

# Lab 7. 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 have not dealt with the idea of what force interactions really are.

The important note made by Newton's Third Law is that forces are not properties of individual objects. What right now is the force of your left hand? What was the force of your body yesterday?

Neither of these questions make enough sense to answer. However, I could ask what force your hand is applying to a book which you are holding up. I could ask what was the force of your body on a chair when sitting down yesterday.

The important change is that I have now asked for a force that is 1) doing something, and 2) involving two objects. Forces are interactions between two objects. There is one force shared by the two objects, and the force is either attractive (direction of force on each object points toward the other object), or repulsive (direction of force on each object points away from the other object).

Many approaches to Newton's Third Law talk about Force Pairs. Questions testing if you understand Newton's Third Law ask things like "If a motorcycle and an 18-wheeler collide, which one exerts the larger force?" These questions and the idea of pairing forces for "equal and opposite reaction force" can lead to much confusion, as it invites the idea that forces are properties of single objects, and that by some coincidence or mechanism there will be a possibility to find two matched forces.

This is a faulty approach to Newton's Third law. Forces are interactions, there is one force which is acting between two objects. You can consider the effects of the force on each object individually, which is what leads to the idea of "How much force did the Motorcycle apply to the 18-wheeler?" but this choice is one we are making in order to calculate vectors, since the direction of the force on each of the two objects are opposite to one another.

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  $v$ . 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 while there is nothing pushing or pulling on the hook of that 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). Notice that if you read the supposedly zero force for a longer period of time, it drifts away from zero. To avoid complications from this "zero drift" you will zero your sensors before each data collection today.

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. It is possible to change the settings to reverse the readings of one sensor so that both forces measure as positive when the carts are pulling apart, and negative when they are pushing together.

### Carts with equal masses

Place both carts on the track and connect the hooks on the force sensors together using the twisted copper wire. Place one hand on each cart (you can use both hands or work with your lab partner) and push them together or pull them apart (not excessively; getting too violent here can damage the force sensors!) all the while recording both forces as a function of time. Sketch a time segment of your data in your lab notes showing each of the push and the pull.

As you answer the following questions, and do the remaining experiments for the day, remember to zero (tare) the force sensors before each set of measurements.

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? (your initial tests should have been done with the pair of carts relatively stationary, now push the carts together while moving the pair of carts along the track, or pull them apart from one another while also moving the pair of carts along the track)

What can you conclude about the direction of the force on each cart due to the other cart?

### **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. When screwing the springs on, you are not screwing them in until they cannot screw any further, you are just getting them to grip enough that you are unable to pull the springs out with a light tug.

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. Does the relative direction of motion change your answer (both carts moving in the same direction compared against both carts moving toward each other)

### **“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. Does the relative direction of motion change your answer (both carts moving in the same direction compared against both carts moving toward each other)

### **“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 re-scale 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. Does the relative direction of motion change your answer (both carts moving in the same direction compared against both carts moving toward each other)

### **“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. Does the relative direction of motion change your answer (both carts moving in the same direction compared against both carts moving toward each other)

### **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.

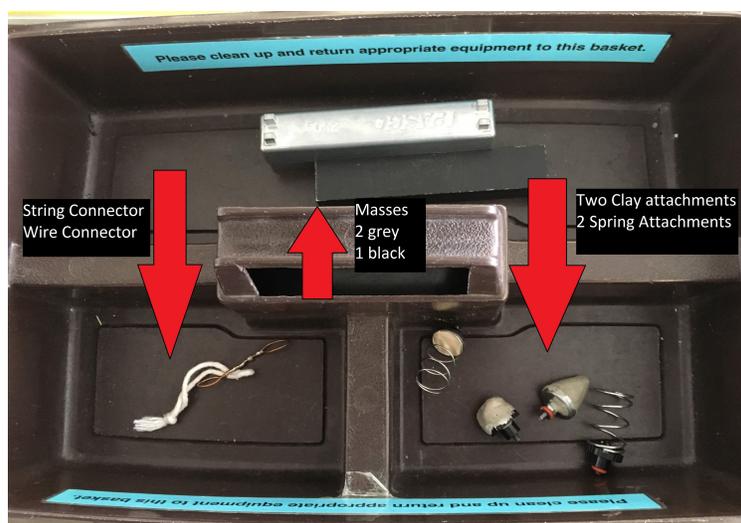


Figure 7.1. Arrange contents as shown, inform the TA if anything is missing or broken.

	No Effort	Progressing	Expectation	Scientific
<p><b>SL.A.b</b> Is able to identify the hypothesis for the experiment proposed</p> <p>Labs: 4, 5, 7, 8, 10</p>	<p>No deliberately identified hypothesis is present in the first half page or so of notes</p>	<p>An attempt is made to state a hypothesis, but no clearly defined dependent and independent variable, or lacking a statement of relationship between the two variables</p>	<p>A statement is made as a hypothesis, it contains a dependent and independent variable along with a statement of relationship between the two variables. This statement appears to be testable, but there are some minor omissions or vague details.</p>	<p>The hypothesis is clearly stated and the direct link to the experiment at hand is apparent to any reasonably informed reader.</p>

	<b>No Effort</b>	<b>Progressing</b>	<b>Expectation</b>	<b>Scientific</b>
<p><b>SL.A.c</b></p> <p>Is able to determine hypothesis validity</p> <p>Labs: 4, 5, 7, 8, 10</p>	No deliberately identified attempt to use experimental results to validate hypothesis is present in the sections following data collection.	A statement about the hypothesis validity is made, but it is not consistent with the data analysis completed in the experiment	A statement about the hypothesis validity is made which is consistent with the data analysis completed in the experiment. Assumptions which informed the hypothesis and assumptions not validated during experimentation are not taken into account.	A statement about the hypothesis validity is made which is consistent with the data analysis and all assumptions are taken into account.
<p><b>CT.A.a</b></p> <p>Is able to compare recorded information and sketches with reality of experiment</p> <p>Labs: 3-8, 10</p>	No sketches present and no descriptive text to explain what was observed in experiment	Sketch or descriptive text is present to inform reader what was observed in the experiment, but there is no attempt to explain what details of the experiment are not accurately delivered through either representation.	Sketch and descriptive text are both present. The sketch and description supplement one another to attempt to make up for the failures of each to convey all observations from the experiment. There are minor inconsistencies between the two representations and the known reality of the experiment from the week, but no major details are absent.	Sketch and description address the shortcomings of one another to convey an accurate and detailed record of experimental observations adequate to permit a reader to place all data in context.
<p><b>CT.A.b</b></p> <p>Is able to identify assumptions used to make predictions</p> <p>Labs: 4, 5, 7, 8, 10</p>	No attempt is made to identify any assumptions necessary for making predictions	An attempt is made to identify assumptions, but the assumptions stated are irrelevant to the specific predicted values or apply to the broader hypothesis instead of the specific prediction	Relevant assumptions are identified regarding the specific predictions, but are not properly evaluated for significance in making the prediction.	Sufficient assumptions are correctly identified, and are noted to indicate significance to the prediction that is made.
<p><b>CT.A.c</b></p> <p>Is able to make predictions for each trial during experiment</p> <p>Labs: 4, 5, 7, 8, 10</p>	Multiple experimental trials lack predictions specific to those individual trial runs.	Predictions made are too general and could be taken to apply to more than one trial run. OR Predictions are made without connection to the hypothesis identified for the experiment. OR Predictions are made in a manner inconsistent with the hypothesis being tested. OR Prediction is unrelated to the context of the experiment.	Predictions follow from hypothesis, but are flawed because relevant experimental assumptions are not considered and/or prediction is incomplete or somewhat inconsistent with hypothesis or experiment.	A prediction is made for each trial set in the experiment which follows from the hypothesis but is hyper-specific to the individual trial runs. The prediction accurately describes the expected outcome of the experiment and incorporates relevant assumptions.

	<b>No Effort</b>	<b>Progressing</b>	<b>Expectation</b>	<b>Scientific</b>
<p><b>QR.A</b></p> <p>Is able to perform algebraic steps in mathematical work.</p> <p>Labs: 3-5, 7-12</p>	No equations are presented in algebraic form with known values isolated on the right and unknown values on the left.	Some equations are recorded in algebraic form, but not all equations needed for the experiment.	All the required equations for the experiment are written in algebraic form with unknown values on the left and known values on the right. Some algebraic manipulation is not recorded, but most is.	All equations required for the experiment are presented in standard form and full steps are shown to derive final form with unknown values on the left and known values on the right. Substitutions are made to place all unknown values in terms of measured values and constants.
<p><b>QR.C</b></p> <p>Is able to analyze data appropriately</p> <p>Labs: 2-12</p>	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed, or inappropriate.	The analysis is appropriate for the data gathered, but contains minor errors or omissions	The analysis is appropriate, complete, and correct.
<p><b>IL.A</b></p> <p>Is able to record data and observations from the experiment</p> <p>Labs: 1-12</p>	"Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. "	"Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. "	Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference.	All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed.
<p><b>IL.B</b></p> <p>Is able to construct a force diagram</p> <p>Labs: 1-12</p>	No force diagrams are present.	Force diagrams are constructed, but not in all appropriate cases. OR force diagrams are missing labels, have incorrectly sized vectors, have vectors in the wrong direction, or have missing or extra vectors.	Force diagram contains no errors in vectors, but lacks a key feature such as labels of forces with two subscripts, vectors are not drawn from the center of mass, or axes are missing.	The force diagram contains no errors, and each force is labelled so that it is clearly understood what each force represents. Vectors are scaled precisely and drawn from the center of mass.

	<b>No Effort</b>	<b>Progressing</b>	<b>Expectation</b>	<b>Scientific</b>
<p><b>WC.A</b></p> <p>Is able to create a sketch of important experimental setups</p> <p>Labs: 2, 4, 5, 7, 8, 10-12</p>	No sketch is constructed.	Sketch is drawn, but it is incomplete with no physical quantities labeled, OR important information is missing, OR it contains wrong information, OR coordinate axes are missing.	Sketch has no incorrect information but has either a few missing labels of given quantities, or subscripts are missing/inconsistent. Majority of key items are drawn with indication of important measurements/locations.	Sketch contains all key items with correct labeling of all physical quantities and has consistent subscripts. Axes are drawn and labeled correctly. Further drawings are made where needed to indicate precise details not possible in the scale of initial sketch.
<p><b>WC.B</b></p> <p>Is able to draw a graph</p> <p>Labs: 2, 3, 5-9, 11, 12</p>	No graph is present.	A graph is present, but the axes are not labeled. OR there is no scale on the axes. OR the data points are connected.	"A graph is present and the axes are labeled, but the axes do not correspond to the independent (X-axis) and dependent (Y-axis) variables or the scale is not accurate. The data points are not connected, but there is no trend-line." "	The graph has correctly labeled axes, independent variable is along the horizontal axis and the scale is accurate. The trend-line is correct, with formula clearly indicated.

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

Lab 7 Newton's Third Law and Momentum:

Name: \_\_\_\_\_ Lab Partner: \_\_\_\_\_

<b>EXIT TICKET:</b>	
<input type="checkbox"/> Put the hooks back on the force sensors. <input type="checkbox"/> Return items to the tray as shown below in Figure 7.1. <input type="checkbox"/> Quit Capstone and any other software you have been using. <input type="checkbox"/> Straighten up your lab station. Put all equipment where it was at start of lab. <input type="checkbox"/> Required Level of Effort. <input type="checkbox"/> Complete the pre-lab assignment <input type="checkbox"/> Arrive on time <input type="checkbox"/> Work well with your partner <input type="checkbox"/> Complete the lab or run out of time	

SL.A.b		CT.A.c		IL.A	
SL.A.c		QR.A		IL.B	
CT.A.a		QR.C		WCA	
CT.A.b				WCB	

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