LAKE FOREST COLLEGE
Department of Physics

Physics 115 Experiment 1: Ballistic Pendulum v1 Spring 2025

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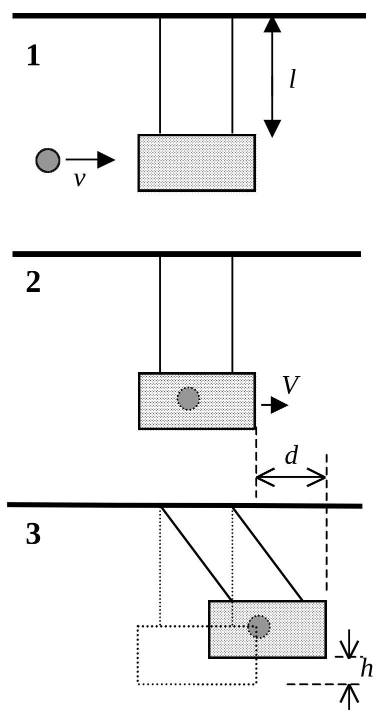
Table number: 8

Preliminary Instructions
As you did last semester, create a folder for you and your lab partner on Teams. Save a copy of these instructions for each student to that folder. Include your name in the filename. As you edit this document put your text in a different color. Save one copy of the *Excel* template with both your and your partner's name included in the filename.

Experimental purpose of today's experiment
Measure the velocity of a projectile.

Pedagogical purpose of today's experiment
Recall laboratory procedures and review concepts of conservation of momentum and energy and of projectile motion.

Background
Part 1 employs a ballistic pendulum and uses the conservation of linear momentum and the conservation of mechanical energy. There are three stages to consider.



In **stage 1** (immediately after the ball is fired from the spring gun), the ball (mass m) has velocity v.

The ball collides with the block (mass M) and sticks inside the block. After the collision, the ball and block move together with velocity V. This is a perfectly inelastic collision. The horizontal component of linear momentum of the system is conserved.

$$mv = (m+M)V \quad (1)$$

Stage 2 is the time after the collision but before the ball and block have moved significantly. The ball and block together then swing upward like a pendulum.

In **stage 3**, the ball and block swing to their maximum height, h. The total mechanical energy of the system is conserved in the swinging process.

$$\frac{1}{2}(m+M)V^2 = (m+M)gh \quad (2)$$

It is hard to measure the height, h, directly, but h is related to the horizontal distance the block recoils, d, and the length of the strings, l. Specifically,

$$h = l - \sqrt{l^2 - d^2} \quad (3)$$

We will measure l and d. From equations (2) and (3), we can find the velocity of the system in stage 2:

$$V = \sqrt{2g\left(l - \sqrt{l^2 - d^2}\right)} \quad (4)$$

With V, we can use equation (1) to find the velocity of the ball, v, before it hits the block.

$$v = \frac{m+M}{m}\sqrt{2g\left(l - \sqrt{l^2 - d^2}\right)} \quad (5)$$

Part 2, the projectile motion portion of the lab, is similar to experiments that you did in PHYS 114. The lab instructor will help you recall the details.

Procedure

Use the medium range setting for the gun spring tension for all parts of the experiment. Make sure that the gun is level (using the protractor scale on the side) and securely mounted.

Part I: Ballistic Pendulum. Find the velocity of the ball as it leaves the gun by firing it horizontally into the pendulum and measuring the recoil distance of the pendulum.

1. **Draw a sketch of the apparatus showing all of the important distances and masses.**

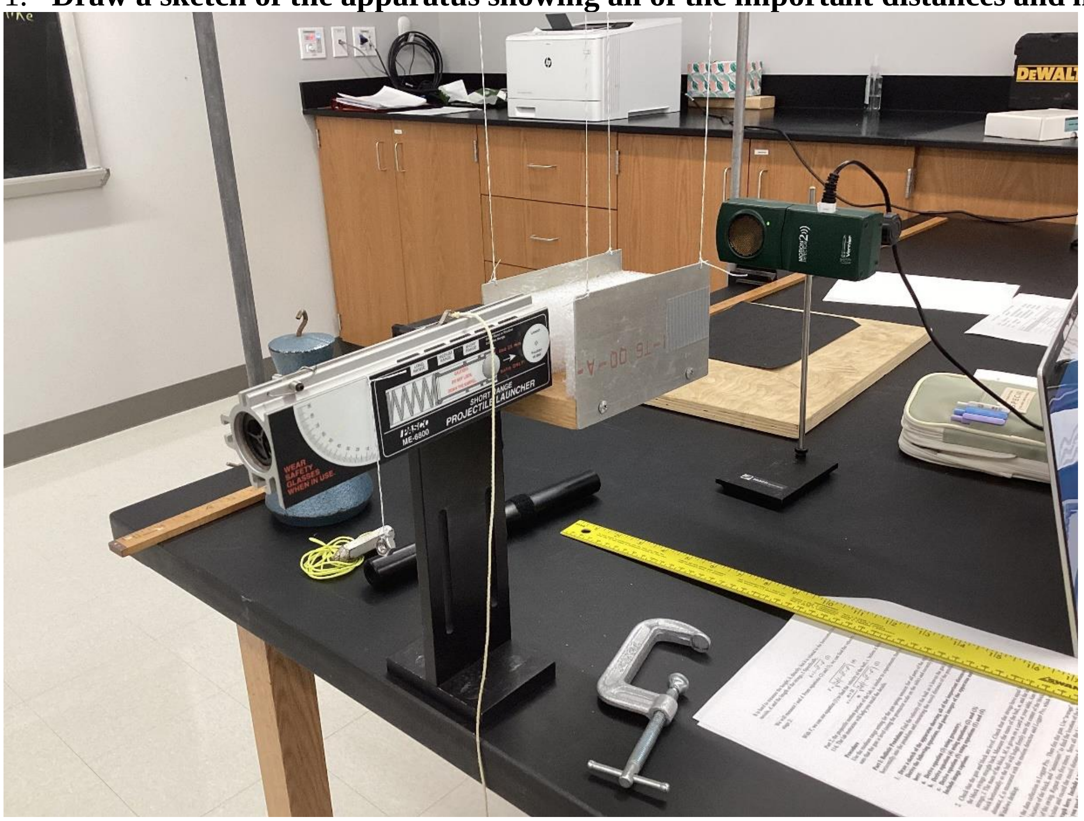


Figure 1. Ballistic Pendulum Apparatus. The PASCO Short Ranged Projectile Launcher is used to launch a 20mm metal ball with a mass (m) of 0.067kg. The box with a mass (M) of

0.0237kg catches the ball and acts as a pendulum. It moves towards the Vernier Motion Detector 2.

Derive the following equations, and paste images of the apparatus and derivations here:

a. Derive equation (3) using geometry.
b. Derive equation (4) using equations (2) and (3).
c. Derive equation (5) using equations (1) and (4).
Include image captions.

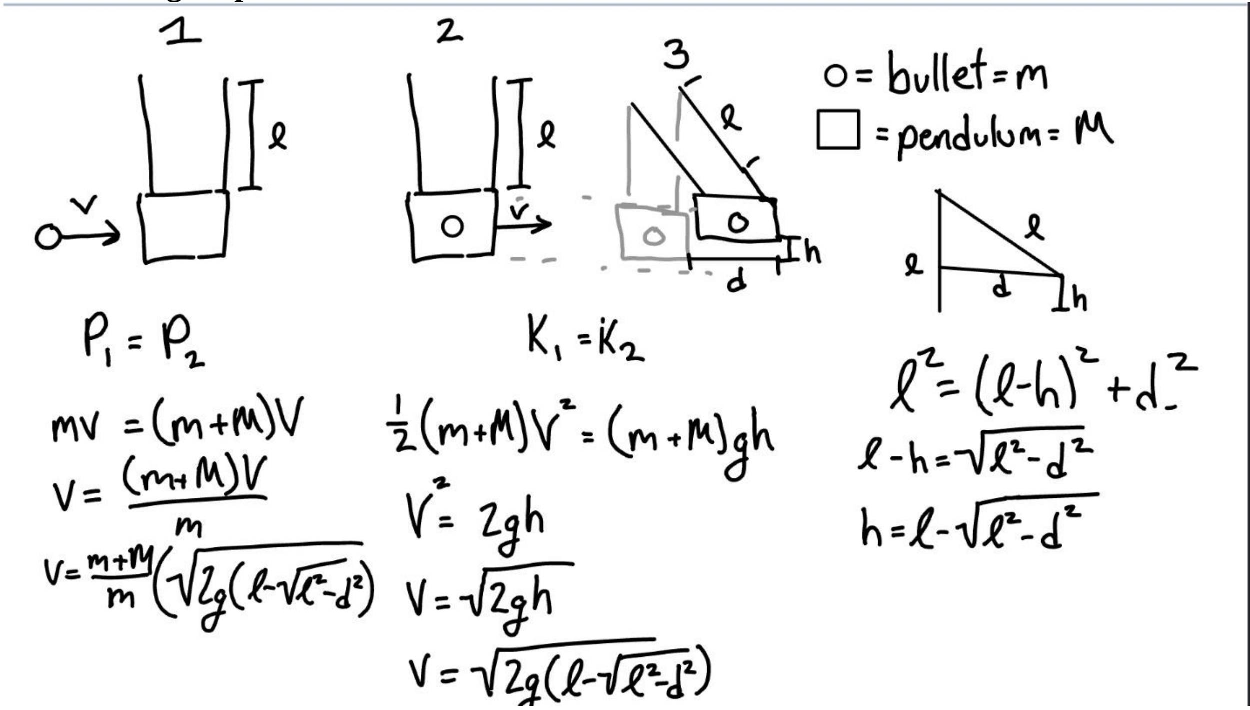


Figure 2. Ballistic Pendulum Equations Derivations. The collision of the ball and the pendulum is completely inelastic so both momentum and energy are conserved. M represents the mass of the pendulum, m represents the mass of the bullet, l represents the length of the string, d represents the horizontal distance, h represents the vertical distance, g represents the force of gravity, and v represents the velocity.

2. Check that the gun and block are level. Check that the strings have equal lengths and that the block swings straight back. Measure the mass of the ball, *m*, and the length of the strings, *l*. The mass of the block, *M*, is given on a card at your table. Aim the gun into the block horizontally so the ball will lodge firmly into the center of the block. The recoil distance, *d*, is measured with the motion detector and *Logger Pro*, which is on the Windows desktop.

3. Start the data collection in Logger Pro. Then fire the gun. Use “average” to obtain the initial location of the block, and “minimum” to find the location of the block at the extreme of the swing. Repeat this five times. Save all the Logger Pro graphs into your folder. Calculate and record the recoil distance for each trial in the *Excel* spreadsheet.

Paste one graph here. Include a caption that describes the shape of the graph and explains how you used it to find the recoil distance.

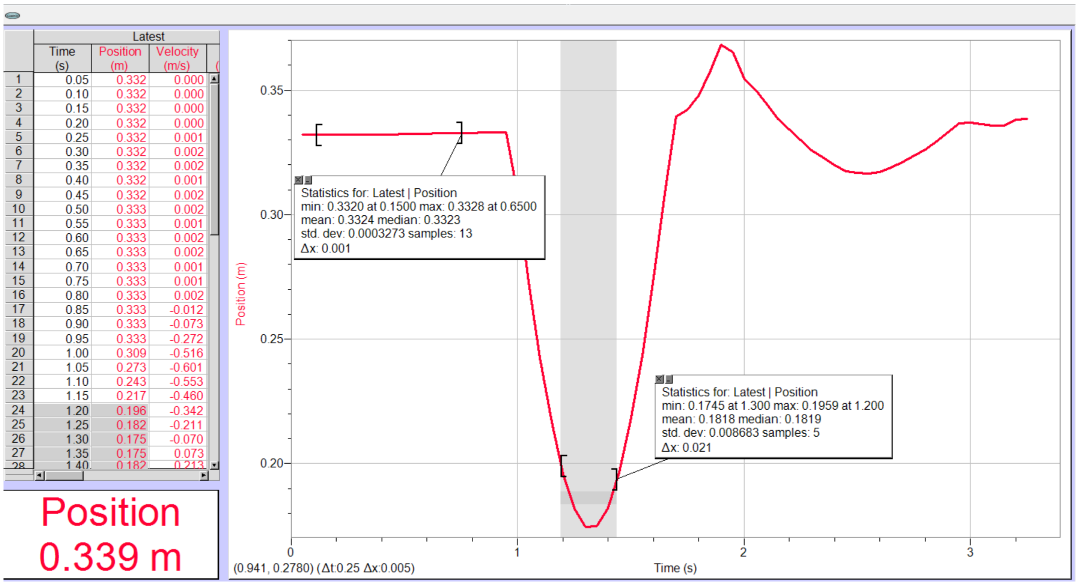


Figure 3. Pendulum Position Logger Pro Graph. The mean of the plateau is the distance from the pendulum to the motion detector at equilibrium. The minimum of the valley is the minimum distance between the pendulum and the motion detector. The difference between the minimum and the mean is the horizontal distance (d) traveled by the pendulum.

4. Use Equation (5) and *Excel* to compute the initial velocity of the ball, *v*, for each trial. Compute the average initial velocity of the ball and the standard deviation of the initial velocities. Adjust the formatting of Excel to show a reasonable number of significant figures for each value. Show all digits of directly measured quantities. Show 1 sig. fig. in the uncertainties and show the values to the same decimal place as their uncertainty. Show relative uncertainties to 2 sig. figs. **Paste a copy of the Excel table here. Include a table caption.**

M (kg)=	0.273

m(kg)=	0.067
l (m)=	0.49

Trial	d (m)	v(m/s)
1	0.158	3.63
2	0.158	3.63
3	0.150	3.45
4	0.148	3.40
5	0.151	3.47
	average	3.52
	std dev	0.11
	rel unc (%)	0.03

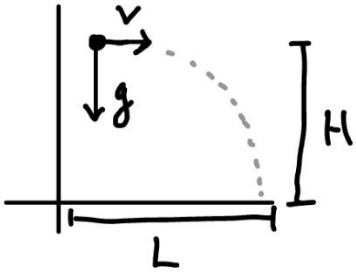
Table 1. Ballistic Pendulum Excel Table. Five trails were performed with the same ballistic pendulum. In the fourth trial the pendulum traveled the least distance and had the lowest velocity at 0.148m and 3.40m/s. The first and second trials are tied for the largest distance and fasted velocity at 0.158m and 3.63 m/s. How far the pendulum swung was relative to the velocity, the faster the velocity the further the pendulum swung.

Part II: Projectile Motion. Find the velocity of the ball as it leaves the gun by firing it horizontally to the floor and measuring the horizontal range and vertical displacement with carbon paper, a ruler, and a plumb bob. This is a similar procedure to that which you used last semester for the conservation of mechanical energy experiment.

5. Using kinematics, derive the formula for the initial velocity of the ball in terms of the initial vertical height, H, and the horizontal range, L, of the ball. Your answer should be:

$$v = L\sqrt{\frac{g}{2H}} \quad (6)$$

Place the derivation here. Include a sketch of the apparatus showing all of the important distances.



F	x	y
$\vec{F_a}$	v	0
$\vec{W}$	0	W

$$x - x_0 = v_x t + \frac{1}{2} a_x t^2$$
$$L = v_x t + \frac{1}{2} a_x t^2$$
$$L = vt$$
$$t = \frac{L}{v}$$

$$y - y_0 = v_y t + \frac{1}{2} a_y t^2$$
$$H = v_y t + \frac{1}{2} g t^2$$
$$H = \frac{1}{2} g t^2$$

$$H = \frac{1}{2} g \left(\frac{L}{v}\right)^2$$
$$\frac{v}{L} = \sqrt{\frac{g}{2H}}$$
$$V = L\sqrt{\frac{g}{2H}}$$

Figure 4. Projectile Motion Equation Derivation. The ball travels a horizontal distance (L) and a vertical distance (H) after launching from the projectile launcher. The vertical distance is the distance from the center of the launcher to the ground. The initial velocity of y is 0 and the acceleration of x is 0. This lets us solve for t and substitute one equation into the other. g represents gravitational acceleration and v represents horizontal velocity.

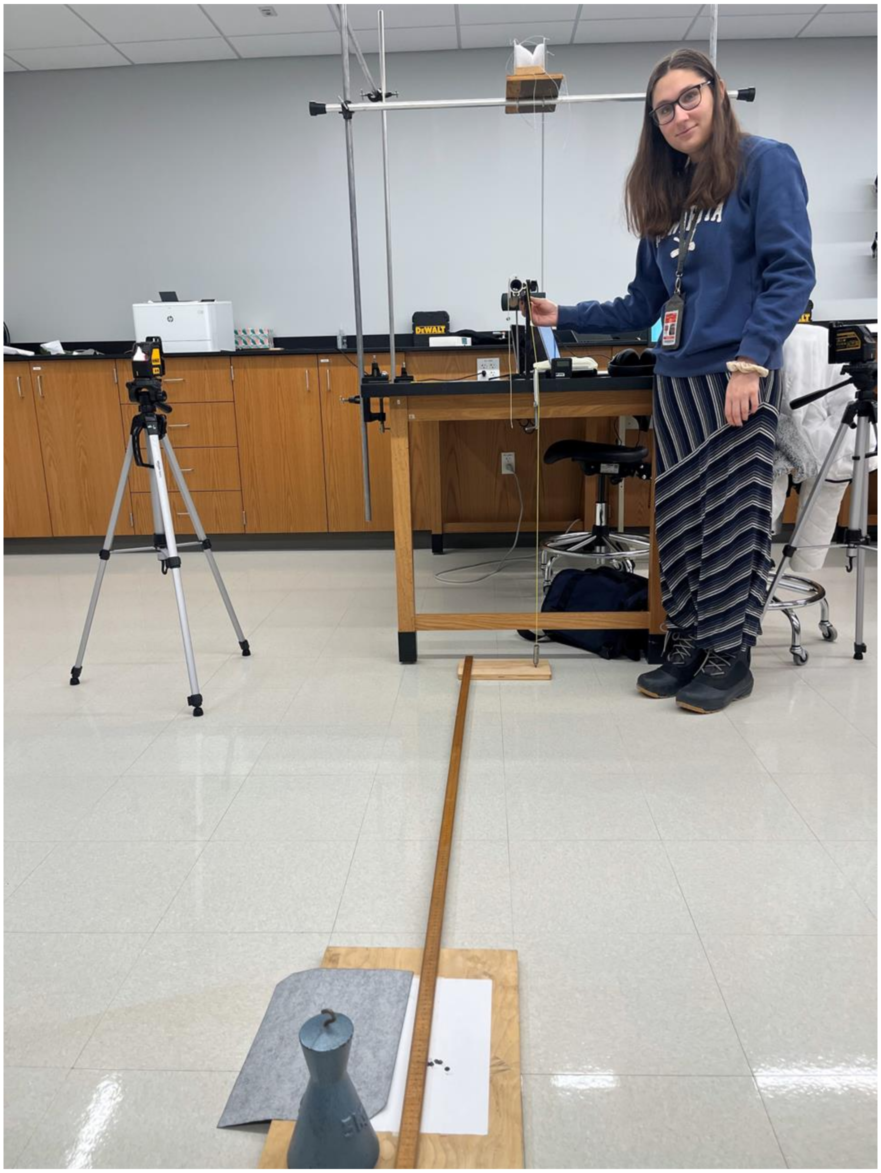


Figure 5. Projectile Motion Apparatus. The 25mm metal ball launches from the PASCO Projectile Launcher and lands on the transfer paper, leaving a mark on the white printer paper. The DeWalt laser level was used to ensure accurate measurement of the distance between the launcher and the floor (H). The pendulum was used to ensure accurate measurement of the distance between the end of the table and the mark (L). An extra 0.1cm was added to each measurement to account for the launch position of the ball.

6. Fire the gun five times and measure the horizontal range of the ball each time. Record the values in the *Excel* spreadsheet.

7. Use the laser level to measure the initial vertical height. Measure from the bottom of the ball in the gun to the height of the laser, and from the height of the laser to the top of the board on which the ball lands.

8. For each range measurement, use *Excel* to calculate the initial velocity using Equation 6. Then compute the average initial velocity and the standard deviation of the initial velocities. Adjust the formatting of your Excel sheet to make it easy to read. As you did in part 1, adjust the number of digits shown in each value. **Place a copy of the Excel table here. Include a table caption.**

bottom of ball in gun to laser (m)=	0.171
Top of board to laser (m)=	0.963
H(m)=	1.134

Trial	L(m)	v(m/s)
1	1.724	3.58
2	1.721	3.58
3	1.712	3.56
4	1.711	3.56
5	1.727	3.59
	average	3.57
	std dev	0.015
	rel unc (%)	0.004

Table 2. Projectile Motion Excel Table. Five trials of projectile motion were performed. The ball traveled the furthest and had the greatest velocity in trail five at 1.727m and 3.59m/s. The ball went the least distance and had the lowest velocity in trial four at 1.711m and 3.56m/s. The velocity is relative to the distance travelled. The further the distance, the greater the velocity.

Part III: Comparisons.

9. Find the difference between the two measured velocities. This says how far apart they are. Adjust the display to show the difference in velocity to the same decimal place as the larger of the two uncertainties of the velocities.

$$\text{diff} = \left|v_1 - v_2\right|$$

10. Find the percent difference between the two measured velocities. This gives a relative sense of how far apart they are. Adjust the display to show 2 sig. figs. in the percent difference.

$$\%\ \text{diff} = \frac{\left|v_1 - v_2\right|}{\text{avg}\left(v_1, v_2\right)}$$

11. Use the ratio test to compare the two measured velocities. This indicates if their difference can be accounted for by the statistical uncertainties. Adjust the display to show 2 sig. figs. in the ratio test.

$$\text{ratio test} = \frac{|v_1 - v_2|}{dv_1 + dv_2}$$

12. **Paste a copy of the comparison table here. Include a table caption.**

Difference (m/s)	0.06
Rel Diff (%)	0.12
Ratio Test	0.47

Table 3. Ballistic Pendulum and Projectile Motion Comparison Excel Table. Measuring the velocity with a ballistic pendulum and projectile motion gave very similar results. The difference between the averages of each experiment was 0.06m/s. The results agree according to the ratio test.

13. **Write an analysis here.** Make sure it includes the following:
    - Do the uncertainties in each of the two methods account for the discrepancy in the determinations?
    - Which of the two parts gives a result with the smaller statistical uncertainty?
    - Consider the effect of air resistance on the ballistic pendulum portion. Would the presence of air resistance cause the velocity you calculated to be larger or smaller than the actual initial velocity of the ball?
    - Consider the effect of air resistance on the projectile motion portion. Would the presence of air resistance cause the velocity you calculated to be larger or smaller than the actual initial velocity of the ball?

The uncertainties do not account for discrepancies that exist in all the trials such as a lightly off angle of the projectile launcher or the energy lost to air resistance or the foam of the pendulum.

Projectile motion had a much smaller uncertainties then the ballistic pendulum with an absolute uncertainty of 0.015m/s compared to 0.11m/s and a relative uncertainty of 0.004 compared to 0.03.

The air resistance slowed down the pendulum so the velocity would be higher without air resistance. We do not account for air resistance, so the calculated velocity is higher than the actual velocity.

The air resistance holds back the ball so with no air resistance it would travel further and have a higher velocity. We do not account for air resistance, so the calculated velocity is higher than the actual velocity.

14. **Write a brief conclusion here**. This should briefly restate your results and uncertainties for each of the two parts.

Ballistic Pendulum shows the ball launched from the projectile launcher has an initial velocity of 3.52 ± 0.11 m/s and the projectile motion shows that it has an initial velocity of 3.57±0.02m/s. The initial velocity of the ball determines the horizontal distance travel by the ball whether that is in free fall or transferred into a pendulum.

15. Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page. Double check that your report, Excel file, and all Logger Pro files are saved in your folder on Teams.

16. Clean up your lab station. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then shut down the computers. Ensure that the laptop is plugged in.

17. Check with the lab instructor to make sure that they received your submission before you leave.