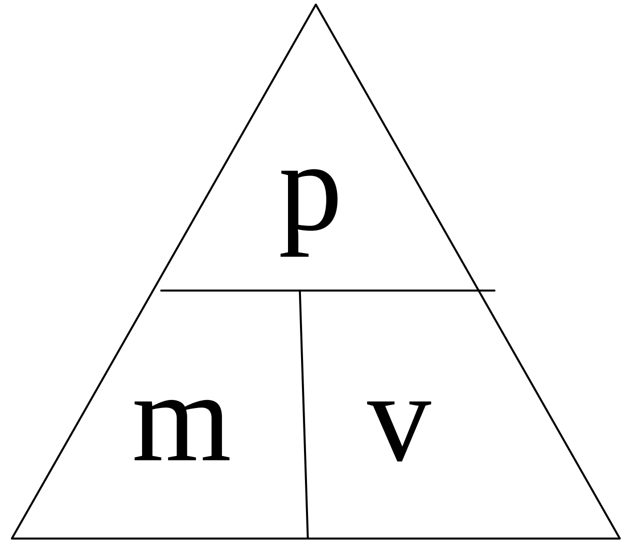
Unit: Momentum – Impulse
Vocabulary - Key

Term	Definition
Momentum **Units: Kg·m/s**	The mass of an object multiplied by its speed or velocity.
Impulse **Units: N·s**	The product of force x time that causes a change in momentum.
Impulse-Momentum	The impulse experienced by an object equals the change in momentum of the object.
Law of conservation of momentum	In the absence of external forces, the total momentum of a system remains constant.
Collision	Occurs when two or more objects hit each other.
Elastic	Occurs when objects collide so that the total kinetic energy remains the same before and after the collision; involves objects “bouncing” off each other.
Inelastic	A type of collision where the total kinetic energy after the collision is less than it was before the collision; usually involves objects sticking together.

Momentum

Inertia in motion.

The mass of an object multiplied by is speed.



Symbols:

p means momentum

m means mass

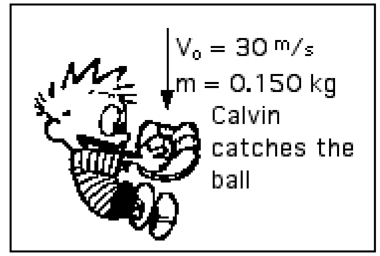
v means velocity

Formulas

If I want to find:	Then I need to know:	My formula will be:	My unit will be:
momentum	**Mass & velocity**	**p=mv**	**kg·m/s**
Mass	**Momentum & Velocity**	**m=p/v**	**Kg**
Velocity	**Momentum & Mass**	**v=p/v**	**m/s**

Class Work

1. Calculate the momentum of a 0.150-kg ball travelling at 30 m/s.

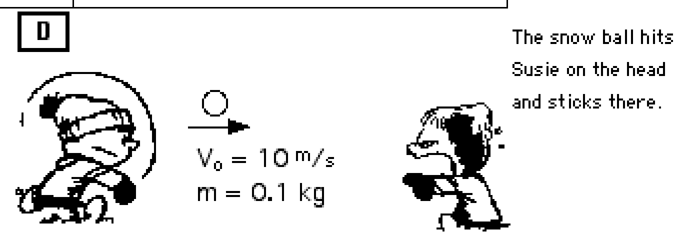


Looking For	Given	Relationship	Solution
Momentum	**m=0.150 kg v=30 m/s**	**p=mv**	**(0.150 kg) x (30 m/s) = 4.5 kg m/s**

2. Calculate the momentum of a 0.150-kg ball after Calvin throws the ball at 20 m/s.

Looking For	Given	Relationship	Solution
Momentum	**m=0.150 kg v=20 m/s**	**p=mv**	**(0.150 kg) x (20 m/s) =3 kg m/s**

3. Calculate the momentum of a 0.1-kg snowball that Calvin throws at 10 m/s at Susie.



Looking For	Given	Relationship	Solution
Momentum	**m=0.10 kg v=10 m/s**	**p=mv**	**(0.1 kg) x (10 m/s) =1 kg m/s**

4. A beach ball is rolling in a straight line toward you at a speed of 0.5 m/sec. Its momentum is 0.25 kg·m/sec. What is the mass of the beach ball?

Looking For	Given	Relationship	Solution
Mass	**v=0.5 m/s p=0.25 kg m/s**	**m=p/v**	**(0.25 kg m/s) / 0.5 m/s =0.5 kg**

Group Work

1. Determine the momentum of a ...

a. 60-kg halfback moving eastward at 9 m/s.

Looking For	Given	Relationship	Solution
Momentum	**m=60 kg** **v= 9 m/s East**	**p=mv**	**(60 kg) x (9 m/s)** **=540 kg m/s East**

b. 1000-kg car moving northward at 20 m/s.

Looking For	Given	Relationship	Solution
Momentum	**m=1000 kg** **v= 20 m/s North**	**p=mv**	**(1000 kg) x (20 m/s)** **=20,000 kg m/s North**

c. 40-kg freshman moving southward at 2 m/s.

Looking For	Given	Relationship	Solution
Momentum	**m=40 kg** **v=2 m/s South**	**p=mv**	**(40 kg) x (2 m/s)** **=80 kg m/s South**

d. 110 kg football player running at 8 m/s forward.

Looking For	Given	Relationship	Solution
Momentum	**m=110 kg** **v=8 m/s**	**p=mv**	**(110 kg) x (8 m/s)** **=880 kg m/s Forward**

2. A car possesses 20,000 units of momentum. Lets say the car has a mass of 10,000 kg and is traveling with a velocity of 2 m/s. What would be the car's new momentum if…

a. its velocity were doubled. Thus, what affect does doubling the velocity have on momentum?

Looking For	Given	Relationship	Solution
Momentum	**V_1= 2 m/s** **V_2= 4 m/s** **m = 10,000 kg**	**p=mv**	**P = 40,000 kg m/s** **Causes P to double**

b. its velocity were tripled. Thus, what affect does tripling the velocity have on momentum?

Looking For	Given	Relationship	Solution
Momentum	**V_1= 2 m/s** **V_2= 6 m/s** **m = 10,000 kg**	**p=mv**	**P = 60,000 kg m/s** **Causes P to triple**

c. its mass were doubled. Thus, what affect does doubling the mass have on momentum?

Looking For	Given	Relationship	Solution
Momentum	**m_1= 10,000 kg** **m_2= 20,000 kg** **v = 2 m/s**	**p=mv**	**P = 40,000 kg m/s** **Causes P to double**

d. both its velocity were doubled and its mass were doubled.

Looking For	Given	Relationship	Solution
Momentum	**m_1= 10,000 kg** **v_1= 2 m/s** **m_2= 20,000 kg** **v_2 = 4 m/s**	**p=mv**	**P = 80,000 kg m/s** **Causes P to quadruple**

HomeWork

1. A cement truck full of cement has a mass of 42,000 kg. It travels north at a speed of 18 m/s.
   a. Calculate the truck's momentum.

Looking For	Given	Relationship	Solution
Momentum	**m=42,000 kg v=18 m/s**	**p=mv**	**(42,000 kg) x (18 m/s) =756,000 kg m/s**

   b. How fast must a 750 kg Chevy travel to have the same momentum?

Looking For	Given	Relationship	Solution
Velocity	**M = 750 kg p = 756,000 kg m/s**	**V = p/m**	**(756,000 kg m/s) / (750 kg) =1,008 m/s**

2. Compare momentum of the 110 kg football player running at 8 m/s with that of a hard-thrown .410 kg football that has a speed of 25 m/s.

Looking For	Given	Relationship	Solution
Momentum	**m=110 kg v=8 m/s**	**p=mv**	**(110 kg) x (8 m/s) =880 m/s**
Looking For	Given	Relationship	Solution
Momentum	**m=0.410 kg v=25 m/s**	**p=mv**	**(0.410 kg) x (25 m/s) =10.25 kg m/s**

Impulse-Momentum

definition

The impulse experienced by an object equals the change in momentum of the object.

formula

$Ft = m(v_2 - v_1)$

Or

$Ft = mv_2 - mv_1$

units

Kg•m/s

Or

N•s

Symbols:

F means force

t means time

m means mass

V_1 means initial velocity

V_2 means final velocity

Formulas

If I want to find:	Then I need to know:	My formula will be:	My unit will be:
Force	Time, mass & velocity	F = mv/t	Newtons
Time	Force, mass & velocity	t = mv/F	seconds
mass	Velocity, force & time	m = Ft/v	kilograms
velocity	Mass, force & time	v = Ft/m	meters/second

Important Idea

Increasing contact time will decrease the force.

Important Idea

The interaction will occur on the same mass.

Class Work

1. A 1000-kg car uses a braking force of 10,000 N to stop in 2 seconds.
   a. What impulse acts on the car?

Looking For	Given	Relationship	Solution
Impulse	**m=10000 kg F=10,000 N t-=2 s**	**Impulse=Ft**	**(10000 N) x (2 s) =20,000 N s**

   b. What is the change in momentum of the car?

Looking For	Given	Relationship	Solution
momentum	**Impulse = 20,000 N s**	**mv =Ft**	**20,000 N s**

2. A 2-kg ball is accelerated from rest to a speed of 8 m/s.
   a. What is the impulse?

Looking For	Given	Relationship	Solution
Impulse	**m=2 kg v=8 m/s**	**mv=Ft**	**(2 kg) x (8 m/s) =16 N s**

   b. What is the ball's momentum?

Looking For	Given	Relationship	Solution
Momentum	**Impulse = 16 kg m/s**	**mv = Ft**	**16 kg m/s**

3. An astronaut floating in space throws a 6-kg rock at 5 m/s.
   a. What is the impulse?

Looking For	Given	Relationship	Solution
Impulse	**m=6 kg v=5 m/s**	**mv = Ft**	**(6 kg) x (5 m/s) =30 N s**

   b. What is the rock's momentum?

Looking For	Given	Relationship	Solution
Momentum	**Impulse = 30 N s**	**mv = Ft**	**30 kg m/s**

Group Work

4. A 500-kg car uses a braking force of 15,000 N to stop in 5 seconds.
   a. What impulse acts on the car?

Looking For	Given	Relationship	Solution
Impulse	**m=500 kg** **t = 5 sec** **F = 15,000 N**	**mv = Ft**	**(15,000 N) x (5 s)** **=75,000 N s**

   b. Calculate the velocity of the car.

Looking For	Given	Relationship	Solution
Velocity	**m=500 kg** **t = 5 sec** **F = 15,000 N**	**mv = Ft**	**75,000 N s / 500 kg** **= 150**

5. A hockey player applies an average force of 80.0 N to a 0.25 kg hockey puck for a time of 0.10 seconds. (a) Determine the impulse experienced by the hockey puck.

Looking For	Given	Relationship	Solution
Impulse	**m=0.25 kg** **t=0.1s** **F=80 N**	**mv = Ft**	**=(80 N) x (0.1 s)** **=8 N s**

(b) Determine the velocity of the puck.

Looking For	Given	Relationship	Solution
Velocity	**m=0.25 kg** **t=0.1s** **F=80 N**	**mv = Ft**	**(0.25 kg)v=(80 N) x (0.1 s)** **v=32 m/s**

6. If a 5-kg object experiences a 10-N force for a duration of 0.1-second, then
   a. what is the momentum of the object?

Looking For	Given	Relationship	Solution
momentum	**m=5 kg F=10 N t=0.1 s**	**mv=Ft**	**(10 N) x (0.1 s) =1 N s**

   b. Calculate the velocity of the object.

Looking For	Given	Relationship	Solution
velocity	**m=5 kg t=0.1s F=10 N**	**mv = Ft**	**(5 kg)v = (10 N) x (0.1 s)** **v=0.2 m/s**

7. What is the average force exerted on a .140 kg baseball by a bat, given that the ball's initial velocity is 45 m/s, after a .0013 s impact?

Looking For	Given	Relationship	Solution
Force	**m=0.140 kg** **v=45 m/s** **t=0.0013**	**mv=Ft**	**(0.140 kg) x (45 m/s)=(0.0013 s)F** **F=4,846 N**

8. Calculate the velocity of a 110 kg football player who collides head on with a padded goalpost and experiences a force of 17600 N for 0.055s.

Looking For	Given	Relationship	Solution
velocity	**m=110 kg** **F=17,600 N** **t=0.055 s**	**mv=Ft**	**(110 kg) v = (17600 N) x (0.055s)** **v=8.8 m/s**

9. Rhonda, who has a mass of 60.0 kg, is riding at 25.0 m/s in her sports car when she must suddenly slam on the brakes to avoid hitting a dog crossing the road.
   a. She strikes the air bag, which brings her body to a stop in 0.400 s. What average force does the seat belt exert on her?

Looking For	Given	Relationship	Solution
Force	**m=60 kg** **v=25 m/s** **t=0.4**	**mv=Ft**	**(60 kg) x(25 m/s)=(0.4 s)F** **F=3750 N**

   b. If Rhonda had <u>not</u> been wearing her seat belt and not had an air bag, then the windshield would have stopped her head in 0.001 s. What average force would the windshield have exerted on her?

Looking For	Given	Relationship	Solution
Force	**m=60 kg** **v=25 m/s** **t=0.001**	**mv=Ft**	**(60 kg) x (25 m/s)=(0.001 s)F** **F=1,500,000 N**

10. What force is needed to stop a 1200 kg car in 20.0 s? The car is moving at 22.0 m/s.

Looking For	Given	Relationship	Solution
Force	**m=1200 kg** **v=22 m/s** **t=20 s**	**mv=Ft**	**(1200 kg) x (22 m/s)=(20 s)F** **F=1320 N**

Homework

11. A snowmobile has a mass of 250 kg. A constant force acts on it for 65.0 s. The snowmobile's speed is 22 m/s. What force causes this change?

Looking For	Given	Relationship	Solution
Force	**m=250 kg** **v=6 m/s** **t=65 s**	**mv=Ft**	**(250 kg) x (6 m/s)=(65 s)F** **F=23.07 N**

12. A 100-kg car moving at 20.0 m/s is acted upon by the brakes. The brakes apply a 650 N force until the car is slows down.
    a. What is the car's initial momentum?

Looking For	Given	Relationship	Solution
Momentum	**m=1000 kg** **v=20 m/s**	**P = mv**	**(1000 kg) x (20 m/s)** **=20,000 kg m/s**

    b. How much time is required for the brakes to slow the car?

Looking For	Given	Relationship	Solution
Time	**m=1000 kg** **v=20 m/s** **F=650 N**	**mv=Ft**	**(1000 kg) x (20 m/s) = (650N) t** **t=30.76 s**

13. Felix and Digby are into extreme adventures. They want to jump off a high bridge. And live to do it again sometime. They agree they should tie one end of a cord of some sort around their waist and attach the other end to the bridge. Felix says they should use a stretchy, rubber (bungee) cord. Digby says they should use a strong metal cable. Who's right and why?

    You need to use a stretchy bungee cord so that it slows down the impact over a period of time, causing a decrease in force. If it was all done at once, it would be a very high force!

14. What is the "physics reason" for padding dashboards?

    To increase the time of the collision which will cause a decrease in the amount of force exerted.

Car Crash Safety
Physics

Stopping in an Accident

When a car crashes to a stop, its momentum drops to zero. **The shorter the amount of stopping time, the larger the force on the car.**

Car bodies are designed to crumple in an accident to **extend (increase)** the stopping time. The ideal car crumples enough to stop gradually but not so much that the passenger compartment is affected.

Seat belts (Inertial Restraints)

The stopping time of a car in a collision is very short even when crumpling occurs. A passenger without a seat belt will have a momentum that drops from very large value to zero when hitting the windshield, the steering wheel, or dashboard. Seat belts are made of a very strong fabric that stretches slightly when a force is applied. **Stretching extends the time** over which the passenger comes to a stop and results in **less** force being exerted on the person's body.

Air Bags

Air bags work together with seat belts to make cars safer. An air bag inflates when the force applied to the front of a car reaches a dangerous level. The air bag deflates slowly as the person's body applies a force to the bag upon impact. The force of impact from the body pushes the air out of small holes in the air bag, bringing the person to a gradual stop.

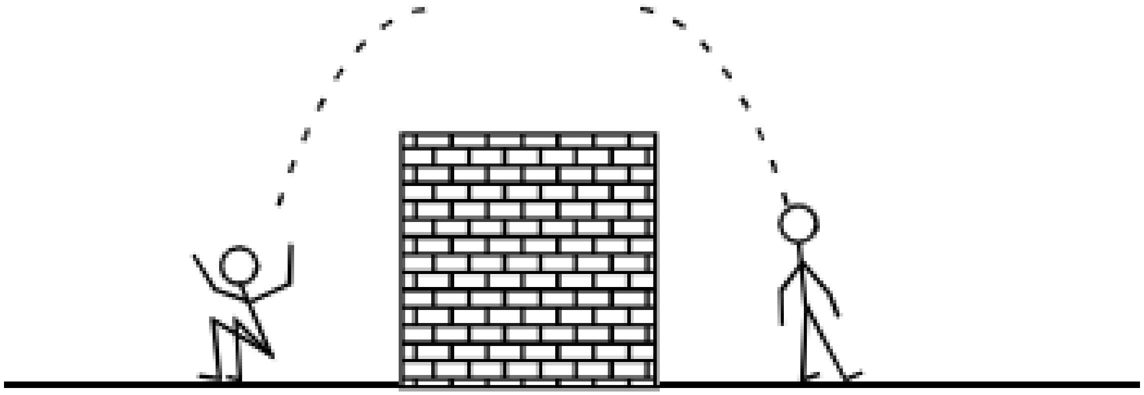
Crash Test Dummies

Automakers use crash test dummies to study the effects of collisions on passengers. Crash test dummies contain electronic sensors to measure the forces felt in various places on the body.

15. How do airbags and seatbelts work?

Airbags allow a person to stop moving after an impact over a period of time instead of instantly. This causes the force of the Impulse to be smaller. Seatbelts work in conjunction with the airbags for safety.

16. When you jump off something is it better to flex your legs when landing (bending at the knees) OR keep your legs straight (locking your knees)? Explain.



You should bend your knees so you come to a stop over a greater period of time instead of all at once. This will cause less force to be exerted on your body.

Collisions
Physics

A **collision** occurs when two or more objects hit each other.

Elastic Collisions

When an **elastic collision** occurs, objects **bounce** off each other with no loss in the total kinetic energy of the system. The collision between billiard balls is very close to a perfectly elastic collision.

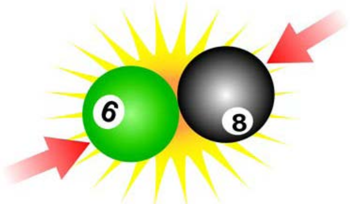
Inelastic Collisions

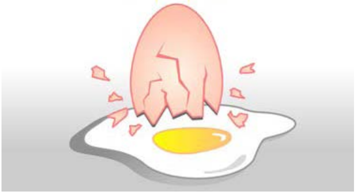
In an **inelastic collision** objects change shape or **stick** together. (An egg dropped on the floor)

Perfectly Elastic Collisions

When two billiard balls collide, it looks like they bounce without a loss of kinetic energy. But the sound of the collision tells you a small amount of kinetic energy is being changed into sound energy.

Perfectly elastic collisions *do* occur on a smaller scale. The collision between two individual atoms in the air is an example of a perfectly elastic collision.
No kinetic energy is transformed into heat or sound.
These collisions are responsible for the pressure that keeps a balloon inflated.





Conservation of Momentum

As long as there are no outside forces (such as friction), momentum is conserved in both elastic and inelastic collisions. This is true even when kinetic energy is not conserved.

Conservation of momentum makes it possible to determine the motion of objects before or after colliding.

Forces in Collisions

Collisions create forces because the colliding objects change their motion.
Momentum conservation can be used to estimate the forces in a collision.
Engineers need to know the forces so they can design things not to break when they are dropped.

A rubber ball and a clay ball are dropped on a gymnasium floor. The rubber ball has an **elastic collision** and bounces back up with the same speed it had when it hit the floor. The clay ball has an **inelastic collision** hitting the floor with a thud and staying there. Both balls have the same mass and are dropped from the same height. They have the same speed as they hit the floor. Which ball exerts a greater force on the floor?

Force Changes Momentum

The total change in momentum is equal to the force multiplied by the time during which the force acts. Because force and time appear as a pair, we define the impulse to be the product of force and time.

****Bounces result in a greater momentum change and therefore almost always create a greater force.****
Suppose each ball shown has a mass of 1 kilogram and hits the floor at a velocity of
-5 m/sec (negative is downward). The momentum of the clay ball changes from
-5 kg m/s to 0. This is a change of 5 kg·m/sec.

The rubber ball also starts with a momentum of -5 kg·m/sec. If the collision is perfectly elastic, it bounces up with the same momentum but in the opposite direction. Its momentum then goes from -5 kg·m/sec to +5 kg·m/sec, a change of +1- kg m/sec. The rubber ball (elastic collision) has twice the change in momentum. The momentum change is **always greater when objects bounce** compared with when they do not bounce.

Bouncing vs. stopping

We can be pretty sure the force from the rubber ball is greater because the momentum of the rubber ball changed twice as much as the momentum of the clay ball. Bouncing nearly always results in a greater force than just stopping because **bouncing creates a larger change in momentum.**

Experiment: Balloon Toss
Physics

Research Question

What variables affect the impact force in a collision and in what manner do they affect the force?

Hypothesis

What effect will a heavier balloon have on the force a balloon experiences when it strikes the ground?

What effect will collision time have on the impact force of a balloon when it strikes the ground?

Procedure

The objective is to catch a thrown balloon without letting it break. The balloon successfully caught after traveling the greatest distance wins a Homework pass.

Rules

The competition must be carried out in a safe and fair manner at all times!

1. Follow the written and spoken instructions of the referee (teacher) at all times. Failure to do so is grounds for disqualification.
2. Each team shall have a **thrower**, a **catcher**, and a **courier**
3. The **thrower** is in charge of throwing the balloon to the catcher. The thrower must keep his/her throws within the team's throwing lane (as specified by the referee). Throwing outside the lane disqualifies the team. The thrower must throw the balloon with his/her bare hands.
   a. The **catcher** must wear the safety goggles and the garbage bag poncho (see construction instructions below) during competition. The catcher is responsible for catching the balloon without breaking it. The catcher must catch the balloon with his/her bare hands.
   b. The **courier** carries the caught balloon from the catcher to the thrower after a successful catch.
4. The details of the throwing and distance requirements will be announced by the referee on the field of competition. Be sure to listen carefully!
5. If the team's balloon is broken, the team is responsible for cleaning up the mess as thoroughly as possible. It is important that we leave the field of competition as we found it, not littered with broken balloons! The garbage bag poncho is a good temporary receptacle for broken balloon parts.
6. No member of any team can help or hinder the performance of any other team.
7. Violation of any of the written or spoken rules or instructions is grounds for disqualification.

Pregame Instructions

1. Alignment. Throwers form a line standing side-by-side. Use shadows for alignment: each thrower stands in the shadow of his/her neighbor nearer the sun. Each thrower can stand with his/her arms stretched out to the side and not touch the outstretched arms of his/her neighbor.
2. Tosses. All tosses are launched on the instructor's/referee's signal.
3. Legal catches. A catcher must catch the balloon with his or her bare hands. The catch must be made at or beyond the distance in play.
4. Penalties. Three strikes and you're out.
   a. Broken balloon = disqualification (three strikes)
   b. Balloon hits ground and doesn't break = one strike + repeat at that distance (do over)
   c. Balloon falls short (catcher must move closer to thrower to make the catch) = two strikes + do over
5. Rounds. After each toss and catch, catchers move back three giant steps and catch from there.

Conclusion Questions

1. What was the strategy for catching a long-range, thrown balloon? Answer using words **and** pictures.

2. How can you use the terms impulse and momentum to explain the success of this approach?

3. Use the principle described in your answer to #2 to discuss why a raw egg could not be used in competitive baseball. Use the terms force and impact time in your answer.

4. Use the concepts of force and impact time to explain why bungee jumpers use a stretchy cord instead of a steel cable.

5. How do your findings explain the purpose of airbags in cars? Refrain from using words like “cushion” or “absorb.” Do use words like “stopping time,” “stopping force,” or “changes in momentum.

In a lab report, you need to include the following:

- State the Research Question of this experiment
- Two predictions with explanations (write the question with your hypothesis)
- Conclusion Questions (write the question with your answer)

Activity: How does a collision affect the motion of marbles?

Procedure:

1. Place 5 marbles, all identical in size and shape, in the center groove of a ruler. Launch a sixth marble toward the five stationary marbles. Note any changes in the marbles' motion.
2. Now launch two marbles at four stationary marbles. Then launch three marbles at three stationary marbles, and so on. Note any changes in the marbles' motion.
3. Remove all but two marbles from the groove. Roll these two marbles towards each other with equal speeds. Note any changes in the marbles' motion.

Number of marbles on the ruler	Number of marbles launched	Observations
5 stationary	**1 launched**	
4 stationary	**2 launched**	
3 stationary	**3 launched**	
2 stationary	**4 launched**	
1 stationary	**5 launched**	
0 stationary	**2 launched towards each other**	

Questions:

1. How did the approximate speed of the marbles before each collision compare to after each collision?
2. What factors determine how the speed of the marbles changes in a collision?
3. What do you think would happen if three marbles rolling to the right and two marbles rolling to the left with the same speed were to collide?

Blast Off
Physics

Research Question

What factors will affect the maximum height a rocket can travel?

Objective

Your goal is to get your rocket to fly (vertically) to the highest height by changing the amount of water and/or air.

Hypothesis

List one factor and explain how the factor will affect the height a rocket travels.

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Introduction

Rockets work on physical principles of Newton's three laws of motion. On a very basic level, a rocket is a pressurized gas chamber. As gas escapes through a small opening at one end, the rocket must be propelled in the opposite direction (Newton's 3^{rd} law). The force that propels the rocket is called thrust. The amount of thrust depends upon how much air you pump inside the rocket (Newton's 2^{nd} law).

A hand pump will be used to add air to the water and build up pressure inside the rocket. When the pressure gets high enough, water will be forced through the opening of the rocket, and the rocket will take off.

Modern rockets use either solid or liquid propellants (or a combination of the two). The propellant is both the fuel and an oxidizer, which is an oxygen compound. Oxygen must be present in order for the fuel to burn. The difference between car/airplane engines and rocket engines is that rocket engines must carry their own oxygen so that they will work in the vacuum-like conditions of space.

Analysis

1. How would the results of the experiment change if we used a larger rocket?

   ____

   ____

2. How could you modify the experiment to produce a rocket that reaches a greater height?

   ____

   ____

3. Explain in your own words how this experiment relates to Newton's laws of motion.

   ____

   ____

4. What factor do you think affected how high the rocket traveled? Explain why.

   ____

   ____

The Basic Idea

Like a balloon, air pressurizes the bottle rocket. When released from the launch platform, air escapes the bottle, providing an action force accompanied by an equal and opposite reaction force (Newton's Third Law of Motion). Increasing the pressure inside the bottle rocket produces greater thrust since a large quantity of air inside the bottle escapes with a higher acceleration (Newton's Second Law of Motion). Adding a small amount of water to the bottle increases the action force. The water expels from the bottle before the air does, turning the bottle rocket into a bigger version of a water rocket toy available in toy stores.