Name(s): ______________________________ Date: __________ Period: ____

ACTIVITY #8: MOMENTUM IN 2-DIMENSIONS

Contributed by Jane & Jim Nelson

Purpose: ____

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Materials and Procedures:

1. Tape six 8.5” x 11” sheets of white paper together … three sheets wide and two sheets high. Do the same for six sheets of carbon paper.
2. Set up the materials as shown in the Diagram of Apparatus to the right. Clamp the ruler (ramp) onto the center edge of the desktop. Watch that the front holder for the target sphere is able to rotate 180^{o} and that the center edge of the six white papers is just under the plumb bob.
3. On the white papers **mark the point** that is directly below the plumb bob.
4. A steel sphere (the incident sphere) will come down the ramp and hit another steel sphere (the target sphere) that will be sitting on the bolt (i.e., perch location). Make sure that when the spheres hit, they do so head on.
   Also check the height of the spheres at the moment of collision. Remember that the incident sphere might fall some distance before contacting the target sphere.

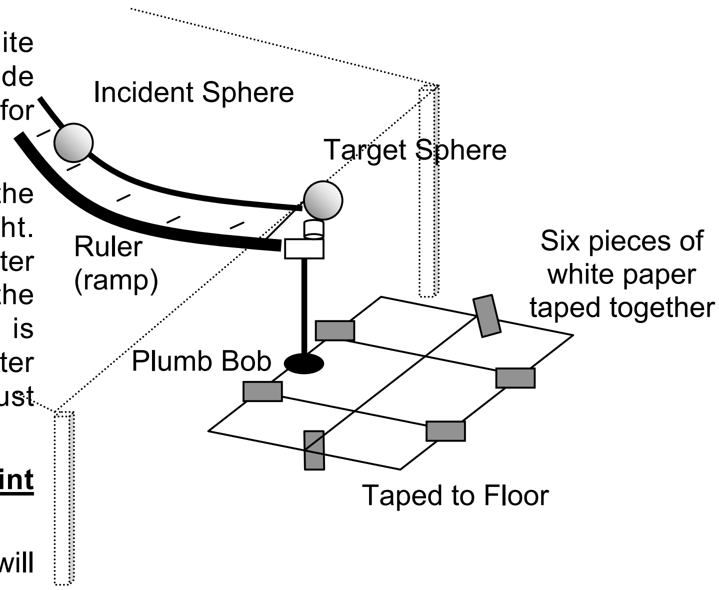


Diagram of Apparatus

5. Lay the carbon papers (taped together) over the white papers, carbon side down. Do not tape the carbon papers down.
6. **PROCEDURE #1:** Let the incident sphere (IS) come down the ramp **without** the target sphere (TS) in place. Don't let the IS hit the perch, and try to catch the sphere after it hits the paper, but before the second bounce. (Put a big "X" on any random marks on the white paper.) Label the point on the white paper where a dark spot indicates the incident sphere's landing point (Perhaps IS_{1A}). Replace the carbon paper, and repeat this step two more times. Label the additional landing points. (Perhaps IS_{1B} and IS_{1C})
7. Circle the three initial landing dots produced on the white paper.
8. **PROCEDURE #2:** Now put the target sphere in position and let the incident sphere hit the target sphere head on. Since the incident sphere will often bounce off the perch, thus adding an external impulse, its landing position is likely to be inconsistent. Label the incident and target sphere landing points (Perhaps IS_{2A} and TS_{2A}). Replace the carbon paper, and repeat this step two more times. Label the additional landing points (Perhaps IS_{2B} and TS_{2B} and IS_{2C} and TS_{2C}).
9. Circle the three incident dots produced on the white paper with one circle and the three target dots with another circle.

10. **PROCEDURE #3:** Repeat steps 8 and 9 except this time let the incident sphere hit the target sphere at an angle by moving the perch to the side about 30° to the right or left of straight ahead.
11. **PROCEDURE #4:** Repeat step 10, (the angular collision) except replace the steel target sphere with a ceramic marble. (Although the mass of the marble is about 1/3 that of the steel sphere, you should check the masses with a balance.)

<u>Analysis:</u>

12. Bring the taped together white papers to the tabletop to continue an analysis of the data. Fold up the carbon papers and return them to the instructor.
13. Determine the "weighted" average (center) of each of the circles you have drawn, draw a dot there, and label each dot appropriately.
14. Using a colored crayon or pencil, draw the displacement vector from the plumb bob point to the center of the initial incident sphere landings when the incident sphere did not hit anything. The vector should point away from the plumb bob position. The horizontal distance traveled by a sphere is proportional to its horizontal velocity as it leaves the ramp/perch. The unit for mass in the system is the mass of one steel sphere, (i.e., 1.0 unit). So if the mass is 1.0 unit, the momentum is numerically equal to the velocity. (i.e., $\mathbf{p} = m\mathbf{v}$, $m = 1.0$, $\mathbf{p} = \mathbf{v}$. Assume there is an arrow above each vector quantity.) Therefore, you may assume the initial incident sphere's displacement vector represents the initial momentum of the IS, and therefore the total momentum of the system, each time a collision occurs.
15. Draw the displacement vectors from the plumb bob position to each of the circular centers for both spheres for every collision. Use a different color for each collision. Put a legend on your paper with each color and the collision (or PROCEDURE) it represents.
16. In each case the vector you just drew represents momentum except for the case of the marble. In this case starting at the plumb bob point, measure 1/3 the length of the marble's whole vector and put slash marks across the rest of the vector. Use only the unslashed portion of the vector to represent momentum.
17. Measure and label the length of each momentum vector.
18. Vectorally add the final momentum vectors for the two spheres for each collision. Draw the resultant vector on the diagram from the plumb bob outward. Use the same color for the momentum resultant that you used for the final momentum vectors for each collision. Measure their lengths and label the resultants. Prepare a white board with a presentation of your results.

Data: See the large chart.

Calculations: (Watch significant figures.)

Initial values before collision **(Procedure #1)**					Final values after collision **(Procedure #2)**			
Sphere	Mass	Velocity	Momentum		Sphere	Mass	Velocity	Momentum
IS	1.0 unit				IS	1.0 unit		
TS	N/A				TS	1.0 unit		
Total Momentum before →					Total Momentum after →			

Final values after collision **(Procedure #3)**					Final values after collision **(Procedure #4)**			
Sphere	Mass	Velocity	Momentum		Sphere	Mass	Velocity	Momentum
IS	1.0 unit				IS	1.0 unit		
TS	1.0 unit				TS	0.33 unit		
Total Momentum after →					Total Momentum after →			

Questions:

1. Is the time of flight the same for the steel spheres as for the marble sphere? ______________
   Explain your answer. ____
   ____
2. Why is the displacement vector proportional to the horizontal velocity of each of the spheres? ____
3. What is the symbol used for momentum? ______
4. Explain under what conditions the displacement vectors can be used to represent momentum vectors? ____
   ____
5. If you add the displacement/velocity vectors for each collision, would you always find that the initial velocity of the system is equal (and thus conserved) to the vector sum of the two spheres' final displacements or velocities? Explain which collision(s) would and defend your answer. ____
   ____
   Under what conditions would this not work? ____
   ____
6. How did you adjust the displacement/velocity vectors to represent momentum vectors? Why did you do that? ____
   ____

7. What is percent difference between magnitude of the total momentum before the collision and the magnitude of the total momentum after the collision? Show sample calculation. Show your equation(s), substitution, and answers in space below.

   Procedure #2: ________________

   Procedure #3: ________________

   Procedure #4: ________________

8. According to your textbook, is momentum a conserved quantity during an interaction? _______
9. If your data contradicts your answer to question #8, then explain why that is. If it supports your answer to question #8, then state this and smile. ☺ ________________________________

   ____

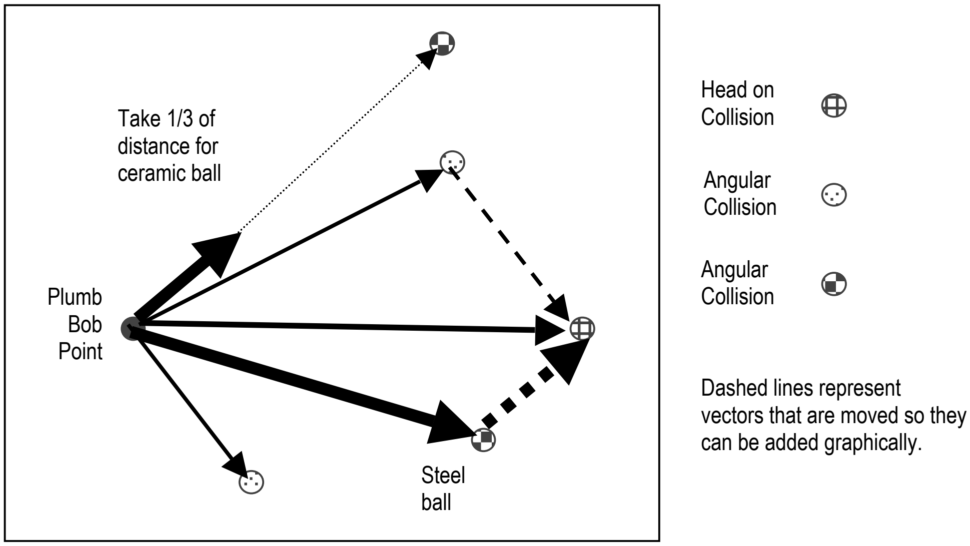
   Conclusion: ____

   ____

ACTIVITY #8: MOMENTUM IN 2-DIMENSIONS (TEACHER NOTES)

Purpose: *To determine if momentum is conserved in 2 – D collisions.*

Sample Data



The initial momentum of the ball rolling down the ramp with no target ball should be represented by a line directly under the head on collision vector in the drawing above.

The students do not have to calculate the actual velocities. Since all the balls fall the same vertical distance, the time for travel is the same for all of them. Therefore, the horizontal distance traveled is proportional to the actual velocity and can represent velocity. The students may use cm readings to represent the velocity in this case. The distances may represent momentum vectors if all the masses are the same. Each velocity would be multiplied by the same mass, so again distance can represent momentum. However, when the mass is 1/3 in the case of the ceramic ball, then only a distance 1/3 of the velocity distance may be used to represent momentum.

Note that when the distances representing momentum data are added vectorally, then the total final momentum is equal to the initial momentum vector. Sometimes the incident ball does not drop directly down onto the plumb bob point as it collides head on with the target ball. It may hit the side of the ruler apparatus and bounce to the side. In that case, explain to the students that it really is a zero momentum vector and that the total momentum is in the target ball.

Data: See the large chart above.

Calculations: (Watch significant figures.)

Initial values before collision **(Procedure #1)**					Final values after collision **(Procedure #2)**			
Sphere	Mass	Velocity	Momentum		Sphere	Mass	Velocity	Momentum
IS	1.0 unit	*46.1 cm*	*46.1 cm*		IS	1.0 unit	*0 cm*	*0 cm*
TS	N/A				TS	1.0 unit	*45.4 cm*	*45.4 cm*
Total Momentum before →			*46.1 cm*		Total Momentum after →			*45.4 cm*

Final values after collision **(Procedure #3)**					Final values after collision **(Procedure #4)**			
Sphere	Mass	Velocity	Momentum		Sphere	Mass	Velocity	Momentum
IS	1.0 unit	*31.9 cm*	*30.9 cm*		IS	1.0 unit	*33.0 cm*	*33.0 cm*
TS	1.0 unit	*15.5 cm*	*15.5 cm*		TS	0.33 unit	*38.5 cm*	*12.8 cm*
Total Momentum after →			*46.4 cm*		Total Momentum after →			*45.8 cm*

Questions:

1. Is the time of flight the same for the steel spheres as for the marble sphere? *Yes*

Explain your answer. *Since all the balls fall the same vertical distance, the time for travel is the same for all of them.*

2. Why is the displacement vector proportional to the horizontal velocity of each of the spheres? *Since $v = d/\Delta t$ and thetime interval is the same for all the drops, the horizontal distance traveled is proportional to the actual velocity and can represent velocity.*

3. What is the symbol used for momentum? *P*

4. Explain under what conditions the displacement vectors can be used to represent momentum vectors? *Since $P = m * v$, the distances may represent momentum vectors if all the masses are the same.*

5. If you add the displacement/velocity vectors for each collision, would you always find that the initial velocity of the system is equal (and thus conserved) to the vector sum of the two spheres' final displacements or velocities? Explain which collision(s) would and defend your answer. *Only collisions using the same mass show conservation of velocity as in collisions # 2 and # 3.*

Under what conditions would this not work? *As soon as the mass changes, it is obvious that momentum, not velocity is conserved as in collision # 4.*

6. How did you adjust the displacement/velocity vectors to represent momentum vectors? Why did you do that? *In the case of mass equal to 1/3 the mass of the other ball,*

7. What is percent difference between magnitude of the total momentum before the collision and the magnitude of the total momentum after the collision? Show sample calculation. Show your equation(s), substitution, and answers in space below.

Procedure #2: *1.5 %* *100 (46.1 – 45.4) / 46.1 = 1.5 %*

Procedure #3: *0.65 %* *100 (46.1 – 46.4) / 46.1 = 0.65 %*

Procedure #4: *0.65 %* *100 (46.1 – 45.8) / 46.1 = 0.65 %*

8. According to your textbook, is momentum a conserved quantity during an interaction? *yes*

9. If your data contradicts your answer to question #8, then explain why that is. If it supports your answer to question #8, then state this and smile. ☺ *Most students will find that their percent difference is less than 10%. That is considered a non-significant difference. See notes above for other areas of concern in data.*

Conclusion: *Momentum is conserved (even) in 2-D elastic collisions.*