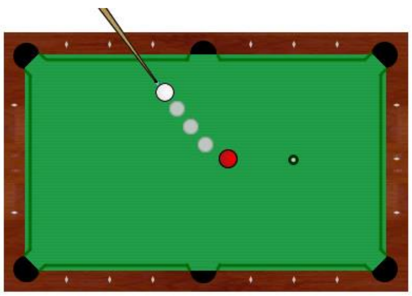
Name: ______________________________________ Date: ________________________

Student Exploration: 2D Collisions

Vocabulary: center of mass, conservation of energy, conservation of momentum, elasticity, kinetic energy, momentum, speed, vector, velocity

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

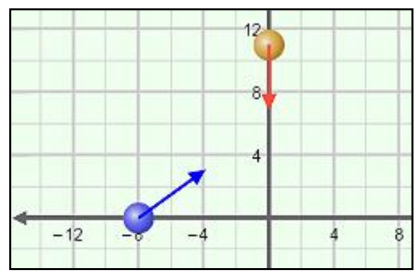


1. A pool cue hits the white cue ball, which travels across the table and strikes the red ball, as shown at right. Draw a solid line to show the path you would expect the red ball to take.

2. Draw a dashed line to show how you think the white ball will move after it has struck the red ball.

Gizmo Warm-up

Objects collide all the time, but often with very different results. Sometimes colliding objects will stick together. Other times, they will bounce off each other at an angle. What determines how objects will behave in a collision? You can use the *2D Collisions* Gizmo™ to find out.



Note the arrows, or **vectors**, on each puck. Click **Play** (▶).

1. How does the direction and length of its vector relate to the motion of a puck? ___________

   ____

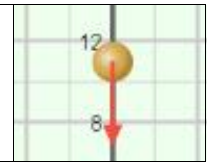
2. The **velocity** (speed and direction) of each puck is described by components in the **i** and **j** directions. The symbol for velocity is **v**. (Vector quantities are shown in bold.)

   A. Which component represents movement in the east-west direction? ____________

   B. Which component represents movement in the north-south direction? ____________

3. The **speed** (*v*) of a puck is equal to the length of its velocity vector. To calculate the speed of a puck with a velocity of *a***i** + *b***j**, use the *Pythagorean theorem*: $v = \sqrt{a^2 + b^2}$

   Set the velocity of the blue puck to 12.00**i** + 5.00**j** m/s. What is its speed? *v* = ____________

Activity A: **Elastic collisions**	Get the Gizmo ready: • Click **Reset**. Make sure **Elasticity** is set to 1.0. • Set the blue puck's velocity to **v** = 4.00**i** + 3.00**j** and the gold puck's velocity to **v** = 0.00**i** – 4.00**j**.	

Introduction: An object's **elasticity** describes how readily it returns to its original shape after it has collided with another object. In a perfectly elastic collision (in which elasticity equals 1), the two colliding objects return to their original shape immediately after the collision takes place.

Question: What is conserved during an elastic collision?

1. Calculate: The **kinetic energy** (*KE*) of an object is a measure of its energy of motion. The equation for kinetic energy is: $KE = mv^2 \div 2$, and the unit for kinetic energy is the joule (J). In the equation, *m* represents an object's mass and *v* represents its velocity.

   A. Calculate the kinetic energy of each puck. (Note: The mass of the pucks can be found on the CONTROLS pane, and the magnitude of the pucks' velocities (***v***) can be found at the bottom of the SIMULATION pane.)

   Blue puck *KE* = ________________ Gold puck *KE* = ________________

   B. Add the kinetic energy of the blue puck to that of the gold puck to find the total kinetic energy for the system. Total system *KE* = ________________

2. Compare: Turn on **Velocity vectors during motion**. Click **Play** and observe the pucks.

   A. Calculate the final kinetic energy of the two pucks and the total system.

   Blue puck *KE* = _________ Gold puck *KE* = _________ Total system *KE* = _________

   Use the CALCULATION tab to check your work.

   B. How did the kinetic energies of the two pucks change, and how can you explain these changes? ____

   ____

   C. How did the total system kinetic energy before the collision compare to that of after the collision? ____

3. Make a rule: Complete the sentence: During an elastic collision, the total kinetic energy of the system _____________________. This rule is part of the law of **conservation of energy**.

(Activity A continued on next page)

Activity A (continued from previous page)

4. Calculate: It takes force to deflect or stop a moving object. **Momentum** (*p*) is a measure of an object's tendency to continue moving in a given direction. The formula for momentum is $p = mv$ and the unit is newton-seconds (Ns). Click **Reset**. Select the CONTROLS tab.

   Because momentum has direction, it can be described in both the **i** direction and **j** direction. Calculate the initial momentums (pay attention to +/- signs):

   Blue puck: *p* in **i** direction = __________ *p* in **j** direction = __________

   Gold puck: *p* in **i** direction = __________ *p* in **j** direction = __________

   Total system: *p* in **i** direction = __________ *p* in **j** direction = __________

5. Calculate: Click **Play** and observe the pucks collide. Calculate the final momentums:

   Blue puck: *p* in **i** direction = __________ *p* in **j** direction = __________

   Gold puck: *p* in **i** direction = __________ *p* in **j** direction = __________

   Total system: *p* in **i** direction = __________ *p* in **j** direction = __________

   Use the CALCULATION tab to check your answers.

6. Compare: Look at the momentum values you calculated for before and after the collision.

   A. What did you notice about the total system momentum in the **i** direction? _________

   ____

   B. What did you notice about the total system momentum in the **j** direction? _________

   ____

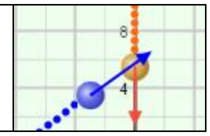
   During an elastic collision, the total momentum in both the **i** direction and the **j** direction remains the same. This rule is part of the law of **conservation of momentum**.

7. Compare: Click **Reset**. Select the MOMENTUM tab. Set up several different collisions. Click **Play**. Then, compare the gray **Total** momentum vector **Before** and **After** the collision.

   A. How do the **Before** and **After** vectors compare? ___________________________

   B. What does this observation confirm? ______________________________________

   ____

Activity B: **Inelastic collisions**	Get the Gizmo ready: • Click **Reset**. • On the CONTROLS tab, turn on **Puck trails**.	

Question: What is conserved during an inelastic collision?

1. Observe: Use the Gizmo to set up a new collision. Run the simulation first with an Elasticity of 1.0. Then, run the simulation with an Elasticity of 0.0.

   What was the effect of decreasing the elasticity? ___________________________________

   ____

2. Predict: In activity A, you found that both total kinetic energy and total momentum are conserved in a perfectly elastic collision. How do you think decreasing the elasticity of a collision will affect the total momentum and total kinetic energy after the collision?

   ____

   ____

   ____

3. Experiment: Move the blue puck to point (-4.0, -6.0). Set its **Initial velocity** to **v** = 3.00**i** + 6.00**j**. Set the **Initial velocity** of the gold puck to **v** = 0.00**i** – 6.00**j**. Use the Gizmo's **Elasticity** slider and CALCULATION tab to complete the table.

Elasticity	**Stage**	**Blue puck**		**Gold puck**		**Total *p* (Ns)**	**Total *TKE* (J)**
		***p* (Ns)**	***TKE* (J)**	***p* (Ns)**	***TKE* (J)**		
1.0	**Before**						
	After						
0.5	**Before**						
	After						
0.0	**Before**						
	After						

(Activity B continued on next page)

Activity B (continued from previous page)

4. Analyze: Study the data you collected in the table on the previous page.

   A. In an inelastic collision, how did the total momentum (p) of the system change?

   ____

   B. In an inelastic collision, how did the total kinetic energy of the system change?

   ____

   C. How were the inelastic collisions different from the elastic collision? _____________

   ____

5. Make a rule: Complete the sentence: During an inelastic collision, the total momentum of the system is ______________________, while kinetic energy is _______________________.

6. Infer: Why do you think some of the kinetic energy is lost during an inelastic collision?

   ____

   ____

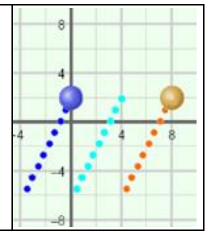
7. Think about it: Suppose a meteorite collided head-on with Mars and becomes buried under Mars's surface. What would be the elasticity of this collision? Explain your answer.

   ____

   ____

   ____

   ____

Activity C: **Center of mass**	<u>Get the Gizmo ready</u>: • Click **Reset**. Turn on **Center of mass trail**. • Move the blue puck to point (-4.0, -6.0). Set its **Initial velocity** to **v** = 3.00**i** + 6.00**j**. • Move the gold puck to point (4.0, -6.0). Set its **Initial velocity** to **v** = 3.00**i** + 6.00**j**.	

Introduction: Suppose you tried to balance a hammer on one finger. If you placed your finger halfway down the handle, the hammer would fall because the head is much heavier than the rest of the hammer. Instead, you would have to place your finger near the head to balance the hammer perfectly. The point where an object balances is called its **center of mass**.

Question: How can you find the center of mass of a system?

1. <u>Identify</u>: The center of mass for the system of two pucks is where the balancing point would be if a weightless rod connected the pucks. Set the mass of both pucks to 5.0 kg.

   What do you think are the coordinates of the center of mass of the two pucks? ___________

2. <u>Compare</u>: Click **Play**. The teal blue trail represents the trail of the system's center of mass. How does the center of mass trail compare to the trails of the two pucks?

   ____

   ____

3. <u>Observe</u>: Click **Reset**. Change the **Blue puck mass** to 10.0 kg. Click **Play**. How did this affect the center of mass? ____

4. <u>Calculate</u>: Click **Reset**. Set the **Elasticity** to 1.0. Move the blue puck to (2.0, -12.0) and change its mass to 6.0 kg. Move the gold puck to (12.0, -4.0) and change its mass to 1.5 kg.

   A. About where do you think this system's center of mass is? ________________

   B. The **i** coordinate of the center of mass can be found using the following equation:

   $$\boldsymbol{i}\ coordinate_{center\ of\ mass} = \frac{(\boldsymbol{i}\ coordinate \times mass)_{blue\ puck} + (\boldsymbol{i}\ coordinate \times mass)_{gold\ puck}}{mass_{blue\ puck} + mass_{gold\ puck}}$$

   What is the **i** coordinate of the center of mass? ________________

   C. The same equation can be used to find the **j** coordinate of the center of mass.

   What is the **j** coordinate for this system? ________________

(Activity C continued on next page)

Activity C (continued from previous page)

5. Run Gizmo: Click **Play**. The first teal dot on the center of mass trail indicates the original position of the center of mass.

   Were your calculations correct? If not, what were the actual coordinates? _______________

6. Compare: Click Reset. Set the blue puck's velocity to **v** = 0.00**i** + 6.00**j** and the gold puck's velocity to **v** = -8.00**i** + 0.00**j**. Click **Play**.

   A. Describe the trail of the center of mass. How is it different from the pucks' trails?

   ____

   ____

   B. Based on the spacing of the trail marks, compare the velocity of the center of mass before and after the collision. ____

   ____

7. Observe: After a collision, the velocities of the pucks will almost always change, but the velocity of the center of mass remains constant.

   A. Why do you think the velocity of the center of mass does not change? ___________

   ____

   B. Select the MOMENTUM tab. How does the center of mass trail compare to the gray arrow representing the total momentum of the system? _______________________

   C. Click **Reset**, and try out various initial settings that result in a collision. For each of these collisions, compare the center of mass trail to the arrow representing the total momentum of the system. What trend do you see?

   ____

   D. What is the relationship between the velocity of a system's center of mass and the law of conservation of momentum? _______________________________________

   ____

   ____