AP Physics C - Mechanics

Spring Lab 4	Tee Time! Angular Momentum

Your Name: ____________________________ **Period:** ______________________

Partner 1: ____________________________ **Partner 2:** _______________________

Lab Overview: In this lab we will investigate the concept of angular momentum and how it applies to the collision between a golf club and golf ball. The goal of this lab is to determine the linear speed of a golf ball after being hit by a golf club. This, of course, depends on "how hard" you hit the ball. In this lab we will vary "how hard" we hit the golf ball and quantify this terms in angular momentum.

The Challenge

Given a particular golf club (rotation point and mass at head of club), and a golf ball of known mass, determine the horizontal displacement of the ball when the golf club is released from a known height (or angle with respect to the vertical), that is, find how far the ball will travel horizontally from where it is hit!

I. Hypothesis - Prelab Questions (pages 1-6)

a. **As shown in the diagram below, we will simulate a golf club swing with "weighted" ruler (i.e. a thin rod with a weight attached to the end to simulate the golf head), rotational motion sensor, and golf ball. The rotational motion sensor will collect angular displacement, angular velocity, and angular acceleration data.**

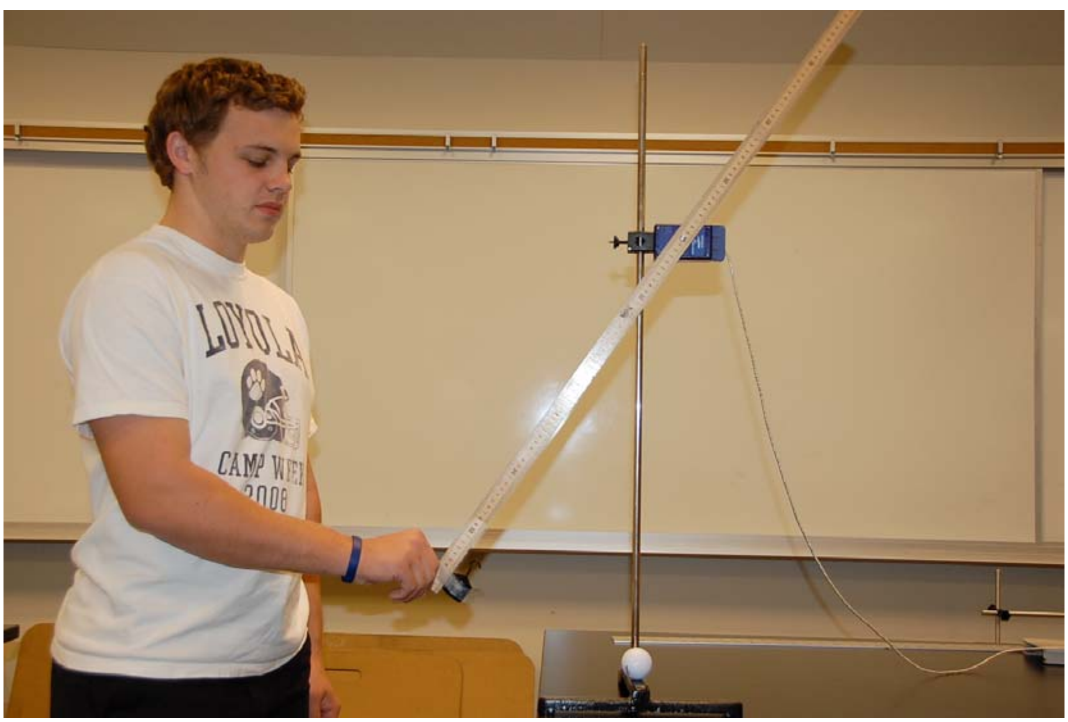

Figure 1 Experimental setup for analyzing a golf swing

b. **If the equation for LINEAR momentum is: p = mv, what do you think the equation for ANGULAR momentum is? What is like "m" in the rotational world? What is like "v" in the rotational world?**

If linear momentum p = mv,

then angular momentum L = __________ (yes, L is the variable for angular momentum)

c. **What are the units for LINEAR momentum that follow from the linear momentum equation?**

d. **What are the units for ANGULAR momentum that follow from the angular momentum equation?**

e. **Are the units for linear and angular momentum equal? If not, by what factor (i.e. unit) do they differ?**

And now, back to our collision…

f. **Since a collision will occur, we will turn to our friend the "Momentum Model." However, instead of two objects colliding along a straight line, one of the objects (the golf club) will be rotating upon impact with the golf ball. Draw the momentum buckets for the THREE possible cases for this type of ELASTIC collision. Write the resulting momentum equation for each of the three cases in terms of I_{club}, $\omega_{club\ before}$, $\omega_{club\ after}$, I_{ball}, $\omega_{ball\ after}$. (or m_{ball} and $v_{ball\ after}$) and any fundamental constants. Assume that the velocity of the ball immediately after the collision is completely horizontal. We will consider hitting the ball "at an angle" later. See the "Momemtum" bucket model sheet for**

Case I: **When the golf club continues to rotate (at a lower angular velocity) in same direction as it did before the collision.**

Case II: **When the golf club comes to a complete stop after the collision.**

Case III: **When the golf club "rebounds" or rotates in the direction OPPOSITE to its original direction of rotation. How will you represent this "backward" momentum in your bucket diagram?**

g. **As you can see, the final momentum of the ball will depend on the moment of inertia of the golf club, I_{club}. Below, derive an expression for the moment of inertia of your weighted golf club given your "pivot point" which will be a distance "d" from the center of mass of the club. Note that we will use a mass attached to the end of the golf club (aka ruler) that will serve as the "head" of the golf club. How will you account for this mass in determining the rotational inertia of the golf club? What theorem can you use to help you find the moment of inertia of the golf club? Note that this part is independent of part (f) above (it is actually review.) Note that there are no more "note"'s for this part.**

h. **Now let's find the angular velocity of the golf club immediately before the collision ($\omega_{club\ before}$) in terms of its initial angle with the respect to the vertical. For this example, let's assume the angle is 90 degrees, i.e. released from horizontal. Note that that we are finding the velocity of the club AT THE INSTANT before the collision. In a "real" golf swing, this velocity will be developed by the golfer AND gravity. Here only consider the acceleration of the club as due to gravity ONLY (i.e. a "falling" golf club). Complete this part as USING A COMPLETE HW FORMAT (less the GIVEN AND FIND parts). Hint: remember the Catapult AP problem…? What model is this?**

i. In the model that you used above, you will need to know the "height" that the golf club falls. How will you find this? Qualitatively describe this below.

Prelab ends here

Lab work begins here

DAY I – Testing "I" – Golf Club as a Physical Pendulum

j. **Test your value of "I" by setting up a physical pendulum with your golf club and measuring the period of the simple harmonic motion using:**

$$T = 2\pi\sqrt{\frac{I}{mgh}}$$

What is the distance "h" represent? Consult your book to determine EXACTLY what measurement this is.

Below, show your calculation for your PREDICTED period. Show your calculation to Mr. Lew NOW.

Test your prediction by setting up a physical pendulum with your golf club. Are your results close?

DAY II – Angular velocity of club BEFORE collision (at bottom of swing)

k. **Calculate the location of the center of mass of the golf club (i.e. ruler with attached weight). Does your calculated CM coincide with the CM that you can find experimentally (i.e. balancing on your hand)?**

l. **If the golf club is released from rest from the HORIZONTAL, calculate the angular velocity of the club in the vertical position, i.e. the instant before it hits the golf ball.**

l. **Use the GLX to measure the angular velocity of the golf club at the vertical position.**

Part III – Velocity of ball the instant after impact
($L_i = L_f$ AND pi = pf)

Now we will use the Law of Conservation of Momentum to determine the velocity of the ball at the instant after the collision. We will perform this analysis using both the angular momentum method and the linear momentum method.

m. **Calculate the velocity of the golf ball immediately after the collision using the Law of Conservation of Angular Momentum. Remember to use l = r x p for a singleton object.**

n. **Calculate the velocity of the golf ball immediately after the collision using the Law of Conservation of Linear Momentum. Hint: we have to find the equivalent singleton "mass" of the golf club in order to use Linear Momentum.**

o. **Look at the final equations for the velocity of the ball that you derived in (m) and (n) above. Are they algebraically equivalent?**

p. **How would the above analysis be changed if the ball's initial velocity immediately after the collision was NOT completely horizontal?**

III. Lab Debrief

Each of these questions is to be answered with an explanation or justification. Three to four sentences for each question will suffice.

a. Discuss at least TWO concrete things that you learned from this lab.
b. Discuss ONE concept that is still unclear to you?
b. What was the difficulty level of the experiment? (1-10, 10 most difficult) Why?
c. What was the "fun" level of this experiment? (1-10, 10 most fun). Why?
d. Describe one extension of this lab that would help your understanding of the physics content and increase the fun level of this lab.