Last Name: _______________ First Name: _____________________ NetID: _________________

Discussion Section: ______ Discussion TA: ____________________________________________

Instructions – ***Turn off your cell phone and put it away. Please keep your calculator on your own desk. Calculators may not be shared.***

This is a closed book exam. You have (1.5) hours to complete it.

I. *Fill in ALL the information requested on the lines above and sign the Formula Sheet.*

II. At the end of this exam, you must return this Exam Booklet complete with all pages, including the formula sheet, along with your answer sheet.

III. If you do not turn in a complete Exam Booklet, including the formula sheet, your Answer Sheet will not be graded and you will receive the grade AB (Absent) for this exam. Kindly paper clip the Answer Sheet to the Exam Booklet.

1. Fill in the circle for each intended input (until there is no white space visible) – both on the identification side of your answer sheet and on the side on which you mark your answers. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers. Light marks or marks extending outside the circle may be read improperly by the scanner.
2. Print your last name in the **YOUR LAST NAME** boxes on your answer sheet and print the first letter of your first name in the **FIRST NAME INI** box. Mark (as described above) the corresponding circle below each of these letters.
3. Print your NetID in the **NETWORK ID** boxes, and then mark the corresponding circle below each of the letters or numerals. Note that there are different circles for the letter "I" and the numeral "1" and for the letter "O" and the numeral "0". **Do not** mark the hyphen circle at the bottom of any of these columns.
4. You may find the version of **this Exam Booklet at the top of page 2**. Mark the **version** circle in the **TEST FORM** box near the middle of your answer sheet. **DO THIS NOW!**
5. Stop **now** and double-check that you have bubbled in all the information requested in 2 through 4 above and that your marks meet the criteria in 1 above. Check that you do not have more than one circle marked in any of the columns.
6. Print your UIN# in the **STUDENT NUMBER** designated spaces and mark the corresponding circles. You need not write in or mark the circles in the SECTION box.
7. On the **SECTION** line, print your **DISCUSSION SECTION**. (You need not fill in the COURSE or INSTRUCTOR lines.)
8. Sign **(DO NOT PRINT)** your name on the **STUDENT SIGNATURE** line.

*CHECK NOW THAT YOU HAVE COMPLETED ALL OF THE ABOVE STEPS*

*Before starting work, check to make sure that your test booklet is complete. You should have* ***25*** *questions and a Formula Sheets at the end. Grading policy is explained on page 2.*

***Academic Integrity—Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including dismissal from the university.***

**This Exam Booklet is Version A.** Mark the **A** circle in the **TEST FORM** box near the middle of your answer sheet. **DO THIS NOW!**

*Exam Grading Policy—*

The exam is composed of three types of questions.

**MC5:** *multiple-choice-five-answer questions, each worth 6 points.* **Partial credit will be granted as follows.**

(a) If you mark only one answer and it is the correct answer, you earn **6** points.
(b) If you mark two answers, one of which is the correct answer, you earn **3** points.
(c) If you mark three answers, one of which is the correct answer, you earn **2** points.
(d) If you mark four answers, one of which is the correct answer, you earn **1.5** points.
(d) If you mark five answers, one of which is the correct answer, you earn **1.2** points

**MC3:** *multiple-choice-three-answer questions, each worth 3 points.* **Partial credit will be granted as follows.**

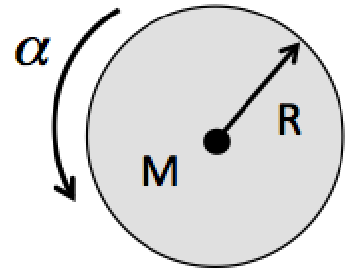
(a) If you mark only one answer and it is the correct answer, you earn **3** points.
(b) If you mark two answers, one of which is the correct answer, you earn **1.5** points.
(c) If you mark three answers, one of which is the correct answer, you earn **1** point.

**MC2:** *multiple-choice-three-answer questions, each worth 2 points.* **Partial credit will be granted as follows.**

(a) If you mark only one answer and it is the correct answer, you earn **2** points.
(b) If you mark two answers, one of which is the correct answer, you earn **1** point.

**The next three questions pertain to the situation described below.**

A wheel is made from a solid cylinder of mass $M = 3.1$ kg and radius $R = 1.1$ m. It can rotate without friction around a central axis (out of the page). The wheel is initially at rest and at $t = 0$ a constant torque $\tau$ is applied around the axis, causing the wheel to rotate with an angular acceleration $\alpha = 3.3$ rad/s$^2$.




1) What is the magnitude of the applied torque?

a. $\tau = 1.14$ N-m
b. $\tau = 6.19$ N-m
c. $\tau = 12.38$ N-m
d. $\tau = 0.88$ N-m
e. $\tau = 1.76$ N-m

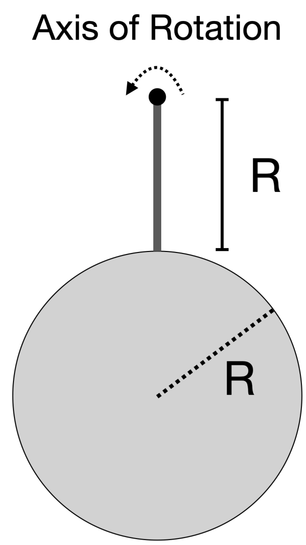
2) How many revolutions $N$ has the wheel made after $t = 21$ seconds?

a. $N = 1455.3$
b. $N = 463.2$
c. $N = 231.6$
d. $N = 115.8$
e. $N = 363.8$

3) In the previous question, the wheel makes $N$ revolutions during a time $t$. How many revolutions would the wheel make in <u>twice</u> the time $(2t)$?

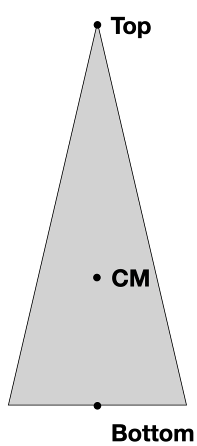
a. $4N$
b. $2\sqrt{2}N$
c. $2N$

A pendulum is constructed by attaching one end of a rod (of mass $M$ and length $R$) to a pivot that is free to rotate and attaching the other end to a <u>hollow sphere</u> (of mass $M$ and radius $R$).




4) What is the moment of inertia of the pendulum for rotations around the axis shown in the diagram?

a. $6MR^2$
b. $3MR^2$
c. $MR^2$
d. $5MR^2$
e. $2MR^2$



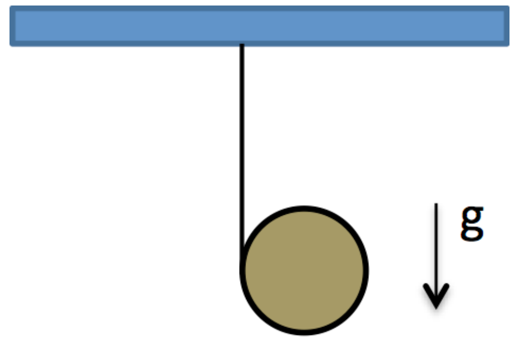

A flat triangular plate of uniform density can be rotated about three axes pointed into the page: one at the top of the triangle, one through the center of mass, and one at the bottom. The CM axis is closer to the Bottom axis than the Top axis.

5) What is the correct ranking of the moments of inertia through these three axes?

a. $I_{CM} < I_{Bottom} < I_{Top}$
b. $I_{CM} < I_{Top} < I_{Bottom}$
c. $I_{CM} = I_{Top} = I_{Bottom}$

**The next three questions pertain to the situation described below.**

A solid disk of radius R = 16 cm and mass M = 600 g has string wound around its rim. It is hung from a ceiling and released from rest as shown in the diagram with the string taut and vertical.




6) What is the acceleration of the disk?

a. 4.9 $m/s^2$
b. 6.54 $m/s^2$
c. 14.72 $m/s^2$
d. 5.89 $m/s^2$
e. 9.81 $m/s^2$

7) After the disk is released from rest, what is the speed of its center of mass after it has fallen 40 cm?

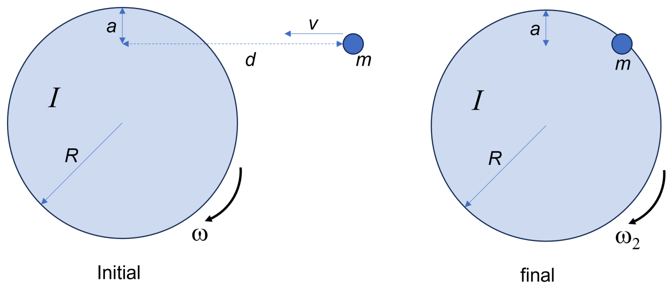
a. 1.98 m/s
b. 2.29 m/s
c. 1.72 m/s
d. 2.43 m/s
e. 3.96 m/s

8) If you replace the solid disk with a hoop having the same mass and radius as the disk, then how would the acceleration of the hoop compare to the acceleration of the disk?

a. The accelerations of the hoop and the disk would be the same
b. The acceleration of the hoop would be smaller than that of the disk
c. The acceleration of the hoop would be larger than that of the disk

**The next four questions pertain to the situation described below.**

The top view of a rotating disk is shown. The uniform disk has moment of inertia I = 210 kg-m$^2$ and radius R = 3.4 m. Initially, it is rotating clockwise (as shown in the figure) at an angular speed ω = 4.9 rad/s. A person with mass m = 55 kg runs to the left with speed v = 3.3 m/s, moving directly toward a location that is a = 1.1 m inside the rim of the disk as shown. The person eventually jumps onto the edge of the disk.




9) What is the direction of the initial angular momentum vector of the disk?

a. out of the page
b. into the page

10) What is the magnitude of the initial angular momentum vector of the person about the <u>center of the disk</u>, at the moment they are a distance d = 7 m from the disk as shown?

a. $|\vec{L}| = 417$ kg-m$^2$/s
b. $|\vec{L}| = 1270$ kg-m$^2$/s
c. $|\vec{L}| = 617$ kg-m$^2$/s

11) What is the direction of the initial angular momentum of the person with respect to the center of the disk when they are a distance $d$ from the disk as shown?

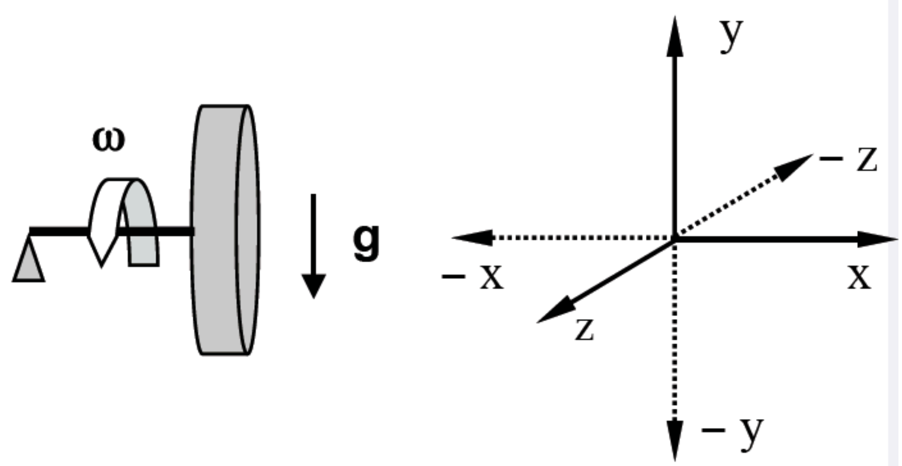
a. out of the page
b. left
c. into the page

12) After the person jumps onto the edge of the disk, what is $\omega_2$, the final angular velocity of the disk with the person on it?

a. $\omega_2 = 2.21$ rad/s
b. $\omega_2 = 1.71$ rad/s
c. $\omega_2 = 0.487$ rad/s
d. $\omega_2 = 5.23$ rad/s
e. $\omega_2 = 0.723$ rad/s

**The next two questions pertain to the situation described below.**

The gyroscope pictured is turning such that the top of the wheel is coming out of the page, and the bar (which is attached to the center of mass of the gyroscope) is sitting on a fulcrum (a pivot point).



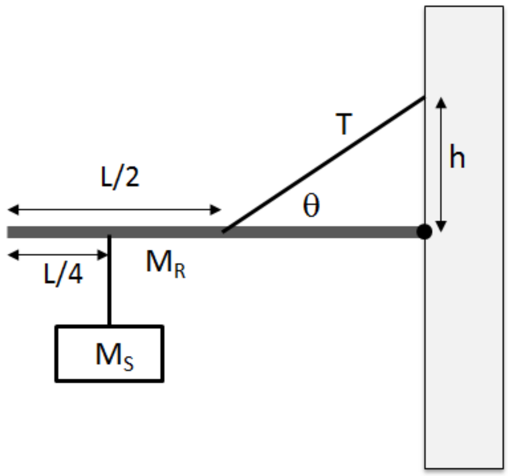

13) At the instant shown in the figure, the angular momentum vector of the gyroscope points in which direction?

a. $+z$
b. $-x$
c. $+x$

14) At the instant shown in the figure, precession causes the disk of the gyroscope to move

a. out of the page, towards the positive $z$ axis.
b. up, towards the positive $y$ axis.
c. into the page, towards the negative $z$ axis.

**The next two questions pertain to the situation described below.**




A horizontal rod of length L and mass $M_R$ = 2.3 kg is used to hang a sign on a wall. The right end of the rod is attached to the wall by a hinge. A wire having tension T runs from the center of the rod to a place on the wall a distance h above the hinge as shown. The wire makes an angle $\theta = 24^o$ with the rod. The sign has mass $M_S$ = 0.767 kg and hangs distance L/4 from the end of the rod. The system is in equilibrium.

15) What is the tension $T$ in the wire that runs between the wall and the rod?

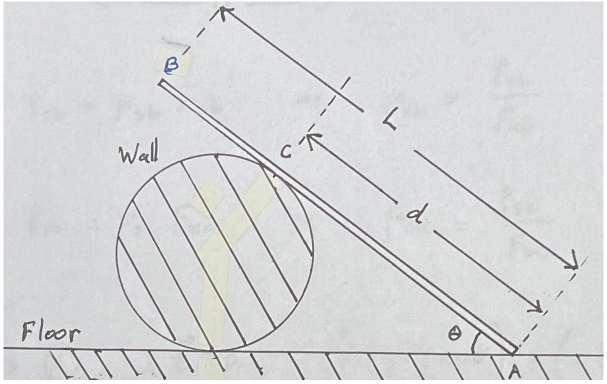
a. $T$ = 27.75 N
b. $T$ = 83.22 N
c. $T$ = 55.47 N
d. $T$ = 12.35 N
e. $T$ = 37.05 N

16) What is $F_V$, the vertical component of the force that the hinge exerts on the right end of the rod? A positive answer indicates an upward force and a negative answer indicates a downward force. Hint: Balance torques about an axis through the center of the rod.

a. $F_V$ = -7.52 N
b. $F_V$ = 3.76 N
c. $F_V$ = -5.64 N
d. $F_V$ = 7.52 N
e. $F_V$ = -3.76 N

**The next four questions pertain to the situation described below.**

A uniform beam of mass $m$ and length $L$ rests on a cylindrical wall as shown in the figure. The cylindrical wall is fixed and does not rotate while the beam is in equilibrium. The angle that the beam makes with the floor is $\theta$. The coefficient of friction between the beam and the cylindrical wall is zero.




17) Calculate the magnitude of the force $F_c$ from the cylindrical wall **on** the beam (at point C).

a. $F_c = \frac{mgL}{2d} \cos\theta$
b. $F_c = \frac{mgL}{2} \cos\theta$
c. $F_c = \frac{mgL}{2d}$

18) Calculate the magnitude of the frictional force $f_{sb}$ **on** the beam (at point A).

a. $f_{sb} = F_c \sin\theta$
b. $f_{sb} = F_c \cos\theta$
c. $f_{sb} = F_c \tan\theta$

19) Calculate the magnitude of the normal force $F_{nb}$ from the floor **on** the beam (at point A).

a. $F_{nb} = mg - F_c \cos\theta$
b. $F_{nb} = mg - F_c \sin\theta$
c. $F_{nb} = mg - F_c$

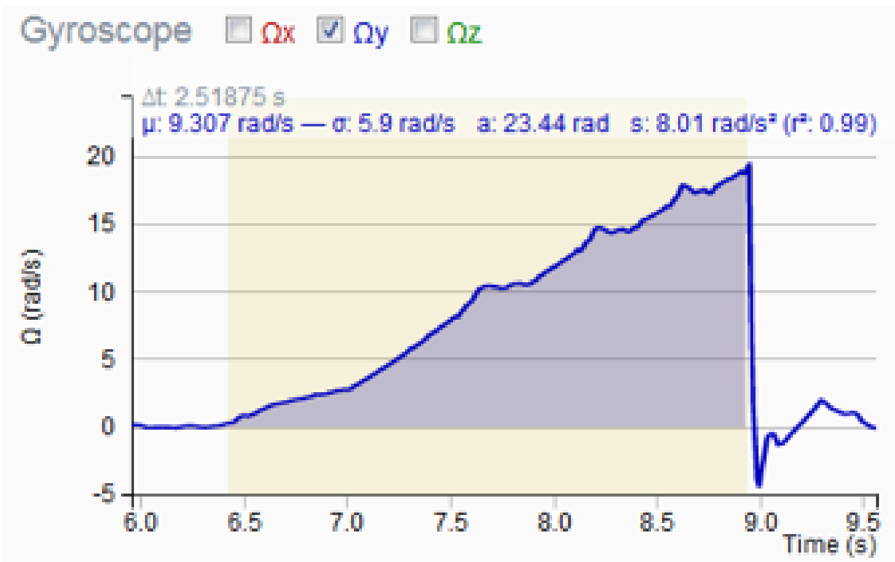
20) What is the minimum coefficient of static friction $\mu_{sb}$ between the floor and the beam to prevent slipping?

a. $\mu_{sb} = f_{sb}/F_{nb}$
b. $\mu_{sb} = \frac{d}{L} \tan\theta$
c. $\mu_{sb} = \tan\theta$

**The next two questions pertain to the situation described below.**

In Lab experiment 8, we attached two tape rolls (radius $r = 4$ cm) on either end of an IOLab and, based on some mass and length measurements, estimated the moment of inertia $I_y$ of this composite object as it is spun around the long (y) axis of the IOLab.


In Lab experiment 9, we measured $I_y$ by rolling this object down a ramp. The plot below shows data from the IOLab gyroscope (angular velocity $\Omega_y$ vs time) from one Lab 9 trial.




21) In this trial, what was the average angular acceleration of the object (rad/s$^2$) as it rolled down the ramp?

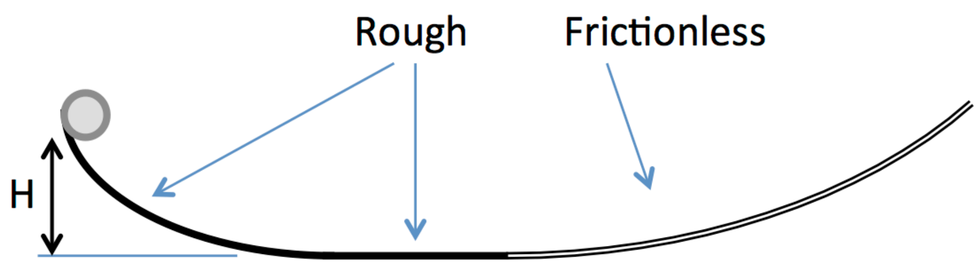
a. 8.01
b. 9.307
c. 23.44

22) Assuming $I_y = 1.3 \times 10^{-4}$ kg m$^2$ and the object rolled without slipping, what is the value of the static frictional force between the object and the ramp as the object rolled?

a. 0.00104 N
b. $4.17 \times 10^{-5}$ N
c. 0.026 N

**The next two questions pertain to the situation described below.**

A hollowed-out ball (i.e., a spherical shell like a basketball) of mass M = 0.13 kg, radius R = 0.012 m, and moment of inertia (2/3)$MR^2$ is released from rest at height H = 0.3 m on a curved rough ramp, and rolls without slipping down the ramp.




23) If the spherical shell now enters a **frictionless** ramp on the other side as shown, how does the new height it reaches, h, relate to the original height, H, from which it was released?

a. h = H
b. h = (3/7)H
c. h = (5/7)H
d. h = (3/2)H
e. h = (3/5)H

24) If instead you had released a solid ball from the same original height H, how would the new height reached by the ball on the frictionless ramp on the right, $h_{\text{solid ball}}$, compare to the height, h, reached by the spherical shell in the previous problem?

a. $h_{\text{solid ball}} < h$
b. $h_{\text{solid ball}} = h$
c. $h_{\text{solid ball}} > h$

**This is the last question of the exam!**

25) Did you check your answer sheet to ensure you

1. Entered your netid

2. Entered your exam version

3. Marked answers for all 25 questions (including this one)

   a. Yes ( I did all 3)
   b. No (I did not enter my netid)
   c. No (I did not enter my exam version)

***Kinematics***
$\vec{v} = \vec{v}_0 + \vec{a}t$
$\vec{r} = \vec{r}_0 + \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$
$v^2 = v_0^2 + 2a(x - x_0)$
$g = 9.81\ \text{m/s}^2 = 32.2\ \text{ft/s}^2$
$\vec{V}_{\text{A,B}} = \vec{V}_{\text{A,C}} + \vec{V}_{\text{C,B}}$

***Uniform Circular Motion***
$a = v^2/r$
$v = \omega r$
$\omega = 2\pi/T = 2\pi f$

***Dynamics***
$\vec{F}_{\text{net}} = m\vec{a} = d\vec{p}/dt$
$\vec{F}_{\text{A,B}} = -\vec{F}_{\text{B,A}}$
$F = mg$ (near Earth's surface)
$F_{12} = Gm_1m_2/r^2$ (in general)
$F_{\text{spring}} = -k\Delta x$

***Friction***
$f = \mu_k N$ (kinetic)
$f \le \mu_s N$ (static)

***Work & Kinetic Energy***
$W = \int \vec{F} \cdot d\vec{l}$
$W = \vec{F} \cdot \vec{\Delta r} = F\,\Delta r \cos\theta$ (constant force)
$W_{\text{grav}} = -mg\Delta y$
$W_{\text{spring}} = -k\left(x_2^2 - x_1^2\right)/2$
$K = mv^2/2$
$W_{\text{net}} = \Delta K$

***Potential Energy***
$U_{\text{grav}} = mgy$ (near Earth's surface)
$U_{\text{grav}} = -GMm/r$ (in general)
$U_{\text{spring}} = kx^2/2$
$\Delta E = \Delta K + \Delta U = W_{\text{nc}}$

***Power***
$P = dW/dt$
$P = \vec{F} \cdot \vec{v}$

***System of Particles***
$\vec{R}_{\text{CM}} = \sum m_i\vec{r}_i / \sum m_i$
$\vec{V}_{\text{CM}} = \sum m_i\vec{v}_i / \sum m_i$
$\vec{A}_{\text{CM}} = \sum m_i\vec{a}_i / \sum m_i$
$\vec{P} = \sum m_i\vec{v}_i$
$\sum \vec{F}_{\text{ext}} = M\vec{A}_{\text{CM}} = d\vec{P}/dt$

***Impulse***
$\vec{I} = \int \vec{F}\,dt$
$\Delta\vec{P} = \vec{F}_{\text{avg}}\Delta t$

***Collisions***
If $\sum \vec{F}_{\text{ext}} = 0$ in some direction, then $\vec{P}_{\text{before}} = \vec{P}_{\text{after}}$ in this direction:
$\sum m_i\vec{v}_i$ (before) $= \sum m_i\vec{v}_i$ (after)

In addition, if the collision is elastic:
- $E_{\text{before}} = E_{\text{after}}$
- *Rate of approach = Rate of recession*
- *The speed of an object in the Center-of-Mass reference frame is unchanged by an elastic collision.*

***Rotational Kinematics***
$s = R\theta,\ v = R\omega,\ a = R\alpha$
$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$
$\omega = \omega_0 + \alpha t$
$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$

***Rotational Dynamics***
$I = \sum m_i r_i^2$
$I_{\text{parallel}} = I_{\text{CM}} + MD^2$
$I_{\text{disk}} = I_{\text{cylinder}} = \frac{1}{2}MR^2$
$I_{\text{hoop}} = MR^2$
$I_{\text{solid-sphere}} = \frac{2}{5}MR^2$
$I_{\text{spherical-shell}} = \frac{2}{3}MR^2$
$I_{\text{rod-cm}} = \frac{1}{12}ML^2$
$I_{\text{rod-end}} = \frac{1}{3}ML^2$
$\tau = I\alpha$ (rotation about a fixed axis)
$\tau = \vec{r} \times \vec{F},\ |\tau| = rF\sin\phi$

***Work & Energy***
$K_{\text{rotation}} = \frac{1}{2}I\omega^2$
$K_{\text{translation}} = \frac{1}{2}MV_{\text{CM}}^2$
$K_{\text{total}} = K_{\text{rotation}} + K_{\text{translation}}$
$W = \tau\theta$

***Statics***
$\sum \vec{F} = 0,\ \sum \tau = 0$ (about any axis)

***Angular Momentum***
$\vec{L} = \vec{r} \times \vec{p}$
$L_z = I\omega_z$
$\vec{L}_{\text{total}} = \vec{L}_{\text{CM}} + \vec{L}^*$
$\tau_{\text{ext}} = d\vec{L}/dt$
$\tau_{\text{cm}} = d\vec{L}^*/dt$
$\Omega_{\text{precession}} = \tau/L$

***Simple Harmonic Motion***
$d^2x/dt^2 = -\omega^2 x$ (differential equation for SHM)
$x(t) = A\cos(\omega t + \phi)$
$b(t) = -\omega A\sin(\omega t + \phi)$
$a(t) = -\omega^2 A\cos(\omega t + \phi)$
$\omega^2 = k/m$ (mass on spring)
$\omega^2 = g/L$ (simple pendulum)
$\omega^2 = mgR_{\text{CM}}/I$ (physical pendulum)
$\omega^2 = \kappa/I$ (torsion pendulum)

***General Harmonic Transverse Waves***
$y(x,t) = A\cos(kx - \omega t)$
$k = 2\pi/\lambda,\ \omega = 2\pi f = 2\pi/T$
$v = \lambda f = \omega/k$

***Waves on a String***
$V^2 = \dfrac{F}{\mu} = \dfrac{\text{(tension)}}{\text{(mass per unit length)}}$
$\overline{P} = \frac{1}{2}\mu v\omega^2 A^2$
$\dfrac{d\overline{E}}{dx} = \frac{1}{2}\mu v\omega^2 A^2$
$\dfrac{d^2y}{dx^2} = \dfrac{1}{v^2}\dfrac{d^2y}{dt^2}$ (wave equation)

***Fluids***
$\rho = \dfrac{m}{V}$
$p = \dfrac{F}{A}$
$A_1v_1 = A_2v_2$
$p_1 + \frac{1}{2}\rho v_1^2 + \rho g_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$
$F_{\text{B}} = \rho_{\text{liquid}} g V_{\text{liquid}}$
$F_2 = F_1\dfrac{A_2}{A_1}$

***Uncertainties***
$\delta = \dfrac{\sigma}{\sqrt{N}}$
$t' = \dfrac{|\mu_{\text{A}} - \mu_{\text{B}}|}{\sqrt{\delta_{\text{A}}^2 + \delta_{\text{B}}^2}}$