth

The journey to create a complete book is strewn with triumphs, failures and near misses. If you think we've nearly missed something or want to applaud us for our triumphs, we'd love to hear from you.
Please write to us on: mail@targetpublications.org

KEY FEATURES

Reading between the lines

Reading between the lines provides elaboration or missing fragments of concept essential for complete understanding of the concept.

QR Codes

QR code provides:

i. Access to a video/PDF in order to boost understanding of a concept or activity
ii. Solutions to Board Question Paper February 2024

Solved Examples

Solved Examples offer complete solution to numerical including log (as seemed required).

Important Formulae

Important Formulae includes all of the key formulae in the chapter.

Quick Review

Quick review includes tables/ flow chart to summarize the key points in chapter.

Exercise

Exercise includes subtopic-wise additional questions and problems.

Multiple Choice Questions

Multiple Choice Question includes textual as well as additional MCQs.

Board Questions & Paper

Includes:

i. Selective and relevant Board questions from March 2013 to July 2023
ii. Board Question Paper 2024

PAPER PATTERN

- There will be single question paper of 70 Marks and practical examination of 30 Marks in Physics.
- Duration of the paper will be 3 hours.

Section A: **(18 Marks)**

This section will contain Multiple Choice Questions and Very Short Answer (VSA) type of questions.
There will be 10 MCQs and 8 VSA type of questions, each carrying one mark.
Students will have to attempt all these questions.

Section B: **(16 Marks)**

This section will contain 12 Short Answer (SA-I) type of questions, each carrying 2 marks.
Students will have to attempt any 8 questions.

Section C: **(24 Marks)**

This section will contain 12 Short Answer (SA-II) type of questions, each carrying 3 marks.
Students will have to attempt any 8 questions.

Section D: **(12 Marks)**

This section will contain 5 Long Answer (LA) type of questions, each carrying 4 marks.
Students will have to attempt any 3 questions.

Distribution of Marks According to the Type of Questions

Type of Questions		
MCQ	1 Mark each	10 Marks
VSA	1 Mark each	8 Marks
SA - I	2 Marks each	16 Marks
SA - II	3 Marks each	24 Marks
LA	4 Marks each	12 Marks

Percentage wise distribution of marks	
Theory	63%
Numerical	37%

CONTENTS

[Reference: Maharashtra State Board of Secondary and Higher Secondary Education, Pune - 04**]**

Note:
1. * mark represents Textual question.
2. # mark represents Intext question.
3. + mark represents Textual examples.
4. symbol represents textual questions that need external reference for an answer.

1 Rotational Dynamics

Contents and Concepts

1.1 Introduction

Q.1. What is the difference between revolution and rotation of an object? [1 Mark]

Ans: During revolution, the object (every particle in the object) undergoes circular motion about some point outside the object or about some other object. During rotation, the motion is about an axis of rotation passing through the object.

1.2 Characteristics of Circular Motion

Q.2. Can you recall? *(Textbook page no. 1)*
What is circular motion? **[1 Mark]**

Ans: Motion of an object around a circular path is called as circular motion.

Q.3. State the characteristics of circular motion. [2 Marks]

Ans:

i. **Accelerated motion:** As the direction of velocity changes at every instant, it is an accelerated motion.

ii. **Periodic motion:** During the motion, the particle repeats its path along the same trajectory. Thus, the motion is periodic.

Q.4. State the analogy of the following linear and rotational quantities:
i. Displacement ii. Velocity
iii. Acceleration [3 Marks]

Ans:

Quantity	Linear	Rotational
Displacement	$\vec{s}$	$\vec{\theta}$
Velocity	$\vec{v} = \frac{d\vec{s}}{dt}$	$\vec{\omega} = \frac{d\vec{\theta}}{dt}$
Acceleration	$\vec{a} = \frac{d\vec{v}}{dt}$	$\vec{\alpha} = \frac{d\vec{\omega}}{dt}$

Q.5. State the expression for tangential velocity (in vector form) when a body is performing circular motion. Also, express it in its magnitude. [1 Mark]

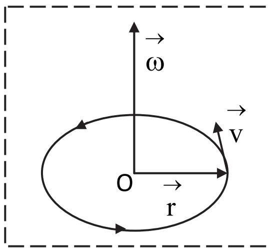
Ans:

i. In vector form, tangential velocity is given by,
$\vec{v} = \vec{\omega} \times \vec{r}$

ii. The magnitude of $\vec{v}$ is given by, $v = \omega r$

Reading between the lines

Tangential velocity describes the motion of an object along the edge of the circle whose direction at any given point on the circle is always along the tangent to that point.



Here, $\vec{v}$ *= tangential velocity,*
$\vec{\omega}$ *= angular velocity,*
$\vec{r}$ *= position vector (radius vector from the centre of circular motion)*

Page no. **2** to **7** are purposely left blank.

To see complete chapter buy **Target Notes** or **Target E-Notes**

iv. In order to continue the horizontal motion, force of static friction f_s should be always less than or equal to $\mu_s N$.

$\therefore$ $f_s \le \mu_s N$

$\therefore$ $mg \le \mu_s \left(\frac{mv^2}{r}\right)$ …[From equation (1) and (2)]

$\therefore$ $g \le \frac{\mu_s v^2}{r} \Rightarrow v^2 \ge \frac{rg}{\mu_s}$

$\therefore$ The minimum safest velocity of a body to move in well of death is, $v_{min} = \sqrt{\frac{rg}{\mu_s}}$

Scan the given Q. R. Code in *Quill - The Padhai App* to get conceptual clarity about well of death with the aid of a linked video.

Q.27. Explain the concept of lower limit and upper limit on the turning speed. [2 Marks]

Ans:

i. If a road is banked at 90°, it imposes a lower limit on the turning speed.

ii. For an unbanked road (banking angle θ = 0°), there is an upper limit for the turning speed.

iii. It means that for any other banking angle (0°< θ < 90°), the turning speed will have the upper as well as the lower limit.

***Q.28. Why are curved roads banked? [2 Marks]**

Ans:

i. While taking a turn on a horizontal road, the force of static friction between the tyres of the vehicle and the road provides the necessary centripetal force (or balances the centrifugal force).

ii. However, the frictional force is having an upper limit. Also, its value is usually not constant as the road surface is not uniform.

iii. Thus, in real life, we should not depend upon it, as it is not reliable.

iv. For this purpose, the surfaces of curved roads are tilted with the horizontal with some angle θ.

v. This is called banking of a road or the road is said to be banked.

vi. When the road is banked, the horizontal component of the normal reaction provides the necessary centripetal force required for circular motion of vehicle.

***Q.29. Do we need a banked road for a two-wheeler? Explain. [3 Marks]**

Ans:

i. When a two-wheeler takes a turn along unbanked road, frictional force provides centripetal force.

ii. The rider makes vehicle lean inward to balance a torque that can cause vehicle to topple outward.

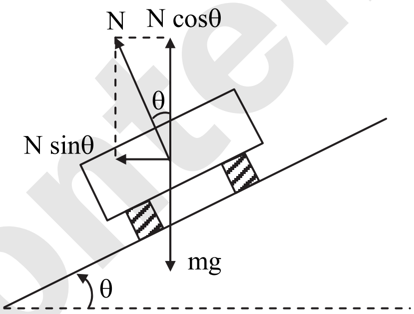
iii. Since friction cannot be relied upon to provide required centripetal force on all road conditions and causes wear and tear of tyres, we need a banked road for a two-wheeler.

iv. Having a banked road allows a vehicle to turn independent of frictional force without damaging the tyres.

Q.30. Derive expression for angle of banking when a vehicle (consider to be a point) moves along a curved banked road neglecting friction. [3 Marks]

Ans:

i. The vertical section of a vehicle on a curved road of radius ‘r’ banked at an angle ‘θ’ with the horizontal is shown in the figure.



ii. Considering the vehicle to be a point and ignoring friction (not eliminating) and other non-conservative forces like air resistance, there are two forces acting on the vehicle:
   a. weight (mg), vertically downwards
   b. normal reaction (N), perpendicular to the surface of the road.

iii. As the motion of the vehicle is along a horizontal circle, the resultant force must be horizontal and directed towards the centre of the track. Hence, the vertical force mg must be balanced.

iv. Thus, normal reaction (N) is resolved into,
   a. N sin θ - along the horizontal.
   b. N cos θ - along the vertical.

v. The vertical component N cosθ balances the weight i.e., $N\cos\theta = mg$ ….(1)

vi. Horizontal component Nsinθ being the resultant force, must be the necessary centripetal force (or balance the centrifugal force).

$\therefore$ $N \sin\theta = \frac{mv^2}{r}$ ….(2)

Dividing equation (2) by equation(1),

$\tan\theta = \frac{v^2}{rg}$

$\therefore$ $\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$

This is an expression for angle of banking when a vehicle moves along a curved banked road neglecting friction.

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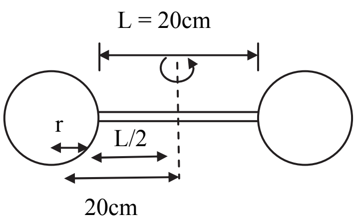
To see complete chapter buy **Target Notes** or **Target E-Notes**

***Q.92. A big dumb-bell is prepared by using a uniform rod of mass 60 g and length 20 cm. Two identical solid thermocol spheres of mass 25 g and radius 10 cm each are at the two ends of the rod. Calculate moment of inertia of the dumb-bell when rotated about an axis passing through its centre and perpendicular to the length. [3 Marks]**

Solution:

Mass of rod, M = 60 g,
Length of rod, L = 20 cm,
Mass of solid sphere, m = 25 g,
Radius of sphere, r = 10 cm



Moment of Inertia of the system = Moment of Inertia of rod (about its perpendicular bisector) + Moment of Inertia of two spheres

$$= \frac{ML^2}{12} + 2\left[\frac{2}{5}mr^2 + m \times \left(r + \frac{L}{2}\right)^2\right]$$

$$= 60 \times \frac{(20)^2}{12} + 2\left[\frac{2}{5} \times 25 \times (10)^2 + 25 \times (10 + 10)^2\right]$$

$= 2000 + 22000 =$ **24000 gcm^2**

Ans: Moment of inertia of the dumb-bell when rotated about an axis passing through its centre and perpendicular to the length is **24000 gcm^2.**

Q.93. A uniform solid sphere has radius 0.2 m and density 8 × 10^3 kg/m^3. Find the moment of inertia about the tangent to its surface. (π = 3.142) [2 Marks] [July 17]

Solution:

Given: R = 0.2m, ρ = 8000 Kg/m^3

To find: Moment of inertia (I)

Formulae: i. $I_o = \frac{7}{5}MR^2$

ii. Mass (M) = volume × density

Calculation: From formula (ii),

$$M = V\rho = \left(\frac{4}{3}\pi R^3\right)\rho$$

From formula (i),

$$I = \frac{7}{5}\left(\frac{4}{3}\pi R^3\rho\right)R^2$$

$$= \frac{28}{15}\pi R^5\rho$$

$$= \frac{28}{15} \times 3.142 \times (2 \times 10^{-1})^5 \times 8000$$

∴ I = **15.02 kg m^2**

Ans: M.I. of the uniform solid sphere about a tangent to its surface is **15.02 kg m^2.**

1.8 Angular Momentum or Moment of Linear Momentum

Q.94. Explain the analogous of angular momentum in rotational motion to linear momentum in translational motion. [2 Marks]

Ans:

i. The quantity in rotational mechanics, analogous to linear momentum is angular momentum or moment of linear momentum.

ii. It is similar to the torque being moment of a force.

iii. If $\vec{p}$ is the instantaneous linear momentum of a particle undertaking a circular motion, its angular momentum at that instance is given by $\vec{L} = \vec{r} \times \vec{p}$, where $\vec{r}$ is the position vector from the axis of rotation.

iv. In magnitude, it is the product of linear momentum and its perpendicular distance from the axis of rotation.

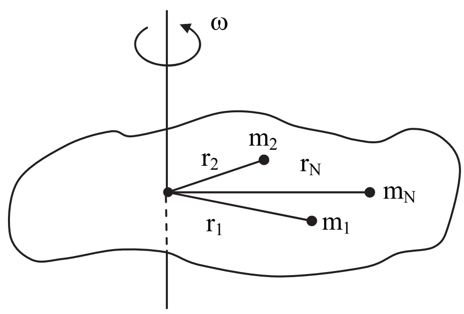
∴ L = P × r sinθ

Where θ is the smaller angle between the directions of $\vec{P}$ and $\vec{r}$.

v. The expression for angular momentum, L = Iω is analogous to the expression, p = mv of linear momentum, if the moment of inertia I replaces mass, which is its physical significance.

***Q.95. Derive an expression that relates angular momentum with the angular velocity of a rigid body. [3 Marks]**

Ans:



A body of N particles

i. Consider a rigid object rotating with a constant angular speed 'ω' about an axis perpendicular to the plane of paper.

ii. Let us consider the object to be consisting of N number of particles of masses m_1, m_2, …..m_N at respective perpendicular distances r_1, r_2, …..r_N from the axis of rotation.

iii. As the object rotates, all these particles perform UCM with same angular speed ω, but with different linear speeds $v_1 = r_1\,\omega$, $v_2 = r_2\,\omega$, ...$v_N = r_N\,\omega$.

iv. Directions of individual velocities $\vec{v}_1$, $\vec{v}_2$, ….. $\vec{v}_N$, are along the tangents to the irrespective tracks.

v. Linear momentum of thefirst particle is of magnitude $p_1 = m_1v_1 = m_1r_1\omega$.Its direction is along that of $\vec{v}_1$.

vi. Its angular momentum is thus of magnitude $L_1 = p_1r_1 = m_1\,r_1^2\,\omega$

vii. Similarly, $L_2 = m_1\,r_2^2\,\omega$, $L_3 = m_3\,r_3^2\,\omega$,…., $L_N = m_N\,r_N^2\,\omega$.

viii. For a rigid body with a fixed axis of rotation, all these angular momenta are directed along the axis of rotation, and this direction can be obtained by using right hand thumb rule.

ix. As all of them have the same direction, their magnitudes can be algebraically added.

x. Thus, magnitude of angular momentum of the body is given by

$$L = m_1\,r_1^2\,\omega + m_1\,r_2^2\,\omega + …. + m_N\,r_N^2\,\omega$$

$$= \left(m_1r_1^2 + m_2r_2^2 + ... + m_Nr_N^2\right)\omega = I\omega$$

where, $I = m_1r_1^2 + m_2r_2^2 + ... + m_Nr_N^2$ is the moment of inertia of the body about the given axis of rotation.

Solved Examples

Q.96. Energy of 1000 J is spent to increase the angular speed of a wheel from 20 rad/s to 30 rad/s. Calculate the moment of inertia of the wheel. [2 Marks][Feb 20]

Solution:

Given: $n_1 = 20$ r.p.s,
$n_2 = 30$ r.p.s,
$\Delta E = 1000$ J

To find: Moment of inertia (I)

Formula: $K.E = \dfrac{1}{2}I\omega^2$

Calculation: From formula,

$$(K.E)_1 = \frac{1}{2} \times I \times \left(2\pi n_1\right)^2$$

$$= 2\pi^2\,n_1^2\,I$$

Similarly,

$$(K.E)_2 = 2\pi^2\,n_2^2\,I$$

$$\Delta E = (K.E)_2 - (K.E)_1$$

$$= (2\pi^2\,n_2^2 - 2\pi^2\,n_1^2)\ I$$

$$\therefore \quad \Delta E = 2\,\pi^2\left(n_2^2 - n_1^2\right)I$$

$$\therefore \quad I = \frac{\Delta E}{2\pi^2\left[n_2^2 - n_1^2\right]}$$

$$= \frac{1000}{2(3.142)^2\left[(30)^2 - (20)^2\right]}$$

$$\therefore \quad I = \mathbf{0.1013\ kg\ m^2}$$

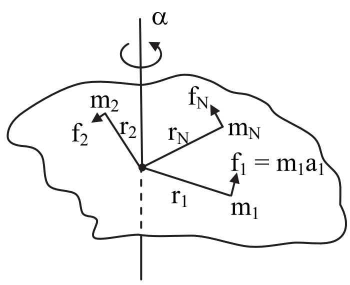
Ans: The moment of inertia of the wheel is **0.1013 kg m²**.

1.9 Expression for Torque in Terms of Moment of Inertia

***Q.97. Obtain an expression relating the torque with angular acceleration for a rigid body. [3 Marks]**

Ans:

i. Consider a rigid object rotating with a constant angular acceleration 'α' about an axis perpendicular to the plane of paper.



A body of N particles

ii. Let us consider the object to be consisting of N number of particles of masses m_1, m_2,…..m_N at respective perpendicular distances r_1, r_2,…..r_N from the axis of rotation.

iii. As the object rotates, all these particles perform circular motion with same angular acceleration α, but with different linear (tangential) accelerations, $a_1 = r_1\alpha$, $a_2 = r_2\alpha$,….,$a_N = r_N\alpha$,etc.

iv. Force experienced by the first particle is, $f_1 = m_1a_1 = m_1r_1\alpha$

v. As these forces are tangential, the irrespective perpendicular distances from the axis are r_1, r_2, …..r_N.

vi. Thus, the torque experienced by the first particle is of magnitude $\tau_1 = f_1r_1 = m_1r_1^2\alpha$

Similarly,$\tau_2 = m_2r_2^2\alpha$, $\tau_3 = m_3r_3^2\alpha$ ….$\tau_N = m_Nr_N^2\alpha$

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To see complete chapter buy **Target Notes** or **Target E-Notes**

Quick Review

Rotational Dynamics

Rotational Motion

Physical quantities

- $I = \sum mr^2$
- K.E. $= \frac{1}{2} I\omega^2$
- $\tau = I\alpha$
- $L = I\omega$
- $K = \sqrt{\frac{I}{M}}$

Parallel axes theorem

Statement: The moment of inertia (I_o) of an object about any axis is the sum of its moment of inertia (I_C) about an axis parallel to the given axis, and passing through the centre of mass and the product of the mass of the object and the square of the distance between the two axes,

$I_o = I_c + Mh^2$

Perpendicular axes theorem

Statement: The moment of inertia (I_z) of a laminar object about an axis (z) perpendicular to its plane is the sum of its moment of inertias about two mutually perpendicular axes (x and y) in its plane, all the three axes being concurrent, $I_z = I_x + I_y$

Rolling motion

Total energy, $E = \frac{1}{2}Mv^2\left(1 + \frac{K^2}{R^2}\right)$

Velocity, $v = \sqrt{\frac{2gh}{\left(1 + \frac{K^2}{R^2}\right)}}$

Acceleration, $a = \frac{g\sin\theta}{\left(1 + \frac{K^2}{R^2}\right)}$

Useful values:

$\left(\frac{K^2}{R^2}\right)_{\text{Solid sphere}} = \frac{2}{5}$; $\left(\frac{K^2}{R^2}\right)_{\text{hollow cylinder}} = 1,$

$\left(\frac{K^2}{R^2}\right)_{\text{Solid Cylinder}} = \frac{1}{2}$; $\left(\frac{K^2}{R^2}\right)_{\text{hollow sphere}} = \frac{2}{3}$

Circular Motion

Uniform Circular Motion

Centripetal force

Centripetal force is directed along the radius towards the centre of a circle.

In vector form, it is given by

$\vec{F} = -\frac{mv^2}{r}\hat{r}_0$

Centrifugal force

Centrifugal force is directed along the radius away from the centre of a circle.

In vector form, it is given by, $\vec{F} = +\frac{mv^2}{r}\hat{r}_0$

Banking of road

Unbanked road

Maximum possible speed,

$v_{max} = \sqrt{\mu_s rg}$

Rider should bend through an angle, $\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$.

Minimum safest velocity of a body for move in well of death, $v_{min} = \sqrt{\frac{rg}{\mu_s}}$

Banked road

Angle of banking: $\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$

Most safe speed, $v_s = \sqrt{rg\tan\theta}$

$v_{min} = \sqrt{rg\left(\frac{\tan\theta - \mu_s}{1 + \mu_s\tan\theta}\right)}$; $v_{max} = \sqrt{rg\left(\frac{\tan\theta + \mu_s}{1 - \mu_s\tan\theta}\right)}$

Conical Pendulum

Angular frequency,

$\omega = \sqrt{\frac{g}{L\cos\theta}}$

Time Period,

$T = 2\pi\sqrt{\frac{L\cos\theta}{g}}$

Frequency,

$n = \frac{1}{2\pi}\sqrt{\frac{g}{L\cos\theta}}$

Vertical Circular Motion

At lowest point:

$v_L = \sqrt{5rg}$

$T_L = \frac{mv_L^2}{r} + mg$

At highest point:

$v_H = \sqrt{rg}$

$T_H = \frac{mv_H^2}{r} - mg$

At midway point:

$v_M = \sqrt{3rg}$

Difference between tension at lower most and uppermost point: $T_L - T_H = 6$ mg

Important Formulae

1. In U.C.M angular velocity:

i. $\omega = \frac{v}{r}$ ii. $\omega = \frac{\theta}{t}$

iii. $\omega = 2\pi n$ iv. $\omega = \frac{2\pi}{T}$

2. Angular displacement:

i. $\theta = \omega t$ ii. $\theta = \frac{2\pi t}{T}$

iii. $\theta = 2\pi nt$

3. Angular acceleration:

i. $\alpha = \frac{\omega_2 - \omega_1}{t}$ ii. $\alpha = \frac{2\pi}{t}(n_2 - n_1)$

4. Linear velocity:

i. $v = r\omega$ ii. $v = 2\pi nr$

5. Centripetal acceleration or radial acceleration: $a = \frac{v^2}{r} = \omega^2 r$

6. Tangential acceleration: $\vec{a}_T = \vec{\alpha} \times \vec{r}$

7. Centripetal force:

i. $F_{CP} = \frac{mv^2}{r}$ ii. $F_{CP} = mr\omega^2$

iii. $F_{CP} = 4\pi^2 mrn^2$ iv. $F_{CP} = \frac{4\pi^2 mr}{T^2}$

v. $F_{CP} = \mu mg = m\omega^2 r$

8. Centrifugal force: $F_{CF} = -F_{CP}$

9. Inclination of banked road: $\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$

10. On unbanked road:

i. Maximum velocity of vehicle to avoid skidding on a curve unbanked road: $v_{max} = \sqrt{\mu rg}$

ii. Angle of leaning: $\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$

11. On banked road:

i. Upper speed limit: $v_{max} = \sqrt{rg\left[\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right]}$

ii. Lower speed limit: $v_{min} = \sqrt{rg\left[\frac{\tan\theta - \mu_s}{1 + \mu_s \tan\theta}\right]}$

iii. $v_{max} = \sqrt{rg\tan\theta}$ (in absence of friction)

12. Height of inclined road: $h = l \sin\theta$

13. Conical Pendulum:

i. Angular velocity of the bob of conical pendulum, $\omega = \sqrt{\frac{g}{L\cos\theta}}$

ii. Period of conical pendulum, $T = 2\pi\sqrt{\frac{L\cos\theta}{g}}$

14. For mass tied to string:

i. Minimum velocity at lowest point to complete V.C.M: $v_L = \sqrt{5rg}$

ii. Minimum velocity at highest point to complete V.C.M: $v_H = \sqrt{rg}$

iii. Minimum velocity at midway point to complete in V.C.M: $v_M = \sqrt{3rg}$

iv. Tension at highest point in V.C.M:

$T_H = \frac{mv_H^2}{r} - mg$

v. Tension at midway point in V.C.M: $T_M = \frac{mv_m^2}{r}$

vi. Tension at lowest point in V.C.M:

$T_L = \frac{mv_L^2}{r} + mg$

vii. Difference between tension at lower most and uppermost point: $T_L - T_H = 6\,mg$

15. Moment of Inertia: $I = \sum_{i=1}^{n} m_i r_i^2 = \int dmr^2$

16. Radius of gyration: $K = \sqrt{\frac{I}{M}}$

17. Kinetic energy:

i. $K.E = \frac{1}{2}I\omega^2 = \frac{1}{2}I(2\pi n)^2$

ii. $K.E_{translational} = \frac{1}{2}Mv^2$

iii. $K.E_{rolling} = \frac{1}{2}[Mv^2 + I\omega^2] = \frac{1}{2}Mv^2\left[1 + \frac{K^2}{R^2}\right]$

18. Velocity of rolling body: $v = \sqrt{\frac{2gh}{1 + \frac{K^2}{R^2}}}$

19. Acceleration of rolling body: $a = \frac{g\sin\theta}{1 + \frac{K^2}{R^2}}$

20. Torque acting on a body:

i. $\tau = I\alpha = \frac{dL}{dt}$ ii. $\tau = I\frac{d\omega}{dt} = 2\pi I\left(\frac{n_2 - n_1}{t}\right)$

21. Angular momentum of a body: $L = I\omega = I(2\pi n)$

22. From principle of perpendicular axes:

$I_Z = I_X + I_Y$

23. From principle of parallel axes: $I_o = I_c + Mh^2$

24. From principle of conservation of angular momentum:

i. $I_1\omega_1 = I_2\omega_2$ ii. $I_1 n_1 = I_2 n_2$

Analogs of kinematical equations of linear and rotational motion:

Equation for translational motion	Analogous equation for rotational motion
$v_{av} = \dfrac{u+v}{2}$	$\omega_{av} = \dfrac{\omega_0 + \omega}{2}$
$a = \dfrac{dv}{dt} = \dfrac{v-u}{t}$ $\therefore\ v = u + at$	$\alpha = \dfrac{d\omega}{dt} = \dfrac{\omega - \omega_0}{t}$ $\therefore\ \omega = \omega_0 + \alpha t$
$s = v_{av} \cdot t = \left(\dfrac{u+v}{2}\right)t = ut + \dfrac{1}{2}at^2$	$\theta = \omega_{av} \cdot t = \left(\dfrac{\omega_0 + \omega}{2}\right)t = \omega_0 t + \dfrac{1}{2}at^2$
$v^2 = u^2 + 2as$	$\omega^2 = \omega_0^2 + 2\alpha\theta$

Analogs of linear and rotation motion:

Translational motion		Rotational motion		
Quantity	Symbol/expression	Quantity	Symbol/expression	Inter-relation, if possible
Linear displacement	$\vec{s}$	Angular displacement	$\vec{\theta}$	$\vec{s} = \vec{\theta} \times \vec{r}$
Linear velocity	$\vec{v} = \dfrac{d\vec{s}}{dt}$	Angular velocity	$\vec{\omega} = \dfrac{d\vec{\theta}}{dt}$	$\vec{v} = \vec{\omega} \times \vec{r}$
Linear acceleration	$\vec{a} = \dfrac{d\vec{v}}{dt}$	Angular acceleration	$\vec{\alpha} = \dfrac{d\vec{\omega}}{dt}$	$\vec{\alpha} = \vec{\alpha} \times \vec{r}$
Inertia or mass	m	Rotational inertia or moment of inertia	I	$I = \int r^2 dm = \sum m_i r_i^2$
Linear momentum	$\vec{p} = m\vec{v}$	Angular momentum	$\vec{L} = I\vec{\omega}$	$\vec{L} = \vec{r} \times \vec{p}$
Force	$\vec{f} = \dfrac{d\vec{p}}{dt}$	Torque	$\vec{\tau} = \dfrac{d\vec{L}}{dt}$	$\vec{\tau} = \vec{r} \times \vec{f}$
Work	$W = \vec{f} \cdot \vec{s}$	Work	$W = \vec{\tau} \cdot \vec{\theta}$	-
Power	$P = \dfrac{dW}{dt} = \vec{f} \cdot \vec{v}$	Power	$P = \dfrac{dW}{dt} = \vec{\tau} \cdot \vec{\omega}$	-

M.I. of different bodies with different axis of rotation:

No.	Shape of regular body	Axis of rotation	Moment of Inertia
i.	Rod of mass M and length L (thin rod)	Centre of rod and perpendicular to length.	$\dfrac{ML^2}{12}$
		One end and perpendicular to length.	$\dfrac{ML^2}{3}$
ii.	Circular ring of mass M and radius R	Line passing through its centre and perpendicular to its plane.	MR^2
		Any diameter.	$\dfrac{1}{2}MR^2$
		Any tangent in the plane of the ring.	$\dfrac{3}{2}MR^2$
		Any tangent perpendicular to the plane of the ring.	$2\ MR^2$
iii.	Circular disc of mass M and radius R	Through centre, perpendicular to plane of disc.	$\dfrac{1}{2}MR^2$
		Any diameter.	$\dfrac{1}{4}MR^2$
		Tangent in the plane of the disc.	$\dfrac{5}{4}MR^2$
		Tangent perpendicular to plane of disc.	$\dfrac{3}{2}MR^2$

iv.	Solid sphere of mass M and radius R	Any diameter.	$\frac{2}{5}MR^2$
		Any tangent.	$\frac{7}{5}MR^2$
v.	Hollow sphere of mass M and radius R	Any diameter	$\frac{2}{3}MR^2$
vi.	Solid cylinder of mass M, radius R and length L	Axis passing through its centre and parallel to its length.	$\frac{1}{2}MR^2$
		Through centre perpendicular to length.	$M\left(\frac{R^2}{4}+\frac{L^2}{12}\right)$
vii.	Hollow cylinder of mass M, radius R	Axis passing through its centre and parallel to its length	MR^2
viii.	Annular ring or thick walled hollow cylinder	Axis passing through its centre and perpendicular to its plane	$I = \frac{1}{2}M\left(r_2^2 + r_1^2\right)$
ix.	Uniform symmetric spherical shell	Any diameter	$I = \frac{2}{5}M\frac{\left(r_2^5 - r_1^5\right)}{\left(r_2^3 - r_1^3\right)}$
x.	Uniform plate or rectangular parallelepiped	Axis passing through its centre of the side and perpendicular to its plane	$I = \frac{1}{12}M(L^2 + b^2)$

Exercise

1.2 Characteristics of Circular Motion

1. Mention characteristics of circular motion. **[2 Marks]**

Ans: *Refer Q.3.*

2. Explain right hand thumb rule. **[1 Mark]**

Ans: *Refer Q.6*

3. With the help of an example, explain the term uniform circular motion. **[2 Marks]**

Ans: *Refer Q.8*

4. Difference between centripetal force and centrifugal force. **[2 Marks]**

Ans: *Refer Q.14*

5. A body of mass 1 kg is tied to a string and revolved in a horizontal circle of radius 1 m. Calculate the maximum number of revolutions per minute, so that the string does not break. Breaking tension of the string is 9.86 N. **[2 Marks]**

Ans: 30

6. A 0.5 kg mass is rotated in a horizontal circle of radius 20 cm. Calculate the centripetal force acting on it, if its angular speed of rotation is 0.6 rad/s. **[2 Marks]**

Ans: 0.036 N

7. A string breaks under a tension of 10 kg-wt. If the string is used to revolve a body of mass 12 g in a horizontal circle of radius 50 cm, what is the frequency of revolution and linear speed with which the body can be revolved? [$g = 9.8\ m/s^2$] **[3 Marks]**

Ans: 20.34 rev/s, 63.95 m/s

8. An object of mass 2 kg attached to wire of length 5 m is revolved in a horizontal circle. If it makes 60 r.p.m. Find its
   i. angular speed ii. linear speed
   iii. centripetal acceleration
   iv. centripetal force **[3 Marks]**

Ans: i. 6.28 rad/s ii. 31.4 m/s
iii. 197.192 m/s^2 iv. 394.384 N

1.3 Applications of Uniform Circular Motion

9. Obtain an expression for maximum possible speed for a vehicle to move on horizontal unbanked road. **[3 Marks]**

Ans: *Refer Q.22*

10. Derive an expression for angle at which the two wheeler rider has to lean with the vertical while driving along an unbanked circular road. **[3 Marks]**

Ans: *Refer Q.23*

11. Describe well of death. **[1 Mark]**

Ans: *Refer Q.25*

12. Obtain an expression for minimum safest velocity of a body to move in well of death. **[2 Marks]**

Ans: *Refer Q.26*

13. Obtain an expression for angle of banking when a vehicle moves along a curved banked road. **[2 Marks]**

Ans: *Refer Q.30*

14. Obtain an expression for lower and upper speed limit for a vehicle moving on a banked road. **[4 Marks]**

Ans: *Refer Q.32*

15. If friction is made zero for a road, can a vehicle move safely on this road? **[1 Mark] [Feb 23]**

Ans: *Refer Q.33 (i)*

16. Define the following terms.
i. Simple pendulum ii. Conical pendulum **[2 Marks]**

Ans: *Refer Q.34(i and ii)*

17. Obtain an expression for time period of a conical pendulum. **[4 Marks]**

Ans: *Refer Q.35*

18. State the factors on which frequency of a conical pendulum depends? **[2 Marks]**

Ans: *Refer Q.36*

19. Can a string become horizontal during revolutions in conical pendulum? Explain. **[2 Marks]**

Ans: *Refer Q.38*

20. With what maximum speed a car be safely driven along a curve of radius 40 m on a horizontal road, if the coefficient of friction between the car tyres and road surface is 0.3? [$g = 9.8\ m/s^2$] **[2 Marks]**

Ans: 10.84 m/s

21. Find the angle of banking of a railway track of radius of curvature 250 m, if the optimum velocity of the train is 90 km/hr. Also find the elevation of the outer track over the inner track if the two tracks are 1.6 m apart. **[3 Marks]**

Ans: $14°19'$, 0.3955 m

22. A stone of mass one kilogram is tied to the end of a string of length 5 m and whirled in a vertical circle. What will be the minimum speed required at the lowest position to complete the circle? [Given: $g = 9.8\ m/s^2$] **[2 Marks]**

Ans: 15.65 m/s

23. A flat curve on a highway has a radius of curvature 400 m. A car goes around a curve at a speed of 32 m/s. What is the minimum value of coefficient of friction that will prevent the car from sliding? ($g = 9.8\ m/s^2$) **[1 Mark]**

Ans. 0.26

1.4 Vertical Circular Motion

24. A particle of mass m, just completes the vertical circular motion. Derive the expression for the difference in tensions at the highest and the lowest points. **[4 Marks] [Mar 13]**

Ans: *Refer Q.53*

25. Obtain an expression for upper limit on the speed when vehicle is at the top of a convex overbridge. **[2 Marks]**

Ans: *Refer Q.60*

1.5 Moment of Inertia as an Analogous Quantity for Mass

26. Give the physical significance of moment of inertia. **[2 Marks]**

Ans: *Refer Q.69*

27. Obtain an expression for moment of inertia of a uniform disc about an axis passing through centre and perpendicular to the plane. **[2 Marks]**

Ans: *Refer Q.72*

28. Calculate the moment of inertia of a uniform disc of mass 10 kg and radius 60 cm about an axis perpendicular to its length and passing through its centre. **[1 Mark] [Mar 22]**

Ans: $I = \frac{1}{2}MR^2 = \frac{1}{2} \times 10 \times (0.6)^2 = 5 \times 0.36 = \mathbf{1.8\ kg\ m^2}$

1.6 Radius of Gyration

29. Define radius of gyration and give its physical significance. **[2 Marks] [Oct 13; July 18; Mar 19]**

Ans: *Refer Q.77(ii) and Q.75*

1.7 Theorem of Parallel Axes and Theorem of Perpendicular Axes

30. State and prove theorem of parallel axes. **[4 Marks] [Mar 14, 16, 20; July 23]**

Ans: *Refer Q.81*

31. State and prove theorem of perpendicular axes about moment of inertia. **[4 Marks]**

Ans: *Refer Q.83*

32. M.I of a solid sphere about its diameter is 25 kg m^2. Find its M.I. about a tangent. **[2 Marks]**

Ans: 87.5 kg m^2

33. The moment of inertia of a disc about an axis passing through its centre and perpendicular to its plane is 20 kg m^2. Determine its moment of inertia about an axis
i. coinciding with a tangent perpendicular to its plane.
ii. passing through a point midway between the centre and a point on the circumference, perpendicular to its plane. **[3 Marks]**

Ans: i. 60 kg m^2 ii. 30 kg m^2

1.8 Angular Momentum or Moment of Linear Momentum

34. Obtain an expression that relates angular momentum with the angular velocity of a rigid body. **[2 Marks]**

Ans: *Refer Q.95*

1.9 Expression for Torque in Terms of Moment of Inertia

35. Derive an expression for torque acting on a body rotating with uniform angular acceleration. **[3 Marks] [July 16]**

Ans: *Refer Q.97*

1.10 Conservation of Angular Momentum

36. State law of conservation of angular momentum. **[1 Mark] [July 22]**

Ans: *Refer Q.99 (Statement only)*

37. State and prove: law of conservation of angular momentum. **[3 Marks] [Oct 15]**

OR

State and prove principle of conservation of angular momentum. **[2 Marks] [Feb 23]**

Ans: *Refer Q.99*

38. An automobile engine develops 62.84kW while rotating at a speed of 1200 rpm. What torque does it deliver? **[1 Mark] [July 22]**

Ans: $\tau = \frac{P}{\omega} = \frac{P}{2\pi n} = \frac{62.84\ \text{kW}}{2 \times 3.142 \times (1200\ \text{rpm})}$

$$= \frac{62840\ \text{W}}{2 \times 3.142 \times (1200/60)\text{rps}} \approx 500\ \text{Nm}$$

39. The angular momentum of a body changes by 80 kg m^2/s. When its angular velocity changes from 20 rad/s to 40 rad/s, find the change in K.E of rotation. **[2 Marks]**

Ans: 2400 J

1.11 Rolling Motion

40. Obtain an expression for total kinetic energy of a rolling body in the form $\frac{1}{2}MV^2\left[1+\frac{K^2}{R^2}\right]$. **[2 Marks] [Mar 16]**

Ans: *Refer Q.106*

41. Obtain expressions for the acceleration of a rigid body along the an incline and the speed after falling through a certain vertical distance. **[3 Marks]**

Ans: *Refer Q.109*

Multiple Choice Questions

[1 Mark Each]

*1. When seen from below, the blades of a ceiling fan are seen to be revolving anticlockwise and their speed is decreasing. Select correct statement about the directions of its angular velocity and angular acceleration.
(A) Angular velocity upwards, angular acceleration downwards.
(B) Angular velocity downwards, angular acceleration upwards.
(C) Both, angular velocity and angular acceleration, upwards.
(D) Both, angular velocity and angular acceleration, downwards.

2. The bulging of earth at the equator and flattening at the poles is due to _______.
(A) centripetal force
(B) centrifugal force
(C) gravitational force
(D) electrostatic force

3. If a cycle wheel of radius 0.4 m completes one revolution in 2 seconds, then acceleration of the cycle is _______ m/s^2.
(A) $0.4\ \pi$ (B) $0.4\ \pi^2$
(C) $\frac{\pi^2}{0.4}$ (D) $\frac{0.4}{\pi^2}$

4. In rotational motion of a rigid body, all particles move with ______. **[Feb 20]**
(A) same linear velocity and same angular velocity
(B) same linear velocity and different angular velocity
(C) different linear velocities and same angular velocities
(D) different linear velocities and different angular velocities

*5. A particle of mass 1 kg, tied to a long string is whirled to perform vertical circular motion, under gravity. Minimum speed of a particle is 5 m/s. Consider following statements.
i. Maximum speed must be $5\sqrt{5}$ m/s.
ii. Difference between maximum and minimum tensions along the string is 60 N.
Select correct option.
(A) Only the statement (i) is correct.
(B) Only the statement (ii) is correct.
(C) Both the statements are correct.
(D) Both the statements are incorrect.

*[**Note:** Question has been modified to get the required answer.]*

6. The minimum velocity (in m s^{-1}) with which a car driver must traverse a flat curve of radius 150 m and coefficient of friction 0.6 to avoid skidding is ($g = 10\ m/s^2$)
(A) 60 (B) 30
(C) 15 (D) 25

7. Maximum safe speed does not depend on
(A) mass of the vehicle.
(B) radius of curvature.
(C) angle of inclination (banking).
(D) acceleration due to gravity.

8. A 500 kg car takes a round turn of radius 50 m with a speed of 36 km/hr. The centripetal force acting on the car will be
(A) 1200 N (B) 1000 N
(C) 750 N (D) 250 N

9. The radius of gyration of a solid sphere of radius r about a certain axis is r. The distance of this axis from the centre of the sphere is _____ r
(A) 0.6 (B) 0.5
(C) $\sqrt{0.5}$ (D) $\sqrt{0.6}$

10. Rotational K.E of a body is 10 J. If the angular momentum vector coincides with the axis of rotation and its M.I about this axis is 5 kgm^2 then its angular momentum is ______ SI units.
(A) 10 (B) 20
(C) 30 (D) 40

11. If the angular velocity of a body rotating about a given axis is doubled, then its rotational K.E
(A) is doubled.
(B) is halved.
(C) becomes four times.
(D) becomes one-fourth.

12. A sphere is rolling on a horizontal surface without slipping. The ratio of the rotational K.E to the total kinetic energy of sphere is
(A) 2/5 (B) 2/7
(C) 5/7 (D) 3/7

13. A body is acted upon by a constant torque. In 4 seconds its angular momentum changes from L to 4L. The magnitude of the torque is _______.
(A) $\frac{L}{4}$ (B) $\frac{3L}{4}$
(C) 3L (D) 12L

14. For a rolling hollow sphere, ratio of translational K.E: rotational K.E: total K.E is
(A) 3 : 2 : 5 (B) 1 : 2 : 5
(C) zero (D) 5 : 3 : 2

*15. Select correct statement about the formula (expression) of moment of inertia (M.I.) in terms of mass M of the object and some of its distance parameter/s, such as R, L, etc.
(A) Different objects must have different expressions for their M.I.
(B) When rotating about their central axis, a hollow right circular cone and a disc have the same expression for the M.I.
(C) Expression for the M.I. for a parallelopiped rotating about the transverse axis passing through its centre includes its depth.
(D) Expression for M.I. of a rod and that of a plane sheet is the same about a transverse axis.

16. The shaft of a motor rotates at a constant angular velocity of 3000 r.p.m. The radian it has turned through in one second is _______ π
(A) 1000 (B) 1
(C) 100 (D) 10

17. If 'L' is the angular momentum and 'I' is the moment of inertia of a rotating body, then $\frac{L^2}{2I}$ represents its
(A) rotational P.E.
(B) total energy
(C) rotational K.E.
(D) translational K.E.

18. A thin ring has mass 0.25 kg and radius 0.5 m. Its M.I. about an axis passing through its centre and perpendicular to its plane is _______. **[Mar 18]**
(A) 0.0625 kg m^2
(B) 0.625 kg m^2
(C) 6.25 kg m^2
(D) 62.5 kg m^2

19. The moment of inertia of a ring of mass 5 gram and radius 1 cm about an axis passing through its edge and parallel to its natural axis is
(A) 5 g cm^2 (B) 2.5 g cm^2
(C) 20 g cm^2 (D) 10 g cm^2

20. Angular momentum of two bodies of moment of inertia I_1 and I_2($I_1 > I_2$) is same. If E_1 and E_2 are rotational K.E, then
(A) $E_1 = E_2$ (B) $E_1 > E_2$
(C) $E_1 < E_2$ (D) $E_1 \geq E_2$

*21. In a certain unit, the radius of gyration of a uniform disc about its central and transverse axis is $\sqrt{2.5}$. Its radius of gyration about a tangent in its plane (in the same unit) must be
(A) $\sqrt{5}$ (B) 2.5
(C) $2\sqrt{2.5}$ (D) $\sqrt{12.5}$

*22. Consider following cases:
i. A planet revolving in an elliptical orbit.
ii. A planet revolving in a circular orbit. Principle of conservation of angular momentum comes in force in which of these?
(A) Only for (i)
(B) Only for (ii)
(C) For both, (i) and (ii)
(D) Neither for (i), nor for (ii)

*23. A thin walled hollow cylinder is rolling down an incline, without slipping. At any instant, the ratio "Rotational K.E.: Translational K.E.: Total K.E." is
(A) 1:1:2 (B) 1:2:3
(C) 1:1:1 (D) 2:1:3

24. When the bob performs a vertical circular motion and the string rotates in a vertical plane, the difference in the tension in the string at horizontal position and uppermost position is _______. **[Mar 22]**
(A) mg (B) 2mg
(C) 3mg (D) 6mg

25. A body performing uniform circular motion has constant _______. **[July 23]**
(A) velocity
(B) kinetic energy
(C) displacement
(D) acceleration

Answers to Multiple Choice Questions

1.	(B)	2.	(B)	3.	(B)	4.	(C)
5.	(C)	6.	(B)	7.	(A)	8.	(B)
9.	(D)	10.	(A)	11.	(C)	12.	(B)
13.	(B)	14.	(A)	15.	(B)	16.	(C)
17.	(C)	18.	(A)	19.	(D)	20.	(C)
21.	(B)	22.	(C)	23.	(A)	24.	(C)
25.	(B)						

Hints to Multiple Choice Questions

5. $v_{max} = \sqrt{5rg}$
$= \sqrt{5} \cdot \sqrt{rg} = 5\sqrt{5}$ ....(since, $v_{min} = \sqrt{rg}$)
$T_L - T_H = 6\text{ mg} = 6 \times 1 \times 10 = 60\text{ N}$

9. $K = \sqrt{\dfrac{I}{M}}$
Using theorem of parallel axes,
$I = I_o + Mh^2 = \dfrac{2}{5}Mr^2 + Mh^2$
$\therefore$ $r = \sqrt{\dfrac{M\left(\dfrac{2}{5}r^2 + h^2\right)}{M}}$
$\therefore$ $r^2 = \dfrac{2}{5}r^2 + h^2$
$\therefore$ $h = \dfrac{3}{5}r^2 \quad \Rightarrow h = \sqrt{\dfrac{3}{5}}\,r = \sqrt{0.6}\,r$

18. $I_c = MR^2 = 0.25 \times 0.5^2 = 0.0625\text{ kgm}^2$

21. **Case I:** $\dfrac{1}{2}MR^2 = MK_1^2$
$\therefore$ $K_1^2 = \dfrac{R^2}{2}$
Case II: $\dfrac{5}{4}MR^2 = M\,K_2^2$
$\dfrac{5}{4}M\left(2K_1^2\right) = MK_2^2$
$\therefore$ $K_2^2 = \dfrac{5}{2}K_1^2 = \dfrac{5}{2} \times 2.5 = 2.5 \times 2.5$
$\therefore$ $K_2 = 2.5\text{ m}$

23. For hollow cylinder, $\dfrac{K^2}{R^2} = 1$
$\therefore$ $\dfrac{K^2}{R^2} : 1 : \dfrac{1 + K^2}{R^2} = 1:1:2$

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