Answer all questions, beginning each new question in the space provided. Show all work. Show all formulas used for each problem prior to substitution of numbers. Label diagrams and include appropriate units for your answers. Write your name and section number at the top of each page in the space provided and write the name of your section instructor in the place provided in the cover sheet. You may use an alphanumeric calculator (one which exhibits physical formulas) during the exam as long as you do not program any formulas into memory. By using an alphanumeric calculator you agree to allow us to check its memory during the exam. Simple scientific calculators are always OK!

A Formula Sheet Is Attached To The Back Of This Examination
For your convenience you may carefully remove it from the Exam. Please take it with you at the end of the exam or throw it in a waste basket.

Be Prepared to Show your Student ID Card

Score on each problem:

1. (20) ____
2. (30) ____
3. (30) ____
4. (20) ____

Total Score (out of 100 pts) ____
1. (20 point) Put a circle around the letter that you think is the best answer.

1.1. (5 pts) Two masses (1 kg and 2 kg) are mounted on a light rod, which mass can be ignored, as shown in the figure. Calculate the moment of inertia of the system when rotated about an axis shown in the figure.

![Diagram of two masses on a light rod with distances labeled 1 m and 3 m, and 2 kg and 1 kg masses.]

A) 10 kgm²
B) 11 kgm²
C) 12 kgm²
D) 130 kgm²

1.2. (6 pts) During a collision with a wall, the velocity of a 1-kg ball changes from 10.0 m/s toward the wall to 10.0 m/s away from the wall. If the time the ball was in contact with the wall was 10.0 ms, what was the magnitude of the average force applied to the ball?

A) 20 N
B) 2 N
C) 0.2 N
D) 200 N
E) 2000 N

1.3. (3 pts) If a constant net torque is applied to an object, that object will

A) rotate with constant linear velocity.
B) rotate with constant angular velocity.
C) rotate with constant angular acceleration.
D) having an increasing moment of inertia.
E) having an decreasing moment of inertia.
1.4. (3 pts) The total linear momentum of the system is a conserved quantity if

A) no net external force acts on a system
B) no net external torque acts on a system
C) no net internal force acts on a system
D) no net internal torque acts on a system

1.5. (3 pts) The total angular momentum of the system is a conserved quantity if

A) no net external force acts on a system
B) no net external torque acts on a system
C) no net internal force acts on a system
D) no net internal torque acts on a system
2. (30 pts) A block of mass $m=2.0 \text{ kg}$ slides down a $30^\circ$ incline which is 3.0 m high (The block $m$ was initially at rest). At the bottom, it strikes a block of mass $M=7.0 \text{ kg}$ which is at rest on a horizontal surface. (Assume a smooth transition at the bottom of the incline). If the collision is elastic, and friction can be ignored, determine

(a) (7 pts) The speed of the block $m$ at the bottom of the incline plane before the collision

(b) (15 pts) The speeds of the two blocks after the collision

(c) (8 pts) How far back up the incline the smaller mass will go.
3. (30 pts) A 2.0-m-long uniform beam (m=5 kg) shown in the figure lies on the frictionless table. Four forces shown in the figure are applied to the beam which can rotate about the axis going through its left end. The second force, F₂, is applied perpendicularly at the point of the CM.

a) (15 pts) Calculate the net torque about the axis shown in the figure.

b) (8 pts) Calculate angular acceleration of the beam if the moment of inertia of the beam is \( I = \frac{1}{3} ml^2 \).

c) (7 pts) What is the angular velocity of the beam after 10 sec if the initial angular velocity is zero.
4. (20 pts) A uniform disc turns at 4 rev/sec around a frictionless spindle. A nonrotating rod, of the same mass as the disc and length equal to the disc’s diameter, is dropped onto the freely spinning disc. They then turn together around the spindle with their centers superimposed. What is the final angular velocity in rev/sec? The moment of inertia of the rod is $I = \frac{1}{12}ml^2$. The moment of inertia of the disc is $I = \frac{1}{2}mR^2$. 
Trig:
\[
\begin{align*}
\sin \theta &= \frac{a}{c} \\
\cos \theta &= \frac{b}{c} \\
\tan \theta &= \frac{a}{b} \\
c^2 &= a^2 + b^2
\end{align*}
\]

Quadratic Formula:
\[
Ax^2 + Bx + C = 0 \text{ has solutions:} \\
x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}
\]

Misc Formulas:
- Circumference of a circle = \(2\pi R\)
- Area of a circle = \(\pi R^2\)
- Surface Area of a Sphere = \(4\pi R^2\)
- Volume of sphere = \((4/3)\pi R^3\)
- Volume of cylinder = \(\pi R^2L\)

Differentiation:
\[
\begin{align*}
\frac{dx^n}{dx} &= nx^{n-1} \quad (n \neq 0) \\
\frac{d\cos(x)}{dx} &= -\sin(x) \quad (x \text{ in radians}) \\
\frac{d\sin(x)}{dx} &= \cos(x) \quad (x \text{ in radians}) \\
\frac{d(f(x) + g(x))}{dx} &= \frac{df(x)}{dx} + \frac{dg(x)}{dx}
\end{align*}
\]

Integration:
\[
\int x^n \, dx = \frac{x^{n+1}}{n+1} + C
\]

1-D Motion:
displacement = \(\Delta x\)
\[
\begin{align*}
\text{vaverage: } \Delta x/\Delta t &= (x_2 - x_1)/(t_2 - t_1) \\
\text{aaverage: } \Delta v/\Delta t &= (v_2 - v_1)/(t_2 - t_1)
\end{align*}
\]

Given \(x(t)\)
\[
\begin{align*}
v(t) &= \frac{dx}{dt} \quad \text{(instantaneous)} \\
a(t) &= \frac{dv}{dt} = \frac{d^2x}{dt^2} \quad \text{(instantaneous)}
\end{align*}
\]

1-D Motion with Const. Acc.:
\[
\begin{align*}
x(t) &= \frac{1}{2} at^2 + v_0x + x_0 \\
v(t) &= at + v_0x \\
v^2 &= v_0^2 + 2a(x - x_0)
\end{align*}
\]

Projectile Motion:
\[
x(t) = v_0x + x_0
\]

Formulae
\[
\begin{align*}
v_x(t) &= v_{0x} \\
a_x(t) &= 0
\end{align*}
\]
\[
\begin{align*}
y(t) &= \frac{1}{2} a_x t^2 + v_{0y} t + y_0 \\
v_y(t) &= a_y t + v_{0y} \\
a_y(t) &= a_y
\end{align*}
\]

For motion over level ground
\[
\text{Range} = \frac{v_0^2 \sin(2\theta_0)}{g}
\]

Acceleration due to gravity:
\[
g = 9.8 \text{ m/s}^2 \text{ downward}
\]

Newton's Second Law:
\[
\vec{F}_{\text{net}} = \sum \vec{F}_{\text{ext}} = ma
\]

Circular Motion:
\[
\begin{align*}
a_{\text{centripetal}} &= \frac{v^2}{R} \\
T &= \frac{1}{f} \\
v &= 2\pi R/T
\end{align*}
\]

Frictional Forces:
\[
\begin{align*}
f_s &\leq \mu_s F_N \\
f_k &= \mu_k F_N \\
\mu_s &> \mu_k
\end{align*}
\]

Work and Kinetic Energy
\[
W = F \Delta x
\]
\[
W = \int_{\gamma_1}^{\gamma_2} \vec{F} \cdot d\vec{r}
\]
\[
K = \frac{1}{2}mv^2
\]
\[
W_{\text{net}} = \Delta K
\]
\[
\Delta K = K_f - K_i
\]

Potential Energy
\[
\Delta U = U(x) - U_0(x_0) = -\int_{x_0}^{x} Fdx
\]
\[
F(x) = -\frac{dU(x)}{dx}
\]

For gravity on earth's surface:
\[
F_g = mg
\]
\[
U(y) = U_0 + mgy
\]

For gravity in general:
\[
F_g = -\frac{GmM_E}{R^2} \\
U(r) = -\frac{GmM_E}{r}
\]
For springs:
\[ F = -kx \]
\[ U(x) = \frac{1}{2}kx^2 \]

With conservative forces only:
\[ E_{tot} = K + U \quad \text{(a constant)} \]
\[ \Delta E_{tot} = \Delta K + \Delta U = 0 \]

With non-conservative forces:
\[ \Delta E_{tot} = \Delta K + \Delta U = W_{NC} \]

Kepler's third law:
\[ T^2/R^3 = \frac{4\pi^2}{GM_{\text{sun}}} \]
\[ G = 6.67 \times 10^{-11} \text{ N.m}^2/\text{kg}^2 \]

Power
\[ P_{\text{avg}} = \frac{W}{t} \]
\[ P = \frac{dW}{dt} \]
\[ P = \vec{F} \cdot \vec{v} \]

Momentum and Impulse
\[ \vec{p} = mv \]
\[ \vec{F} = d\vec{p}/dt \]
\[ \vec{J} = \int \vec{F}dt = \vec{F}_o \Delta t \]
\[ \vec{J} = \Delta \vec{p} \]

For elastic collision:
\[ \vec{p}_A + \vec{p}_B = \vec{p}'_A + \vec{p}'_B \]
\[ \frac{1}{2}m_Av_A^2 + \frac{1}{2}m_Bv_B^2 = \frac{1}{2}m_Av'_A^2 + \frac{1}{2}m_Bv'_B^2 \]

For 1-D elastic head-on collisions:
\[ v_A - v_B = -(v'_A - v'_B) \]

Center of Mass
\[ r_{\text{cm}} = \Sigma m_i r_i / M \]
\[ \Sigma F_{\text{ext}} = Ma_{\text{cm}} \]

Rotation
\[ \omega = d\theta/dt \]
\[ \alpha = d\omega/dt \]

For constant angular acceleration
\[ \theta(t) = \frac{1}{2}\alpha t^2 + \omega_0 t + \theta_0 \]
\[ \omega(t) = \alpha t + \omega_0 \]
\[ \omega^2 = \omega_0^2 + 2\alpha (\theta - \theta_0) \]

\[ I = \Sigma m_i R_i^2 \]
\[ K_{\text{rot}} = \frac{1}{2}I\omega^2 \]
\[ K_{\text{tot}} = \frac{1}{2}I_{\text{CM}}\omega^2 + \frac{1}{2}Mv_{\text{CM}}^2 \]

\[ \Sigma \tau = I\alpha \]
\[ \vec{L} = \vec{r} \times \vec{p} \]
\[ \vec{L} = I\vec{\omega} \]
\[ \vec{\tau} = \vec{r} \times \vec{F} \]
\[ \tau = rF\sin\theta \]

\[ v_{\text{tangential}} = R\omega \]
\[ a_{\text{tangential}} = R\alpha \]
\[ a_R = \omega^2 R \]