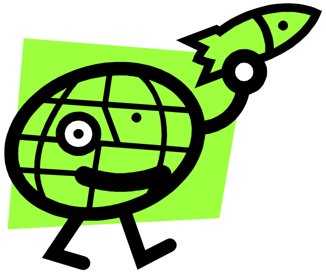
Newton's Laws of Motion

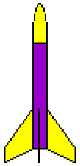


SP1d.Measure and calculate the magnitude of frictional forces and Newton's three Laws of Motion.

Force and mass

- Force – push or pull; required to change an object's motion.

- Vector – show magnitude and direction

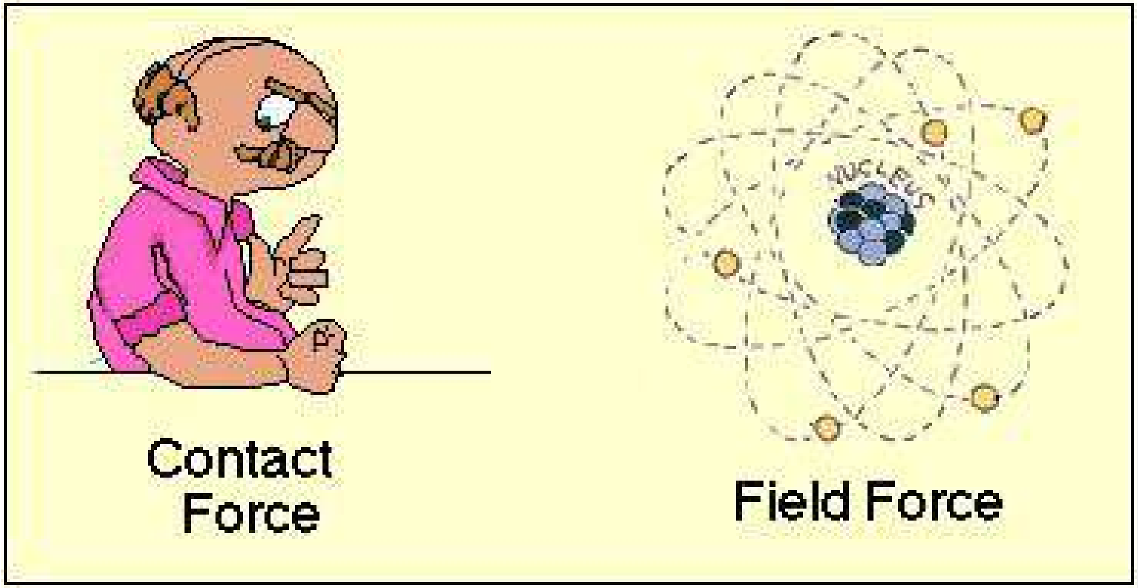


Four Forces Known in the Universe

- Electromagnetic- caused from electric and magnetic interactions
- Strong Nuclear- Responsible for holding nucleus together in the atom; strongest force; acts over the shortest distance
- Gravitation- weakest force; acts over the longest distance
- Weak Nuclear- Responsible for radioactivity in atoms

Types of Forces

- There are two main types of forces
  - Contact
  - Field



Contact Forces

- Contact Force
  - Exists when an object from the external world touches a system and exerts a force on it
- Think About a Book on a Table
  - If you push it, you are exerting a contact force
  - If you put it down, no longer interacting… so no more force from you
  - But table is touching it- table is now exerting a force

Field Forces

- An object can move without something directly touching it
- What if you dropped the book?
  - It falls due to gravity
- Gravitational Force is a field force.
  - They affect movement without being in physical contact
- Can you think of other field forces?
  - Magnetic fields
  - Electric Forces
  - Nuclear Forces

Two Types of Forces

- Example of Contact Forces
- Friction
- Tension

- Examples of Field Forces
- Gravitational
- Electric
- Magnetic
- Applied
- Spring

Force and mass

- Mass – measurement of how difficult it is to change the objects velocity
- Inertia – resistance to change in velocity

- So mass is a measurement of an object's inertia

Newton’s Laws

Background

Sir Isaac Newton (1643-1727)

an English scientist and mathematician famous for

his discovery of the law of

gravity also discovered the

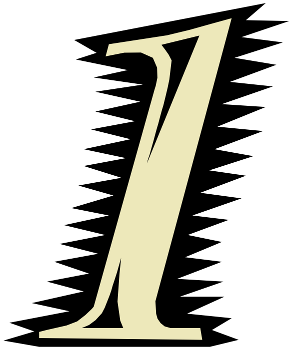
three *laws of motion*.

Today these laws are known as *Newton's Laws of Motion* and describe the motion of all objects on the scale we experience in our everyday lives.

Newton’s Laws of Motion

1. An object in motion tends to stay in motion and an object at rest tends to stay at rest unless acted upon by an unbalanced force.
2. Force equals mass times acceleration (F = ma).
3. For every action there is an equal and opposite reaction.

Newton's First Law



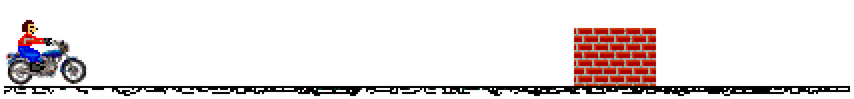
An object at rest tends to stay at rest and an object in motion tends to stay in motion unless acted upon by an unbalanced force.

What does this mean?

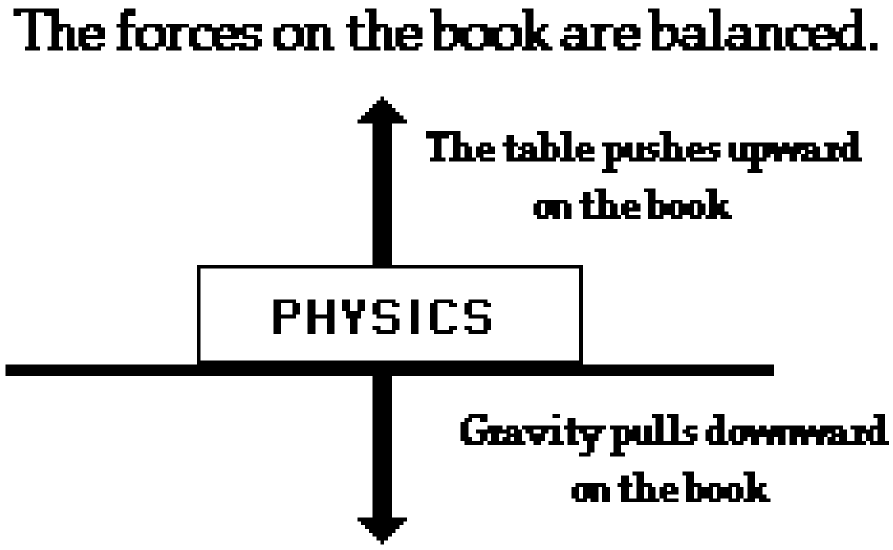
Basically, an object will “keep doing what it was doing” unless acted on by an unbalanced force.

If the object was sitting still, it will *remain stationary*. If it was moving at a constant velocity, it will *keep moving*.

It takes *force* to change the motion of an object.



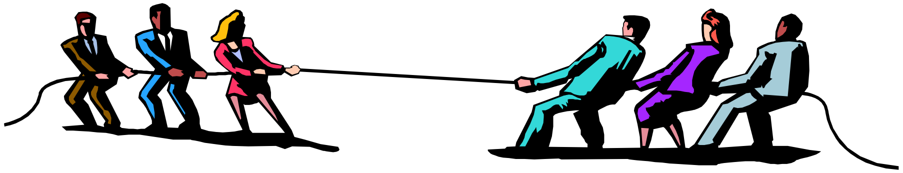
What is meant by *unbalanced force?*



If the forces on an object are equal and opposite, they are said to be balanced, and the object experiences no change in motion. If they are not equal and opposite, then the forces are unbalanced and the motion of the object changes.

Some Examples from Real Life

A soccer ball is sitting at rest. It takes an unbalanced force of a kick to change its motion.



Two teams are playing tug of war. They are both exerting equal force on the rope in opposite directions. This balanced force results in no change of motion.

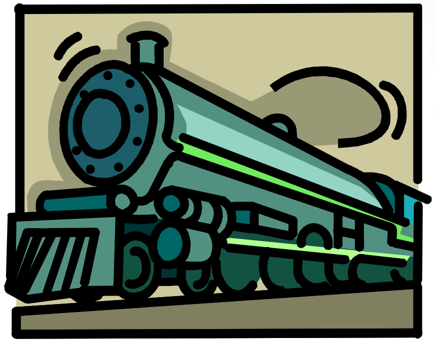
Newton's First Law is also called the *Law of Inertia*

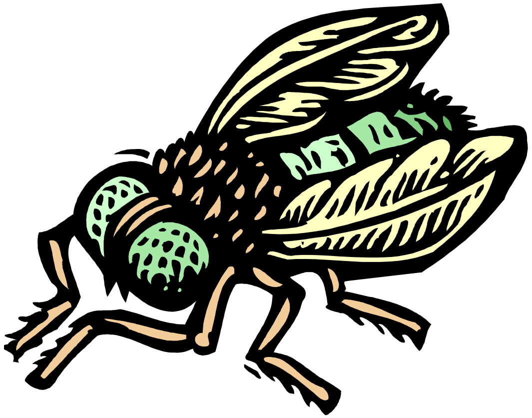
Inertia: the tendency of an object to resist changes in its state of motion

The First Law states that *all objects have inertia*. The more mass an object has, the more inertia it has (and the harder it is to change its motion).

More Examples from Real Life

A powerful locomotive begins to pull a long line of boxcars that were sitting at rest. Since the boxcars are so massive, they have a great deal of inertia and it takes a large force to change their motion. Once they are moving, it takes a large force to stop them.





On your way to school, a bug flies into your windshield. Since the bug is so small, it has very little inertia and exerts a very small force on your car (so small that you don't even feel it).

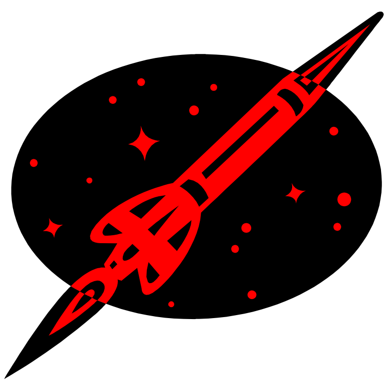
If objects in motion tend to stay in motion, why don't moving objects keep moving forever?

Things don't keep moving forever because there's almost always an unbalanced force acting upon it.

A book sliding across a table slows down and stops because of the force of *friction*.

If you throw a ball upwards it will eventually slow down and fall because of the force of *gravity*.

In outer space, away from gravity and any sources of friction, a rocket ship launched with a certain speed and direction would *keep going in that same direction and at that same speed forever.*



Question

- What is the relationship between mass and inertia?
- Mass is a measure of how much inertia something has.

Question

- Is inertia a force?
- No, inertia is a *property* of matter. Something has inertia. Inertia does not act on something.

Question

- A force of gravity between the sun and its planets holds the planets in orbit around the sun. If that force of gravity suddenly disappeared, in what kind of path would the planets move?
- Each planet would move in a straight line at constant speed.

Question

- The Earth moves about 30 km/s relative to the sun. But when you jump upward in front of a wall, the wall doesn't slam into you at 30 km/s. Why?
- both you and the wall are moving at the same speed, before, during, and after your jump.

Newton’s Second Law

Force equals mass times acceleration.

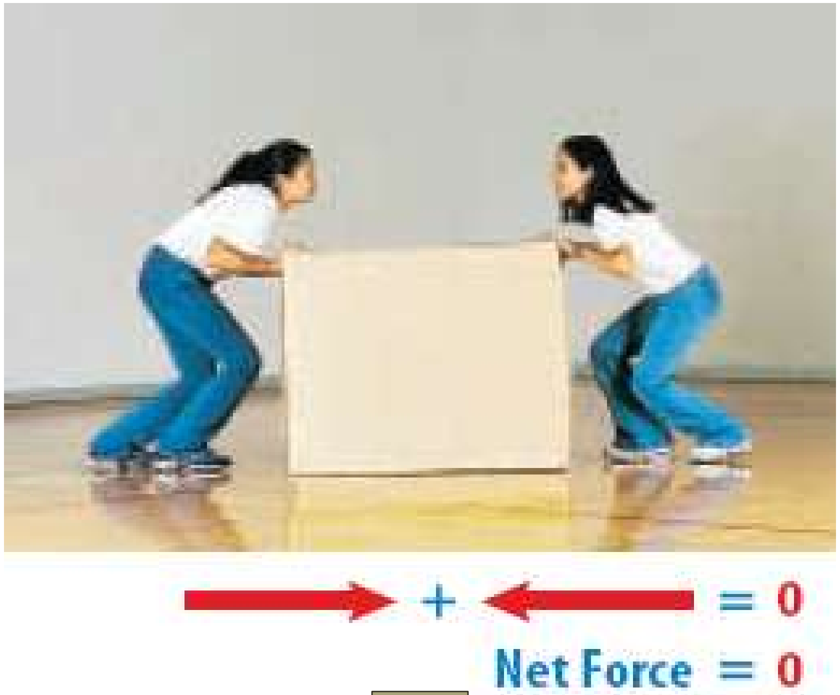
$F = ma$

<u>Acceleration</u>: a measurement of how quickly an object is changing speed.

Acceleration

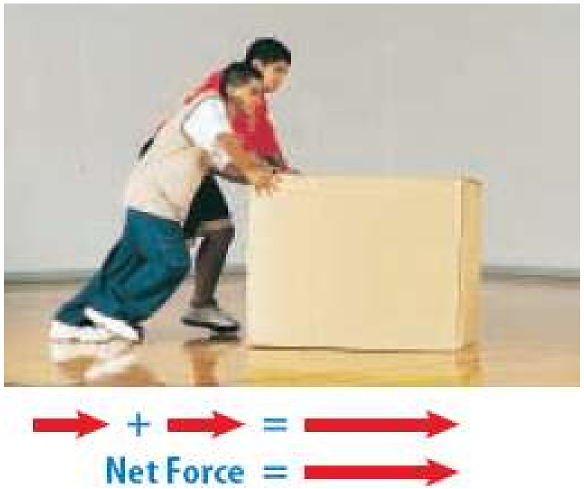
- An ***unbalanced force*** causes something to accelerate.
- A force can cause motion only if it is met with an ***unbalanced force***.
- Forces can be balanced or unbalanced.
- Depends on the **net force** acting on the object
- **Net force (F_{net}):** The sum total and direction of all forces acting on the object.
    - **Net forces: Always cause acceleration.**

Balanced Versus Unbalanced



Balanced forces cause no acceleration.

Balanced Versus Unbalanced



Unbalanced forces cause acceleration.

What does F = ma mean?

Force is *directly proportional* to mass and acceleration. Imagine a ball of a certain mass moving at a certain acceleration. This ball has a certain force.

Now imagine we make the ball twice as big (double the mass) but keep the acceleration constant. F = ma says that this new ball has *twice the force* of the old ball.

Now imagine the original ball moving at twice the original acceleration. F = ma says that the ball will again have *twice the force* of the ball at the original acceleration.

In Other Words…

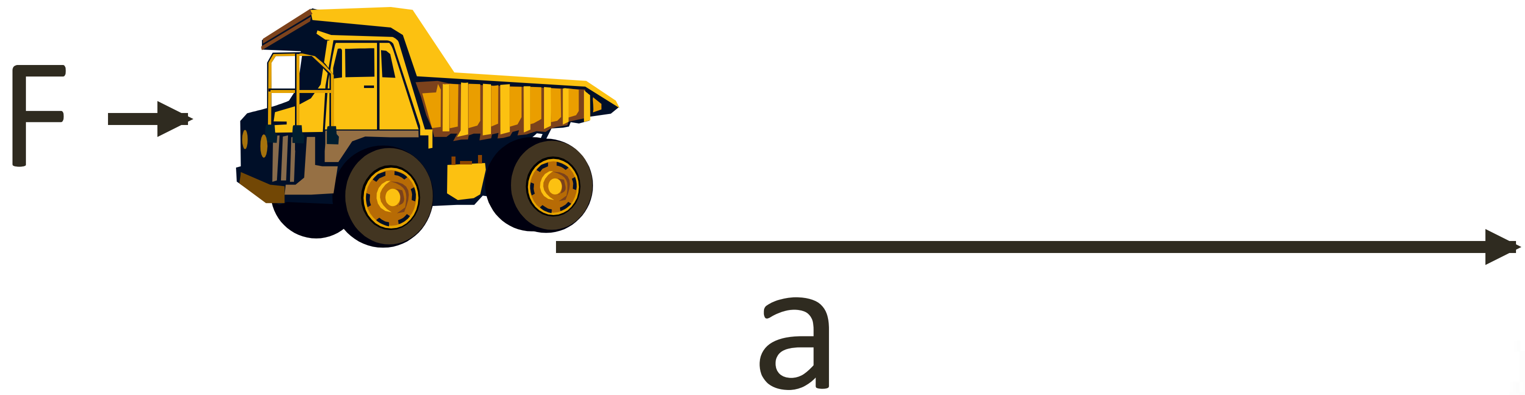
Small Force = Small Acceleration

F

a

In Other Words…

Large Force = Large Acceleration

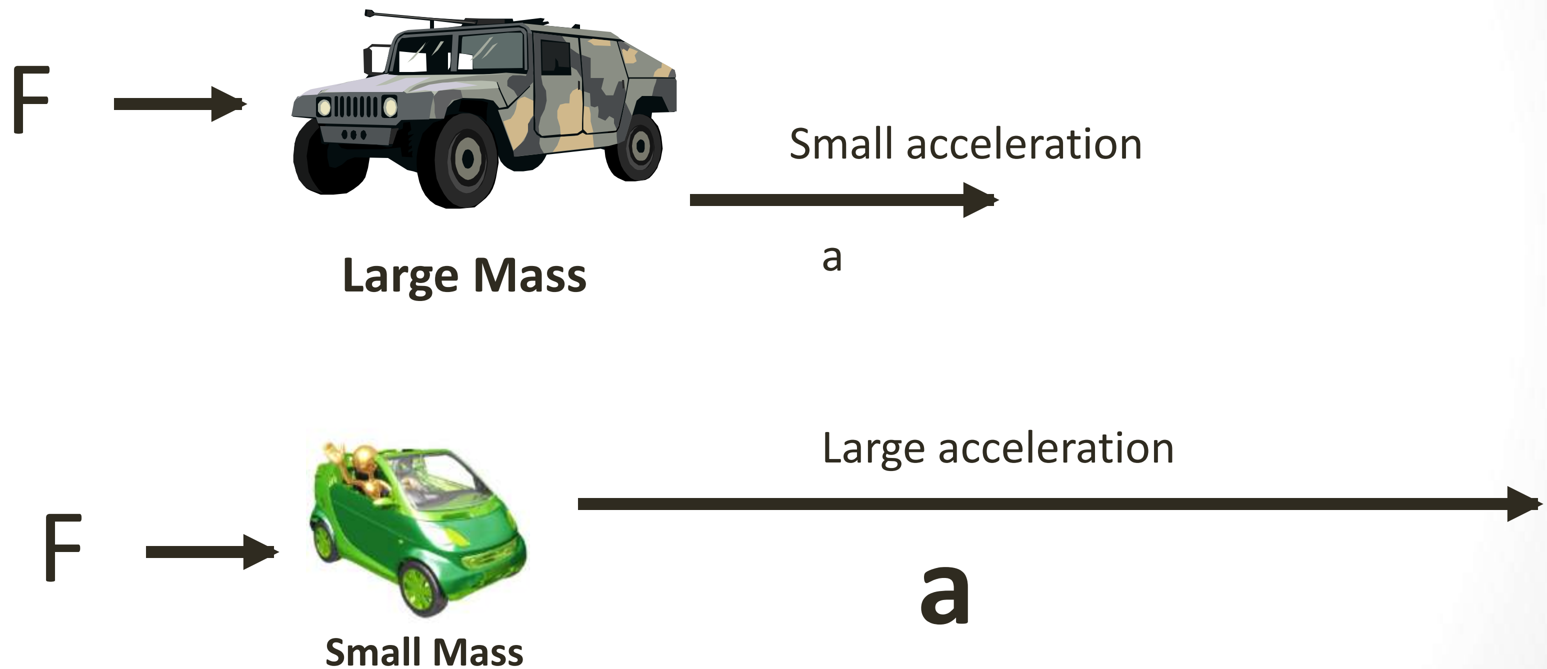


So….if you push twice as hard, it accelerates twice as much.

But there is a twist….

- Acceleration is INVERSELY related to the mass of the object.

In other words…..using the same amount of force….



More about F = ma

If you *double* the mass, you *double* the force. If you *double* the acceleration, you *double* the force.

What if you double the mass *and* the acceleration?

$$(2m)(2a) = 4F$$

Doubling the mass *and* the acceleration *quadruples* the force.

What does F = ma say?

F = ma basically means that the force of an object comes from its mass and its acceleration.

Force is measured in

Newtons (N) = mass (kg) x acceleration (m/s^2)

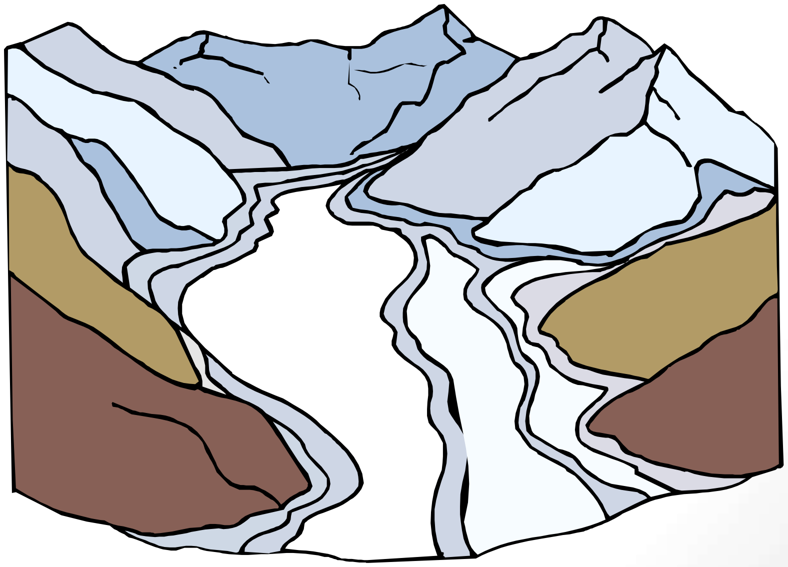
Or

kg m/s^2

$$1\ \text{Newton} = 1\ \text{kg} * \frac{m}{s^2}$$

High Mass

Something very massive (high mass) that's changing speed very slowly (low acceleration), like a glacier, can still have great force.



Low Mass

Something very small (low mass) that's changing speed very quickly (high acceleration), like a bullet, can still have a great force. Something very small changing speed very slowly will have a very weak force.

In Summary

- The acceleration of an object is directly proportional to the net force & inversely proportional to its mass.

- F = ma
- Force = Mass x Acceleration

How Does Weight Tie In?

- **Mass** is the quantity of matter in an object. More specifically, mass is a measure of the inertia, or "laziness," that an object exhibits in response to any effort made to start it, stop it, or otherwise change its state of motion.
- **Weight** is the force of gravity on an object.
- If force is equal to mass x acceleration then, Weight is equal to mass x acceleration due to gravity

Weight

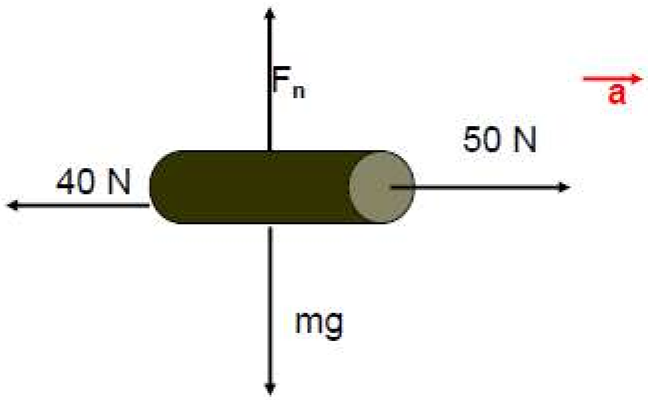
- So on earth, your weight is
- Your Mass x 9.8 m/s/s
- When you are drawing FBDs and the force of gravity factors in (almost always), you can figure out the value of that force
- For example, if I say a 2kg book is resting on a table…
- The force due to gravity (weight) is 2 x 9.8
- The normal force would be the same but opposite direction

Solving Newton Second Law Problems

- **1.Draw a free body diagram**
- **2.Break vectors into components if needed**
- **3.Find the NET force by adding and subtracting forces that are on the same axis as the acceleration.**
- **4.Set net force equal to "ma" this is called writing an EQUATION OF MOTION.**
- **NOTE: To avoid negative numbers, always subtract the smaller forces from the larger one. Be sure to remember which direction is larger.**

Example

- A 50 N applied force drags an 8.16 kg log to the right across a horizontal surface. What is the acceleration of the log if the force of friction is 40.0 N?



$$F_{NET} = ma$$

$$F_a - F_f = ma$$

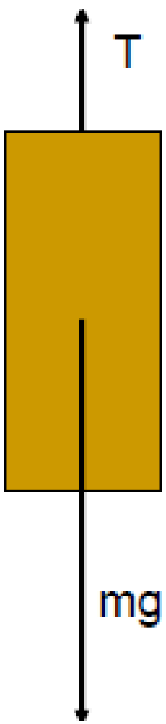
$$50 - 40 = 8.16a$$

$$10 = 8.16a$$

$$a = \text{1.23 m/s/s}$$

Tougher Example

- An elevator with a mass of 2000 kg rises with an acceleration of 1.0 m/s/s. What is the tension in the supporting cable?



Equation of Motion

$$F_{NET} = ma$$

$$\boxed{T - mg = ma}$$

$$T = ma + mg$$

$$T = (2000)(1) + (2000)(9.8)$$

$$T = \text{21,600 N}$$

Net Forces and Newton’s Second Law

CHECK YOUR UNDERSTANDING

Question

- Suppose that the acceleration of an object is zero. Does this mean that there are no forces acting on it?
- No, it means the forces acting on it are balanced and the net force is zero.
- Think about gravity and normal force acting on stationary objects.

Question

- When a basketball player dribbles a ball, it falls to the floor and bounces up. Is a force required to make it bounce? Why? If a force is needed, what is the agent.
- Yes, when it bounced it changed direction. A change in direction = acceleration. Acceleration requires a force. The agent was the floor.

EQUILIBRIUM

Things that are in balance with one another illustrate ***equilibrium***.

Things in *mechanical equilibrium* are stable, without changes of motion.

The rocks are in mechanical equilibrium.

An unbalanced external force would be needed to change their resting state.

Mechanical Equilibrium

Mechanical equilibrium is a state wherein no physical changes occur.
Whenever the net force on an object is zero, the object is in mechanical equilibrium—this is known as the **equilibrium rule.**

Mechanical Equilibrium

$$\Sigma F = 0$$

The Σ symbol stands for "the sum of."

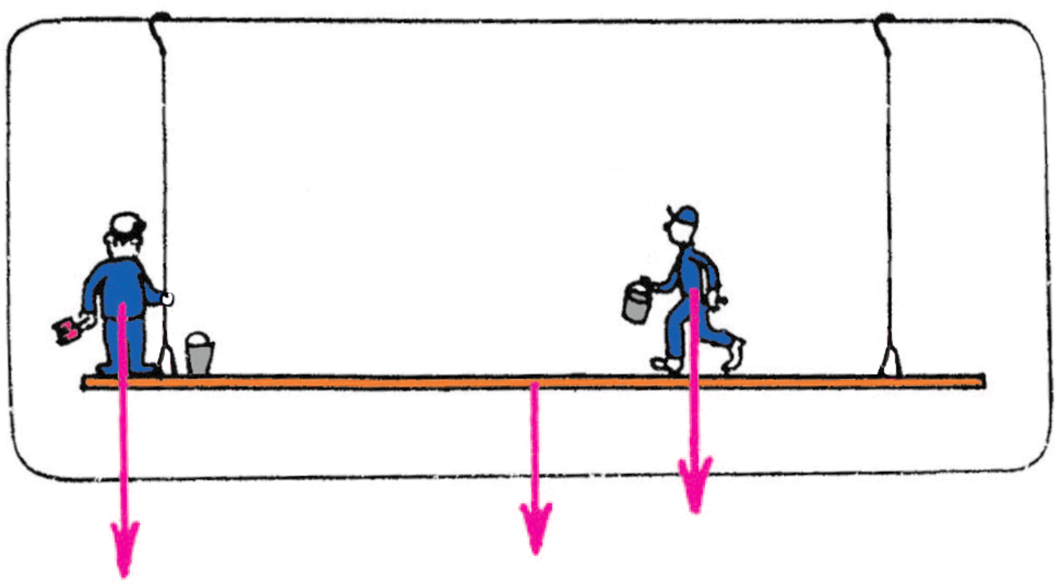
F stands for "forces."

For a suspended object at rest, the forces acting upward on the object must be balanced by other forces acting downward.

The vector sum equals zero.

Mechanical Equilibrium

The sum of the upward vectors equals the sum of the downward vectors. $\Sigma F = 0$, and the scaffold is in equilibrium.



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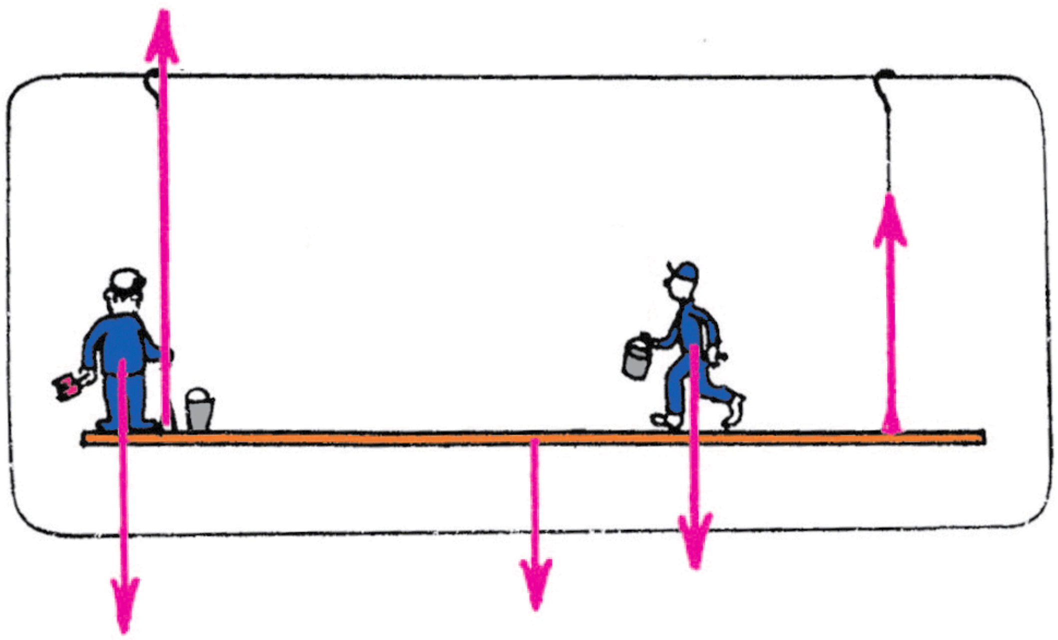

Mechanical Equilibrium

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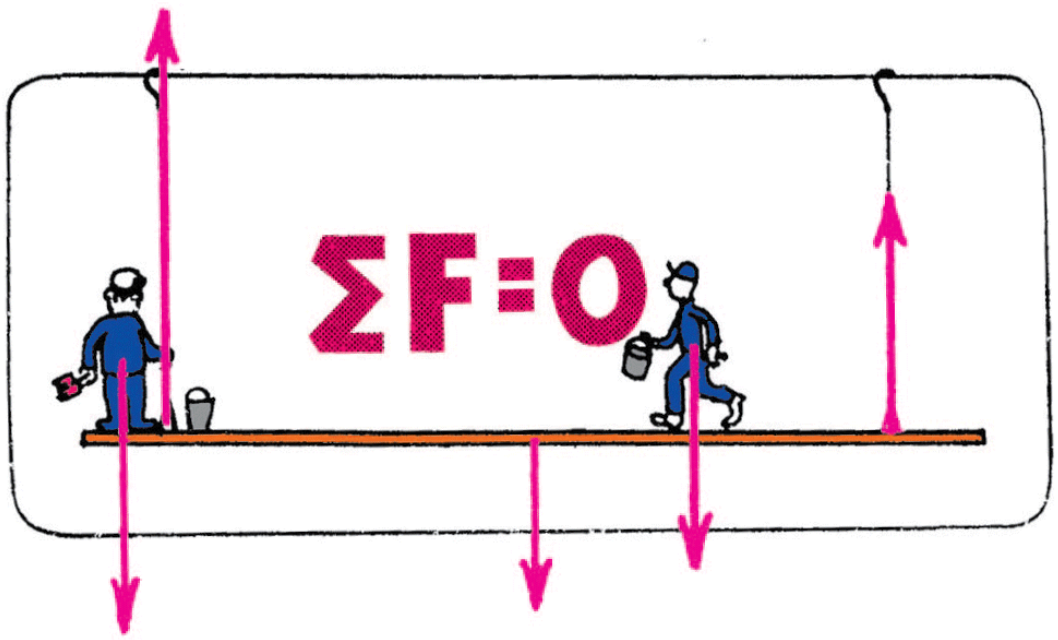


Equilibrium for stationary objects

- To find the force necessary to put something in equilibrium, first find the **resultant**.
- The force necessary to put something in equilibrium is called the **equilibrant force.**
- The equilibrant force is **equal but opposite** to the resultant.

Equilibrium for Moving Objects

The state of rest is only one form of equilibrium.
An object moving at constant speed in a straight-line path is also in a state of equilibrium. Once in motion, if there is no net force to change the state of motion, it is in equilibrium.

Equilibrium for Moving Objects

An object under the influence of only one force cannot be in equilibrium.
Only when there is no force at all, or when two or more forces combine to zero, can an object be in equilibrium.

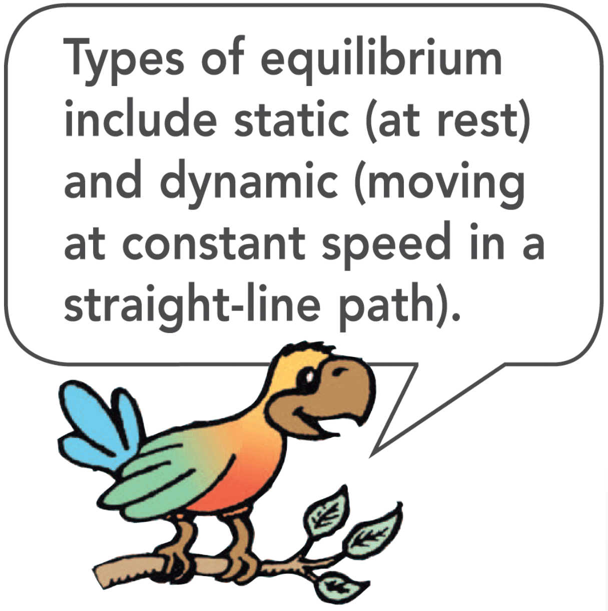
Equilibrium for Moving Objects

When the push on the desk is the same as the force of friction between the desk and the floor, the net force is zero and the desk slides at an unchanging speed.

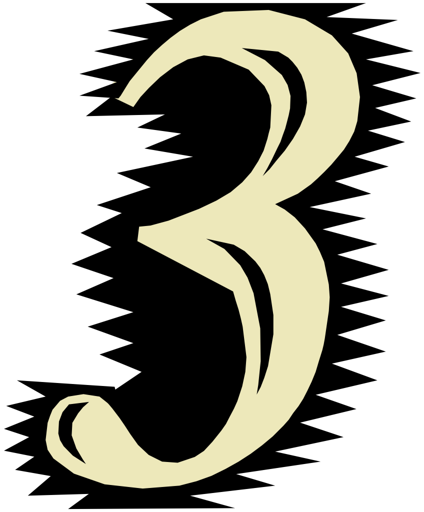
Equilibrium for Moving Objects

If the desk moves steadily at constant speed, without change in its motion, it is in equilibrium.

- Friction is a contact force between objects that slide or tend to slide against each other.
- In this case, $\Sigma F = 0$ means that the force of friction is equal in magnitude and opposite in direction to the pushing force.



Newton’s Third Law



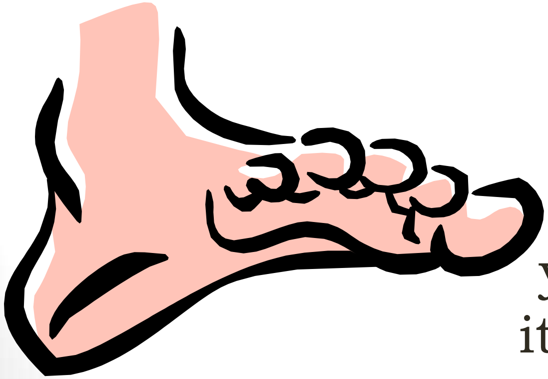
For every action there is an equal and opposite reaction.

What does this mean?

For every force acting on an object, there is an equal force acting in the opposite direction. Right now, gravity is pulling you *down* in your seat, but Newton's Third Law says your seat is pushing *up* against you with *equal force*. This is why you are not moving. There is a *balanced force* acting on you– gravity pulling down, your seat pushing up.

Think about it . . .

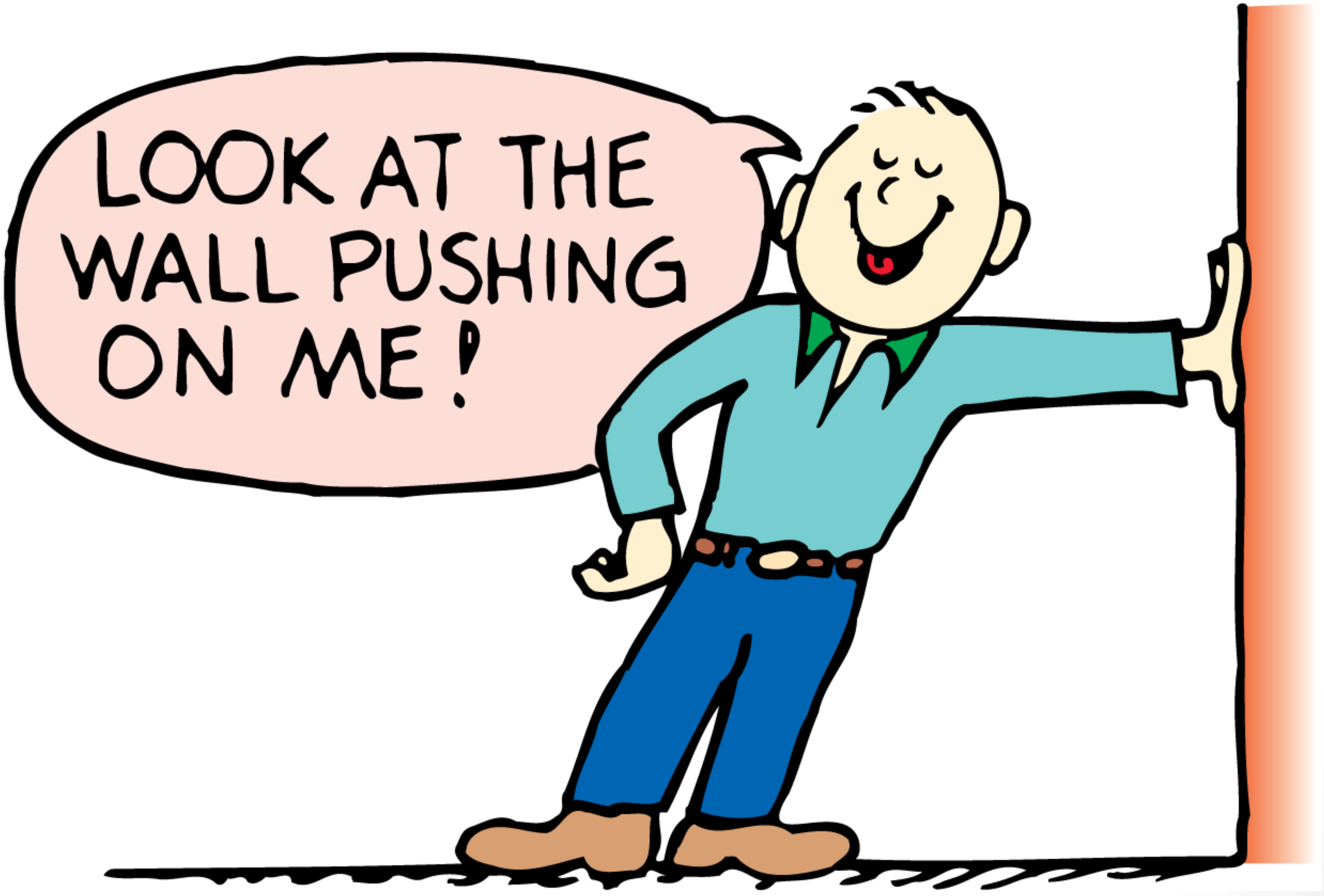
What happens if you are standing on a skateboard or a slippery floor and push against a wall? You slide in the opposite direction (away from the wall), because you pushed on the wall but the wall pushed back on you with equal and opposite force.



Why does it hurt so much when you stub your toe? When your toe exerts a force on a rock, the rock exerts an equal force back on your toe. The harder you hit your toe against it, the more force the rock exerts back on your toe (and the more your toe hurts).

Forces and Interactions

When you push on the wall, the wall pushes on you.



Newton’s Third Law

Newton’s third law describes the relationship between two forces in an interaction.

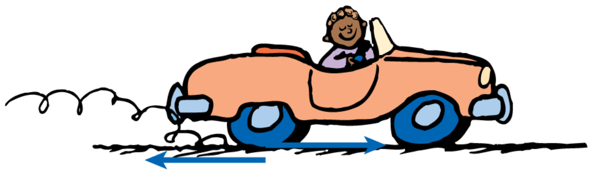
- One force is called the **action force.**
- The other force is called the **reaction force.**
- Neither force exists without the other.
- They are equal in strength and opposite in direction.
- They occur at the same time (simultaneously).

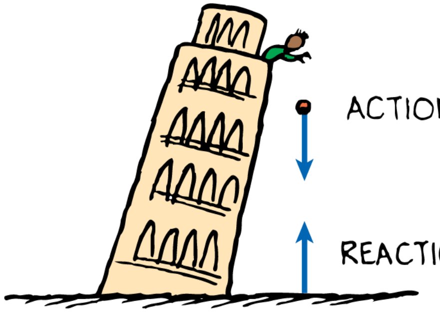
Newton’s Third Law

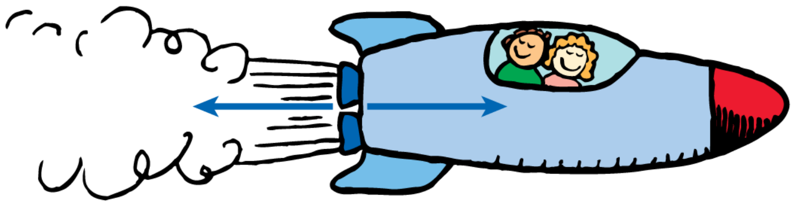
When the girl jumps to shore, the boat moves backward.

Identifying Action and Reaction Pairs

When action is *A exerts force on B,* the reaction is simply *B exerts force on A*.

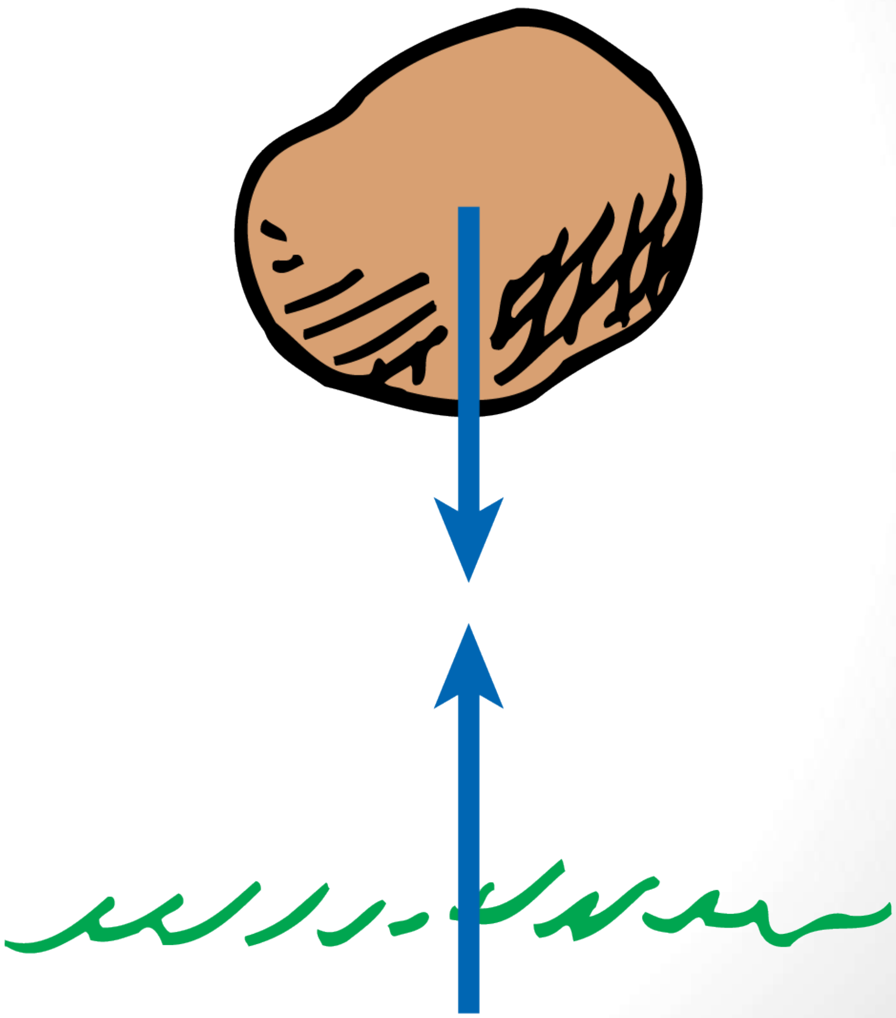






Action and Reaction on Different Masses

Earth is pulled up by the boulder with just as much force as the boulder is pulled down by Earth.



Question

1. A force interaction requires at least a(n)
   a. single force.
   b. pair of forces.
   c. action force.
   d. reaction force.

Question

3. The force that directly propels a motor scooter along a highway is that provided by the
   a. engine.
   b. fuel.
   c. tires.
   d. road.

Question

- We know that Earth pulls on the moon. Does the moon also pull on Earth? If so, which pull is stronger?
- Asking which pull is stronger is like asking which distance is greater—between New York and San Francisco, or between San Francisco and New York. The distances either way are the same. It is the same with force pairs. Both Earth and moon pull on each other with equal and opposite forces.

Question

- Suppose a friend who hears about Newton's third law says that you can't move a football by kicking it because the reaction force by the kicked ball would be equal and opposite to your kicking force. The net force would be zero, so no matter how hard you kick, the ball won't move! What do you say to your friend?
- If you kick a football, it will accelerate. No other force has been applied to the ball. Tell your friend that you can't cancel a force on the ball with a force on your foot.

Review

Newton's First Law:

Objects in motion tend to stay in motion and objects at rest tend to stay at rest unless acted upon by an unbalanced force.

Newton's Second Law:

Force equals mass times acceleration ($F = ma$).

Newton's Third Law:

For every action there is an equal and opposite reaction.