Lab 6. Newton's Third Law and Momentum

Goals

- To explore the behavior of forces acting between two objects when they touch one another or interact with one another by some other means, such as a light string.
- To compare the magnitudes of the forces exerted by one object on another object and vice versa during collisions.
- To experimentally explore the relationship between an impulse and a change in motion.
- To understand the relationship between impulse and momentum.
- To explore and understand conservation of momentum.

Introduction

You have already explored how the motion of an object is affected by applied forces, such as gravity. We can extend our understanding of forces by recognizing that all forces are exerted by some object on some other object. This raises the question of whether forces operate in a reciprocal fashion. Suppose Object A exerts a force on Object B. Does Object B exert any kind of force on Object A? If so, what can we say about this second force? Most of our work so far has involved the force of gravity, where Earth is the actor or agent of force. The great size and mass of Earth make it difficult to measure changes in its motion due to any forces we might apply to it. In this experiment we focus on forces acting between two smaller objects.

We also wish to explore the relationship between the impulse, defined as the area under the force-versus-time graph during a brief interaction, to changes in the momentum, mv, of an object with mass m and velocity v. (For 201 students, the impulse J can also be defined as $J = \int F dt$, where the integral is calculated over over the time during which the force, F, is applied.) Finally we will look at the momentum of a two-body system of masses immediately before and after they interact with each other.

Forces of interaction—Connected objects

Two force sensors are attached individually to the tops of two carts that can roll on an aluminum track. Before beginning any measurements, make sure that both force sensors are "zeroed" by pressing the "tare" button on the side of each sensor. Check by means of a quick force-time graph that both sensors really read very close to zero. Also make certain that the data sampling rate that you have set is sufficiently high to record the force variations that take place. If the graphs look "jagged," with straight line segments connecting the data points, then increase the sampling rate until the lines connecting the data points form a smooth curve (even when you expand the time scale). Note that the force sensor mounted on Cart 1 measures the force exerted on Cart 1 by Cart 2, and the force sensor mounted on Cart 2 measures the force exerted on Cart 2 by Cart 1. Since the force sensors are oriented "back-to-back," one sensor will measure positive forces to the right and the other will measure positive forces to the left. This difference is critical because forces are vector quantities.

Carts with equal masses

Place both carts on the track and connect the hooks on the force sensors together. Place one hand on each cart (you can use both hands or use one of your's and one of your lab partner's) and push them together or pull them apart (not literally; getting too violent here can damage the force sensors!) all the while recording both forces as a function of time. Sketch a representative time segment of your data in your lab notes. From your data what can you conclude about the magnitudes of the forces exerted by Cart 1 on Cart 2 and by Cart 2 on Cart 1? Do your conclusions change if the carts experience a nonzero acceleration? What can you conclude about the direction of the force on each cart due to the other cart? Remember to zero (tare) the force sensors before each set of measurements!

Carts with unequal masses

Add two steel bars (approximately 0.5 kg each) to the cart on the right. With your hand touching only the cart on the left, pull and push the cart on the right while recording a graph displaying both forces as a function of time. (Of course the force sensor hooks must still be connected.) From your data what can you conclude about the magnitudes of the forces exerted by Cart 1 on Cart 2 and by Cart 2 on Cart 1? Do your conclusions change if the carts experience a nonzero acceleration? What can you conclude about the direction of the force on each cart due to the other cart?

Carts connected by string

Now connect the carts with a short length of string. (Only "pulls" are possible with a string, because the string goes slack if you push the carts together.) Do your conclusions change if the carts experience a nonzero acceleration? How does the presence of the string between the carts affect your answers regarding the forces you observed previously?

Summary of forces of interaction—connected objects

Summarize your conclusions for connected objects clearly and concisely before continuing. Compare your results with what you would predict on the basis of Newton's Third Law. Several common mistakes in homework and on exams relate to the observations you have just made. Ask your teaching assistant if you have any doubts.

Force of interaction—Colliding objects

“Bouncy” collisions with equal cart masses

Mount the springs in place of the hooks on the ends of the force sensors. Starting with one cart stationary, give the other cart a push so it collides with the stationary cart. Don’t push the cart so hard that the springs totally compress during the collision. Display both forces as a function of time in a graph. Focus on the time interval from just before the collision to just after the collision and rescale the graph to show this region clearly. You may also need to adjust the sampling rate of the force sensors to get sufficient data during the collision itself. From your data what can you conclude about the magnitudes of the forces exerted by Cart 1 on Cart 2 and by Cart 2 on Cart 1? What can you conclude about the direction of the force on each cart due to the other cart?

What difference does it make in the force relationships if both carts are moving prior to the collision? Support your answer with additional data.

“Bouncy” collisions with unequal cart masses

Add two steel bars (approximately 1 kg) to one of the carts. Starting with one cart stationary, give the other cart a push so it collides with the stationary cart. Perform two trials, first with the high-mass cart stationary and second with the low-mass cart stationary. Again avoid pushing the cart so hard that the springs totally compress during the collision. Display both forces as a function of time in a graph. Focus on the time interval from just before the collision to just after the collision and rescale the graph to show this region clearly. From your data what can you conclude about the magnitudes of the forces exerted by Cart 1 on Cart 2 and by Cart 2 on Cart 1? What can you conclude about the direction of the force on each cart due to the other cart?

What difference does it make in the force relationships if both carts are moving prior to the collision? Support your answer with additional data.

‘Sticky” collisions with equal cart masses

Remove the springs from the ends of the force sensors and replace them with small metal “cups” holding pieces of clay. Starting with one cart stationary, give the other cart a push so it collides with the stationary cart. Disregard any trial in which the carts don’t remain stuck together after the collision. Display both forces as a function of time in a graph. Focus on the time interval from just before the collision to just after the collision and rescale the graph to show this region clearly. You may also need to adjust the sampling rate of the force sensors to get sufficient data during the collision itself. From your data what can you conclude about the magnitudes of the forces exerted by Cart 1 on Cart 2 and by Cart 2 on Cart 1? What can you conclude about the direction of the force on each cart due to the other cart?

What difference does it make in the force relationships if both carts are moving prior to the collision? Support your answer with additional data.

"Sticky" collisions with unequal cart masses

Add two steel bars (approximately 1 kg) to one of the carts. Starting with one cart stationary, give the other cart a push so it collides with the stationary cart. Perform two trials, first with the high-mass cart stationary and second with the low-mass stationary. Disregard any trial in which the carts don't remain stuck together after the collision. Display both forces as a function of time in a graph. Focus on the time interval from just before the collision to just after the collision. Rescale the graph to show this region clearly. From your data what can you conclude about the magnitudes of the forces exerted by Cart 1 on Cart 2 and by Cart 2 on Cart 1? What can you conclude about the direction of the force on each cart due to the other cart?

What difference does it make in the force relationships if both carts are moving prior to the collision? Support your answer with additional data.

Summary for forces of interaction—colliding objects

Summarize your conclusions for "bouncy" and "sticky" collisions clearly and concisely before proceeding. Based on your observations how are the results changed by the different collision conditions? You will eventually learn that mechanical energy is lost in sticky collisions but is mostly conserved in bouncy collisions. Something that is true in both kinds of collisions can help you when the concept of conservation of energy is not useful.

Impulse and momentum during collisions

In this experiment, you will measure the impulse delivered to a cart as it strikes the end of the track. The bracket mounted at one end of the Pasco track has a small hole at just the right height for mounting a spring or clay cup to meet the end of the force sensor on the cart. The impulse is calculated by finding the "area" under the force-time curve during the collision using Capstone. This area has the units of force $\times$ time, or N-s. The impulse will be compared to the change in momentum of your cart. Momentum has units of kg-m/s. Show that units of N-s are equivalent to momentum units in your notes.

The change in momentum experienced by the cart can be calculated from the velocities of the cart just before and after the collision. An ultrasonic motion sensor is used to measure the velocity of the cart. Please refer to the Computer Tools Supplement at the end of your lab manual for more information on using the motion sensor.

Impulse and momentum in "sticky" collisions

Screw the clay cup from the unused force sensor into the bracket at the end of the track, and set up the motion sensor to measure the velocity of the cart as it moves down the track. The force sensor on the cart you are using should still have the clay cup attached to it. Give the cart a quick push down the leveled track so that it sticks to the clay on the end bracket. Disregard any trial when it doesn't stick securely. Display graphs of the force and the velocity as functions of time as the cart travels down the track and sticks to the end.

To find the impulse (the area under the force-time plot), use the "Highlight range of points in active data" tool (icon with yellow pencil and red points) along the top of the graph to select the force data that correspond to the collision. Then click on the "Display area under active data" icon (red line shaded below in gray). The area under the selected force data will appear in a box on the graph in units of N-s. Now compare the values of the impulse of the contact force during the collision with the change in momentum of the cart. What conclusion can you draw from your data? Several trials may be necessary to discover a pattern. Remember that impulse and momentum are vector quantities, so the positive x-directions for the force sensor and the motion sensor need to be considered carefully.

Impulse and momentum in "bouncy" collisions

Replace the clay cups with the springs to produce a bouncy collision at the end of the track. Again compare the values of the impulse of the contact force during the collision with the change in momentum of the cart. What conclusion can you draw from your data? Several trials may be necessary.

Summary for impulse and momentum in collisions

Summarize your conclusions for "sticky" and "bouncy" collisions clearly and concisely before proceeding. Based on your observations, how do the results compare when the collision conditions change?

Conservation of momentum

Using the motion sensor with clay cups on both carts, explore whether the sum of the momenta of the two carts is the same before and after a "sticky" collision. We investigate only the "sticky" collision, because we can determine the total momentum with only one velocity measurement before the collision and one after. That is all the motion sensor can do.

Equal cart masses

Push the cart closest to the motion sensor toward the second stationary cart so the carts stick together and move off together after the collision. Compare the momentum of the system of the two carts just prior to the collision with the combined momentum just after the collision. Several trials may be necessary to get a good measurement of the velocity after collision, where the carts stick together.

Unequal cart masses

Add two steel bars to the cart closest to the motion sensor and repeat the experiment. Compare once again the momentum of the two-cart system before and after the collision. Several trials are in order.

Summary for conservation of momentum

Summarize your conclusions for equal and unequal cart masses clearly and concisely before going to the Synthesis section. Based on your observations, how are the results changed by varying the cart masses? What predictions can be made regarding the total momentum of both carts just prior to a collision compared to the total momentum of both carts just after the collision? Do your experimental momentum measurements results agree with your predictions about the momentum of the two-cart system before and after the collision?

Synthesis

Using your observations on forces between interacting objects, discuss how the impulses given to the carts in a two-cart collision are (should be) related. (Refer to Newton's Third Law.) From your observations of impulse and momentum, how do the momenta of the two carts change during a collision if the contact forces during the collision represent for all practical purposes the net forces acting on the carts? Remember that the change in any quantity is defined as the final value minus the initial value. Impulse and momentum are vector quantities, so you need to pay close attention to directions as well as magnitudes.

Before you leave the lab please:

- Quit all computer applications that you may have open.
- Put the hooks back on the force sensors.
- Place equipment back in the plastic tray as you found it.
- Report any problems or suggest improvements to your TA.