Lab 8: Impulse and Momentum

Experiment for Physics 211/225 at CSU Fullerton.

What You Need To Know:

The Physics

There are many concepts in physics that are defined purely by an equation and not by a description. In some cases, this is a source of much frustration for students since the math doesn't hold much meaning for them. In this lab, we will be dealing with two such cases where students have a particularly difficult time giving meaning to the math.

Impulse

In sports, one of the major actions is to hit an object. For example, in baseball, a player will hit a ball with a bat. To be more technical - over a period of time, a baseball player will apply an average force to a ball. In physics, it is said that the player is applying an *impulse* to the ball. Impulse is defined by the following equation …

$$I = F_{avg}\Delta t$$

I is the impulse (in Newton-seconds, N·s)

F_{avg} is the average force (in Newtons, N)

Δt is the change in time (in seconds, s)

Equation 1 – Impulse

Momentum

When hitting the baseball, the main objective is to have the ball change direction and move away from the player (preferably at a high speed). In other words, you want the ball to have a change in velocity. So, impulse must have some relationship to a change in the ball's velocity since, in order to make the ball change its velocity, you have to hit it (i.e. apply a force). Impulse does have a relationship but it is related to the ball's *momentum* which is based on the ball's velocity. Momentum is defined by the following equation …

$$p = mv$$

p is the momentum (in kilogram-meters per second, kg·m/s)

m is the mass (in kilograms, kg)

v is the velocity (in meters per second, m/s)

Equation 2 – Momentum

Impulse then can also be defined by the following equation …

$$I = \Delta p$$

| I is the impulse (in N·s)

| Δp is the change in momentum (in kg·m/s)

So, combining the two ideas together, we can say that applying a force to an object should give it a

$$F_{avg}\Delta t = m\Delta v$$

change in velocity through the ideas of impulse, momentum, and velocity …

Momentum for a System

In the paragraphs above we were dealing with the momentum for a single object. Now we are going to deal with the *total* momentum for a *system* of objects.

You have already seen that when dealing with *energy* for a system of objects, the *energy* is conserved only on the condition that there are no *non-conservative forces* (like friction) acting in your system. When dealing with *conservation of momentum*, there is also a condition that must be met; there must be no *external forces* acting on your system.

So, what's an external force? Let's say we have two balls moving towards each other which then collide. We are going to define **both** balls as our "system". At the moment of impact, there are two forces acting in our system. **See** *Figure 1*. Ball #1 hits ball #2 with a force to the right and ball #2 hits ball #1 with a force to the left. These two forces compose an action-reaction pair. Remember Newton's 3rd law? … Equal and opposite forces acting on different objects. If **both** forces in the pair are acting on objects in your **defined system** then they are considered to be *internal* forces. If only **one** force from the action-reaction pair is acting in your **defined system,** then the force is considered to be *external*. This idea will come up later in the lab.

Figure 1 – Two balls colliding with action-reaction pair
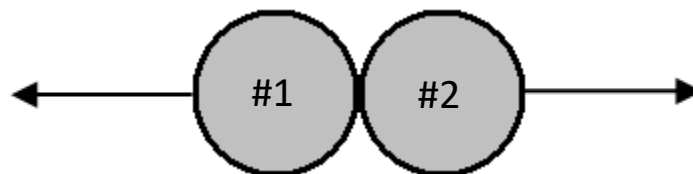
Conservation of Momentum

So, if there are no external forces acting on your defined system then we can say the total momentum for the system will be conserved.   Most of the time you'll apply this idea to collisions between two objects. The total momentum of all of your objects before your collision will equal the total momentum of all your objects after your collision. We write this out like the equation below …

$$\sum p = \sum p'$$

Σp is the sum of momentum before the collision

$\Sigma p'$ is the sum of momentum after the collision

*Equation 5 – Conservation of Momentum*

There are three different types of collisions; *elastic*, *inelastic*, and *perfectly inelastic.* In all three types, the momentum is conserved; however, the kinetic energy is not. In an *elastic* collision, the total kinetic energy of all the objects *is conserved* from before the collision to after. An example of this would be a collision between two balls from a pool table. Since the pool balls are very smooth, there is very little energy loss due to friction. Also, when the balls collide, they don't permanently deform (which also requires energy).

In an *inelastic* collision, the kinetic energy is not conserved. This is because, during the collision, there is a loss of energy due to permanent deformation of the objects and friction. An example of this would be a car accident. When the cars collide, the metal of the car is usually bent. It takes quite a bit of energy to do this and that energy is taken from the kinetic energy of the cars. A *perfectly inelastic* collision is basically the same idea as an *inelastic* collision, except the objects stick together.

The Equipment

For this lab you will be using carts with signal bouncers, a track, a motion sensor, and a force probe. **See** Figure **2.** You will be pushing the carts on the tracks to give them velocities. Please do not allow them to slam into the stop-brackets in front of the motion sensors. Also, in the first part of the lab you will be using a force probe attached to a rubber band. Please use reasonable velocities so the carts do not ricochet violently.

Figure 2 – Equipment Setup
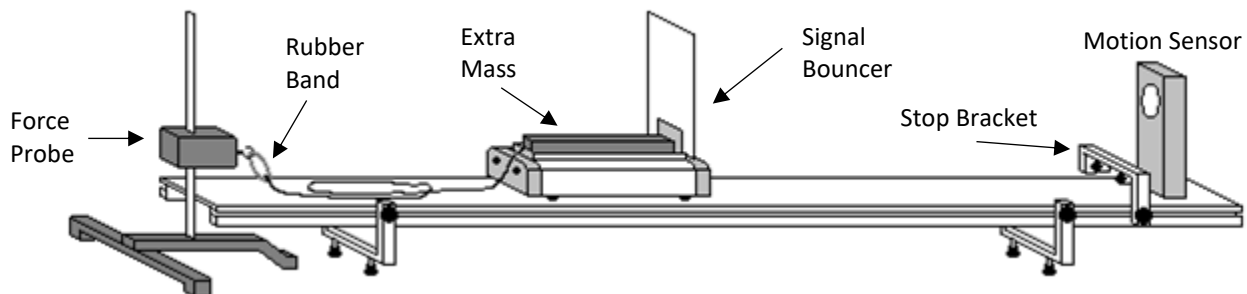
What You Need To Do:

Part 1 – Impulse

In the first part of the lab, you will be examining the relationship between the average force, F_{avg}, acting on an object and the time, Δt, over which it is applied. Remember, when you multiply these values together, you get the impulse delivered to an object. That impulse is also related to the velocity of an object.

Preparation

The setup should already match *Figure 2* above. If anything is missing call your instructor.

Before you leave the room today your setup must be returned to how it is in *Figure 2* or your instructor will be in trouble.

A) First place your cart on the track and verify it stays stationary. If it starts rolling either way call over your instructor so they can fix your track leveling.

B) Make sure the flat side of the signal bouncer is facing the motion detector, if it isn't then just pull it out and switch the side.

C) Place a black bar mass on your cart. **See *Figure 2*.** It should fit very snugly between the end of the cart and the signal bouncer. Make sure it rests in the cart bay so that it is secure otherwise it'll slide off the cart during the experiment.

D) Using the digital scales measure the total mass of the cart, the signal bouncer, and the extra mass all together. Record this value.

E) Verify the paper clip is attached to the hole in the end of the cart, on the opposite side of the signal bouncer.

F) Attach one of the rubber bands (Thick or Thin) to the eyehook on the force probe. *Do not attach both rubber bands at the same time.*

G) On your computer, open the file **IMPULSE**. Click CONNECT on the Sensor Confirmation window if it comes up.

    a. The top portion of the screen is a *position vs. time* graph for the cart.

    b. The lower portion of the screen is a *force vs. time* graph due to the force on the cart from the rubber band.

H) Push the ZERO button (next to the green COLLECT button). A smaller window will open. Have only the Dual Range Force item checked and then click OK.

I) On the physical force probe device, make sure the ±10 N is selected.

Table 1 – Part 1 Data

Rubber Band	Initial Velocity	Final Velocity	Average Force	Change in Time	Impulse by mΔv	Impulse by FΔt	% Diff
THIN							
THICK							

Thin or Thick Rubber Band

A) Take a measurement of the cart rebounding with the rubber band you chose.

    a. Position the cart so that it is roughly 30 cm away from the force probe.

    b. Make sure that the string is looped and placed on the track. **See** *Figure 2*. This will ensure that, when the cart moves, the string will not get caught on anything.

NOTE: You will need to move the string out of the way after it ricochets otherwise the wheels will get caught up on the string and slow the cart down.

    c. Push COLLECT in the Logger Pro File.

    d. Give the cart a push towards the motion sensor. The cart will move out and then get pulled back because of the rubber band.

Now you need to collect data from the computer.

B) Get the Average Force:

    a. In the force graph, there will be a red "hill" that represents the changing force of the rubber band on the cart. First, do a sketch of the hill in your lab report, include the approximate y-axis values.

    b. Next, highlight the region from just where the force begins to increase to just after it becomes zero again.

    c. Then click on the "Statistics" button. This will create a little window that will tell you the mean value of the force (among other things which you can ignore).

    d. Record this in your table under Average Force.

C) Get the Change in Time During the Stretching of the rubber band:

a. As long as you have the same highlight as the previous step; In the lower left-hand corner of the force graph there is a set of parentheses with a **Δt** in it.

b. The number to the right of this is your change in time value. Record this in your table.

D) Get the Initial Velocity before the rubber band acts on the cart. You'll get the initial velocity from the position graph from the region just before the start of the "Force Hill"

a. On your position graph go to the left edge of the region you highlighted in the last two steps.

b. Click and hold the mouse, dragging to the **left** until the "Δt" value in the lower left of the graph is roughly 0.250, then unclick.

c. You should now have highlighted about 0.25s before the start of the action of the rubber band.

d. Now push the "Linear Fit" button on your position graph; this will open a window which will give you the slope of the line in that region. (Recall what the slope of a position vs. time graph gives you)

e. Record this value in the table in the Initial Velocity column. Make sure you include the sign.

f. If your initial velocity was not between – 0.50 m/s and – 0.95 m/s, then continue to do the above procedure until you achieve a value in that range with nice smooth lines in your graphs.

E) Get the Final velocity of the cart after the rubber band acts on it. You'll repeat the previous steps but on the right side, just after the rubber band action instead:

a. The gray area from the force graph will now be gone so re-highlight the hill on the force graph.

b. In the position graph on top go to the right edge of the gray region.

c. Click and drag the mouse to the **right** until **Δt** = 0.250.

d. Push "Linear Fit" again and record your final velocity value in your table.

Note: You will be measuring many velocities this way during this lab, so if you aren't clear on what you are doing then grab your Instructor and ask them to help you.

F) Using the data you have collected, calculate the impulse in the two different ways discussed in the introduction of this lab. Put these values in *Table 1* and show sample calculations.

G) Calculate a percent difference using these two values and place that in the row matching your rubber band choice in *Table 1*. If you got a percent difference more than 8%, you are probably doing something wrong. Figure out your problem before you move on to the next part.

H) Do your calculations with these acceptable values and then proceed.

Checkpoint 1:

Was the cart's momentum conserved from before the cart ricocheted to after? How can you tell? HINT: Momentum is a *vector* value.

Checkpoint 2:

In a car collision, the driver's body must change speed from a high value to zero. This is true whether or not an airbag is used, so why use an air bag? How does this reduce injury?

Question 1:

Explain why the momentum was or was not conserved based on what was discussed in the intro to the lab.

Part 2 – Conservation of Momentum

In the first part of the lab, you examined the velocity and momentum for a single object. Now you are going to examine the total momentum of TWO objects before and after a collision.

Preparation

You'll need to do a quick change from the previous section:

A) Both stop brackets should already be on the track, verify that they're both screwed on tightly.

B) Remove the paperclip/string from the cart:

   a. Do not untie the string on either end, just take the clip hook out.

   b. Hang the string back over the bracket it's passing through so its out of the way, leave it through the stop bracket.

   c. No need to unplug the force sensor just leave it be.

C) Add a motion sensor to your setup:

   a. Plug the second motion sensor into dig/sonic2 if it isn't already.

   b. Place it on the track flush against the stop bracket.

Table 2 – Part 2 Data

Trial	Cart #1			Cart #2			Total Momentum		Kinetic Energy		
	Mass	Initial Velocity	Final Velocity	Mass	Initial Velocity	Final Velocity	Before	After	Before	After	KE loss
Elastic – Same Mass											
Elastic – Diff Mass											
Perfectly Inelastic											

D) Add the second cart to your track. You will be using both carts now either with or without the extra mass. From now on:

   a. Cart #1 refers to the cart closest to the PCs in the center of the lab.

   b. Cart #2 refers to the cart farthest from the PCs, and closest to the outer walls.

   c. You may need to rename your graphs in your logger pro file for this later.

E) Use the digital scales to find the mass of the cart and bouncer without the extra mass. For the first trial you will be using the carts without the extra mass so write down the appropriate masses for both carts in your table for Trial #1.

F) Some things to know about the carts:

   a. Each cart has a magnetic side and a Velcro/Spring pillar side, we'll be using the magnetic side as the reference for which way the carts point. You can see the circle magnets through the clear plastic.

   b. The Spring Pillar has a setting where it's flush with the edge of the cart. You may have to push the button down a bit to get it into this setting.

   c. The best data will be collected when the bouncer's flat side is facing the motion sensor. You can just pull it up and switch sides as needed.

Elastic Collision – Same Mass

A) For this collision place the carts so that the magnetic sides are facing each other. Adjust the signal bouncers if needed.

B) Place Cart#1 near the motion sensor (nearest the PC) and Cart #2 about half way down the track. This will be referred to as the "Starting Position" in later parts.

C) The carts are now set up for an elastic collision.   Both carts should now have the same mass. You do not need the computer for this step. Give Cart #1 a little push and let it collide with Cart #2 which is at rest and observe what happens. **Please** keep in mind that this is not NASCAR.

Checkpoint 3:

Based on what you observed, what happened to the momentum from Cart #1? Why do you think the collision occurred the way it did?

Checkpoint 4:

What do you think will happen if Cart #2 had the extra mass in it when they collide? Explain why you think this.

J) On your computer, open the file named **MOMENTUM**. Both graphs are position vs. time graphs. First, we'll have to adjust the graph labels to match your setup:

    a. Press collect and move just Cart#1, closest to the PC, (while keeping the other stationary) until you can identify which graph is changing.

    b. If the graph labelled Cart#1 is the one changing you're good to go onto step E.

    c. If the graph labelled Cart#2 is changing then adjust the LoggerPro graph labels to match which cart is which:

        i. Click the title "Cart#2"

        ii. Click "More…" at the bottom to open an axis data window.

        iii. Change the label appropriately, then close.

        iv. Repeat with the other graph.

K) Return both carts to Starting Position.

L) Push COLLECT on the computer.

M) Give Cart #1 a push and let it collide with Cart #2 at rest. You should see on the screen graphs that look similar to the ones in *Figure 3*. If not, then try another run or grab your Instructor.

  d. Note half of you will see Cart#2 on top and Cart#1 on the bottom.

N) Now you are going to measure both carts' velocities before and after the collisions using your graphs. Do this in the same way you did in the first part of the lab.

  e. Make sure you highlight your regions *just before* and *just after* the collision. **See** *Figure 3*.

  f. As before, make sure the width of the region is about 0.250 seconds.

Figure 3 – Position vs. Time Graphs
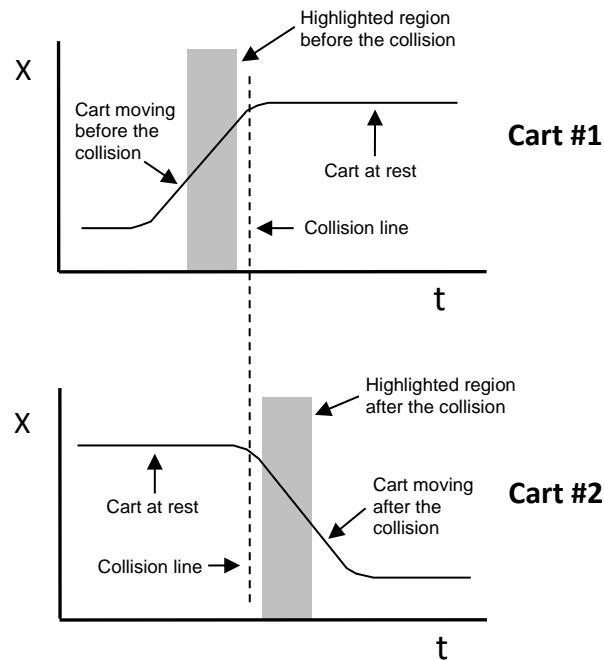
NOTE: Since the motion sensors are facing opposite directions, their directional signs do not agree, therefore, you choose a direction that you will call positive and assign negative velocity values so that they agree with your choice.

O) Try to get an initial velocity for Cart #1 to be in between 0.3 m/s and 0.5 m/s. Keep doing trial runs until you are good at getting smooth graphs and a velocity in the given range. When you have a good run then record the values in your table.

P) Calculate the total momentum before and after the collision and put these values in the table. For example, …

$$p_{total,before} = p_{cart\#1,before} + p_{cart\#2,before}$$

$$p = mv$$

Q) Calculate the total kinetic energy before and after in the same way. Calculate the kinetic energy loss too. Place all of these values in the table. Recall…

$$KE = \frac{1}{2}mv^2$$

Question 2:

Explain your answers to the following in terms of what was discussed in the intro.

Was the momentum conserved for your *system* from before to after?

Was the momentum conserved for *Cart #1* from before to after?

Question 3:

Physically speaking, why is this collision considered to be elastic? Do your calculated values for the kinetic energies reflect this? Explain.

Elastic Collision – Different Mass

Place the extra mass on Cart #2. Return both carts to Starting Position. You do not have to take data for this run. Give Cart #1 a push, let the carts collide, and observe what happens.

Checkpoint 5:

Referring back to **Checkpoint 4**, was your prediction correct?

Checkpoint 6:

What do you think will happen if Cart #2 is moving first and Cart #1 is at rest? Try it. What do you conclude?

Perfectly Inelastic Collision – Different Mass

A) Add the extra mass to Cart #2.

B) Flip the carts around so that the magnetic sides are now facing outward, the Velcro™ on the other sides of the carts will make them stick together when they collide.

C) Flip the signal bouncers so they face the detectors, be sure to press them in firmly into the bed.

D) Place the carts at the starting position.

E) Give Cart #1 a push and let it collide with Cart #2 at rest.

F) Take data on one run in which Cart #1's initial velocity is between 0.6 m/s and 0.7 m/s.

G) Do your calculations as before and fill in the remainder of *Table 2*.

H) Now before you're done you need to return the lab to how it was when you entered.

    a. Remove the second motion sensor and verify the remaining sensor is plugged into Dig/Sonic 1. (This should be the case if you relabeled your graphs instead of switching the ports)

    b. Flip the signal bouncers back around so that the flat side is on the same side as the cart's magnets.

    c. Reattach the hooked string to the cart as it was setup in Part 1 for impulse.

    d. Thank you, now answer the remaining questions that follow.

Question 4:   Was the total momentum conserved for this collision? Is this consistent with what you read in the intro? Explain.
Question 5:   Physically speaking, why is this collision considered to be inelastic? Do your calculated values reflect this?

Conclusion

Follow the lab report guide to write a conclusion on this lab.

Submit any excel or graphical analysis data your instructor requests along with your report.

Conclusion