Physic 141, Midterm Exam # 3  
Tuesday December 6, 2016  
8.00 am - 9.30 am

Exam rules: You may use only a writing instrument while taking this test. You may not consult any calculators, computers, books, nor each other.

1. Answer the multiple-choice questions (problems 1 – 10) by marking your answer on the scantron form. For each multiple-choice question (problems 1 – 10), select only one answer. Questions with more than one answer selected will be considered incorrect. **If your student ID is not listed properly on the Scantron form (in the bubbles on the lower-left corner), the form will not be processed and you lose points for all multiple-choice questions.**

2. Problems 11, 12, and 13 must be answered in the blue exam booklets **(answer questions 11 and 12 in booklet 1 and question 13 in booklet 2.)** The answers need to be well motivated and expressed in terms of the variables used in the problem. You will receive partial credit where appropriate, but only when we can read your solution. Answers that are not motivated will not receive any credit, even if correct.

At the end of the exam, you need to hand in your exam, the blue exam booklets, and the scantron form. All items must be clearly labeled with your name, your student ID number, and the day/time of your recitation. **If any of these items are missing, we will not grade your exam, and you will receive a score of 0 points.**

You are required to complete the following **Honor Pledge for Exams.** Copy and sign the pledge before starting your exam.

“I affirm that I will not give or receive any unauthorized help on this exam, and that all work will be my own.”

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

Name:  __________________________________________________

Signature:  ________________________________________________
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Useful Relations:

\[ \cos(30^\circ) = \frac{1}{2} \sqrt{3} \quad \sin(30^\circ) = \frac{1}{2} \quad \tan(30^\circ) = \frac{1}{3} \sqrt{3} \]
\[ \cos(45^\circ) = \frac{1}{2} \sqrt{2} \quad \sin(45^\circ) = \frac{1}{2} \sqrt{2} \quad \tan(45^\circ) = 1 \]
\[ \cos(60^\circ) = \frac{1}{2} \quad \sin(60^\circ) = \frac{1}{2} \sqrt{3} \quad \tan(60^\circ) = \sqrt{3} \]

\[ \cos\left(\frac{1}{2} \pi - \theta\right) = \sin(\theta) \quad \sin\left(\frac{1}{2} \pi - \theta\right) = \cos(\theta) \]
\[ \cos(2\theta) = 1 - 2 \sin^2(\theta) \quad \sin(2\theta) = 2 \sin(\theta) \cos(\theta) \]

<table>
<thead>
<tr>
<th>Circle</th>
<th>Sphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>circumference</td>
<td>(2\pi r)</td>
</tr>
<tr>
<td>(surface) area</td>
<td>(\pi r^2)</td>
</tr>
<tr>
<td>volume</td>
<td>(\frac{4}{3} \pi r^3)</td>
</tr>
</tbody>
</table>
Properties of the scalar product:

\[ \vec{a} \cdot \vec{b} = |\vec{a}| |\vec{b}| \cos \phi \]

\[ \vec{a} \cdot \vec{a} = |\vec{a}|^2 \]

\[ (\vec{a} + \vec{b}) \cdot (\vec{a} + \vec{b}) = \vec{a} \cdot \vec{a} + \vec{b} \cdot \vec{a} + \vec{a} \cdot \vec{b} + \vec{b} \cdot \vec{b} = |\vec{a}|^2 + 2 \vec{a} \cdot \vec{b} + |\vec{b}|^2 \]
Moments of inertia of various objects of uniform composition.

(a) Thin hoop of radius $R_0$ Through center

(b) Thin hoop of radius $R_0$ and width $w$ Through central diameter

(c) Solid cylinder of radius $R_0$ Through center

(d) Hollow cylinder of inner radius $R_1$ and outer radius $R_2$ Through center

(e) Uniform sphere of radius $r_0$ Through center

(f) Long uniform rod of length $l$ Through center

(g) Long uniform rod of length $l$ Through end

(h) Rectangular thin plate, of length $l$ and width $w$ Through center
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Problem 1 (2.5 points)

A device consists of eight balls, each of mass \( M \), attached to the ends of low-mass spokes of length \( L \). The device is mounted in the vertical plane, as shown in the Figure below. The axle is held up by supports that are not shown and the wheel is free to rotate on the nearly frictionless axle. A lump of clay with mass \( m \) falls and sticks to one of the balls at the location shown. Just before the collision, the device is rotating counter-clockwise with a constant angular velocity.

Which of the following statements are true if the angular momentum is calculated relative to the axle of the device?

A. The angular momentum of the device + clay just after the collision is equal to the angular momentum of the device + clay just before the collision.

B. The angular momentum of the clay is zero because the clay is moving in a straight line.

C. Just before the collision, the angular momentum of the device is 0.

D. The angular momentum of the device is the sum of the angular momenta of the eight balls.

E. The angular momentum of the device is the same before and after the collision.

1. AB  
2. AC  
3. BE  
4. AD  
5. AE  
6. CD  
7. BC  
8. BD  
9. CE
Problem 2 (2.5 points)

Which of the pictures shown above is connected to December 5th?

1. A
2. B
3. C
4. D
Problem 3 (2.5 points)

A ball falls straight down in the $xz$ plane. The linear momentum of the ball is shown by the arrow. What is the direction of the angular momentum of the ball about the origin of the coordinate system (point A)?

1. $+\hat{x}$
2. $-\hat{x}$
3. $+\hat{y}$
4. $-\hat{y}$
5. $+\hat{z}$
6. $-\hat{z}$
7. 0
Problem 4 (2.5 points)

At a certain temperature, the specific heat capacity $C_V$ of a diatomic gas is measured to be $(5/2)k_B$.

What degrees of freedom are accessible at this temperature?

1. Translational and rotational.
2. Translational and vibrational.
3. Rotational and vibrational.
4. Translational and electronic.
5. Electronic and rotational.
8. Electronic, rotational, and vibrational
Problem 5 (2.5 points)

A diatomic molecule, such as molecular nitrogen, consists of two atoms, each of mass $M$, whose nuclei are a distance $d$ apart. What is the moment of inertia of the molecule about its center of mass?

1. $Md^2$
2. $2Md^2$
3. $\frac{1}{2}Md^2$
4. $\frac{1}{4}Md^2$
5. $4Md^2$

Problem 6 (2.5 points)

A bicycle wheel with a heavy rim is mounted on a lightweight axle, and one end of the axle rests on top of a post. The wheel is observed to precess in the horizontal plane. With the spin direction shown in the Figure, in what direction will the wheel precess?

1. Counter clockwise.
2. Clockwise.
Problem 7 (2.5 points) SCANTRON FORM

Initially the entropy of object A is 100 J/K and the entropy of object B is also 100 J/K. Both objects are immersed in large vats of hot water. When the thermal energy of A has increased by 1000 joules, its entropy is 200 J/K. When the thermal energy of B has increased by 2000 joules, its entropy is 300 J/K. Which object is at a higher temperature?

1. Object A is at a higher temperature than Object B.
2. Object B is at a higher temperature than Object A.
3. Their temperatures are the same.

Problem 8 (2.5 points) SCANTRON FORM

A gas is made up of diatomic molecules. At temperature $T$, the ratio of the number of molecules in vibrational energy state 2 to the number of molecules in the ground state is measured to be 0.35. The difference in energy between state 2 and the ground state is $\Delta E$. Which of the following conclusions is correct?

1. $\Delta E \approx k_B T$
2. $\Delta E \ll k_B T$
3. $\Delta E \gg k_B T$
**Problem 9 (2.5 points)**

Two wheels with fixed hubs, each having a mass of 1 kg, start from rest, and forces are applied as shown. Assume the hubs and spokes are massless, so that the rotational inertia is $I = mR^2$. In order to impart identical angular accelerations, how large must $F_2$ be?

1. 0.25 N
2. 0.5 N
3. 1 N
4. 2 N
5. 4 N
Problem 10 (2.5 points)  
A person spins a tennis ball on a string in a horizontal circle (so that the axis of rotation is vertical). At the point indicated in the Figure, the ball is given a sharp blow in the downward direction. In which direction does the axis of rotation tilt after the blow?

1. +x direction.
2. –x direction.
3. +y direction.
4. -y direction.
5. It stays the same (but there is a change in magnitude).
6. The ball starts wobbling in all directions.
Problem 11 (20 points)  
ANSWER THIS QUESTION IN BOOKLET 1.

The entropy $S$ of a certain object is the following function of the internal energy $E$:

$$S = b \sqrt{E}$$

where $b$ is a constant.

a) Determine the internal energy $E$ of this object as function of its temperature $T$.

b) What is the specific heat of this object?

Express all your answers in terms of the variables provided. Your answers must be well motivated.
Problem 12 (30 points)

A wheel of radius $R$ and moment of inertia $I$ is mounted on a low-friction axle, as shown in the figure.

A string is wrapped around the edge of the wheel, and you pull on it with a force $F$. At a certain time, the angular speed of the wheel is $\omega_i$.

a) What is the angular velocity of the wheel after a certain time interval $\Delta t$?

b) How far did your hand move during this time interval?

c) What is the change in the rotational kinetic energy of the wheel? Use two different techniques to calculate the change in the kinetic energy and verify that they produce identical results.

Express all your answers in terms of the variables provided. Your answers must be well motivated.
Problem 13 (25 points)

For the step ladder shown in the Figure below, sides $AC$ and $CE$ have a length $L$ and are hinged at $C$. $BD$ is a tie rod of length $r$, installed halfway up the ladder. A man of mass $m$ stands at a position $\frac{3}{4}$ up the ladder. Assume the floor is frictionless and neglect the weight of the ladder.

a) Calculate the magnitude of the normal force exerted by the ground at position $A$.

b) Calculate the magnitude of the normal force exerted by the ground at position $E$.

c) Calculate the tension in the tie rod.

Your answers must be well motivated.