Ballistic Pendulum

P4-1975

BACKGROUND:

The ballistic pendulum, invented in 1742 by English mathematician Benjamin Robins, revolutionized the science of ballistics as it provided the first way to accurately measure the velocity of a bullet. The method to measure the velocity was to directly measure the bullet momentum by firing it into the pendulum. Robins experimented with musket balls of one ounce in mass while other scientists used his methods with cannon shot of one to three pounds. Although the ballistic pendulum is considered obsolete in today's modern testing ballistics, it remains an accurate way to demonstrate the properties of momentum and energy in science classrooms. Unlike other methods of measuring the speed of a bullet, the basic calculations for a ballistic pendulum do not require any measurement of time, but rely solely on measurements of mass and distance.

Conservation Laws state that the conditions prior to the collision equal the conditions after the collision. Specifically, the Law of the Conservation of Momentum dictates that the momentum of the system before the collision is equal to the momentum of the system after the collision. Likewise, the Law of Conservation of Energy states that the Total Energy of the system before the collision is equal to the Total Energy of the system after the collision. In theory, an inelastic collision is a collision between two objects in which momentum is conserved and kinetic energy is not conserved. However, in using this ballistic pendulum, both Conservation of Momentum AND Conservation of Energy Laws can be assumed as long as the pendulum swings to its largest angle without being impeded in any way due to friction, heat or physical loss at the collision site.

In the ballistic pendulum experiment, your students will be able to demonstrate the Conservation of Momentum, find the Initial Velocity of the fired "bullet", be able to verify the initial velocity of the "bullet" and find the Potential and Kinetic energies in the system. When the bullet is fired into the resting pendulum, the energy and momentum of the "bullet" is transferred to the pendulum. By measuring the height of the pendulum's swing, the potential energy of the pendulum when it stops can be measured. This allows the pendulum's initial velocity to be calculated. Using the conservation of momentum, the student can calculate the velocity of the bullet.

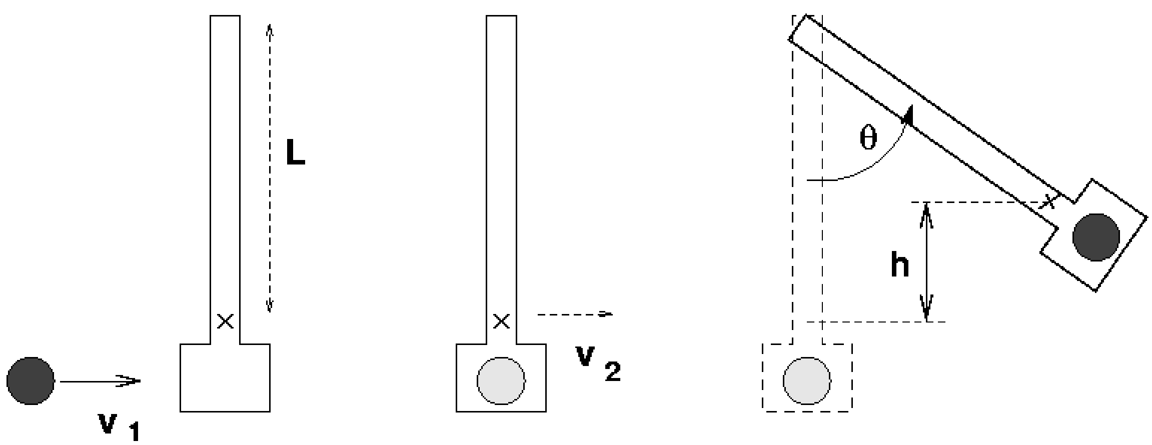
DESCRIPTION:

Analyze conservation of momentum and energy with this classic lab! The ballistic pendulum demonstrates simple concepts – collisions, conservation and transformation of energy – in a captivating hands-on lab. Launch the projectile into the pendulum and analyze the resulting swinging motion. Where can conservation of energy be applied, and where can it not?

Quality engineering assures repeatable, consistent results. The precision angle indicator allows for accurate measurements while an adjustable launch mechanism gives the ability to change velocities quickly. Includes experiment guide.

INSTRUCTIONS:

When performing the experiment, be certain that the pendulum is in its resting state, the angle meter is reset to the "0" position and the spring gun is loaded and set to the desired velocity. After firing, the angle meter will indicate the maximum angle for which the pendulum swing. The height of the pendulum bob after firing is the most crucial measurement to ensure accurate results in determining the velocity of the bullet. By utilizing the angle meter on the ballistic pendulum and some simple trigonometry, your students can determine the height of the pendulum after firing.



Inelastic collision

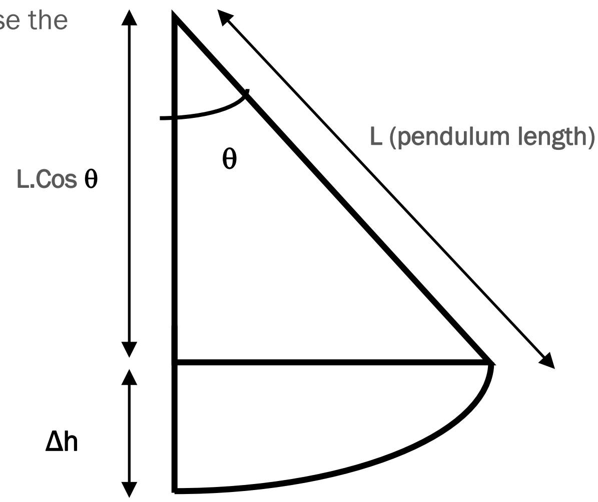
KE turns into GPE

CALCULATIONS:

To find the height of the pendulum after firing, use the schematic on the next page to help students understand the importance of the angle meter in the calculation. Record the angle meter reading and determine the height with precision.

To determine the height gained by the pendulum use the use the relationship…

$\Delta h = L - L\cos\theta$



After the height is found, use the Law of Conservation of Energy to determine the pendulum's velocity.

$KE = GPE$ →

$\frac{1}{2} mv^2 = mgh$ →

$\frac{1}{2}$ (mass of bullet + pendulum) v^2 = (mass of bullet + pendulum)gh

(Mass can be ignored since it appears on both sides of the equation.)

$\frac{1}{2} v^2 = g \Delta h$ →

$v^2 = 2g \Delta h$ →

$v_{(bullet + pendulum)} = \sqrt{2g \Delta h}$

Now, we can then use the Law of Conservation of Momentum to find the speed of the bullet…

$p_{bullet} = p_{(pendulum + bullet)}$ →

$m_{bullet} \cdot v_{bullet} = m_{(bullet + pendulum)} \cdot v_{(bullet + pendulum)}$ →

$v_{bullet} = [m_{(bullet + pendulum)} \cdot v_{(bullet + pendulum)}] / m_{bullet}$

VERIFYING THE VELOCITY OF THE BULLET:

Method #1

In the first method, the ball can be fired through a photogate to determine the time and distance resulting in the velocity of the ball.

Method #1

The second method of finding the ball's velocity is to fire the ball horizontally off a lab table utilizing 2-dimensional motion considerations. Measuring the vertical height of the ball at firing and the horizontal distance the ball traveled, students will be able to verify the ball's horizontal velocity. This method allows students to conceptualize the connections in Physics and make realizations that relationships are interwoven throughout Physics.

Use the relationship below for using the 2-dimensional projectile motion method of verifying the ball's velocity. Since the time of flight for vertical & horizontal motion is the same, the velocity of the ball can be determined.

$V_{horizontal} . t_{horizontal} = d_{horizontal}$

$t_{horizontal}$ = horizontal flight time of ball

$d_{horizontal}$ = horizontal distance of ball

$d_{vertical} = \frac{1}{2} g t^2 vertical$

$t_{vertical}$ = vertical flight time of ball

$d_{vertical}$ = vertical distance of ball from floor