

Experiment 6: Conservation of Momentum

Elastic Collisions

1. Obtain a lump of clay, the balance system, and two Hot Wheels cars.
2. Check the cars to make sure they will produce a clean “hit” with the spring between them. Also check that the cars roll about the same. If there is a big mismatch, try a new car.
3. Start with the cars of equal mass. Equalize the masses of the chosen cars by adding a small amount of clay to the lighter one.
4. Think about how Newton’s *third* law is at work during the small time of impact (less than 0.1 sec). Is the force applied to the target by the striker the same or different than the force applied to the striker by the target? Use Newton’s 3rd law to write an equation relating these forces, using subscripts to keep track of each of the terms.

5. Now think about how Newton’s *second* law is at work during the small time of impact, for each car. Write out Newton’s second law (as an equation) for each car, using subscripts to keep track of each of the terms.

Striker:

Target:

6. From these two laws, what can you predict about the *absolute value of the cars’ accelerations (or decelerations)* during the instant of impact: are they equal, or one is greater than the other? Recall Steps 3, 4, and 5 above for this. Show calculations.

Striker:

Target:

7. Experiment with running one car into the other, and observe the *change in speed* of *both* cars due to the impact (not due to the rolling friction). Note: the change in a variable always means the final value minus the initial value. Impacts tend to be a bit unpredictable: do at least 3 trials so you can be certain of what is typical. Circle whether the car is decelerating or accelerating. Use your visual judgment to rate the *change in speed* from 0 to 10, with 10 being the speed of the faster car. The acceleration is proportional to the change in speed, since the time of impact is the same for each car: $a = \Delta v / \Delta t$

Striker: Decelerating or Accelerating ? How much (0-10)? _____

Target: Decelerating or Accelerating ? How much (0-10)? _____

8. Evaluate your analysis and prediction in step 6 (keeping in mind this is an "eyeball" measurement):

9. Now using additional clay and the balance, make one car twice as massive as the other.

10. Predict the effect of a 2x more massive striker on the *change in speed* (proportional to acceleration) of both cars. I.e., a 2m striker hits a 1m target. Circle your prediction:

Predicted change in speed of striker: High Medium Low

Predicted change in speed of target: High Medium Low

11. Now test your prediction by running a 2m striker into a 1m target, and observe the *change in speed* of both cars.

Striker: Decelerating or Accelerating ? How much (0-10)? _____

Target: Decelerating or Accelerating ? How much (0-10)? _____

Evaluate your prediction in step 10 (keeping in mind this is an "eyeball" measurement):

12. Now reverse the cars so a 1m striker hits a 2m target. First predict like in step 10:

Predicted change in speed of striker: High Medium Low

Predicted change in speed of target: High Medium Low

13. Now test your prediction by running a 1m striker into a 2m target, and observe the *change in speed* of both cars.

Striker: Decelerating or Accelerating ? How much (0-10)? _____

Target: Decelerating or Accelerating ? How much (0-10)? _____

Evaluate your prediction in step 12 (keeping in mind this is an "eyeball" measurement):

14. Now go back and apply Newton's second and third laws for these cases: show how the accelerations relate to each other for the two cars (2m and 1m) during the moment of impact. Show calculations using Newton's second and third laws (like step 6):

2m car:

1m car:

15. Discuss what you found in step 14 compared to the results in steps 11 and 13:

Inelastic Collisions

Introduction

In the "matchbox car" lab the cars bounced off each other—this is called an "elastic collision," and the cars retain most of their kinetic energy. The same physics principles of Newton's laws and Conservation of Momentum apply to both elastic and inelastic collisions. Momentum is much easier to measure than either forces or accelerations, so this lab will look at momentum..

1. *Conservation of Momentum* says that the total momentum of a system does not change as long as there is no external force on the system. Momentum is defined as **mass × velocity**, for each mass. The "system" is defined as both masses. The momentum of the system, before and after, is

$$\begin{array}{ccc} \underline{\text{Before}} & & \underline{\text{After}} \\ m_1 v_1 + m_2 v_2 & = & m_1 v_1' + m_2 v_2' \end{array}$$

where v_1 and v_2 are the velocities of mass 1 and mass 2 before the collision and v_1' and v_2' are the respective velocities after the collision. If mass two is stationary before the collision, then v_2 would be 0. Thus the momentum equation would be simplified:

$$\begin{array}{ccc} \underline{\text{Before}} & & \underline{\text{After}} \\ m_1 v_1 & = & m_1 v_1' + m_2 v_2' \end{array}$$

In this lab the carts will stick together after the collision, so $v_1' = v_2'$. The momentum equation becomes:

$$\begin{array}{ccc} \underline{\text{Before}} & & \underline{\text{After}} \\ m_1 v_1 & = & (m_1 + m_2) v_1' \end{array}$$

2. Each empty cart has a mass of 1kg and the added masses are also 1kg each. Add 1 mass to each cart, for a total of 2kg per cart (this is the "2/2" case in the Data Table). Place the carts on the track, and set the track slope to just overcome friction (such that either cart will roll at a constant speed).

3. Place the 'target' cart (m_2) near the midpoint. Set up the Velcro coupling block on the target so it meets the striker (m_1) cleanly.

4. From the high end of the track, push the striker from its top/rear near the pulley (to prevent it swinging). Practice getting a "clean" collision. In the experiment you will find the speed of the striker cart before the collision, and of the two carts together after collision.

5. For the best data:

- 1) Choose a relatively small distance so that the cart doesn't slow down very much in the interval. But, too small a distance will amplify stopwatch inaccuracies. Suggestion: select distances for before and after that give a time of about one second.
- 2) When timing the cart through the distance intervals, be sure to track the same point on the same cart (e.g., the front of the striker).
- 3) Push the striker with fairly high velocity to minimize friction effects.
- 4) Do about 3 trials for each case, and use multiple stopwatches.

6. Find the speeds of each cart for the combinations in the table below, and calculate Momentum % Conserved for each combination. *Show units.* Note: $\% \text{ Conserved} = 100 * (\text{Final} / \text{Initial})$.

7. Evaluate whether Conservation of Momentum seems to hold based on the data, and discuss your results. Recall friction is still present in this experiment, and is a bit unpredictable at the moment of impact. Friction robs the system of momentum, so the Momentum % Conserved of our experiment will be a bit lower than the ideal case.

distance interval for striker pre-collision: _____

distance interval for striker+target post-collision: _____

Mass Striker (kg)	Mass Target (kg)	$\Delta\tau$ Pre-coll. (sec)	$\Delta\tau$ Post-coll. (sec)	Velocity Pre-coll. _____	Velocity Post-coll. _____	Momentum Pre-Coll. _____	Momentum Post-Coll. _____	Momentum % Conserved
2	2							
1	2							
2	1							

8. In the "matchbox lab" we looked at the *change in velocity* of each car due to the impact. In the next table, examine the cases from today's lab to see how the change in velocity and acceleration are affected by the mass ratios. Since the time of impact is the same for both cars, and acceleration = (change in velocity)/(time of impact), we can calculate the *acceleration ratio* of the two cars:

$$(v_1' - v_1) / (v_1)$$

That ratio will roughly tell us how the hypothetical occupants of the cars will fare, *relative to each other*, in a crash.

Mass Striker (m ₁) (kg)	Mass Target (m ₂) (kg)	Change in Velocity of Striker (v ₁ '-v ₁)	Change in Velocity of Target (v ₁ ')	Acceleration Ratio of both cars (e.g., 3.2 : 1)
2	2			
1	2			
2	1			

9. Is the data consistent with what you found in the matchbox lab? I.e., ideally, the "1/2" case will be just the inverse of the "2/1" case, with the lighter car experiencing much more acceleration than the heavier one. And, the "2/2" case will have a ~1:1 acceleration ratio. Are the data consistent with predictions and what you found with matchbox cars (allowing for experimental error)?

Elastic Collisions

1. Start with 1 added 1kg mass in each cart (each empty cart is 1kg as well, for a total of 2kg per cart). Place the carts on the track, and set the track slope to just overcome friction, such that either cart will roll at a *constant* speed.
2. Place the 'target' cart near the midpoint, and the 'striker' cart at one end, with the spring on either cart but between the two.
3. From the high end, push the 'striker' cart from it's top/rear near the pulley (to prevent it swinging). Practice getting a "clean" collision, and finding the speeds (record the time to travel a specified distance) of the striker before and after the collision, and the target after collision. Unlike the last lab, there are generally going to be two objects moving apart after the collision, and you want both of their speeds. Thus, 3 stopwatches are necessary, and probably 3 people per setup. Follow the same general practices you used in the inelastic case.
4. If the target cart jumps off the track (likely only for the 3:1 combination), adjust the location of the spring by moving it <1/8" in the same direction as the jump of the cart.

5. Make a hypothesis about whether Energy and Momentum will be conserved before and after the collision for the carts bouncing apart upon impact (called an “elastic collision”)

Energy _____ Momentum _____

6. Find the speeds of each cart for the combinations below, and calculate Momentum and Energy for each combination. *Note units for each column.*
7. Note: $\% \text{ conserved} = 100 * (\text{Final} / \text{Initial})$

Mass Striker (kg)	Mass Target (kg)	Δd Striker Pre (m)	Δd Striker Post (m)	Δd Target Post (m)	Δt Striker Pre (sec)	Δt Striker Post (sec)	Δt Target Post (sec)	Vel. Striker Pre	Vel. Striker Post	Vel. Target Post
2	2									
2	1									
3	1									

Mass Striker (kg)	Mass Target (kg)	Mom. Pre	Mom. Post	Mom. % Conserv ed	Energy Pre	Energy Post	Energy % Conserv ed
2	2	_____	_____		_____	_____	
2	1						
3	1						

8. Evaluate your hypotheses based on the above data, and discuss your results.

9. Generally, how do the % Conservation for Momentum compare to the last lab, where the carts stuck together?

10. Think about automobile collisions (which are somewhere in between “inelastic” and “elastic”). Recall that $F=ma$, and the average acceleration for each car is the (*change in velocity of the car*) / (time of collision). Which combination is most likely to result in an injury, and, is #1 different or the same as #3, from an acceleration standpoint?

1. 2000 lb vs. 2000 lb.
2. 2000 lb vs. 3000 lb.
3. 3000 lb vs. 3000 lb.