# Testing the Impulse Theorem via Collision Barriers

**Materials:** *Dynamics cart (without spring bumper), picket-fence flag dynamics track with impulse-collision bumper set, force probe, (1) PASCO Smartgate Photogate, computer with PASCO Capstone software and a ruler*

## 1 Purpose

The goal of this lab is to test the impulse-momentum theorem. This will be done by performing collision experiments using a force sensor and photogate timer and four different collision barriers.

## 2 Introduction

The impulse-momentum theorem states that the impulse experienced by an object is related to the change in momentum of the object. The algebraic relationship is

$$\vec{J} = \Delta\vec{p} = m\vec{v_f} - m\vec{v_o} \tag{1}$$

but impulse ($\vec{J}$) is also

$$\vec{J} = \overline{\vec{F}}\Delta t \tag{2}$$

Here, $\overline{\vec{F}}$ is the average force acting *on* an object through an interaction time of $\Delta t$. One should notice that the impulse-momentum theorem is a restatement of Newton's second law, that is $\vec{F} = \frac{\Delta\vec{p}}{\Delta t} \to \Delta\vec{p} = \vec{F}\Delta t$.

The impulse during a collision can be directly measured with a force sensor. The force sensor is a pressure sensitive electronic device which converts applied forces into a change in voltage. This voltage change is interpreted as a force by the software. Measuring the force several hundreds of times per second allows means to map out the force experienced during a collision as a function of time. Then we use the software to determine the area under the resulting curve which is the impulse experienced by the system.

## 3 Procedure

A photogate (to directly measure velocity) and force sensor will be used to provide two different measures of impulse (i.e. via equation 1 and 2). An example setup is shown in Fig. 1. As always, read and follow the directions carefully.

### 3.1 Equipment Setup

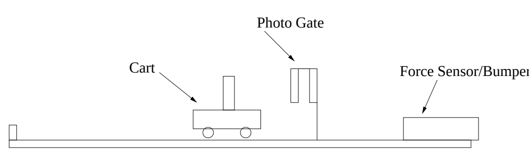


Figure 1: Setup of the impulse-momentum experiment showing the general placement the components.

1. Measure and record (a) the mass of the dynamics cart with the flag and (b) Smartgate Photogate separation distance, $S$. (Look for a set of small holes within the 'U' part of the photogate, you should find $S$ to be between 1 and 2 [cm]). If you are not using a Smartgate photogate then you will need the flag width.)
2. Connect the SmartGate to the 'PasPort 1' channel and force probe to the 'Analog A' channel.
3. If an experiment file has been provided, open the file and verify the sensors are appropriately configured. If no file has been provided then complete the following steps to configure the sensors
   - Under the 'Hardware Setup' tab, add a force probe and Photogate to the appropriate channels
   - If using the 'PASCO Smartgate', configure the timer to use both of the built-in photogates. If you have a traditional photogate you will need to configure the timer to measure the *time the photogate is blocked* and then measure the *width of the flag* used in the experiment.

- Set the sample rate of the force probe to 500 Hz (or as big as possible).
- Create a plot of the '*Measured Force, F (N)*' versus '*Time, t (s)*'.
- Create a table to display the *time photogate blocked* and show at least 3 digits after the decimal.
- [Optional] Create a column in your table to calculate the speed of the cart through the gate.

### 3.2 Data Collection

The procedure is the same for all bumpers and the order in which your data are collected is not important. However, you will report your data and results in order of (1) Magnetic Bumper (2) Weak Spring (3) Stiff Spring (4) Rubber bumper; unless your instructor specifies otherwise. Not every lab bench will have all of the bumpers, so work with what you have and then borrow from another group, as needed.

**Procedure**

1. Attach a bumper to the force sensor. Ensure that the sensor is properly seated and snug to the mounting block (finger tight is fine; any more than that and you are likely to break something, which is *not* allowed).
2. Properly seat the flag on top of the dynamics cart
3. Ensure the photogate is vertically positioned so that the appropriate flag blocks the beam as it passes
4. Position the photogate so that the flag completely passes through the gate before the collision begins ($\sim 30$ [cm] for the magnetic bumper works fairly well; the others can be closer).
5. Press the 'tare' button on the force sensor. This zeros the sensor and *must* be done before *every* run.
6. One person now needs to brace the track so it does not shift during the collision.
7. Start recording data and then gently send the cart through the photogate towards the bumper. It may take several trials before finding a good speed for the bumper in use. Note a few things
   - The cart should be rolling freely *before* it enters the photogate.
   - The cart should be sent *fast enough* to complete the collision and then pass back through the photogate but *slow enough* so the cart wheels do *not* bounce out of the grooves on the track before or after the collision.
   - The cart should *not* come into physical contact with the magnetic bumper.

## 4 Analysis

1. Record both time (and velocity) values for each run. The velocity before the collision $v_i$ and after the collision $v_f$ should have opposite signs appropriately reflecting the direction of travel. Use the convention that produces a *positive* change in momentum $\Delta\vec{p}$.
2. Use the cart's mass and measured velocities to calculate the cart's total change in momentum ($\Delta\vec{p}$) during the collision. (This is one measure of the impulse via Equation 1.)
3. Measure the impulse ($\overline{\vec{F}}\Delta t$ c.f. Eqn 2) by
   (a) Scaling the *Force* versus *Time* plot so the measurement of the collision dominates the plot.
   (b) 'Measure' $\overline{\vec{F}}\Delta t$ by using the plot tools (i) to select the relevant data and then (ii) determine the area under the curve [use the mouse to hover over icons until you find the relevant tool].
   (c) Record this *area* value and save the plot with a 'screenshot' that is then pasted in a document where you can add an appropriate title, axes labels and notation for the measured area.

## References

e.g. see [OpenStax, *Physics*, Chapter 8] or [*Physics*, Cutnell and Johnson, 8th Edition, Chapter 7]

# Responses and submission

Complete this section and attach (as required) the specified materials in order.

1. **Diagram of experimental setup**. This may be hand drawn. Show where all experimental parameters are measured (e.g. $m_{\text{cart}}, v_i, v_f, \bar{F}, \Delta t, ...$) and identify the bumpers used.

2. **Plots $F$ vs $t$ for each collision**. Attached; in order (1) Magnet, (2) Weak spring, (3) Stiff spring, (4) Rubber.

   Complete the analysis for each collision in the Capstone software. Save a properly scaled plot as a 'pdf' or take a 'screenshot' so that plots for each experiment can be assembled in a single document (e.g. word or publisher), properly titled, clearly labeled (axes, labeling $t_1, t_2$, etc) and the measured area clearly indicated. The final document should have two plots per page (see example).

3. **Summary data table**.

   Complete Table 1.

   The columns are: (a) Initial time between gates, $\Delta t_i$; (b) Initial velocity, $v_i$; (c) Final time between gates, $\Delta t_f$; (d) Final velocity, $v_f$; (e) Total change in momentum, $\Delta\vec{p} = m(\vec{v}_f - \vec{v}_i)$; Impulse measured via area under the curve, $\vec{J} = \overline{\vec{F}}\Delta t$; Percent difference between $\Delta\vec{p}$ and $\overline{\vec{F}}\Delta t$.

Table 1: Summary data table for impulse-theorem experiment.

| | $\Delta t_i$ [s] | $v_i$ [m/s] | $\Delta t_f$ [s] | $v_f$ [m/s] | $\Delta\vec{p}$ [kg·m/s] | $\vec{J} = \overline{\vec{F}}\Delta t$ [kg·m/s] | % Diff |
|---|---|---|---|---|---|---|---|
| Magnet | | | | | | | |
| Weak Spring | | | | | | | |
| Stiff Spring | | | | | | | |
| Rubber | | | | | | | |

4. **Calculations**

   Show one example calculation each for

   - $\vec{v}_i = \frac{\text{[gate sep]}}{t_i} =$

   - $\vec{v}_f = \frac{\text{[gate sep]}}{t_f} =$

   - $\Delta\vec{p} = m\left(\vec{v}_f - \vec{v}_i\right) =$

   - %Difference $= \frac{\Delta\vec{p} - [F\Delta t]}{0.5(\Delta\vec{p} + [F\Delta t])} \times 100\% =$

5. Which bumper best demonstrate the impulse-theorem? Briefly support your claim.

6. Which bumper is the worst at demonstrating the impulse-theorem? Briefly support your claim.

7. Choose the bumper you think best demonstrates the impulse-theorem and calculate the average force exerted on the cart during the collision.

8. **Experimental Uncertainty**

   Calculate the estimated uncertainty for each of the following measurements made during this experiment.

   Note that the measured velocities are determined utilizing (i) time measurement and (ii) two length measurements

   - Timing
     $$\delta t = \left( \frac{\left[\frac{1}{\text{sample rate in Hz}}\right]}{\text{shortest measured photogate time in sec}} \right) \times 100\% =$$

   - Length of block that interrupts the photogate beam
     $$\delta l = \frac{\text{Uncertainty of ruler}}{\text{measured length}} \times 100\% =$$

   - Force sensor (look up technical specifications for the provided force sensors, either the instruction manual or actually look at the sensor itself)

   - Total estimated experimental uncertainty (note: there are convolved measurements here but we will make the rough approximation that they are uncorrelated)
     $$\text{Total } \delta = \sqrt{4 \times (\delta t)^2 + 2 \times (\delta l)^2 + (\delta\text{Force Sens})^2} =$$

   - Look back at your calculated percent differences for the measured impulse and *briefly* comment on the validity of your experiment and the conclusion drawn regarding validating the impulse theorem.