Unit 2 Parent Guide: Forces

What is *force*?

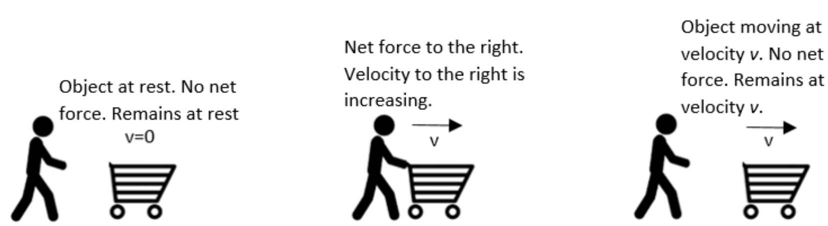
A force is a push or pull. That is an easy definition to remember, but there's more. A force is a push or pull on an object as the result of an *interaction* between that object and another object. The word interaction is important because it implies that objects are not isolated, but instead they do something together. A grocery cart is an object. It can be pushed by another object, a shopper. That push is what we call a force. But the force is really the result of an interaction between the cart and the shopper. The cart and the shopper are two objects that are interacting by pushing one another.

Force is a measureable quantity. That means that it has a magnitude, or an amount. A bathroom scale is a device to measure force. When you step on a scale, the reading on the scale is the amount of force that the scale pushes you upward to balance the force that earth pulls down on you. When a 180 lb. man steps on a scale, the scale reads 180 pounds because it is pushing upward with the same amount of force that the earth is pulling down. In the imperial (British) system of measurement, forces are measured in pounds. In the S.I. system (metric), forces are measured with the unit Newtons. 1 pound is approximately 4.45 Newtons. The unit Newton is equivalent to $kg \cdot m/s^2$, since it is the product of the unit for mass (kg) and the unit for acceleration (m/s^2).

Force is a vector quantity. That means that it has direction. Anytime an object experiences a force from another object, that force must be applied in a certain direction. Forward, backward, right, left, up, down, etc. Since directions always have opposites, it useful to designate the direction of a vector with a positive or negative. Suppose a shopper is pushing a cart to the right, and we designate rightward as the positive direction. Then any vector pointed in that direction (velocity, acceleration, or force) is also designated as positive. And any vector pointed to the left would be designated as negative. The choice of positive or negative for the direction of a vector is arbitrary, but should be chosen for convenience.

Newton's Three Laws of Motion:

<u>First Law</u>: *An object will continue its current state of motion unless an unbalanced external force acts on it.* Often called the law of inertia, the first law is really a special case of the 2^{nd} law. When all forces acting on an object are balanced, there is no net force, and therefore no acceleration. In this condition, the object will keep a constant velocity. The cart in Scenario A is initially an object at rest. The cart will remain at rest until an unbalanced external force acts on it. But after it is moving and the shopper lets go, the cart is now an object in motion. Without an unbalanced external force acting on it, the cart will remain in the same state of motion, which is at a constant speed and direction. Newton's 1^{st} Law simply says that an object's motion cannot change unless there is an unbalanced external force acting on it. The motion of the cart changes when the shopper pushes it.



Scenario A: A cart at rest is pushed forward by a shopper, then let go.

<u>Second Law</u>: *The acceleration of an object is directly proportional to the* *net force acting on it, and inversely proportional to the object's mass.* Put simply, the second law could be interpreted like this: the harder you push an object, the more it accelerates, and the more mass it has, the less it accelerates.

The second law can be mathematically represented by the equation:

$$a = \frac{F_{net}}{m}$$

Suppose in Scenario A, the cart has a mass of 20 kg, and the shopper pushes the cart with a force of 50 N. According to Newton's 2nd Law, the acceleration of the cart will be

$$a = \frac{F_{net}}{m} = \frac{50N}{20kg} = 2.5\ m/s^2$$

Because the direction of the net force is to the right, the direction of the acceleration is also to the right. The cart was initially at rest, so the acceleration to the right means the cart will have increasing velocity in the rightward direction.

Scenario B: A moving cart is brought to rest by a shopper.

Suppose in Scenario B, the cart has a mass of 20 kg, is moving to the left at 8 m/s, and the shopper pushes the cart to right with a force of 200 N. The acceleration of the cart will be

$$a = \frac{F_{net}}{m} = \frac{200N}{20kg} = 10\ m/s^2$$

In Scenario B, the cart was initially moving to the left, so it will slow down as the force is applied. Then applying the equation for kinematics we can determine how much time would be required to stop the cart. We will choose positive for the rightward direction, so the initial velocity of the cart is -8m/s.

$$v = v_o + at$$

$$0 = -8 + 10t$$

$$t = 0.8\ s$$

Scenario C: A moving cart is pushed by two shoppers.

In Scenario C, there are two shoppers pushing on the cart in opposite directions. We can use Newton's 2nd Law and kinematics to analyze the motion of the cart. Suppose the smaller shopper pushes to the right with a force of 200 N, and the larger shopper pushes with a force of 320 N, and the cart is initially moving to the right with a velocity of 16 m/s. How far will the cart travel in 1.9 s? The net force is the difference between the two forces since they are pointed in opposite directions.

$$F_{net} = 320N - 200N = 120\ N\ to\ the\ left$$

$$a = \frac{F_{net}}{m} = \frac{120N}{20kg} = 6m/s^2\ to\ the\ left$$

To determine the distance traveled, we use kinematics equations. The initial velocity of the cart is to the right and the acceleration is directed to the left. Designating rightward as positive:

$$d_f = d_i + v_i t + \frac{1}{2}at^2$$

$$d_f = 0 + (16)(1.9) + (0.5)(-6)(1.9^2) = 19.6\ m$$

The cart moved 19.6 meters toward the right as the shopper pushed it for 1.9 seconds.

And for the final velocity of the cart:

$$v_f = v_i + at$$

$$v_f = 16 + (-6)(1.9) = 4.6m/s\ to\ the\ right\ (since\ the\ velocity\ is\ positive)$$

Third Law: *For every action, there is an equal and opposite reaction.* This may be interpreted to mean "forces always exist in pairs resulting from an interaction between two objects that push or pull each other equally". In each scenario A, B, & C, there is an interaction between two objects. An important question to ask is this: What is the action and reaction in each scenario? There is only one simple answer to this question and the answer is the same for each scenario:

The shopper is pushing the cart to the right, and the cart is pushing the shopper equally to the left.

The magnitude of these two forces must be equal, even though the masses, velocities, and resulting accelerations of the two interacting objects are different. As long as there is an interaction between to objects, there is an action/reaction force pair.

In Scenario C, there are two action/reaction pairs. The small shopper/cart interaction, and the large shopper/cart interaction. These two sets of force pairs are not the same, because they are separate pairs of objects. It is important to note that the two shoppers are NOT interacting with one another (they aren't even touching).