

Center of Mass

INTRODUCTION

In the most of the previous experiments you have examined the motion of a single object as it underwent a variety of motions. You learned that an object subject to no external force moves at constant velocity. Suppose now that the system consists of two objects that undergo a collision. Clearly, the velocity of each object will change as a result of the collision. But if you were to consider both carts as a *system*, how would the center of mass of this *system* change, if at all, after a collision? In this experiment you will use video analysis techniques to examine the behavior of the center of mass of a *system* of moving objects.

OBJECTIVES

In this experiment, you will

- Use video analysis techniques to obtain position, velocity, and time data for two carts undergoing a variety of collisions.
- Analyze the position-time graphs for the individual carts and compare these to the position-time graph for the center of mass of the system.
- Compare the momentum of the system before and after collisions.

PRE-LAB QUESTION

Imagine two carts, connected by a 10 cm string, moving down a long dynamics track at constant velocity. Where would you imagine the center of mass of this system of carts to be? Now, suppose the leading cart is twice as massive as the trailing cart. Where would you expect the center of mass of this system to be? Sketch diagrams to support your answer to both questions.

PROCEDURE

1. Open the Logger *Pro* file, 19 Elastic equal mass.cmbl. In this file is a short video clip of an elastic collision between two carts of equal mass. The file should be in the folder: Advanced Physics-Mechanics. There are multiple files marked with a "19" so make sure you're opening the one indicated.

Experiment 19

2. Enable Video Analysis by clicking the button in the lower right corner. This brings up a toolbar with a number of buttons (see Figure 1).

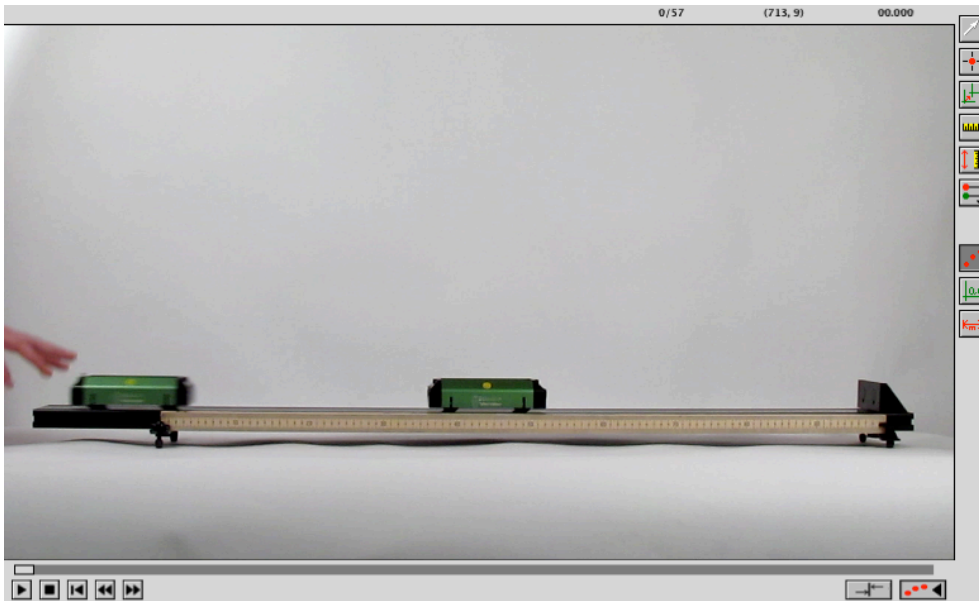


Figure 1 Video Analysis window

3. Click the **Set Origin** button (third from top), then click on the movie frame to set the location of the origin. If needed, this coordinate system can be rotated by dragging the yellow dot on the horizontal axis.
4. Click the **Set Scale** button (fourth from top), then drag across an object of known length in the movie. In this movie, the object of known length is a 1 m stick next to the track. When you release the mouse button, enter the length of the object; be sure the units are correct.
5. Select Movie Options from the Options menu. Check the two boxes under Video Analysis and choose to advance the movie 3 frames after adding a new point. Doing so will make the interval between frames 0.10 s.
6. Now click the **Add Point** button (second from the top). Click on the yellow dot on the left cart. Each time you mark the object's location, the movie advances three frames. Notice that position-time data are being plotted on the graph.
7. Continue this process until several frames after the carts collide. Should you wish to edit a point, click the **Select Point** button (top). This allows you to move or delete a mismarked point.
8. Now rewind the video to the first frame used for the left cart, click the Set Active Point button and choose Add Point Series so that you can mark the position of the right cart. **Note:** in this movie, the right cart is motionless for several frames, so these points will be superimposed upon one another. Marking the points will be easier if you turn off the Toggle Trails feature.
9. **After you have completed the Evaluation of Data for this first movie, use the same procedure for the next two movies, 19 Inelastic unequal mass.cmbl and 19 Elastic unequal mass.cmbl.**

EVALUATION OF DATA

Part 1 Elastic collision with $m_1 = m_2$

1. Examine the graphs of x -position vs. time for both carts. Explain the shape of the graphs for each cart. Use the linear fit tool to find the velocity of each cart during that portion of the movie in which it was moving. How do these velocities compare?
2. You can simplify your data table by choosing Table Options from the Options menu and selecting to display only the columns for time and x -position for the two carts. Choose Auto Arrange from the Page menu to facilitate working with the data table.
3. Use the Draw Prediction tool from the Analyze menu to sketch a position-time graph of the Center of Mass of the *system*. If you are unsure about how the location of the CoM changes with time, you can create a calculated column to determine the CoM for the two cart system.
4. Return to the Video Analysis window. Click the Set Active Point button and choose Add Center of Mass Series. Logger *Pro* opens a dialog box where you could enter the masses of the two carts. Since they are the same in this part, it doesn't matter if you enter values here. Later, when the masses are different, you can enter the actual masses. Click OK to add the Center of Mass Series. Logger *Pro* marks the position of the Center of Mass for the frames where you have marked the positions of the two carts.
5. On the vertical axis of the position-time graph choose More and add the Center of Mass plot to your graph. How does the plot of $x(\text{CoM})$ vs. time compare with your predicted sketch?
6. What relationship appears to exist between the velocity of the CoM and the average value of the velocities of the carts when they were moving? Explain.

Part 2 Inelastic collision with $m_1 > m_2$

1. As you did in Part 1, examine the graphs of x -position vs. time for both carts. Use the linear fit tool to find the velocity of cart 1 *before* the collision. Use what you have learned from conservation of momentum to predict the velocity of the coupled carts *after* the collision. Now graphically determine the velocity of the carts after the collision. Account for any discrepancy between the predicted and experimental values.
2. Choose the Draw Prediction tool from the Analyze menu to sketch a position-time graph of the Center of Mass of the *system*.
3. Return to the Video Analysis window and, as you did in Part 1, and add the Center of Mass Series so that you can view this plot on your graph.
4. Examine the position-time graph. How does the plot of $x(\text{CoM})$ vs. time compare with your predicted sketch? In what ways is this graph similar to the one you obtained in Part 1? In what ways does it differ? Account for your findings.

Experiment 19

Part 3 Elastic collision with $m_1 < m_2$

1. As you did in Part 1, examine the graphs of x -position vs. time for both carts. Use the linear fit tool to find the velocity of cart 1 before and after the collision. Use conservation of momentum to predict the velocity cart 2 *after* the collision. Now graphically determine the velocity of cart 2 after the collision. Account for any discrepancy between the predicted and experimental values.
2. Choose the Draw Prediction tool from the Analyze menu to sketch a position vs. time graph of the Center of Mass of the *system*.
3. Return to the Video Analysis window and, as you did in Part 1, and add the Center of Mass Series so that you can view this plot on your graph
4. Examine the position-time graph. How does the plot of $x(\text{CoM})$ vs. time compare with your predicted sketch? In what ways is this graph similar to the one you obtained in Part 2? In what ways does it differ?

Part 4 Consolidation of your findings

1. What do the CoM motions have in common? How do you account for this similarity?
2. How is the velocity of the CoM related to the total momentum of the system?
3. Based on your analysis of the motion of the carts in the video clips, write an expression for the center of mass (CoM) of a system of two bodies.

EXTENSION

Using existing data, determine the total kinetic energy of the system before and after the collisions. Is kinetic energy conserved in each type of collision? If not, explain any change.