Elastic Collisions

Conservation laws are some of the most powerful concepts in physics. In this lab we will explore the conservation of momentum and energy by studying collisions.

1 Learning Goals

- Experiment with momentum and energy conservation.

2 Background

Conservation laws can be used to describe complicated physical systems. For example, collisions involving fundamental particles can be accurately reconstructed using the conservation of energy and momentum. At larger scales, conservation laws allow us to describe stellar and galactic dynamics.

Conservation laws require that the initial and final quantities of an observable are the same. The conservation of energy and momentum are often useful for solving many problems in general physics.

2.1 Conservation of Momentum

Recall that the momentum of a system is given by:

$$\vec{P} = m\vec{v}, \tag{2.1}$$

where m is the mass of an object and $\vec{v}$ is the velocity.

The total momentum $\vec{P}_T$ of a system of n discrete parts can be expressed as the sum of each of the parts:

$$\vec{P}_T = m_1\vec{v}_1 + m_2\vec{v}_2 + \cdots + m_n\vec{v}_n \tag{2.2}$$

When the sum of external forces acting on a system is zero, momentum is conserved. That is, the total initial momentum of the system $\vec{P}_i$ is equal to the total final momentum $\vec{P}_f$:

$$\vec{P}_i = \vec{P}_f. \tag{2.3}$$

2.2 Kinetic Energy

An object of mass m and velocity $\vec{v}$ has a kinetic energy given by:

$$K = \frac{1}{2} m \vec{v}^2 \tag{2.4}$$

The total kinetic energy K_T of a system of n discrete parts can be expressed as the sum of each of the parts:

$$K_T = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 + \cdots + \frac{1}{2} m_n v_n^2. \tag{2.5}$$

2.3 Elastic Collisions

Elastic collisions involve only conservative forces. In these collisions the total kinetic energy of the objects involved is conserved:

$$K_i = K_f, \tag{2.6}$$

where K_i and K_f are the total initial and final kinetic energies respectively.

In an elastic collision, the total initial kinetic energy (sum of the parts) is equal to the total final kinetic energy. Examples of (nearly perfect) elastic collisions are those between billiard balls.

3 Procedure

You will use gliders on an (approximately frictionless) air track to study elastic collisions.

The goal is to experimentally determine the masses required such that, after an elastic collision, the carts have velocities that are equal in magnitude and opposite in direction.

The velocity of each cart can be measured using Logger Pro and two photogates. A photogate is an optical device that is used to accurately time events. When an object obstructs the beam of a photogate the timer starts, when the obstruction is removed, the timer stops. Based on the dimensions of the object that obstructs the photogate and the measured time, a velocity can be calculated.

Most of the work of photogate timing is handled by the Logger Pro DAQ software. In Logger Pro, open the file: ‘‘`File`’’ → ‘‘`Open...`’’ → ‘‘`Probes & Sensors`’’ → ‘‘`Photogates`’’ → ‘‘`Collision Timer.cmbl`’’. This same configuration will be used throughout the experiment.

Setup elastic collisions between a stationary glider (Cart 2) and a moving glider (Cart 1). Describe how the apparatus is used to achieve (approximately) elastic collisions. Add mass to the stationary cart to adjust the ratio of the masses m_2/m_1. To achieve a greater mass ratio, a third cart may be coupled to the stationary glider.

For each mass configuration m_2/m_1 run several trials with different cart 1 initial velocities v_{1i}. Compute the ratio of the measured final velocities v_{1f}/v_{2f} for each trial. Also compute the average velocity ratio $\overline{v_{1f}/v_{2f}}$, standard deviation $\sigma_{v_{1f}/v_{2f}}$ and standard deviation of the mean $\sigma_{\overline{v_{1f}/v_{2f}}}$.

Visualize the data collected from all of the tested mass ratios by generating the linearized plot described in the Pre-lab Quiz.

At what mass ratio do you observe equal and opposite recoil velocities $v_{2f} = -v_{1f}$? Quantitatively compare your observational result with the theoretical prediction calculated in the Pre-lab Quiz.

4 Lab Notebook

Your submission will be evaluated using the following rubric:

Lab Notebook Practices

- Lab Notebook Mechanics (4 points)
  - Relevant information *e.g.*: your name, your lab partner's name, date, *etc.* is present.
  - The notebook is organized and easy to read. Markdown cells are used for narrative text. Code cells are clearly organized and commented.
  - The ZIP file of the notebook is healthy and runs correctly.
- Experiment Purpose (2 points)
  - In your own words, state the purpose of this experiment.
  - The work you record in your notebook should specifically address the stated purpose.
- Calculations & Error Propagation (6 points)
  - Present the equations used to analyze your collected data.
  - Present the equations used to account for and propagate error.
- Data Collection & Analysis (6 points)
  - The notebook tells a scientific story; it is an accurate record of the work that you did.
  - Record the informal observations you made during the experiment.
  - The notebook should show evidence of trial and error. Keep a good record of your work – recording mistakes is useful.
  - *Briefly* describe the methods you used to collect your data.
  - Measured quantities – that do not appear directly in your plot(s) – are clearly recorded.
  - Record rough data and plots that you used to verify that the analysis was on the right track.

Results and Interpretation

- Results (5 points)
  - Clearly state the final result(s) of your experiment. Remember to quote your result with units and appropriate significant digits.
  - Final result plots are well formatted and meet the standards described in the Figure Formatting reference.

- Physical Interpretation (4 points)
  - Throughout the notebook, interpret the data, rough plots, and final results in terms of the underlying physics.
- Significance (5 points)
  - Compare measured results to each other and/or to a known/expected value.
  - Choose the best available tools for your comparison (*e.g.* plots, pictures, discrepancy, significance, etc).
- Confidence (8 points)
  - Communicate to your audience how seriously your result should be taken. How confident you are in your result?
  - Discuss factors that may be affecting the *accuracy* and *precision* of your result.
  - Suggest improvements to your experiment to address your confidence, accuracy, and precision.