Experiment Number 12

Impulse & Momentum

PURPOSE: To better understand the relationship between the impulse on a moving object and the resulting change in momentum experienced by that object.

To understand the graphical relationship between the force applied on an object and the time over which that force acts on the object.

MATERIALS:

Bathroom Scale
iPad or iPhone
SparkVue iOS application
Personal computer
Microsoft Excel data program

INTRODUCTION:

Any object in motion has a **momentum** that can be calculated as:

$$\boldsymbol{\rho = m \cdot v}$$

where ρ = momentum in units of $\frac{kg \bullet m}{s}$, m= object's mass in kilograms, and v= object's velocity in m/s. The momentum of an object can best be understood as how difficult it is to bring a moving object to rest; the greater the momentum, the more difficult it is.

In order to **change the momentum** of an object, one must either affect the object's mass or its velocity. For our purposes, we will only consider momenta changes as a result of changing the object's velocity. Therefore:

$$\boldsymbol{\Delta\rho = m \cdot \Delta v}$$

In order for there to be a change in an object's momentum, there must be a force applied to the object over some period of time, as we've learned previously with Newton's laws of motion. The quantity of that force multiplied by the time over which it is applied is called the **impulse**, or

$$\boldsymbol{J = F \cdot \Delta t}$$

Which has units of $\boldsymbol{N \cdot s}$. The quantity of this impulse is exactly **equal** to the change in momentum experienced by the object, or more specifically:

$$\boldsymbol{J = \Delta\rho} \quad \text{or} \quad \boldsymbol{F \cdot \Delta t = m \cdot \Delta v}$$

In order to better understand this relationship between the **impulse** applied to an object and the resulting **change in momentum** the object experiences, in this lab, you will first calculate the theoretical change in momentum for a person who is dropped from a known height, hits the floor, and then pushes off the floor to be airborne again. You will then perform an experiment in which you measure the average force experienced by the floor on the person over the time in which the force is applied. With the force and time in hand, you can then calculate the impulse experienced by the person and compare your calculated value for impulse to the theoretical value for change in momentum you previously found. These two values, the impulse and the change in momentum, should be the SAME. After, you will graph your values for Force & Time to see their relationship.

PROCEDURE: Part I→ Calculating theoretical change in momentum.

1. Measure the mass of the person who is to be "dropped". Record this in your data sheet under "Mass of Person ($\mathbf{M_p}$)".

2. Measure the height from which the person is to be dropped, and record this value in your data sheet under "Vertical Distance ($\mathbf{d_y}$)".

3. Next, using the values assigned in your data sheet for initial velocity of the person ($\mathbf{v_i}$) and acceleration due to gravity (**g**), calculate the velocity of the person just before they hit the ground and record this value under "Maximum Velocity ($\mathbf{v_{max}}$)".

[*Use your reference tables to find an equation that will allow you to solve for this velocity, given what you already know.*]

4. Immediately before the person hits the ground, their velocity is the greatest and therefore so is their momentum. In order for the person to **bounce** off the ground and return in the opposite direction, they must come to **a rest** midway through the impact with the floor; at this point, the person's momentum is ZERO, as they are no longer moving downward at the moment. In the very next moment, they must completely change directions and push off the floor and then leave with a speed similar to that which they initially hit the ground with, and therefore must leave with a momentum that is equal in magnitude to their initial momentum.

As a result, the person's change in momentum is actually DOUBLE their original momentum, as they go from some positive value, to zero, then to a negative value, all as a result of changing direction. In other words: **[+……→……0……→…….-].** On your data sheet, calculate the person's initial and final momenta and show that the person's change in momentum ($\boldsymbol{\Delta\rho}$) is TWICE their momentum immediately before making impact with the floor. Record this value under "Change in Momentum ($\boldsymbol{\Delta\rho}$)".

PROCEDURE: Part II→ Calculating impulse using measured force & time.

5. Using the iPad, have the program "SparkVue" open and ready to record the acceleration of the person.

6. With the person positioned to be "dropped" from the height of a table, start recording the acceleration and let the program collect a few values for acceleration before being dropped. Then, while still recording the acceleration, slide off the edge of the table [**be careful not to JUMP**], make impact with the ground, and then push off the ground so as to be in the air again. When the person has finally come to rest, stop the program.

7. Email the program file to a PC and open the file with Microsoft Excel. [*The file you get will already be prepared and labeled*].

8. Next, create a column that indicates the force experienced by the person [labeled, "Force (N)"]. Fill the column with values for each data point by realizing <u>that this force is equal to the person's mass multiplied by the acceleration they *experience*, as given in the data you collected. This is the force you will use to determine the impulse.</u>

9. Using Excel, determine the average force applied to the person during the impact with the floor, from initial to departing impact, and record this value on your data sheet as "Average Force Applied ($\mathbf{F_{avg}}$)". Then, using the values for time collected in your data, record the impact duration in your data sheet as "Total Time of Impact ($\mathbf{t_{tot}}$)"

10. Using the values you obtained for Force and Time, calculate the impulse applied to the person during the impact. Be sure to show your calculations for this value, and record it as "Impulse (**J**)" in your data sheet.

11. Calculate the percent difference between the theoretical value for the change in momentum and the impulse you calculated from the recorded data. [*Because* $\boldsymbol{J = \Delta \rho}$*, these values should be the* ***same***, right?!.] Be sure to use your theoretical change in momentum as the ACCEPTED VALUE.

12. Finally, using the values found in the Excel spreadsheet under the data segment labeled "Force Applied", plot a scatter graph of Force vs. Time. These are the values for force and time during the impact. Be sure to choose the scatter plot option with "smooth lines".

13. Type your final report using the standard report format, making sure to also include a data table for the impact forces and times, your graph of F vs. T, your data sheet, and the questions below.

QUESTIONS:

1. In your own words, describe the relationship between the impulse experienced by an object and the **change** in momentum experienced by the object.

2. When you calculated the impulse experienced by the person, you multiplied "force" and "time"; what "force" did you use to make this calculation.

3. For the person in your experiment, hitting the floor and then pushing off of it is very similar to a tennis ball being thrown toward a racket with some initial speed, being hit by a tennis racket, and then shot in the opposite direction from which it came. Explain WHY these situations are similar by **explaining the momentum changes of the object-in general- before, during, and after the impact**.

4. A ball of putty with mass 1 kg is dropped from a height of 1 meter and sticks without bouncing as it makes impact with the floor. A rubber ball with the same mass is dropped from the same height, but bounces. Which object, the putty or the rubber ball, experiences the greater ***change*** in momentum? Explain why.

5. When calculating the impulse experienced by the person, do you use the maximum force of impact, or the average force? Explain why it makes sense to use the force that you did.

6. Given your graph of Force vs. Time:

a) What is maximum force experienced by the person during their impact with the floor, in newtons?
b) What is the significance of the area under the curve for your Force vs. Time graph? This also relates to another familiar quantity; what is that?

Considerations for your Conclusion:

- Provide a statement that indicates how your understanding of impulse and change in momentum has changed.
- Provide specific values for any calculations, conclusions you can make from these values, as well as any mathematical relationships from graphed data.
- List some of the opportunities for error to be introduced in this experiment.
- How can these issues be addressed, if you had more control of the variables? (i.e. lighter cart, laser photo gate timer, etc.)
- Was your result “successful”, in relative terms? Explain

DATA SHEET:

*Mass of Person ($\mathbf{M_p}$): _____ kg

*Vertical Distance ($\mathbf{d_y}$): _____ m

*Initial Velocity of Person ($\mathbf{v_{iy}}$): **0** m/s

*Accel. Due to Gravity ($\mathbf{a_g}$): **9.8** m/s^2

In the space below, calculate the velocity of the person immediately before making impact with the ground (v_{max}) . SHOW ALL WORK, including general equation, equation with substitution and units, and report your final answer in the space provided.

*Maximum Velocity ($\mathbf{v_{max}}$): _____ m/s

In the space below, use your values for the person's mass and maximum velocity to determine their momentum immediately before their impact with the ground.

*Momentum Before Impact ($\boldsymbol{\rho_i}$): _____ with units: _____

*Assuming the person bounces off the ground with the same velocity at which they made impact, the magnitude of their momentum after the impact should be the same as before, but in the **opposite direction**.*

*Momentum After Impact ($\boldsymbol{\rho_f}$): _____ with units: _____

Now, in the space below, calculate the magnitude of the total change in momentum of the person as a result of their impact with the ground.

*Change in Momentum ($\boldsymbol{\Delta\rho}$): _____ with units: _____

Using values from your Excel data, record the values for the average force applied and the total time of impact.

*Average Applied Force ($\mathbf{F_{avg}}$): _____N

*Total Time of Impact ($\mathbf{t_{tot}}$): _____s

Remember, an object does not experience a change in momentum unless there is an impulse that is experienced. In the space below, calculate the impulse experienced by the person needed to change their momentum. SHOW ALL WORK, including general equation, equation with substitution and units, and report your final answer in the space provided.

*Impulse Applied (***J***): _____ with units: _____

This impulse SHOULD be equal to the value for the change in momentum that you calculated previously using your measured value for mass and the theoretical value for their maximum velocity. In the space below, calculate the percent difference between your calculated value for the impulse and the theoretical value for momentum change. Be sure to use the value for momentum change as your accepted value.