NAME ______________________________

DATE ______________________________

Carolina™ Introduction to Force and Motion

You will investigate Newton's laws by performing a series of experiments that measure force, mass, velocity, and acceleration, and the relationships between them. In one activity, you will test the friction of four different surfaces and then use the surface with the least friction to determine the effect of mass on friction resistance. In another activity, after lifting a block vertically (using a spring scale to measure the force required to do so), you will use ramps to lift the same block and determine how the length of an inclined plane affects the effort force required to move an object. In other activities, you will use dynamics carts and other materials to investigate velocity, collisions, and the effect of mass on acceleration and momentum.

Activity 1: Friction

Background

Slide your finger across your tabletop and several other surfaces. The force you feel opposing the movement is called friction. Without friction you could not walk across a floor or even brake a car or bicycle. Variances in the texture and composition of surfaces influence how much friction different surfaces generate.

There are two types of friction. One is static friction (F_s), the initial force that must be overcome to move an object. The other type is kinetic friction (F_k), the opposing force that works against the movement of objects.

You can measure these values with a spring scale attached to a hook secured to a small wooden block. Attach a spring scale to the hook on the block, and then pull horizontally. Note that the pointer on the spring scale moves, indicating an increase in magnitude of force exerted, until the block moves. The maximum amount of force, just before the block moves, is a measure of the amount of static friction present between the block and the surface underneath. When the block moves with the force of a steady push or pull, the force decreases and then remains constant during the steady movement. This is a measure of the kinetic friction opposing the movement.

The amount of static friction and kinetic friction present depends on two variables: (1) the coefficient of friction (mu, μ) which varies in value from 0 to more than 1; and (2) the normal force (F_N), which is the force pressing objects together. The product of these values determines the amount of friction.

For static friction: $F_s = \mu_s F_N$

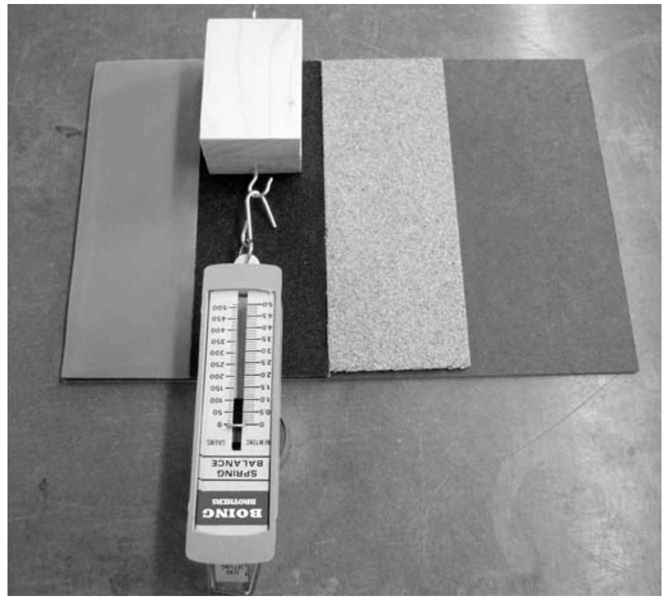
For kinetic friction $F_k = \mu_k F_N$

This activity consists of two parts. In Procedure 1A, you will use wooden blocks to test four surfaces (rubber, sandpaper, cork, and masonite) and rank them in terms of friction encountered with the wooden blocks. In Procedure 1B, working with the surface that has the least friction, you will add fixed amounts of mass to the blocks and measure the static and kinetic friction of the surface for each mass. Then, you will calculate the static and kinetic coefficients of friction by finding the slope of the graphs of F_s versus F_N and F_k versus F_N, respectively. **Be sure to recalibrate the spring scale before every trial.**

Materials

- friction board with 2 small blocks
- 2 10-g weights in a weigh boat
- 4 5-g weights in a weigh boat
- 4 5-g weights or 20 1-g weights in a weigh boat
- spring scale
- balance(s)

Procedure 1A: Friction and Different Surfaces



1. Stack the two small blocks at the end of the rubber strip on the friction board.
2. Connect a calibrated spring scale to the hook on the bottom block and slowly pull it horizontally.
3. Note the force in newtons (N) just before the blocks move. Do this several times until you get a consistent reading. Record the value in Data Table 1A the static friction of rubber.
4. Recalibrate the spring scale and reattach it to the hook. Pull the spring scale until you actually move the blocks. As you do so, note the force in newtons. Repeat this step until you get a consistent reading. Record this value in Data Table 1A as the kinetic friction of rubber.
5. Repeat the preceding steps for the sandpaper, cork, and masonite surfaces. Record all your data in Data Table 1A.
6. Using the data you recorded in Data Table 1A, rank the rubber, sandpaper, cork, and masonite surfaces from least friction (1) to most friction (4).

Data Table 1A: Two Stacked Small Blocks

Material	Static Friction, F_s (N)	Kinetic Friction, F_k (N)	Rank, 1–4 (1 = least friction)
Rubber			
Sandpaper			
Cork			
Masonite			

Procedure 1B: Coefficient of Friction

1. Add two 10-g weights to the stack of two blocks. Find the total mass of the blocks and the weights, and record the total mass of the objects in Data Table 1B for "2 blocks + 20 g."
2. Place these blocks on the surface that you have ranked as having the least friction.
3. Measure the static friction of the blocks and weights in newtons, as in Procedure 1. Record this value in Data Table 1B.
4. Next, measure the kinetic friction of the blocks and weights in newtons, as in Procedure 1. Record this value in Data Table 1B.
5. Add an additional 20 g of weight (four 5-g weights) to the blocks. Measure the total mass of the objects being tested (2 blocks + 40 g), and record this data in Data Table 1B.

6. Measure the static friction of the blocks and weights in newtons, as in Procedure 1. Record this value in Data Table 1B.
7. Next, measure the kinetic friction of the blocks and weights in newtons, as in Procedure 1. Record this value in Data Table 1B.
8. Add an additional 20 g of weight (four 5-g weights or twenty 1-g weights) to the blocks. Measure the total mass of the objects being tested (2 blocks + 60 g), and record this data in Data Table 1B.
9. Measure the static friction of the blocks and weights in newtons, as in Procedure 1. Record this value in Data Table 1B.
10. Next, measure the kinetic friction of the blocks and weights in newtons, as in Procedure 1. Record this value in Data Table 1B.
11. Now, convert all the mass measurements from grams (g) to newtons (N) by multiplying by the constant 0.00980 N. The resulting value is the normal force. Record these values in Data Table 1B.

Data Table 1B: Mass and Coefficients of Friction

Objects Tested	Total Mass of Objects (g)	Normal Force, F_s (N)	Static Friction, F_s (N)	Kinetic Friction, F_k (N)
2 blocks + 20 g				
2 blocks + 40 g				
2 blocks + 60 g				

Procedure 1B Graphs

Static Friction (F_s) vs. Normal Force (F_N)

1. Using the data in Data Table 1B, plot normal force on the *x*-axis and static friction on the *y*-axis.
2. Determine the slope of the graph, which can be calculated $(y_2 - y_1) \div (x_2 - x_1)$. The slope of this line is the coefficient of static friction (μ_s).

   Record the slope, i.e., the coefficient of static friction, here: ________________________

Kinetic Friction (F_k) vs. Normal Force (F_N)

1. Using the data in Data Table 1B, plot normal force on the *x*-axis and kinetic friction on the *y*-axis.
2. Determine the slope of the graph, which can be calculated $(y_2 - y_1) \div (x_2 - x_1)$. The slope of this line is the coefficient of kinetic friction (μ_k).

   Record the slope, i.e., the coefficient of kinetic friction, here: ________________________
3. Compare the coefficients of friction. Which one is smaller? On a scale of 0 to 1 for coefficients of friction, how would you rate this surface for kinetic friction: low, medium, or high? Record your answers in the space provided.

Activity 2: Inclined Planes

Background

One alternative to lifting an object straight up to a given height is to push or pull the object up an inclined plane to the desired height. Inclined planes make work easier by reducing the amount of effort force (F_e) exerted to do the work.

Does the length of an inclined plane affect the amount of effort force needed to move an object to a given height? In Procedure 2A, you will use a spring scale to measure the force required to lift a large wooden block vertically. In Procedure 2B, you will set up inclined planes with different lengths but the same height, and measure the effort force required to pull the same wooden block up each incline. Finally, you will plot your data to show the relationship between effort force and the length of an inclined plane. Be sure to recalibrate the spring scale before each trial.

Materials

- foam board
- large wooden block with a screw hook
- spring scale
- ring stand with iron ring (or set of textbooks with a total height of 10 cm)
- meterstick
- metric ruler
- pencil
- additional book(s) to support the inclined plane

Procedure 2A: Force Necessary to Lift a Large Block Vertically

1. Place the hook of the spring scale into the hook on the large wooden block.
2. Slowly lift the block vertically and read the force in newtons. Repeat this process several times until you obtain a consistent value. Record the value in Data Table 2A as the normal force (F_N) exerted on the block and the surface beneath it.

Data Table 2A

Material	Normal Force, F_N (N)
Large Block	

Procedure 2B: Effort Force With an Inclined Plane

1. Attach a ring to a ring stand at a height of 10 cm from the tabletop. Alternatively, stack books to a height of 10 cm.
2. Using a meterstick or metric ruler, measure 45.0 cm from the right end of the foam board and make a mark with a pencil.
3. Align the pencil mark on the foam board with the edge of the ring or stack of books. You now have a 45-cm long inclined plane.
4. Place the large wooden block at the bottom of the inclined plane, attach the spring scale to the hook on the block, and slowly pull the block up the plane. Read the force in newtons. This value is the effort force required to do the work of pulling the block up the ramp.

5. Repeat this several times until you obtain a consistent reading. Record the effort force value in Data Table 2B for the 45-cm long inclined plane.
6. Repeat Step 2, but this time draw the pencil mark 60.0 cm distant from the right end of the foam board.
7. Align the 60.0 cm mark with the edge of the ring or stack of books. Approximately halfway down the incline, place one or more books underneath the foam board to provide support.
8. Repeat Step 4 and Step 5, and record the effort force in Data Table 2B for the 60-cm long inclined plane.
9. Use the meterstick to measure 90.0 cm from the right end of the foam board, and make a pencil mark; this will be near the left edge of the foam board.
10. Align the 90.0 cm mark with the edge of the ring or stack of books. Approximately halfway down the incline, place one or more books underneath the foam board to provide support.
11. Repeat Step 4 and Step 5, and record the effort force in Data Table 2B for the 90-cm long inclined plane.

Data Table 2B

Length (cm)	Effort Force, F_e (N)
45.0	
60.0	
90.0	

Graph 2B: Effort Force vs. Length of Plane

1. Plot the data in Data Table 2B, with length (in cm) on the *x*-axis and effort force in newtons on the *y*-axis.
2. Is the graph linear?
3. Describe how the effort force changes as the inclined plane becomes longer.
4. What is the advantage of using an inclined plane to raise an object to a given height?
5. What is a disadvantage of using an inclined plane? **Hint:** Compare vertical distance to move an object versus distance moved on an inclined plane and consider any opposing force(s) on the plane.

Activity 3: Newton's Second Law

Background

Newton's Second Law applies even to the world of drag racing—an acceleration contest between two cars over a straight, short, dual track. Both cars are timed from the starting line to the finish line. The car with the lowest elapsed time to the finish line wins.

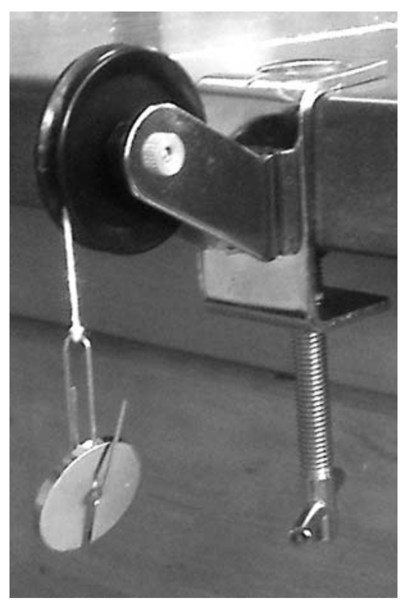
In this activity, you will use a specially designed rolling cart called a Hall's car to measure acceleration. In Procedure 3A, you will change the mass of the car. In Procedure 3B, you will change the amount of net force exerted on the car. The car will be accelerated horizontally by a falling mass connected by a string hanging over the end of a lab table and attached to a pulley. The car will accelerate through a distance (*d*) of 80.0 cm or, if your lab table is lower than 80 cm, a distance equal to the height of your lab table. You will calculate acceleration using the expression ($a = 2d \div t^2$), and record your results in cm/s^2.

Materials

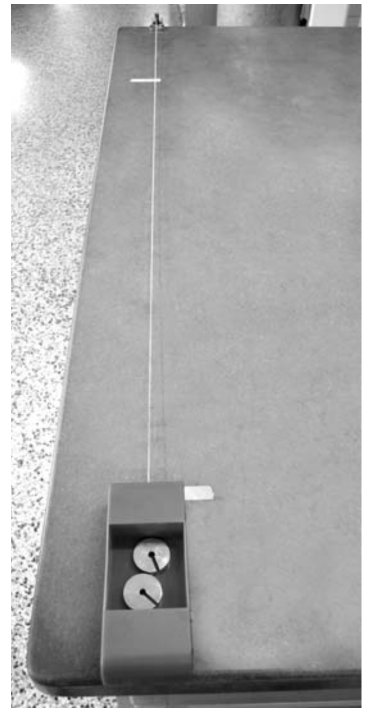
Hall's car
pulley
string, 1.5 m
weight hanger with weights
scissors
masking tape, 4 inches
stopwatch or timer
meterstick
metric ruler
paperclip
weigh boat
balance(s)

Procedure 3A: How Mass Affects Acceleration

1. Mass the empty Hall's car, and record this value in Data Table 3A.
2. Measure the height of your lab table in centimeters.
3. Attach a clamp pulley to the end of a lab table.
4. From the pulley on the edge of the lab table, measure 25 cm on the tabletop. Place a 2-inch piece of masking tape at this point, 25 cm from the edge of the table.
5 a. From the end of the piece of tape, measure another 80.0 cm or, if your lab table is shorter than 80 cm, the height of your lab table as measured in Step 2. Place a second 2-inch piece of tape at that point.
   b. Either 80 cm or the height of your lab table (if less than 80 cm) is the distance (*d*) the car will travel. Record the distance in the title of Data Table 3A.



6. Tie one end of the string to the hole in the front of the car.
7. Place the front bumper of the car at the second tape mark, drape the string over the pulley wheel, pull the string taut, and then use scissors to cut the other end of the string about 5 cm below the pulley.
8. Tie a paperclip to the dangling end of the string and then bend one end of the paperclip to create a hanger for slotted masses, as shown in the image.
9. Place a 5-g slotted mass on the paperclip hook below the pulley. Then, pull the front of the car behind the second piece of tape, as shown.



10. Place a weigh boat on the floor to catch the 5-g mass as it falls.
11. Time how long it takes the car to move from one piece of tape to another. Have another partner stop the car after it crosses the second piece of tape. Perform three trials, and record your results for time (T) in seconds in Data Table 3A.
12. Add a 20.0-g mass to the car, and record the total mass.
13. Repeat Step 11.
14. Add another 20.0-g mass, and record the total mass.
15. Repeat Step 11.
16. a. Find the average time (t) in seconds, for each mass of the car, and record these values in Data Table 3A.
    b. Square the average time for each mass of the car to get t^2, and record your results in the data table.
    c. Double the distance (d) that the car traveled in each trial to get $2d$. Record this value in the data table. (**Hint:** This will be either 160 cm or twice the height of your lab table.)
17. Calculate the acceleration (a) using the equation ($a = 2d \div t^2$), and record your results in cm/s^2 in Data Table 3A.

Data Table 3A [Distance traveled (d) = __________ cm]

Mass of Car (g)	Time, T (s)	Average Time, t (s)	t^2 (s^2)	$2d$ (cm)	Acceleration = $\frac{2d}{t^2}$ (cm/s^2)
	Trial 1 =				
	Trial 2 =				
	Trial 3 =				
	Trial 1 =				
	Trial 2 =				
	Trial 3 =				
	Trial 1 =				
	Trial 2 =				
	Trial 3 =				

Graph 3A: Acceleration vs. Mass

1. Using the data in Data Table 3A, plot the mass of the car on the x-axis and acceleration on the y-axis.
2. Based upon your graph, how is acceleration affected by mass?

Procedure 3B: How Net Force Affects Acceleration

1. Use the same car and distance measured in 3A.
2. The mass of the system will remain constant. Masses will be moved from the car to the paperclip hanger to increase the net force (F_{net}) on the car.
3. Place a 50-g hanger with three 20-g masses in the front of the compartment of the car, and place three 20-g masses in the rear, as shown.
4. One person in the group should hold the car behind the second tape strip while another prepares to attach a slotted 10-g mass to the hook on the paperclip. This mass, when allowed to drop into the weigh boat, will pull the car with a net force of 10 g. In a later step, you will convert this mass in grams to a net force (F_{net}) expressed in newtons. A third member of the group should adjust the location of the weigh boat on the floor to catch the mass as it falls.
5. a. Have one group member hold the car in place while another lets the mass and paperclip fall into the weigh boat. This will pull the car down the track from its starting point and past the piece of tape near the pulley. Have one student in position to stop the car after it crosses the second piece of tape, while another times how long it takes the car to move the predetermined distance. When everyone is ready, perform three trials, and record your results for Time (*T*) in Data Table 3B.

   b. When everyone is ready, perform three trials, and record your results for Time (*T*) in Data Table 3B.
6. Transfer another 20-g mass from the rear of the car to the paperclip. The mass pulling the car will now exert a net force of 30 g.
7. Conduct three time trials for this 30-g force. Record the result of each trial in Data Table 3B.
8. Transfer another 20-g mass from the rear of the car to the paperclip. The mass pulling the car will now exert a net force of 50 g.
9. Conduct three time trials for this 50-g force. Record the result of each trial in Data Table 3B.
10. Convert the mass pulling the car to net force (F_{net}) in newtons by multiplying the mass in grams (g) by a constant, as follows (g × 0.00980 N/g). Record your results in Data Table 3B.
11. a. Find the average time (*t*) in seconds, for each mass of the car, and record these values in Data Table 3B.

    b. Square the average time for each mass of the car to get t^2, and record your results in the data table.

    c. Double the distance (*d*) that the car traveled in each trial to get 2*d*. Record this value in the data table. (**Hint:** This will be either 160 cm or twice the height of your lab table.)
12. Calculate the acceleration (*a*) using the equation ($a = 2d \div t^2$), and record your results in cm/s² in Data Table 3B.

Data Table 3B

Mass Pulling Car (g)	Net Force in Newtons, F_{net} (N)	Time, *T* (s)	Average Time, *t* (s)	t^2 (s^2)	2*d* (cm)	Acceleration = $\frac{2d}{t^2}$ (cm/s^2)
10.0		Trial 1 =				
		Trial 2 =				
		Trial 3 =				
30.0		Trial 1 =				
		Trial 2 =				
		Trial 3 =				
50.0		Trial 1 =				
		Trial 2 =				
		Trial 3 =				

Graph 3B: Acceleration vs. Net Force (F_{net})

1. Using the data in Data Table 3B, plot net force on the *x*-axis and acceleration on the *y*-axis.
2. Based upon your graph, how is acceleration affected by net force?

Activity 4: Elastic Collisions

Background

Momentum (p) is the product of an object's mass and its velocity ($p = M \times V$). If either the mass or the velocity is a large value, an object will have a large momentum. For example, a small golf ball may inflict a lot of damage upon impact because it travels at a high velocity after being struck by a club. Likewise, a large truck will have a high momentum, even though it may be moving at a low velocity, due to its great mass.

The law of conservation of momentum holds that the amount of momentum in a system remains constant; therefore, when two objects collide, momentum is neither created nor destroyed, but it will change on the basis of the masses and velocities involved.

The game of billiards, or pool, offers a good example of this conservation law. After being struck with a pool cue, a moving cue ball has momentum, a product of its mass and velocity. It hits a stationary ball with mass but zero velocity, and therefore zero momentum. After the collision, the two balls move at different velocities. Their individual momentums have changed, but the sum of the product of the mass and velocity for each ball after the collision will equal the sum of the momenta for the two balls before the collision. This type of collision is called an elastic collision.

You will prove the law of conservation of momentum using two dynamics carts of known mass. You will take measurements as a moving Cart A collides with a stationary Cart B. The law of conservation of momentum dictates that the combined momentum of Cart A plus Cart B before the collision equals the combined momentum of Cart A plus Cart B after the collision. You will compare momenta before and after the collision using the following equation:

$M_aV_a + M_bV_b = M_aV_{a'} + M_bV_{b'}$

V_a and V_b represent the velocities of Cart A and Cart B before the collision.

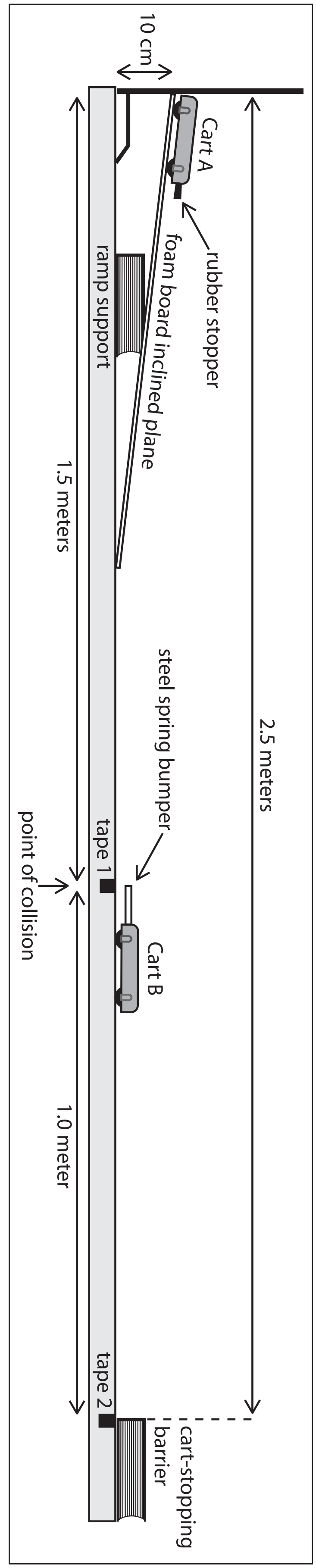
$V_{a'}$ and $V_{b'}$ represent the velocities of Cart A and Cart B after the collision.

The mass of Cart A remains the same before and after the collision, as does the mass of Cart B.

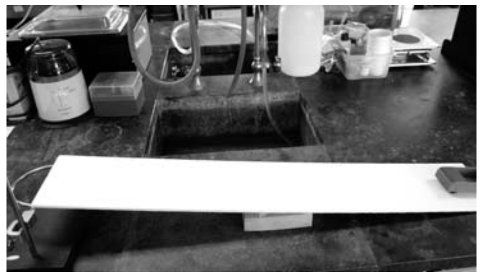
Materials

- foam board
- dynamics cart set (two carts)
- ring stand with iron ring (or set of textbooks with a total height of 10 cm)
- meterstick
- metric ruler
- masking tape, 4 inches
- cart-stopping barrier (e.g., book or ring stand)
- 2 stopwatches or timers
- 20-g weight in a weigh boat
- 20-g weight (or 2 10-g weights) in a weigh boat
- balance(s)
- additional book(s) to support the inclined plane

Procedure 4A: Equal Masses, Moving and Stationary



1. a. Attach a rubber stopper to the front of one cart with the steel nut provided. This is Cart A.
   b. Secure a steel spring with a rubber stopper, and attach it to the front bumper of the other cart. This cart, with the steel spring bumper, is Cart B.
2. Mass Cart A and record its mass in the appropriate section of Data Table 4A. Mass Cart B and record its mass in the other section of Data Table 4A.
3. On a level surface indicated by your instructor, set up an inclined plane using the foam board and an iron ring and ring stand (or a stack of books that reaches a height of 10.0 cm). Place textbooks underneath the foam board, at approximately the halfway point, to prevent the ramp from sagging.



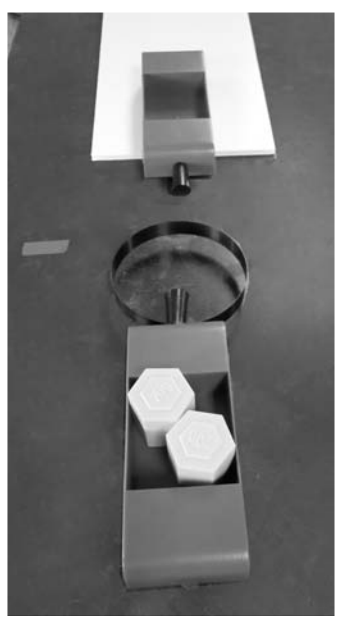
4. On the level surface, measure from the point below the highest point of the ramp out a distance of 1.5 meters. Mark this 1.5-m distance with a 2-inch piece of masking tape.
5. Measure 1.0 meter from the first piece of masking tape, and mark this distance with another 2-inch piece of tape.
6. Place a cart-stopping barrier (such as a textbook or ring stand) at the end of the second piece of tape. You should now have a track that is 2.5 meters long.
7. Place Cart B with the edge of the steel spring at the tape line indicating 1.5 m.
8. Align the foam board so Cart A will roll down the center of the ramp and collide with the middle of the steel spring on Cart B.
9. With the cart positioned in the center of the ramp, align Cart A's rear bumper with the upper edge of the ramp.
10. Find distance (*d*) for Cart A. Measure the length of Cart A, in centimeters, from the front edge of the rubber stopper to the rear of the cart. Subtract the length of Cart A from the total distance of 1.5 meters, because the reference point for distance traveled will be measured from the front edge of the rubber stopper. Record this distance in Data Table 4A.

    Remember: 1 m = 100 cm

    Example: If Cart A is 16.0 cm long, then:

    d = 150 cm – 16.0 cm = 134 cm or 1.34 m

    In this case, Cart A would travel a distance of 1.34 m before the collision.



11. Find distance (d) for Cart B. Measure the length of Cart B, in centimeters, from the front edge of the spring to the rear of the cart. Subtract the length of Cart B from the 1.00-m distance, because the reference point for distance traveled will be measured from the front edge of the spring. Record this distance in Data Table 4A.

    Example: If Cart B reaches the barrier, and the length of Cart B is 22.4 cm, then:
    d = 100 cm – 22.4 cm = 77.6 cm or 0.776 m
    In this case, Cart B would travel a distance of 0.776 m after the collision.

12. Read the following steps, and conduct several practice runs before recording any data.
13. One partner should release Cart A at the top of the ramp while another times Cart A from its release until it collides with the spring on Cart B.
14. Another partner times Cart B from the time Cart A collides with it until Cart B reaches the cart-stopping barrier.
15. Record the time (T) for Cart A (before collision) and Cart B (after collision) in the appropriate parts of Data Table 4A.
16. Conduct two more trials, and record the cart times in the appropriate parts of Data Table 4A.
17. Find the average time (t) of the three trials for each cart. Record the average times for Cart A (before collision) and Cart B (after collision) in the appropriate parts of Data Table 4A.
18. Calculate the velocity (distance ÷ time) of Cart A before the collision and of Cart B after the collision, and record these velocities in the Data Table. Record your calculations in the space provided after Data Table 4A.

    For an explanation of the equation, refer to the Background section for Activity 4.

Data Table 4A: Before Collision

Cart A Mass (g)	Distance, d (m)	Time, T (s)	Average Time, t (s)	Velocity = d/t (m/s)

Data Table 4A: After Collision

Cart B Mass (g)	Distance, d (m)	Time, T (s)	Average Time, t (s)	Velocity = d/t (m/s)

Calculations for 4A

$M_aV_a + M_bV_b = M_aV_{a'} + M_bV_{b'}$

Procedure 4B: Heavier Moving Mass

1. Add 40.0 g to Cart A. Mass Cart A and Cart B and record their masses in the appropriate sections of Data Table 4B. The moving cart, Cart A, is heavier than the stationary cart, Cart B. How do you think this will affect the collision of the carts?
2. Repeat the elastic collision experiment as described in Procedure 4A.
3. Be sure to record your data in the appropriate sections of Data Table 4B, and show your calculations in the space provided. For an explanation of the equation, refer to the Background section for Activity 4.

Data Table 4B: Before Collision

Cart A Mass (g)	Distance, *d* (m)	Time, *T* (s)	Average Time, *t* (s)	Velocity = *d/t* (m/s)

Data Table 4B: After Collision

Cart B Mass (g)	Distance, *d* (m)	Time, *T* (s)	Average Time, *t* (s)	Velocity = *d/t* (m/s)

Calculations for 4B

$M_aV_a + M_bV_b = M_aV_{a'} + M_bV_{b'}$

Procedure 4C: Heavier Stationary Mass

1. Remove the 40.0 g mass from Cart A and place it in Cart B. Mass Cart A and Cart B and record their masses in the appropriate sections of Data Table 4C. The stationary cart, Cart B, now is heavier than the moving cart, Cart A. How do you think this will affect the collision of the carts?
2. Repeat the elastic collision experiment as described in Procedure 4A.
3. Be sure to record your data in the appropriate sections of Data Table 4C, and show your calculations in the space provided. For an explanation of the equation, refer to the background section for Activity 4.

Data Table 4C: Before Collision

Cart A Mass (g)	Distance, *d* (m)	Time, *T* (s)	Average Time, *t* (s)	Velocity = *d/t* (m/s)

Data Table 4C: After Collision

Cart B Mass (g)	Distance, *d* (m)	Time, *T* (s)	Average Time, *t* (s)	Velocity = *d/t* (m/s)

Calculations for 4C

$M_aV_a + M_bV_b = M_aV_{a'} + M_bV_{b'}$

NAME ____________________

DATE ____________________

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Analysis of 4A–4C Calculations

1. What is the significance of a negative value for $V_{a'}$ in your calculations for 4A through 4C?

2. What happens to the velocity of Cart B when 40.0 g of mass is added to Cart A?

3. What happens to the velocity of Cart B when the 40.0 g of mass is moved to Cart B?

4. Recall that momentum is the product of an object's mass and its velocity ($p = M \times V$). Recall also that the law of conservation of momentum dictates that the combined momentum of the objects involved in a collision is the same before and after the collision. Choose one of the collisions (4A, 4B, or 4C) and compare the values before and after the collision. Show your work, and explain any discrepancies in your calculations.

NAME ______________________________

DATE ______________________________

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Title: ____

Label (*y*-axis): ______________________________

Label (*x*-axis): ______________________________