

PHYS 1P91 Experiment 07

Momentum and impulse

Notes

- Words in [blue](#) are links to additional reading or videos.
- Text in gray boxes are hints and things to take note of.
- Text in red boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

1 Objectives

- Use the iOLab to study the concepts of momentum and impulse.
- Show how the change of momentum of an object is related to the force applied.
- Test the conservation of momentum in a nearly elastic collision.

2 Introduction

Force is an intuitive concept; a push or pull that causes an object to accelerate. But in fact, a *better*, more useful description of what a force is found in Newton's Second Law; a force is that which causes a change in an [object's momentum](#) over the period of time the force is applied:

$$\mathbf{F}_{\text{net}} = \frac{\Delta \mathbf{p}}{\Delta t} \quad (1)$$

This is a much more useful equation than $F = ma$. With this definition, we can better understand things like the orbits of the planets (where the magnitude and direction of velocity vector \mathbf{v} is changing), rocket propulsion (where the mass m is changing in time), and the collisions of objects (where the total momentum of the objects needs to be conserved).

In situations like collisions, the varying forces act for fairly short times. It is only their effects (ie. the momentum changes they cause) that are of real interest since we know there

is a law of conservation that must be upheld. The numerator of equation 1 is the total change in an object's momentum. This is equal to the the net force, times the duration of the force, which is known as the [impulse of the force](#);

$$\Delta\mathbf{p} = \mathbf{F}_{\text{net}}\Delta t \quad (2)$$

[Impulse](#) is a term that quantifies the overall effect of a force acting over time. The longer the force is applied, the more the momentum will change.

In this lab, we will verify equation 2 with two simple iOLab collision experiments.

3 Prepare the iOLab

Insert the iOLab USB dongle and turn on the iOLab. Start the software.

In the iOLab accessory pack, there was a [screw/spring combination attachment](#). Follow the [video](#) to attach it. Make certain the bolt that attaches the spring to the screw is tightened, then use the screwdriver to attach the screw to the force sensor. Do not over tighten!

4 Take data

REMINDER - if you need to *calculate* any uncertainty value(s), you need to include a separate file with your error propagation derivation(s).

4.1 Starting from rest

First we need to calibrate the Force gauge sensor in the +y direction as we have done before (*i.e.* only the mass hanging portion) with the following changes:

1. instead of using the eye-bolt have the mass and paperclip hang from the spring sensor
2. change the number in the Calibrate to the weight of box to -100g instead of the usual 100g

After calibrating with the +y-axis pointed up, place the iOLab at rest on its wheels on a flat surface, and have nothing touching the spring on the Force gauge sensor. If you take 3 seconds of data with the device like this you will notice the force is non-zero.

This means we need to calibrate the Force gauge sensor for this setup. Take another 3 seconds of data with the wheels on the flat surface and then hit set zero.

Can you think of a physical reason why the weight of the calibration mass needs to be changed for this experiment?

Think of the direction of the forces acting on the sensor from this experiment compared to those you have done in the past.

Now it's time for the impulse. Choose to record both the Force gauge and Wheel sensors. Set the software to collect ~ 6 seconds of data.

Click Start, and give the spring attached to the force sensor a gentle tap with your hand or something flat. This will start the iOLab slowly rolling away. Don't "push" it forward – instead give the spring a soft, short hit.

That's it. That tap, or collision between your hand and the iOLab was the impulse. It was very brief in duration, but that force was enough to change the momentum of the iOLab from zero to $p > 0$

Switch to view the force-time graph, then click Draw. It might look like something like Figure 1, where the impulse registered as a sharp peak, but was recording zero force otherwise.

Does the force-time graph have an initial value of zero before the impulse? If not, go back and re-zero the force sensor.

When we calculate impulse using equation 2, we are multiplying a force by a time. Unlike a hypothetical situation typically found in a homework question, the force here is not constant.

However, if the force F_{net} in equation 2 is not the *peak* force, but an average, effective force, then equation 2 is equivalent to finding the area under a force-time curve. (For example, see Figure 8.2 [here](#).) In Figure 1, the green rectangle of effective force multiplied by the time interval has the same area as the area under the red data curve.

Save your data.

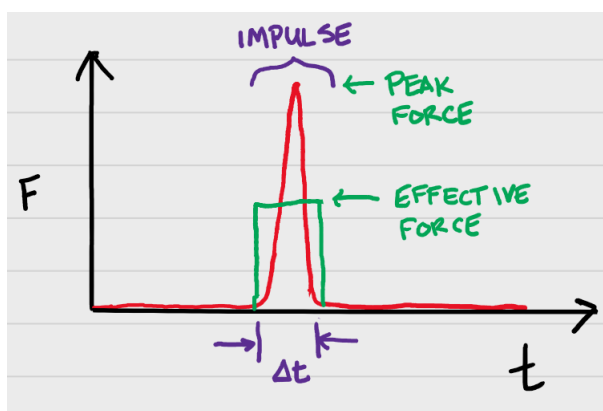


Figure 1: Hypothetical force-time graph of an impulse. Our textbook equation 2 assumes a constant **effective force** like the green rectangle. In real experiments you get something that looks like the red curve where there is a **peak force**. Both of these graphs represent the same change in momentum the area under both the green and red curves are the same.

In the force-time graph, zoom into view the impulse. Using the cursor and your best estimation, record the start (t_0) and stop (t_f) time points of the impulse, and calculate the time interval of how long the force was applied, Δt and its uncertainty.

Record the area (with proper units) of the impulse from the reported statistics.

The area of the impulse is equal to $F_{\text{net}}\Delta t$. Assuming F_{net} is a constant value, calculate F_{net} using your data.

What is the uncertainty in F_{net} if you assume the area under the curve has no error?

What law determines the force that the spring imparts on the force sensor?

As the force increases up to **peak force** describe what happens to the compression of the spring.

What would happen to your graphs if you changed the spring constant of the spring on the spring/screw attachment?

Switch to view the wheel velocity-time graph $v(t)$ using the drop down menu above the data window. It should look something like Figure 2, and if you could multiply the velocity by the mass, it would become a momentum-time graph $p(t) = m \cdot v(t)$.

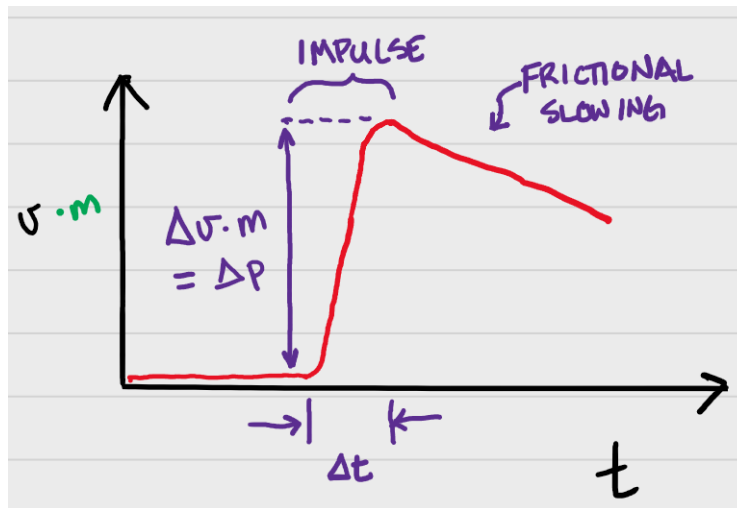


Figure 2: Hypothetical velocity-time graph of an impulse when the initial momentum was zero. If you multiply the velocity by the mass, you will have a momentum-time graph.

Zoom in to view the change in velocity. Using the cursor select a few points near the end of the impulse (minimum 3). Record the total change in velocity at the end of the impulse along with its uncertainty.

Note: You already have the correct time point marking the end of the impulse from above.

Why do you only need to look at the velocity at the end of the impulse?

Compute the change in momentum (and its uncertainty) from the velocity and the mass of the iOLab: $\Delta p = m\Delta v$. You can use the value of the mass of the iOLab (with its uncertainty) from a previous lab.

Compare Δp with the area of the force-time graph impulse by computing the percent difference. It should be possible to get to within 15% difference - were you able to do this? Were your values for Δp within uncertainty?

4.2 Simple collision

In this part, you will run your iOLab spring-first into a solid object. This is a head-on collision with a “wall” such as you might encounter in a homework assignment.

- Don't forget to select the Force and Wheel sensors
- Give the iOLab a gentle tap/push so that it rolls freely (but slowly) into the wall.
- Make sure it rolls slowly. The peak force from this collision can be quite high.
- Let the iOLab bounce back and roll backwards from the spring's force.
- Make sure the rebound is *straight* back and not at an angle.

The force-time curve will look much like Figure 1 above; a short duration, high-force impulse. You need a fairly large distance to make this work; otherwise the time scale will make it hard to distinguish the velocity caused by *pushing* at the beginning versus *hitting* the wall.

Save your data.

In the force-time graph, zoom into view the impulse. Using the cursor and your best estimation, record the start and stop time points of the impulse, and calculate the time interval of how long the force was applied, Δt and its uncertainty.

Record the area (with proper units) of the impulse from the reported statistics.

The area of the impulse is equal to $F_{\text{net}}\Delta t$. If we assume F_{net} is a constant, effective average force of your push, what is it? What is its uncertainty?

Is F_{net} more or less than what you did with your hand above? Why?

Switch to view the wheel velocity-time graph. It might look a bit something like Figure 3, where $p = mv$.

You may wish to note several key aspects of your curve:

- You may or may not see your initial push to get the iOLab rolling into the wall, but you should see the large, sudden change in velocity from the collision.
- The initial roll is the $-y$ direction, so the initial velocity is negative, and slopes upward as it slows down from friction.
- The impulse changes the sign of the momentum (velocity) when the iOLab rebounds from the impact of the spring into the object.

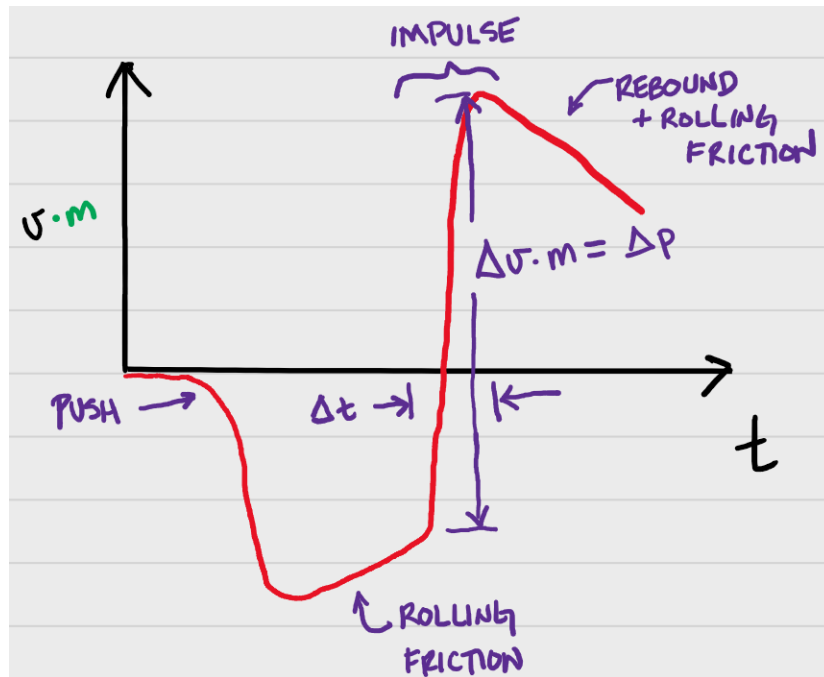


Figure 3: Hypothetical velocity-time graph of an impulse of a head-on collision and rebound. If you multiply the velocity by the mass, you will have a momentum-time graph.

Zoom in to view the change in velocity. Using the cursor and your best estimation, record the total change in velocity at the from the beginning to the end of the impulse. You have both the start and end time points of the impulse from above.

Compute the change in momentum from the velocity and the mass of the iOLab $\Delta p = m\Delta v$. Calculate the uncertainty in Δp as you did above.

Compare Δp with the area of the force-time graph impulse by computing the percent difference. It should be possible to get to within 15% difference - were you able to do this? Were your values for Δp within uncertainty?

In an *elastic* collision, the momentum of all the objects before and after the collision should total up to the same. The “wall” you iOLab ran into had zero momentum before and after. This means your iOLab should have had the same momentum before and after the collision, but in opposite directions.

Was your collision an elastic or inelastic collision?

Where would some of the momentum gone if it were inelastic?

Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found on [Sakai](#)), include figures, and develop a robust discussion using prompts found throughout the manual.

Ensure to give yourself enough time to complete the report and to hand it in by the due date as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email Phys1P91@brocku.ca.