AP Physics Lab #7: Conservation of Momentum (Big Idea 5)

In this experiment you will use the principles of conservation of momentum and conservation of energy to determine the velocity of a ball launched by a projectile launcher. You will then verify your results by determining the launch velocity using an alternate method of your own design.

College Board Big Ideas:

5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.

5.D.1.1: The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions.

5.D.1.2: The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations.

5.D.1.3: The student is able to apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy.

5.D.1.4: The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome.

5.D.1.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values.

5.D.2.1: The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [SP 6.4, 7.2]

5.D.2.3: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy.

Conservation of Momentum Pre-Lab:

The Law of Conservation of Momentum states that the total momentum of a closed system remains unchanged. When two objects collide, momentum is always conserved, without exception. In contrast, when objects other than atoms or molecules collide, <u>energy is always lost</u> due to the deformation of the object, no matter how slight the deformation is. This is because it takes energy to break the bonds between atoms in the object.

There are two general categories of collisions: elastic and inelastic. Atoms undergo elastic collisions. In an elastic collision, both momentum and energy are conserved. Atoms do not undergo deformation during a collision, so energy is not lost. Collisions between objects other than atoms undergo inelastic collisions. In an inelastic collision, momentum is conserved but energy is not. When two objects collide and stick together, the collision is called a completely (or perfectly) inelastic collision. The collision is said to be complete since the two objects have united as one.

The conservation of momentum between two objects undergoing an elastic or inelastic collision may be summarized as follows: $m_1v_{1(i)} + m_2v_{2(i)} + \; m_1v_{1(f)} + m_2v_{2(f)}$

Since objects are combined during a completely inelastic collision, the formula above is often modified for a completely inelastic collision as follows: $m_1v_{1(i)} + m_2v_{2(i)} + \; (m_1 + m_2)v_{(f)}$

When analyzing a collision, it is often useful to try to view the problem in terms of momentum rather than energy, since energy can be lost. Most likely the amount of energy lost would be difficult to measure. Suppose you want to determine how fast you can throw a baseball. To do so, you design an experiment using the principles of momentum. If you launch the baseball at a target object, such as an open box filled with newspaper, the ball will collide with the box in a completely inelastic fashion. If the box is placed on a smooth surface such as the floor, the collision will cause the box to slide until friction brings the system to a stop. The speed at which you threw the baseball may be determined by analyzing the scenario in terms of conservation of energy and conservation of momentum.

The scenario can be divided into a sequence of three intervals: a) Ball moves from your hand to the box. b) Ball collides with box. c) Ball-in-box slides across floor.

P1. Describe the motion of the object(s) in terms of their displacement, speed, acceleration during each of the intervals. a) Ball moves from your hand to the box.

Since the sequence begins with a velocity which can vary in magnitude, it is best to analyze the sequence in reverse order, beginning with how the ball-in-box stops. Friction causes the ball-in-box to come to rest.

P2. Outline how to experimentally determine the work done by friction in bringing the ball-in-box to rest. List the variables that must be measured, state the equations needed to calculate the work, outline how to measure each variable.

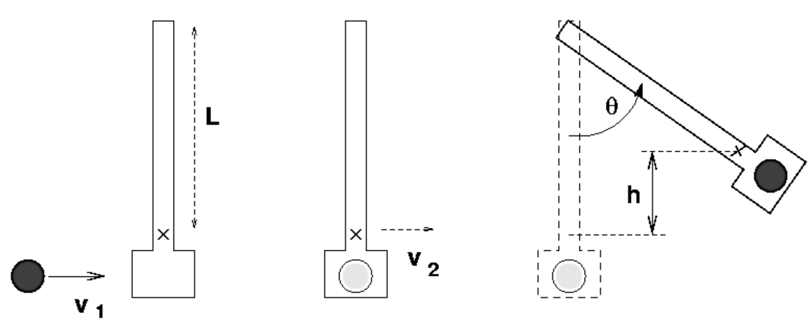
The work done by friction, W_F*, is used to consume the kinetic energy possessed by the ball-in-box system after its collision.*

P3. State the equation that summarizes the transfer of the kinetic energy from the ball-inbox to work done by friction.

Energy is lost during a completely inelastic collision. Consequently, it is not possible to easily determine the initial velocity of the baseball using the principles of energy conservation during the collision. Momentum, however, is <u>*always conserved*</u> *during a collision, providing an opportunity to determine, with a high degree of certainty, the initial velocity of the baseball.*

P4. State the equation that summarizes the conservation of momentum during the collision of the ball and box.

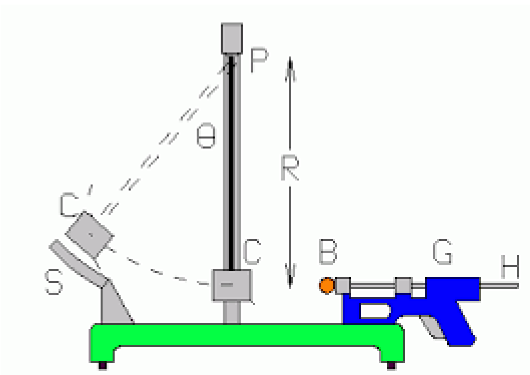
P5. Write a description for the schematic shown to the right. You must use the following terms in your answer: perfectly inelastic collision, kinetic energy, momentum, conserved, not conserved, system, gravitational potential energy, trigonometry

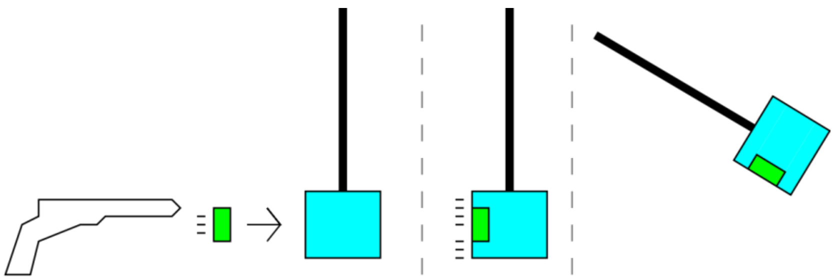


Conservation of Momentum Lab:

Materials: Ballistic pendulum, meter stick, digital scale, ruler, LabQuest 2 interface, digital probeware of your choice, video analysis (optional), Smart phones

The ballistic pendulum is a device specifically designed for this activity. The device has two main components: the projectile launcher and a pendulum (see diagram). The launcher is powered by a spring that, once compressed, can launch a small metal ball toward the pendulum. The pendulum consists of a small block suspended by a rigid rod or a pair of strings. The block serves as the pendulum bob. To use the apparatus, the piston of the launcher is pulled back, causing the compression of its spring. When released from its locked position, the spring launches the ball towards the block. The center of the block contains a hole into which the ball enters as it collides with the block. The initial kinetic energy of the ball causes the entire pendulum to rise. The ballistic pendulum includes a mechanism that records the rise of the pendulum in terms of an angle measured with respect to the vertical. The rise of the pendulum may be calculated using the principles of trigonometry.





Since the ball and block becomes a single moving unit, the collision is classified as a completely inelastic collision. As with all collisions, momentum is conserved, but some energy is lost to friction and deformation of the colliding objects. In terms of energy, the initial energy in the ballistic pendulum is provided by the spring potential energy, PEs, of the launcher. During launch, this energy is then transferred to the ball, giving the ball kinetic energy, KE. Most of the kinetic energy of the ball is transferred to the ball-block system; however, some of the energy is lost to friction between the components of the device, as well as to the (microscopic) deformation of the block and ball during the collision. Some energy is also lost to the surrounding air as sound waves; however, the magnitude of these is exceptionally low. In terms of energy, the initial energy in the ballistic pendulum is provided by the spring potential energy, PEs, of the launcher. During launch, this energy is then transferred to the ball, giving the ball kinetic energy, KE. Most of the kinetic energy of the ball is transferred to the ball-block system; however, some of the energy is lost to friction between the components of the device, as well as to the (microscopic) deformation of the block and ball during the collision. Some energy is also lost to the surrounding air as sound waves; however, the magnitude of these is exceptionally low.

Although, the collision is difficult to analyze in terms of energy, one can compare the initial and final velocities of the colliding objects by using the principles of conservation of momentum. Following the collision, the kinetic energy of the ball-block unit converts to energy, PEg, as the pendulum rises. A protractor may also be used to determine the maximum angle attained by the pendulum in order to determine its maximum height.

Part 1- Measuring Launch Velocity Through a Collision: *In this activity you will determine the velocity ofa ball launched by a projectile launcher Dofa Ballistic Pendulum by measuring how high the pendulum rises after a collision.*

Q1. Record the mass of the ball, length of the pendulum, and the mass of the block. I will write the mass of the block on the board, so you will not need to disassemble the apparatus.

Place the ball into the launcher and practice launching the ball into the block of the pendulum. If the ball does not land in the hole of the block, the device may need adjustment. Practice launching the ball a few times before proceeding, each time returning the mechanism that measures the rise angle to its starting position.

Q2. After completing a few practice launches, do you believe there may be some confounding factors that could lead to systematic error? Think about this for a moment and be detailed in your answer.

Q3. Launch the ball into the block of the pendulum and then record the rise angle of the pendulum. Repeat numerous times, keeping the launch position constant, until you are confident that your measurements are reproducible. Record your data in a data table.

Q4. Draw a sketch of the apparatus. On your sketch label the following: U_g zero line, Δh, V_0, V_f, FBD of the ball immediately after it leaves the launcher, U_{spring}, θ

Q5. Calculate the launch velocity of the ball using the average rise angle. Show all work.

Part 2- Alternate Methods of Measuring the Launch Velocity: *In this activity you will determine the velocity of a ball launched by a projectile launcher of a ballistic pendulum using a method of your choice.*

Q6. The launch velocity of the projectile launcher may be measured using other approaches including using the principles of horizontal projectile motion, free-fall kinematics, using photogates, and video analysis. Design an experiment to determine the velocity of a ball launched by a projectile launcher of a ballistic pendulum. Briefly outline each step of the procedure you will use. Include labeled diagrams as you deem appropriate.

Q7. It is time to conduct the experiment. Design a table for your experiment. In the table, summarize your data and show all calculations. You may choose to attach data from the LabQuest 2 or your video analysis for this question.

Q8. Calculate the percent difference between the averages of your launch velocities for parts 1 and 2.

Please self-assess your lab report using the rubric/checklist.