Momentum & Impulse

At-Home | Two Weeks | Draft & Report Submissions

Introduction

This lab is designed to provide students with the opportunity to explore the concepts of momentum and impulse using their phone as the measurement device. This lab is meant to be done at-home, but it is important that students get started as early as possible so questions can be answered before submitting the final assignment. This is a two-week lab; a report draft will be due at the end of the first week and a full report will be due at the end of the second week. In this lab, students will (a) find the velocity of a phone under free fall, (b) obtain momentum of the phone as a function of time, (c) estimate impulse of the phone due to collision when it comes to a stop and (d) obtain a measurement for the average force imparted on the phone due to the collision.

Theory

Momentum is a measurement of mass in motion. It is one of the key concepts in the physics of moving objects and it is defined as follows:

$$\vec{p} = m\vec{v}$$

Here "m" denotes the mass of the object and "v" denotes its velocity. It is a vector quantity, and it has the same direction as velocity.

The net change in momentum of an object is known as Impulse, which can directly be related to the net change of the object's velocity, assuming the object's mass remains constant.

$$\vec{I} = \Delta\vec{p} = m\Delta\vec{v}$$

We know from Newton's laws that a net change in an object's velocity can only occur in the presence of external forces. From Newton's Second Law, we know that force is related to mass times the acceleration of the object, which can then be related to the change in velocity.

$$\vec{F} = m\vec{a} = m\frac{\Delta\vec{v}}{\Delta t}$$

Thus, using the above two equations, the average net force acting on the object can be found as:

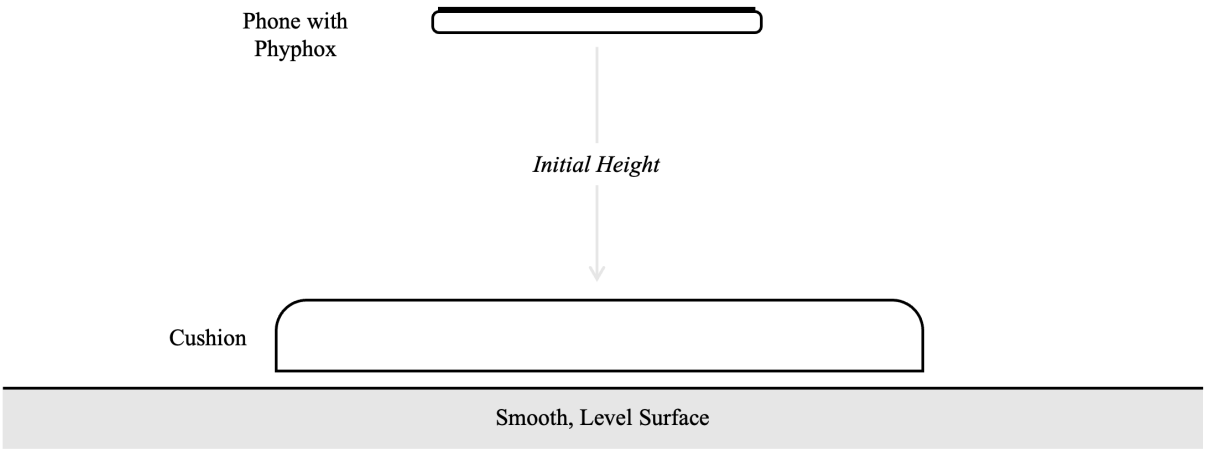
$$\overline{\vec{F}_{net}} = \frac{\Delta \vec{p}}{\Delta t}$$

These equations can describe most situations in which an object is in motion. You are expected to be familiar with these expressions and be comfortable with using them.

Procedure

For this lab, we will utilize the following equipment:

- A smartphone with Phyphox installed. You can find the Phyphox app in any app store, or by visiting the website: https://phyphox.org/. If you struggle with this, please let your TA know ASAP.
- A smooth, level surface (tabletop, countertop, uncarpeted floor, etc.)
- Excel (or equivalent) for data analysis and making graphs.
- Word (or equivalent) for writing up your report.



There are three activities to be performed in two weeks. The goal is to study the free fall data collected in Phyphox to estimate the velocity and momentum of the phone during and after the fall, then using the change in momentum of the phone during collision with the (soft) base to estimate the total force imparted on the phone.

Activity 1: Measure Acceleration v Time and Obtain Velocity

The goal of this activity is to drop the phone from various heights, collect acceleration vs time data in Phyphox and obtain the velocity vs time data.

1. Measure the mass of your phone. **You can do this in the last in-person lab you have. Please coordinate accordingly with your TA.**

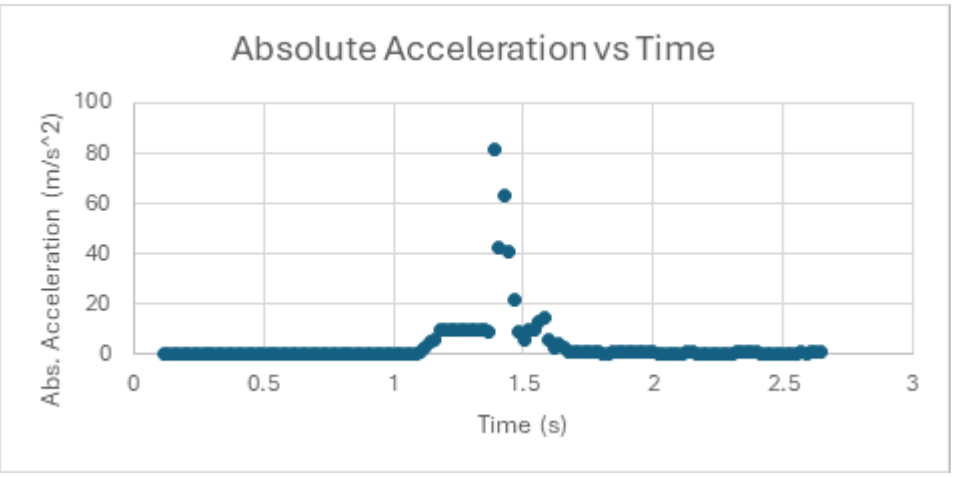
2. Open the "Phyphox" app on your phone and choose the "Acceleration (without g)" sensor. You should be comfortable with using the Phyphox app by now.

3. Measure the height you want to drop your phone from. Make sure that you keep something soft underneath the phone to catch it, like a cushion, pillow, blanket etc. **Do not break your phone!**

4. Hit collect data on the Phyphox app and drop the phone on the cushion. Stop the data collection.

5. Export the data to Excel and make a graph of absolute acceleration vs time.

6. Identify the four different regions in your graph and discuss what is happening to the phone in each one of them. You should be familiar with this analysis from your "Accelerometer in your Phone" lab. Your graph should look similar to the one below.



7. Using the Euler numerical integration method, obtain the velocity of the phone for each time step. You should be familiar with this method from your "Air Resistance Simulation" lab. Please refer back to that handout for guidance if you have questions.

8. Make a plot of the velocity obtained vs time. Identify the different regions in this plot.

9. Note the final velocity obtained (velocity of the phone right before collision).

10. Now, using the measured height of the drop, find the initial potential energy of the phone.

11. Using energy conservation, find the final expected velocity of the phone (right before collision). You should have seen energy conservation in lecture, but for the sake of brevity, energy conservation can be given *simply* as: Potential Energy + Kinetic Energy = Constant. It's worth noting that work due to forces would be included as well, but we will ignore that for this lab (source of error anyone?). So, for this case, finding the velocity is as simple as setting the initial potential energy equal to the final kinetic energy:

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

12. Compare this theoretically expected final velocity with the measured (obtained) final velocity. Comment on the discrepancies, if any.

13. Repeat all the above steps for at least a few different drop heights.

14. What happens as the height changes? Does the mismatch in the expected and measured final velocities increase or decrease as height increases? Why?

Activity 2: Obtaining Momentum

The goal of this activity is to use the data collected in the previous activity to obtain the momentum of the phone during its free-fall and collision.

1. From the calculated theoretical final velocity and mass of the phone, find the theoretical final momentum for any one drop height.

2. For that height, use the velocity vs time data obtained experimentally from the previous activity to find momentum at each time step.

3. Plot the momentum vs time data obtained experimentally.

4. Note the final value of momentum obtained experimentally (right before collision).

5. Compare the values of the final momentum obtained experimentally and calculated theoretically.

6. Repeat the steps above for the multiple heights chosen previously.

7. How does the comparison of the experimental and theoretical momentum change as height is changed? Why?

Activity 3: Impulse & Force

The goal of this activity is to look at the collision data to obtain the impulse and the net force imparted on the phone by the cushion.

1. For any one drop height, find the momentum of the phone right after the collision with the cushion. This is your experimentally obtained value of momentum just after collision. What do you theoretically expect this value to be? Why?

2. Obtain the impulse, Δp the difference in momentum just before and after collision.

3. From the data collected, find of the collision.

4. Find the average net force acting on the phone during collision from impulse and Δt obtained.

5. Repeat the steps above for the multiple heights chosen previously.

Analysis

In your submission, you will need to include:

- All graphs made for acceleration vs time, velocity vs time and momentum vs time, for all the different values of height chosen.

- Calculations of theoretical values of velocity and momentum.

- Obtained experimental values of velocity and momentum.

- Values obtained for impulse and net force on the phone, for all the different height values.

Discussion

As *parts* of your discussion, please make sure to include:

- Discussion on the nature and meaning of the plots obtained for Activity 1 and Activity 2.

- Comparisons of theoretical and experimental values of velocity and momentum. Comment on the effect of changing heights on the same.

- Discussion on Activity 3. What did you find? What did you expect?

You must discuss the possible sources of error in your report. What could have caused your experimental values to not match up? Think about systematic vs random errors. How can they apply to this experiment?

FAQ's & Recommendations

How should I prepare for lab time?

You only have so much time in lab each week, so proper preparation makes a huge difference in what you're able to accomplish! Read the handout ahead of time so that you can ask clarifying questions immediately and get started as soon as you arrive!

What goes in my lab notes?

The purpose of lab notes is to enable your or a colleague to reconstruct what was done and why after you've left the lab and are performing analysis or writing a submission.

- You can use any form you like to record experiment information: notebook, spreadsheet, etc.
- They don't have to be neat, in complete sentences, etc., but they do have to be useful!
- Make sure to take detailed notes about your setup, how to use the equipment, what results you found, measurements related to the environment you may need, etc. You may not be able to get back into the lab later in the week if you miss something, so record as much detail as possible!
- When storing multiple data files while in lab, make sure to name the files clearly so they're easy to find later.

When should I work on the experiment and analysis?

We strongly recommend doing the lab as early in the week as possible, rather than waiting until it is almost due. This is just so that, if you run into trouble and need help, you'll have plenty of time to talk to your TA and get issues resolved before the deadline.

How do I turn in my results?

After leaving lab, performing your analysis, and completing your submission, you're ready to turn in your work!

- Every lab session requires submission of either an assignment, summary, draft report, or report.
- Collaborate with your partners on data collection, analysis, and writing.
- Turn in a single group submission and make sure the names of all group members are included.
- Upload your submission to Canvas/Brightspace as a .pdf by the deadline in the course calendar.
- Other than the spreadsheet assignment, you will not upload any spreadsheets. Just copy and paste figures and other elements from your spreadsheet into your formal submission as needed.

Where can I get help?

Your lab TA can answer questions during the lab, by email, or by setting up a time to meet. You can also ask advice from lab partners and/or other students.

General DO's and DON'T's

- *DON'T* break the equipment – always be careful when using lab supplies!
- *DO* consult with your lab TA before leaving a lab session about your experimental method, the validity of your results, and any confusion you have about the analysis process.
- *DON'T* forget to record all the parameters and measurements for your experiment, including saving files.
- *DO* be creative in your experimental design and enjoy!