Chapter 4

Forces and Motion

Think About IT!

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1. **A car accelerates:**

   There is a force of friction between the tires and the road. The tires push backwards against the surface of the road. This pushes the car forward.

A car slows down:

Friction acting on the car opposes the motion. The car is slowed by friction.

The driver applies the brakes. Friction between the brake pads and rotors slow the movement of the wheels, slowing the car down.

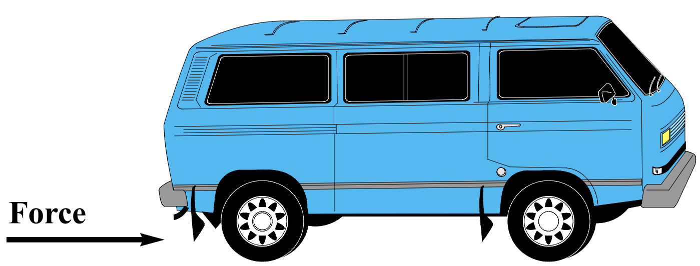
A car turns left:

A change in the direction of velocity is also **acceleration**. Any acceleration requires a force. The force of friction between the tires and the road pushes the car to the left, causing it to change the direction of motion.

A car brakes to stop:

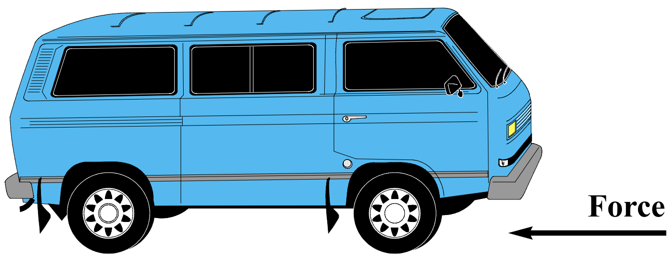
Again the force of friction between the brake pads and the rotors slows the movement of the wheels, slowing the car down.

2. **Accelerates:**



This is the force pushing the car forward as it accelerates.

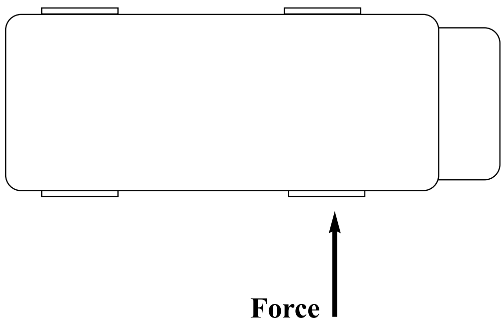
Slows down:



This is the braking force that slows the car down.

Turns left :

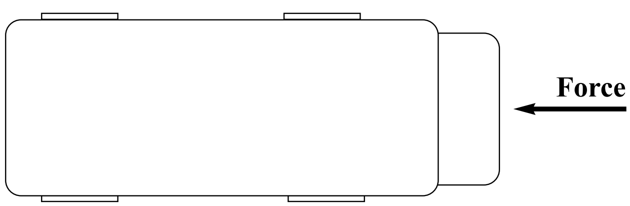
Top view:



This force turns the car left. The force does not speed up the car or slow it down, but changes the direction of the motion. This is also an acceleration.

Brakes:

Top view:



This force brings the vehicle to a stop. This force is due to the brake pads rubbing against the rotors, slowing down the rate of rotation of the wheels.

Investigation #3 FORCE AND ACCELERATION

Object:

How does the unbalanced force acting on an object affect its motion if the mass of the object is kept constant?

Independent variable = unbalanced force (weight of falling mass)

Dependent variable = motion of cart

Controls:

Mass being accelerated. Include both the mass of the cart and the falling mass.

Note to Teacher: Physics labs should have masses that would be convenient to use. An appropriate mass to use would be 100 g or 0.100 kg with a dynamics cart with a mass of about 1.00 kg. Have students label the carts they use. Later on, they must double the mass of their cart.

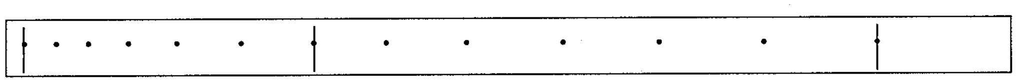
Forces are measured in newtons. Mass is measured in kilograms. The force of gravity on the hanging mass is about is about 1 N (Force of gravity = mass x 9.8 N/kg).

The acceleration of a 1.0-kg cart plus the 0.1-kg hanging mass should be about 1N/1.1 kg = 0.9 m/s/s. Due to friction, expect accelerations to be less than 0.9 m/s/s.

The tables C, D, and E from pp. 18–20 have been combined into one. See the following page for a sample blank table.

Students should analyze the dots on the ticker tape using 6 dots = 0.10 s for a ticker timer with a frequency of 60 vibrations/second.

Be sure students do **not** count the first dot at the start of the time interval as one of the six dots. There should be six spaces visible between dots in a 6 dot = 0.10 s time interval.



Once the table is complete, students graph **time** at the midpoint of the interval and average velocity.

The graph should be a straight line with a positive slope.

The slope of a Velocity-Time graph yields **acceleration**.

Typical Results:

Table A

Unbalanced force due to weight of hanging mass (N)	Mass of cart and hanging mass (kg)	Acceleration (m/s/s)
1		
1		
1		
1		
1		

Conclusion:

A constant unbalanced force exerted on an object causes the object to accelerate at a constant rate.

Table B

Time (s)	Position (cm)	Time at midpoint of interval(s)	Displacement during time interval (cm)	Average velocity (cm/s)

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1. The dots on the tape show that the displacement between adjacent dots increases. This indicates that the velocity is increasing (i.e., the object is speeding up). The change in velocity implies there is an acceleration. A constant, unbalanced force acting on an object produces a constant acceleration.

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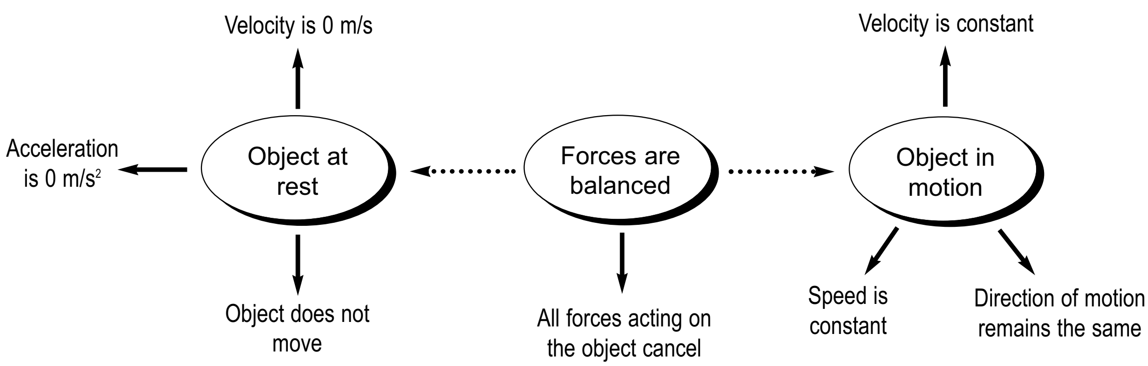
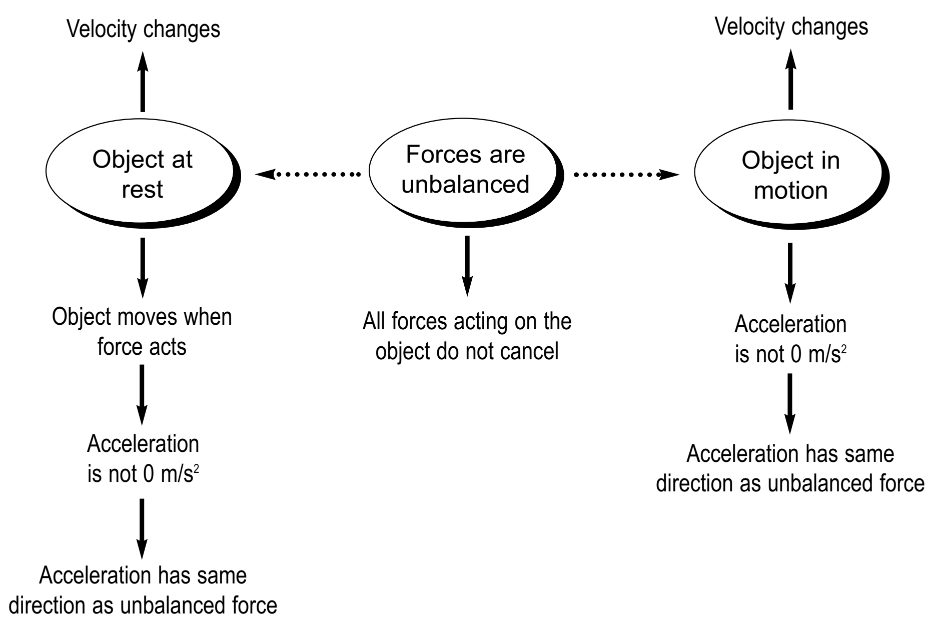
1.





Investigation #4 MASS AND ACCELERATION

Note to Teacher: Using ticker tapes to measure acceleration is a long process that needs reinforcement. Students must perform the necessary calculations many times to become proficient at them.

If the students understand these ideas conceptually without calculations, a good deal of time can be saved.

A suggested alternative to develop the inverse relationship between mass and acceleration for a constant force is to use dynamics carts, bricks for added mass, and scales or elastics to provide the unbalanced force. Students can pull a cart with a constant force measured on a scale. Students must accelerate with the scale and the cart in order to keep the force constant. As the mass increases, students can see and feel that the acceleration required becomes smaller. This develops the concept very effectively.

An elastic attached at one end to the cart and stretched at the other end by a metrestick can also be used to provide the force. The student must keep the elastic stretched a certain amount, say 40 cm, in order to maintain a constant force.

Object:

How does the mass of the cart affect the acceleration if the unbalanced force is kept constant?

Independent variable = mass of cart **plus** falling weight

Dependent variable = acceleration

Control: unbalanced force

Note to Teacher: The mass being accelerated is the mass of the cart **plus** the mass of the falling weight.

Students will already have one set of data for the acceleration of the cart.

Have each group add different masses to its cart and perform this one trial. Each group should keep the same falling weight as the previous trial. Once the group has determined the acceleration, the information can be shared with the other groups.

Weights or bricks or extra dynamics carts can be used to provide the extra mass on the carts.

Sample Data:

These trials used a falling mass of 100 g (force = 1 N). The students used dynamics carts, to which were added weights of 0.500 kg, 1.000 kg, 1.500 kg, and 2.000 kg. The total mass accelerated was the mass of the cart, the added mass, and the hanging mass.

Each group performed a trial for all the above added masses (four trials in all). This gave each member of the group one tape to analyze. The groups then shared their results with the class. Graphs of acceleration and total mass were plotted. The graph clearly shows the inverse relationship between the total mass and its acceleration.

The results given here represent the averages for five sets of data.

Table C

Mass on cart (kg)	Total mass (kg)	Falling mass (kg)	Acceleration (cm/s/s)
0	1.08	0.100	51
0.500	1.58	0.100	35
1.000	2.08	0.100	30
1.500	2.58	0.100	24
2.000	3.08	0.100	21

Conclusion:

If the unbalanced force acting on the cart is kept constant as the mass of the cart increases, the acceleration of the cart decreases.

Alternate Method:

If you have access to the Internet, an applet called Newton's Second Law by Walter Fendt can be used to do this experiment virtually. Students can adjust the masses of the cart and the falling mass, and the applet will calculate the acceleration. Again, remember that the mass being accelerated is not just the mass of the cart, but the combined mass of the cart and the falling mass.

<http://www.walter-fendt.de/ph14e/n2law.htm>

The applet is called Newton's Second Law.

These applets can be downloaded if required, then utilized offline.

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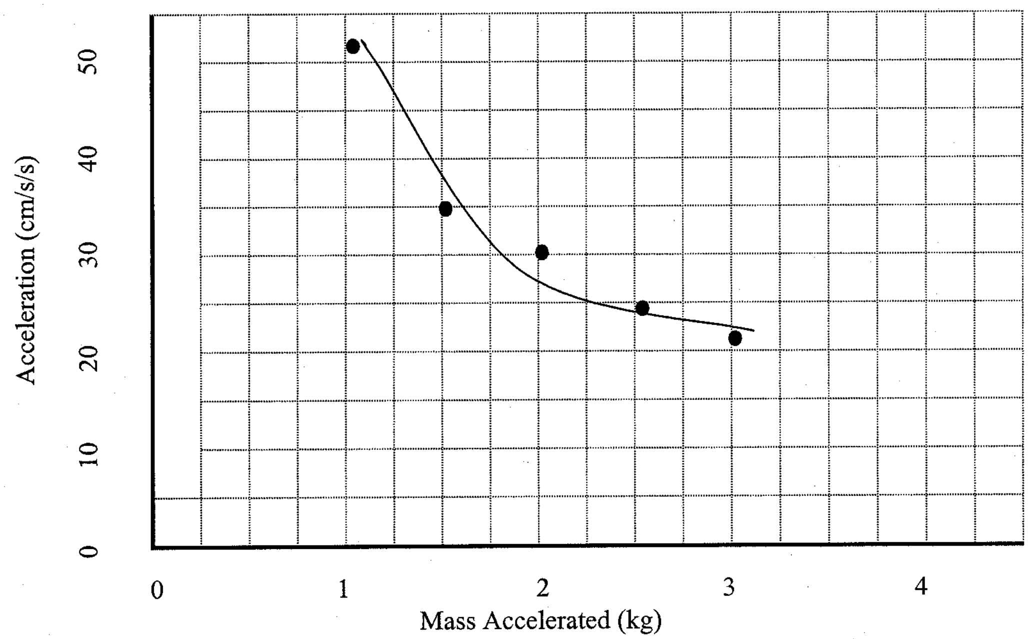
1. As the mass of the cart increases, the acceleration decreases if the unbalanced force is kept constant.

Math Connection

The graph of mass accelerated and acceleration should yield a curve. The relationship is an inverse one (i.e., as mass increases), acceleration decreases for the same unbalanced force. A typical graph appears as follows.



Investigation #5 FORCE AND MASS

Object:

How is the unbalanced force acting on the cart related to the mass of the cart if the acceleration is constant?

Independent Variable = mass of cart and hanging mass

Dependent Variable = hanging mass providing the unbalanced force

Controls = acceleration

Note to Teacher: It is expected, based on $\vec{F} = m\vec{a}$, that to maintain a constant acceleration, a doubling of the mass implies a doubling of the force. That is, $\vec{F}$ a m for constant acceleration.

Before the students actually perform the experiment, ask them to hypothesize about the force needed to accelerate double the mass. Then they can experiment to test the hypothesis.

Students can double the mass by accelerating two carts instead of one, provided they have equal masses. The students used 0.5-kg masses for the unbalanced force in previous investigations. This can easily be doubled or tripled.

In this case, doubling the mass of the cart and doubling the falling mass essentially doubles the total mass of the system. This system should show the same acceleration as the original cart and falling mass.

Sample Data:

Table D

Mass measured in carts	Falling mass providing unbalanced force (kg)	Acceleration (cm/s/s)	Average acceleration (cm/s/s)
1	0.100	77, 54, 57, 60, 60, 56, 47, 60	59
2	0.200	77, 63, 34, 37, 52, 62, 58, 58	55
3	0.300	48, 69, 50, 35, 68, 51, 60, 62	55

Analysis:

Students can analyze the ticker tapes to obtain the acceleration from a Velocity-Time graph.

If CBLs are used, the graphing calculators can be used to calculate the acceleration.

Conclusion:

The unbalanced force required to provide a constant acceleration is related directly to the mass that is being accelerated. If the mass doubles, the force needed to provide a constant acceleration also doubles.

If the results do not show that $\vec{F} \propto m$, students should critically analyze the experiment to suggest ways to improve the procedure.

Alternate Method:

This activity lends itself nicely to a virtual demonstration using the Newton's Second Law applet by Walter Fendt, which is available on the Internet.

<http://www.walter-fendt.de/ph14e/n2law.htm>

Think About IT!

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1. As the mass increases, the unbalanced force needed to provide a constant acceleration increases directly in proportion to the increase in mass.

Think About IT!

Think About IT!—Page 36 (Bottom of Page)

1. The dots for the Car A grow increasingly farther apart. This indicates that the velocity of Car A is increasing (speeding up to the right). Car A is accelerating to the right. This acceleration is caused by a constant, unbalanced force acting to the right.

The dots for Car B also grow increasingly farther apart, but the separation of the dots increases more rapidly than Car A. This indicates that the velocity of Car B is increasing (speeding up to the right). Car B is accelerating to the right. However, the acceleration of Car B, the rate at which velocity changes, is larger than for Car A. This larger acceleration indicates the force acting on Car B is larger than on Car A if their masses are equal.

A ball rolling out into the street can be a warning that a child may dart out to retrieve the ball. At the point where the driver of Car A can see the ball, Car A will have reached a certain velocity. The driver of Car A must brake the car (i.e., give it a negative acceleration to bring it to a stop). The force to cause this braking is the force between the tires and the road.

Car B reaches the point where the driver can see the ball, but it has a larger velocity than Car A. The driver of Car B applies the brakes and the force of friction between the tires and the road supply the unbalanced force needed to stop Car B. If the force of friction between the tires and the road is the same for both cars, Car B will take a longer time to brake to a stop and travel a larger distance than Car A. This larger stopping distance may carry Car B past the point where the ball, and a child trying to retrieve it, are located. The result could be a collision between Car B and the child.

Force and Direction

Think About IT!

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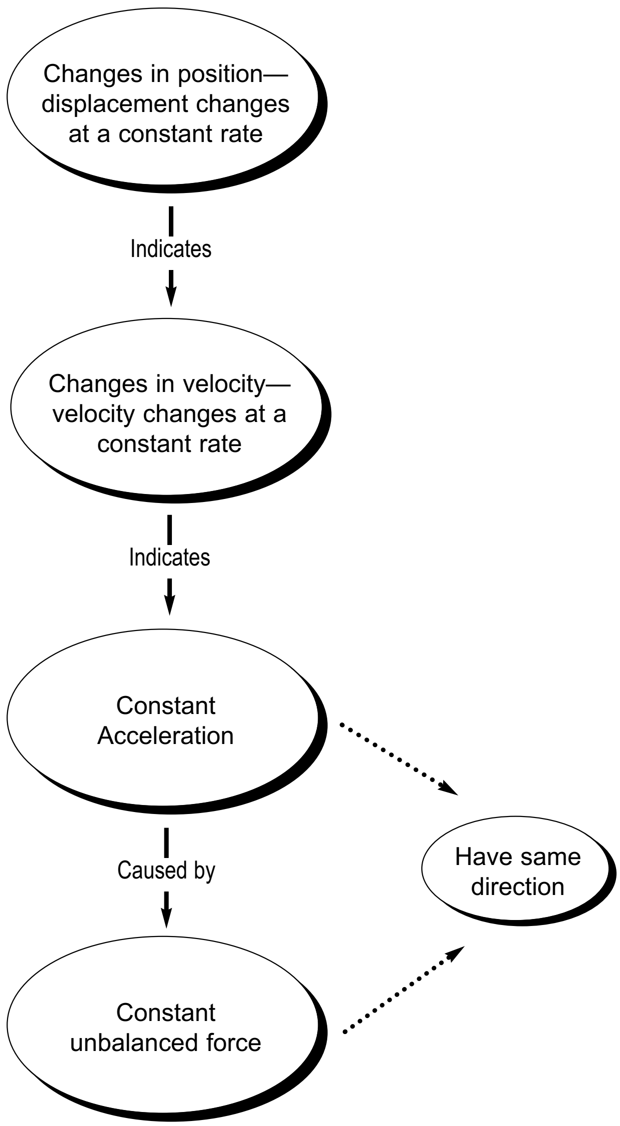
1.



2. The racetrack is banked to maximize the turning force required to accelerate the object. This acceleration changes the direction of motion of the object, not its speed.

3. A fi B: Car accelerates

Second Law—An unbalanced force acting on an object (the car) causes the object (the car) to accelerate in the direction of the unbalanced force.

B fi C: Driver removes his foot from the pedal

First Law—An object in motion remains in motion with a constant velocity unless acted upon by an unbalanced force.

C: Black ice

Second Law—An unbalanced force is required to accelerate the car by changing the direction of its motion.

The force of friction between the tires and the road creates this force.

The ice reduces the friction between the tires and the road.

First Law—Since there is no unbalanced force, the rear wheels move in a straight line (skidding) outside the radius of the curvature of the road.

D: Car moves in a straight line

First Law—An object in motion, the car, continues in motion with a constant velocity because there is no unbalanced force acting on the object.

There is no force between the tires and the road to turn the car around the curve.

E: Car slams into the bank and stops

Second Law—The bank exerts an unbalanced force on the car, causing it to accelerate. The force acts in the opposite direction to the velocity of the car, so the acceleration is negative.

F: Windshield is cracked

First Law—An object in motion (passenger) remains in motion at a constant velocity when acted upon by an unbalanced force. The passenger continues moving when the car stops.

Second Law—The passenger striking the windshield exerts a force on the windshield, cracking it. The force of the windshield on the passenger accelerated the passenger in the opposite direction compared to the velocity.

4. Water skiers or hockey players lean in order to turn so that the cornering forces (forces that change the direction of velocity) are maximized and properly balanced. Otherwise, they would topple over.

Car Crash

The motorcyclist was heading south. The motorcycle is in the intersection after the accident. This indicates the motorcycle hit an object, which stopped the motion of the motorcycle. A large force was needed to stop the motorcycle quickly. Such a force could be provided by the crash between the motorcycle and the car. This is Newton's Second Law.

The motorcyclist and her helmet are found south of the intersection and the motorcycle. Since the motorcycle was traveling south when it crashed into the car, the motorcyclist and her helmet, which were in motion, continued in motion until an unbalanced force acted on them. This is Newton's First Law.

When the motorcyclist landed on the ground, the force of friction between the road and the motorcyclist brought her to a stop. Again, this is Newton's Second Law.

If the motorcycle struck the front fender of Car A, the force of the collision would have pushed the front of Car A in a southerly direction. Car A would then have traveled in a more southeasterly direction. If the motorcyclist struck the rearmost portion of Car A, this would push the rear of Car A to the south. Car A was already turning north (we could assume), so the rear of Car A would slide to the east, and the direction Car A would take would then be more northerly and somewhat east of north. The skidmarks east of the intersection would be consistent with the rear tires sliding sideways in an easterly direction. Alternatively, the skidmarks may have nothing whatever to do with this particular incident. What about those oil drops?

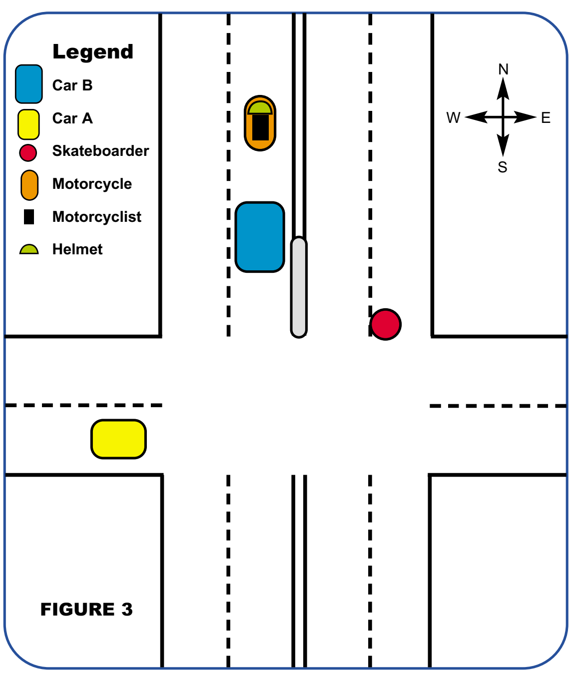


FIGURE 3

Car Crash After

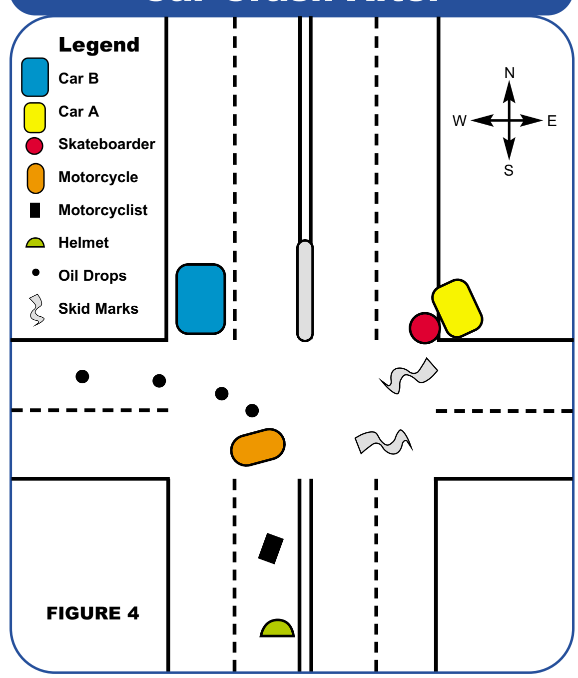


FIGURE 4

Action - Reaction Forces

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The sprinkler head turns because an unbalanced force is exerted on it.

Water is forced out of the nozzle of the sprinkler. The sprinkler must exert a force on the water to cause the water to move (accelerate).

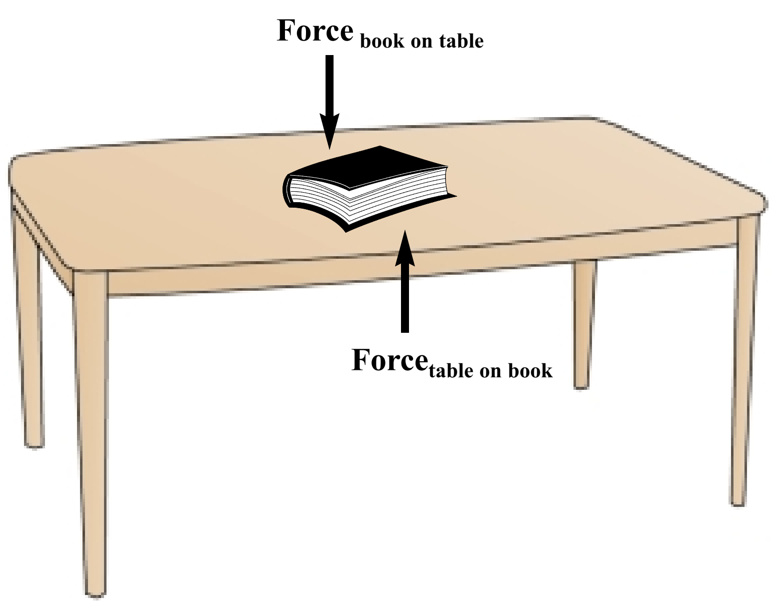
The water exerts an equal but opposite force on the sprinkler. The sprinkler accelerates due to this unbalanced force of the water acting on the sprinkler.

Note to Teacher:

- Action-reaction pairs of forces do not cancel each other out.
- Each force for two objects in contact acts on a different object.
- Therefore, they cannot cancel.

For example, a book rests on the table. The force of gravity pulls the book down, causing it to exert a force on the table. The table pushes the book upwards with the normal force, which is equal but opposite to the force of gravity on the book.

If we isolate the book and the table, we can show exactly the forces that act on each object.



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The scale reads 16 newtons.

The lighter student and heavier student are exerting forces to keep the spring scale motionless. Therefore, the net force on the scale is 0N.

The lighter student pulling on the scale can be thought of as the scale being attached to a rigid object like the wall. The heavier student must pull on the rope with a force of 16N to make the scale read 16N.

Conversely, the heavier student pulling on the scale can also be thought of as the scale being attached to a rigid object like a wall. The lighter student must pull on the rope with a force of 16N to make the scale read 16N.

Therefore, the students exert the same force. However, one student pulls to the right and the other student pulls to the left.

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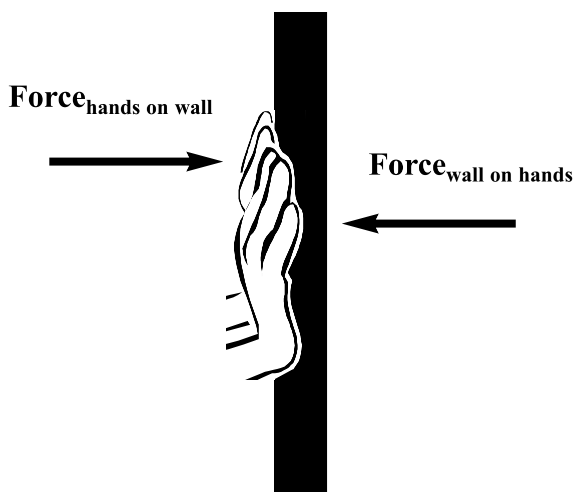
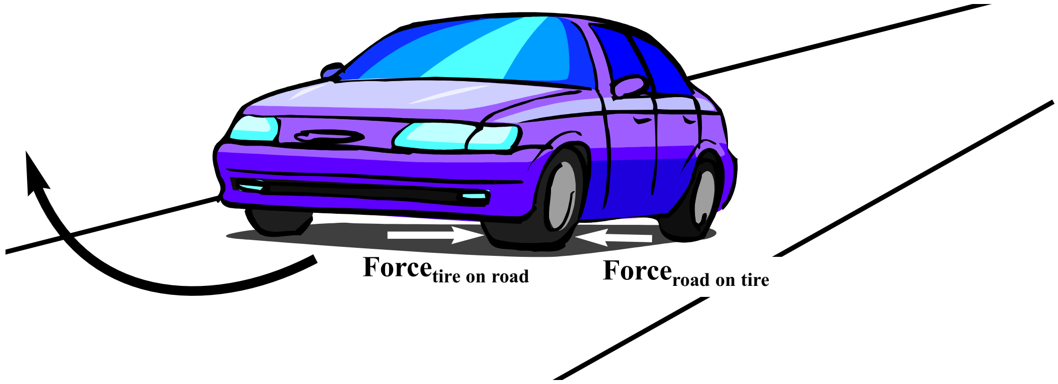
Note to Teacher: Question 3 is difficult. Break the situation down for the students into smaller interactions.

1. a. A person leans against a wall



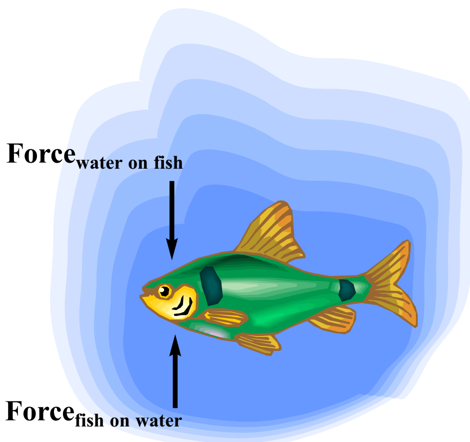
b. A car rounds a corner with constant speed.



This is a top view of the tire in contact with the surface of the road. The car is accelerated in the direction of the unbalanced force acting on the car (i.e., the force the road exerts on the tire). The car turns to the right. This type of force that causes only the direction of velocity to change is called *centripetal force*.

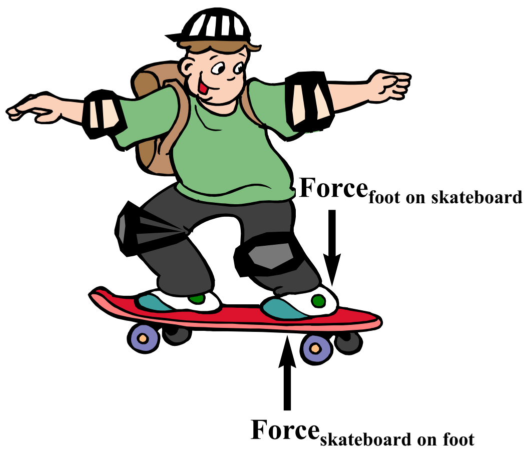
c. Fish swims

The fish pushes water one way and is propelled in the opposite direction.



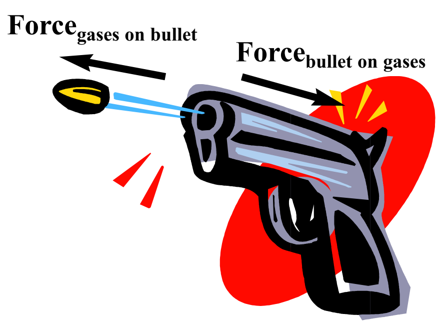
d. Skateboarder jumps

When jumping, the skateboarder pushes down on the skateboard with his foot. The skateboard pushes up on the skateboarder with an equal but opposite force.

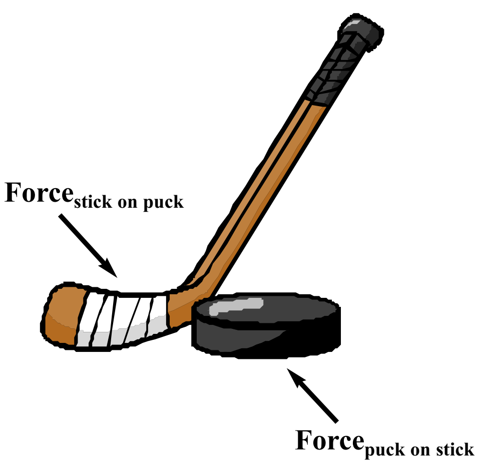


e. A gun recoils

The expanding gases inside the barrel of the gun push on the bullet, propelling it in one direction. The gases also push on the end of the barrel of the gun in the opposite direction.



f. A hockey player's slapshot



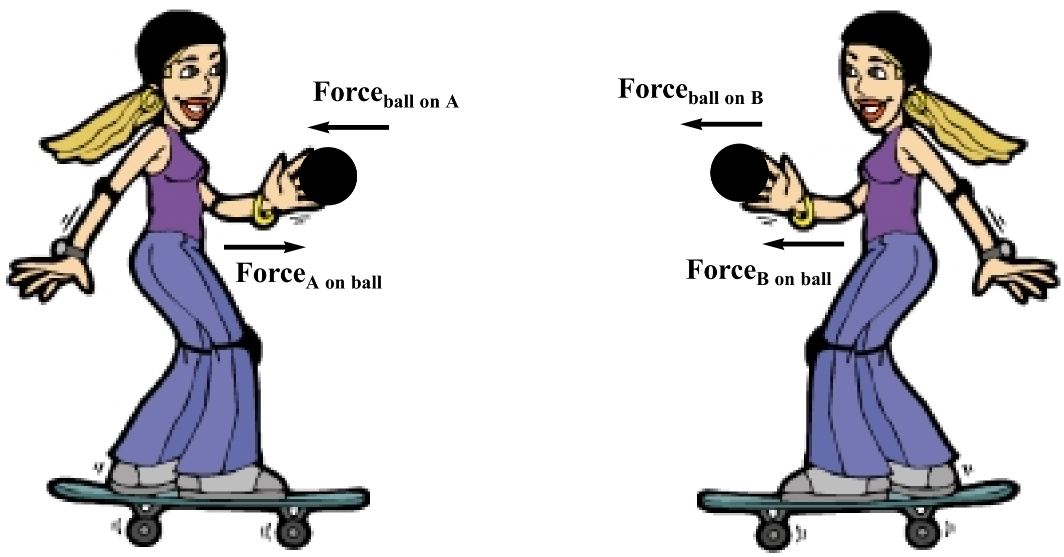
2. The two forces are equal, but opposite.

$\text{Force}_{\text{car on mosquito}} = \text{Force}_{\text{mosquito on car}}$

3. Separate this problem into parts: Student A throwing the ball; the ball flying through the air; Student B catching the ball; after Student B catches the ball.

Student A pushes the ball to the right (**action force**). This force accelerates the ball to the right. The student is pushed by the ball to the left (**action-reaction pair of forces**). This reaction force accelerates Student A to the left.

After the ball is released, the student rolls along at constant velocity to the left (no unbalanced force). The ball flies along to the right with constant velocity towards student B (no unbalanced force—Newton's First Law).



Student A **Student B**

Student B catches the ball. The ball is moving to the right. The ball exerts a force on the student to the right as the student catches the ball (**action force**). This action force accelerates the student to the right. The student exerts a force to the left on the ball (**reaction force**). This causes the ball to accelerate to the left (slows down).

After the ball is caught, the ball and Student B roll along to the right at a constant velocity (no unbalanced force acting).

4. Whenever a part of your body collides with another object, like the surface of the road, your body part exerts a force on the road (**action force**).

By Newton's Third Law, the road must exert an equal but opposite force on your body part. This is the force that can damage you.

The protective equipment provides a cushion for these action-reaction forces so that the forces are decreased.

The smaller forces reduce the damage done to you.