LECTURE 5. BALLISTICS PENDULUM

1. Purpose:

This experiment demonstrates the conservation of momentum during a collision, and distinguishes between the conservation of total energy and the conservation of mechanical energy.

2. Equipment

For this lab you will be using these equipments:

- A Sargent-Welch WL0870 Ballistics Pendulum
- 2 meter sticks
- 3 spheres
- 2 Carbon papers.

3. Background

We used to teach this lab with live ammunition. Students would fire their guns at a wooden block suspended by a rope (i.e., a simple pendulum). By measuring how high the pendulum would swing, one could determine the initial velocity of the bullet. It's unclear why we stopped using real rifles. Today, the basic idea remains the same: a projectile is fired into a (hollow) pendulum bob and remains embedded in it.

We have seen, in previous labs, that it is generally a good idea to perform multiple independent experiment. This is especially true when you are looking at a new idea, when you can use what you have already found to be valid as a sort of check. As such, you will perform two experiments and compare the results.

3.1 Experiment 1: Conservation of Momentum

When the projectile collides with the pendulum bob, the projectile remains embedded in the pendulum bob - a completely inelastic collision. Applying conservation of momentum to the collision yields:

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

After the collision, the pendulum bob will swing upward until all of its kinetic energy is converted into gravitational potential energy. If the vertical distance traveled by the pendulum bob is h, conservation of energy tells us that:

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

As we discussed earlier in this lab, you will be comparing the initial velocity of the bob, as determined using two different methods. In the space below, use the above results to find an expression for the velocity of the projectile immediately before the collision in terms of easily measurable quantities.
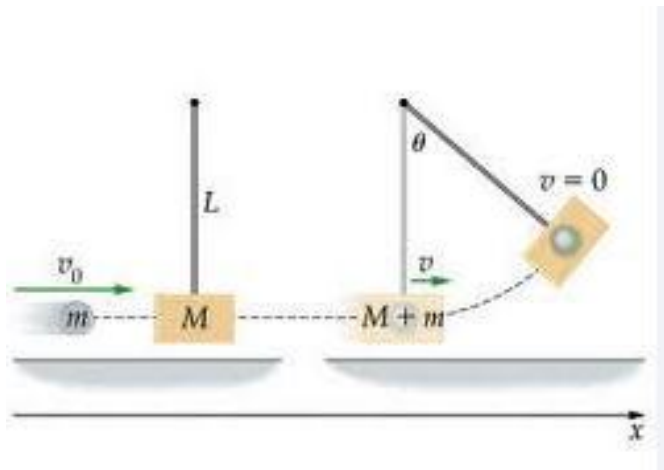
$$V = \frac{(m+M)}{m}\sqrt{2gh} \qquad (3)$$

where V is the velocity of the projectile before the collision, g is the acceleration due to gravity, h is the vertical displacement, M is the mass of the pendulum bob and m is the mass of the projectile.

3.2. Experiment 2: Kinematics

Of course, for the projectiles fired from the spring-loaded guns we use these days, you never really needed to use the pendulum to find the initial velocity, right? If you fire the gun and measure how far the projectile travels, you can use the kinematic equations to determine the initial velocity of the projectile. In a previous lab, we determined that these equations are valid. This means that we can test the validity of conservation of momentum by comparing the initial velocities found using the kinematic equations and conservation of momentum.
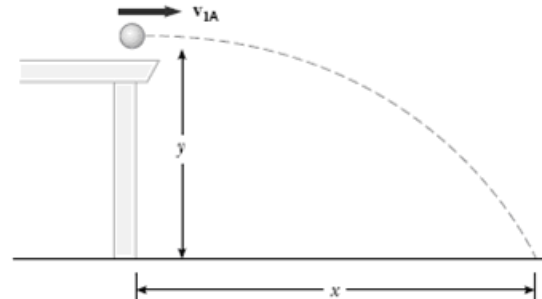
Suppose that the projectile is fired horizontally a distance, y, above the floor with an initial velocity, v_{1A}. According to the kinematic equations, what are the horizontal and vertical positions of the projectile when it hits the ground? Be sure to clearly identify any variables that you use. Sketches are always useful.

Use these results to find the initial velocity of the projectile in terms of easily measured quantities.

$$x = vt \qquad (4)$$

$$y = \frac{1}{2}gt^2 \qquad (5)$$

$$V_{1A} = \sqrt{\frac{g \cdot x^2}{2h}} \qquad (6)$$

4. Procedure:

You will determine the initial velocity of a projectile, steel ball shot with a spring loaded gun, using each of the methods outlined above.

4.1. Part 1: Momentum and Kinetic Energy after the Collision

➢ Before using the ballistic pendulum, as described in Method 1, make sure that the pendulum bob is screwed snugly into its axle (there is a knurled knob on the underside of the top support). Then, simply fire the steel ball into the hollow pendulum bob.

➢ After the collision the pendulum will be brought to rest at its highest point by a set of ratchet teeth mounted on the base of the instrument. This is a convenience, which allows you to take your time when measuring the distance, h, that the pendulum was raised. Several values of h should be averaged. These heights should be measured from the tabletop up to the center of mass of the system, which is indicated by a red dot on the pendulum bob.

➢ Measuring the masses of the two colliding bodies will then supply all of the information needed to calculate the initial velocity of the projectile using Equation (3).

➢ Record any relevant data

4.2. Part 2: Momentum and Kinetic Energy before the Collision

➢ Before using the ballistic pendulum, as described in Method 2, make sure that the pendulum bob is out of the way so that you can fire the projectile across the room. There is no need to unscrew the pendulum from its support, simply raise it until the ratchet teeth engage the bob.

➢ The first time you test the range, please make sure you aren't likely to hit anything other than the floor. It may take a shot or two until you have a feel for where the ball is likely to land. Once you have a pretty good idea of where the ball will land, place a piece of carbon paper (carbon side up) on the landing spot and tape a white sheet of paper on top of the carbon.

➢ When the ball lands, it will leave a mark. By measuring the location of the marks, you can determine the range of the projectile.

➢ As always, several measurements should be made. Be sure that you use the same spring compression as you did in the previous part of this lab.

LECTURE 5. BALLISTICS PENDULUM
RESULT

Name:…………………………………………………………………….

Class:……………………………………………………………………..

1. Purpose:

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2. Results:

a. Part 1: Momentum and Kinetic Energy after the Collision

m = …………………   M = ……………………..

Trial	1	2	3	4	5
Height, h ( )					

Average h = ……………..

Calculate the velocity of the projectile after the collision:

V_f = ………………….

Calculate the kinetic energy and momentum of the projectile after the collision:

$K_f = -\Delta U = $ ………………………

$p_f = $ …………………………..

b. **Part 2: Momentum and Kinetic Energy before the Collision**

y = …………………………..

Trial	1	2	3	4	5
x ( )					

$\bar{x} = $ ....

Calculate the velocity of the projectile before the collision:

$v_{1A} = $ ....

Calculate the kinetic energy and momentum of the projectile before the collision:

$K_0 = $ ....

$p_0 = $ ....

3. Discussion of results

$v_{1A} = $ ....

$K_0 = $ ....

$p_0 = $ ....

➤ How do the initial and final velocities compare? What is the percent difference?

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➤ Is momentum conserved? Why or why not?

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➤ Is kinetic energy conserved? Does this result make sense? (Hint: If kinetic energy was not conserved, where is the missing energy? If energy was lost, where did it go? If it was gained, where did it come from?)

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Questions:

i. Discuss how the two conservation laws of mechanics (*i.e.,* conservation of

momentum, and conservation of energy) were used in the ballistic pendulum method.

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ii. Compute the fractional loss of energy involved in the inelastic collision:

$(\% loss = \dfrac{K(final) - K(initial)}{K(initial)} \cdot 100)$. Does this result make sense?

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iii. If the ball had bounced off the pendulum with a smaller fractional loss of energy, would the pendulum have risen to a higher height, or not quite as high? By what factor?

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iv. Calculate, theoretically, the ratio of the kinetic energy of the system before the collision to the kinetic energy of the system after the collision, *i.e.* $K_{final}/K_{initial}$. Eliminate all other variables from your answer except for *m* and *M*.

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