Dynamics Track

Mechanical Force, Impulse and Momentum

An object subjected to unbalanced forces undergoes acceleration, which changes the velocity of the object in question. This change in motion can be further described and quantified in terms of impulse and momentum. Combining the applied force with the time over which the force was applied as a product gives us the quantity called impulse: impulse = Ft

Combining the velocity of the moving object with its mass as a product gives us the quantity called momentum: momentum = mv

Each of these quantities, impulse and momentum, incorporates more information than just the force or the velocity alone. Force and velocity are both subject to changes over time. Both impulse and momentum represent cumulative effects, or running totals, so to speak, of the overall effects of changes that occur over some period of time. The measurements for this lab include force, time, mass, and velocity, and consideration of these quantities as they change together.

Consider, briefly, the units of measurement for impulse and momentum:

Impulse = Ft, using Newtons (1N = 1 kg m/s^2) and seconds (s) yields Ns = kg m/s

Momentum = mv, using kilograms (kg) and meters per second (m/s) yields kg m/s

Note that the common units, kg m/s, suggest a similarity between impulse and momentum. In fact, the abbreviated symbols for impulse and momentum generally use the same letter; “p” for example:

impulse: \( \Delta p = Ft \)

momentum: \( p = mv \)

The Greek letter delta (\( \Delta \)) preceding the “p” for impulse signifies a change, as usual in the notation of Physics: \( \Delta p = p_2 - p_1 \), where \( p_1 \) and \( p_2 \) signify the momentum of an object before and after it has been affected by the force, \( F \), over the time interval, \( t \) (often written as \( \Delta t \)). This summarizes the relationship between impulse and momentum, and further explains why they are measured in equivalent units: impulse represents the change in momentum due to an applied force. So the momentum you end up with equals whatever momentum you started with plus the applied impulse.

Purpose:
This lab activity is designed to demonstrate and investigate the relationships among force, time, speed, and mass as summarized by impulse and momentum.

Equipment:
 Logger Pro data collection software
 Dual-Range Force Sensor
 Ring stand with mounting clamp and crossbar
 Dynamics Track Adapter (Vernier product for PASCO track)
 Balance, scale, OR a second Dual-Range Force Sensor
 PASCO Dynamics Track

iBook
End Stop
Collision Cart
Motion Detector
LabPro Interface

Cautions:
This equipment is delicate. Do not force anything!
Procedure to set up the equipment

1. Check to confirm that the Dynamics Track has been set up with three support feet at approximately 20 cm, 115 cm, and 210 cm. Check to confirm that the End Stop is mounted with its inboard face at 225 cm on the distance scale, and that it is not loose. Note that the End Stop is equipped with a pair of magnets which may affect any memory media (floppy disks, hard drives, memory sticks, ATM cards, etc.) which are placed or passed too close to the magnetic surfaces.

2. Check to confirm that the track is level, using a small bubble. Place the level in the middle of the lane over each support foot. If the bubble appears off center over any of the three supports, check with the Teacher regarding adjustment.

3. Check to see that the Dual-Range Force Sensor selector switch is set to the 10 N range, where it should remain for the entire experiment.

4. Confirm that the Dual-Range Force Sensor is mounted, using the Dynamics Track Adapter, with the Force Sensor’s rubber tipped compression force plunger end at 100 cm, facing the End Stop. Once again, this Track Adapter may be equipped with a pair of magnets which may affect any memory media (floppy disks, hard drives, memory sticks, ATM cards, etc.) which are placed or passed too close to the magnetic surfaces.

5. Confirm that the Motion Detector is on the track, against the End Stop, with the threaded brass-mounting hole down (no screw attachment is necessary for this lab), and the hinged segment opened 90 degrees so that the ultrasonic transducer (circular screen on hinged segment) faces along the length of the track away from the End Stop. This should place the actual transducer surface approximately between 207 cm and 208 cm along the distance scale.

6. Check to confirm that the Spring Plunger Dynamics Cart has an Adapter For PASCO Dynamics Cart mounted on top, with the flange up on the end opposite the cart’s spring plunger.

7. The cart will be started on each test run from the position where the blank end of the cart (without the dynamics plunger, facing the Motion Sensor) aligned with the 160 cm mark.

8. Note Force Sensor and Motion Detector plugs are mechanically different to prevent making the following connections incorrectly by accident. Be careful not to force a plug into an incompatible socket.

   Confirm that the Dual Range Force Sensor cable is connected to the LabPro interface socket CH 1.
   Confirm that the Motion Sensor cable is connected to the Lab Pro interface socket DIG/SONIC 2.

9. Confirm that the LabPro interface cable is connected to iBook laptop computer USB port (1 or 2, either is OK), and that the LabPro interface is plugged into wall or lab bench power socket using its transformer cord.

10. The iBook laptop computer may be operated on battery power, or through the Apple Portable Power Adapter plugged into a wall or lab bench power socket, as determined by the Teacher, depending upon lab conditions.

11. Be sure that the iBook laptop computer is turned on at this time. (The power switch is near the right hand speaker, above keyboard, if you find the power off.)

12. To LOGIN, click on the Student section, the password is also “student”.

13. Click on the icon labeled “FtmVlogA” to activate the data collection software. (If a box appears announcing that LabPro Has Data, select the bottom button in the box to Ignore/Erase the leftover data.)

14. The data log screen should include graph axes for Distance vs. Time (-0.2 m to 0.5 m), Velocity vs. Time (-1.0 m/s to +1.0 m/s), and Force vs. Time (-12 N to +0.5 N), all over a 0.0 s to 3.5 s time span. Scales may be adjusted later in the lab to magnify specific graph areas of interest.

15. Place the dynamics cart on the track in its starting position (blank end at 160 cm). Check to see that the cart sits at rest here without rolling or moving due to a tilted track, tangled sensor cables, etc. The menu bar at the top of the computer screen lists File, Edit, Experiment, Data, etc. Select Experiment, and then select Zero from the Experiment menu. With the Motion Detector and Dynamics cart at rest and correctly positioned, select Zero All Sensors and wait while the Motion Sensor clicks quietly, measuring the starting distance. This procedure also sets the unloaded Force Sensor measurement to zero. (Note: If the computer does not recognize the interface connection, it may be necessary to use the Setup menu to scan the LabPro-USB port. Consult with the Teacher if this happens.)
16. Roll the Cart gently 20 cm toward the Force Sensor and settle the cart there at rest for a distance check. Move the cursor on the computer screen to the “Collect” button near the middle of the top of the Logger Pro window. With the cart at rest and no obstructions between the cart and the Motion Sensor, activate the “Collect” button and check the data screen to confirm that the Motion Sensor is directed properly at the cart and recording its distance accurately.

17. Repeat the Motion Sensor confirmation step with the cart at rest against the Force Sensor.

While collecting data, make sure to split up the work among the members of your lab group!

Data Collection and Storage:
1. Move the cursor on the computer screen to the “Collect” button pictured near the middle of the top of the screen. Return the Cart to the starting position (blank end at 160 cm). When you are ready to start the cart and collect data, click the “Collect” button on the computer and gently roll the cart toward the force sensor. You will be identifying the actual release time by examining the graphs later. After the cart rebounds, stop it before it reaches the Motion Detector. Assign one lab team member to protect the Motion Detector on each run, just to be safe. Notice that the Distance and Velocity measurements for motion away from the Motion Detector are positive, and Distance and Velocity toward the Motion Detector, and the Force pushing the Force Sensor are all recorded as negative numbers. This is normal, and the minus sign in each case only indicates the direction of the displacement, velocity, and force vector, respectively.

2. Store this data set using the File menu, Save As using the following scheme: P#G#R#; whereas P is the period followed by the appropriate number, G is the group number (found on the front-left-edge of the computer), and R is the run number (each set of conditions for which you must keep track). All of these data files will be downloaded to external storage media later for future analysis on other computers.

3. Reposition the cart to 160 cm. Initiate the computer data collection and gently nudge the cart toward the Force Sensor when the Motion Sensor begins to click, and the data graphs begin to form, as before, but varying the initial velocity slightly. Be sure that the cart stops before it reaches the Motion Detector.

4. Store this data set as Run #2, as before.

5. Repeat the data collection and storage for one more repetition. Save this file as Run #3.

6. Weigh the Cart, with mounting hardware, to determine the moving mass. This may be accomplished with a simple two-pan or triple beam balance, an electronic scale with a capacity up to a kilogram, or by using a second Force Sensor mounted on a stand with room to hang the Cart assembly. In order to use the second Force Sensor, disconnect the Dynamics Track force sensor from the LabPro interface, and replace it with the connection to the second Force Sensor, mounted securely on a ring stand, measuring hook down. Confirm that the selector switch on the second Force Sensor is set to the 10N range. Use the Experiment menu item Zero to set the unloaded zero point for the second Force Sensor, as you did in Equipment Setup step 13. VERY CAREFULLY remove the Cart from the track, and hang it from the second Force Sensor’s hook, using the hook in the mounting bracket on the Cart. Wait until the Cart hangs still and quiet, then activate the Collect button on the computer screen once more. Ignore the Distance and Velocity measurements (they should both be basically zero), and read the weight of the cart in the Force column of the data table. Note the range of values measured, and round to the last significant digit that provides agreement among the vast majority of measured values. Divide this weight (in Newtons of force: 1 N = 1 kg m/s²) by the Earth surface gravitational field strength (9.8 m/s²) to calculate the mass of the Cart assembly (in kilograms: e.g. (9.56 N) / (9.8 m/s²) = (9.56 kg m/s²) / (9.8 m/s²) = 0.98 kg, note: this is NOT the mass of the cart).

7. Download the stored experiment files to the external storage medium of choice. If Data Analysis is scheduled for a later time, Quit the data collection program using the File menu.
Data analysis:
The analysis of Run 3 data may proceed immediately, once the data have been captured by the computer and stored, or later by retrieving the stored data file.

1. Open the Run 3, -2, or -1 LabPro data file, if it is not already open. You will need to identify the start point of the Run by examining the Velocity data, with reference to the Force data. The ending point for purposes of analysis will also be identified based upon Velocity data, with reference to the Force data. The Distance data have been included for reference, because the Velocity data are really conversions of the Distance and Time data, which the Motion Sensor and software calculate automatically.

2. **Identifying the Start Point:** Examine the Velocity graph. Notice that the velocity remains consistently positive approaching Force Sensor, so the Start Point is indicated where the velocity begins to change. Estimate the Time of the Start Point from the graph, and then find the corresponding time in the data table. Line numbers for the data table are in the gray column at the far left of the data table. Click on the line number of the time you have selected to highlight that line, and to mark reference lines on all three graphs. If the graph mark does not quite match the point you had in mind, select another line in the table to try to find a closer match. Also, consider the patterns of change which may be apparent in the data table to choose point which best represents the moment of release. The Force should be nearly zero, but on the verge of getting stronger (negative direction).

3. Record the Line Number, Time, Force, and Velocity for the Start Point.

4. **Identifying the End Point:** Examine the Velocity graph. The Velocity graph may be rather jagged, as a calculated derivation of the Distance data. Nevertheless, it should be reasonably level until the Start Point. From the start point, the speed should reverse (more and more negative velocity) rather suddenly, as long as a significant collision force remains. Once the collision force is effectively gone, the Velocity levels off, then approaches zero under the influence of the Cart’s inertia, some friction, or other forces acting on the Cart. Use the greatest speed (most negative Velocity) as the main indicator of the experimental End Point. Locate specific measurements for this point using the data table line references, as before. The Force should be nearly 0.0 N, and the straighter the Distance graph at this point, the better. (Note: “straighter” means “more nearly constant slope”, NOT “more vertical”, NOT “more horizontal”).

5. Record the Line Number, Time, Force, and Velocity for the End Point.

6. Repeat the identification of Start Point and End Point for the other two runs, and determine the impulse for each of these runs as above. The graphs may be rescaled manually to improve viewing for the points of interest. Click on one of the numbers at the middle of the x or y axis to bring up a scaling box. Select Manual Scaling and specify upper and lower limits as needed. Note that clicking on numbers at the end of an axis allows you to reset the value of that end (max or min) only.

7. Use the Velocity of the End Point and the moving mass of the Cart with Force Sensor (Data Collection step 6) to calculate the momentum at the End Point for each of the three runs.

8. Record the mass of the Cart Assembly and tabulate Time, Force, and Velocity for the Start Point and End Point in each of the three runs. Also tabulate Ending Momentum (at End Point) and Impulse (up to End Point) for each of the three runs.

   Cart Mass = __________ kg

9. Graph one point for each run to show the absolute value of impulse vs. the absolute value of momentum on conventional equal interval coordinate axes.
Examine the tabulated and graphed data.

A. What is evident about the relationship between the impulse applied and the resulting momentum in this lab?

B. What relationship is expected to exist between impulse and momentum under ideal conditions?

C. Describe how the lab conditions are likely to have resulted in any observed deviations from the ideal case.