Preface

We are going to try something different this week. We are going to repeat the previous experiment with different equipment. We will use air tracks instead of the “frictionless” carts we used previously. The goal is to see if we can reduce the systematic errors that we had in the previous experiment and to get some experience with the scientific process of testing previous results. I will show you how to use the airtracks. The remainder of the write-up is identical to the previous write-up. Do the same things but use the new equipment instead. We will then compare with the previous experiment. Make sure you have a copy of your results from Lab 7 to use for comparing to these results.

Instead of the metal fins that you used with the carts, you will use paper note cards folded to and taped to the carts. I will show you how at the beginning of lab. These will simply be referred to as “note cards” below.

Introduction

Physicists study simplified systems in order to test fundamental ideas. The most basic interaction between two objects is the collision. A collision is a brief interaction between the objects where the only relevant force is the force of one object on the other. Note that a collision does not necessarily imply that the objects make physical contact. An example is the scattering experiments of Ernest Rutherford that lead to the planetary model of the atom. Another example is when a space probe “slingshots” around a planet.

In today’s experiment, you are going to enact two different kinds of collisions. For each kind of collision, you will qualitatively investigate the validity of two of the most fundamental concepts in physics: conservation of momentum, and conservation of energy.

Keep in mind, as you analyze the results of this lab, that there are many assumptions that go into the analysis. One of the important things I want you to think about is, to what degree are each of the assumptions valid in this experiment?

Measurement note: In the following, you should always do at least three trials for each measurement specified.

Activity 1: Using the light gates to find instantaneous speed.

Adjust the height of a photogate so that the photogate is blocked by the note card as the cart goes by. You can then set the timer on the “GATE” setting so that it measures the time it took the cart to go by, \( t \). If you divide the length of the protrusion, \( L \), by the time it took to go by, you will have a good approximation of the instantaneous speed, \( v \), at that moment. Couple this with your observation of the direction of motion and you know the instantaneous velocity, \( \vec{v} \), at that point. With two light gates attached to one timer, you can measure the time for the cart to go by at one place, quickly read the timer, reset it, then read it again after the cart has gone by the second place. If there are enough timers, you can also have a separate timer at each place. Practice using the light gates in this manner.

Conservation of momentum.

In this lab you will be colliding two carts on a nearly frictionless track. For such a collision, as long as the force of friction on the track is negligible, and as long as the track is perfectly horizontal, then the only forces involved will be those of the carts on each other. Whatever the carts do to each other, the net force on the system consisting of the two carts together should be zero and so the total momentum of the system consisting of the two carts should be the same after the collision as it was before the collision. What is the total momentum of the system consisting of the two carts together? It is just the momentum of one cart, \( \vec{p}_1 = m_1 \vec{v}_1 \), plus the momentum of the other cart, \( \vec{p}_2 = m_2 \vec{v}_2 \). (But remember that \( \vec{p}_1 \) and \( \vec{p}_2 \) are vectors! If they happen to point in the same direction then you add their magnitudes, but if they point in opposite directions you take the difference between their magnitudes.) To test for conservation of total momentum, \( \vec{P} \), all you need to do is measure the mass of each of the carts, and find the velocities of each of the carts before and after the collision (that’s why you did activity 1).
Mathematically, conservation of momentum is expressed as

\[ m_1 \vec{v}_{1i} + m_2 \vec{v}_{2i} = m_1 \vec{v}_{1f} + m_2 \vec{v}_{2f} \] (1)

where \( i \) subscripts denote initial values and \( f \) subscripts denote final values. Remember that the velocities are vectors, their direction is important.

**Kinetic energy**

We have learned that kinetic energy is energy of motion. An object will have kinetic energy if it has a speed, \( v \). The kinetic energy is

\[ K = \frac{1}{2}mv^2 \] (2)

where \( m \) is the mass of the object. We can also write this in terms of the magnitude of the momentum as

\[ K = \frac{p^2}{2m} \] (3)

Unlike momentum, kinetic energy is not always conserved. Sometimes it gets converted into other types of energy. But there are situations in which the kinetic energy is conserved. A simple and common example of this is what is called an elastic collision.

**Conservation of kinetic energy in an elastic collision.**

An elastic collision, by definition, is one in which the total kinetic energy of the system after the collision is equal to the total kinetic energy of the system before the collision. Since the kinetic energy of an object of mass \( m \) and velocity \( \vec{v} \) is \((1/2)mv^2\), you can calculate the total kinetic energy before and after if you know the mass of each cart, and the velocity of each cart before and after the collision,

\[ \frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2 \] (4)

**Activity 2: Practice elastic collisions.**

These carts can be adjusted so that they have oppositely oriented magnets facing each other when they collide, and, to a good approximation, the collision is elastic (hardly any energy is lost in the form of sound or heat). Practice doing elastic collisions between the carts, using the light gates to find the velocity of each cart before and after the collision. Using the light gates in this manner is not easy, and you’ll need to practice. Note that, since the carts may lose energy due to friction as they travel along, you want to make the “before” and “after” times as close to the collision as possible. The simplest way to do this (and this is how I recommend you do it) is to have one of the carts be stationary before the collision–that gives you one less measurement to take.

**Activity 3: Elastic collision.**

Measure the mass of each cart (to make things interesting, make the masses different by placing a metal bar on one of the carts). Then do an elastic collision, with one of the carts initially stationary, carefully measuring the time for each moving cart to pass a light gate immediately before and immediately after the collision. From these data, find the total momentum and the total kinetic energy before and after the collision. Did either of them change? If so, by what percent of the initial value? Did they increase or decrease?

**Totally inelastic collisions.**

For an elastic collision, we know that both total momentum and total kinetic energy is conserved. For an inelastic collision we know that total momentum is conserved, but some (we don’t know how much) of
the initial total kinetic energy is lost in the collision to sound, heat, and perhaps work done to bend and break things. So, we just don’t know as much for an inelastic collision. But there is a particular kind of inelastic collision in which you can “know something”, and that is one in which the maximum amount of kinetic energy allowed is lost, and it is called a totally inelastic collision. In this case, the two carts are stationary with respect to each other after the collision (that is, they are moving with exactly the same velocity). The center of mass of the system may still be moving, and if it is there will still be some kinetic energy left associated with the motion of the center of mass.

**Kinetic energy associated with the motion of the center of mass.**

Kinetic energy can be expressed in terms of mass and either magnitude of velocity or magnitude of momentum:

\[
K_c = \frac{1}{2} M v_c^2 = \frac{1}{2} (M v_c)^2 = \frac{2}{M} \frac{P^2}{2M}
\]

where \(K_c\) is the kinetic energy of the center of mass, \(v_c\) is the speed of the center of mass, \(M\) is the total mass of the system, and \(P\) in the total momentum of the system.

If you lose as much kinetic energy as is allowed, how much is that? Well, since the total mass, \(M\), can’t change, and the total momentum, \(\vec{P}\), doesn’t change, then the kinetic energy associated with the motion of the center of mass, \(K_c = P^2/(2M)\), can’t change. That amount—and only that amount—better be left after the collision if it is truly a totally inelastic collision. You can calculate \(K_c\) from data gathered before the collision, and if it is a totally inelastic collision then \(K_{\text{total}}\) after the collision better be equal to \(K_c\) before.

**Activity 4: Practice totally inelastic collisions.**

The simplest way to make a totally inelastic collision happen is to make the two carts stick together after the collision, using Velcro. Practice doing some totally inelastic collisions, again measuring the time for each moving cart to pass a light gate before and after the collision. Again, I suggest that you start with one of the carts initially stationary. Note that for this kind of collision, since the two carts are stuck together after the collision, there is only one time to measure after the collision.

**Activity 5: Totally inelastic collision.**

Using the same two carts as for activity 4, do a totally inelastic collision, with one of the carts initially stationary, carefully measuring the time to for each moving cart to pass a light gate immediately before and immediately after the collision. From these data, find the total momentum before and after the collision. Did it change? If so, by what percent? In addition, from your “before” data, find \(K_c\), and from your “after” data find \(K_{\text{total}}\). Are they equal?

**To Hand In**

For activity 1: Nothing

For activity 2: Nothing

For activity 3:

- All your measurements and all results calculated from those measurements. In particular, clearly present:
• The total momentum before and after the collision, and the percent of the original total momentum lost or gained during the collision,

• The total kinetic energy before and after the collision and the percent of the original total kinetic energy lost or gained during the collision.

For activity 4: Nothing

For activity 5:

• All your measurements and all results calculated from those measurements. In particular, clearly present:

• The total momentum before and after the collision, and the percent of the original total momentum lost or gained during the collision, and

• The kinetic energy associated with the motion of the center of mass before the collision, and the total kinetic energy after the collision.

The answers to the following questions:

Questions
1. What are some sources of error? Distinguish between random and systematic error.
2. How elastic was your elastic collision, i.e. how close was it to a perfectly elastic collision? Explain.
3. How inelastic was your inelastic collision, i.e. how close was it to a perfectly inelastic collision? Explain.
4. How do your results for this version of the experiment compare with the previous version when you used the “frictionless” carts?