★ Newton's Second Law of Motion

When an unbalanced force is exerted on an object, the object will accelerate in the direction of the force according to the relationship:

F = ma

Force (N) mass (kg) acceleration (m/s^2)

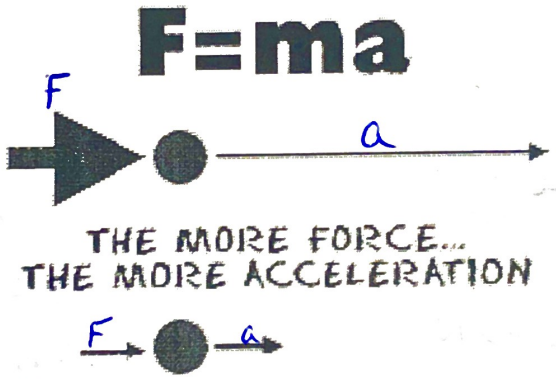
- In Newton's Second Law, we are considering the relationship between an object's mass and its acceleration. The mass of an object is not simply the quantity of matter, as Newton himself theorized. The mass of an object is actually a measure of inertia of an object.

F = m ↑ a ↓

F = m ↓ a ↑

- The more mass an object has, the more difficult it becomes to change the object's state of motion.

- For example, it is more difficult to budge a piano from rest than a piano bench. This is because the piano has more inertia than the bench does and much more mass.



How Force Relates to Motion:

- **A force is any kind of push or pull on** an object. Simply applying a force does not mean that an object will move. You can push as hard as you can on a wall and never move it.

- The law also implies that, to achieve a certain acceleration, the amount of applied force is somehow related to the mass of an object. The more massive an object becomes, the greater the force necessary to change its speed—hence its acceleration.

- Newton's Second Law states that a force is capable of changing the direction of motion on an object.

Newton's Second Law is often stated as:

Proportions

$$F = ma$$

$F = ma$ > Force stays the same.

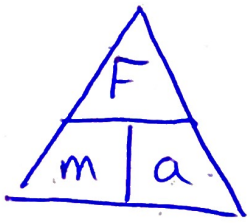
F - net force (Newtons (N) or kg•m/s²)
m - mass of an object (kg)
a - acceleration (m/s²)

$F = ma$ > mass stays the same

$F = ma$ > acceleration

Let's try these examples:

1. What force is exerted upon a 10kg mass if it accelerates 10 m/s²?



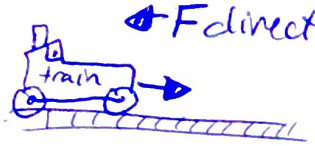
$F = ?$
$m = 10kg$
$a = 10m/s^2$

$F = ma$
$= (10kg)(10m/s^2)$
$F = 100N$
or
$100\ kg \cdot m/s^2$

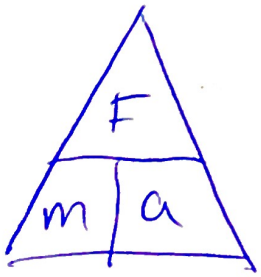
-ve acceleration

2. A freight train slows down as it approaches a train yard. If a force of -3.8×10^6N is required to provide an acceleration of $-0.33m/s^2$ what is the train's mass?

$F = -3\,800\,000\ N$
$a = -0.33\ m/s^2$
$m = ?$



*negative force is acting in the opposite direction of the movement



$$m = \frac{F}{a} = \frac{-3\,800\,000N}{-0.33\ m/s^2}$$

$m = 11,515,151.52\ kg$

$1\ kg = 1000g$

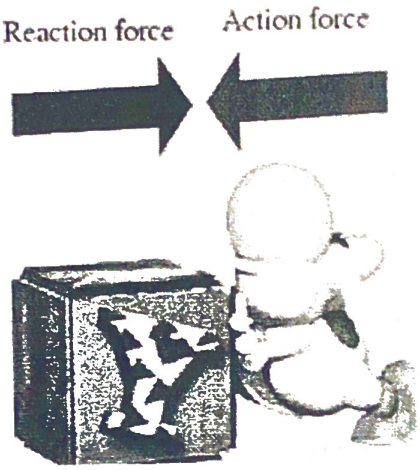
★ Newton's Third Law of Motion

For every action there is an equal and opposite reaction.

Since forces always occur in pairs, either balanced forces or unbalanced forces, try to consider the "opposite" force acting when a more obvious force is acting in an everyday activity. Remember that unbalanced forces cause acceleration, but there will be no acceleration if the forces are balanced.

Action force – the force that initiates the reactions

Reaction force – the force that responds to the initial action.



Example 1:

You prepare to jump while on a skateboard ... as you jump:

Action: Your feet push down on the upper surface of the skateboard.
Reaction: The skateboard pushes up on your feet with an equal but opposite force

Example 2:
A hunter places his rifle against his shoulder and pulls the trigger. As the bullet flies forward, the rifle recoils backwards into the hunters shoulder.

$$-F_{\text{bullet on rifle}} = F_{\text{rifle on bullet}}$$

KEY

Newton's Laws Practice Questions

1. **State Newton's first law:**
   Law of Inertia (object at rest stays at rest; object in motion stays in motion)
2. **State Newton's second law:**
   $F = ma$
3. **State Newton's third law:**
   Every action has an equal & opposite reaction

LAW 2
4. **Explain why a person wearing a cast on one leg becomes more tired than usual by the end of the day.**
   More mass = more force to move the same. ($F = ma$)

LAW 2
5. **Suggest reasons why large vehicles such as vans and trucks tend to have larger engines and higher rates of fuel consumption than smaller and more compact cars.**
   More Mass = more force needed to be produced to move ($F = ma$)

LAW 1
6. **Use Newton's Laws to explain why people in a car often get neck injuries like whiplash when struck from behind.**
   Your body wants to keep moving... car crash creates a force that changes that which causes your neck to snap/hit headrest.

LAW 1
7. **Explain why small rabbits can often escape bigger and faster bobcats in pursuit by zigzagging as they run.**
   More mass means it is harder to change the direction of their movement.

LAW 3
8. **While driving down the road, a mosquito collides with the windshield of your car. Which of the two forces is greater: the force that the mosquito exerts on the windshield, or the force that the windshield exerts on the mosquito?**
   They are the same... less mass of the mosquito means it gets squished.

LAW 3
9. **Two students are facing each other while standing on their skateboards. One student throws a mass (such as a medicine ball) to the other student. Describe what happens in terms of force and motion.**
   - Student who threw will go backwards from same force as their throw
   - student who caught will move from force of ball.

LAW 3
10. **In terms of action-reaction force pairs, explain why it is important to use helmets, elbow pads, knee pads, and other protective clothing when using skateboards or in-line skates.**
    Whatever force you hit the ground with, the ground hits you with!

Key

Newton's Law Practice - Again

NEWTON'S FIRST LAW

1. If an elephant were chasing you, its enormous mass would be most threatening. But if you zigzagged, its mass would be to your advantage. Why? Law 1 → harder to change its motion

2. Two closed containers look the same, but one is packed with lead and the other with a few feathers. How could you determine which has more mass if you and the containers were orbiting in a weightless condition in outer space? Law 1 → See which one is easier to change direction of (or stop)

NEWTON'S SECOND LAW

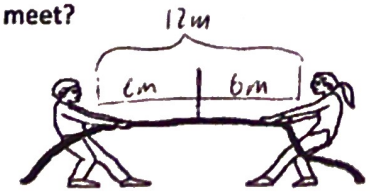
1. If the force exerted on a 2-kg object is 30 N, what is object's acceleration? $a = 15 m/s^2$
2. Suppose a cart is being pushed by a certain net force. If the net force is doubled, by how much does the acceleration change? $F = m\,a$ ⇒ Force doubled = acceleration doubled (if mass stays the same)
3. Suppose a cart is being moved by a certain net force. If a box is dumped into the cart, so its mass is doubled, by how much does the acceleration change?

$F = m\,a$ ⇒ mass doubled = acceleration halved (if Force stays the same)

NEWTON'S THIRD LAW

1. When a hammer exerts a force on a nail, how does the amount of force compare to that of the nail on the hammer? They are equal but opposite
2. Why does a cannon recoil when it fires a cannonball? Recoil is the equal but opposite reaction
3. Why is it easier to walk on a carpeted floor than on a smooth, polished floor? More friction = more force pushing back at your feet
4. When a rifle is fired, how does the size of the force of the rifle on the bullet compare to the force of the bullet on the rifle? They are equal (smaller mass accelerates more)
5. If a bicycle and a massive truck have a head-on collision, upon which vehicle is the impact force greater? They are equal. (smaller mass feels it more)

Two people of equal mass attempt a tug-of-war with a 12-meter rope while standing on frictionless ice. When they pull on the rope, they each slide toward each other. How far does each person slide before they meet?



Meet in middle at 6m!

KEY

More Newton's Laws Practice Questions

1. What force is exerted upon a 60kg mass if it accelerates 15 m/s²?

$F = ma$
$= 60kg \cdot 15m/s^2$
$= 900N$

2. How much net force is required to accelerate a 1000 kg car at 5.00 m/s²?

$F = ma$
$= 1000kg \cdot 5m/s^2$
$= 5000N$

3. If you apply a net force of 1 N on a 200 g book, what is the acceleration of the book?

convert to kg
$200g \times \frac{1kg}{1000g} = 0.2kg$

$a = \frac{F}{m}$
$= \frac{1N}{0.2kg} = 5m/s^2$

4. A car slows down as it approaches a stop light. If a force of -2800 N is required to provide an acceleration of -0.33m/s² what is the car's mass?

$m = \frac{F}{a} = \frac{-2800N}{-0.33m/s^2} = 8484.85kg$

5. If a 600kg racing Formula One car crashes into the barrier at 85m/s (305km/h) and it takes 3 seconds for the car to stop still. What is the force that the car hit with?

calculate a first!

$F = ?$
$m = 600kg$
$a = \frac{\Delta V}{\Delta t}$
$= -28.33m/s^2$

$a = \frac{V_f - V_i}{\Delta t}$
$= \frac{0 - 85m/s}{3s}$
$a = -28.33m/s^2$

$F = ma$
$= 600kg \cdot -28.33m/s^2$
$= -16998N$