611-1720 (40-130) Ballistic Pendulum

Introduction: The ballistic pendulum is a classic in the Physics lab with an impressive military history. Its premise had long been known by the makers of munitions. Invented in 1742 by Benjamin Robins to measure the speed of bullets, he soon realized that, by knowing the weight of the pendulum with its target, the weight of the shot fired, and the distance the pendulum moved when struck, he could calculate the velocity of the shot. By performing experiments at various distances, he was also able to determine the effects of air density and gravity as the range increased.

Your ballistic pendulum is modified from the ones used in those early days. An ideal instrument would have a bob to catch the projectile, and a massless, perfectly rigid rod connecting it to a scale for readings. That way, the only mass the shot has to move is the bob, giving more accurate readings. Unfortunately, such a unit is impossible to manufacture. To improve accuracy, we have used a carbon fiber rod to attach the bob to the scale. This material is exceptionally stiff and very light, making it close to our ideal. In addition, leveling feet have been added to mitigate the effects of gravity.

Operation: To use your ballistic pendulum, you will first need to prepare it.

Level the unit. You will see a small omnidirectional bubble level and three thumbscrews attached to the feet. Slowly turn these screws until the bubble is in the exact center of the level. This will help mitigate the effects of gravity on the shot.

The pendulum shaft is detached from the shaft for shipping purposes. In order to use the ballistic pendulum, you will need to attach the shaft. The shaft is carbon fiber, which is very strong but can crack if handled roughly, so be careful**!** You will notice a bracket at the top of the post, near the scale. On one end of the shaft is a bearing with a screw placed in it. Remove this screw, and place the bearing between the holes in the bracket. Slide the screw through the bracket and bearing, and thread it into the post.

The pendulum bob is detached from the shaft for shipping purposes. In order to use the ballistic pendulum, you will need to attach the bob. To do so, carefully thread the bob onto the end of the shaft (leave the brass nut in place). The shaft is carbon fiber, which is very strong but can crack if handled roughly, so be careful. Once you have the bob in line with the spring gun, use the small brass nut at the end of the shaft to lock it in place. Make sure that the open portion of the bob (the part without rubber) is facing the spring gun. **Do not over tighten either the bob or the nut! Damage can occur!**

Next, you will need to obtain an accurate mass for the projectiles. We have measured the shots to be as follows:

- ☐ Steel: 8.3 grams
- ☐ Brass: 8.5 grams
- ☐ Aluminum: 2.8 grams
- ☐ Bob: 35 grams.
- ☐ Please note: our measurements may be slightly inaccurate due to differences in the manufacturing process. It is strongly recommended that students weigh their own shots before proceeding.

The scale included with the unit measures angles. To simplify calculations, we have included a table below that describes how high the bob rises for any given angle.

angle on scale	**height of pendulum / mm**
1	0.05
2	0.19
3	0.44
4	0.78
5	1.22
6	1.75
7	2.39

8	3.11
9	3.94
10	4.86
11	5.88
12	6.99
13	8.20
14	9.51
15	10.90
16	12.40
17	13.98
18	15.66
19	17.43
20	19.30
21	21.25
22	23.30
23	25.44
24	27.67
25	29.98
26	32.39
27	34.88
28	37.46
29	40.12
30	42.87
31	45.71
32	48.62
33	51.63
34	54.71
35	57.87
36	61.11
37	64.44
38	67.84
39	71.31
40	74.87
41	78.49
42	82.19
43	85.97
44	89.81
45	93.73

To fire a shot, first insert one of the spheres into the barrel of the launcher, and pull back on the tab to the desired distance. There are 3 different positions that can be used. When you fire a shot, the bob should catch the projectile. If it does not, make sure to repeat the experiment, as accuracy will suffer otherwise.

The scale can be reset by hand. Simply allow the pendulum rod to hand straight, and gently push the arrow back into the '0' position.

How to Teach with the Ballistic Pendulum:
Concepts Taught: Conservation of energy; conservation of momentum; projectile motion; kinetic energy; gravitational potential energy
Curriculum Fit: Physics Sequence; Momentum and Energy; Motion.

Additional Materials Needed:
- Laboratory Balance (**7920-A120 Top-Loading Balance)**
- Masking tape
- Sheets of plain paper and carbon paper
- Cartesian graph paper
- Meter stick
- Safety glasses

Theory:
What is gravitational potential energy?
What is kinetic energy?
What is the conservation of momentum?
What is the conservation of energy?
What is projectile motion?

Safety Factors:
There is potential for injury from any moving object. We recommend these safety precautions.
- Avoid sudden, unannounced movements. Before pursuing a rolling ball, notify those in your path. This prevents you from interfering with their experiment and keeps you out of the path of a launch.
- All people in the lab should wear safety glasses when watching a demonstration or performing an experiment.

<u>Experiment 1: The Ballistic Pendulum</u>

Procedure:
1. Determine the mass of the steel ball projectile using a top-loading balance. Record this mass below.

   Mass of ball (m_{ball}) = ______________________________(kg)
2. Place the projectile ball in the spring gun opening.
3. Pull the spring mechanism back to launch the ball that is inside the gun's chamber. This will show you how the apparatus operates. If the block does not catch and come to a stop, you should adjust the pendulum suspension to obtain the proper alignment.
4. Record the starting angle of the pointer. Ideally, this angle should be set a 0° before firing the ball in Step 6.
   Angle (θ) = ___________________________°
5. Fire the ball into the freely hanging, stationary pendulum and note the angle in degrees at which the pointer stops on the protractor. Record data in Table 1 below. This procedure should be repeated a total of five times total.

Table 1

Trial #	Angle (θ)
1	
2	
3	
4	
5	
Average (θ)	

6. Determine the average angle of the trials in Step 6 and record the value in Table 1. Next, calculate the height, h, of the ball/pendulum after the collision. Use the average angle value in the calculation. This is calculated as follows:

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

   L = length of the pendulum to its center of mass (cm)

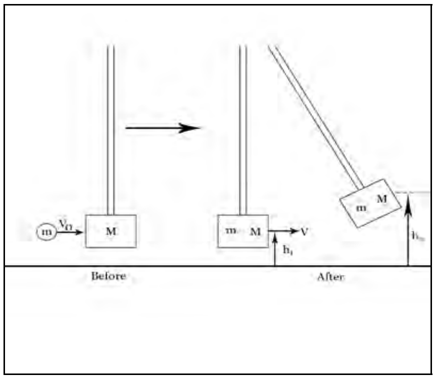

Figure 1

7. Carefully remove the pendulum with steel ball embedded from the apparatus. Weigh the pendulum support containing the steel ball on a top-loading balance. Record this value below.
   Mass of ball plus pendulum ($m_{ball+pendulum}$) = _____________________(kg)

8. Calculate the magnitude of the initial velocity using the equation below.

$$v_{initial\ 1} = \frac{m_{ball+pendulum}}{m_{ball}} \times \sqrt{2gh}$$

g = acceleration due to gravity (9.8 m/sec^2)

$h = h_{center\ of\ mass}$

$v_{initial\ 1}$ = ________________________

<u>Experiment 2: Shooting the Ball Across a Room</u>

General Idea: Students will fire the steel ball across a room to determine the initial velocity of a projectile from range-fall measurements. Then, the students will compare this value to the initial velocity, $v_{initial\ 1}$, determined in Step 9 of Experiment 1.

Procedure: Secure the pendulum rod and bob out of the way, so as not to obstruct the path of the ball. Position the ballistic pendulum near the edge of a laboratory bench, so that the spring gun is unobstructed if one was to fire the gun. Make sure that there is plenty of free floor space.

1. Place the steel ball projectile in the gun and pull the spring mechanism back to launch the ball. Tape a blank piece of paper on the floor where the ball hit the floor. Take the paper to the floor and cover the sheet with a piece of carbon paper. Tape the carbon paper to the blank sheet. When the ball strikes the carbon paper, the mark made on the sheet of paper below will help to determine the range of the projectile.

2. Mark the position of the apparatus on the table. Use a piece of masking tape to indicate the point on the table where the end with the spring should rest prior to firing the gun. It is important that the gun is fired from the same starting position each time.

3. Fire the steel ball five times and measure the horizontal distance (range), x, in meters that the ball travels for each trial. Record these values in Table 2 below. Find the average range.

Table 2

Trial #	Range, x (meters)
1	
2	
3	
4	
5	
Average Range (meters)	

Note: Range is determined by measuring from the open end of the gun to the marks that are on the carbon paper on the floor.

4. Measure the height of the gun from the floor and record this value below. The height is measured from the bottom of the gun's muzzle to the floor.

Height (h) = ___________________________(m)

5. Compute the magnitude of the initial velocity of the ball using the equation below.

$$v_{initial\ 2} = \sqrt{\frac{gx^2}{2h}}$$

h = height from Step 6
g = acceleration due to gravity (9.8 m/sec^2)
x = range (meters)

Discussion and Questions:

1. How does the initial velocity in experiment 1 compare with the initial velocity calculated in experiment 2? Calculate the percent difference and record your answer below.

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$$\text{Percent Difference} = \frac{|v_{initial1} - v_{initial2}|}{\left(\frac{v_{initial1} + v_{initial2}}{2}\right)} \times 100\%$$

Percent Difference = _________________________(%)

2. Is the collision between the ball and the pendulum elastic or inelastic? Define elastic and inelastic below. Justify the definitions by calculating the kinetic energy of the system before collision using the initial velocity from Experiment 1 and the kinetic energy just after the collision using the value of h in the equations on page 7.

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Kinetic Energy Before Collision:

$K_{initial} = \frac{1}{2} m_{ball} \cdot v_{initial1}^2$

$K_{initial}$ = ________________________________(kgm^2/sec^2)

Kinetic Energy Just After Collision:

$$K_{final} = \tfrac{1}{2} \times \frac{\left(m_{ball}{}^{2} \cdot v_{initial1}{}^{2}\right)}{m_{ball+pendulum}}$$

2. Calculate the potential energy, U, using the equation below.

$U = (m_{ball+pendulum})gh$

U = ___________________________________(kgm^2/sec^2)

References:

1. Wilson, Jerry D. Physics Laboratory Experiments. Lexington: D.C. Heath and Company, 1990. (pp. 99-107).

Warranty and Parts:
We replace all defective or missing parts free of charge. Additional replacement parts may be ordered toll-free. We accept MasterCard, Visa, checks and School P.O.s. All products warranted to be free from defect for 90 days. Does not apply to accident, misuse or normal wear and tear. Not designed for children under 13 years of age.