  Graphical Analysis 19

Impulse and Momentum

(Sensor Cart)

The impulse-momentum theorem relates impulse, the average force applied to an object times the length of time the force is applied, and the change in momentum of the object:



Here, we will only consider motion and forces along a single line. The average force,, is the average net force on the object, but in the case where one force dominates and other forces are negligible, it is sufficient to use only the large force in calculations and analysis.



For this experiment, a Sensor Cart equipped with a hoop string will roll along a level track. Its momentum will change as it collides with the end stop at the end of the track. The hoop will compress and apply an increasing force until the cart stops. The cart then changes direction and the hoop expands back to its original shape. The force applied by the spring and cart velocity throughout the motion are measured by the Sensor Cart. You will then use data-collection software to determine the impulse in order to test the impulse-momentum theorem.

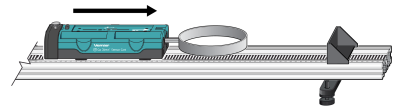


Figure 1

objectives

* Measure a cart’s momentum change and compare it to the impulse it receives.
* Compare average and peak forces in impulses.

Materials

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Go Direct Sensor Cart

Vernier Dynamics Track

Accessories from the Bumper and Launcher Kit: Hoop Bumper, clay, and clay holder

Preliminary questions

1. 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 airbag? How does it reduce injuries?
2. Two playground balls, the type used in the game of dodgeball, are inflated to different levels. One is fully inflated and the other is flat. Which one would you rather be hit with? Why?

Procedure

1. Attach the hoop spring to the cart. Measure the mass of the cart and record the value in the data table.
2. Attach the End Stop to the end of the track as shown in Figure 1.
3. Place the track on a level surface. Confirm that the track is level by placing the cart on the track and releasing it from rest. It should not roll. If necessary, adjust the track to level it.
4. Set up the sensor and data-collection software.
   1. Launch Graphical Analysis.
   2. Connect the Go Direct Sensor Cart to your Chromebook, computer, or mobile device.
   3. Click or tap Sensor Channels.
   4. Enable the Force channel in addition to the Position channel. Click or tap Done.
5. Zero the Force channel.
   1. Remove all force from the hoop spring.
   2. Click or tap the Force meter and choose Zero.
6. Set up the data-collection mode.
   1. Click or tap Mode to open data-collection settings.
   2. Change the Rate to 250 samples/s and End Collection to 5 s. Click or tap Done.

Part I  Elastic collisions

1. Practice releasing the cart so it rolls toward the end stop, bounces gently, and returns to your hand. The cart must stay on the track.
2. Position the cart so that the cart is approximately 50 cm from the end stop. Click or tap Collect to start data collection, then roll the cart as you practiced in the previous step.
3. Study your graphs to determine if the run was useful. Confirm that you can see a region of constant velocity before and after the impact. If necessary, repeat data collection.
4. Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse. To find these values, work with the graph of velocity vs. time.
   1. On the Velocity graph, select an interval corresponding to a time before the impulse, when the cart was moving at approximately constant speed toward the end stop.
   2. Click or tap Graph Tools, , and choose View Statistics. Read the average velocity before the collision (vi) and record the value in the data table.



* 1. Dismiss the Statistics box.
  2. Repeat parts a–c of this step to determine the average velocity just after the impulse, when the cart was moving at approximately constant speed away from the end stop. Record this value in the data table.

1. Now you will calculate the value of the impulse. Use the first method if you have studied calculus and the second if you have not.

Method 1 Calculus version

Calculus tells us that the expression for the impulse is equivalent to the integral of the force vs. time graph, or



Calculate the integral of the impulse on your force vs. time graph.

* 1. Select the region that represents the impulse (begin at the point where the force becomes non-zero).
  2. Click or tap graph tools, , and choose View Integral.



* 1. Read the value of the integral of the force data, the impulse value, and record the value in the data table.

Method 2 Non-calculus version

Calculate the impulse from the average force on your force vs. time graph. The impulse is the product of the average (mean) force and the length of time that force was applied, or .



* 1. Select the region that represents the impulse (begin at the point where the force becomes non-zero).
  2. Click or tap Graph Tools, , and choose View Statistics.



* 1. Record the average (mean) force value in the data table.
  2. Since time is on the horizontal axis of the graph, the Δx provided in the statistics is the Δt for the selected region. Record this value as Δt in your data table.
  3. From the average force and time interval, determine the impulse, , and record this value in your data table.



1. Repeat Steps 8–11 two more times to collect a total of three trials; record the information in your data table.

Part II  Inelastic collisions

1. Replace the hoop spring bumper with one of the clay holders from the Bumper and Launcher Kit. Attach cone-shaped pieces of clay to both the clay holder and to the end stop, as shown in Figure 2. Measure the mass of the cart and record the value in the data table.

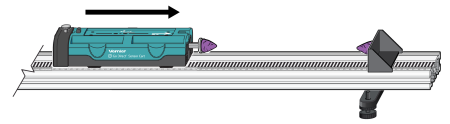


Figure 2

1. Place the cart on the track as shown in Figure 2. Click or tap the Force meter and choose Zero to zero the Force Sensor.
2. Practice launching the cart so that when the clay on the front of the cart collides with the clay on the end stop, the cart comes to a stop without bouncing.
3. Position the cart so that the cart is approximately 50 cm from the end stop. Click or tap Collect to start data collection, then roll the cart so that the clay pieces collide and stick together.
4. Study your graphs to determine if the run was useful. Confirm that you can see a region of constant velocity before and after the impact. If necessary, reshape the clay pieces and repeat data collection.
5. Once you have made a run with good position, velocity, and force graphs, analyze your data. To test the impulse-momentum theorem, you need the velocity before and after the impulse.
   1. On the Velocity graph, select the interval corresponding to the time before the impact. Click or tap Graph Tools, , and choose View Statistics. Record the average velocity in the data table.



* 1. Dismiss the Statistics box.
  2. Select the interval corresponding to the time after the impact. Then, click or tap Graph Tools, , and choose View Statistics. Record the average velocity in the data table.



* 1. Dismiss the Statistics box.

1. Now you will calculate the value of the impulse. Similar to Step 11, use the first method if you have studied calculus and the second if you have not.

Method 1 Calculus version

Calculate the integral of the impulse on your force vs. time graph.

* 1. Select the impulse, then click or tap graph Tools, , and choose View Integral.



* 1. Record the impulse value in the data table.

Method 2 Non-calculus version

Calculate the impulse from the average force on your force vs. time graph.

* 1. Select the impulse. Click or tap Graph Tools, , and choose View Statistics. Record the average force in the data table.



* 1. Since time is on the horizontal axis of the graph, the Δx provided in the statistics is the Δt for the selected region. Record this value as Δt in your data table.
  2. From the average force and time interval, determine the impulse, , and record this value in your data table.



1. Repeat Steps 16–19 two more times to collect a total of three trials; record the information in your data table. Note: You will need to reshape the clay pieces before each trial.

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| Data Table   |  |  | | --- | --- | | Mass of cart (elastic collision) | kg | | Mass of cart (inelastic collision) | kg |      |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Method 1  Calculus version | | | | | | | | Trial | Final velocity vf (m/s) | Initial velocity vi (m/s) | Change of velocity Δv (m/s) | Impulse (N•s) | Change in momentum (kg•m /s) or (N•s) | % difference between Impulse and Change in momentum | | Elastic 1 |  |  |  |  |  |  | | 2 |  |  |  |  |  |  | | 3 |  |  |  |  |  |  | | Inelastic 1 |  |  |  |  |  |  | | 2 |  |  |  |  |  |  | | 3 |  |  |  |  |  |  | |

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| Method 2  Non-calculus version | | | | | | | | |
| Trial | Final velocity vf (m/s) | Initial velocity vi (m/s) | Change of velocity  Δv (m/s) | Average force  (N) | Duration of impulse Δt (s) | Impulse   (N•s) | Change in momentum (kg•m /s) or  (N•s) | % difference between Impulse and Change in momentum |
| Elastic 1 |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  |
| Inelastic 1 |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  |

Analysis

1. Calculate the change in velocities and record the result in the data table. From the mass of the cart and the change in velocity, determine the change in momentum that results from the impulse. Make this calculation for each trial and enter the values in the data table.
2. If the impulse-momentum theorem is correct, the change in momentum will equal the impulse for each trial. Experimental measurement errors, along with friction and shifting of the track, will keep the two from being exactly the same. One way to compare the two is to find their percentage difference. Divide the difference between the two values by the average of the two, then multiply by 100%. How close are your values, percentage-wise? Do your data support the impulse-momentum theorem?
3. Look at the shape of the last force vs. time graph. Is the peak value of the force significantly different from the average force? Is there a way you could deliver the same impulse with a much smaller force?
4. Revisit your answers to the Preliminary Questions in light of your work with the impulse-momentum theorem.