

Lab Section (circle):

Day: Monday Tuesday

Time: 8:00 9:30 1:10 2:40

Lab 10: Ballistic Pendulum

Name: _____ Partners: _____

Pre-Lab

You are required to finish this section before coming to the lab – it will be checked and graded by one of the lab instructors before the lab begins.

In this lab, you will use a ballistic pendulum apparatus to investigate whether momentum is conserved when two objects collide. The ballistic pendulum consists of a spring gun that fires a metal ball, and a pendulum with a “cage” that catches the ball after it is fired. After the cage catches the ball, the cage-ball system swings upward. Understandably, the height to which the system swings depends on the speed at which the ball is shot. The ball can also be shot with the pendulum cage moved out of the way so that its motion can be analyzed using the equations for projectile motion. As you will see, comparing the data obtained using the ballistic pendulum with the data obtained using the projectile launcher will allow you to determine if momentum is conserved in the collision between the ball and the pendulum cage.

Review the textbook sections on mechanical energy and momentum.

1) Under what condition is the mechanical energy of a system conserved?

2) Under what condition is the momentum of a system is conserved?

Review the textbook sections and labs on projectile motion. Consider a ball launched horizontally from a starting point that has height h above the floor. The initial velocity of the projectile has a speed v and is in the horizontal direction only. You will measure the horizontal distance R that this projectile travels while falling the vertical distance h .

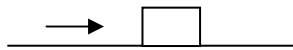
Pre Lab continues on the next page.

3) Derive an equation that gives v in terms of the measured variables R and h .

Conservation of Momentum

Momentum is a very useful concept when one studies collisions between two objects. Because there is no net force on the ball-cage system in the direction of travel, the total momentum of this system (the momentum of the ball plus the momentum of the cage) remains unchanged. That is, the total momentum immediately before the collision is equal to the total momentum immediately after the collision. Whenever the total momentum is unchanged in a collision, we say that the total momentum is conserved.

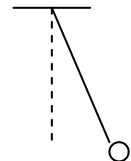
In order to better understand what is going on in the ballistic pendulum experiment, first consider a wood block of M sitting on a frictionless table. A bullet of mass m , which is shot from a spring gun on the left, comes to rest inside the block. As a result, the block and bullet slide to the right.



4) If the speed of the bullet is v_0 before it enters the block, use conservation of total momentum to find the speed of the block-bullet system after the collision.

Conservation of Mechanical Energy

A simple pendulum consisting of a bob and a light rod is shown. For simplicity, you can neglect friction at the pivot. The mass of the bob is m and the length of the rod is l . Initially the bob is pulled to the right so the rod makes an angle θ with the vertical direction. The rod is then released.



5) Using conservation of energy, find an expression for the speed of the rod when it returns to its lowest position in terms of the variables m , l , and θ .

End of Pre Lab .

I. Speed of the “Bullet” from a Spring Gun—Theoretical Analysis.

Examine four main parts of the apparatus: the spring gun, with adjustable spring tension; the pendulum and cage, which catch the projectile; the angle marker, which determines how high the pendulum rises; and the projectile (a steel ball). Note that the gun may be used without the pendulum by rotating the pendulum in the counterclockwise direction until it rests on top of the gun.

In the ballistic pendulum experiment, you load the spring gun and fire the ball. The ball and the cage “collide”, the cage catches the ball and then the ball-cage system swings up to a maximum angle that can be read from the apparatus. To determine if momentum is conserved, you must know the initial velocity of the ball just as it leaves the spring gun.

- 1) Recall what you did in the pre-lab section on Conservation of Momentum. How is the momentum of the system (ball and cage) before the ball enters the cage related to the momentum of the system after the ball is caught? State your reasoning.

- 2) Find an expression for the launch speed of the ball (its speed before entering the pendulum) in terms of the post-impact speed of the cage-ball system immediately after the ball impacts and lodges in the cage, and other relevant physical quantities (e.g. the mass of the ball, etc.).

- 3) Recall what you did in the pre-lab. Express the post-impact speed of the ball-cage system in terms of the maximum angle swung to which it swings (as indicated by the marker), and other relevant physical quantities (e.g., the length of the rod, etc.)..

- 4) What law of conservation did you use in deriving the expression of the speed in question 3?

- 5) Combining the answers to questions two and three, derive an expression for the launch speed of the ball in which any physical quantities may appear except the post-impact speed.

- 6) What quantities will you need to measure in order to find the launch speed of the ball using data from the pendulum's swing?

Talk to an instructor before you continue.

II. Measurement of launch speed – Pendulum Method

- 1) Measure the length of the pendulum (from the pivot point to the center of the bob). Each member of your group should measure independently for a minimum of three trials. Then use the “worst-case” method to get the uncertainty.
- 2) Measure the mass of the ball. Each member of your group should measure independently for a minimum of three trials. Then use the “worst-case” method to calculate the uncertainty.
- 3) Record the mass of the pendulum (it is printed on the apparatus), also estimating its uncertainty.
- 4) The spring is set at a relatively high compression value, so when the projectile (ball) will be launched at a fairly high velocity. **Be careful when launching the projectile: make sure no people or breakable objects are in the projectile path!!** Load the gun, hold the base securely, and fire the projectile into the pendulum. If the cage does not catch the ball, adjust the screw on the bottom of the cage, and try again. If the cage still doesn't catch the ball when it is fired, adjust the tension a bit and repeat the procedure until it can be caught. When the system is working correctly, fire the ball into the cage and record the maximum angle indicated by the marker. To prevent the marker from wandering, catch the pendulum as it swings back down. Complete ten trials, making certain to estimate the uncertainty of the reading of angle.

5) Use one of your trials to find the speed of the pendulum immediately after it catches the ball.

6) Use the result from question 5 and other necessary data to get the launch speed of the ball (V_{ball}).

7) Now suppose the ball is launched horizontally with the speed V_{ball} . Using your pre-lab work, predict the horizontal distance (range) that the ball will travel if the pendulum is moved out of the way, so that the ball is fired as a projectile.

III. Measurement of launch speed – Projectile Method

1) To check your result using another method, rotate the pendulum arm out of the path of the ball. **Do not adjust the spring tension.** Now this is the same setup you used in the projectile lab. Tape a piece of paper on the floor at the estimated location and place carbon paper on it. The landing

position of ball will be marked on the paper. Fire the ball 10 times onto the paper and measure the horizontal distance for each trial. Record them in a table below.

2) How do your results from the measurement compare with the predicted range?

Talk with an instructor before you leave the lab.

Homework Problems

While a calculator is a very powerful and useful tool, it is not always the appropriate piece of equipment for the job. In this lab you took ten data points from which you'll need to calculate the launch velocity of a ball fired from a spring gun (V_{ball}). You could use a calculator to calculate V_{ball} for each point or you could use software: enter the data and a formula into a spreadsheet and it would calculate them for you. In this lab we will do the latter. Using a spreadsheet saves time, allows for more sophisticated analysis, and minimizes 'calculator errors'.

Use Excel to make a spreadsheet that calculates V_{ball} for both the pendulum and trajectory methods. Be sure to attach your spreadsheet to the homework before turning it in. Be sure you answer the questions at the end of the homework.

Pendulum Method

Following the example included in this lab, create an Excel worksheet for your pendulum data. First, type in cell **A1** the label "Pendulum Method". Below this label the columns as follows:

<u>Column</u>	<u>Heading</u>	<u>Comments</u>
A:	length (m)	pendulum length-put the best value in all rows
B:	angle (deg)	in degrees, each trial in a different row
C:	M_{pend} (kg)	pendulum mass, best value in all rows
D:	M_{ball} (kg)	mass of the ball, best value in all rows
E:	V_{ball} (m/s)	ball speed, calculated by Excel formula from data in rows A-D.

The column headings are meant to be descriptive, yet as short as possible to reduce the column widths and conserve paper. In the row below the column headings, put the uncertainty corresponding to each variable.

Enter all appropriate data in columns A-D. To calculate V_{ball} select a cell in column E and type in the formula that you are using. It is necessary to type an equals sign [=] before a formula to let excel know that you want it to perform a calculation. When entering the formula you can click on the appropriate cell number or you can type the cell number to reference the appropriate data. **Caution:** Excel assumes angles are in radians. You can convert your angles to radians or make an adjustment in your formula to convert the angle to radians there.

When the formula has been entered appropriately a value for V_{ball} should appear in that cell. If you move the cursor to the lower right hand corner of the cell it will turn into a small cross. This is your fill handle. Click and drag down the column to calculate the V_{ball} for the remaining data.

Calculate the average V_{ball} for all points below the individual V_{ball} calculations. To do this type an equal sign and then select the function wizard from the toolbar. Select AVERAGE and then highlight or enter the cells from which you want to calculate the average. You can also type AVERAGE() and enter the cells you want to average in the parentheses.

Choosing one row of your data, use the 'worst case' analysis method to calculate the uncertainty in your calculation of V_{ball} . Start by highlighting a cell below the data in your spreadsheet and labeling it "Uncertainty Analysis". To do the uncertainty analysis, highlight one row of data. Right click on that row of data and select copy from the menu. Highlight a cell below your Uncertainty Analysis label and right

click and paste your row of data there. Highlight the copied row of data and place your cursor in the lower right hand corner of the highlighted cells. When it turns to a small cross again click and drag down two more rows. This copies the data to the other cells. Within each cell you can change the data to their max and min values to calculate the worst-case uncertainty. Notice when you change the variables the V_{ball} changes accordingly. Calculate the uncertainty and again state your final result as (best +/- uncertainty).

Projectile Method

Skip a row and create a new table to analyze the projectile data for the same spring tension. Start by labeling this table “Projectile Method”. In this table, there should be only three columns.

<u>Column</u>	<u>Heading</u>	<u>Comments</u>
A:	height (m)	vertical distance the ball travels, best value in all rows
B:	range (m)	horizontal distance the ball travels, each trial in a different row
C:	V_{ball} (m/s)	ball speed, calculated by Excel formula from data in rows A & B

Calculate the best V_{ball} from the height and range data.

Again find an average V_{ball} , formatting the data as you did in the previous method.

Choosing one row of your data, use the ‘worst case’ analysis method to calculate the uncertainty in your calculation of V_{ball} , formatting the data as you did in the previous method.

Questions:

- 1) State the two final results you obtained above. Do they agree within uncertainty limits? If not, what may contribute to the discrepancy?

2) For most, the uncertainty for the pendulum method is higher than the uncertainty for the projectile method. Even if this is not the case for your data discuss what might lead us to expect this?

3) Does the mechanical energy of the ball-pendulum system change before and after the collision? To answer this question, find the energy of the system before and after collision, respectively. Is there any difference between them?

4) During the collision, is mechanical energy gained or lost by the system? State your reasoning.

5) If mechanical energy is NOT conserved by the system, explain where the missing energy went?