Lab 10. Ballistic Pendulum

Goals

- To determine the launch speed of a steel ball for the short, medium, and long range settings on the projectile launcher apparatus using the equations for projectile motion.
- To use the concepts of gravitational potential energy and conservation of mechanical energy to determine the speed of the ball plus pendulum as it first begins to swing away from the vertical position after the "collision."
- To explore the relationships between the momentum and kinetic energy of the ball as launched and the momentum and kinetic energy of the ball plus pendulum immediately after the ball is caught by the pendulum apparatus.

Introduction

The "ballistic pendulum" carries this name because it provides a simple method of determining the speed of a bullet shot from a gun. To determine the speed of the bullet, a relatively large block of wood is suspended as a pendulum. The bullet is shot into the wooden block so that it does not penetrate clear through it. This is a type of "sticky" collision, where the two masses (bullet and block) stick to one another and move together after the collision. By noting the angle to which the block and bullet swing after the collision, the initial speed can be determined by using conservation of momentum. This observation incorporates some predictions that we can check. In this experiment, the ballistic pendulum apparatus will be used to compare the momentum of the steel ball before the "collision" to the momentum of the ball and pendulum apparatus, equivalent to the wooden block plus the bullet, after the collision. A comparison of the kinetic energy of the ball before the collision with the kinetic energy of the system afterward will also be made.

Figure 10.1 shows a diagram of the ballistic pendulum apparatus. For the ballistic pendulum experiment, the projectile launcher from the projectile motion laboratory is mounted horizontally so that the pendulum can catch the emerging steel ball. The angle indicator can be used to measure the maximum angle reached by the pendulum as it swings after the collision. The angle indicator should read close to zero when the pendulum is hanging in the vertical position. If the reading is measurably different from zero, then take the difference in the angle readings (maximum angle reading minus initial angle reading).

Warning: Never look down the launcher barrel. Wear eye protection until everyone is finished launching projectiles.

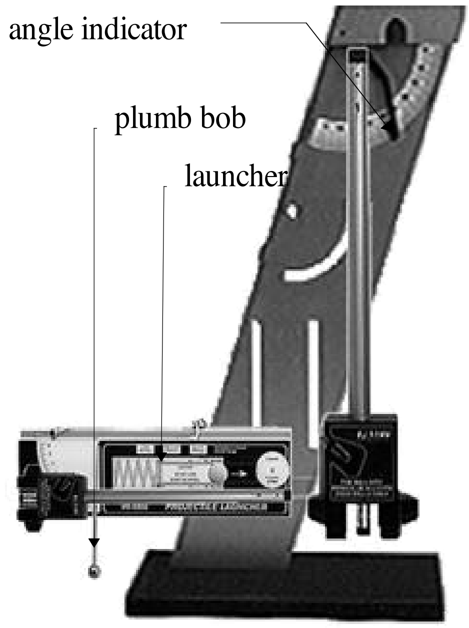

Figure 10.1. Ballistic pendulum apparatus.

Momentum of steel ball before collision

For this part of the experiment, remove the pendulum by gently unscrewing the rod that supports its upper end. Now determine the muzzle velocity of the steel ball by firing it horizontally and measuring the distance traveled horizontally before striking the ground. Do this for the short, medium, and long range settings of the launcher. The momentum of the ball is found by multiplying its mass times its velocity. Quantitatively estimate the uncertainties in these momentum values based on the uncertainties of the measured horizontal distance traveled and the measured vertical height. The momentum of the ball-pendulum system before the ball collides with the pendulum is now known.

Momentum of ball and pendulum after collision

The speed (and from it the momentum) of the ball and pendulum just after the collision is computed by assuming that the kinetic energy of the ball and pendulum just after the collision is totally converted into gravitational potential energy at the top of its swing. This requires that the frictional forces on the ball and pendulum system during the swing are small (negligible). The increase in gravitational potential energy is just the weight of the pendulum times the change in height, and the change in height can be computed from the maximum angle of the pendulum swing and some straightforward trigonometry. Since the pendulum is not a point mass, the change in potential energy is given by the change in height of its center of gravity. The center of gravity can be located by removing it from its support screw at the top and then balancing it on a “knife edge”. (A thin ruler works.) While you have the pendulum disassembled, be sure to measure the mass of the pendulum and the distance from the pivot point at the top to the center of gravity.

Mount the pendulum so that it will catch and trap the steel ball before proceeding. Be gentle as you screw in the pendulum support rod; it does not need to be tight. Now launch the ball into the pendulum using the short, medium, and long range settings of the projectile launcher. Repeat each measurement several times and take appropriate averages. (Remember to check the initial angle of the pendulum at rest.)

From your data calculate the speed of the pendulum and ball together just after the collision. Multiply by the appropriate mass to get the momentum. The momentum of the ball-pendulum system just after the collision is now known.

Is momentum conserved?

Compare the initial momentum of the ball and pendulum system before the collision with the final momentum of the same system just after the collision using your calculated velocities and measured masses just before and just after the collision. Is momentum conserved? You cannot answer this question without comparing the difference between the two momenta with the uncertainty of this same difference. If the difference between the momenta is more than three times the uncertainty of the difference, the odds of the difference being due to random variations is small—your data do not support conservation of momentum in this case. If you expect momentum to be conserved, examine your calculations and procedures for errors.

Is kinetic energy conserved?

Since you know the masses and speeds of the objects before and after the collision, you can calculate the kinetic energies of the system before and after the collision. Is kinetic energy conserved? To answer this question, you will need to estimate your experimental uncertainties and compare them with any observed differences, as you did to test conservation of momentum. Assuming that momentum is conserved before and after the collision, find a general symbolic mathematical expression for the ratio of the final kinetic energy over the initial kinetic energy. You may need some help from your TA here. Using the data from your earlier calculations, compare your experimental kinetic energy ratio to that predicted by assuming momentum is conserved. Is it the same ratio? Is overall energy conserved in this collision? If so, what forms of energy would need to be included to satisfy the general energy conservation principle?

Footnote: A simplification has been made by assuming that the pendulum consists of a point mass on the end of a string whose length is equal to the distance from the pivot point to the center of gravity. When the pendulum swings, it necessarily rotates. This suggests that some rotational kinetic energy is imparted to the ball and pendulum system along with its translational kinetic energy ($mv^2/2$). If significant, this would produce a systematic error in the calculated speed of the ball and pendulum system after the collision. Would it make the calculated speed too high or too low? Can you detect any systematic error in your calculated values? Discuss.

Summary

Mechanical energy and momentum are conserved only when certain conditions are met. Qualitatively summarize your results, explaining why the collision between the ball and the pendulum conserves momentum but not mechanical energy. Similarly, explain why the motion of the pendulum during its swing conserves mechanical energy but (apparently) not momentum.

Before you leave the lab please: Quit all computer applications that you may have open. Place equipment back in the plastic tray as you found it. Report any problems or suggest improvements to your TA.