

Lab 9: Ballistic Pendulum

Experiment for Physics 211 Lab at CSUF

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.

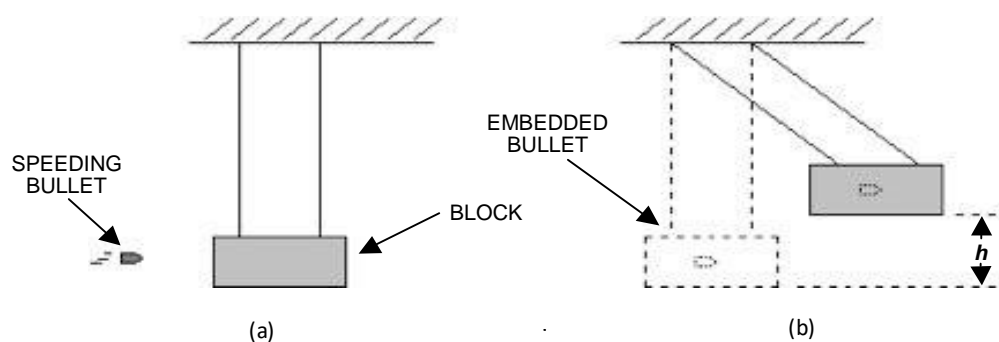
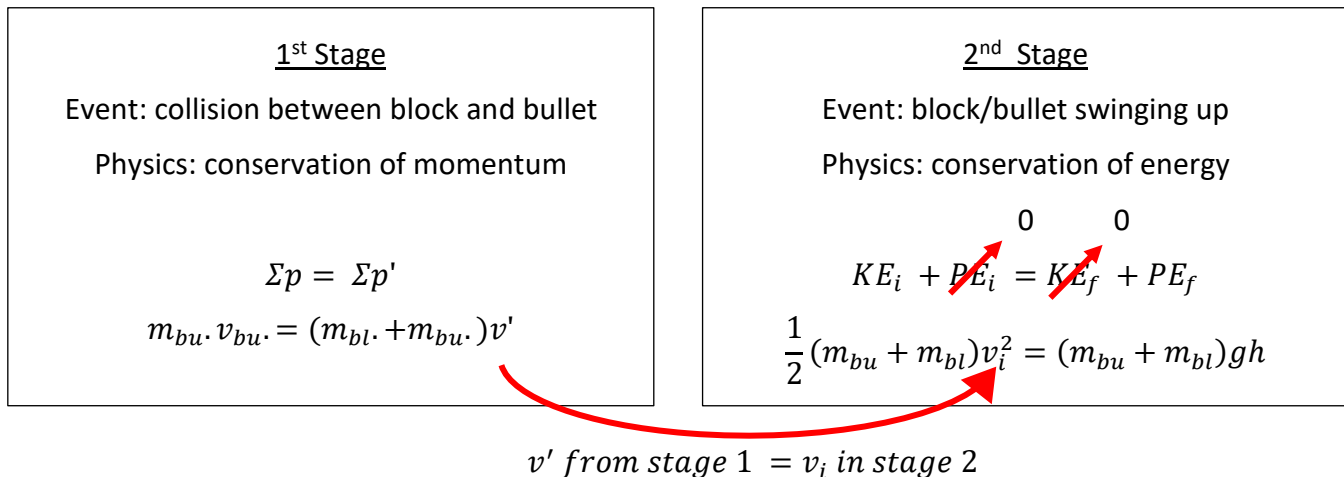


Figure 1 – Ballistic Pendulum

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.**

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.**

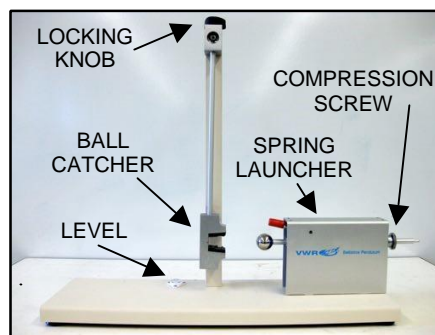
The initial part of the 2nd stage is right after the collision as the block/bullet begins its swing into the air. The final part of the 2nd stage is when the block/bullet is stopped at its highest point in its swing. The area of physics that this stage relates to is conservation of energy. At the beginning 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.

Figure 3 –
Ballistic
Pendulum



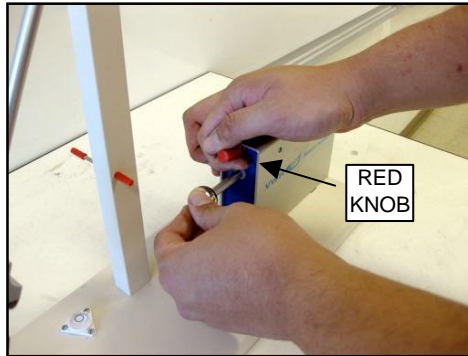
The pendulum should be levelled already but if you are concerned call your instructor over to check the leveling.

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 4. This way it won't accidentally launch and slam into your hand.

Figure 4 - Arming the Launcher



Next, while the ball catcher arm is in the vertical position, tighten the locking knob snugly 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 continuing.

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 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.

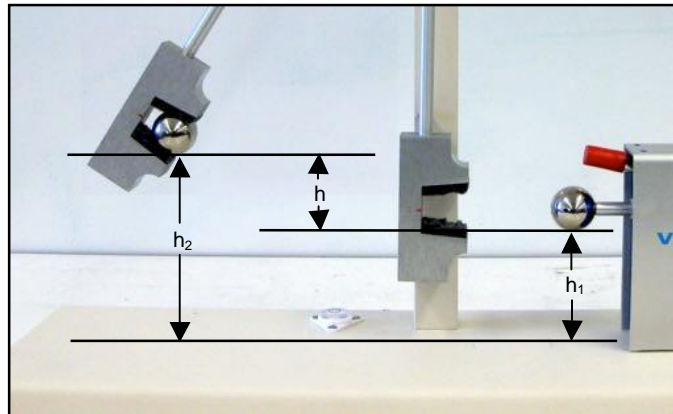
In other words, you will be dealing with the *last stage first* and vice versa. You'll work backwards through the stages, using the result from stage 3 in the setup for stage 2, and then the result from stage 2 in the setup for stage 1.

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. 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 instructor to make sure you are correct.

Figure 5 -
Pendulum
Diagram



- 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.

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

Table 1 – Part 1
3rd stage Data

Trial	h_2
1	
2	
3	
4	
5	
6	
Ave. h_2	
h_1	
h	
v_i	

- C) Measure the initial height, h_1 , and put it in the table. (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 table.

- D) Take the average of your h_2 data and put it in the table.
- E) Using your average h_2 and the equation above, calculate h and put the value in the table.
- F) Using the equation you derived in **A)**, calculate the velocity of the ball and catcher, v_i , as it starts its swing. Place this value in your table.

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 instructor to make sure that you are correct.

Table 2 – Part 1
2nd stage Data

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

- B) Measure the mass of the ball and place this value in the table. The mass of the catcher is given on the device. It's the same for everyone, so it's already in the table.
- C) 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, v' . Place this value in your table.
- D) Using the equation you just derived, calculate the velocity of the ball, v_{ball} , right before it collides with the catcher. Show your calculation below. Place this value in your table.

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.

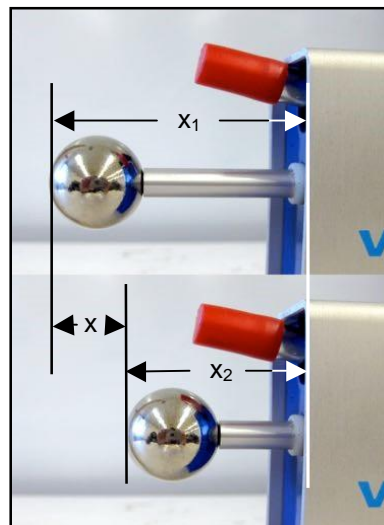
- A) You need an equation to calculate the spring constant of the spring in the launcher. Determine this equation using conservation of energy. You will need the potential energy equation for a spring ... $PE = \frac{1}{2}kx^2$. Before proceeding, check with your instructor to make sure you are correct.

Table 3 – Part 1 1st stage Data

v_f (m/s)	m_{ball} (kg)	x_1 (m)	x_2 (m)	x (m)	k (N/m)

- B) 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 table.
- C) You will also need the mass of the ball that you measured in the last section. Place this value in the table.
- D) 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 6. Place this value in the table. 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 table. Subtract the two values to get x and place it in the table.

Figure 6 - Measuring the compression distance



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.

- E) 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 table.

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*.

For this part use your spring constant from the end of part 1 as the given value of the Spring constant.

- 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.

Question 2:

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 instructor to see if your equations are correct before you move on.

Checkpoint 1:

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

Checkpoint 2:

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.

Checkpoint 3:

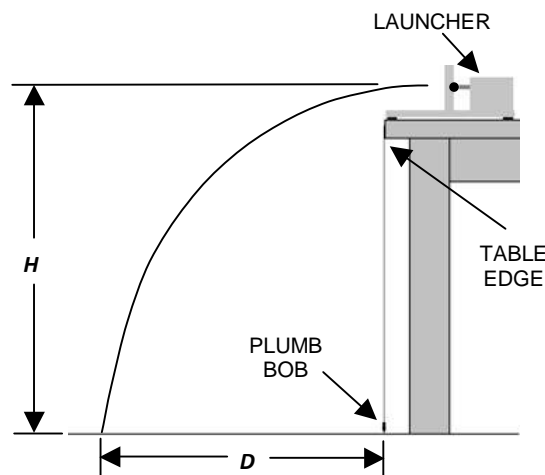
If a spring launcher with constant k is compressed a distance x , how fast is the ball moving immediately after it is launched? Solve this problem algebraically.

Question 3:

Combine the results of Question 2 and Checkpoints 1-3 to derive an equation for the horizontal distance D that the ball moves in terms of things you know or can measure. Ask your instructor to check your result before continuing.

- 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 7.

Figure 7 – Part 2
Setup Diagram



- C) 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 (360°) to no more than 5 complete turns.
- D) 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 7. You should have a *plumb bob* which you can hang from the edge of the table which will allow you to find where the edge of the table is relative to the floor. Use your blue tape on the floor once you find the reference point with the plumb bob.
- E) Based on your equations you should decide on what data you need to take. Fill in the header of the following table with the variables you need to measure (You may add/subtract columns as desired but your final column should be D)

Note that the height of the table is NOT the height, H , in Figure 7. How should you measure H ? (If you're not sure why, please ask your TA.)

Table 4 – Part 2 D calculation Data

						D (m)

- F) Take your data and fill out the table.
- G) 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 7. What is the correct way to measure D ? Again, please ask your instructor if you aren't sure why.

- H) Get a piece of graph paper from the front of the lab and use your blue tape to tape it onto the rubber in the catch box on the floor, place your tape back on the table far away from where you might be tempted to use it any further. Place (DO NOT TAPE) your carbon paper on top of the center of that paper (WITHOUT USING ANY TAPE AT ALL ON THE CARBON PAPER IT SHOULD JUST BE SITTING THERE, PUT YOUR TAPE BACK ON THE TABLE)
- I) Move the catch box so the center of the paper/carbon paper is located at the distance, D , that you calculated.
- J) Now you are going to run 5 trials of launching the ball. Make a data table 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.

Table 5 – Part 2 D Measurement and Analysis

<i>Trial</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>average</i>	<i>% diff</i>
D							

-
- K) Take the average of your **D** data. Calculate a percent difference between this value and the one you calculated in **I**).
 - L) Turn the compression screw all the way back in before you leave.

Conclusion

Remove the graph paper from the rubber in the catch box and submit it to your instructor with your names on it.

Submit any excel or graphical analysis data your instructor requests along with your report.

Follow the lab report guide to write a conclusion on this lab.

Conclusion
