Momentum, Impulse and Momentum Change

Read from **Lesson 1** of the **Momentum and Collisions** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/momentum/u4l1a.html
http://www.physicsclassroom.com/Class/momentum/u4l1b.html

MOP Connection: Momentum and Collisions: sublevels 1 and 2

Momentum

1. The momentum of an object depends upon the object's ________. Pick two quantities.
   a. mass - how much *stuff* it has
   b. acceleration - the rate at which *the stuff* changes its velocity
   c. weight - the force by which gravity attracts *the stuff* to Earth
   d. velocity - how fast and in what direction its *stuff* is moving
   e. position - where the *stuff* is at

2. Momentum is a ____________ quantity.
   a. scalar b. vector

3. Which are **complete** descriptions of the momentum of an object? Circle all that apply.
   a. 2.0 kg/s b. 7.2 kg•m/s, right c. 6.1 kg•m/s^2, down
   d. 4.2 m/s, east e. 1.9 kg•m/s, west f. 2.3 kg•m/s

4. The two quantities needed to calculate an object's momentum are __________ and ___________.

5. Consider the mass and velocity values of Objects A and B below. Compared to Object B, Object A has ____ momentum.
   a. two times the b. four times the
   c. eight times the d. the same
   e. one-half the f. one-fourth the
   g. ... impossible to tell without knowledge of the F and a.

6. Calculate the momentum value of ... . (Include appropriate units on your answers.)
   a. ... a 2.0-kg brick moving through the air at 12 m/s.

   b. ... a 3.5-kg wagon moving along the sidewalk at 1.2 m/s.

7. With what velocity must a 0.53-kg softball be moving to equal the momentum of a 0.31-kg baseball moving at 21 m/s?

Impulse and Momentum Change

8. Insert these words into the four blanks of the sentence: **mass**, **momentum**, **acceleration**, **time**, **impact**, **weight**, **impulse**, and **force**. (Not every word will be used.)

   In a collision, an object experiences a(n) _________________ acting for a certain amount of ___________________ and which is known as a(n) ______________ ; it serves to change the _______________ of the object.

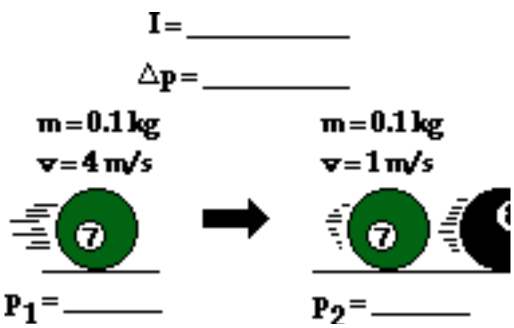
9. A(n) _______________ causes and is equal to a change in momentum.
   a. force   b. impact   c. impulse   d. collision

10. Calculate the impulse experienced by .... .   (Show appropriate units on your answer.)
    a. ... a 65.8-kg halfback encountering a force of 1025 N for 0.350 seconds.

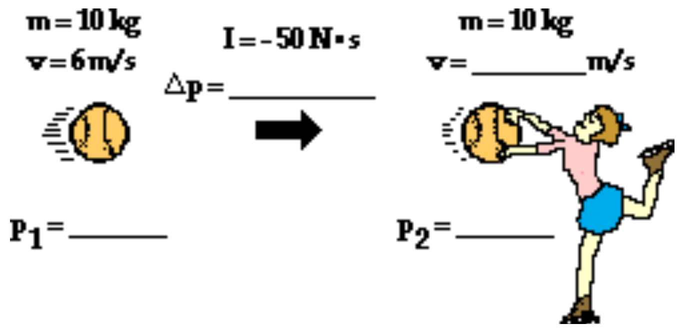
    b. ... a 0.168-kg tennis ball encountering a force of 126 N that changes its velocity by 61.8 m/s.

11. Determine the impulse (**I**), momentum change (**Δp**), momentum (**p**) and other values.

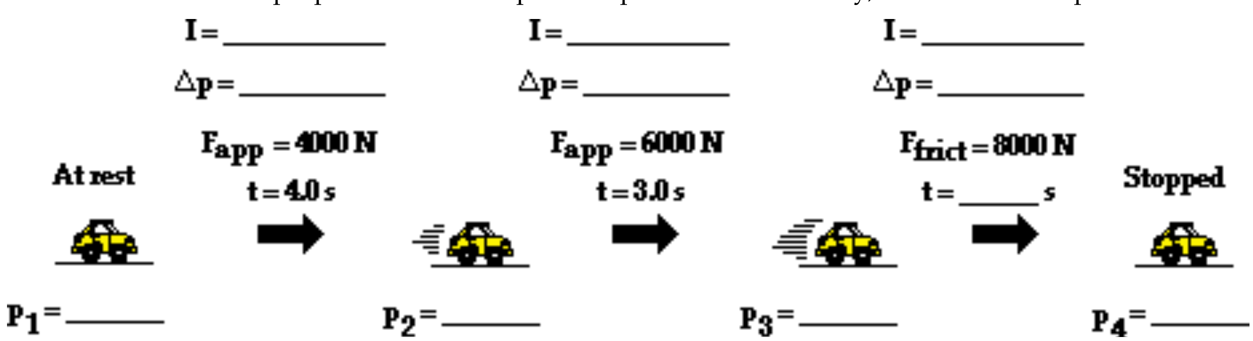
A 7-ball collides with the 8-ball.



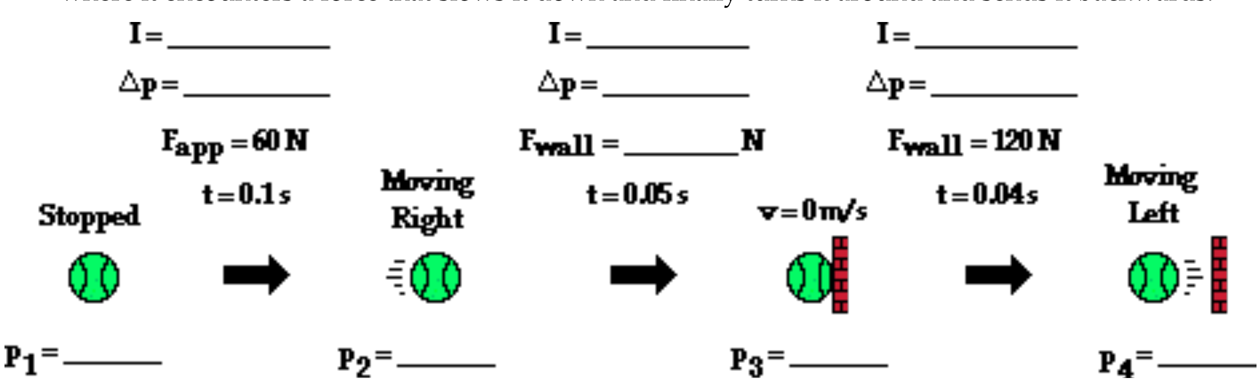
A moving medicine ball is caught by a girl on ice skates.



A car is at rest when it experiences a forward propulsion force to set it in motion. It then experiences a second forward propulsion force to speed it up even more. Finally, it brakes to a stop.



A tennis ball is at rest when it experiences a forward force to set it in motion. It then strikes a wall where it encounters a force that slows it down and finally turns it around and sends it backwards.



Controlling a Collision

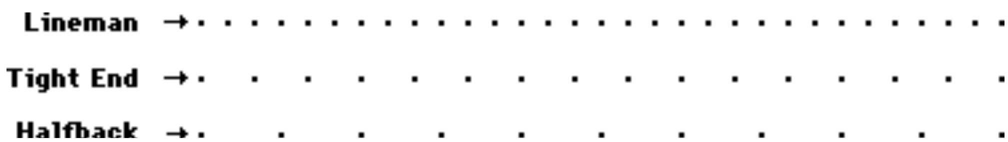
Read from **Lesson 1** of the **Momentum and Collisions** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/momentum/u4l1a.html
http://www.physicsclassroom.com/Class/momentum/u4l1b.html

MOP Connection: Momentum and Collisions: sublevel 3

Review:

1. A halfback (m = 80 kg), a tight end (m = 100 kg), and a lineman (m = 120 kg) are running down the football field. Consider their ticker tape patterns below.



The lineman's velocity is 3 m/s (right). The tight end's velocity is ______ m/s and the halfback's velocity is _______ m/s. Which player has the greatest momentum and how much momentum does he have? ___________________________ Explain.

2. A football fullback is running down the field at constant speed until he encounters a defensive back. The dot diagram depicts the motion of the fullback.

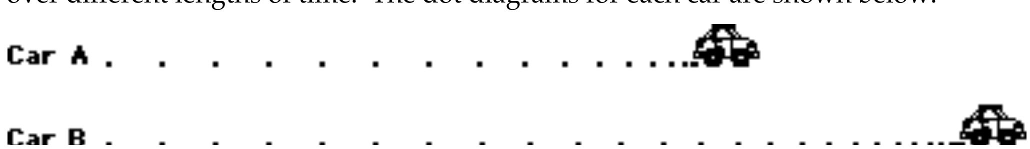
Indicate on the dot diagram (by means of an arrow) the approximate location at which the fullback-defensive back collision occurs.

Which direction (right or left) does the force upon the fullback act? ________ Explain how you know.

What happens to the momentum of the fullback upon colliding with the defensive back?

Using the F•t = m•Δv Equation to Analyze Impulses and Momentum Changes:

3. Two cars of equal mass are traveling down Lake Avenue with equal velocities. They both come to a stop over different lengths of time. The dot diagrams for each car are shown below.



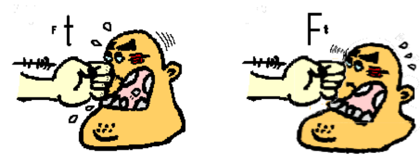
Which car (A or B) experiences the greatest acceleration? ______ Explain.

Which car (A or B) experiences the greatest change in momentum? ______ Explain.

Which car (A or B) experiences the greatest impulse? ______ Explain.

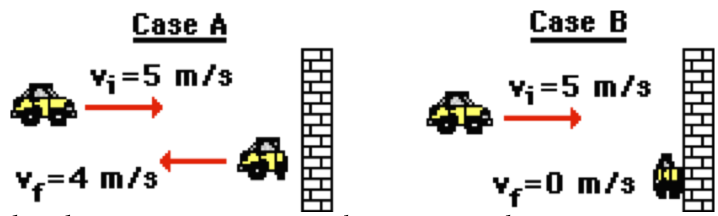
Which car (A or B) experiences the greatest force? ______ Explain.

4. When a boxer recognizes that he/she will be hit by an opposing fist, he/she rides the punch. Use physics to explain why.



5. Mountain climbers use nylon safety ropes due to their tendency to stretch considerably under stress. Use physics to explain why.

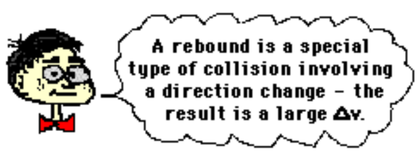
Consider the diagram at the right for the next three questions. The diagram depicts **Before** and **After** velocities of an 800-kg car in two different collisions with a wall. In case A, the car rebounds upon collision. In case B, the car hits the wall, crumples up and stops. Assume that the collision time for each collision is the same.



_________ 6. In which case does the car experience the greatest momentum change?
a. Case A b. Case B c. Both the same d. Insufficient information

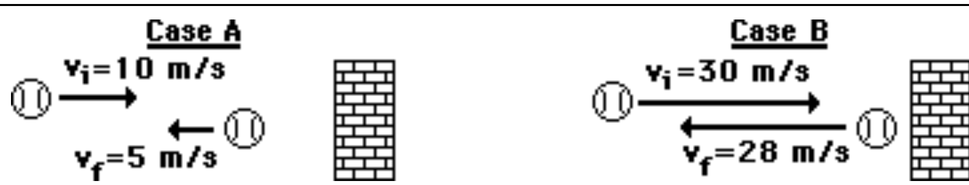
_________ 7. In which case does the car experience the greatest impulse?
a. Case A b. Case B c. Both the same d. Insufficient information

_________ 8. The impulse encountered by the 800-kg car in case A has a magnitude of ___ N•s.
a. 0 b. 800 c. 3200 d. 4000
e. 7200 f. Not enough information to determine.



9. Evaluate the potential hazard to a passenger involved in a head-on collision in which the two cars stick together compared to when they rebound upon impact. Explain.

10. The diagram below depicts the changes in velocity of a ball that undergoes a collision with a wall. Indicate which case (A or B) has the greatest change in velocity, greatest acceleration, greatest momentum change, and greatest impulse. Support each answer.



Greatest Δv? _____ Explanation: ______________________________

Greatest a? _____ Explanation: ______________________________

Greatest Δp? _____ Explanation: ______________________________

Greatest FΔt? _____ Explanation: ______________________________

Simple Computations with Impulse = Momentum Change

Read from **Lesson 1** of the **Momentum and Collisions** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/momentum/u4l1b.html
http://www.physicsclassroom.com/Class/momentum/u4l1c.html

A car with a mass of 1000 kg is at rest at a stoplight. When the light turns green, it is pushed by a net force of 2000 N for 10 s.

1. What is the value of the **acceleration** that the car experiences?

2. What is the value of the **change in velocity** that the car experiences?

3. What is the value of the **impulse** on the car?

4. What is the value of the **change in momentum** that the car experiences?

5. What is the **final velocity** of the car at the end of 10 seconds?

The car continues at this speed for a while.

6. What is the value of the change in momentum the car experiences as it continues at this velocity?

7. What is the value of the impulse on the car as it continues at this velocity?

The brakes are applied to the car, causing it to come to rest in 4 s.

8. What is the value of the **change in momentum** that the car experiences?

9. What is the value of the **impulse** on the car?

10. What is the value of the **force** (average) that causes the car to stop?

11. What is the **acceleration** of the car as it stops?

There is a disease known as *formula fixation* that is common among physics students. It particularly infects those who perceive physics as an applied math course where numbers and equations are simply combined to solve algebra problems. However, this is **not** the true nature of physics. Physics concerns itself with ideas and concepts that provide a reasonable explanation of the physical world. When students divorce the mathematics from the ideas, formula fixation takes root and even mathematical problem solving can become difficult. Do you have *formula fixation*? Test your health by trying these computational problems.

12. A force of 800 N causes an 80-kg fullback to change his velocity by 10 m/s. Determine the impulse experienced by the fullback. **PSYW**

13. A 0.80-kg soccer ball experiences an impulse of 25 N•s. Determine the momentum change of the soccer ball. **PSYW**

14. A 1200-kg car is brought from 25 m/s to 10 m/s over a time period of 5.0 seconds. Determine the force experienced by the car. **PSYW**

15. A 90-kg tight end moving at 9.0 m/s encounters a 400 N•s impulse. Determine the velocity change of the tight end. **PSYW**

16. A 0.10-kg hockey puck decreases its speed from 40 m/s to 0 m/s in 0.025 s. Determine the force that it experiences. **PSYW**

17. **A Real Brain Twister:** A 0.10-kg hockey puck is at rest. It encounters a force of 20 N for 0.2 seconds that sets it into motion. Over the next 2.0 seconds, it encounters 0.4 Newtons of resistance force. Finally, it encounters a final force of 24 N for 0.05 seconds in the direction of motion. What is the final velocity of the hockey puck? **PSYW**

You may have been *tricked*, but those were not intended as trick questions. The questions were intended to test your understanding of the concepts of momentum change, impulse, mass, force, time and velocity change. How is your understanding level progressing? Do you have formula fixation?

Action-Reaction and Momentum Conservation

Read from **Lesson 2 of** the **Momentum and Collisions** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/momentum/u4l2a.html
http://www.physicsclassroom.com/Class/momentum/u4l2b.html

MOP Connection: Momentum and Collisions: sublevels 4, 5 and 6

Newton's Third Law and Collisions: In a collision between object 1 and object 2, both objects encounter a force resulting from their mutual interaction with each other. The force on object 1 (F_1) is equal to and opposite in direction as the force on object 2 (F_2).

Plus a Little Logic: The forces which these two objects experience endure for the same amount of time. Since $\mathbf{F_1 = -F_2}$ and $\mathbf{t_1 = t_2}$ it stands to reason that $\mathbf{F_1 \cdot t_1 = -F_2 \cdot t_2}$. This is to say that each object encounters the same impulse. If this is the case, then one can also reason that each object must experience the same momentum change.

Use the above principles to answer the next four questions.

1. The club head (m=0.170 kg) of a golf club collides with a golf ball (m=0.046 kg) at rest upon a tee.

a. Which object experiences the greatest force?	club head	golf ball	both the same
b. Which object experiences the greatest impulse?	club head	golf ball	both the same
c. Which object experiences the greatest Δmomentum?	club head	golf ball	both the same
d. Which object experiences the greatest acceleration?	club head	golf ball	both the same

2. A woman (m = 45 kg) is kneeling on the shoulders of a man (m = 70 kg) in pair figure skating. The man gracefully tosses the woman forward through the air.

a. Which object experiences the greatest force?	man	woman	both the same
b. Which object experiences the greatest impulse?	man	woman	both the same
c. Which object experiences the greatest Δmomentum?	man	woman	both the same
d. Which object experiences the greatest acceleration?	man	woman	both the same

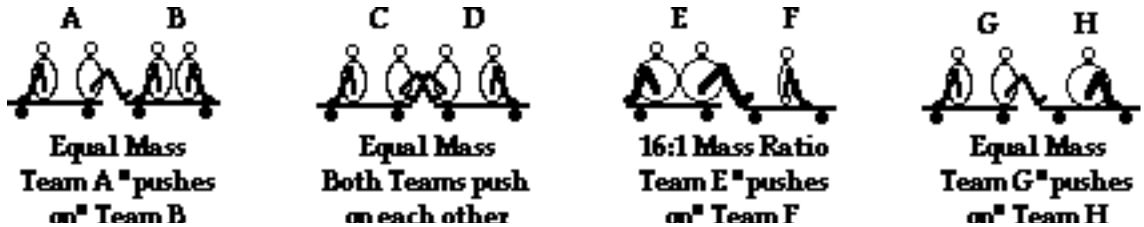
3. A moving cue ball collides head-on with the eight ball that is at rest upon the pool table. Assume the balls have the same mass.

a. Which object experiences the greatest force?	cue ball	8-ball	both the same
b. Which object experiences the greatest impulse?	cue ball	8-ball	both the same
c. Which object experiences the greatest Δmomentum?	cue ball	8-ball	both the same
d. Which object experiences the greatest acceleration?	cue ball	8-ball	both the same

4. A large truck and a Volkswagon (VW) beetle have a head-on collision.

a. Which object experiences the greatest force?	truck	VW	both the same
b. Which object experiences the greatest impulse?	truck	VW	both the same
c. Which object experiences the greatest Δmomentum?	truck	VW	both the same
d. Which object experiences the greatest acceleration?	truck	VW	both the same

In a series of physics demos, students of varying mass are placed on large *massless* carts and deliver impulses to each other's carts, thus changing their momenta. In some cases, the carts are loaded with equal mass; in other cases they are unequal. In some cases, the students push off each other; in other cases, only one team does the pushing. These situations are depicted below.



5. In which cases (AB, CD, EF, GH) do the carts encounter unequal impulses? ___________ Explain.

6. In which cases do the carts encounter unequal momentum changes? ___________ Explain.

7. In which cases do the carts encounter unequal velocity changes? ___________ Explain.

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8. Identify the following statement as True or False. If false, correct the statement.

   According to the law of momentum conservation, if a collision occurs in an isolated system, then any object involved in the collision will conserve its own momentum.

9. Identify the following statement as True or False. If false, correct the statement.

   A person pushes down on the Earth in order to jump into the air. The person gains upward momentum but the Earth *doesn't even budge*. In this example, the law of momentum conservation does not hold.

10. Miles Tugo and Ben Travlun are riding in a bus at highway speed on a nice summer day when an unlucky bug splatters onto the windshield.

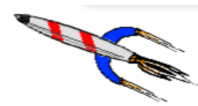
    Miles and Ben begin discussing the physics of the situation. Miles suggests that the momentum change of the bug is much greater than that of the bus. After all, argues Miles, there was no noticeable change in the speed of the bus compared to the obvious change in the speed of the bug. Ben disagrees entirely, arguing that both bug and bus encounter the same force, momentum change, and impulse.

    Who do you agree with? _______ Support your answer.

11. The gunpowder explosion in a gun results in an expansion of gases that cause a bullet to be propelled forward. The gun in turn "kicks" or "recoils" backwards. The recoil momentum of a gun that kicks is _______ the momentum of the bullet that it fires.
a. more than b. less than c. the same as

12. Airplane wings are designed to push air downwards during take off. Explain it is necessary for the wing to push air downwards.

13. There is no *physical object* in space upon which a rocket is able to push off of. Nonetheless a rocket is able to accelerate in space. How can this be? Explain.



14. Kent Swimm (who is taking physics for the second year in a row, and not because he likes it) has rowed his boat to within three feet of the dock. In an effort to save a little time, he decides that he will simply jump off his boat onto the dock, turn around and then tie down his boat. Explain to Kent why this would not be too wise an idea.

15. Consider the interaction between a large cannon and the cannonball that it fires. During the explosion, which object experiences the greatest ...

a. force (F)?	Cannon	Cannonball	Both the same
b. time duration (t) of the force?	Cannon	Cannonball	Both the same
c. impulse (F•t)?	Cannon	Cannonball	Both the same
d. momentum change (m•Δv)?	Cannon	Cannonball	Both the same
e. velocity change (Δv)?	Cannon	Cannonball	Both the same
f. acceleration (a)?	Cannon	Cannonball	Both the same

16. Express your understanding of momentum conservation by filling in the following <u>momentum tables</u>:

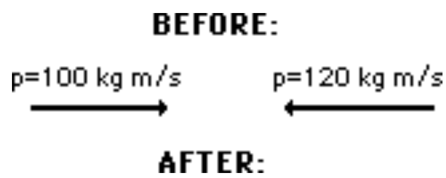
a. Kent Swimm is drifting towards the dock and suddenly jumps forward to *dock* his boat.

	Before Explosion	After Explosion
Kent	50	200
Boat	100	
Total		

b. A cannon is loaded with a ball, placed on a cart, set in motion and fired.

	Before Explosion	After Explosion
Cannon	121	117
Ball	5	
Total		

17. The following two systems are isolated systems. The vector nature of momentum is depicted by the diagram that shows momentum vectors for the two colliding objects before the collision. Express your understanding of momentum conservation by drawing and labeling the magnitude of the after-collision momentum vector.

<table>
<tr>
<td>a. A fullback collides in mid-air with a linebacker above the goal line. The linebacker and fullback hold each other and move together after the collision.


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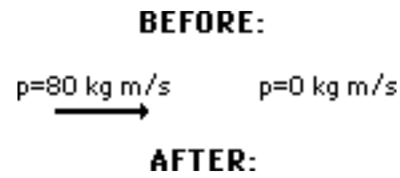
<td>b. A medicine ball is thrown to a clown who is at rest upon the ice. After the "collision" (i.e., the catch), the clown and ball travel together across the ice.


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18. If a ball is projected upward from the ground with ten units of momentum, what is the momentum of recoil of the Earth? ____________ Do we feel this? Explain.

19. If a 5-kg bowling ball is projected upward with a velocity of 2.0 m/s, then what is the recoil velocity of the Earth (mass = 6.0 x 10^{24} kg). **PSYW**

20. A 120 kg lineman moving west at 2 m/s tackles an 80 kg football fullback moving east at 8 m/s. After the collision, both players move east at 2 m/s. Draw a vector diagram (similar to the one drawn in question #17) in which the before- and after-collision momenta of each player is represented by a momentum vector. Label the magnitude of each momentum vector.

<u>Before Collision:</u> **<u>After Collision:</u>**

Write a few sentences to explain how this collision shows that momentum is conserved. Use some numbers in your explanation.

Collision Analysis

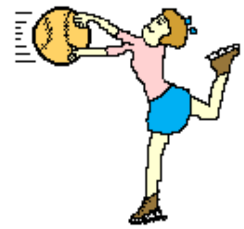
Read from **Lesson 2** of the **Momentum and Collisions** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/momentum/u4l2d.html
http://www.physicsclassroom.com/Class/momentum/u4l2e.html

MOP Connection: Momentum and Collisions: sublevels 7, 8 and 9

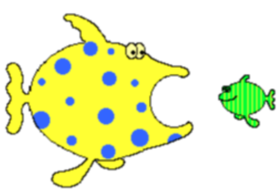
1. A 10-kg medicine ball is thrown at a velocity of 15 km/hr to a 50-kg skater who is at rest on ice. The skater catches the ball and subsequently slides with the ball across the ice.

   Consider the skater and the ball as two separate parts of an isolated system. (no external forces). Fill in the before- and after-collision table below.



	Momentum Before Collision	Momentum After Collision	Momentum Change
Ball			
Skater			
Total			

Determine the velocity of medicine ball and the skater after the collision. **PSYW**



2. A large fish with a mass of 1-kg is in motion at 45 cm/s when it encounters a smaller fish (m=0.25 kg) that is at rest. The large fish swallows the smaller fish and continues in motion at a reduced speed. Fill in the before- and after-collision table below.

	Momentum Before Collision	Momentum After Collision	Momentum Change
Large Fish			
Small Fish			
Total			

Determine the velocity of the large and the small fish after the collision. **PSYW**

3. A 0.150-kg baseball moving at a speed of 45.0 m/s crosses the plate and strikes the 0.250-kg catcher's mitt (originally at rest). The catcher's mitt immediately recoils backwards (at the same speed as the ball) before the catcher applies an external force to stop its momentum. If the catcher's hand is in a relaxed state at the time of the collision, it can be assumed that no net external force exists and the law of momentum conservation applies to the baseball-catcher's mitt collision. Fill in the before- and after-collision table below.

	Momentum Before Collision	Momentum After Collision	Momentum Change
Baseball			
Catcher's Mitt			
Total			

Determine the velocity of the baseball/catcher's mitt immediately after the collision. **PSYW**

4. A 4800-kg truck traveling with a velocity of +4.0 m/s collides head-on with a 1200-kg car traveling with a velocity of -12 m/s. The truck and car entangle and move together after the collision. Fill in the before- and after-collision table below.

	Momentum Before Collision	Momentum After Collision	Momentum Change
Truck			
Car			
Total			

Determine the velocity of the truck and car immediately after the collision. **PSYW**

Momentum Problem-Solving

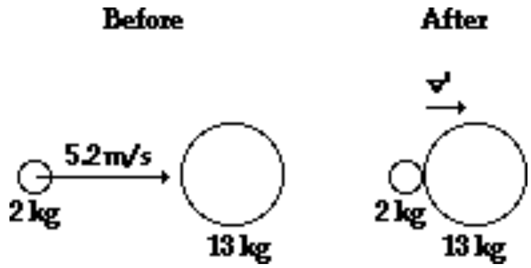
Read from **Lesson 2** of the **Momentum and Collisions** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/momentum/u4l2d.html
http://www.physicsclassroom.com/Class/momentum/u4l2e.html

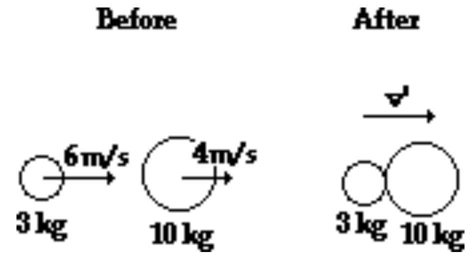
MOP Connection: Momentum and Collisions: sublevels 8 and 9

1. Determine the post-collision velocities of the following objects or combination of objects.

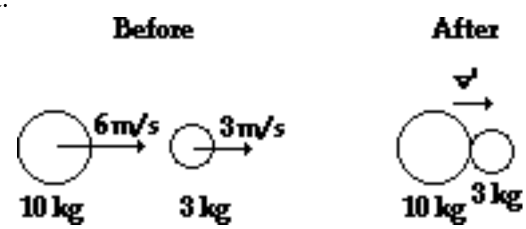
a.



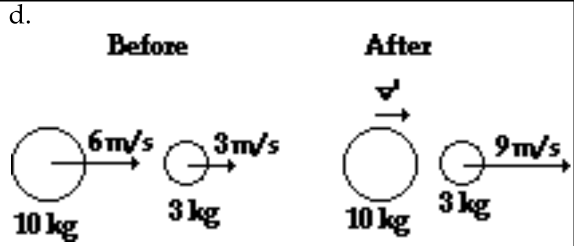
b.



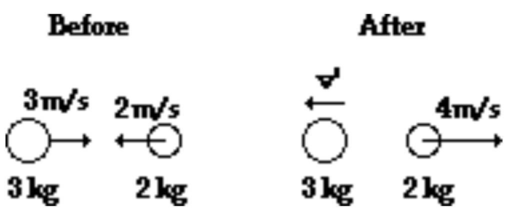
c.



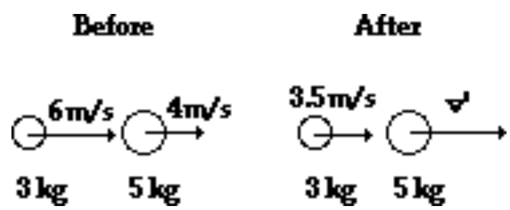
d.



e.



f.



2. A 2.1-kg brick is placed gently upon a 2.9-kg cart originally moving with a speed of 26 cm/s. Determine the post-collision speed of the combination of brick and cart.

3. A 98-kg fullback is running along at 8.6 m/s when a 76-kg defensive back running in the same direction at 9.8 m/s jumps on his back. What is the post-collision speed of the two players immediately after the tackle?

4. A 0.112-kg billiard ball moving at 154 cm/s strikes a second billiard ball of the same mass moving in the opposite direction at 46 cm/s. The second billiard ball rebounds and travels at 72 cm/s after the head-on collision. Determine the post-collision velocity of the first billiard ball.

5. A 225-kg bumper car (and its occupant) is moving north at 98 cm/s when it hits a 198-kg car (occupant mass included) moving north at 28 cm/s. The 198-kg car is moving north at 71 cm/s after the head-on collision. Determine the post-collision velocity of the 225-kg car.

6. A 4.88-kg bowling ball moving east at 2.41 m/s strikes a stationary 0.95-kg bowling pin. Immediately after the head-on collision, the pin is moving east at 5.19 m/s. Determine the post-collision velocity of the bowling ball.

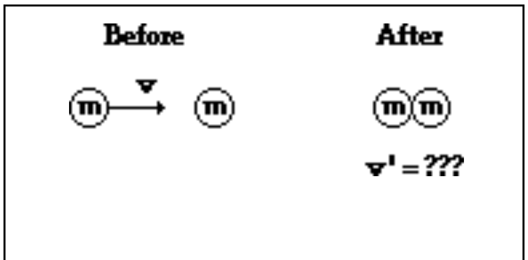
Momentum Conservation as a Guide to Thinking

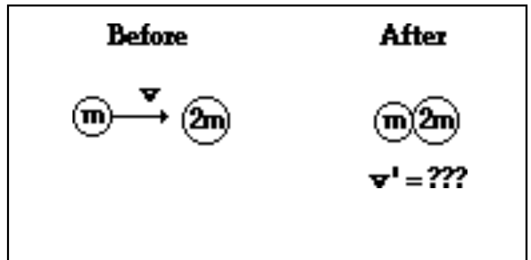
Read from **Lesson 2** of the **Momentum and Collisions** chapter at **The Physics Classroom**:

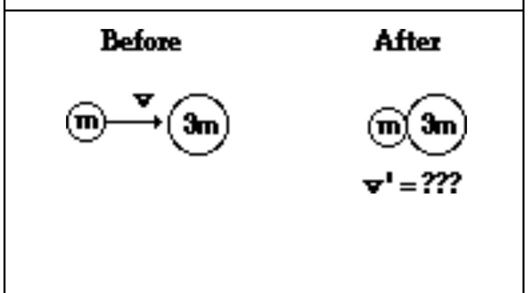
http://www.physicsclassroom.com/Class/momentum/u4l2dd.html

MOP Connection: Momentum and Collisions: sublevel 10

1. The following diagrams depict inelastic collisions between objects of different mass. For each case, determine the post-collision velocity (**v'**) of the two *coupled* objects. Express **v'** in terms of **v**.

a.


b.


c.


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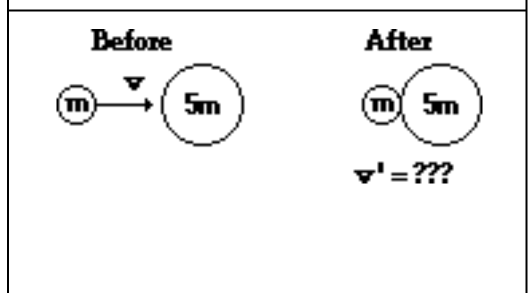

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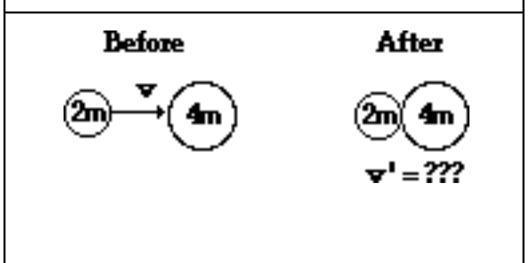

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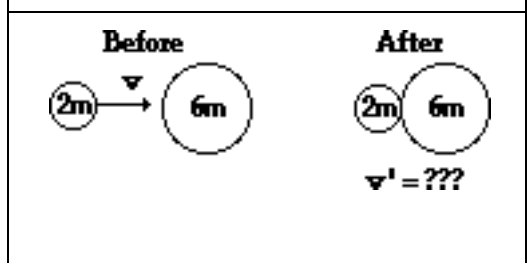

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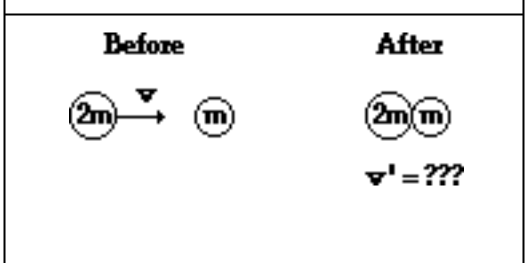

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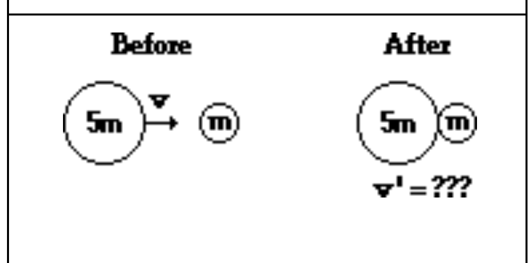
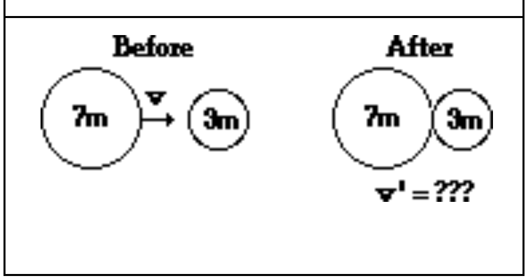


i.


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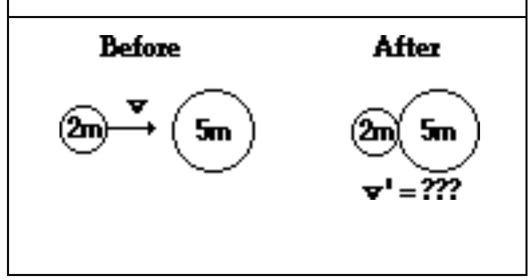


2. Complete the following verbal statements to illustrate your understanding of the effect of varying mass on the post-collision velocity.

   a. If an object of mass **m** collides and velocity **v** collides inelastically with an object of mass **3m** that is initially at rest, then the amount of total *system* mass in motion will increase by a factor of _______ and the velocity of the system will decrease by a factor of _______ . The new velocity (**v'**) will be _______ **v**.

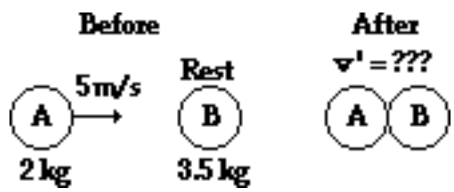
   b. If an object of mass **m** collides and velocity **v** collides inelastically with an object of mass **4m** that is initially at rest, then the amount of total *system* mass in motion will increase by a factor of _______ and the velocity of the system will decrease by a factor of _______ . The new velocity (**v'**) will be _______ **v**.

   c. If an object of mass **3m** collides and velocity **v** collides inelastically with an object of mass **4m** that is initially at rest, then the amount of total *system* mass in motion will increase by a factor of _______ and the velocity of the system will decrease by a factor of _______ . The new velocity (**v'**) will be _______ **v**.

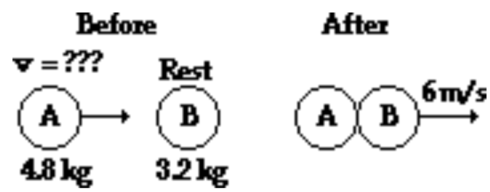
   d. If an object of mass **5m** collides and velocity **v** collides inelastically with an object of mass **3m** that is initially at rest, then the amount of total *system* mass in motion will increase by a factor of _______ and the velocity of the system will decrease by a factor of _______ . The new velocity (**v'**) will be _______ **v**.

3. Use proportional reasoning to determine the unknown quantity in the following collisions.

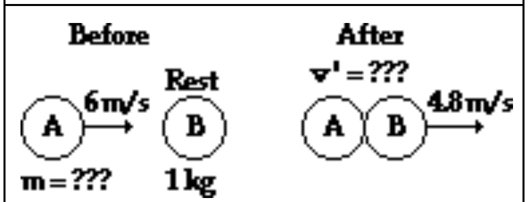
a.



b.



c.



d.