Physics 200 (Stapleton) Name: ____________________ ①

Chapter 8: Momentum/Impulse/Collisions

Notes - 8.1 Linear Momentum and Force

1. Write the symbol and equation for momentum.

2. Why is the symbol for momentum a lowercase p?

3. What are the units for momentum?

4. Calculate the momentum of a 110-kg football player running at 8.00 m/s.

Notes - 8.2 Impulse

5. Use Newton's 2nd Law and the momentum formula to write an equation for Δp in terms of Force and time.

6. $F_{net}\,\Delta t$ (more commonly written as Ft) is called ________________.

7. Impulse is equivalent to a change in ______________________.

8. Imagine a ball falling to the floor and then bouncing upward to a height of 40cm. Now imagine someone throwing the same ball upward a height of 40cm. In which case is a greater impulse applied to the ball? Why?

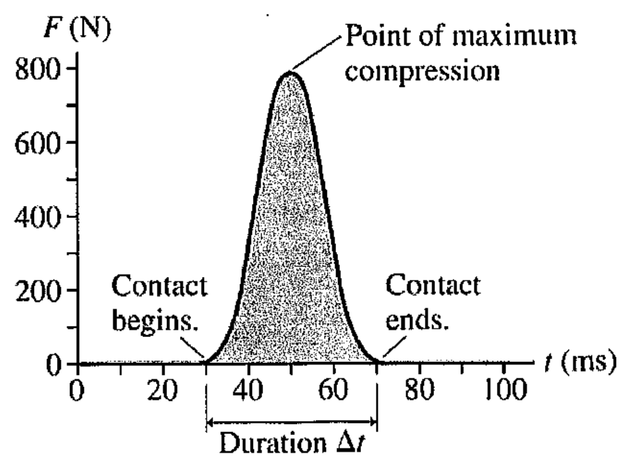
9. The effect of a force on an object depends on the force's ____________________ and ____________________. A very large force acting for a short time will have a great effect on the momentum of a tennis ball. A small force could cause the same change in momentum, but it would have to act for a ____________________. Quantitatively, the effect we are talking about is the change in ____________________.

10. Use the impulse formula to show how the same change in momentum can be accomplished by a variety of forces and times.

11. **Example Problem:** Suppose a 60kg human is falling from the sky at a rate of 20m/s. If the human is brought to a stop by hitting the bare ground, the average force applied to the person during impact is 24,000N. What is the duration over which the impact force is applied?

12. Name a few ways in which an understanding of impulse can save lives:

13. What does the area under a force-time graph represent?



Notes - 8.3 Conservation of Momentum

14. Conservation of momentum formula for 2 objects in an isolated (closed) system…

15. An isolated system is defined to be one in which the net force acting on the system = _____.

16. For an entire isolated system, since $F_{net}\,\Delta t = \Delta p$, when $F_{net} = 0$ then $\Delta\, p_{Tot}$ = __________ (i.e. the total momentum is constant).

17. **Example Problem:** A 3kg object has a velocity of 2m/s before it crashes into a second object that has been traveling with a velocity of -5m/s. After the collision, the 3kg object has a velocity of 1m/s, and the other object has a velocity of 2m/s. What is the mass of the second object?

Notes - 8.4 & 8.5 Elastic and Inelastic Collisions

18. How are elastic and inelastic collisions defined?

19. When a collision is **inelastic** (not elastic), where does the "lost" kinetic energy go?

20. Give some examples of nearly elastic collisions between macroscopic objects.

21. When collisions are perfectly elastic, both momentum and KE are conserved, so one can use a system of 2 equations to find two unknowns when two objects collide (e.g. when objects with known masses, and initial velocities collide, we can find both final velocities). One equation comes from conservation of momentum. The other comes from conservation of KE. However, the math can get ugly. An alternative is to solve problems using the coefficient of restitution...

Coefficient of Restitution: a number from zero to one that tells how elastic a collision is; a ratio of the separation speed of objects after a collision to their approach (or "closing") speed before the collision.

Coefficient of Restitution = $\frac{Separation\ Speed}{Closing\ speed}$

When e =1...

- objects separate as fast as they came together
- collision is **perfectly elastic.**
- No kinetic energy is lost.
- Example: A perfectly bouncy ball approaches the ground at 2m/s (closing speed) and then bounces back up with a speed of 2m/s (separation speed). e = 2/2 = 1

When e=0...

- objects do not separate
- the collision is **perfectly inelastic.**
- Kinetic energy is lost to friction.
- Example: a bullet approaches a ballistic pendulum at 500m/s (closing speed) and the bullet and pendulum then swing upward together (separation speed = 0; no separation). e =0/2

When 1>e>0, objects separate, but not as fast as they came together. Some energy is lost to friction.

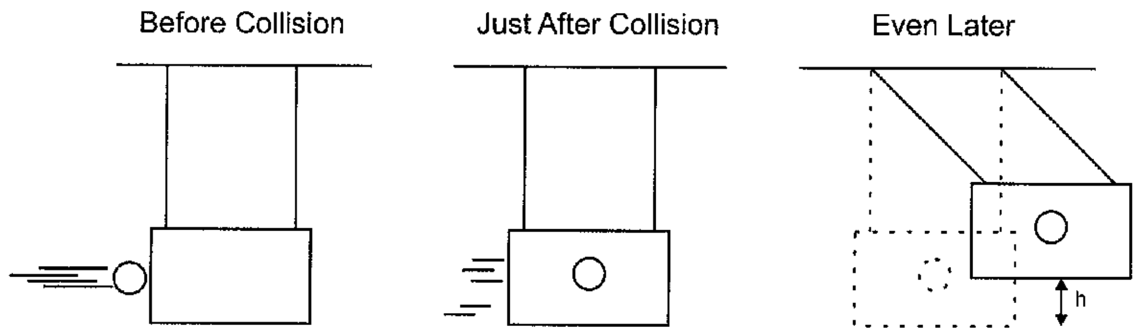
Coefficient of Restitution Formula = $e = \frac{V_b' - V_a'}{V_a - V_b}$ ...where Va = initial velocity of object A, Vb = initial velocity of object B, and Va' and Vb' = their final velocities.

When e=1, $V_b' - V_a' = V_a - V_b$

22. Example Problem: Cart A has a mass of 4kg and an initial velocity of -2m/s. Cart B has a mass of 3kg and an initial velocity of 0m/s. If the carts collide with perfect elasticity (e=1), what are the carts' velocities after the collision?

Ballistic Pendulums

Consider the system below, which includes a ballistic pendulum (target/box) and a projectile (circle). Assume that the string supports of the pendulum have negligible friction, that air resistance is also negligible, and that the projectile does not drop significantly before it hits the pendulum...

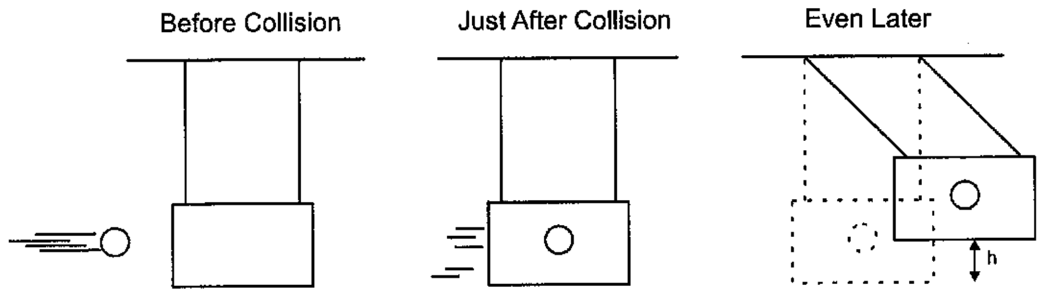


...when is momentum conserved? Why?

...when is momentum <u>not</u> conserved? Why?

...when is KE conserved? Why?

...when is KE <u>not</u> conserved? Why?



	Launch 1	Launch 2	Your Launch
Projectile Mass (kg)	0.01	0.5	
Pendulum Mass (kg)	1	0.02	
Swing Height, "h" (m)	0.5	0.4	
Projectile Initial Velocity (m/s)			

As a class, answers the following questions using "launch 1" data. Complete the rest on your own.

1. What is the total potential energy of the ball and pendulum in the "even later" picture?

2. What was the total kinetic energy of the ball and pendulum in the "just after" picture?

3. What was the shared velocity of the ball and pendulum in the "just after" picture?

4. What was the net momentum of the ball and pendulum in the "just after" picture?

5. What was the momentum of the ball before the collision?

6. What was the velocity of the ball before the collision?

7. Is this an elastic or inelastic collision? How can you tell?

Momentum and Impulse problems

7

1. What is the magnitude of the momentum of a 28-g sparrow flying with a speed of 8.4 m/s?

2. A constant friction force of 25 N acts on a 65-kg skier for 20s. What is the skier's change in velocity?

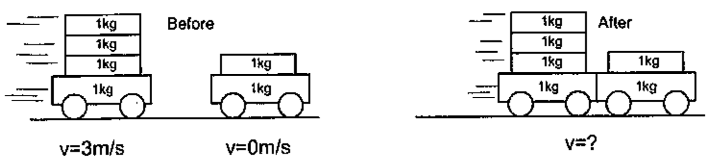
3. A 0.145-kg baseball pitched at 39.0 m/s is hit in a horizontal line drive straight back toward the pitcher at 52.0 m/s. If the contact time between bat and ball is 3.00×10^{-3}s, calculate the average force between the ball and bat during contact.

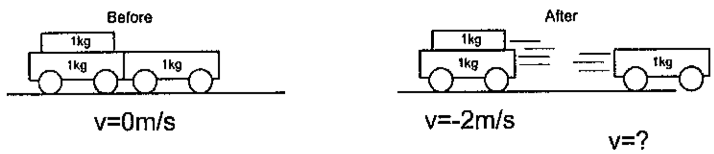
4. Calculate the force of a rocket's thrust, given that the propelling gases are expelled at a rate of 1500 kg/s with a speed of 4.00×10^{4}m/s (at the moment of takeoff). The force on the gas can be found from its change in momentum.

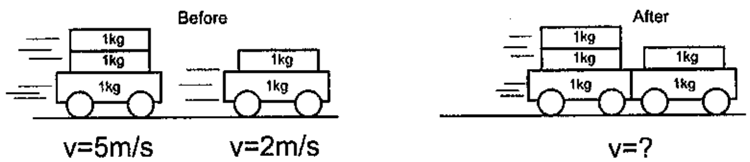
5. A golf ball of mass 0.045 kg is hit off of a tee at a speed of $45\,\text{m/s}$. The golf club was in contact with the ball for 3.5×10^{-3} s. Find (*a*) the impulse imparted to the golf ball, and (*b*) the average force exerted on the ball by the golf club.

6. You are the design engineer in charge of the crashworthiness of new automobile models. Cars are tested by smashing them into fixed, massive barriers at $50\,\text{km/h}$ (30 mph). A new model of mass 1500 kg takes 0.15 s from the time of impact until it is brought to rest. (*a*) Calculate the average force exerted on the car by the barrier. (*b*) Calculate the average deceleration of the car.

Conservation of Momentum – Basic Problems

7. 

8. 

9. 

10. A child in a boat throws a 6.40 kg package out of the boat horizontally with a speed of 10.0 m/s. Calculate the velocity of the boat immediately after, assuming that it was initially at rest. The mass of the child is 26.0 kg, and that of the boat is 45.0 kg. Ignore water resistance.

11. A 12,600-kg railroad car travels alone on a level frictionless track with a constant speed of 18.0m/s. A 5350-kg load, initially at rest, is dropped onto the car. What will be the car's new speed?

12. A 3800 kg open railroad car coasts along level tracks with a constant speed of 8.60 m/s. Snow begins to fall vertically and fills the car at a rate of 3.50 kg/min. Ignoring friction with tracks, what is the speed of the car after 90 min?

<u>Elastic/Inelastic Collision Problems (Conservation of Momentum and, possibly Conservation of KE)</u>

13. Boat A has a mass of 10kg and a velocity of 3m/s. Boat B has a mass of 15kg and a velocity of -1m/s. The two boats collide and bounce away from one another. The collision lasts for 0.1 second, and after the bounce, boat B has a velocity of 1.4m/s.

a. What is the velocity of boat A after the bounce?

b. What impulse is experienced by boat A during the collision?

c. What impact force is felt by boat A?

d. What impulse is experienced by boat B?

e. What impact force is felt by boat B?

f. What is the coefficient of restitution for this collision?

g. Is this collision elastic or inelastic? Explain.

14. A softball of mass 0.220 kg that is moving with a speed of 8.5 m/s collides head-on and with another ball initially at rest. The <u>collision is perfectly elastic</u>. Afterward the incoming softball bounces backward with a speed of 3.7 m/s. Calculate (*a*) the velocity of the target ball after the collision, and (*b*) the mass of the target ball.

15. Two bumper cars in an amusement park ride collide with perfect elasticity as one approaches the other directly from the rear (Fig. 7–34). Car A has a mass of 450 kg and car B 550 kg, owing to differences in passenger mass. If the velocities of car A and Car B before the collision are $4.50\ m/s$ and $3.70\ m/s$, respectively,

calculate their velocities after the collision.

Conceptual Questions

16. Use one of Newton's Laws to prove that momentum must be conserved for ALL collisions, regardless of whether they are elastic or not.

17. A Superball is dropped from a height **h** onto a hard steel plate (fixed to the Earth), from which it rebounds at very nearly its original speed. (a) If the ball alone is considered to be "the system," is the momentum of the ball conserved during any part of this process? If so, when is its momentum conserved? (b) If we consider the ball and Earth as our system, during what parts of the process is momentum conserved? Explain.

Ballistic Pendulum – Conservation of Momentum and Conservation of Mechanical Energy

18. A 0.2kg projectile is fired at a 1kg ballistic pendulum. After the projectile embeds in the target, the pendulum and projectile swing upward a height of 0.4m. What was the initial velocity of the projectile (just before it hit the pendulum)?

Answers:

1. 0.235kgm/s	2. 7.69m/s	3. 4,398N	4. 6.0×10^7N	5. 2.025kgm/s, 579N	6. 139,000N, 93m/s^2	
7. 2m/	8. 4m/s	9. 3.8m/s	10. -0.901m/s	11. 12.6m/s	12. 7.9m/s	
13a. -0.6m/s	13b. -36kgm/s	13c. -360N	13d. 36kgm/s	13e. 360N	13f. 0.5	
13g. Inelastic because KE is lost		14. 4.8m/s, 0.56kg	15. 3.62m/s	16. See solutions	17. See solutions	18. 16.8m/s

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Collisions – Force, Impulse, and Coefficient of Restitution

In this activity you will compare two collisions between a dynamics cart and a force meter. In one case, the collision will be cushioned by the spring end of the cart. In the other, the rigid end of the cart will contact the force meter directly. You will use Logger Pro tools to measure maximum forces and impulse for both types of collision. You will also collect acceleration distance data and use those data to calculate the coefficient of restitution for each collision type.

1. Collect the necessary data to complete the table below.
2. Measure closing and separation distances from the force sensor to the nearest part of the cart (either flat edge or plunger tip, depending on the trial). *[Closing distance = distance traveled on the approach to the sensor; separation distance = distance traveled away from the sensor.]*
3. Keep the ramp slope constant for all trials, and keep the ramp firmly clamped in position.
4. Keep the closing distance constant for all trials (<u>i.e.</u> release the bottommost point on the cart from the same position each time).
5. Use the closing distance and the average separation distance to calculate the average coefficient of restitution.

<u>Collision Type I. Flat end of cart faces the force probe</u>

Trial	Max Force (N)	Impulse (N·s)	Linear Closing distance (cm)	Linear Separation Distance (cm)	Coefficient of Restitution
1					
2					
3					
Avg.					

<u>Collision Type II. Spring end of cart faces the force probe</u>

Trial	Max Force (N)	Impulse (N·s)	Linear Closing distance (cm)	Linear Separation Distance (cm)	Coefficient of Restitution
1					
2					
3					
Avg.					

II Questions:

A. How do the maximum forces for each collision type compare? Why? Use the concept of impulse to explain the reason for the difference in maximum force.

B. How do the average impulses for the two collision types compare?

C. Do you think the relationship (from question B) that you observed between impulses in "springy" and "hard" collisions is correct? If so, explain why. If not, explain what the relationship should have been, and explain why.

D. Explain how and why the concepts of coefficient of restitution and impulse are closely related to one another in this activity.

E. If you decreased the slope of the ramp slightly, what effects would you expect to see on maximum force, impulse, and coefficient of restitution?

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2017-2018 Test: Momentum and Impulse

Multiple Choice:

1. The momentum of an object is not directly proportional to its
   A. Velocity B. Mass x Velocity C. Kinetic Energy D. Mass

2. The change in an object's momentum is equal to
   A. its average acceleration
   B. the force applied to the object
   C. its velocity multiplied by the applied force
   D. the impulse imparted to the object
   E. Work done on the object

3. The correct units for momentum are:
   a. kgm/s b. Nm/s c. kgm/s² d. Nm/s²

4-6. Three eggs of equal mass are thrown with the same horizontal velocity at three different walls. The walls are identical in every aspect except for their hardness. The first egg splatters against a hard wall and comes to a stop. The second egg hits a soft wall and comes to a stop without splattering. The third egg bounces backward off of a springy wall.

4. Compared to the first egg (hard wall), the second egg (soft wall) experiences...
   a. Greater force and the same impulse
   b. Less force and the same impulse
   c. Greater force and greater impulse
   d. Less force and greater impulse
   e. Same force and impulse

5. Which egg experiences the greatest change in momentum?
   A. First egg B. Second egg C. Third egg D. None of them

6. Now consider the walls in number 4. Which wall is most likely to be knocked over by the egg impact?
   a. Hard wall b. Soft wall c. Springy wall d. None of them

7. *(Not a great test question, but a fine practice test question)* The Law of Conservation of Momentum is most directly supported by:
   a. Newton's 1st Law (Objects in motion remain in motion...)
   b. Newton's 2nd Law (F=ma)
   c. Newton's 3rd Law (For every action, there is an equal and opposite reaction...)
   d. Newton's law of Gravitation ($F = G\frac{m_1 m_2}{r^2}$)

8. A motionless mass M suddenly explodes breaking apart into two separately moving pieces. The first piece has a mass of $\frac{1}{3}M$ and second piece has a mass of $\frac{2}{3}M$. After the explosion, if the velocity of the first piece is -V, what is the velocity of the second piece?
   A. V/2 B. V/3 C. V D. 2V E. 3V

9. A 1kg ball is dropped to the ground. It hits the ground with a velocity of -6m/s and bounces back up with a velocity of +4m/s. What impulse was imparted to the ball?
   A. -2kgm/s B. 4 kgm/s C. -6kgm/s D. 10kgm/s E. 24kgm/s

10. A 1,200-kilogram car traveling at 30 meters per second hits a huge pile of cardboard boxes and is brought to rest in 6 seconds. What is the magnitude of the average force acting on the car to bring it to rest?
    A. 6×10^2 N B. 6×10^3 N C. 6×10^4 N D. 6×10^5 N E. 6×10^6 N

Formulas:

$p = mv$ $F\Delta t = \Delta p$ $P_i = P_f$ $m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$

$e = \frac{v_B' - v_A'}{v_A - v_B}$ $PE = mgh$ $KE = \frac{1}{2}mv^2$ $PE_0 + KE_0 = PE_f + KE_f$

Problems:

1. A 1,000kg car is traveling at a speed of 25m/s. When the brakes are applied the car is brought to a stop by a constant 800N force.

   a. What is the momentum of the car before the brakes are applied?

   b. How many seconds does it take for the brakes to stop the car?

2. A golf ball of mass 0.045 kg is hit off the tee at a speed of 45 m/s. The golf club was in contact with the ball for 3.5×10^{-3} s.

   a. What is the impulse imparted to the golf ball?

   b. What is the average force exerted on the ball by the golf club?

3. A piece of putty with a mass of 0.24kg velocity of 15m/s collides with a second piece of putty that is moving with a velocity of -28m/s. After the collision, the two pieces of putty stick together and travel with a shared velocity of -4m/s. What is the mass of the second piece of putty?

4. A 0.15kg projectile is fired into a 2.0kg ballistic pendulum. The projectile embeds in the pendulum and then the pendulum + projectile swing upward to a height (h) of 0.3m before stopping.

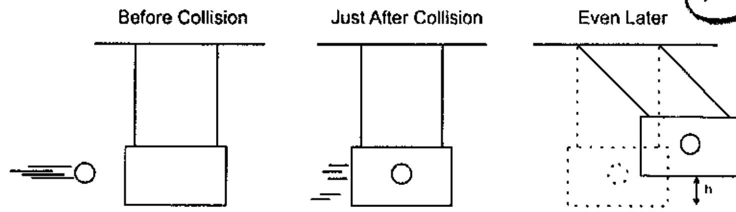

Fig. 1 Fig. 2 Fig. 3

a. What is the shared velocity of the pendulum + the projectile just after impact, as they begin the swing (as in figure 2)?

b. What is the velocity of the projectile before it hits the pendulum (as in figure 1)?

5. In a game of bocce, large spheres (3.0 kg) are thrown at a small, motionless target called the pallino (1.0 kg). Suppose a large ball has a speed of 2.0 m/s and collides, head-on, with the pallino. If the collision has a coefficient of restitution of e = 0.7, find the speed of the pallino and the speed of the large ball after the collision.