Experiment 5

Collisions in One Dimension

5.1 INTRODUCTION

In this experiment, you will investigate whether momentum is conserved in collisions between two carts on a low-friction track.

When two bodies collide, linear momentum is conserved if there is no net external force acting on the system. Consider two carts of masses m_1 and m_2 moving with initial velocities $v_{1\mathrm{i}}$ and $v_{2\mathrm{i}}$ respectively. (The subscript i stands for "initial" here.) Prior to the collision, the total momentum of the system is

$$p_\mathrm{i} = m_1 v_{1\mathrm{i}} + m_2 v_{2\mathrm{i}} \tag{5.1}$$

After the carts collide, they have final velocities $v_{1\mathrm{f}}$ and $v_{2\mathrm{f}}$, and the total momentum of the system is

$$p_\mathrm{f} = m_1 v_{1\mathrm{f}} + m_2 v_{2\mathrm{f}} \tag{5.2}$$

The law of conservation of momentum simply states that if there is no net external force acting on the system, then $p_\mathrm{i} = p_\mathrm{f}$.

As a separate issue, we may also be interested in whether or not the total mechanical energy of the system is conserved. (Conservation of energy might not yet have been discussed in lecture, but the details are provided below.)

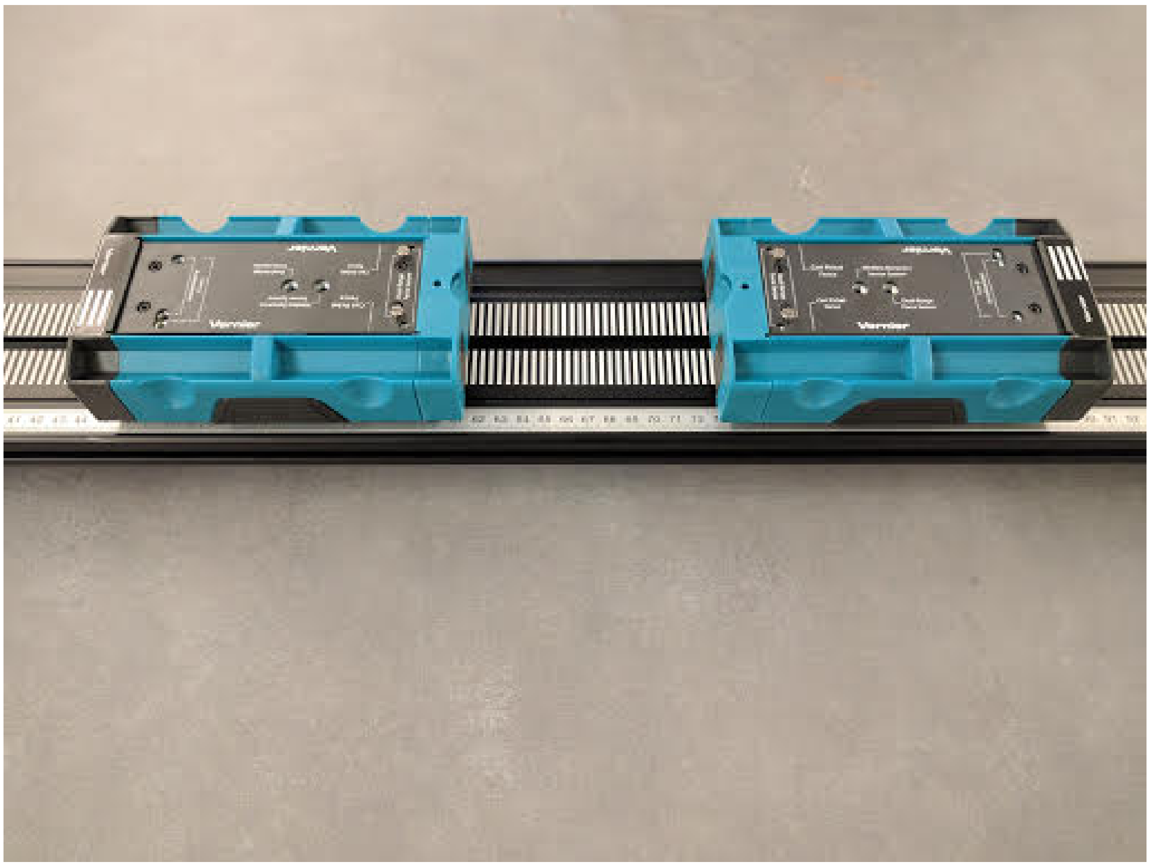

Figure 5.1: Photograph of the one-dimensional collision apparatus.

Prior to the collision, the total mechanical energy is

$$E_{\mathrm{i}} = \frac{1}{2}m_1 v_{1\mathrm{i}}^2 + \frac{1}{2}m_2 v_{2\mathrm{i}}^2 \ , \tag{5.3}$$

while after the collision, it is

$$E_{\mathrm{f}} = \frac{1}{2}m_1 v_{1\mathrm{f}}^2 + \frac{1}{2}m_2 v_{2\mathrm{f}}^2 \ . \tag{5.4}$$

If $E_{\mathrm{i}} = E_{\mathrm{f}}$, then we say the collision is elastic. Otherwise, we say the collision is inelastic.

In this experiment, you will study several collisions and check whether momentum and mechanical energy are conserved.

5.2 DATA ACQUISITION

1. Place a cart on the track to ensure that the track is level. If it is not, make appropriate adjustments to its feet.

2. Plug the Motion Encoder Receivers into the ports labelled DIG 1 and DIG 2 on the LabQuest Mini interface.

3. Open the `LoggerPro` software. If it is working correctly, you will see two plots: Position versus time for the two carts on the top of the screen, and velocity versus time on the bottom. If you instead see three plots, `LoggerPro` is misidentifying your Motion Encoder Receivers. Consult your instructor to fix this problem.

4. `LoggerPro` defines motion towards the Motion Encoder Receiver as positive and motion away from the receiver as negative. Since the two receivers are mounted on opposite ends of the track, it's convenient to reverse the direction of the data collected by second receiver by choosing `Experiment`→`Set up Sensors`→`Show all Interfaces`, click on the DIG SONIC 2 icon, and select Reverse Direction.

5. Turn on each Motion Encoder Cart by pressing the transparent button on the front. You are now ready to collect data.

6. Investigate four different collisions: two with magnetic bumpers (allowing the carts to repel) and two with Velcro bumpers (allowing the carts to stick together). Analyze your first collision in its entirety before proceeding to the next one. That way, if there is a major problem with your procedure, or if you are forgetting to obtain any important data, you can catch your mistake early. A neat `Excel` or `Google Sheets` table is an essential tool to perform this analysis with the greatest efficiency. If your comfort level with `Excel` remains low, please consult your instructor for help.

   Among the types of collisions you might consider are the following:

(a) Two nearly equal masses, initially moving toward each other, with different speeds.

(b) Two nearly equal masses, initially moving in the same direction, with different speeds.

(c) Two unequal masses, the smaller initially at rest.

(d) Two unequal masses, the larger initially at rest.

(e) Two unequal masses, both initially in motion.

Read through all experimental hints listed in the section below before starting.

7. Make a neat table for your data. For each collision, describe the type of bumpers, and include the masses m_1 and m_2 of the carts, and all the relevant velocities. Also include a quick sketch showing "before" and "after" pictures (including the direction of motion of each cart.) Record a velocity of 0 if a cart stops. Be sure to adopt a consistent sign convention: One direction should be called `+` while the other should be called `-`.

8. Neatly compile your data and calculations using `Excel` or `Google Sheets`.

5.2.1 Experimental Hints

You are interested in the velocities immediately prior to, and just after each collision. To determine these values, click and drag to highlight the relevant data on the graph and select `Analyze`→`Statistics` to find the mean value.

You can add mass to a cart by using the provided weights. Be sure to add equal amounts to both sides of the cart so that it remains balanced.

Use *moderate* velocities throughout. Speeds in the range of 0.5 m/s seem to work fairly well. If the velocity is too low, the residual friction or tilt of the track will dominate your results. If the velocity is too high, the carts may jump up off the track during the collision. Further, at high velocities the times recorded by `LoggerPro` will be very short, and the uncertainties in the timing will dominate. The timings produced by `LoggerPro` are accurate on the order of milliseconds (0.001 s), so you want to be sure all the times in your experiment are *much* larger than that.

Try to avoid collisions where the final velocity of either car is very close to zero. Such collisions tend to be dominated by friction or any remaining tilt in the track and to give very poor results.

If you hear a loud "clunk" sound during the collision, it probably won't work well. Check these hints again, and ask your instructor to look over your set-up.

5.3 ANALYSIS

For each collision, calculate p_{i} and compare it to p_{f}. Is momentum conserved?

Since there is no easy way to reproduce the exact same initial conditions, you won't be able to do a statistical analysis of the uncertainties. However, you should at least discuss whether any discrepancies you find seem plausible. One way to do that is to compare the change in momentum $|p_{\mathrm{f}} - p_{\mathrm{i}}|$ to the sum of the magnitudes of the initial momenta $|p_{1\mathrm{i}}| + |p_{2\mathrm{i}}|$. For example, suppose that $p_{1\mathrm{i}} = +101$ and $p_{2\mathrm{i}} = -99$, so that the total initial momentum is $p_{\mathrm{i}} = 2.0$. Next, suppose that you measure $p_{\mathrm{f}} = 3.0$. Is that difference significant? No. The difference between your expected value of 2.0 and the actual value of 3.0 is so small compared to the total initial magnitude of $|101| + |-99| = 200$ that it is probably not significant. Generally, for this experiment, momentum changes of less than 5% are probably not significant.

For each collision, calculate E_{i} and compare it to E_{f}. Is the collision approximately elastic? Again, no statistical analysis is needed, but you should discuss whether any discrepancies are large or small compared to the total initial energy. (Note that since the kinetic energy is always positive, you can't get cancellation effects as you might for momentum.) For this experiment, energy changes of less than 10% are probably not significant.

As always, discuss sources of uncertainty and ways in which the experiment or write-up could be improved.