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.

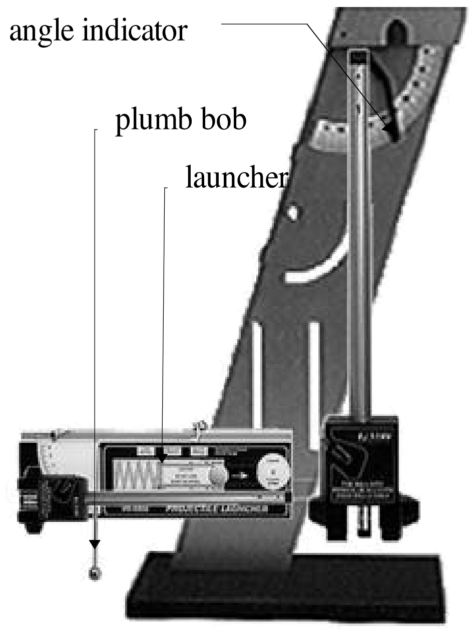

Figure 10.1. Ballistic pendulum apparatus.

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. Refer back to your notebook pages from Projectile Motion if you need equations and procedures for determining velocity.

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. Both of these measurements should be done with the ball bearing inserted into the pendulum.

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, attempting to screw it in "all the way" will break the pendulum. 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.)

Each measurement should be done with two launches if you are able to manage it. Launch the ball into the pendulum, and then (being careful not to lift the pendulum further than the current angle reading) release the bearing and launch once again. The reason for the double launch is that your angle indicator is held in place after the launch by friction. This same friction resists the motion of the pendulum, causing your measured angle to be $1° - 3°$ shorter than the actual angle were we not attempting to measure in this manner. Returning the bearing to the launcher and preparing for a new launch may not be possible with the short range setting.

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 (moving) and pendulum (stationary) 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 (meaning manipulate equations with variables only, do not enter any values you measured). 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 (The ratio found by doing the symbolic mathematical expression). Is it the same ratio?

Is overall energy (all forms of energy, not just KE & PE) conserved in this collision? If so, what forms of energy would need to be included to satisfy the general energy conservation principle?

Note: 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 its center of mass. When the pendulum swings, it necessarily rotates about its center of mass. This suggests that some rotational kinetic energy is imparted to the ball and pendulum system along with its translational kinetic energy ($\frac{1}{2}mv^2$). 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.

	No Effort	Progressing	Expectation	Scientific
SL.A.b Is able to identify the hypothesis for the experiment proposed Labs: 4, 5, 7, 8, 10	No deliberately identified hypothesis is present in the first half page or so of notes	An attempt is made to state a hypothesis, but no clearly defined dependent and independent variable, or lacking a statement of relationship between the two variables	A statement is made as a hypothesis, it contains a dependent and independent variable along with a statement of relationship between the two variables. This statement appears to be testable, but there are some minor omissions or vague details.	The hypothesis is clearly stated and the direct link to the experiment at hand is apparent to any reasonably informed reader.
SL.A.c Is able to determine hypothesis validity Labs: 4, 5, 7, 8, 10	No deliberately identified attempt to use experimental results to validate hypothesis is present in the sections following data collection.	A statement about the hypothesis validity is made, but it is not consistent with the data analysis completed in the experiment	A statement about the hypothesis validity is made which is consistent with the data analysis completed in the experiment. Assumptions which informed the hypothesis and assumptions not validated during experimentation are not taken into account.	A statement about the hypothesis validity is made which is consistent with the data analysis and all assumptions are taken into account.

	No Effort	Progressing	Expectation	Scientific
CT.A.a Is able to compare recorded information and sketches with reality of experiment Labs: 3-8, 10	No sketches present and no descriptive text to explain what was observed in experiment	Sketch or descriptive text is present to inform reader what was observed in the experiment, but there is no attempt to explain what details of the experiment are not accurately delivered through either representation.	Sketch and descriptive text are both present. The sketch and description supplement one another to attempt to make up for the failures of each to convey all observations from the experiment. There are minor inconsistencies between the two representations and the known reality of the experiment from the week, but no major details are absent.	Sketch and description address the shortcomings of one another to convey an accurate and detailed record of experimental observations adequate to permit a reader to place all data in context.
CT.A.b Is able to identify assumptions used to make predictions Labs: 4, 5, 7, 8, 10	No attempt is made to identify any assumptions necessary for making predictions	An attempt is made to identify assumptions, but the assumptions stated are irrelevant to the specific predicted values or apply to the broader hypothesis instead of the specific prediction	Relevant assumptions are identified regarding the specific predictions, but are not properly evaluated for significance in making the prediction.	Sufficient assumptions are correctly identified, and are noted to indicate significance to the prediction that is made.
CT.A.c Is able to make predictions for each trial during experiment Labs: 4, 5, 7, 8, 10	Multiple experimental trials lack predictions specific to those individual trial runs.	Predictions made are too general and could be taken to apply to more than one trial run. OR Predictions are made without connection to the hypothesis identified for the experiment. OR Predictions are made in a manner inconsistent with the hypothesis being tested. OR Prediction is unrelated to the context of the experiment.	Predictions follow from hypothesis, but are flawed because relevant experimental assumptions are not considered and/or prediction is incomplete or somewhat inconsistent with hypothesis or experiment.	A prediction is made for each trial set in the experiment which follows from the hypothesis but is hyper-specific to the individual trial runs. The prediction accurately describes the expected outcome of the experiment and incorporates relevant assumptions.
QR.A Is able to perform algebraic steps in mathematical work. Labs: 3-5, 7-12	No equations are presented in algebraic form with known values isolated on the right and unknown values on the left.	Some equations are recorded in algebraic form, but not all equations needed for the experiment.	All the required equations for the experiment are written in algebraic form with unknown values on the left and known values on the right. Some algebraic manipulation is not recorded, but most is.	All equations required for the experiment are presented in standard form and full steps are shown to derive final form with unknown values on the left and known values on the right. Substitutions are made to place all unknown values in terms of measured values and constants.

	No Effort	Progressing	Expectation	Scientific
QR.C Is able to analyze data appropriately Labs: 2-12	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed, or inappropriate.	The analysis is appropriate for the data gathered, but contains minor errors or omissions	The analysis is appropriate, complete, and correct.
IL.A Is able to record data and observations from the experiment Labs: 1-12	"Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. "	"Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. "	Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference.	All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed.
IL.B Is able to construct a force diagram Labs: 1-12	No force diagrams are present.	Force diagrams are constructed, but not in all appropriate cases. OR force diagrams are missing labels, have incorrectly sized vectors, have vectors in the wrong direction, or have missing or extra vectors.	Force diagram contains no errors in vectors, but lacks a key feature such as labels of forces with two subscripts, vectors are not drawn from the center of mass, or axes are missing.	The force diagram contains no errors, and each force is labelled so that it is clearly understood what each force represents. Vectors are scaled precisely and drawn from the center of mass.
WC.A Is able to create a sketch of important experimental setups Labs: 2, 4, 5, 7, 8, 10-12	No sketch is constructed.	Sketch is drawn, but it is incomplete with no physical quantities labeled, OR important information is missing, OR it contains wrong information, OR coordinate axes are missing.	Sketch has no incorrect information but has either a few missing labels of given quantities, or subscripts are missing/inconsistent. Majority of key items are drawn with indication of important measurements/locations.	Sketch contains all key items with correct labeling of all physical quantities and has consistent subscripts. Axes are drawn and labeled correctly. Further drawings are made where needed to indicate precise details not possible in the scale of initial sketch.

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

Lab 10 Ballistic Pendulum:

Name: ____________________ Lab Partner: ____________________

EXIT TICKET:

☐ Quit Capstone and any other software you have been using.
☐ Remove any blue tape from equipment and area around lab table.
☐ Straighten up your lab station. Put all equipment where it was at start of lab.
☐ Required Level of Effort.
  ☐ Complete the pre-lab assignment ☐ Arrive on time
  ☐ Work well with your partner ☐ Complete the lab or run out of time

SL.A.b		CT.A.b		IL.A	
SL.A.c		CT.A.c		IL.B	
CT.A.a		QR.A		WC.A	
		QR.C			

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SL.A.c		CT.A.c		IL.B	
CT.A.a		QR.A		WC.A	
		QR.C			