Lab 9 Ballistic Pendulum

What You Need To Know:

The Physics Today's lab is not going to cover any new physics. However, based on what you've learned in lecture and in lab, we will be combining together several different physics concepts into a single problem.

"Combo" problems like this are easiest to solve if you first break down the problem into *stages*. Typically there are two or three stages to a single problem. Each stage relates to a particular physics concept. The different concepts that you've learned so far are:

- **Linear Motion**
- **Projectile Motion**
- **Summation of Forces**
- **Centripetal Forces**
- **Conservation of Energy**
- **Conservation of Momentum**

As an example, we are going to discuss an apparatus called a *ballistic pendulum.* There is one sitting on the desk in front of you. This one, however, is slightly more complicated than the example we are going to use.

The ballistic pendulum was created to measure the "muzzle velocity" of a gun. In other words, it measures the velocity of a bullet as it leaves a gun. The device consists of a block that is suspended by cables. **See Figure 1a.** A gun is positioned near the block and a bullet is fired horizontally into the block. The bullet embeds itself into the block. The block swings up into the air a distance ***h***. **See Figure 1b.** After doing some calculations you would see that there is a direct relationship between the velocity of the bullet and the height that the block swings.

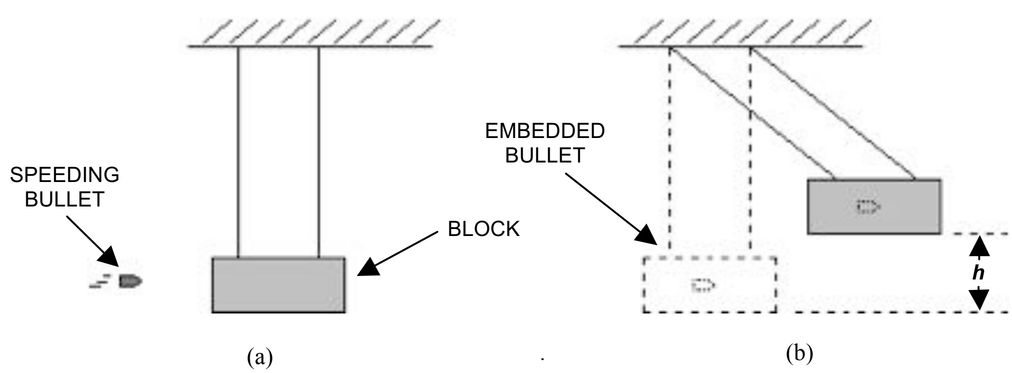

FIGURE 1 – Ballistic Pendulum

This example would be a *two stage combo problem*. The 1st stage would be a collision between the bullet and the block. The area of physics that this relates to is conservation of momentum (a perfectly inelastic collision). We could do a calculation that determines the velocity of the block/bullet after the collision based on the velocity of the bullet as well as the masses of each. **See Figure 2.**

1st Stage

Event: collision between block and bullet

Physics: conservation of momentum

$$\Sigma p = \Sigma p'$$

$$m_{bu.} v_{bu.} = (m_{bl.} + m_{bu.})v'$$

2nd Stage

Event: block/bullet swinging up

Physics: conservation of energy

$$KE_{ini.} + \cancelto{0}{PE_{ini.}} = \cancelto{0}{KE_{fin.}} + PE_{fin.}$$

$$\frac{1}{2}(m_{bu.} + m_{bl.})v_{ini.}^{2} = (m_{bu.} + m_{bl.})gh$$

$$v' = v_{ini.}$$

FIGURE 2 – Stages for Combo Problem

When analyzing these combo problems it is useful to be clear on the *beginning* and *ending* of each stage. The *initial* part of the 1st stage is the bullet approaching the block. The *final* part of the 1st stage is after the collision, at which point the block/bullet just begins to move up into the air. There is always a final piece of information that you calculate at the end of a stage that becomes an initial piece for the next stage. In this case, the final velocity of the block/bullet after the collision becomes the initial velocity of the block/bullet as it begins its swing upward. **See Figure 2.**

The initial part of the 2nd stage is right after the collision as the block/bullet begins its swing into the air. The final part of the 2nd stage is when the block/bullet is stopped at its highest point in its swing. The area of physics that this stage relates to is conservation of energy. At the beginning of this stage all the energy is kinetic and by the end of the stage the energy has turned into gravitational potential energy. **See Figure 2.**

For this lab you will be working through two different combo problems. You will be guided through the first process and then for the second one you will have to work it out on your own.

The Equipment The ballistic pendulum apparatus on your desk is a little different from the "block/bullet" one described above. **See Figure 3.** Instead of a gun, you have a spring launcher. Instead of a bullet, you have a ball. Instead of a block, you have a ball catcher that swings up into the air and locks into place.

The first thing you should do before proceeding is to make sure the device is level. There is a level on the base of the device. **See Figure 3.**

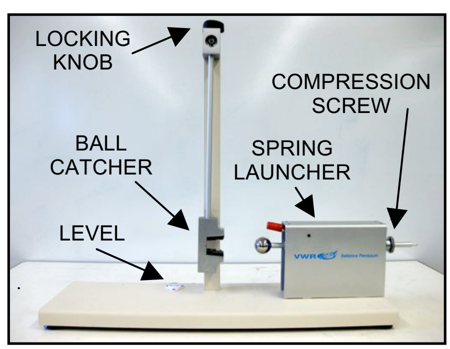

FIGURE 3 – Ballistic Pendulum

Under the base of the device there are rotatable black feet that you can use to lower and raise the device. Adjust the feet until the bubble in the level is centered. **See Figure 4.**

FIGURE 4 – Feet

You should also turn the compression screw (**See Figure 3**) so that it goes all the way into the device. There will be one or two threads showing when it's in all the way.

What You Need To Do:

Part 1 – Guided Combo Problem Before we discuss the stages for this problem, try out the device by doing the following. Put the ball at the end of the launcher and compress it in until the red knob catches. Sometimes the red knob doesn't engage completely, so after you compress the spring, hold the red knob up with your finger while you take your hand away. **See Figure 5.** This way it won't accidently launch and slam into your hand.

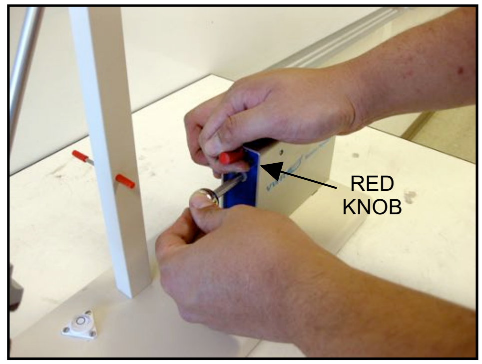

FIGURE 5 – Arming the Launcher

Next, while the ball catcher arm is in the vertical position, tighten the locking knob snuggly but not overly tight. **See Figure 3.** The locking knob will allow the ball catcher to only swing up to its maximum height and then hold it in position. It's now armed and ready to go. Push down on the red knob and observe what happens.

(Note: please do not move the ball catcher back to its vertical position while the locking knob is tightened. This will strip the locking mechanism, and damage like this could make the pendulum inoperable.)

Question 1 Based on what you observed, how many stages do you think there are in this situation? What kind of physics does each stage use? Decide on your answer before turning the page.

There are three stages to this combo problem. The 1^{st} *stage* is the launching of the ball from the spring launcher. The 2^{nd} *stage* is the collision between the ball and the catcher. The 3^{rd} *stage* is the ball and the ball catcher swinging up into the air.

The main objective for **Part 1** of this lab is to measure the spring constant in the launcher. You are going to be taking data on a variety of things in this section but your main piece of data will be measuring the height to which the ball catcher swings into the air. This means that for your calculations you will be working backwards, since the quantity we want to know (the spring constant) is used in the first stage, while the quantity you will measure (the height) appears only in the third stage.

In other words, you will be dealing with the *last* stage *first* and vice versa. You'll work backwards through the stages, using the result from stage 3 in the setup for stage 2, and then the result from stage 2 in the setup for stage 1.

3^{rd} Stage The beginning of this stage takes place after the ball collides with the catcher, just as it starts its swing into the air. The end of the stage takes place when the catcher is at the peak of its swing. In this part, we will work backwards, relating the final height to the velocity of the ball + catcher just as they start to swing.

A) You need an equation to calculate the velocity of the ball and catcher right as it starts its swing based on the height it swings to. Determine this equation using conservation of energy. Before proceeding, ask your TA to make sure you are correct.

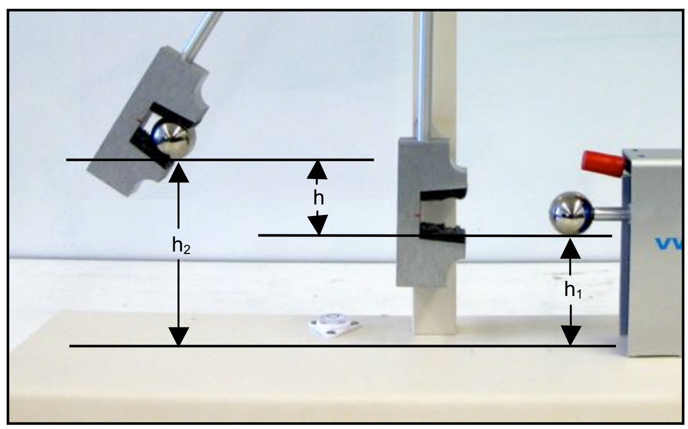

FIGURE 6

B) In the equation you derived you will need a value for the height that the ball swings in the air. If you measure the height from the base of the device to the bottom of ball for each of its two locations, then you can subtract these two values to get the height, $h = h_2 - h_1$. **See Figure 6.**

Trial	h_2
1	
2	
3	
4	
5	
6	
Ave. h_2	
h_1	
h	
$v_{ini.}$	

CHART 1

NOTE: All units should be in SI (meters and kilograms).

C) Make a data chart in your lab report like the one in **Chart 1**. Measure the initial height, h_1, and put it in the chart. (You only have to measure this once, since the starting height will be the same every time.) Do six trials of launching the ball into the catcher. Measure h_2 each time and put the values in the chart.

D) Take the average of your h_2 data and put it in the chart.

E) Using your average $\boldsymbol{h_2}$ and the equation above, calculate $\boldsymbol{h}$ and put the value in the chart.

F) Using the equation you derived in **A)**, calculate the velocity of the ball and catcher, $\mathbf{v_{ini.}}$, as it starts its swing. Place this value in your chart.

2nd Stage The beginning of this stage takes place after the ball has been launched from the spring launcher, just before it collides with the catcher. The end of the stage takes place after the ball collides with the catcher, just before it swings up into the air.

A) You need an equation to calculate the velocity of the ball right before it collides with the catcher. Determine this equation using conservation of momentum. Before proceeding, check with your TA to make sure that you are correct.

Object	Mass
Ball	
Catcher	116 g
$\mathbf{v'}$	
$\mathbf{v_{ball}}$	

CHART 2

B) Make a data table like the one in **Chart 2**.

C) Measure the mass of the ball and place this value in the chart. The mass of the catcher is given on the device. It's the same for everyone, so it's already in the chart.

E) The piece of information that you will use from the 3rd Stage is the initial velocity of the ball/catcher. This now becomes the final velocity after the collision, $\mathbf{v'}$. Place this value in your chart.

F) Using the equation you just derived, calculate the velocity of the ball, $\mathbf{v_{ball}}$, right before it collides with the catcher. Show your calculation below. Place this value in your chart.

1st Stage The beginning of this stage takes place right when you launch the ball from the spring launcher. The end of the stage takes place right after the ball leaves the launcher.

A) You need an equation to calculate the spring constant of the spring in the launcher. Determine this equation using conservation of energy. You will need the potential energy equation for a spring … $PE = \frac{1}{2}kx^2$. Before proceeding, check with your TA to make sure you are correct.

$v_{fin.}$	
m_{ball}	
x_1	
x_2	
x	
k	

CHART 3

B) Make a data table like the one in **Chart 3**.

C) The piece of information that you will use from the 2nd Stage is the initial velocity of the ball before it collides with the catcher. This now becomes the final velocity of the ball after it is launched. Place this value in your chart.

D) You will also need the mass of the ball that you measured in the last section. Place this value in the chart.

E) The only data that you need to take for this section is the compression distance for the spring, x. When the launcher is un-armed, measure the distance from the left side of the ball to the edge of the device, x_1. **See Figure 7**. Place this value in the chart. Now compress and arm the launcher. Measure the distance from the left edge of the ball to the edge of the device, x_2, and put this value in the chart. Subtract the two values to get x and place it in the chart. NOTE: Please make sure you have read the lab introduction before completing this step; it has important information about correctly and safely using the spring.

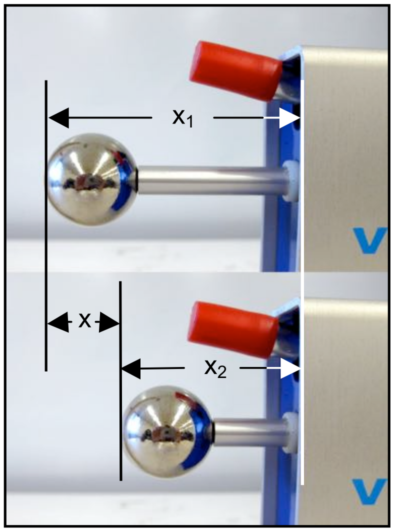

FIGURE 7 – Measuring the compression distance

F) Using the equation you just derived in **A)** and the result from the 2nd Stage, calculate the spring constant. Show your calculation below. Place this value in your chart.

Part 2 – Combo Problem On Your Own You are now going to go through basically the same procedure from **Part 1** but for a somewhat different experiment. However, unlike the last time, you are *not* going to be working backwards through the stages, you will be working *forwards*.

A) Your combo problem will be to determine where on the floor the ball will land if it is launched from the spring launcher. Determine how many stages this combo problem has. Write out the stages in your lab report in the same way that it was done in **Figure 3**. For each stage, write down what type of physics you are using and also derive the equation for each stage. Check with your TA to see if your equations are correct before you move on.

B) If a ball is launched horizontally from a height h, how long does the ball take to hit the floor? Solve this problem algebraically.

C) If the same ball from part b takes time t to hit the floor when it has a horizontal velocity v, at what horizontal distance D from the launch position does the ball hit the floor? Solve this problem algebraically.

D) If a spring launcher with constant k is compressed a distance x , how fast is the ball moving immediately after it is launched? Solve this problem algebraically.

E) Combine the results of A, B , C, and D to derive an equation for the horizontal distance *D* that the ball moves in terms of things you know or can measure. Ask your TA to check your result before continuing.

F) Before you start taking data you need to set up a few things. First, situate the launcher so that it is right at the edge of the table. See **Figure 8**.

G) Second, you are going to adjust the compression distance of the spring launcher. Currently, the compression screw should be all the way in. (If it's not, then go back and read the end of the intro to the lab and do your data over again.) Turn the compression screw anywhere from 2 complete turns (360º) to no more than 5 complete turns.

You are going to reference where the ball lands to a point on the floor that is directly below the edge of the table. **See Figure 8**. At the front of the lab there is a *plumb bob* which you can hang from the edge of the table. This will allow you to find where the edge of the table is relative to the floor. There is also tape at the front of the lab that you can use to make a mark on once you find the reference point with the plumb bob.

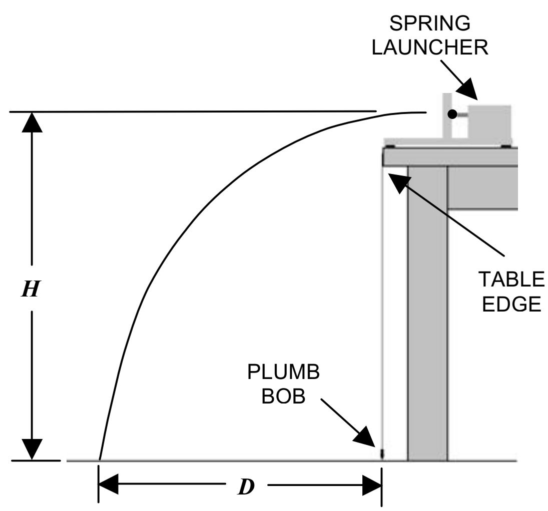

FIGURE 8

H) Based on your equations you should decide on what data you need to take. Make your own chart to hold this data. Note that the height of the table is NOT the height, ***H***, in **Figure 8**. How should you measure ***H***? (If you're not sure why, please ask your TA.) Keeping this in mind, take your data and fill out the chart.

I) Use your equations and your data to determine the distance, ***D***. Note that the *horizontal distance that the ball travels from the launcher* is NOT the distance, ***D***, in **Figure 8**. What is the correct way to measure ***D***? Again, please ask your TA if you aren't sure why.

J) Get a piece of carbon paper and a piece of regular paper from the front of the lab. *Tape down* the regular paper so that the center of the paper is at the distance, ***D***, that you calculated. *Rest* (do not tape) the carbon paper upside-down on top of this regular paper.

K) Now you are going to run 5 trials of launching the ball. Make a data chart to hold your data. Launch the ball. It should hit and make a carbon mark on the regular paper. Measure the distance, ***D***, from the carbon mark to your reference point from the plumb bob, for each trial. Do this 5 times.

L) Take the average of your ***D*** data. Calculate a percent difference between this value and the one you calculated in **I)**.

M) Please turn the compression screw all the way back in before you leave.

What You Need To Turn In:

Questions and Calculations Along with your data, make sure that you include a calculation where it asks for one. Also make sure you have answered all questions.