AP Physics Lab #7B: Momentum and Collisions (Big Idea 5)

5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.

5.D.1.1: The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions.

5.D.1.2: The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations.

5.D.1.3: The student is able to apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy.

5.D.1.4: The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome.

5.D.1.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values.

5.D.2.1: The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [SP 6.4, 7.2]

5.D.2.3: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy.

Introduction: You may have learned that a moving object possesses kinetic energy. Momentum is another property of an object, related to its mass and velocity, which is useful to describe its behavior. Momentum, p, is the product of the mass and velocity of an object, $p = mv$.

You may have learned an external force produces a change in the momentum of an object. If we consider as our system two carts that undergo a collision, then any forces they exert on one another are *internal* to the system. In this experiment you will examine the momentum of both carts before and after collisions to see what effect, if any, these forces have on the momentum of a *system*.

Objectives:

In this experiment, you will

- Collect velocity-time data for two carts experiencing different types of collisions.
- Compare the system momentum before and after collisions.
- Compare the kinetic energy of the system before and after collisions.

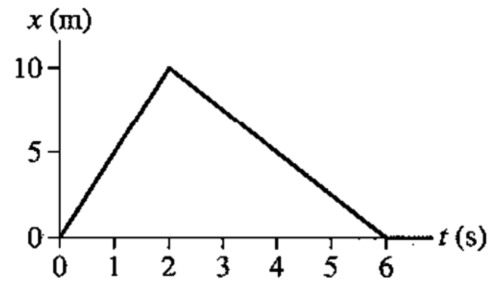
Materials:

Vernier data-collection interface
Logger *Pro* or LabQuest App
two Vernier Motion Detectors
two Motion Detector brackets
neodymium magnets and Velcro®
patches for carts

Vernier Dynamics Track
standard cart
plunger cart
500 g standard lab mass
Video analysis

Pre-Lab:

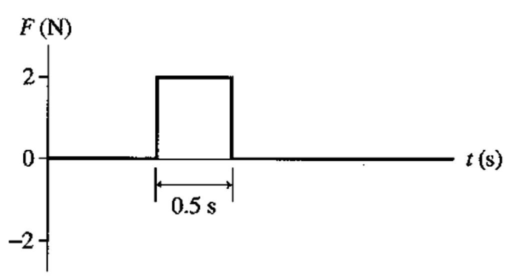
P1. Consider a head-on collision between a cue ball and a billiard ball initially at rest. Sketch a velocity-time graph for each ball for the interval shortly before until shortly after the collision. Justify your predictions for the final velocity of each billiard ball.



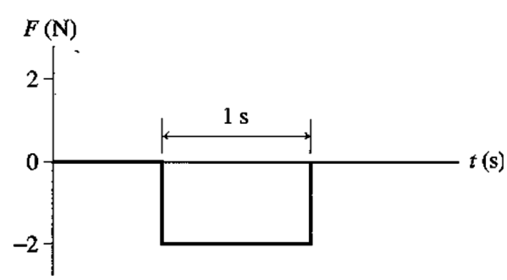
P2. The position versus time graph is shown to the right for a 500 gram object. Sketch the corresponding momentum versus time graph. Include an appropriate vertical scale in this sketch.

P3. A 2-kg object is moving to the right with a speed of 1 m/s when it experiences an impulse due to the force shown on the graphs. What is the object's speed and direction after the impulse? Analyze each graph separately.

a.



b.

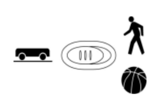


P4. A carnival game requires you to knock over a wood post by throwing a ball at it. You are offered a choice of either a bouncy rubber ball or a sticky clay ball of equal mass. Assume you can throw each with equal speed and accuracy. Which ball will you choose and why?

Procedure:

1. Attach the Motion Detectors to the brackets and position them at opposite ends of the Dynamics Track.

2. If your motion detectors have a switch, set each of them to Track.

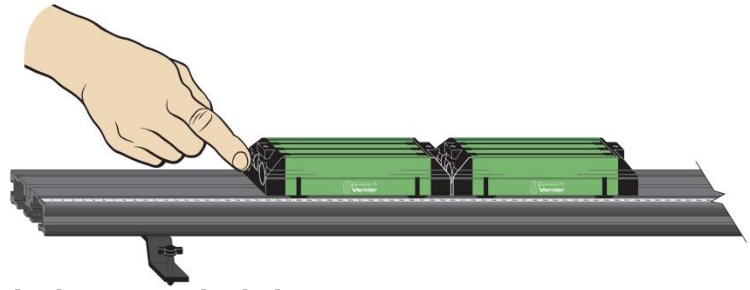


3. Adjust the leveling screws on the feet as needed to level the track. To make sure the track is level, place a cart on the track and give it a gentle push. It should not slow more in one direction than in the other. You may also use the level app on your phone.

4. Connect both motion detectors to the interface and start the data-collection program. Make the necessary adjustments so that a velocity *vs*. time graph for each detector is shown in the graph window.

5. You will probably need to install the neodymium magnets at one end and the Velcro patches at the other of the carts. Please be careful with the magnets and do not lose the tiny screws that you will need to remove to insert the magnets. To install magnets so that carts will repel one another, as well as the adjustable end stop, use the following procedure: 1) Remove the teardrop from the cart end or the end stop. 2) Insert the silver magnet (supplied with the cart) into the teardrop, oriented so that the outside of the teardrop will attract the south-pointing end of a compass needle. 3) Insert a foam plug (supplied with the cart) into the teardrop. 4) Reinsert the tear drop into the cart end or the end stop, and fasten the screw.

Place both carts, linked with their Velcro patches, in the center of the track. Zero both motion detectors and reverse the direction of one of them.



6. Begin collecting data, then gently push the linked carts towards one of the motion detectors (see figure). Be sure to keep your hands out of the way of the motion detectors. Catch the carts before they run off the track. The velocity-time graphs from each detector should be nearly mirror images of one another; they will also show a slight decrease in velocity due to friction. Adjust the level of the track until this decrease appears to be nearly the same in both directions.

Part 1 Elastic collisions

7. Reverse the carts so that their magnet ends face one another. Separate them by about 40 cm. Practice launching one cart toward the other so that at closest approach they exert forces on each other without touching. A jarring collision will not yield satisfactory data.

8. Place the target cart in the middle of the track. Position the other cart at least 20 cm in front of one of the motion detectors.

9. Start data collection. Then, when you hear the motion detectors clicking, launch one of the carts toward the other. Because momentum, like velocity, is a vector quantity, check to see if the signs of the velocities match your experimental setup. If necessary, reverse the direction of one or both sensors.

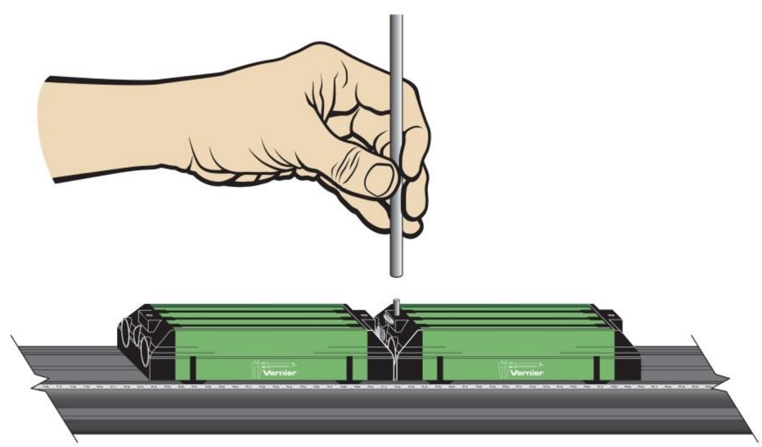
10. In this experiment you are concerned with changes in momentum due to the collisions of the carts. Some slowing due to friction is inevitable. To minimize the effect of frictional losses in your analysis, you should select short intervals of the *velocity-time* graphs just before and just after a collision. Then, choose Statistics from the Analyze menu and record the mean velocity of each cart for these intervals.

Q1. Collect data for up to six elastic collisions, varying the initial velocity and the mass of either cart. Try a collision in which both carts have an initial velocity, but different masses. A data table template has been provided for you on the next page.

Part 2 Inelastic collisions

1. Reverse the carts so that the ends with the Velcro patches face one another. Practice launching one cart toward the other so that when they collide, the carts link smoothly and continue moving without a noticeable bounce. A jarring collision will not yield satisfactory data.

Q2. Collect data as before for at least three inelastic collisions, varying the initial velocity and the mass of either cart. Determine the velocity of the carts before and after the collision as you did in Part 1. Since both motion detectors provide velocity data after the collision, you will have to decide how to record the velocity of the linked carts.



Part 3 Explosions

1. Place the carts in the center of the track with the plunger end of one cart facing the other. Depress and lock the mechanism on the plunger cart. Position the carts so that they are touching.

2. Begin data collection, then give a quick tap to the release pin with something hard, such as the support rod for a force sensor, as shown in the figure. Catch the carts before they run off the track.

Q3. Repeat this procedure by varying the mass of either cart. Determine the velocity of the carts after the explosion as you did in Part 1. Record all data in your "explosions" data table.

Post Lab Analysis: (the data tables below are suggested templates to use for Q1-Q3):

Part 1 Elastic collisions

1. You can use the tables below to help with your evaluation of the momentum before and after the collisions of the carts.

	Cart 1			Cart 2		
Run	Mass (kg)	Initial velocity (m/s)	Final velocity (m/s)	Mass (kg)	Initial velocity (m/s)	Final velocity (m/s)
1						
2						
3						
4						
5						
6						

	Before			After			Ratio
Run	*p* of cart 1 (kg-m/s)	*p* of cart 2 (kg-m/s)	*p* of system (kg-m/s)	*p* of cart 1 (kg-m/s)	*p* of cart 2 (kg-m/s)	*p* of system (kg-m/s)	*p* after / *p* before
1							
2							
3							
4							
5							
6							

Another approach is to use Logger *Pro* to help you organize your calculations.

Q4. How does the total momentum of the system after the collision compare with that before the collision? Do your results agree with your expectations? Explain.

Q5. Calculate the total kinetic energy, $E_k = \frac{1}{2} m v^2$, of the system both before and after each of the collisions. How do these quantities compare?

Part 2 Inelastic collisions

1. You can use the tables below to help with your analysis of the momentum before and after the collision.

	Cart 1			Cart 2		
Run	Mass (kg)	Initial velocity (m/s)	Final velocity (m/s)	Mass (kg)	Initial velocity (m/s)	Final velocity (m/s)
1						
2						
3						

	Before	After	Ratio

Run	*p* of cart 1 (kg-m/s)	*p* of cart 2 (kg-m/s)	*p* of system (kg-m/s)	*p* of cart 1 (kg-m/s)	*p* of cart 2 (kg-m/s)	*p* of system (kg-m/s)	*p* after / *p* before
1							
2							
3							

Q6. How does the total momentum of the system after the collision compare to that before the collision? Is the agreement in these inelastic collisions as good as that in the elastic collisions? Try to account for any differences.

Q7. Calculate the total kinetic energy of the system both before and after each of the collisions. How do these quantities compare? Compare your findings with those of others in your class.

Q8. We have used "elastic" to describe collisions in which the objects bounce, and "inelastic" to describe collisions in which the objects stick. Based on your comparison of the kinetic energy before and after collisions, provide a more conceptual definition of these descriptors.

Part 3 Explosions

1. You can use the tables below to help with your analysis of the momentum before and after the collision.

	Cart 1			Cart 2		
Run	Mass (kg)	Initial velocity (m/s)	Final velocity (m/s)	Mass (kg)	Initial velocity (m/s)	Final velocity (m/s)
1						
2						
3						

	Before			After			Ratio
Run	*p* of cart 1 (kg-m/s)	*p* of cart 2 (kg-m/s)	*p* of system (kg-m/s)	*p* of cart 1 (kg-m/s)	*p* of cart 2 (kg-m/s)	*p* of system (kg-m/s)	% diff
1							
2							
3							

Q9. How does the total momentum of the system after the explosion compare to that when the carts were stationary? Report any discrepancy as a percentage of the momentum of one of the carts.

Q10. Calculate the total kinetic energy of the system both before and after each of the explosions. How do you account for the increase in kinetic energy?

Please self-assess your lab report using the rubric/checklist.