JoVE: Science Education

Conservation of Momentum

--Manuscript Draft--

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Overview: The goal of this experiment is to test the concept of conservation of momentum. By setting up a surface with very little friction, collisions between moving objects can be studied including their initial and final momenta.

Conservation of momentum is one of the most important laws in physics. When something is conserved in physics it means that the initial value is equal to the final value. For momentum this means that the total initial momentum of a system will be equal to the total final momentum. Newton's second law states that the force on an object will be equal to the change in the objects momentum with time. This fact combined with the idea that momentum is conserved underpins the workings of classical mechanics and is a powerful problem solving tool.

Principles of Conservation of Momentum: Momentum($\vec{p}$) is defined as the mass of an object times its velocity($\vec{v}$)

$$\vec{p} = \vec{v} * m \quad \text{(Equation 1)}$$

~~You~~One can also define momentum in terms of the forces acting on an object (Newton's second law).

$$\sum \vec{F} = \frac{\vec{p}-\vec{p}\prime}{t-t\prime} \quad \text{(Equation 2)}$$

Here $\vec{p}$ is the initial momentum and $\vec{p}'$ is the final momentum with the same convention for time t and t'. T~~t~~he sum of the forces acting on an object is equal to the change in the objects momentum with time. Therefore if there is no net force acting on an object the change in the momentum will be zero. Said another way, ~~if you have~~in a closed system with no external forces, ~~than~~ the initial momentum will be equal to the final momentum.

This concept is most easily understood in the context of 1D and 2D collisions. In a 1D collision an object with mass m_A and initial velocity $\overrightarrow{v_A}$ collides with another object with some mass and initial velocity m_B and $\overrightarrow{v_B}$. In these collisions ~~we consider there to be no~~ external forces will be assumed to be too small to have an effect. In the lab an air track is used to reduce the amount of friction, an external force, on the gliders. If the initial momentum is equal to the final momentum then we can write

$$m_A\overrightarrow{v_A} + m_B\overrightarrow{v_B} = m_A\vec{v}'_A + m_B\vec{v}'_B \quad \text{(Equation 3)}$$

Where the primed velocities represent that final velocity and the unprimed velocities represent initial velocity.

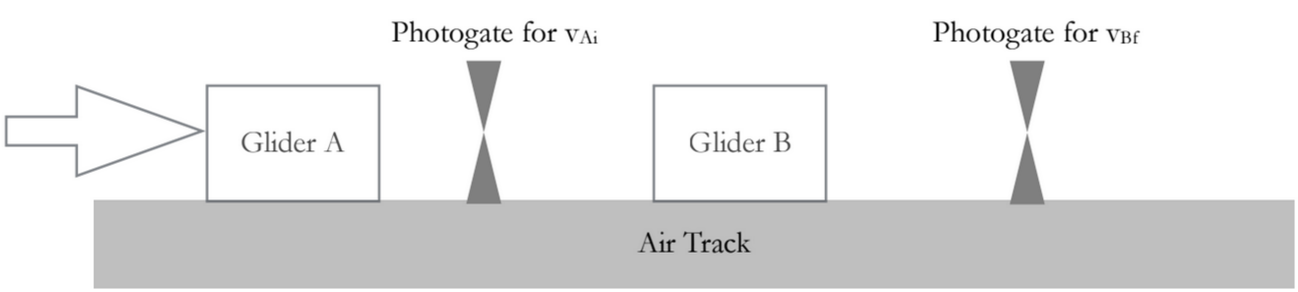

Figure 1

Procedure:

1. Understanding the photogate timer.

   1.1) Place one glider on the track with one photogate timer.

   1.2) Set the photogate timer to the 'gate' setting.

   1.3) When the glider passes through the photogate it will record the time in which the flag above the glider passes through the gate. On a return trip the photogate will not display new time but if you switch the toggle to 'read' it will display the initial time plus the time of the second pass through the gate.

   1.4) The flag is 10 cm long, ~~and~~ so using the fact the speed is distance divided by time the velocity of the glider can be measured.

   1.5) Send the glider through the photogate several times including return trips after it has bounced off the far wall and measure the velocities in order to familiarize oneself with the equipment. Remember that velocity has a direction. Let the initial velocity direction be positive and the opposite direction represent negative values of velocity.

2. Two gliders of equal mass

   2.1) Place two gliders and two photogate timers on the track as in Figure 1

   2.2) If the two gliders have equal mass use E~~e~~quation 3 to determine what the expression for the final velocities will be. In this part of the experiment the glider B will start from rest.

   2.3) Give glider A some initial velocity so that it will collide with glider B and record the initial velocity of glider A as well as the final velocities of each glider. Do this three times, record your results and compare to the theoretical prediction.

3. Two gliders of unequal mass.

   3.1) Repeat the previous steps but this time add 4 weights to glider B which will double the mass of glider B. ~~Do this three times~~ Repeat step 2.3~~,~~ record your results and compare with the theoretical prediction.

4. Equal masses not starting from rest

   4.1) Remove the weights from glider B.

   4.2) This time repeat the same procedure but have glider B start with some initial velocity in the direction of glider A. Do this three times, record your results and compare with the theoretical prediction.

Representative Results:

Part 2

Glider (trial)	$\vec{v}$ (cm/s)	$\vec{v}'$ (cm/s)	$\sum \overrightarrow{v_A} + \overrightarrow{v_B}$ (cm/s)	$\sum \vec{v}'_A + \vec{v}'_B$ (cm/s)	Difference (%)
A (1)	5.0	-0.2	-	-	-
B (1)	0.0	5.5	5.0	5.3	6
A (2)	6.5	-0.3	-	-	-
B (2)	0.0	6.9	6.5	6.6	2
A (3)	5.5	0.0	-	-	-
B (3)	0.0	5.7	5.5	5.7	4

Part 3

Glider (trial)	$\vec{v}$ (cm/s)	$\vec{v}'$ (cm/s)	$\sum \overrightarrow{m_A} v_A + m_B \overrightarrow{v_B}$ (kg cm/s)	$\sum \overrightarrow{m_A} v'_A + m_B \vec{v}'_B$ (kg cm/s)	Difference (%)
A (1)	6.0	-3.0	-	-	-
B (1)	0.0	5.0	6.0	7.0	15
A (2)	6.5	-4.0	-	-	-
B (2)	0.0	5.5	6.5	7.0	14
A (3)	5.5	-2.5	-	-	-
B (3)	0.0	4.5	5.5	6.5	15

~~Parts 2 & 3~~

Part 4

Glider (trial)	$\vec{v}$ (cm/s)	$\vec{v}'$ (cm/s)	$\sum \overrightarrow{v_A} + \overrightarrow{v_B}$ (cm/s)	$\sum \vec{v}'_A + \vec{v}'_B$ (cm/s)	Difference (%)
A (1)	8.0	2.5	-	-	-
B (1)	-6.5	-1.5	2.5	1.5	40
A (2)	6.5	-4.5	-	-	-
B (2)	-10.0	-1.5	-4.5	-6.0	25
A (3)	12.0	4.0	-	-	-
B (3)	-3.0	6.0	9.0	10.0	10

The results for parts 2, 3 and 4 confirm the predictions made by Equation 3. in part 2 glider A comes to almost a complete stop after colliding with glider B. Therefore nearly all its momentum is transferred to glider B. In part 3 glider A does not come to a stop when colliding with the heavier glider B but returns in the opposite direction after imparting some momentum unto glider B. In part 4 the two gliders have again the same mass but the glider with more initial momentum continues in the same direction after the collision while the glider with less momentum has its direction changed. In all 3 parts the total initial momentum is approximately equal to the total final momentum as predicted.

~~Part 4~~

Summary: In this experiment the law of conservation of momentum was verified by considering the collision of two gliders on a near frictionless track. This fundamental law is perhaps most important because of its power to solve problems. If one knows the initial momenta then they know the final momenta and vice versa.

Applications: Without momentum conservation rockets would never leave the ground. Rockets don't actually push against anything, they rely on thrust to lift off. Initially the fuel of a rocket and the rocket itself are motionless and have zero momentum. When launching, the rocket propels spent fuel out very rapidly. This spent fuel has mass and momentum. If the final momentum must be equal to the initial momentum (zero) then there has to be some momentum in the opposite direction of the discarded fuel. Thus the rocket is propelled upward.

If you have ever fired a gun then you understand the conservation of momentum. Like the rocket/fuel system from above the gun/ammunition system also starts at rest. When the ammunition is fired out of the gun at a tremendous speed there has to be sum momentum in the opposite direction to cancel out the momentum of the speeding bullet. This is known as recoil and can be very powerful.

The popular desk ornament which consists of several metal balls hanging from strings is called a “Newton's cradle” for good reason. It is another example of the conservation of momentum. When a ball is lifted and released it strikes its neighbor transferring its momentum which goes on down the line until the final ball has the momentum of the first and it swings outward. This would go on forever if not for outside forces like air resistance and energy loss due to the collisions.

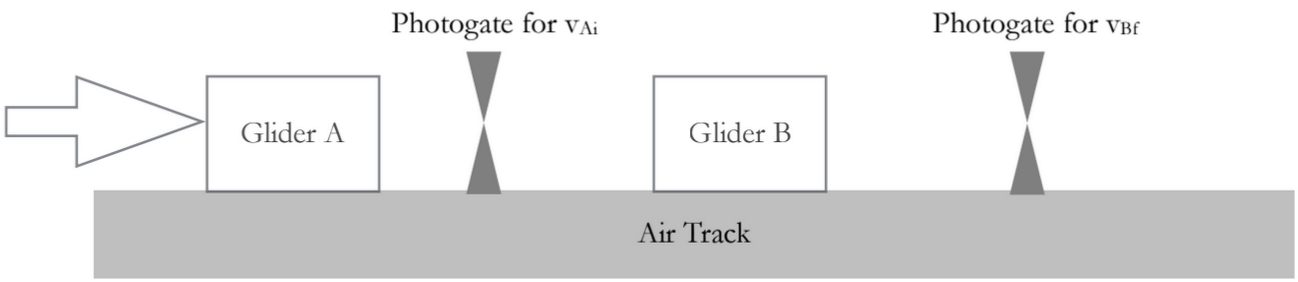
Photogate for v_{Ai}
Photogate for v_{Bf}
Glider A
Glider B
Air Track

Figure 1