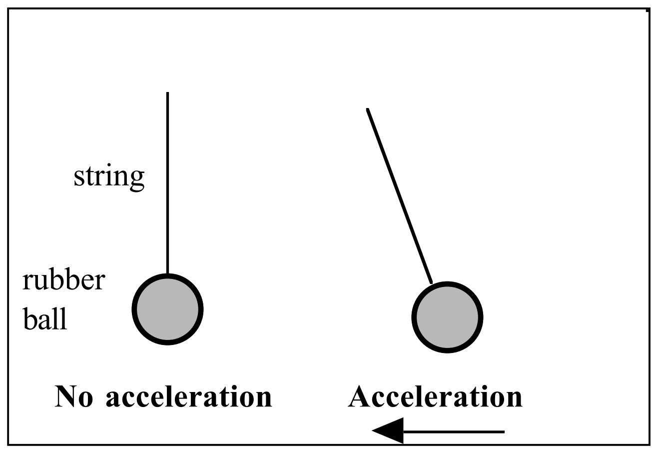
Make and Use Your Own Accelerometer

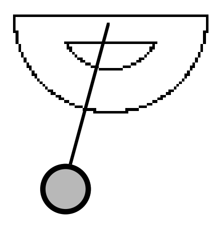
Action: Students use a rubber ball on a string to indicate acceleration. They then try to identify the applied force causing it.

Background: Acceleration is a change in speed or a change in direction of motion. In a car, the "accelerator" is the pedal we push to speed up the car. Actually the brake is also an "accelerator" except that it slows the car down, which most people call a deceleration. In physics, this is just considered a negative acceleration. The third "accelerator" in a car is the steering wheel. By turning it you change your direction of motion, which is also acceleration.



Basically, if you speed up, slow down, or turn, you are accelerating, and a force must be causing this acceleration. A ball on a string can show you the acceleration because there is a delay in the force (changing your motion) working its way down the string to change the motion of the ball. The ball tends to continue to move the same direction at the same speed as it was moving before the force was applied. Only when you see the string pulling on the ball sideways, it is able to change the motion of the ball and speed it up, slow it down or change its direction. You see the ball deflect in a direction opposite the force changing the motion and opposite the direction of your acceleration.

Construction: A rubber ball can be attached to a string in several ways. One would be to simply wrap the string around the ball, tie it, then use masking tape to hold the string on the ball. Another would be to use a large needle to push the string through the ball and then knot the string on the other side. A tennis ball could be used as well as a small play ball.



Note: If you need to make measurements, the string can be hung from the central point of a protractor and the angle the string makes with the vertical can be measured. The larger the angle, the larger the acceleration.

Inside a car with the windows raised, where wind isn't an issue, another type of accelerometer may be used. A helium balloon on a string will move in response to accelerations. If it is too hard to hold and watch at the same time, the balloon could be fastened to a heavy object on the floor of the car. Note that this type of accelerometer will not work at the amusement park or in the classroom. The car is a special place where it will work. (You must keep the ball from blocking this person's view in the rear view mirror as they drive. Hold the ball low enough to be below the level of the rear view mirror.)

Measuring Acceleration as You Walk

Materials: Rubber ball on a string, you

1. Hold the string in your hand. Observe the ball when you are standing still. What does it do?

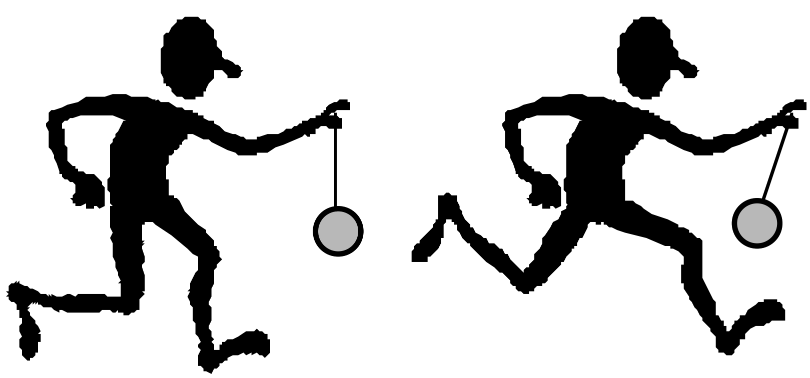
2. If you walk at a steady speed, what does the ball do? Is the string straight up and down?

3. When you speed up, which way does the ball move? When you speed up, a force pushes you forward. This force comes from the floor. Is the direction the ball moves the same as the force that makes you speed up? (If you have trouble figuring out which way this force points, think of which way someone would have to push you to make you go faster.)

4. If you speed up more quickly, accelerate faster, does the ball move more or less? Does it move in the same direction?

5. When you slow down, which way does the ball move? Is that in the same direction as the force that makes you slow down? (Which way would someone have to push you to slow you down?)

6. If you turn left, which way does the ball move? Which direction does this say the force must be acting?



Measuring Acceleration as You Ride

Materials: Ball on a string, You (preferably in the backseat), Parent willing to drive you around in a car

(Remember to wear your seat belt.)

1. Observe the ball while the car builds up speeds after stopping. Which way does the ball move?

2. Observe the ball as the car slows down for a stop light/sign. Which way does the ball move this time?

3. By just watching the ball, can you "magically" tell your driver when they are using the accelerator or brake without looking at their feet?

4. Observe the ball as the car turns right and left. Which way does the ball move now?

5. Does the ball move in the same direction as the force on the car, or opposite?
   Speeding up – force on car is forward
   Slowing down – force on car is backward
   Turning right – force on car is to the right
   Turning left – force on car is to the left?

6. Does the amount the ball moves depend on how fast/slow you turn? Does it depend or how quickly you speed up/slow down?

7. If you could not see out the window but could only watch the ball, could you tell when you are speeding up, slowing down, turning left or right?

8. Can you design an accelerometer you could take on a rollercoaster to measure the forces (acceleration) on you?

Newton’s First Law (Law of Inertia)

A body at rest will stay at rest until an unbalanced force acts on it.

A body moving at a constant speed in a straight line will continue until an unbalanced force acts on it. (All bodies resist changes in their motion.)

Newton’s Second Law

How fast a body speeds up, slows down or changes direction (its acceleration) increases if it is pushed/pulled harder and gets smaller if the body is heavier (has more mass).

$$F = m\,a$$

Newton’s Third Law

When object A exerts a force on object B, object B exerts and equal and opposite force on object A. This is often written: For every action (force) there is an equal and opposite reaction.

Experiments to demonstrate Newton’s First Law

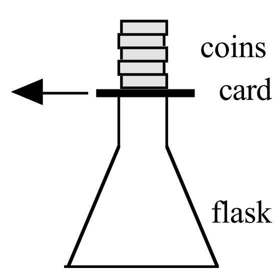
A. The Tablecloth Trick

1. Pull the tablecloth quickly out from under dishes (use the heaviest dishes you can find, stoneware works well, with smooth underside and place a piece of foam rubber in front on the floor if the dishes might break if they fall.)

2. Can you explain using Newton’s First Law?

B. How Many Nickels?

1. How many nickels can you get to drop into the flask when you quickly pull a playing card out from under them. Be sure to hold the flask securely so it doesn’t go flying!



2. Can you explain using Newton’s First Law?

C. Bumper Car Collisions

1. Watch the driver of one of the cars when he crashes. What direction does the driver move upon crashing, towards the direction of his original motion or away?

2. What might happen if the driver were to ride without the seat belt fastened around him/her?

3. Can you now explain using Newton's First Law, why seat belts are necessary?

4. Can you use the accelerometer to measure this force? When was it bigger/smaller? Why?

Explanation – A.2. When you or the magician pulls the tablecloth quickly enough, the sideways force on the plate is not enough to overcome its inertia (the plate's wanting to stay stationary). If you pull too slowly the sideways force is applied for a longer time and the plate will be made to move sideways.

B.2. The same explanation applies to the nickels. If the card is removed quickly and smoothly enough the nickels will not move sideways at all and will fall directly into the flask.

C.3. When the bumper car is moving forward, it and its driver want to continue moving forward until a force acts to stop them. The force of the other car acts on the bumper car first and the car's driver does not stop until the force is transmitted through the seat belt to the driver, stopping the driver too. So at first we see the driver jerk towards the direction of the original motion, a rubber washer accelerometer would move the same direction (opposite the force applied to stop the car and driver's motion).

C.2. The driver would continue to move forward and be flung out of the car over the hood

C.4. The force is bigger when the car is moving faster or if the car has a larger driver(more inertia so more force needed to stop)

Experiments to demonstrate Newton's Second Law

A. Rollercoaster Motion

1. When do you feel the most force on you as you ride the rollercoaster? Indicate and label the point on a sketch of the rollercoaster. What direction is the force? Why is this force needed?

2. Can you use your accelerometer or your hands under your thighs to measure the force? How big was it compared to other points on the ride?

B. Bumper Car Collisions 2

1. As you step on the pedal, what direction is the force on you? Why?

2. As you quickly stop in a collision, what direction is the force on you? Why?

Explanation – A.2. When the car is being accelerated up the hill, you will experience a force in the direction of the final motion (towards the front of the car – could be measured with a rubber washer accelerometer held sideways, parallel to your legs or with your hand placed between the small of your back and the seat behind you) as you build up to a constant speed. (Your partner may need to read this measurement.) This force makes you and your car speed up. You will also feel a force downward as you come to the bottom of a hill and change to moving upwards (due to change of direction – could be measured with your hands) and upward at the crest of the hill as your motion changes from upward to downward. When you move around a curve, you feel a force pushing toward the center of the curve, called centripetal force, which is needed to change the direction of your motion – this could be measured with an accelerometer held with the protractor facing you or with your hand between you and the car on the side away from the center of the turn.

B.1. As you step on the gas, you speed up (accelerate), the force is forward and increases your speed.

B.2. As you stop in a collision, the force is backward, against your motion and slows you down.

Experiment for Circular Motion/Newton's Second Law

Are Vertical Loops Safe?

They are if you believe Newton. If you rotate quickly enough, (more acceleration due to more applied centripetal force) you feel pushed into your seat, even without any restraints! (Actually the seat is pushing you to make your motion change direction - creating your circular motion.) So, if you circle fast enough you are held in your seat.

1. Rotate the small water bottle with a small amount of colored liquid slowly, then quickly. What difference do you observe?

2. Optional: Try the same with the bucket of water – Quickly only please.

3. Observe the effect on the position of the cars of Flying Eagles or seats on the Celebration Swings as the ride moves faster around the center. Draw what it looks like at the beginning (moving slowly) and later (moving faster) How does it feel? Interview a rider if you do not wish to ride yourself.

4. What happens on Flying Eagles as the riders bend the vanes toward the center? Why?

5. Observe one of the coasters with a vertical loop. Do the riders fall out at the top? (obviously not, the park wouldn't be in business for long if they did) Why not? Can you explain using the model of the water as the passenger and the bottle as the car? Ride and see if you can tell the direction of the force on you by placing your hands under you as you ride. What forces are at work in the vertical loop? How does it feel? Interview a rider if you do not wish to ride yourself.

Explanation: 1. When the bottle is being circled around slowly , the water splashes from the top of the container to the bottom and back again. If you circle the bottle fast enough, the water stays at the bottom of the bottle, just like the rider stays in their seat of the car.

2. The water in an open bucket will not spill out as long as the bucket is circled quickly enough as it goes upside down.

3. As you circle faster, there is more force pulling you inward to make you turn around and the cars move upward as part of that force along the cable works against your weight pulling you down. As you circle faster you feel the seat pushing inward and upward more.

4. As the vanes are bent inward more, the shape causes lift like the air moving over the wing of an airplane . This lifting force, pulls you outward and the diameter of your path gets bigger.

5. No, the riders do not fall out. As the seat pulls you around in a vertical circle, as long as you move quickly enough, you feel pushed into the seat even without the restraint system. With the Klotoid loop, the strongest force on you is at the very top of the loop and the force on you is downward, so you feel pushed into your seat.

Experiments to demonstrate Newton’s Third Law
(Action and Reaction)

A. Balloon Demonstration

1. Blow up a long thin balloon and let it go. Why does it move the direction it does?

B. Alka-Seltzer Film Canister Rocket

1. Place 2 ml of tap water in a clean, dry film canister. The lid also needs to be dry. (Pipet filled up to black line is 1 ml. Disposable plastic pipets can be used many times. Just instruct the students to squeeze the bulb, put the end in the water while still squeezing, holding the fingers still while withdrawing from the water when the water reaches the black line, squeeze over the canister to put water in. Demonstrate first then talk them through the steps. There should be just enough water to barely cover the bottom of the canister.) Demonstrate steps 2, 3 and 4 before having all students do the steps but not until you say the magic word – GO.

2. Place one-quarter of Alka-Seltzer and QUICKLY place the lid on firmly with your heel of your hand, you should hear a snap when it seals.

3. Hold the canister pointed up with your face well away from it over a bin if you need to contain the mess. (If you work outside you also might want to hot glue short pieces of tinsel (not long enough to reach past the edge of the lid) since the clear Fuji film canisters that seal most reliably have clear lids that are easy to lose/hard to see sometimes. Do NOT shake as water can get in and spoil the seal around the top of the canister. Always dry the seal area of lid and canister if you try to reuse the canister.) NEVER point at anyone.

4. Feel the force on your hand when the lid launches. How does this relate to Newton’s Third Law?

5. Optional: Try again holding the canister against the ground – your face well away from the canister. Does this effect the launch height? Why? Turn the film canister over and try again, what do you think will happen? Why? Were your predictions proven right? You can also experiment with different amounts of fuel and water, what changes? Why do you think it changes?

6. Please rinse and dry your canister and lid for the next person.

C. Bumper Cars Collisions 3

1. When one bumper car is standing still, what happens when another bumper car crashes into it? Why?

2. What happens if the cars collide while moving in the same direction?

3. What if the cars are heading straight for each other?

Explanations: A.1. When the balloon is released, the air pushed out of the back of the balloon is the action and the force on the balloon forward is the equal and opposite reaction. The action and reaction forces always act on two different objects. This is the same way that rocket propulsion works. The hot gases being pushed downward cause the rocket to be pushed upward.

B.4. The force on your hand when the lid pops is downward. Your hand is pushed down as the lid flies upward. These are the action and reaction forces.

B.5. If the canister is held firmly against the ground, the lid will fly even higher because some of the energy before was used up pushing your hand downward. If you turn the canister over so the larger bottom portion of the canister points upward, then the canister will not fly as high as the lid because of its greater weight (inertia). The same force will not make the canister achieve the same speed as the lid. The use of more fuel will generally cause the lid to fly quicker because the pressure builds to popping point more quickly with more fuel, because more gas is created. The effect of the amount of water is less consistent, I have found that with more water, there are more misfires, possibly because with more water it is easier for some of the water to find its way into the sealing area at the top of the canister.

C.1. If car 1 is still and car 2 hits it while moving forward, then after the collision, car 1 will move forward and and car 2 will come close to a complete stop. During the collision, car 1 exerts a forward force on car 2 and car 2 exerts a backward force on car 1.

C.2. Since the car coming from behind must be moving faster, the car in back pushes the front car forward , speeding it up and the front car pushes the back car backward, slowing it down.

C.3. If they are equally matched for weight and speed, they both stop. Each car pushes backward equally on the other slowing it down to a stop.