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. These types of problems are called "combo" problems.

Combo problems 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.

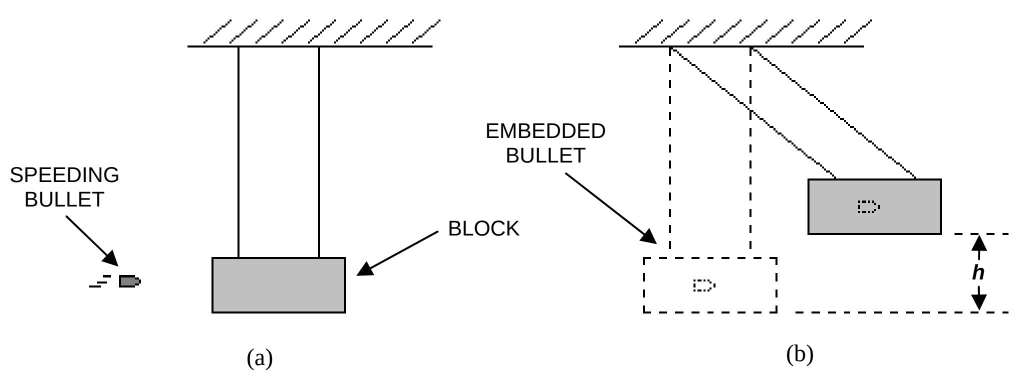


FIGURE 1 – Ballistic Pendulum

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. Instead of a gun, you have a spring launcher. Instead of a bullet, you have a ball and, instead of a block, you have a "ball catcher" that swings up into the air. **See Figure 3.**

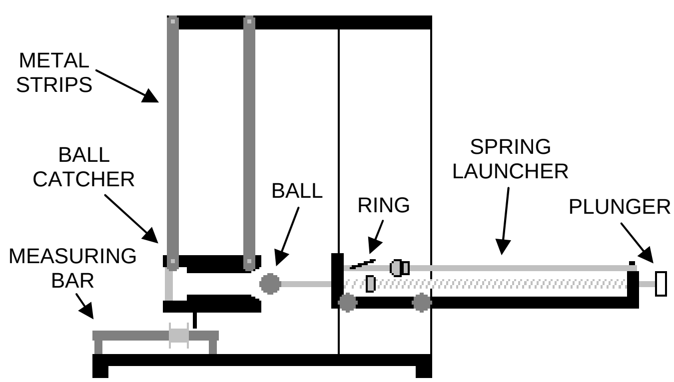


FIGURE 3 – Ballistic Pendulum

At the front of the lab there are some levels. Place a level on the base of the device. If it is not level then there are paper strips at the front of the lab you can use to prop up an end of the device to make it level. Return the level to the front of the lab.

What You Need To Do:

Part 1 – Guided Combo Problem Before we discuss the stages for this problem, try out the device. Put the ball at the end of the launch arm. Pull back the plunger until the nut on the upper bar passes the nut on the plunger bar and they lock into place. Put one hand on the base to hold the device down and use the other to pull up on the ring with a quick motion. **See Figure 3.**

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?

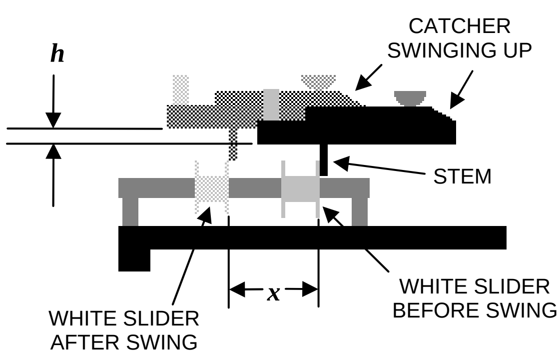
There are three stages to this combo problem. The *1st stage* is the launching of the ball from the spring launcher. The *2nd stage* is the collision between the ball and the catcher. The *3rd stage* is the ball and the ball catcher swinging up into the air.

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 our result (the spring constant) is used in the first stage. In other words, you will be dealing with the *last* stage *first* and vice versa.

3rd 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.

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.

In order to determine the height we need to examine the ballistic pendulum more closely. Below the catcher there is a measuring bar with a white piece of plastic that slides along the bar. **See Figure 4.**



$$h = \frac{x^2}{2L}$$

h is the vertical distance of the swing
x is the horizontal distance of the swing
L is the length of the metal strips holding up the catcher. **See Fig. 3**

FIGURE 4 – Swing of the catcher

There is a stem that protrudes down from the catcher. As the catcher swings up a vertical distance, ***h***, the stem pushes the white slider along the metal bar a horizontal distance, ***x***. **See Figure 4.** There is a ruler on the top of the metal bar that you can use to measure ***x***.

Trial	*x*
1	
2	
3	
4	
5	
6	
Ave. *x*	
L	
h	
$v_{ini.}$	

FIGURE 5

NOTE: All units should be in meters and kilograms.

B) Make a data chart in your lab report like the one in **Figure 5**. Do six trials of launching the ball into the catcher. Measure ***x*** each time and put the values in the chart. The white slider won't start at zero so you'll have to take an *initial* and *final* reading and then subtract the two readings to get ***x***. NOTE: The units on the slider are in *centimeters* NOT in millimeters like it shows.

C) Take the average of your ***x*** data and put it in the chart.

D) Use a ruler to measure ***L*** (the length of the metal strips, **See Figure 3**) and place this value in the chart.

E) Using your average ***x*** and the equation in **Figure 4**, calculate ***h*** and put the value in the chart. Show your calculation off to the side.

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.

B) Make a data table like the one in **Figure 6**.

C) <u>**CAREFULLY**</u> remove the ball catcher from the metal strips. Also, remove the metal strips from the apparatus. The strips can bend and break easily so <u>be careful</u>.

Object	Mass
Ball	
Catcher	
v'	
v_{ball}	

FIGURE 6

D) Go to the back of the lab and find the mass of the ball and the ball catcher. Place these values in the chart. **NOTE:** You don't need to reattach the strips and catcher to the apparatus. You will need them off for **Part 2**.

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 off to the side. 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	
k	

FIGURE 7

B) Make a data table like the one in **Figure 7**.

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 to measure the compression distance for the spring, **x**. Use the caliper on your desk to measure this. When the launcher is un-armed, measure the distance from the far side of the nut on the left to the far side of the nut on the right. **See Figure 8**. Grab your TA for help either measuring the distance or reading the caliper. Place this value in the chart.

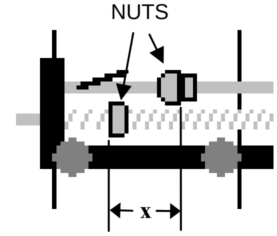


FIGURE 8 – Measuring the compression distance

F) Using the equation you just derived in **A)** and the result from the 2nd Stage, calculate the spring constant. Show your calculation off to the side. 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 2**. 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) 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 9** on the next page.

C) Second, you are going to adjust the compression distance of the spring launcher. You should be able to loosen the nuts on the top arm of the launcher with your fingers. **See Figure 8.** If the nut is too tight then there is a pair of pliers at the front of the lab. Change the compression distance, ***x***, so that it is at least 0.5 cm either greater than or less than what it was when you started the lab. Your compression distance should not be less than 3 cm. NOTE: This will not change the spring constant of the launcher.

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 9**. 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.

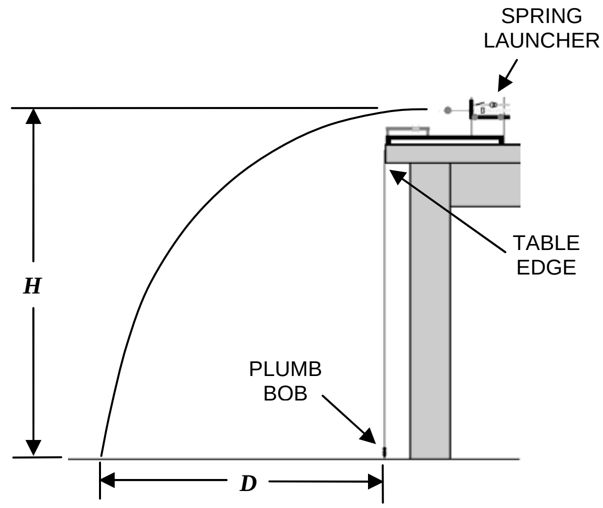


FIGURE 9

D) 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 9**. Keeping this in mind, take your data and fill out the chart.

E) 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 9**.

F) 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* (no need to tape) the carbon paper upside-down on top of this regular paper.

G) 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. Do this 5 times.

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

I) Please remount the ball catcher when you are done.

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.