Lab 04: Momentum and Collisions DUE: 15 Feb 2024

Introduction

Do you know what you are looking at there on the left? If you said 'Go Bears!' or 'Fear the Stripes!' you're only half right.

A perfectly inelastic collision is one where two (…or three…) objects (…or football players…) collide and stick together. It may not look like it, but momentum is being conserved here (also, the Bears kicked the stuffing out of Nicholls State).

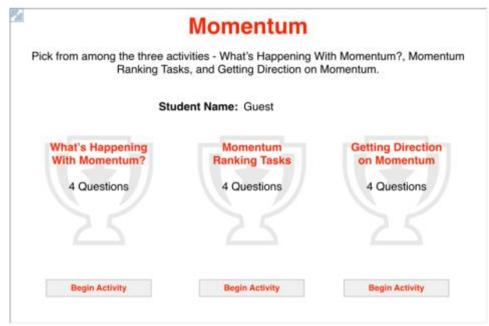
Now that we understand vectors, we're going to expand our repertoire and add momentum. Why? The point is that momentum lets us understand and analyze collisions in a way that kinematics can't.

Objectives

- Visualize the vector concept of momentum
- Analyze the changes in momentum of two objects in collision
- Calculate conservation of momentum for inelastic collisions
- Examine experimental results, and suggest methods for improvement

Equipment

- Internet-connected device capable of running a browser
- Paper and pen or pencil (you're always going to need these)
- Scientific Calculator



Procedure

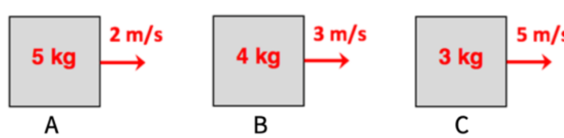
1. Read this handout completely before you try to dive in. It will save you time and frustration later. If you are able to print it, you will not have to tab between windows—you can look at this and the simulation at the same time.
2. Do you have paper and pencil handy? Don't forget your calculator.
3. In a browser window, navigate to the Momentum Concept Builder. Don't try to start doing the lab yet! Just verify that when you click LAUNCH the interactive opens properly.

Understanding Momentum Vectors

You should proceed with the Momentum exercise as GUEST. No need to log in. There are three separate exercises, each with a few situations to resolve. You should begin at WHAT'S HAPPENING WITH MOMENTUM? and work your way through GETTING DIRECTION ON MOMENTUM. Once you have, you should be able to answer the questions below easily (Hint: Clicking the HELP ME! button is always really useful.)

1. The momentum of an object at rest is
   A) positive. B) zero. C) negative.
2. The momentum of an object in motion is
   A) positive. B) zero. C) negative. D) non-zero, but might be either (+) or (–).
3. A car is moving in the $+x$–direction, and it is slowing down. The momentum of the car is
   A) positive and decreasing. B) positive and increasing. C) negative and decreasing. D) negative and increasing. E) zero.
4. True or false: An object with a constant mass increases its speed. Its momentum remains constant.

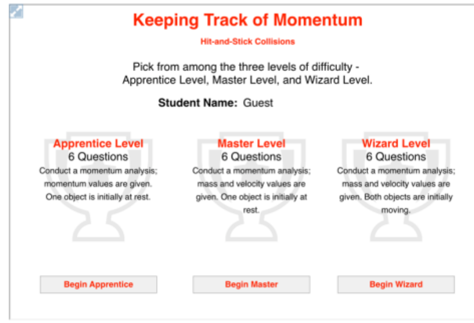
Examine the figure on the right and answer Questions 5–7.



5. Which object has the **greatest momentum**? Use the multiple choices on the figure.
6. What is the magnitude p of the momentum of the object with the **smallest momentum**?
   A) $p = 2\frac{\text{kg·m}}{\text{s}}$ B) $p = 3\frac{\text{kg·m}}{\text{s}}$ C) $p = 4\frac{\text{kg·m}}{\text{s}}$
   D) $p = 5\frac{\text{kg·m}}{\text{s}}$ E) $p = 6\frac{\text{kg·m}}{\text{s}}$ F) $p = 8\frac{\text{kg·m}}{\text{s}}$
   G) $p = 10\frac{\text{kg·m}}{\text{s}}$ H) $p = 12\frac{\text{kg·m}}{\text{s}}$ I) $p = 15\frac{\text{kg·m}}{\text{s}}$

7. If the speed of an object **doubles**, what happens to its momentum?
   - A) Nothing. The momentum remains constant. Momentum does not depend on speed.
   - B) The magnitude of the momentum remains the same, but its direction changes to its opposite (from + to – or from – to +).
   - C) The momentum decreases to ½ its previous value. Its direction remains the same.
   - D) The momentum increases to 2× its previous value. Its direction remains the same.

Hit–and–Stick Collisions



Return to your browser window and launch the Keeping Track of Momentum (Hit and Stick Collisions) Concept Builder. Like last time, continue as a GUEST. Also like the previous simulation, there are three sets of exercises to complete. Each one practices a different skill, so don't skip any! Once you have worked through all three, you should be able to answer the following questions easily. (Hint: Clicking the HELP ME! button is always really useful.)

Let's complete an analysis together before you try to work one through on your own. Pay careful attention to the method of filling in the table below.

A red cart is moving rightward with a momentum of $p_{Ri} = 60\frac{\text{kg·m}}{\text{s}}$ when it collides with a blue cart that is initially at rest. The blue cart has twice the mass of the red cart. The two carts stick together and move to the right with the same speed after the collision. Enter the momentum values (in $\frac{\text{kg·m}}{\text{s}}$) of each individual cart and of the system of two carts before and after the collision. Also indicate the change in momentum of each cart.

Cart	Before Collision	After Collision	Momentum Change
Red Cart: $m_R = 1\text{kg}$	$p_{Ri} = 60\frac{\text{kg·m}}{\text{s}}$	$p_{Rf} = \left(\frac{m_R}{m}\right)p_i = \left(\frac{1}{3}\right)60 = 20\frac{\text{kg·m}}{\text{s}}$	$\Delta p_R = p_{Rf} - p_{Ri} = 20 - 60$ $\Delta p_R = -40\frac{\text{kg·m}}{\text{s}}$
Blue Cart: $m_B = 2\text{kg}$	$p_{Bi} = 0\frac{\text{kg·m}}{\text{s}}$	$p_{Bf} = \left(\frac{m_B}{m}\right)p_i = \left(\frac{2}{3}\right)60 = 40\frac{\text{kg·m}}{\text{s}}$	$\Delta p_B = p_{Bf} - p_{Bi} = 40 - 0$ $\Delta p_B = +40\frac{\text{kg·m}}{\text{s}}$
System: $m = 3\text{kg}$	$p_i = p_{Ri} + p_{Bi} = 60 + 0 = 60\frac{\text{kg·m}}{\text{s}}$	$p_f = p_{Rf} + p_{Bf} = 20 + 40 = 60\frac{\text{kg·m}}{\text{s}}$	$\Delta p_R + \Delta p_B = -40 + 40 = 0$

Look at exactly how each step gets calculated. Everything is really obvious before the collision, right? But how do the after-collision numbers make sense? Without going into a detailed derivation, let's think about this: after they collide, they are stuck together and traveling with the same speed. Effectively, it's now a single object with a total mass $m = m_R + m_B$.

Since momentum must be conserved, $p_i = p_f$. How much of that momentum belongs to the red cart? How much belongs to blue? Because it's effectively one object, what fraction of the mass belongs to red? That's the same fraction of the momentum that red will retain. What fraction of the mass belongs to blue? Same fraction of the momentum that blue will gain!

Now it's your turn to fill in the details!

A red cart is moving rightward with a momentum of $p_{Ri} = 60\frac{\text{kg·cm}}{\text{s}}$ when it collides with a blue cart that is initially at rest. The red cart has three times the mass of the blue cart. The two carts stick together and move to the right with the same speed after the collision. Enter the momentum values (in $\frac{\text{kg·cm}}{\text{s}}$) of each individual cart and of the system of two carts before and after the collision. Also indicate the change in momentum of each cart.

Cart	Before Collision	After Collision	Momentum Change
Red Cart: $m_R =$	$p_{Ri} =$	$p_{Rf} =$	$p_{Rf} - p_{Ri} =$
Blue Cart: $m_B =$	$p_{Bi} =$	$p_{Bf} =$	$p_{Bf} - p_{Bi} =$
System: $m =$	$p_i =$	$p_f =$	$\Delta p_R + \Delta p_B =$

8. What is the total system momentum p_i before the collision?
   - A) $p_i = 0\frac{\text{kg·cm}}{\text{s}}$
   - B) $p_i = 60\frac{\text{kg·cm}}{\text{s}}$
   - C) $p_i = 180\frac{\text{kg·cm}}{\text{s}}$
   - D) $p_i = 240\frac{\text{kg·cm}}{\text{s}}$

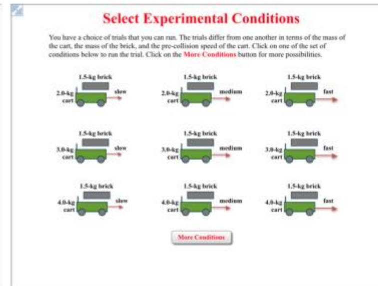
9. What is the momentum of the **red** cart p_{Rf} after the collision?
   - A) $p_{Rf} = 0\frac{\text{kg·cm}}{\text{s}}$
   - B) $p_{Rf} = 15\frac{\text{kg·cm}}{\text{s}}$
   - C) $p_{Rf} = 30\frac{\text{kg·cm}}{\text{s}}$
   - D) $p_{Rf} = 45\frac{\text{kg·cm}}{\text{s}}$
   - E) $p_{Rf} = 60\frac{\text{kg·cm}}{\text{s}}$
   - F) $p_{Rf} = 120\frac{\text{kg·cm}}{\text{s}}$
   - G) $p_{Rf} = 180\frac{\text{kg·cm}}{\text{s}}$
   - H) $p_{Rf} = 240\frac{\text{kg·cm}}{\text{s}}$

10. What is the momentum of the **blue** cart p_{Bf} after the collision?
   - A) $p_{Bf} = 0\frac{\text{kg·ccm}}{\text{s}}$
   - B) $p_{Bf} = 15\frac{\text{kg·m}}{\text{s}}$
   - C) $p_{Bf} = 30\frac{\text{kg·cm}}{\text{s}}$
   - D) $p_{Bf} = 45\frac{\text{kg·cm}}{\text{s}}$
   - E) $p_{Bf} = 60\frac{\text{kg·cm}}{\text{s}}$
   - F) $p_{Bf} = 120\frac{\text{kg·cm}}{\text{s}}$
   - G) $p_{Bf} = 180\frac{\text{kg·cm}}{\text{s}}$
   - H) $p_{Bf} = 240\frac{\text{kg·cm}}{\text{s}}$

11. How much momentum does the **system** gain as a result of the collision?
   - A) $\Delta p = 0\frac{\text{kg·cm}}{\text{s}}$
   - B) $\Delta p = 15\frac{\text{kg·cm}}{\text{s}}$
   - C) $\Delta p = 30\frac{\text{kg·cm}}{\text{s}}$
   - D) $\Delta p = 45\frac{\text{kg·cm}}{\text{s}}$
   - E) $\Delta p = 60\frac{\text{kg·cm}}{\text{s}}$
   - F) $\Delta p = 120\frac{\text{kg·cm}}{\text{s}}$
   - G) $\Delta p = 180\frac{\text{kg·cm}}{\text{s}}$
   - H) $\Delta p = 240\frac{\text{kg·cm}}{\text{s}}$

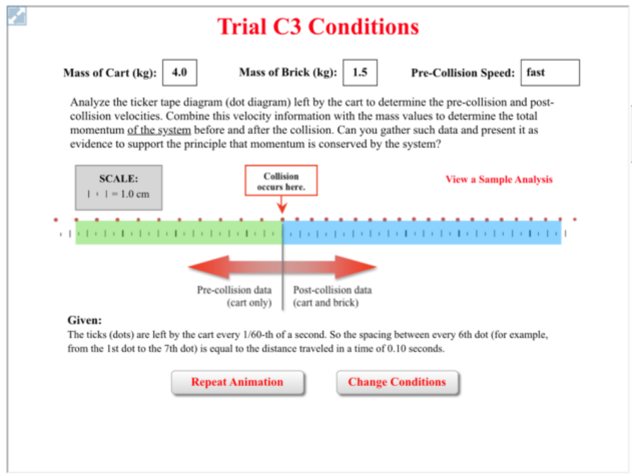
Now let's analyze a collision for which we have to collect the data. Return to your browser window and launch The Cart and The Brick interactive. This is a little different, because we're going to view a simulated experiment, take some data, and analyze it!

Click BEGIN ACTIVITY to get to SELECT EXPERIMENTAL CONDITIONS. Choose the center option: the 4.0kg cart (traveling at fast speed) with a 1.5kg brick. This is TRIAL C3.



12. Watch the animation. The cart is traveling forward with a constant speed when a brick lands right on top of it. What happens to the velocity of the cart + brick system after the collision?
    - A) The speed of the system decreases, still moving in the forward direction.
    - B) The speed of the system increases, still moving in the forward direction.
    - C) The speed of the system does not change. Dropping the brick has no effect.
    - D) The direction of motion is reversed, and the cart + brick system speeds up.
    - E) The direction of motion is reversed, and the cart + brick system slows down.

Click on ANALYZE DATA. Spend a minute examining how you are going to be able to measure the speed of the cart before the collision, and the speed of the cart + brick system after the collision. On the figure to the right, notice the green and blue highlighting. To calculate the velocity, you'll need to know how far the cart travels, Δx, and how much time it takes, Δt. The major tick marks on the ruler are 1.0cm apart, and each dot is separated by $1/60^{\text{th}}$ of a second.



13. How far does the cart travel before the collision? Measure Δx_i from the second dot (because the first dot is not on the ruler) to the instant of collision.
    - A) $\Delta x_i = 5.75\text{cm}$
    - B) $\Delta x_i = 10\text{cm}$
    - C) $\Delta x_i = 11.75\text{cm}$
    - D) $\Delta x_i = 23.5\text{cm}$
14. How much time Δt_i does this take?
    - A) $\Delta t_i = \left(\frac{1}{60}\right) = 0.017\text{s}$
    - B) $\Delta t_i = \left(\frac{10}{60}\right) = 0.17\text{s}$
    - C) $\Delta t_i = 6\text{s}$
    - D) $\Delta t_i = 10\text{s}$
15. What is the initial velocity v_i of the cart before the collision?
    - A) $v_i = 1.7\frac{\text{cm}}{\text{s}}$
    - B) $v_i = 2.3\frac{\text{cm}}{\text{s}}$
    - C) $v_i = 57.5\frac{\text{cm}}{\text{s}}$
    - D) $v_i = 69\frac{\text{cm}}{\text{s}}$
16. What is the initial momentum p_i of the cart?
    - A) $p_i = 9.2\frac{\text{kg}\cdot\text{cm}}{\text{s}}$
    - B) $p_i = 230\frac{\text{kg}\cdot\text{cm}}{\text{s}}$
    - C) $p_i = 276\frac{\text{kg}\cdot\text{cm}}{\text{s}}$
    - D) $p_i = 379\frac{\text{kg}\cdot\text{cm}}{\text{s}}$
17. How far does the cart + brick travel after the collision? Measure Δx_f from the instant of collision to the next-to-last last dot (because the last dot is not on the ruler).
    - A) $\Delta x_f = 11.75\text{cm}$
    - B) $\Delta x_f = 15.75\text{cm}$
    - C) $\Delta x_f = 19\text{cm}$
    - D) $\Delta x_f = 31.5\text{cm}$
18. How much time Δt_f does this take?
    - A) $\Delta t_f = 0.088\text{s}$
    - B) $\Delta t_f = 0.32\text{s}$
    - C) $\Delta t_f = 11.4\text{s}$
    - D) $\Delta t_f = 19\text{s}$
19. What is the final velocity v_f of the cart after the collision?
    - A) $v_f = 1.7\frac{\text{cm}}{\text{s}}$
    - B) $v_f = 2.3\frac{\text{cm}}{\text{s}}$
    - C) $v_f = 49\frac{\text{cm}}{\text{s}}$
    - D) $v_f = 69\frac{\text{cm}}{\text{s}}$
20. What is the final momentum p_f of the cart + brick system?
    - A) $p_f = 10\frac{\text{kg}\cdot\text{cm}}{\text{s}}$
    - B) $p_f = 196\frac{\text{kg}\cdot\text{cm}}{\text{s}}$
    - C) $p_f = 270\frac{\text{kg}\cdot\text{cm}}{\text{s}}$
    - D) $p_f = 276\frac{\text{kg}\cdot\text{cm}}{\text{s}}$
21. According to your calculations, does the system conserve momentum?
    - A) Of course it does. Conservation of momentum is a physical law, so the initial momentum and final momentum are identical.
    - B) Not even close. The difference between the initial and final momentum is large enough to disprove momentum conservation.
    - C) Mostly. The values are not identical, but the discrepancy can be explained by the uncertainties in the measurements; neither of the distance measurements land exactly on a tick mark, so both distances had to be estimated.
22. If you performed this experiment in the lab, how could you improve your measurements?
    - A) LOL. If we really had to do this, there's no way to make it better. The results would always be off because of human error.
    - B) LOL, if you're afraid of 'human error,' you should repeat the experiment! Multiple trials will let you calculate an average, which will diminish the effects of random error and improve your accuracy.
    - C) It would be pretty easy to improve the precision of the measurements! Any common meter stick would have a more precise scale: 1/10cm instead of 1/2cm. And any common digital stopwatch would be able to measure to 1/100s.
    - D) Both B) and C) are pretty good ideas. By implementing both, you will improve both the precision *and* accuracy of your results!