

Experiment 3: Conservation of Momentum

Pre-lab questions

1. (1 point) Which statement about force and acceleration is always true?
 - a. An object accelerates in proportion to any force acting on it.
 - b. An object accelerates if it receives a force in the direction of its velocity.
 - c. An object accelerates in proportion to the net force acting on it.
 - d. An object accelerates if the net force acting on it changes with time.

2. (1 point) Data measured in this lab will be used in another lab as well.
 - a. True.
 - b. False.

3. (1 point) When you will study collisions between rail carts, what is the function of the Velcro bumpers on the carts?
 - a. To hold carts together after collision instead of bouncing apart.
 - b. To prevent carts from moving when you push them.
 - c. To allow you to measure the effects of friction.
 - d. To protect the carts from damage during collisions.

4. (1 point) You will measure three types of collisions between gliders on the air track. Which three descriptions below identify them? (Choose three descriptions. Scoring is right answers minus wrong answers.)
 - a. A massive glider rams a stationary low-mass glider.
 - b. A low-mass glider rams a stationary massive glider.
 - c. Stationary gliders of equal mass will be forced apart by a spring-release “explosion.”
 - d. A glider rams a stationary glider of approximately equal mass.
 - e. Approximately equal-mass gliders move toward each other and collide.
 - f. A massive and a low-mass glider move toward each other and collide.
 - g. A fast glider overtakes a slow glider moving in the same direction.
 - h. A moving glider bounces off a stationary glider held in position.

These questions are provided for your convenience. Submit your answers to these questions on Sakai before the first lab period begins. Do not submit them in your lab section.

EXPERIMENT 3. CONSERVATION OF MOMENTUM

3.1 Problem

- How does the behavior of two colliding carts depend on the carts' masses and velocities?
- What are the units of momentum?

3.2 Equipment

meter sticks, low-friction apparatus with two carts, extra masses; linear air track (produces a cushion of air on which the gliders move, i.e. friction is minimized), gliders, photogates or timers

3.3 Background

Momentum is defined as momentum = mass \times velocity, or in symbols,

$$p = mv \quad (1)$$

In words, momentum is a measure of how hard it is to stop a moving object. Objects with a large amount of momentum, such as loaded semis barreling down the highway, are difficult to stop. Objects with little momentum are easy to stop. The terms “hard” and “easy” refer to the amount of force and time needed in each case. The force and time depends on the change in momentum; in fact, Newton's second law ($F = ma$) can be rewritten in terms of momentum:

$$F = \frac{\Delta p}{\Delta t} \quad (2)$$

where the symbol Δ (delta) means “change in the following quantity”.

When two or more objects interact, the total momentum of the system equals the sum of the momenta of the individual objects. Strictly speaking, momentum is a vector quantity (do you see why?), so the momenta must be added as vectors. In this lab, we will be primarily dealing with objects traveling along a line, so the vector nature of the momentum will show up as a positive or negative sign. If the total momentum after an interaction is the same as the total momentum before the interaction, then the momentum is said to be *conserved* in the interaction.

3.4 Measurement

A. Qualitative Observations

Using the low-friction apparatus (short track and two carts), describe the physical behavior of the carts in terms of velocity (especially direction), mass and momentum before and after the collision. Explore the following four cases. Try each one multiple times until everyone

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understands the behavior. You may need to level the track first. Also try to use carts that roll freely, with little friction.

I. One cart stationary, one moving toward it in an elastic collision.

Set up the two carts so that the magnetic bumpers repel upon close approach.

1. (0.2 point) What are the speeds of the two carts before and after the collision? How do they compare to each other? Since you don't know the numerical values, use the symbol "v" and subscripts to distinguish them (v_1 , v_2 , etc.).

cart	before	after

2. (0.2 point) In what direction (+ or -) does each cart move before and after the collision?

cart	before	after

3. (0.2 point) After the collision, where has the momentum of the first cart gone?

4. (0.2 point) Is momentum conserved in the collision? Justify your answer.

II. One stationary, one moving with two sticking together after collision.

Set up the carts so that the Velcro bumpers will stick together after collision.

1. (0.2 point) What are the speeds and directions of the two carts before and after the collision? Since you don't know numerical values, use symbols as before.

cart	before		after	
	speed	direction	speed	direction

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2. (0.4 point) Is momentum conserved in the collision? Defend your claim by describing the collision in terms of velocities (including direction) and masses.

III. Both carts in bumper contact with spring release “explosion.”

The button on top releases a spring-driven plunger. Set the two carts in contact in the center of the track and release the plunger by tapping it with a stick (fingers tend to add a horizontal force).

1. (0.2 point) What is the relative speed of the two carts after the “explosion?” What are their directions?

cart	before		after	
	speed	direction	speed	direction

2. (0.2 point) Write equations for the momenta of each cart after the explosion using the appropriate signs and symbols.

3. (0.2 point) Now write an equation for the *net* momentum of the system after explosion. What is the numerical value of this net momentum after the explosion?

4. (0.1 point) What was the momentum *before* the explosion? Describe how momentum is conserved in this case, even though there was no motion at the beginning but lots of motion after the explosion.

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IV. Carts with unequal masses.

Add an extra mass to one of the carts and repeat the above investigations. Describe the velocities of each cart before and after each collision or explosion.

1. (0.4 point) One cart stationary, one moving toward it in an elastic collision.

cart	before	after

2. (0.4 point) One stationary, one moving with the two sticking together after collision.

cart	before	after

3. (0.4 point) Spring release explosion.

cart	before	after

4. (0.2 point) What initial conditions make it so that both carts move forward after the elastic collision?

5. (0.4 point) Does momentum seem to be conserved when the carts have different masses? Defend your answer.

B. Quantitative Measurements

For these investigations, you will use the linear air track. Small holes in the track provide a cushion of air supporting the gliders so that they can move with almost no friction.

Your instructor will explain how to set up the photogates for measuring times and velocities. These situations get harder to measure as you go along. You will need lots of practice and cooperation.

When calculating and recording velocities, be sure that the velocities of gliders moving in the same direction are given the same sign, and that velocities of gliders moving in opposite directions are given opposite signs. So, if one glider is moving to the right and another to the left, one has a positive velocity and the other has a negative velocity. It doesn't matter whether you make right or left positive—just pick a convention and stick with it.

(0.4 point) Read all of the experimental procedures and examine the apparatus. Identify at least two sources of measurement error. How will they affect the measured times in the three cases?

Sources of Error	Effect

CASE 1: Collision between two gliders of (nearly) equal mass, with one initially at rest

1. Record the glider masses m_1 and m_2 and the reference lengths S_1 and S_2 in Table 1.
2. Place one of the gliders (2) stationary at the center position of the air track.
3. Start the other glider (1) moving toward the stationary glider.
4. Determine the time (Δt_1) it takes for glider 1 to travel between the reference marks as it approaches glider 2.
5. After the collision, determine the time (Δt_2) for glider 2 to travel between the other set of reference marks.
6. Carry out this procedure three times and record data in Table 1.

Table 1. Air Track Case 1: Equal-Mass Target (3.0 points)

Masses			Distances		
Glider 1: m_1	Glider 2: m_2		Starting side: S_1	Ending side: S_2	
Before Collision: Glider 1			After Collision: Glider 2		
Δt_1 (s)	v_1 (cm/s)	p_1 (g cm/s)	Δt_2 (s)	v_2 (cm/s)	p_2 (g cm/s)

7. Compute the gliders' velocities ($v = S/\Delta t$) and momenta ($p = mv$) and enter in Table 1. (You may use a spreadsheet if you wish.)
8. Enter the mass and velocity values into Table 1 of Lab 5.

CASE 2: Collision between two gliders of unequal masses, the massive glider initially at rest

1. Place the massive glider (3) at the center of the track.
2. Start the other glider (1) moving toward the stationary glider. In this case, in which direction will the glider of mass m_1 travel after the collision?
3. Measure Δt_1 , the time it takes for glider 1 to travel distance S_1 between the reference marks before the collision, $\Delta t_1'$, the equivalent time for glider 1 to return through the marks after the collision, and $\Delta t_2'$, the time it takes for glider 3 to travel the distance S_2 between the reference marks after the collision. Record the values in Table 2. Use the same units as in Table 1 (there is no room to indicate them in this table).
4. Repeat the procedure three times.

Table 2. Air Track Case 2: Massive Target (3.6 points)

Masses			Distances						
Glider 1 : m_1		Glider 3: m_3	Starting side: S_1		Other side: S_2				
Before Collision			After Collision						
Glider 1			Glider 1			Glider 3			p_{total}
Δt_1	v_1	p_1	$\Delta t_1'$	v_1'	p_1'	$\Delta t_2'$	v_2'	p_2'	

5. Compute the velocity and momentum of the carts at each time and the total momentum before and after the collision and record the data in Table 2. Remember to keep the signs of the velocities and momenta consistent: opposite directions require opposite signs.
6. Enter the mass and velocity values into Table 2 of Lab 5.

CASE 3: Head-on collision between two gliders of (nearly) equal mass

1. Start the gliders 1 and 2 at opposite ends of the track so that they are initially moving toward each other.
2. Measure the time required to travel the marked distances before and after the collision and record the data in Table 3. Use the same units as in the previous cases.

Table 3. Air Track Case 3: Head-On (4 points)

Masses						Distances							
Glider 1: m_1			Glider 2: m_2			Glider 1: S_1			Glider 2: S_2				
Before Collision						After Collision							
Glider 1			Glider 2			p_{tot}	Glider 1			Glider 2			p_{tot}'
Δt_1	v_1	p_1	Δt_2	v_2	p_2		$\Delta t_1'$	v_1'	p_1'	$\Delta t_2'$	v_2'	p_2'	

3. Compute the velocity and momentum of each individual cart and the total momentum of both carts before and after the collision. Don't forget to account for the *directions* the carts are moving. Enter the values in Table 3.
4. Enter the mass and velocity values into Table 3 of Lab 5.

3.5 Analysis and Conclusion

1. (1 point) Do the results of this experiment support the hypothesis that momentum is conserved in a collision? Refer specifically to the qualitative results with the rail carts and the numerical data in Tables 1, 2, and 3. Is momentum conserved in these interactions? How do you know?