Experiment 4

Inelastic Collisions

4.1 Objectives

- Measure the momentum and kinetic energy of two objects before and after a perfectly inelastic one-dimensional collision.
- Observe that the concept of **conservation of momentum** is independent of **conservation of kinetic energy**, that is, the total momentum remains constant in an inelastic collisions while the kinetic energy changes.
- Calculate the percentage of KE which will be lost (converted to other forms of energy) in a perfectly inelastic collision between an initially stationary mass and an initially moving mass.

4.2 Introduction

One of the most important concepts in the world of physics is the concept of conservation. We are able to predict the behavior of a system through the **conservation of energy** (energy is neither created nor destroyed). An interesting fact is that while total energy is **always** conserved, kinetic energy is not. However, momentum is always conserved in both elastic and inelastic collisions. In this experiment and the following experiment, we will see how momentum always remains a conserved quantity while kinetic energy does not.

4.3 Key Concepts

As always, you can find a summary on-line at Hyperphysics.[1] Look for keywords: elastic collision, and inelastic collision.

4.4 Theory

The following two experiments deal with two different types of one-dimensional collisions. Below is a discussion of the principles and equations that will be used in analyzing these collisions. For a single particle, **momentum** is defined as the product of the mass and the velocity of the particle:

$$p = mv \tag{4.1}$$

Momentum is a **vector** quantity, making its direction a necessary part of the data. For the one-dimensional case, the momentum would have a direction in either the $+x$ direction or the $-x$ direction. For a system of more than one particle, the **total momentum** is the vector sum of the individual momenta:

$$p = p_1 + p_1 + ... = mv_1 + mv_2 + ... \tag{4.2}$$

So you just add the momentum of each particle together. One of the most fundamental laws of physics is that the **total momentum** of any system of particles is **conserved**, or constant, as long as the net external force on the system is zero. Assume we have two particles with masses m_1 and m_2 and velocities v_1 and v_2 which collide with each other without any external force acting. Suppose the resulting velocities are v_{1f} and v_{2f} after the collision. **Conservation of momentum** then states that the total momentum before the collision ($p_{initial} = p_i$) is equal to the *total* momentum after the collision ($p_{final} = p_f$):

$$p_i = m_1 v_{1_i} + m_2 v_{2_i} \qquad p_f = m_1 v_{1_f} + m_2 v_{2_f} \qquad p_i = p_f \tag{4.3}$$

In a given system, the **total energy** is generally the sum of several different forms of energy. **Kinetic energy** is the form associated with motion, and for a single particle

[1] http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html

$$KE = \frac{mv^2}{2} \tag{4.4}$$

In contrast to momentum, kinetic energy is *not* a vector; for a system of more than one particle the total kinetic energy is simply the sum of the individual kinetic energies of each particle:

$$KE = KE_1 + KE_2 + ... \tag{4.5}$$

Another fundamental law of physics is that the **total energy** of a system is **always conserved**. However within a given system one form of energy may be converted to another, such as in the freely-falling body lab where potential energy was converted to kinetic energy. *Therefore, kinetic energy* alone *is often not conserved.*

There are two basic kinds of collisions, elastic and inelastic:

In an **elastic collision**, two or more bodies come together, collide, and then move apart again with *no loss in kinetic energy.* An example would be two identical "superballs," colliding and then rebounding off each other with the same speeds they had before the collision. Given the above example conservation of kinetic energy then implies

$$\frac{m_1 v_{1_i}^2}{2} + \frac{m_2 v_{2_i}^2}{2} = \frac{m_1 v_{1_f}^2}{2} + \frac{m_1 v_{2_f}^2}{2} \qquad KE_{initial} = KE_{final} \tag{4.6}$$

In an **inelastic collision**, the bodies collide and come apart again, but *some kinetic energy is lost.* That is, some kinetic energy is converted to some other form of energy. An example would be the collision between a baseball and a bat.

If the bodies collide and stick together, the collision is called **perfectly inelastic**. In this case, *much of the kinetic energy is lost* in the collision. That is, much of the kinetic energy is converted to other forms of energy.

In the following two experiments you will be dealing with a perfectly inelastic collision in which much of the kinetic energy of the objects is lost, and with a nearly elastic collision in which kinetic energy is conserved. Remember, in both of these collisions total momentum should always be conserved.

Since we are considering inelastic collisions today, let's consider what the kinetic energy should be in the initial and final states. If we look at Eq. 4.4, we can see that the initial kinetic energy is

$$KE_i = \frac{m_1 v_{1_i}^2}{2} + \frac{m_2 v_{2_i}^2}{2} = \frac{m_1 v_{1_i}^2}{2} \tag{4.7}$$

because Cart 2 is initially at rest ($v_{2_i} = 0$).

The final kinetic energy is defined as

$$KE_f = \frac{(m_1 + m_2) v_f^2}{2} \tag{4.8}$$

because the two carts have stuck together after the collision ($v_f = v_{1f} = v_{2f}$ is the common velocity of the two carts).

Using the conservation of momentum, we can calculate the final momentum as

$$m_1 v_{1_i} + m_2 v_{2_i} = m_1 v_{1_i} = (m_1 + m_2) v_f \tag{4.9}$$

Using Eqs. 4.7, 4.8, and 4.9, we arrive at the equation for KE_f in terms of KE_i.

$$\boxed{KE_f = \left(\frac{m_1}{(m_1 + m_2)} \right) KE_i} \tag{4.10}$$

This is the prediction for the final kinetic energy of a perfectly inelastic collision.

4.5 In today's lab

Today you will get to see how inelastic collisions work while you vary the masses on two colliding carts. You will then see how there is a significant energy loss in these types of collisions and will try to figure out where this energy goes.

4.6 Equipment

- Air Track
- Air Supply

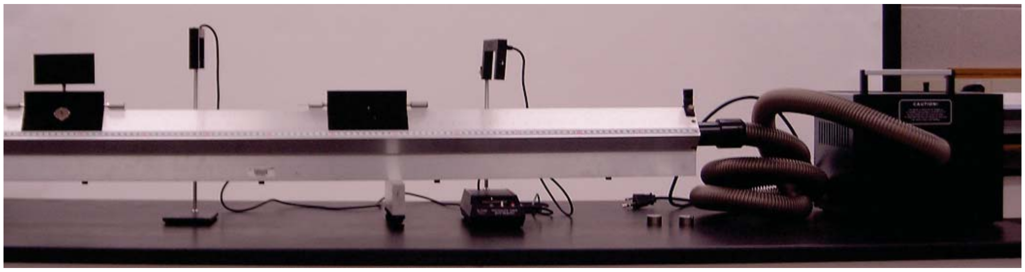

Figure 4.1: Equipment used in lab fully set up.

- Two carts one with needle and one with clay (carts are sometimes called gliders)
- Photogate Circuit
- 4 - 50g masses

4.7 Procedure

Do not move the carts on the air track when the air is not turned on. It will scratch the track and ruin the "frictionless" environment we need to get accurate data.

1. Start by making sure that the air track is level. Your instructor will demonstrate how at the beginning of class.
2. Set up the photogates such that there is sufficient room for the collision to happen in the middle and enough room on the remainder of the track for the carts to move freely.
3. Set the photogates to `GATE` mode.
4. We will define Cart 1 as the cart with the fin and Cart 2 as the cart without. We will always push Cart 1 for each trial and will always start with Cart 2 stationary ($v_{2_i} = 0\text{cm/s}$) in the middle. Before placing the carts on the track, measure the mass of them *without* the extra masses. Record the empty cart masses data on the given results sheet.

5. Measure the length of the fin on Cart 1 and record this on your results sheet and in excel. Be sure to put a reasonable uncertainty for the fin length in excel as well.

6. Input the uncertainty for the times measured by the photogate into excel (0.0005 s).

7. Put all four 50g masses on Cart 2 such that it is evenly distributed (2 masses on each side).

8. Place Cart 2 in between the photogates and have one partner hold it steady up until the collision takes place.

9. Place Cart 1 "outside" of the photogates.

10. Making sure that your photogates are reset, give a brief but firm shove to Cart 1 such that it collides and sticks together with Cart 2. Allow the two carts to leave the middle completely before stopping them. **Do not allow the carts to pass through the photogates again until you finish recording their times.**

11. Record the time for Cart 1 to pass through the first photogate (t_i) in excel, then press the `READ` switch and record (t_{mem}) as well.

12. Calculate the time for the combined cart system to pass through the second photogate using the formula $t_f = t_{\text{mem}} - t$ and input that into your notebook and excel file.

13. Note that the initial velocity of Cart 1 (v_{1_i}) is calculated using the formula L/t_i and that the final velocity of the combined cart system is calculated using the formula L/t_f.

14. Make sure that the absolute value of the percent difference between initial and final momentum is **less than** 5% (the spreadsheet does this calculation for you). If it is not, rerun the trial until it is. Compress the putty in the counterbalance in between trials. Also make sure that the fin on top of Cart 1 is completely through the photogate before the collision occurs. If the trial is acceptable, record the times on your worksheet. Always try to keep your best trial written down on your worksheet, even if it does not fit our desired percent difference.

15. Repeat this trial one more time and record the results.
16. Repeat steps 6–15 for the cases when you have:
    - 2 mass disks on Cart 1 and 2 mass disks on Cart 2
    - 2 mass disks on Cart 1 and no mass disks on Cart 2
17. Be sure to include hand calculations for the light blue boxes in excel.

4.8 Uncertainties

In today's experiment we have already input all of the equations into excel for you out of the interest of brevity, but it is important to understand the uncertainties for the values you used in this experiment. The uncertainty for velocity is:

$$\delta v = v\left(\frac{\delta L}{L} + \frac{\delta t}{t}\right)$$

The uncertainty for momentum is:

$$\delta P = P\frac{\delta v}{v}$$

And the uncertainty for kinetic energy is:

$$\delta KE = 2KE\frac{\delta v}{v}$$

The uncertainties for the differences for the momenta and kinetic energies are then:

$$\delta P_{\text{diff}} = \delta P_f + \delta P_i \text{ and } \delta KE_{\text{diff}} = \delta KE_f + \delta KE_i$$

4.9 Checklist

1. Excel sheets
2. Questions
3. Hand Calculations

4.10 Questions

1. For which of your trials was momentum conserved? The scientific way to address this question is to ask, for which of your trials is P_{diff} compatible with zero? Also, if momentum is not conserved for any of your trials, suggest a possible source of error.

2. Was kinetic energy conserved for any of your trials? If not, how much kinetic energy was lost?

3. Compare one of your measured KE_f trials with the $KE_{f\ calc}$ prediction of equation 4.10 for a perfectly inelastic collision. Use your measured masses and KE_i value. Are they compatible? The uncertainty of $KE_{f\ calc}$ is:

$$\left(\delta KE_{f\ calc} = KE_{f\ calc} \frac{\delta KE_i}{KE_i} \right)$$

4. Combine equations 4.7, 4.8 and 4.9 to obtain the expression in equation 4.10. Hint: solve equation 4.9 for v_f, then substitute this into equation 4.8.