HAVERFORD COLLEGE
DEPARTMENT OF PHYSICS

PHYSICS 101A

MIDTERM EXAM #2

55 minute, timed, in-class exam

Wednesday, 15 November, 2000

INSTRUCTIONS

1. You will need a calculator. A pencil for sketches and other drawings would be a good idea. If your calculator is programmable or capable of graphing you are not allowed to make use of those features.

2. Partial credit can be earned, so even if you get stuck, look at the rest of the problem to see if there are other parts you can do, or explain how you would have done them, had you succeeded in getting the earlier part.

3. When asked to ‘show’ something, make sure to explain the steps of your reasoning using words as well as equations.

4. Always specify the units in your answer.

5. The exam will begin at 11:35 exactly and will be collected at 12:30.

6. This is a closed-book exam. You may prepare an equation sheet or sheets for use during the exam. The equation sheet(s) may contain only equations, no words or diagrams. (Compliance on this point was not complete on the first exam. Points will be deducted from your exam score for each word or sketch on your equation sheets.) Put your name on your equation sheet(s) and hand it (them) in with the exam.

7. Please answer all questions on this exam. (No blue books.) If you run out of room in the space left for an answer, please continue on the reverse of the page.

NAME: ____________________________

(please print)

HONOR PLEDGE

I accept full responsibility under the Haverford Honor System for my conduct on this examination.

Signed ____________________________ date

Max. 100
High 99.5
Mean 82.7
σ 12.7
Part I: Quick Answer Questions and Short Problems:

1) (10 points) -- Explain the concept of escape velocity. When we launch spacecraft into orbit, why do we usually choose to launch in an easterly direction?

*Escape velocity is the velocity an object needs to be given in order for it to completely escape the gravitational pull of the object from which it is trying to leave. Spacecraft are launched in an easterly direction in order to take advantage of the Earth’s rotation to achieve escape velocity or orbit.*

2) (25 points) -- An asteroid in outer space has a mass of 1000 kg. The asteroid is headed directly toward the space station as shown in the sketch, and so it must be accelerated sideways up to a velocity of 10 m/s. This is done by attaching a rocket motor to the side of the asteroid and firing it at constant thrust, thus providing a constant sideways force, for a pre-determined time interval.

(a) How much kinetic energy does the asteroid gain? Hint: you do not need to know the initial velocity of the asteroid to figure this out.

\[
KE = \frac{1}{2} m (v_x^2 + v_y^2) \quad v_y = v_{\text{initial}}
\]

\[
\Delta KE = \frac{1}{2}m v_x^2 = \frac{1}{2} \times 1000 \text{ kg} \times (10 \text{ m/s})^2
\]

\[
\Delta KE = 5 \times 10^4 \text{ J}
\]

(b) How much work is done on it by the rocket motor?

\[
W = \Delta KE \quad (\text{no change in } PE)
\]

(c) What is the change in momentum, \(\Delta p\), experienced by the asteroid? (Specify both magnitude and direction.)

\[
\Delta p = m \Delta v_x \left( -\hat{i} \right) = -1000 \text{ kg} \times 100 \text{ m/s} \hat{i}
\]

\[
= 10^4 \text{ kg m/s}
\]

(d) If the rocket motor is fired for 50 s in order to achieve the necessary change in velocity, what force was the motor supplying?

\[
\Delta p = \text{Impulse} = F \Delta t \quad \Rightarrow \quad F = \frac{10^4 \text{ kg m/s}}{50 \text{ s}}
\]

\[
= 200 \text{ N}
\]

HELP!
(e) Use your result in part (b) in order to determine how far the asteroid moved sideways during the thrust interval. Show your work. No credit will be given for an approach that requires making further use of the time interval over which the rocket fired. That is, do not use the methods of Chapter 3.

\[ W = 5 \times 10^4 \, J = F \cdot d = F \cdot s \]

\[ s = \frac{W}{F} = \frac{5 \times 10^4 \, J}{300 \, N} = 160 \, m \]

3) (10 points) Rotational motion is highly analogous to linear motion. In the following table a quantity and its units are specified in each case for either rotational or linear motion. Fill in the other quantity which is analogous to it and give its units.

<table>
<thead>
<tr>
<th>Quantity for linear motion</th>
<th>Units</th>
<th>Quantity for rotational motion</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>distance</td>
<td>m</td>
<td>angle</td>
<td>(radians)</td>
</tr>
<tr>
<td>velocity</td>
<td>m/s</td>
<td>angular velocity</td>
<td>(rad)/s</td>
</tr>
<tr>
<td>acceleration</td>
<td>m/s²</td>
<td>angular acceleration</td>
<td>(rad)/s²</td>
</tr>
<tr>
<td>mass</td>
<td>kg</td>
<td>moment of inertia</td>
<td>kg m²</td>
</tr>
<tr>
<td>force</td>
<td>N</td>
<td>torque</td>
<td>Nm</td>
</tr>
<tr>
<td>momentum</td>
<td>kg m/s</td>
<td>angular momentum</td>
<td>kg m²/s</td>
</tr>
</tbody>
</table>

4) (5 points) State the “fundamental law of pool”, i.e. billiards, and name the law of physics from which it follows. (No need to explain; just state and name the respective laws.)

When one pool ball strikes another the target ball and projectile ball will leave at a 90° angle.

This follows from the law of conservation of momentum.
Part II: Problems

1) (30 points) Football players use a 'blocking sled' to practice 'hitting'. Players lunge horizontally at the sled, striking a padded bumper with their shoulders, driving it backwards. The sled is designed to slide along the ground, and friction rapidly brings it to rest, after it has been hit by the players. Often the coach stands on the sled, yelling at players and pointing out the pitiable puniness of their effort in order to spur greater exertion and love of the game. The sled in this problem is designed to be hit by two players at once, and their impacts point in the same direction. The mass of the sled is 120 kg and a coach, who has a mustache that makes him look like a walrus and a mass of 80 kg, is standing on it.

Two players lunge at the sled. Player #1 has a mass of 80 kg and player #2 60 kg. (The players are not shown in the sketch because I cannot draw football players. Only their velocity vectors are depicted.) Both players achieve a horizontal velocity of 10 m/s in their lunges, and then collide simultaneously with the sled. As a result of the collisions, the motion of both players is stopped completely (but they do not bounce back either) as the sled springs forward.

(5) (a) What impulse is given to the sled? (The players do not remain in contact with the sled after the impact.)

\[ \Delta p = m \Delta v = (60 \text{ kg} \times 10 \text{ m/s}) + (80 \text{ kg} \times 10 \text{ m/s}) \]
\[ = 1400 \text{ kg m/s} \]

(5) (b) What is the velocity of the sled (+coach) immediately after the impact of the players?

By conservation of momentum

\[ 1400 \text{ kg m/s} = (m_{sled} + m_{coach}) \Delta v = 200 \text{ kg} \times v_f \]

\[ v_f = 7 \text{ m/s} \]

(c) Is this an elastic collision? Check your answer by determining the kinetic energies before and after the collision.

(7)\[ KE_i = \frac{1}{2} 60 \text{ kg} (10 \text{ m/s})^2 + \frac{1}{2} 80 \text{ kg} (10 \text{ m/s})^2 = 7000 \text{ J} \]

\[ KE_f = \frac{1}{2} 200 \text{ kg} (7 \text{ m/s})^2 = 4900 \text{ J} \]

(2100 J of energy were dissipated in the impact)
(d) What happens (in the end) to the energy that the sled received during impact?

(5) Friction with the ground turns it into heating of the sled and ground.

(e) Consider a vertical axis through the center of gravity of the sled. Did the sled experience any net torque during the impact of the players? Based on your answer to this part, discuss whether we should also expect any rotational motion of the sled immediately after impact.

\[ |\vec{F}_1| > |\vec{F}_2| \text{ because } \Delta p_1 > \Delta p_2 \text{ (same collision time)} \]

The impacts both impart torques about an axis through the c.m. The torques tend to cancel but \( |\vec{r}_1| = |\vec{r}_1 \times \vec{F}_1| > |\vec{r}_2| = |\vec{r}_2 \times \vec{F}_2| \). The sled tends to rotate counter-clockwise, due to the net torque in that direction.

2) (20 points) In the clock on the right only the second hand is shown. It is 10 cm long and is a uniform strip of metal of mass 50 g. (Since it is uniform, its center of gravity is halfway out from the pivot to the tip.)

(5) (a) What is the angular velocity of the second hand?

The second hand moves 2\pi radians in 60 seconds, so

\[ \omega = \frac{2\pi}{60s} = 0.105 \text{ (rad)/s} \]

(15) (b) At what speed is its tip moving?

\[ v = \omega r = 0.105 \text{ (rad)/s} \times 0.1 \text{ m} = 0.0105 \text{ m/s} \approx 1 \text{ cm/s} \]

(c) The clock motor exerts a torque on the hand in order to keep it moving at a steady angular velocity. With the clock mounted on the wall (so that gravity is pulling down on the hand) at what point does the clock motor have to exert the largest torque to overcome the force of gravity on the clock hand? (Specify the position of the hand by what number it is pointing to, when the torque is maximum.) What is the magnitude of the torque at that time? What is the direction of the torque exerted by the clock motor at that time?

Gravity exerts the largest torque when \( \vec{F}_1 + \vec{F}_2 \), i.e., when the hand points toward 3 or 9. C.M. is in middle of hand so \( \tau = rF = (0.05 \text{ m})50 \text{ g} \)

\[ \tau = 2.45 \times 10^{-2} \text{ Nm} \]

Clock motor has to fight gravity at 9 so that's where the torque is biggest.