LEARNING CYCLE 13
CONSERVATION OF LINEAR MOMENTUM
GETTING STARTED

Overview

This learning cycle is about conservation of linear momentum. When two or more objects interact, the total momentum before the interaction is equal to the total momentum after the interaction. All events in this learning cycle are interactions in a straight line. The activity, THREE-STAGE HUMAN ROCKET, allows students to explore an "explosion" and the resulting motions. SPRING INTO ACTION, the concept development activity, allows students to demonstrate the conservation of linear momentum before and after an "explosion." Students will apply the Law of Conservation of Linear Momentum in LOOK OUT BEHIND YOU!, to calculate the velocity at which a toy car is sent out of a launcher.

National Science Education Standard(s) Being Addressed

Content Standard 5-8 Physical Science B Motions and Forces
The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.

If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

Content Standard 9-12 Physical Science B Motions and Forces
Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of force on the motion of objects. The magnitude of the change in motion can be calculated using the relationship $F = ma$, which is independent of the nature of the force. Whenever one object exerts a force on another, a force equal in magnitude and opposite in direction is exerted on the first object.

Benchmark(s) for Science Literacy Being Addressed

Benchmark 6-8 The Physical Setting 4F Motion
An unbalanced force acting on an object changes its speed or path of motion, or both.

Benchmark 9-12 The Physical Setting 4F Motion
The change in motion of an object is proportional to the applied force and inversely proportional to the mass.

Whenever one thing exerts a force on another, an equal amount of force is exerted back on it.

Prerequisite Knowledge and Skills

On order for students to understand this learning cycle, they should know that force is a vector quantity. They should also be able to do basic algebra, such as, solve linear equations.

Setting the Stage for Student Learning

1. Prior to this learning cycle, students should have been introduced to impulse and linear momentum. They should have completed the IMPULSE AND CHANGE IN MOMENTUM learning cycle. Students, however, should be reminded that linear momentum (p) is defined as the product of the mass of the object and the velocity of the object.
2. Ask students how a balloon behaves when it is released without being tied off. What forces act on the balloon? Why does the balloon go one direction while the air goes in the opposite direction? Students may try to use only Newton's Laws to answer these questions. Try to lead them into using the concept of momentum in their answers.
3. You might introduce this learning cycle with a demonstration. Tape a 20 oz. plastic soda bottle to a light dynamics cart (use a 2L bottle for a heavy dynamics cart). Place 6 grams of baking soda in the bottle and add 38 mL of vinegar (10 grams and 50 mL for the 2 L bottle). Quickly stopper the bottle and point it toward the wall. In approximately 3 - 5 seconds, the stopper will fly across the room. Use some of the following questions to stimulate thinking among your students. The purpose of this demonstration is only to raise some issues related to interactions within a system. It is not intended to be used to introduce the concept of conservation of momentum. So do not answer these questions for the students, but have them look for patterns in interactions which will help them with developing this concept later in the learning cycle.
    - Is there any relationship between the velocity of the cork, the masses of the bottle/cart and cork, and velocity of the bottle/cart?
    - For example, what do you think would happen to the velocity of the cork if we increased the mass of the cork but kept the mass of the bottle/cart the same?
    - What variables do you think would affect how far the stopper travels?
    - How could you determine the velocity of the stopper? What measurements would you have to make?
    - How would you compare the linear momentum of the system (which includes the bottle/cart and stopper) before the explosion with the linear momentum of the system right after the explosion?

   Make sure your students understand the linear momentum of the system is zero before the explosion, but there is motion (and therefore linear momentum) after the explosion. If momentum is indeed conserved, this demonstration appears to present contrary information. Someone may remember that momentum is a vector quantity and because the motions of the two objects are opposite, perhaps the momenta of the two may add to zero. At this point do not worry about quantitative measurements for the demonstration.

Taking Account of Student Ideas

You should take the following into account as you work with students on this learning cycle.

1. Students often believe momentum concepts apply only to collisions. Discuss the application of action-reaction to momentum situations such as rockets, recoil of a gun, and a bow and arrow.
2. To overcome the idea that direction of momentum is insignificant, emphasize the direction before and after interactions, such as the air and released balloon, the cork and plastic bottle/cart combination, and the toy cars.
3. Some students may think masses in space do not have linear momentum. They've heard that objects in space are "weightless" and confuse that with the mass of the object. During the concept development stage of this learning cycle as you show sample linear momentum calculations using momentum = (mass) (velocity) or $p = mv$, remind students that you are using the mass of the object in kilograms to solve the problems rather than the weight of the object.
4. Students may believe that linear momentum and kinetic energy are the same thing. As questions arise, discuss and emphasize the difference between the two. This depends on the order of your teaching – you may not have discussed kinetic energy yet so it may not be an issue at this point in time.
5. This may be the first time your students are introduced to the idea of a system. Spend some time talking about the choice of a system.
6. Stress that the linear momentum of a system is a vector quantity. As stated in the pop bottle/cart demonstration, knowledge of vectors helps students to understand the conservation of linear momentum.

Activity Teaching Notes and Answers

EXPLORATION: THREE – STAGE HUMAN ROCKET

Lab setup	<u>easy</u>		moderate		difficult	
Calculations	<u>easy</u>		moderate		difficult	
Reliability	<u>excellent</u>		good		fair	
Interest	<u>excellent</u>		good		fair	
Lab time	<u>-1 class</u>		1 class		+1 class	
Process Skill	<u>A</u>	B	<u>C</u>	<u>D</u>	<u>E</u>	F
Reasoning	<u>1</u>	<u>2</u>	3	4	5	

Engaging Students with Phenomena

<u>Materials</u>

Three carts per laboratory group

Carts should be low-friction and hold at least one seated person. You may be able to borrow suitable carts from the custodians or from the physical education department. These carts can also be built from a 1" x 12" x 3' board and two 2" x 4" pieces of lumber used as cross members for wheel attachment (Figure TG 13.1). Note that the front board extends past the main platform and fastened with only one bolt to allow for steering.

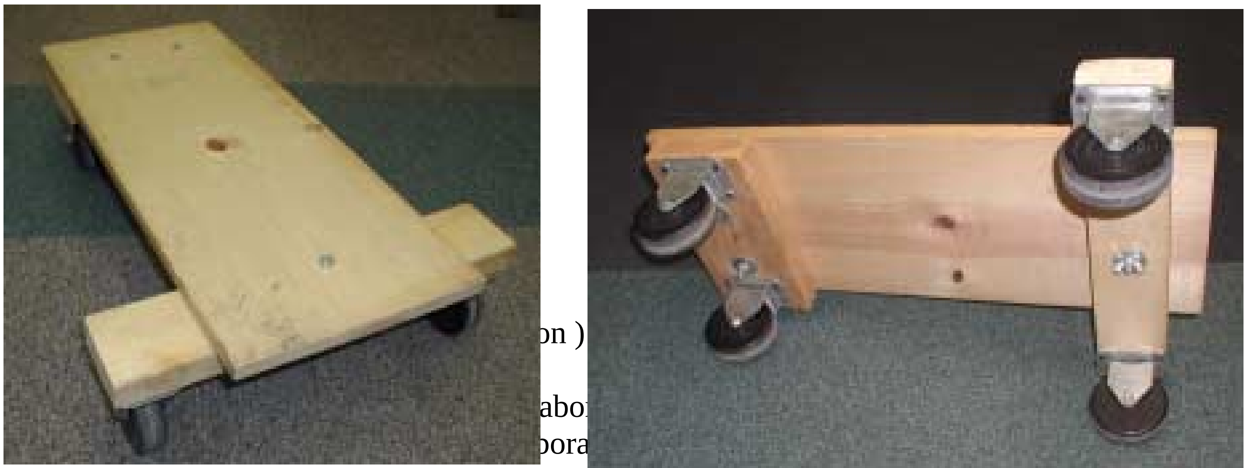

Figure TG 13.1

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groups some planning time and then have them take turns with the set of carts.

2. Students must be cautioned to be careful when using the carts. Cautions given to the students are:
    - All students must be seated.
    - Students placed on the carts should fit comfortably on the cart.
    - Carts must be placed one behind the other. To place the carts side by side and use a "slingshot" approach may cause excessive speeds and be dangerous. This possibility should not be allowed.
    - Make sure clothing and fingers will not get caught under the wheels.
    - Make sure you produce speeds that are appropriate for the situation.
    - Classmates must act as spotters along the way to avoid dangerous collisions.
    - Extra caution should be exercised for the student on the third stage cart. If a sudden large force is exerted on the cart and friction between the student and the board not sufficiently large, the cart could get shoved out from under the rider (Newton's 1st law) and the student dropped to the floor. Handles fastened to this cart would give the student a better chance to remain on the cart.
3. Give students the following instructions:
    - The only forces allowed are between carts.
    - No pushing off a wall or the floor.
    - The wheels on the carts must be aligned parallel to each other.
4. Allow the lab groups 5 – 10 minutes to create their plan. Plans will be adapted as they watch other groups. You may want to have each student describe the motion of his/her cart during the interaction. You may want to allow each lab group two trials.

5. It is assumed that students have completed the previous learning cycle (IMPULSE AND CHANGE IN MOMENTUM) and have a working knowledge of impulse and linear momentum.

Sample Data/Calculations

Student plans will vary and will change as they observe other trials.

Developing and Using Scientific Ideas

1. There are advantages to watching other groups carry out their plans! Describe how students' plans were modified as they observed other trials.
   Ans. Plans and modifications will vary with the student groups. Modifications may include bringing their feet closer to their seat, holding tighter to the other students, rearranging a student's body position, putting the more or less massive student in a different location, etc.
2. Describe the motion of each cart during the run when the student and cart traveled the furthest.
   Ans. Although student answers will vary, one possible answer is:

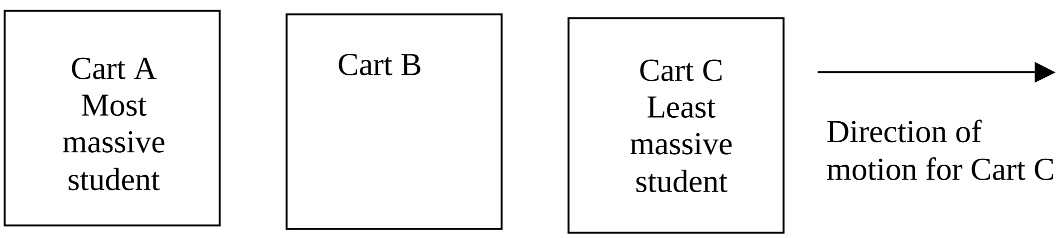

Figure TG 13.2

   With the students arranged as illustrated in Figure 13.2, when the most massive student gives a push, Carts B and C move forward and Cart A moves backwards. The rider of Cart B then gives a push and slows down or moves backwards as Cart C moves forward. The heavier cart/rider moves a shorter distance than the lighter cart/rider does.
3. What patterns exist between the change in velocity and the mass of each cart?
   Ans. The cart with the least mass experiences the greatest change in velocity. The cart with the greatest mass experiences the least change in velocity.
4. What is the linear momentum of the system before any interaction takes place? Why?
   Ans. The linear momentum of the system before anyone pushes is zero. Since none of the carts and occupants are moving ($v = 0$), the momentum (p) which is defined as mv, is 0.
5. What do you believe the sum of the linear momenta of all the parts to be after the interactions take place? Why?
   Ans. Some, but not all, students should be thinking that maybe it is zero. There are both forward and backward directions involved and students should be thinking momentum is a vector and vector addition must be used.

Extending the Activity

In this activity you had students on three carts. These carts could represent the stages of a rocket. Research why most rockets are multistage. Report your findings in a short paper. Ans. Multistage rockets are capable of attaining the high speeds needed for long flights through and out of the Earth's atmosphere. As the fuel in each stage is used up, the stage drops off. This lessens the mass of the remaining parts of the rocket. One source reports a three-stage rocket can attain almost three times the speed of a single stage rocket – each using the same amount of fuel. Students desiring to investigate further could experiment with model rockets. If you desire, have your students check out NASA's web resources. Some of your students will find the information about the Apollo missions very interesting. A search using NASA + Apollo will result in many sites to explore.

CONCEPT DEVELOPMENT: SPRING INTO ACTION

Lab setup	easy		moderate		difficult	
Calculations	easy		moderate		difficult	
Reliability	excellent		good		fair	
Interest	excellent		good		fair	
Lab time	-1 class		1 class		+1 class	
Process Skill	A	B	C	D	E	F
Reasoning	1	2	3	4	5	

Engaging Students with Phenomena

Materials

Two dynamics carts (one with a spring), stopwatch (computer interface timer or ticker tape timer - see Teaching Strategies below for options), balance, meter stick

Teaching Strategies

1. The dynamics carts referred to in this activity can be purchased from any scientific supply company. One cart needs to be spring-loaded to provide a force to separate the two carts.
2. The linear momentum of each cart before the "explosion" is zero. (Since neither cart is moving, the total linear momentum before is zero.) If linear momentum is conserved, the total linear momentum after the explosion should also be zero. This is true because momentum is a vector quantity (it has magnitude and direction). Since the carts will travel in opposite directions, one direction should be assigned positive and the other negative. The two momenta will be equal or nearly equal but opposite in sign and hence their sum close to zero.
3. To find the velocity of each cart after the explosion, you could use either of the following methods:
   (a) After the explosion friction will cause the carts to slow down and stop. By measuring distance with a meter stick and time with a stopwatch, the average velocity can be computed for each cart. The average velocity is also equal to the

sum of the final and initial velocities divided by 2 or $(v_f + v_o)/2$. Since each cart comes to a stop, the final velocity is 0. Thus, the initial velocity of each cart (the velocity the instant after the explosion) will be twice the average velocity.

(b) Acceleration timers (also known as ticker timers) can be used. When connected to an outlet, they produce dots on a paper strip at a rate of 60 dots per second. Displacement and time can be measured to calculate the average velocities after the explosion.

(c) Motion detectors can be used to display the velocity of each cart. From the graphs the maximum velocity will be the velocity just after the explosions, which are the velocities to be used in the calculations. Care must be exercised in setting up the motion detectors to not have the sonic pulses from one detector enter the other detector. To avoid this problem, a cardboard shield may be taped on each cart (Figure TG 13.3). If two motion detectors are used, students will not have to make all the calculations shown below.

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Figure TG 13.3

Sample Data/Calculations

Data shown was taken with a stopwatch and a meter stick. Cart A is assumed to have a positive (right) displacement, velocity and momentum while Cart B moves in the negative (left) direction and has negative values.

	Displacement (m)	Time (s)	Ave Velocity (m/s)	Initial velocity (m/s)	Momentum (kg m/s)
Cart A					
Mass = 1.57 kg	+0.279	1.03			
	+0.292	1.41			
	+0.279	1.42			
Average	+0.283	1.29	+0.219	+0.438	+0.688
Cart B					
Mass = 1.09 kg	- 0.330	1.16			
	- 0.368	1.18			

	- 0.394	1.20			
Average	- 0.364	1.18	- 0.308	- 0.616	- 0.671

3. Students should observe the more massive cart does not move as far and has a lower velocity than the less massive cart. The velocity as a result of the force provided by the spring is calculated as follows for Cart A:

   Average velocity = total displacement/total time = (+0.283 m)/(1.29 s) = +0.219 m/s

   But average velocity is also equal to the (final velocity + initial velocity)/2. Since the cart came to rest after the elapsed time, v_f = 0 m/s. Thus, the initial velocity of the cart (the velocity the instant after the explosion) is two times the average velocity.

   $v_{ave} = (v_f + v_i)/2$ or $v_i = 2v_{ave}$
   $= 2(+0.219 \text{ m/s})$
   $v_i = +0.438 \text{ m/s}$

4. The momentum of each cart is calculated with the formula, $p = mv$. Student values for the momentum of each cart should be nearly equal to one another but with opposite signs. Momentum is a vector quantity and direction must be taken into account.

Developing and Using Scientific Ideas

1. Compare the size of the force of the first cart on the second cart with the force of the second cart on the first cart. Compare the directions of the two forces.
   Ans. The size of these two forces is the same. They are in opposite directions.

2. What relationship can you develop between the momentum of the carts before and after the "explosion"?
   Ans. The momentum of the system before the explosion is nearly equal to the combined momenta after the explosion.

3. How does this activity show that linear momentum is conserved in an “explosion”?
   Ans. Momentum was neither created nor destroyed during the explosion. The momentum of the carts before the explosion was zero. The vector addition of the two momenta after the explosion is also (very nearly) zero. We are assuming the frictional affects of each car is identical.

Extending the Activity

What factors affect the motion after an explosion? Does the relationship you developed hold true when these factors are varied? Devise an experiment to find the answer. Share your results with the class.
Ans. Students will come up with a list of factors that may affect the motion after an explosion. Two factors are the mass of the parts and the amount of force applied. Students can develop a controlled procedure to determine the effects. Mass can be varied

easily by adding lab masses or bricks to one or both of the carts. Setting the spring in different positions can vary the force. They will find out that momentum is still conserved.

CONCEPTUAL PRACTICE

CONSERVATION OF LINEAR MOMENTUM
Answer Key

1. Two dynamics carts are sitting together with a spring compressed between them. When the spring is released what will you observe? Describe how momentum is conserved in this situation.
   Ans. When the spring is released, the carts will move away from each other. The momentum of the carts before the spring was released equals zero. The vector sum of the momenta of the two carts after the release of the spring will also be zero. Momentum is conserved.

2. A linebacker from the home team runs into an opposing stationary running back. What will you observe? Describe how linear momentum is conserved in this situation. Assume that the only interacting forces are between the two players and that there is little force between the turf and the players shoes, such as when a playing field would be quite slippery.
   Ans. The moving linebacker will transfer some of his momentum to the stationary running back. That linebacker will slow down and the once stationary running back will increase in speed. The momentum lost by the moving player will equal the momentum gained by the once stationary player. Linear momentum is conserved.

3. Two dynamics carts, each with a mass of 1.0 kg, are sitting together with a spring compressed between them (Figure TG 13.4). Cart A has a 2 kg brick sitting on top of it. When the spring is released cart B moves to the left with a velocity of 0.53 m/s. Ignoring friction, what is the velocity of cart A immediately after the interaction?
   Ans. Momentum is conserved within the system. Before the explosion the momentum of the system is zero.
   $\text{momentum}_{\text{before}} = \text{momentum}_{\text{after}}$
   $0 = mv_{\text{cart B}} + mv_{\text{cart A}}$
   $0 = (1\text{ kg})(-0.53\text{ m/s} - 0\text{ m/s}) + (3\text{ kg})(v_f - 0\text{ m/s})$
   $0 = -0.53 + 3v_f$
   $-3v_f = -0.53$
   $v_f = +0.18$ m/s or 0.18 m/s to the right

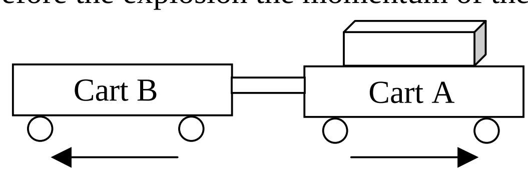


Figure TG 13.4

4. Suppose the same two carts are rolling toward each other. The initial velocity of cart B was 0.63 m/s to the right and the velocity of cart A was 0.75 m/s to the left. After the collision cart B bounces back to the left at a velocity of 0.80 m/s. Assuming friction is negligible calculate the speed and direction of cart A.
   Ans. Momentum is conserved within the system. The momentum of the moving carts before the collision is equal to the momentum of the moving carts after the collision.

$momentum_{before} = momentum_{after}$
$mv_{cart\ B\ before} + mv_{cart\ A\ before} = mv_{cart\ B\ after} + mv_{cart\ A\ after}$
$(1\ kg)(0.63\ m/s) + (3\ kg)(-\ 0.75\ m/s) = (1\ kg)(-\ 0.80\ m/s) + (3\ kg)\ (v_f\ m/s)$
$0.63 + (-2.25) = (-\ 0.80) + 3\ v_f$
$-\ 1.62 = (-\ 0.80) + 3\ v_f$
$-\ 0.82 = 3\ v_f$
$v_f = -\ 0.27$ m/s or 0.27 m/s to the left

5. You and a friend are roller skating. You are behind and hurry to catch up, but you were a little careless and gave your friend a push. Is momentum conserved in this situation? Explain.
Ans. The answer depends on what is chosen as the system. If both skaters make up the system then the force is an internal force and momentum is conserved. The momentum lost by one skater is gained by the other. The vector sum of the momenta before the interaction is equal to the vector sum of the momenta after the interaction. If only one of the skaters is considered to be the system, then an outside force is involved and momentum is not conserved.

APPLICATION: LOOK OUT BEHIND YOU!

Lab setup	easy		moderate		difficult	
Calculations	easy		moderate		difficult	
Reliability	excellent		good		fair	
Interest	excellent		good		fair	
Lab time	-1 class		1 class		+1 class	
Process Skill	A	B	C	D	E	F
Reasoning	1	2	3	4	5	

Engaging Students with Phenomena
Materials

Two lightweight small toy cars that will coast in a fairly straight line (one with a soft piece of Velcro® attached to the back end and the other with the hook part of the Velcro® glued (or stuck) to its front end), a launcher, balance, meter stick, stopwatch

Teaching Strategies

1. The Velcro® pieces should be glued to the front of one car and the back of another in such a way that they will stick together when they hit. Use quick drying glue. It would be best to do this ahead of time. Velcro® with adhesive surfaces is also available.
2. Cars should be of the Matchbox® or Hot Wheels® variety. Check to make sure you have cars that roll straight and are not too massive. These cars sometimes come with launchers and track. Discount stores sometimes have inexpensive cars and launchers. If no launchers are available, cars can be given a reproducible initial velocity by elevating a section of track and having the car descend down the ramp from a given point.

3. Prior to distributing the student activity sheets you might ask your students how they could determine the velocity of a toy car launched from a launcher. After you discuss various possibilities, ask the students how the conservation of linear momentum could be used to determine the velocity as a car is launched. You might even continue by asking them to list the equipment they might need.
4. Since this is an application activity, the students should understand that in a closed system momentum is conserved. In this particular experiment the system under consideration is Car A (in the launcher) transferring some of its linear momentum to the Car B.
5. The velocity of the Car A and B must be determined as soon as the interaction between the cars is completed. Assuming the frictional force is constant, the negative acceleration will be constant. Students determine the average velocity by timing the coupled cars for the displacement from the impact to the stopped position. Students may then calculate the average velocity. Knowing the average velocity, the velocity of the car just after impact will be twice the average velocity, $v_{ave} = (v_f + v_i)/2$.
6. Reaction time variations may become a rather significant part of the total time recorded. Therefore, it is important for students to organize a countdown procedure for the launching and timing to begin.
7. Have the students decide how many trials should be run. (Data below is the average of 5 different trials.)
8. You have the opportunity to introduce your students to elastic and inelastic collisions in this learning cycle. In an elastic collision the objects may hit and rebound off each other. In an inelastic collision the objects hit, become distorted, generate heat and stick together. Nearly elastic collisions take place between steel balls or pool balls. Inelastic collisions take place between lumps of clay or anything else that sticks together. Linear momentum is conserved in both cases (as long as there are no outside forces acting on the system). So how are elastic and inelastic collisions different? In an elastic collision, kinetic energy is conserved. In an inelastic collision, kinetic energy decreases as a result of the interaction. This is because some of the kinetic energy was converted to thermal energy. Total energy was however, conserved. This topic should be revisited with more depth during your discussion of kinetic energy. That would allow you to revisit the concept of momentum and reinforce the conservation laws of physics.

Sample Data/Calculations

The basic equation describing the relationship for the conservation of momentum for this system is:

Momentum before impact = momentum after impact, or

$$(m_A)(v_A) = (m_{A+B})(v_{A+B})$$

where m_A = mass of the launched car, Car A
v_A = velocity of the launched car, Car A (the unknown variable)

m_{A+B} = mass of the cars after impact
v_{A+B} = velocity of cars after impact

Sample data may be organized as follows (+ indicates displacement to the right):

$Mass_A$ (g)	$Mass_B$ (g)	$Mass_{A+B}$ (g)	Displace-$ment_{A+B}$ (cm)	Time (s)	Ave v_{A+B} (cm/s)	Final v_{A+B} (cm/s)	Initial v_{A+B} (cm/s)
19.5	20.6	40.1	+148	3.03	+48.8	0.0	+97.6

From $(m_A)(v_A) = (m_{A+B})(v_{A+B})$ or $v_A = (m_{A+B})(v_{A+B})/m_A$
v_A = (40.1 g) (+97.6 cm/s)/(19.5 g)
v_A = +201 cm/s, or to the right

Developing and Using Scientific Ideas

1. What factors most limit the accuracy of this activity?
   Ans. A major source of error in this activity may be determining the length of the coasting time of Car B after impact with Car A. Reaction time could be a big part of the total time recorded. Since the car is restricted to move in a horizontal plane, Car A should impact Car B with a horizontal force. Use of a launcher that is relatively flat to the floor and having Car A hit a vertical surface of Car B should minimize this effect. Also, in this lab friction does not necessarily introduce error, but actually makes the car's initial velocity easier to calculate. This assumes constant friction and constant negative acceleration.

2. Why isn't the mass of the launcher needed to find the velocity of Car A?
   Ans. The mass of the launcher is not needed because it is not a part of the system. Only moving Car A and stationary Car B are part of the system. Moving Car A hits Car B and causes it to start moving. Car A transfers some of its momentum to Car B. The velocity of Car A can be calculated knowing its mass, the mass of the stuck cars and the initial velocity given to Car B by Car A.

3. How does this activity demonstrate the transfer of linear momentum?
   Ans. Some of the linear momentum of the Car A is transferred to Car B.

4. Occasionally Car A will hit Car B without sticking to the Velcro®. How does this support conservation of linear momentum?
   Ans. Car A may hit and bounce backwards while Car B moves slowly forward. Momentum is still conserved. The momentum of the moving car before the collision is equal to the vector sum of the momentum of the cars after the collision.

Extending the Activity

1. List other methods that may or may not involve computer applications for finding the velocity of Car A.

Ans. A photo diode could be used to time the car as a check on the initial velocity if an appropriate computer and software are available. The velocity of the launched car could also be determined by making measurements of its displacement and time traveled after the launch. The average velocity could then be calculated and used to calculate its initial velocity since the final velocity is zero.

2. Your teacher may have introduced this learning cycle with a demonstration involving a plastic soda bottle taped to a dynamics cart. Use the information learned in this activity to take measurements and show that momentum is conserved in that explosion.
   Ans. Students must find the initial velocity of the stopper and of the bottle/cart combination. Finding the velocity of the stopper after it is ejected from the system may be a challenge, since they will need to measure the distance and time the stopper travels before hitting the table or floor. Perhaps a reaction time needs to be added to the measured time to get best results. Once the math is done, students should find momentum is conserved.

3. When a "break" is made in the game of pool, one moving ball hits 10 stationary balls (Figure 13.5). The balls scatter in many directions. How is momentum conserved in such an "explosion"?
   Ans. Momentum is conserved no matter what the direction or number of the pieces after the explosion. Momentum is a vector quantity and the vector sum of the momenta after the explosion is equal to the momentum before the explosion.

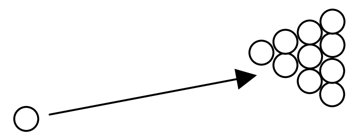


Figure 13.5

WRAPPING IT UP

Building a Case and Promoting Student Reflection

Momentum is conserved; the momentum before an interaction is equal to the momentum after an interaction. Take a few moments and see how your students apply the transfer and conservation of momentum to everyday situations. Start with these and then have students branch off and make up other questions.

- Why does your stationary bumper car move when hit by another bumper car? Ans. Momentum is conserved in a closed system. The momentum of your stationary bumper car is zero. When hit, your car moves because some momentum was transferred within the system to it. The other car has changed its motion (and momentum). The momentum of your now moving car and the car that hit you, is the same as before the crash.

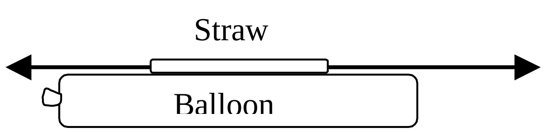
- How does the strongman hammer/tower at the fair demonstrate momentum concepts?

Ans. The hammer you swing hits the mechanism on the ground. Momentum is transferred from your moving hammer through the mechanism to the ball in the column.

- A girl who is standing on a frozen pond wants to return back to shore. The pond's surface, however, is so slippery that she falls when she tries to walk. Explain how she can reach the shore by using some stones that she collected in her backpack. What, if any, assumptions must we make?
  Ans. Your students could have fun with this scenario and their answers will vary. Let them use their imaginations. Watch that their ideas show how linear momentum is conserved. Ask them to describe their system to you. Are the stones included in the system or not? If the stones are thrown do they remain a part of the system or not? Have fun applying physics to this situation.

Extending Student Knowledge and Promoting Student Inquiry

You may have had your students construct a balloon rocket if you completed NEWTON'S THIRD LAW. You can have your students use the balloon rocket and apply the conservation of linear momentum to determine the speed of the air moving leaving the balloon. Have your students construct a balloon rocket as shown in Figure TG 13.4. Have them blow up a long balloon, tape a straw on one long side, and string fishing line through the straw. They should attach one end of the fishing line to the wall. A student can hold the loose end so the line is level or it may be attached to another wall. Remind your students that the air inside the balloon exerts pressure in all directions on the balloon wall. The escaping air at the nozzle end is not pushing on the balloon wall. This leaves an unbalanced force pushing on the wall opposite the nozzle. The force pushes the balloon forward.



The dark arrow represents the fishing line passing through the straw.

Figure TG 1.13.4

Ans. Students will have to use an electronic balance to find the mass of the empty balloon and the air inside the balloon. The mass of the air inside the balloon can be found by measuring the mass of the inflated balloon and subtracting the mass of the balloon. Students will also use their calculated value of the balloon rocket's average velocity (by dividing its displacement by time) to calculate the initial velocity of the balloon. The momentum of the balloon rocket/air system is zero before releasing the mouth of the balloon. Thus, the momentum of the system is zero after releasing the mouth of the balloon. The general equation is:

$$momentum_{before} = momentum_{after}$$
$$momentum_{before} = momentum_{balloon\ rocket} + momentum_{air}$$

$0 = m_{balloon\ rocket}v_{balloon\ rocket} + m_{air}v_{air}$

The only value not known is the velocity of the air. Students should easily make the calculations. Sample data is indicated below:

A round balloon was used. A tiny portion of a straw was attached to the end of the balloon to act as nozzle. The balloon was inflated through this straw and then the straw was sealed with tape. The balloon was attached to a straw. The mass of the balloon rocket with air was then measured. The balloon rocket was then placed on the fishing line. The straw nozzle was cut to release the air and the appropriate measurements of balloon rocket's displacement and the elapsed time were made. The masses of the balloon rocket (without air) and the tiny straw nozzle that was cut off were measured.

mass of the balloon rocket with air = 4.15 g
mass of balloon rocket without air and straw nozzle that was cut off = 3.56 g
mass of straw nozzle that was cut off = 0.32 g
mass of air = 4.15 g – 3.56 g – 0.32 g = 0.27g

total displacement of balloon rocket = +6.10 m
total elapsed time = 10.06 s
average velocity of balloon rocket = (+6.10 m)/(10.06 s) = +0.600 m/s

But average velocity is also equal to the (final velocity + initial velocity)/2. The balloon rocket came to rest at the end of the elapsed time. Thus, the initial velocity of the balloon rocket (the velocity of the balloon rocket the instant after the air is released) can by found.
$v_{ave\ of\ balloon\ rocket} = (v_f + v_i)/2$ but $v_f = 0$ m/s, so $v_i = 2v_{ave}$
$v_i = v_{balloon\ rocket} = 2(+0.600\text{ m/s}) = +1.20\text{ m/s}$

Since $\text{momentum}_{before} = \text{momentum}_{balloon\ rocket} + \text{momentum}_{air}$

$0 = m_{balloon\ rocket}v_{balloon\ rocket} + m_{air}v_{air}$

$0 = (4.15\text{ g})(+1.20\text{ m/s}) + (0.27\text{ g})(v_{air})$

$v_{air} = -(4.15\text{ g})(+1.20\text{ m/s})/(.27\text{g}) = -18.4\text{ m/s}$