

# PHYS 2211L - Principles of Physics Laboratory I

## Laboratory Advanced Sheet Ballistic Pendulum

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1. Objective. The objective of this laboratory is to use the ballistic pendulum to predict the initial velocity of a projectile using the principles of conservation of linear momentum and conservation of total mechanical energy.

2. Theory. The initial velocity of the projectile will be measured by two independent methods. Those measurements will then be compared.

a. The first measurement method will use the range of a projectile launched horizontally from a given height above the ground to measure the initial velocity of the projectile. From the results of the projectile motion laboratory:

$$v_{1i} = \sqrt{\frac{g x^2}{2 y_0}}$$

where

$v_{1i}$  is the initial velocity of the projectile,

$g$  is the acceleration due to gravity near the Earth's surface,

$x$  is the range of the projectile, and

$y_0$  is the initial height of the projectile above the ground.

b. Derive the expression for the initial velocity of a projectile in a ballistic pendulum system ( $v_{1i}$ ). Hint: Refer to Serway's discussion of the ballistic pendulum. The pendulum we use will be very similar to that shown Figure 9-11 of your text. Explain all assumptions and show all steps.

3. Apparatus and experimental procedures.

a. Equipment.

1) Ballistic pendulum apparatus

2) Meter stick.

3) Carbon paper.

4) Mass balance.

b. Experimental setup. The experimental setup is shown in Figure 1 (provided by the student).

c. Capabilities. To be provided by the student.

#### 4. Requirements.

a. In the laboratory.

1) Using the techniques you learned in the projectile motion laboratory, determine the initial velocity of the launcher by measuring the initial height and range of the mass when projected horizontally. (**Warning:** *Keep the pendulum portion of the apparatus out of the line of fire during this part of the laboratory.*) Conduct five range trials.

2) Measure the distance from the pivot point to the center of mass of the pendulum/ball system.

2) Conduct five trials allowing the projectile and the pendulum to collide. Measure the angle of the swing for the pendulum/ball system.

3) Measure the masses of the projectile and the pendulum.

b. After the laboratory. The items listed below will be turned in at the beginning of the next laboratory period. A complete laboratory report is not required for this laboratory.

#### **Para. 2. Theory.**

Provide the portion of the theory section dealing with the development of the equation used to calculate the initial velocity ( $v_{1i}$ ) of the projectile using the ballistic pendulum. Use the following symbols in your development:

1) The distance from the pivot to the center of mass of the pendulum/ball system is  $R_{cm}$ .

2) The angle of the swing of the ball and pendulum system is  $\theta$ .

3) The mass of the ball is  $m_1$ ; the mass of the pendulum is  $m_2$ .

#### **Para. 3. Apparatus and experimental procedures.**

1) Provide a figure of the experimental setup.

- 2) Provide a description of the capabilities of the equipment used in the experiment.

**Para. 4. Data.**

- 1) Provide a copy of your data (Annex A contains tables for data).
- 2) Provide the following calculations in a spreadsheet (Annex B provides equations for calculations which are contained in the [ballistic.xls](#) spreadsheet provided by your instructor):
  - a) The initial velocity of the projectile as determined by the range method.
  - b) The uncertainty in the velocity of the projectile as determined using the range method.
  - c) The initial velocity of the projectile as determined using the ballistic pendulum.
  - d) The uncertainty in the velocity of the projectile as determined using the ballistic pendulum.
  - e) The percent fractional errors in the initial velocity of the projectile determined using both the range method and the ballistic pendulum.
  - f) The percent discrepancy between the two initial velocities. Use the initial velocity determined using the projectile motion measurements as the accepted value in this calculation.

**Para 5. Results and Conclusions.**

- 1) Provide a statement of the initial velocities determined by each method and their uncertainties.
- 2) Provide a statement of the percent fractional error and percent discrepancy in your results for the initial velocity determined using the ballistic pendulum.
- 3) Assess the precision and accuracy of the experiment.
- 4) Describe sources of random error in the experiment.
- 5) Describe sources of systematic error in the experiment.

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**Annex A**  
**Data**

1. Initial height of projectile (use bottom of mass).

$y_0$ (m)	$\delta y_0$ (m)

2. Range of projectile.

trial	x (m)
1	
2	
3	
4	
5	

3. Mass measurements.

	mass (kg)	$\delta m$ (kg)
$m_1$		
$m_2$		

4. Pivot-center of mass distance.

$R_{cm}$ (m)	$\delta R_{cm}$ (m)

5. Swing angle.

trial	$\theta$ (°)
1	
2	
3	
4	
5	

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## Annex B Calculations

The calculations associated with the propagation of error are somewhat tedious and are, therefore, computed in a spreadsheet to avoid numerical mistakes. The Excel<sup>TM</sup> spreadsheet file is [ballistic.xls](#). Derivations of the formulas used in the spreadsheet are provided.

1. The "accepted" initial velocity is given by

$$v_{li,acc} = \sqrt{\frac{g x^2}{2 y_0}}$$

2. The uncertainty in the "accepted" initial velocity is given by

$$\delta v_{li,acc} = \sqrt{\left(\frac{\partial v_{li,acc}}{\partial g} \delta g\right)^2 + \left(\frac{\partial v_{li,acc}}{\partial x} \delta x\right)^2 + \left(\frac{\partial v_{li,acc}}{\partial y_0} \delta y_0\right)^2}$$

where,

$$\frac{\partial v_{li,acc}}{\partial g} = \frac{x}{\sqrt{\delta y_0 g}}$$

with  $g = 9.800 \text{ m/s}^2$  and  $\delta g = 0.005 \text{ m/s}^2$ ,

$$\frac{\partial v_{li,acc}}{\partial x} = \sqrt{\frac{g}{2 y_0}}$$

and

$$\frac{\partial v_{li,acc}}{\partial y_0} = -x \sqrt{\frac{g}{\delta y_0^3}}$$

3. The calculated value of the initial velocity measured using the ballistic pendulum is given by

$$v_{li} = \left(\frac{m_1 + m_2}{m_1}\right) \sqrt{2gR_{CM}(1 - \cos \theta)}$$

4. The uncertainty in the measured initial velocity is given by

$$\delta v_{li} = \sqrt{\left(\frac{\partial v_{li}}{\partial m_1} \delta m_1\right)^2 + \left(\frac{\partial v_{li}}{\partial m_2} \delta m_2\right)^2 + \left(\frac{\partial v_{li}}{\partial R_{CM}} \delta R_{CM}\right)^2 + \left(\frac{\partial v_{li}}{\partial g} \delta g\right)^2 + \left(\frac{\partial v_{li}}{\partial \theta} \delta \theta\right)^2}$$

where,

$$\frac{\partial v_{li}}{\partial m_1} = -\left(\frac{m_2}{m_1^2}\right) \sqrt{2gR_{CM}(1 - \cos \theta)}$$

$$\frac{\partial v_{1i}}{\partial m_2} = \left( \frac{1}{m_1} \right) \sqrt{2gR_{CM}(1 - \cos \theta)}$$

$$\frac{\partial v_{1i}}{\partial R_{CM}} = \left( \frac{m_1 + m_2}{m_1} \right) \frac{g(1 - \cos \theta)}{\sqrt{2gR_{CM}(1 - \cos \theta)}}$$

$$\frac{\partial v_{1i}}{\partial g} = \left( \frac{m_1 + m_2}{m_1} \right) \frac{R_{CM}(1 - \cos \theta)}{\sqrt{2gR_{CM}(1 - \cos \theta)}}$$

$$\frac{\partial v_{1i}}{\partial \theta} = \left( \frac{m_1 + m_2}{m_1} \right) \frac{gR_{CM} \sin \theta}{\sqrt{2gR_{CM}(1 - \cos \theta)}}$$

