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Laboratory Report

Determining the Initial Velocity of a Projectile Kinetic Equation and Ballistic Pendulum

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ABSTRACT

This experiment aimed to determine the initial velocity ((v_0) of a small metallic bal) using two methods: the **Kinetic Equation method** and the **Ballistic Pendulum method**. In the Kinetic Equation method, velocity was calculated based on kinematic principles, whereas the Ballistic Pendulum method involved inelastic collision principles, relying on conservation of momentum and energy in a pendulum setup. By comparing the initial velocities from both methods, the experiment assessed the accuracy and reliability of each approach, with considerations for energy losses and sources of error.

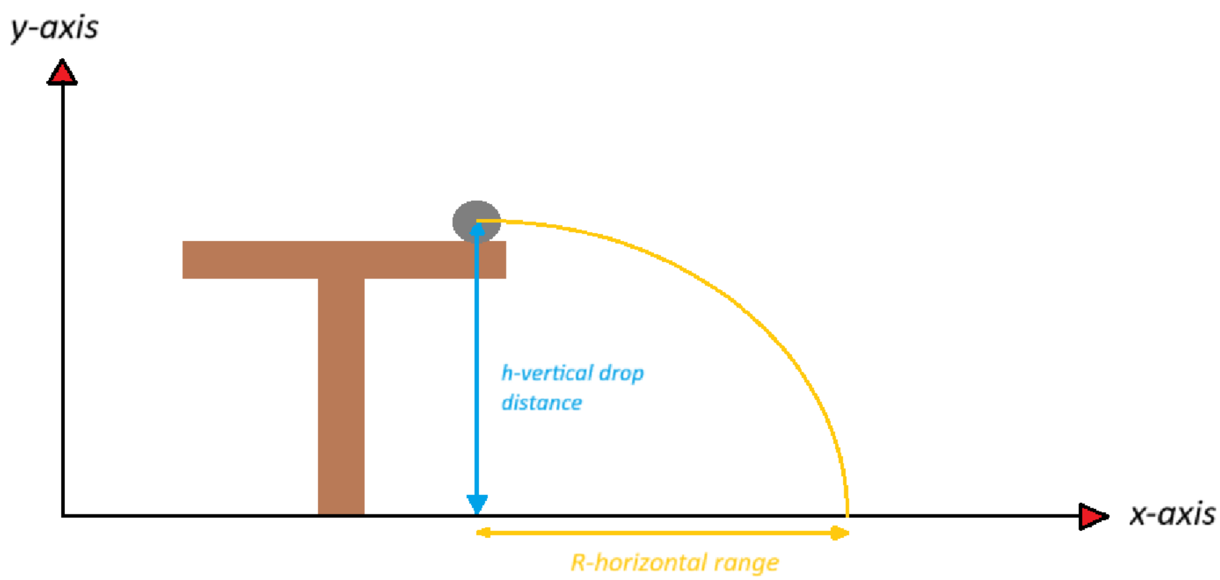
THEORETICAL BACKGROUND

The study of projectile motion involves understanding the principles of kinematics and energy conservation. This experiment uses two different methods to determine the initial velocity of a projectile: the Kinetic Equation Method and the Ballistic Pendulum Method. Each approach relies on distinct physics concepts and mathematical formulations.

KINEMATIC EQUATIONS AND PROJECTILE MOTION

Projectile motion is the motion of an object thrown or projected into the air, subject to only the acceleration of gravity. In this type of motion:

- The horizontal and vertical motions of the projectile are independent.
- The horizontal velocity remains constant (assuming no air resistance), while the vertical velocity is influenced by gravity.



In the **Kinetic Equation Method**, the initial velocity is determined by measuring the horizontal range and vertical drop distance. Using the kinematic equations, we can describe the horizontal range R and the time of flight t based on the following principles:

- The time t it takes for an object to fall from a height h is given by:

$$t = \sqrt{\frac{2h}{g}}$$

- Since horizontal velocity remains constant, the horizontal range R can be expressed as:

$$R = v_{Kinetic} \times t$$

By substituting the expression for t from the first equation, we get:

$$v_{Kinetic} = \frac{R}{\sqrt{\frac{2h}{g}}} = R\sqrt{\frac{g}{2h}}$$

This equation allows us to calculate the initial velocity $v_{Kinetic}$ based on the horizontal range R, the gravitational acceleration g, and the vertical drop distance h.

CONSERVATION OF MOMENTUM AND ENERGY IN THE BALLISTIC PENDULUM

The **Ballistic Pendulum Method** is an application of the principles of conservation of momentum and energy. A ballistic pendulum consists of a projectile (usually a small ball) fired into a pendulum bob. The projectile becomes embedded in the bob, and they swing together to a certain height after the collision. *FIG. 1* shows a schematic idealization of a ballistic pendulum.

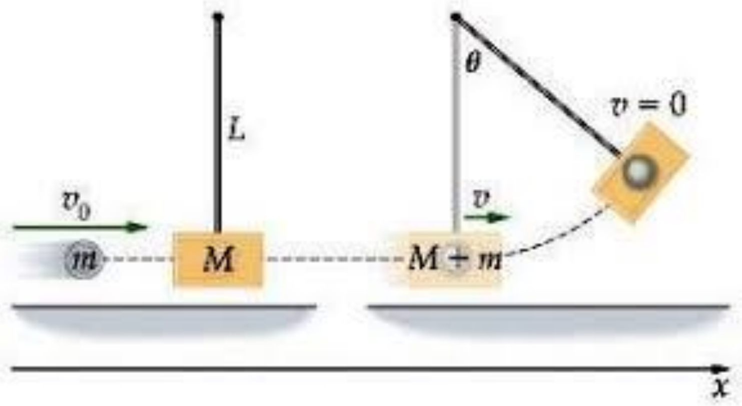


FIG. 1 Simple single rod ballistic pendulum schematic

This method relies on two key conservation laws:

- **Conservation of Momentum**: In an inelastic collision, where the projectile becomes embedded in the bob, the total momentum of the system before and immediately after the collision remains constant. This conservation allows us to calculate the combined velocity V of the projectile and pendulum bob right after the collision:

$$v_{Pendulum} = (m + M)V$$

Where m is the mass of the projectile, $v_{Pendulum}$ is the initial velocity of the projectile, M is the mass of the pendulum bob, and V is the velocity of the combined mass right after the collision.

- **Conservation of Mechanical Energy**: After the collision, the combined mass (projectile and pendulum) rises to a maximum height h, at which point all kinetic energy has been converted into gravitational potential energy. The maximum height h allows us to determine V:

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

Solving for V, we get:

$$V = \sqrt{2gh}$$

Where h can be calculated, using **pendulum arm length L** and a **maximum angle θ** (measured in radian) projectile swings up to, as:

$$h = L(1 - \cos(\theta))$$

Using the expression for V, we can substitute back into the momentum conservation equation to solve for $v_{Pendulum}$, the initial velocity of the projectile:

$$v_{Pendulum} = \frac{(m + M)}{m}\sqrt{2gL(1 - \cos(\theta))}$$

These two methods provide different approaches for calculating the initial velocity of a projectile and allow for a comparative analysis of experimental accuracy and reliability.

PROCEDURE

MATERIALS:

- **Projectile Launcher** (FIG. 2): A device used to launch the small metallic ball at a consistent initial velocity, ensuring a controlled horizontal projection for each trial.
- **Ballistic pendulum setup** (FIG. 3): A pendulum bob that can capture the projectile.
- **Small Metallic Ball** (FIG. 4): A spherical ball with a diameter of 0.01588 meters, used as the projectile in the experiment.
- **Carbon Paper** (FIG. 5): Placed on top of A4 paper to mark the impact point where the ball lands, enabling accurate distance measurement.
- **A4 Paper**: Used as a base under carbon paper to make the landing mark visible, aiding distance measurement.
- **Ruler**: Used to measure the horizontal distance between the launch point and the impact point on the paper.
- **Protractor/Angular measurement tool /Software for Data Analysis**: Utilized to measure the pendulum's swing angle.

FIG. 2. Projectile Launcher

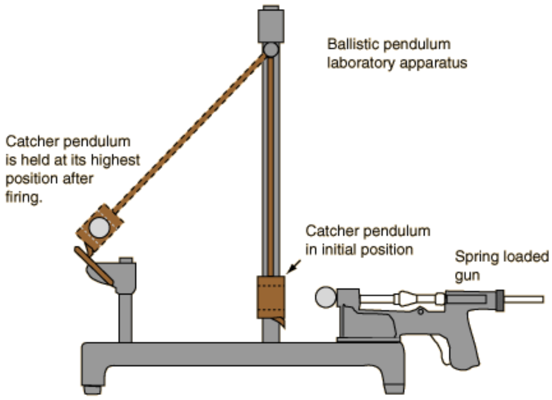


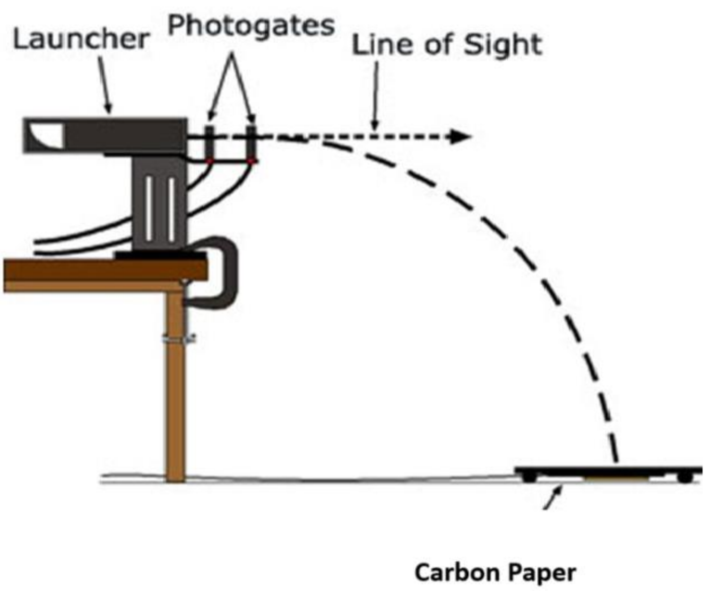
FIG. 3. Ballistic pendulum setup

FIG. 4. Metallic Ball

FIG. 5. Carbon Paper

METHODOLOGY

Kinetic Equation Method



1. **Setup**: Position the launcher to ensure the projectile is launched horizontally from a specific height h above the ground. Measure this vertical drop distance carefully. Refer to *FIG. 6* for visual representation of a final setup.

FIG.6. Final Setup for Kinetic Equation Method

2. **Launch and Measure Range**: Launch the projectile and measure the horizontal distance R it travels before it hits the ground.
3. **Calculate Initial Velocity**: Use the following formula to calculate the initial velocity $v_{Kinetic}$:

$$v_{Kinetic} = R\sqrt{\frac{g}{2h}}$$

Where:

- R is the horizontal range,
- g is the gravitational acceleration (9.81 m/s^2),
- h is the vertical drop distance.

Ballistic Pendulum Method

1. **Setup the Ballistic Pendulum:** Position the pendulum bob so it is at rest before the projectile is fired. Ensure the bob can capture the projectile upon impact. Refer to *FIG. 7* for the visual representation of a final setup.

FIG. 7. Ballistic Pendulum Method final Setup

2. **Launch the Projectile**: Fire the projectile directly into the pendulum bob. Upon impact, the bob and projectile swing together to a maximum angle (θ).

3. **Measure the Maximum Angle**: Store the angle (θ) in radians from the software after the projectile collision.
4. **Calculate Initial Velocity Using Conservation Laws**: Immediately after the collision, the initial momentum of the system (projectile + pendulum) can be represented as:

$$v_{Pendulum} = \frac{(m + M)}{m} \sqrt{2gL(1 - \cos(\theta))}$$

where:

- m is the mass of the projectile,
- $v_{Pendulum}$ is the initial velocity of the projectile,
- M is the mass of the pendulum bob,
- L is the pendulum arm length

DATA & ANALYSIS

The following table summarizes results from three trials:

Trial	M - Mass of Pendulm bob (kg)	m - Mass of the projectile (kg)	L - Pendulum arm length (meter)	R - Horizontal range (meter)	h - vertical drop distance (meter)	θ - Angle (radians)	Velocity - Kinetic Equation Method (m/s)	Velocity - Ballistic Pendulum Method(m/s)	Error (%)
1	0.1261	0.0163	0.372	1.300	0.842	0.162	3.14	2.70	15%
2	0.1261	0.0163	0.372	1.301	0.842	0.152	3.14	2.53	21%
3	0.1261	0.0163	0.372	1.306	0.842	0.156	3.15	2.60	19%

The results indicate that the initial velocity calculated by the Kinetic Equation Method is consistently higher than that calculated by the Ballistic Pendulum Method. This difference may suggest that factors such as air resistance, friction, or minor imprecision in angle measurements could have influenced the Ballistic Pendulum Method more significantly, leading to a reduced calculated velocity.

CONCLUSION

In this experiment, we aimed to determine the initial velocity of a projectile using two distinct methods: the Kinetic Equation Method and the Ballistic Pendulum Method. Our results showed a consistent difference between the velocities obtained from each method, with the Kinetic Equation Method yielding higher values than the Ballistic Pendulum Method. The percentage error between the two methods ranged from 15% to 21%, suggesting that each method is affected by different sources of experimental error.

The Kinetic Equation Method relies on measurements of horizontal range and vertical drop distance, which may introduce minimal error due to relatively straightforward measurements. On the other hand, the Ballistic Pendulum Method requires precise angle measurements during the pendulum's maximum swing, which can be challenging to capture accurately, potentially leading to a greater margin of error.

This experiment demonstrates the importance of choosing appropriate methods and understanding potential sources of error when measuring physical quantities. While both methods provide useful approximations of the projectile's initial velocity, factors such as air resistance, friction, and measurement inaccuracies impact the results. Future experiments could explore ways to minimize these sources of error, such as using more precise measuring tools or conducting the experiment in a controlled environment to reduce external influences.

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