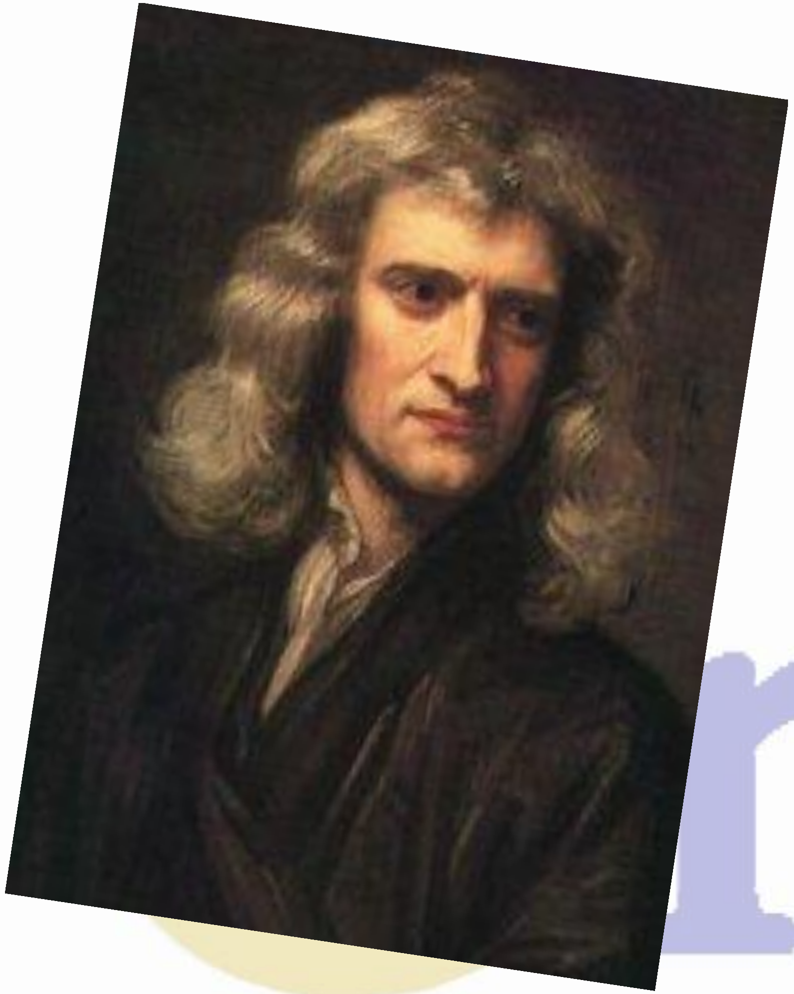
Newton's Laws of Motion



"If I have ever made any valuable discoveries, it has been owing more to patient attention, than to any other talent."

-Sir Isaac Newton

Sir Isaac Newton (1642 – 1727)

- Sir Isaac Newton - an English scientist and mathematician famous for his discovery of the law of gravity also discovered the three *laws of motion*.

- He published them in his book **Philosophiae Naturalis Principia Mathematica** (mathematic principles of natural philosophy) in 1687.

The 1st Law of Motion

(Law of Inertia)

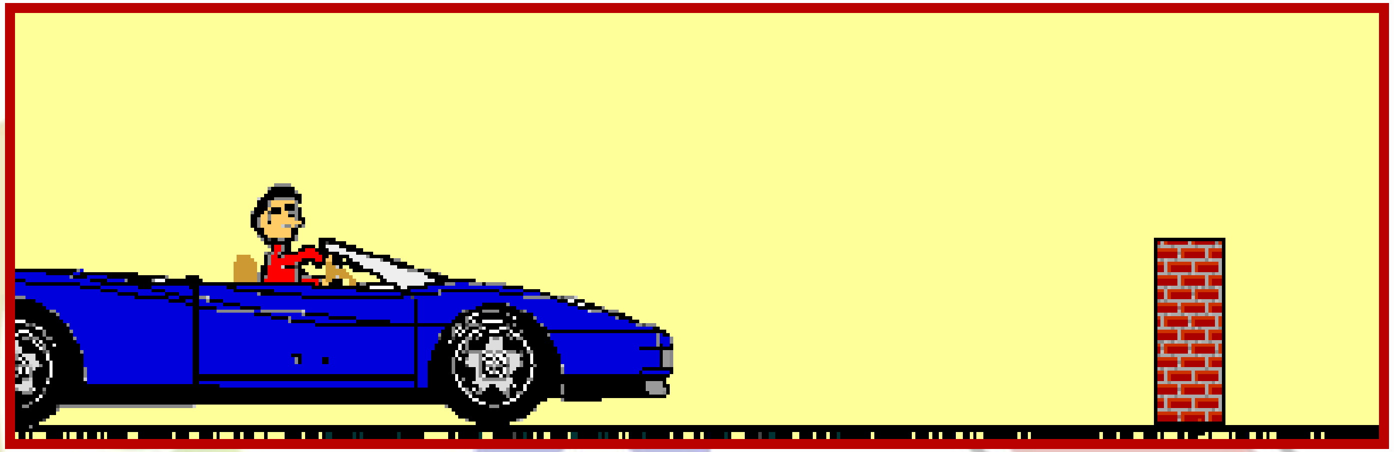
An object at rest will stay at rest, and an object in motion will stay in motion at constant velocity, unless acted upon by an unbalanced (an external) force.

It is the natural tendency of objects to keep on doing what they're doing. All objects resist changes in their state of motion. In the absence of an unbalanced force, an object in motion will maintain its state of motion. This is often called the **Law of Inertia**.

Inertia means not wanting to change what you are doing.

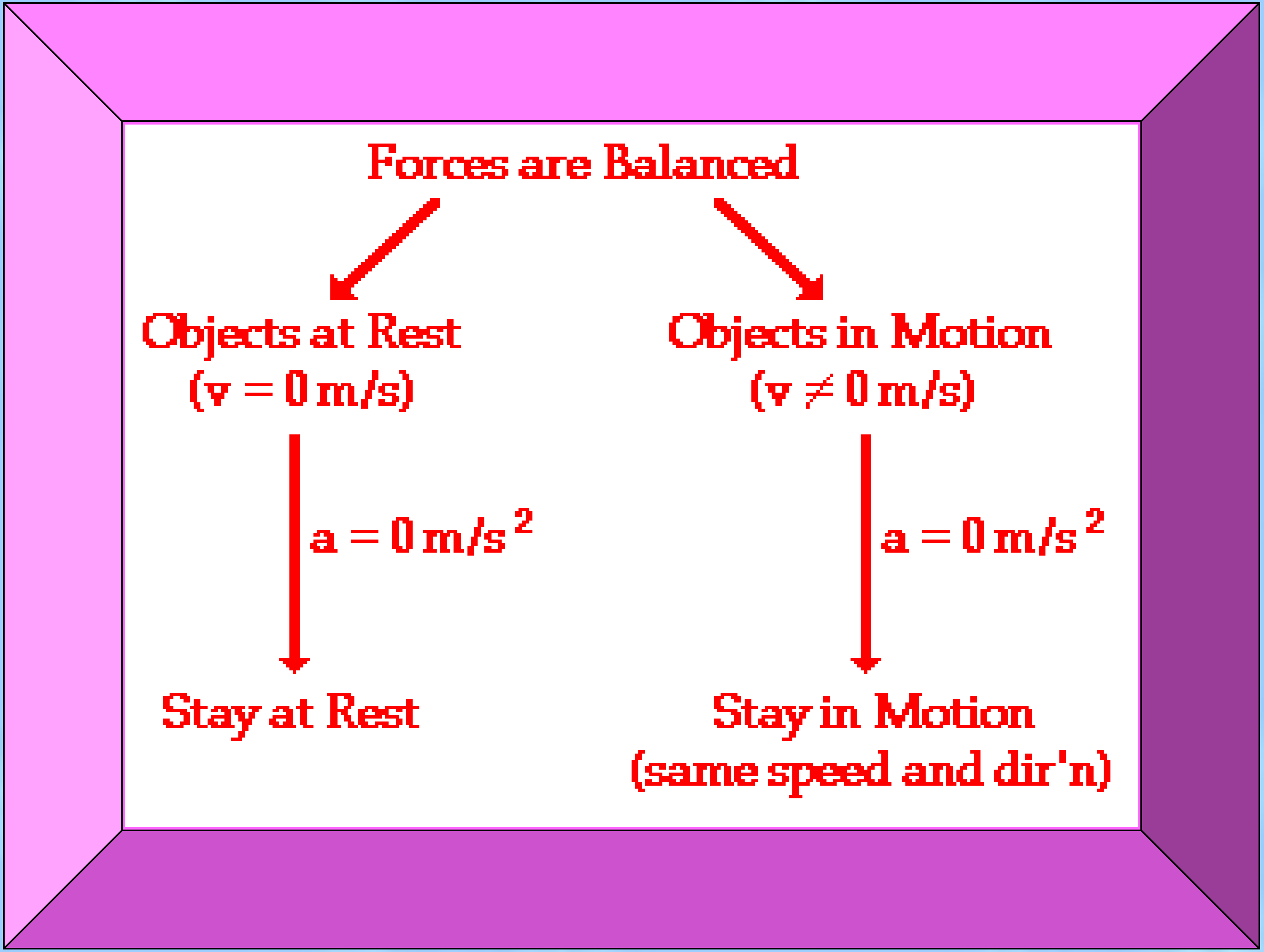
- *Inertia is the tendency of an object to resist changes in its velocity: whether in motion or motionless.*

These pumpkins will not move unless acted on by an unbalanced force.



Because of inertia, objects (including you) resist changes in their motion. When the car going 80 km/hour is stopped by the brick wall, your body keeps moving at 80 m/hour.

a) Balanced and Unbalanced Forces



Forces are Balanced
Objects at Rest
(v = 0 m/s)
a = 0 m/s 2
Stay at Rest
Objects in Motion
(v ≠ 0 m/s)
a = 0 m/s 2
Stay in Motion
(same speed and dir'n)

Forces are Unbalanced

↓

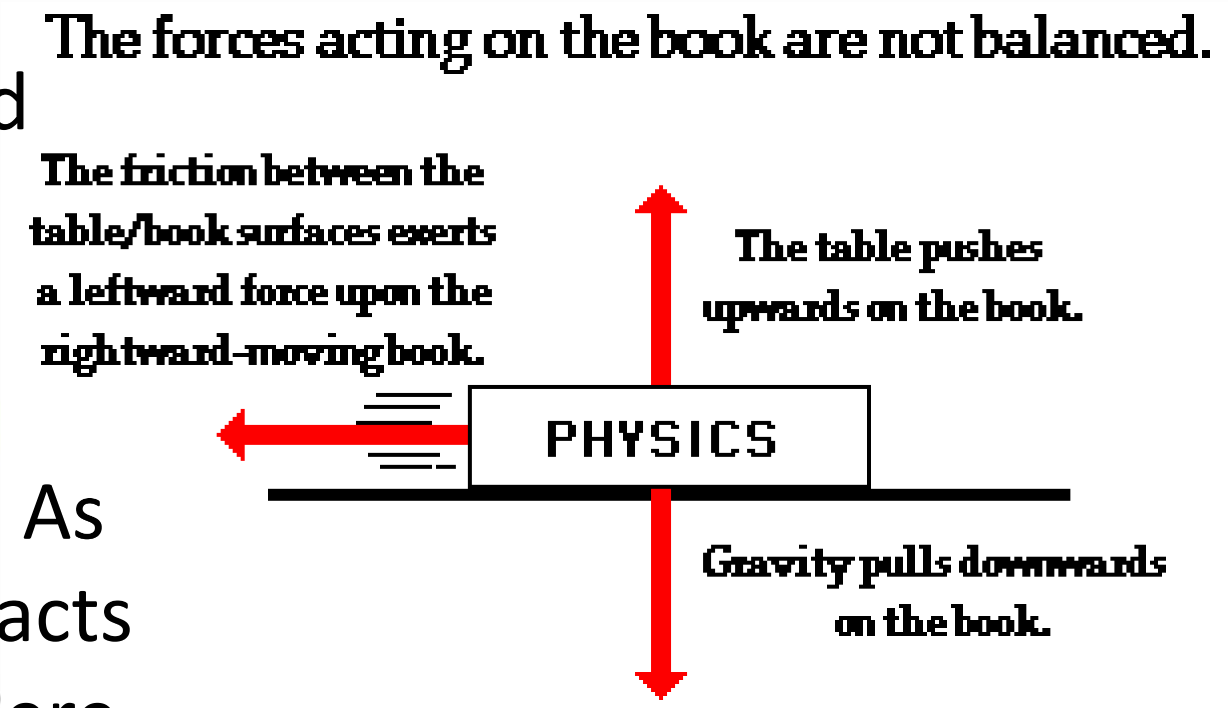
There is an acceleration

The acceleration depends directly upon the "net force"

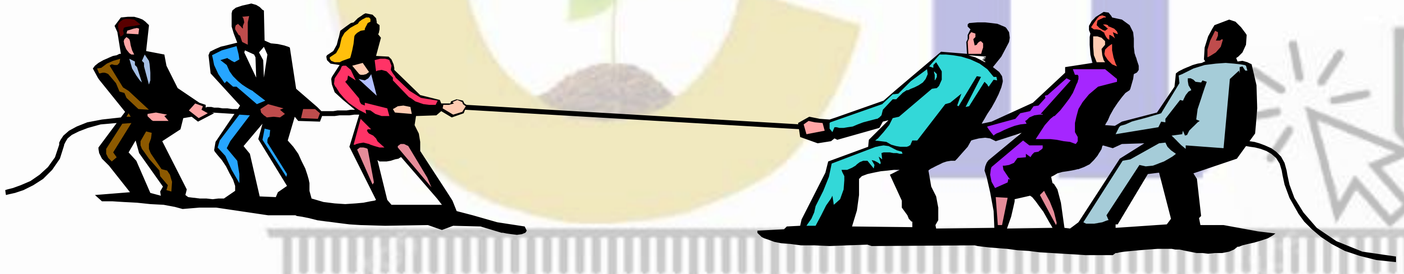
The acceleration depends inversely upon the object's mass.

Unbalanced Forces

The force of gravity pulling downward and the force of the table pushing upwards on the book are of equal magnitude and opposite directions. These two forces balance each other. As the book moves to the right, friction acts to the left to slow the book down. There is an unbalanced force; and as such, the book changes its state of motion. The book is not at equilibrium and subsequently accelerates. [Unbalanced forces cause accelerations].

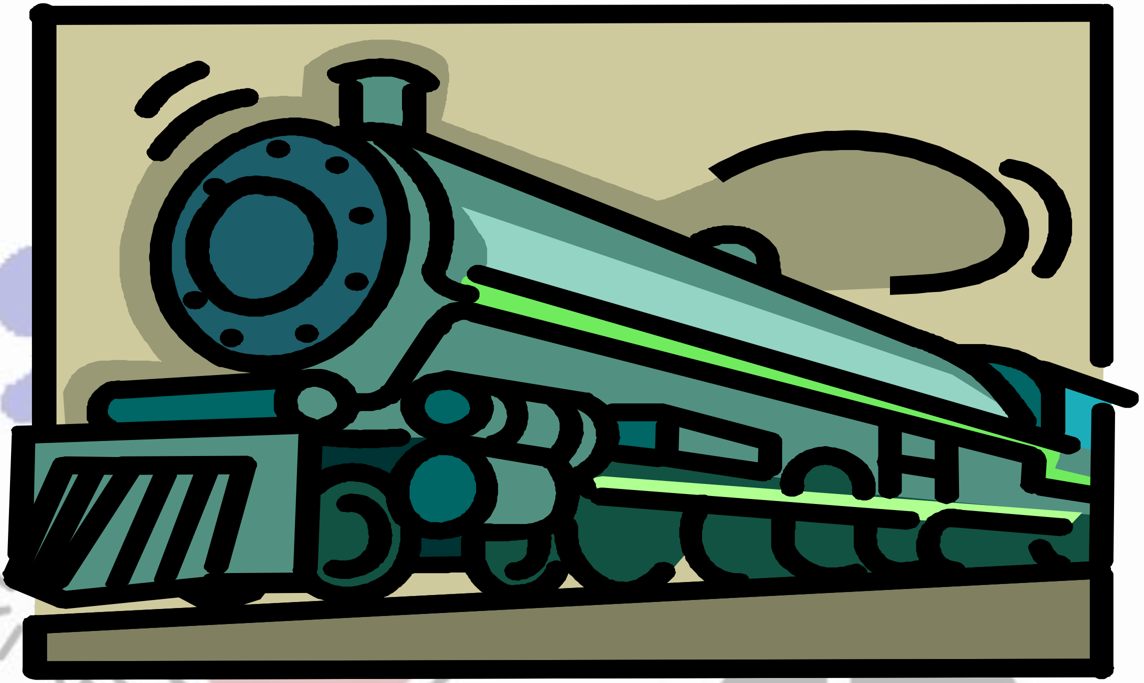


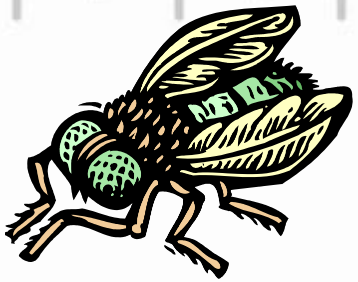
A soccer ball is sitting at rest. It takes an unbalanced force of a kick to change its motion.



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.

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.



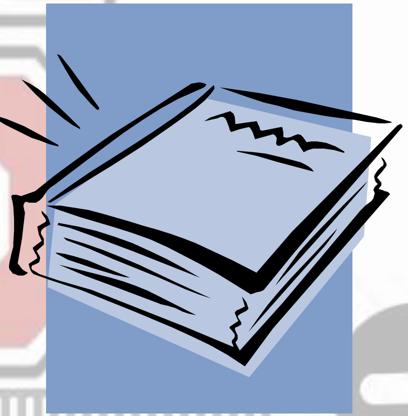


On your way to school, a bug flies into your windshield. Since the bug is so small, it has very little inertia and exerts a very small force on your car (so small that you don't even feel it).

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

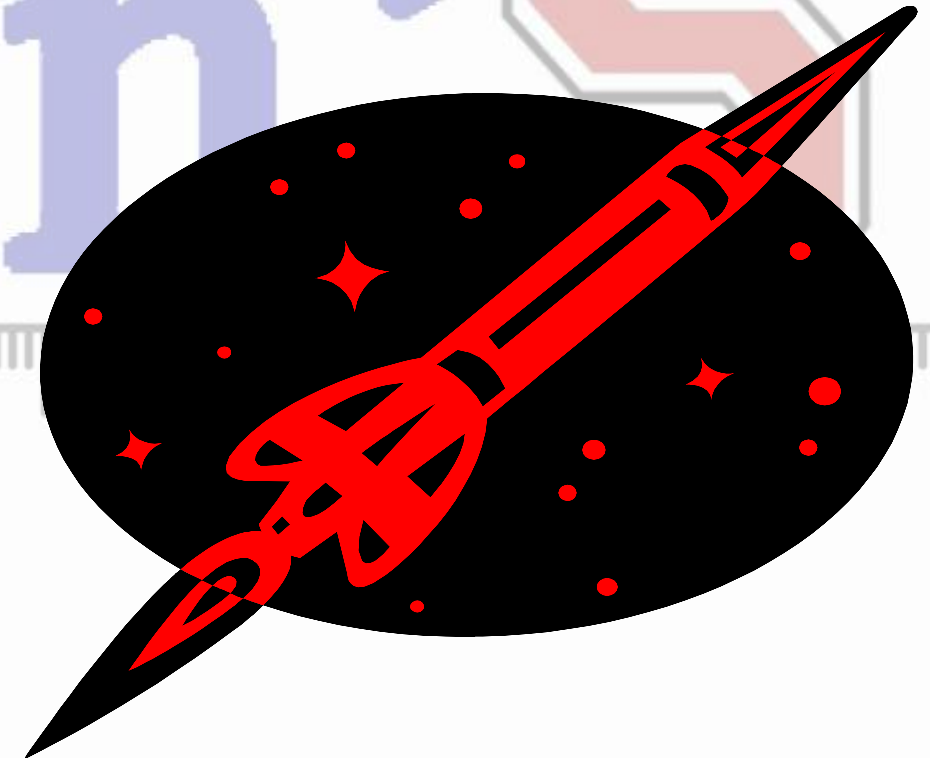
Things don't keep moving forever because there's almost always an unbalanced force acting upon it.

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.*



Why was it so difficult to stop the TITANIC from colliding with the iceberg?

The mass of the Titanic is very large.

Inertia is proportionate to mass.

The Titanic could not change its direction because its extremely high inertia forces it to continue in a straight line, thereby colliding with the iceberg.

Why then, do we observe every day objects in motion slowing down and becoming motionless seemingly without an outside force?

It's a force we sometimes cannot see – friction.

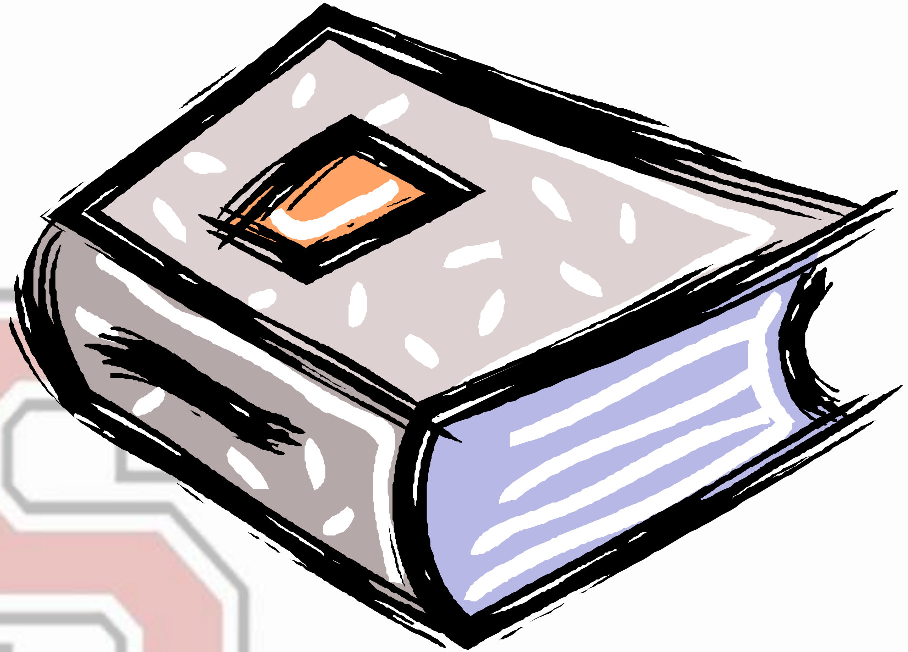
Objects on earth, unlike the frictionless space the moon travels through, are under the influence of friction.

What is this unbalanced force that acts on an object in motion?

Friction!

- There are four main types of friction:
  - Sliding friction: ice skating
  - Rolling friction: bowling
  - Fluid friction (air or liquid): air or water resistance
  - Static friction: initial friction when moving an object

Slide a book across a table and watch it slide to a rest position. The book comes to a rest because of the *presence* of a force - that force being the force of friction - which brings the book to a rest position.



In the absence of a force of friction, the book would continue in motion with the same speed and direction - forever! (Or at least to the end of the table top.)

The 2nd Law of Motion

When a net (or unbalanced) force acts on a body, the body is accelerated in the direction of the force. The acceleration is directly proportional to the force and inversely proportional to the mass.

F = ma

Force = mass x acceleration

What are the units of force?

Newtons (N) (after Isaac Newton)

What do we measure forces with?

A spring balance.

What is a Newton?

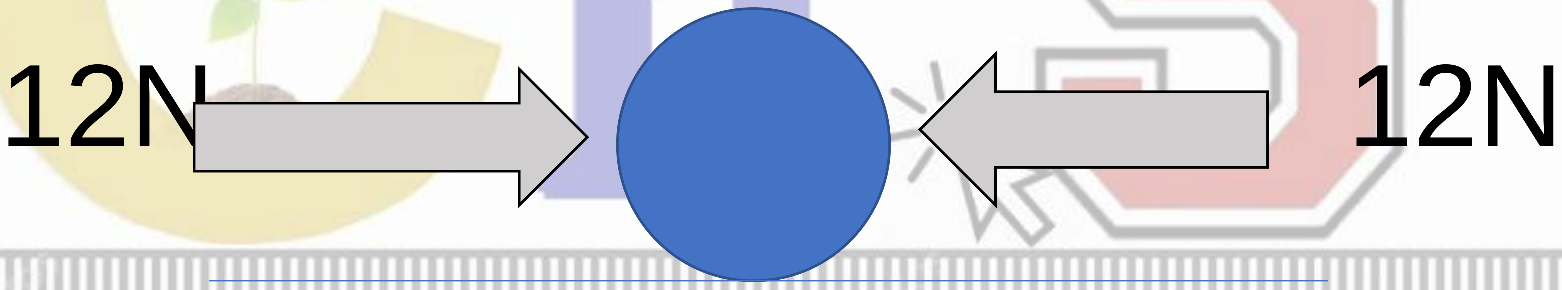
One Newton (1N) is the force required to give a mass of 1kg an acceleration of $1 m/s^2$.

- How much force is needed to accelerate a 1400 kilogram car 2 meters per second/per second?
- F = m x a
- F = 1400 kg x 2 meters per second/second
- 2800 kg-meters/second/second or **2800 N**

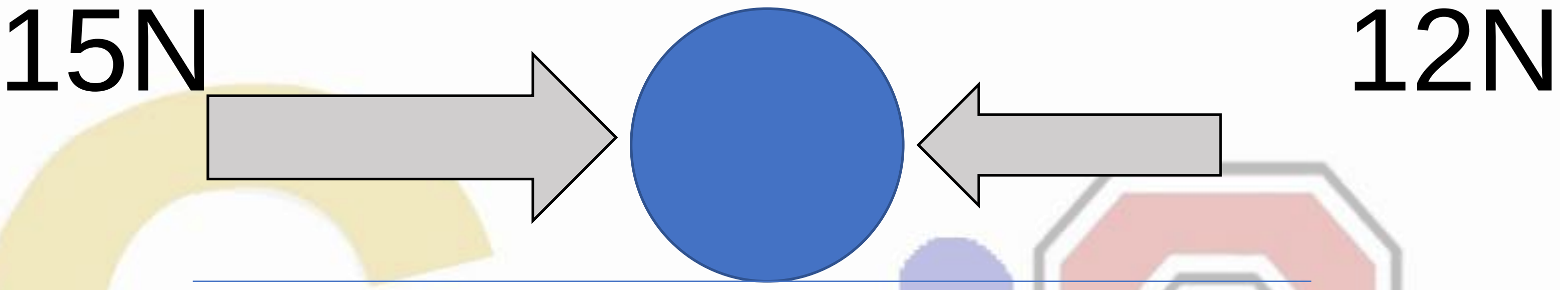
Net Force N	Mass Kilograms	Acceleration m/s/s
10	2	5 m/s/s
20	2	10 m/s/s
20		5 m/s/s
10	5	m/s/s
	1	10 m/s/s

If mass remains constant, doubling the acceleration, doubles the force.
If force remains constant, doubling the mass, halves the acceleration.

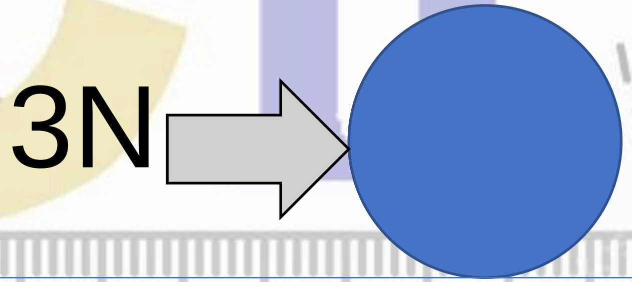
Lets look at combining the forces acting on an object to see what the **resultant force** would be.



Resultant = 0 N



Resultant = 15 – 12 = 3N (to the right)

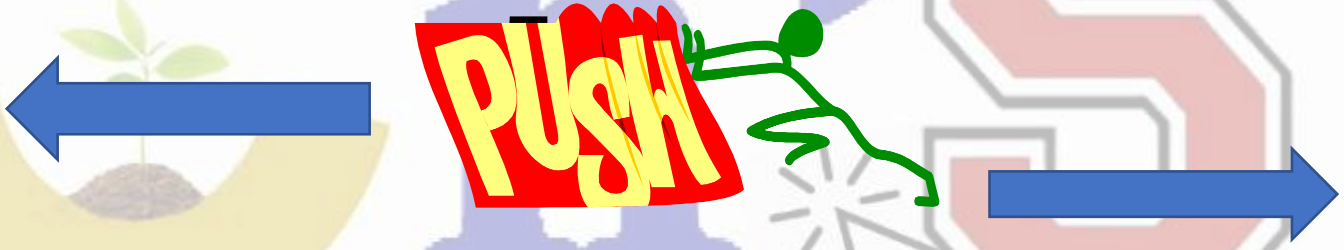


Lets look at an example.

Kay is pushing a box along the floor at a constant velocity with a force of 20N. The mass of the box is 5kg.

1. What must the frictional force be?

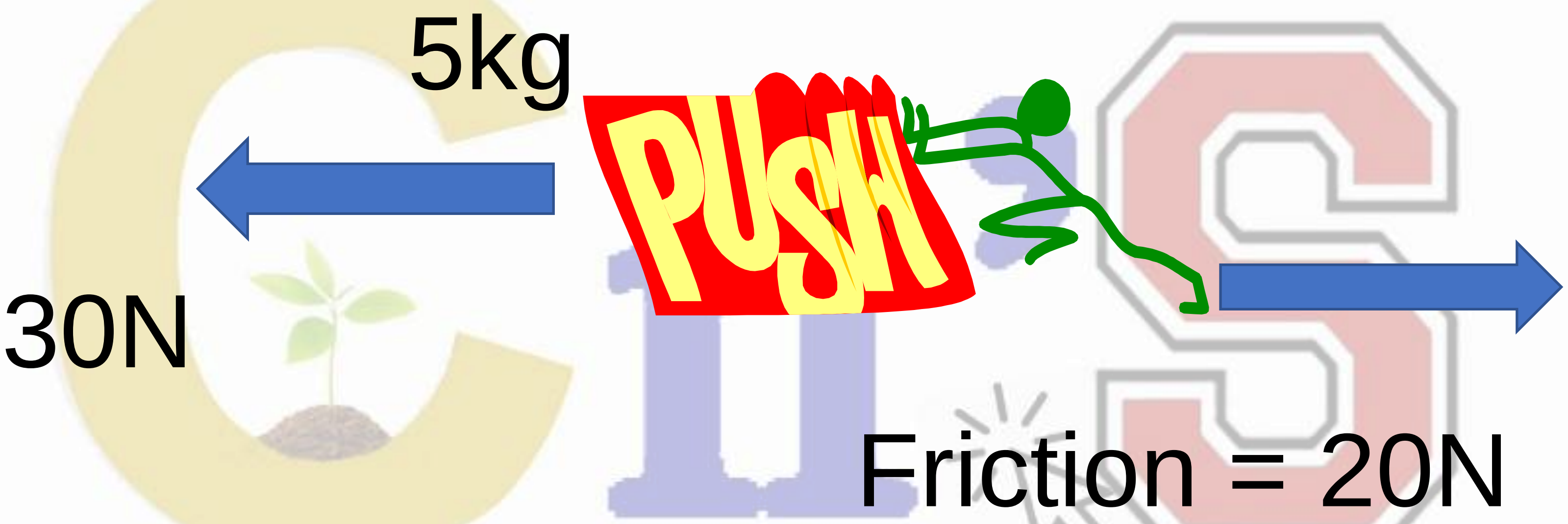
20N



Friction

Constant velocity means forces must be balanced so friction will be 20N too but in the opposite direction!

2. When the force is increased to 30N, what acceleration will Kay be giving the box?



Resultant or Net force = 10N forward.

2. When the force is increased to 30N, what acceleration will Kay be giving the box?

5kg

Resultant

10N

Resultant or Net force = 10N forward.

F = m x a or a = F/m

a = 10/5 = 2m/s^2.

NEWTON'S FIRST LAW FOLLOWS FROM THE SECOND

- **F=**m **a**
- IF THE FORCE IS CONSTANT THE ACCn ALSO IS CONSTANT.CONVERSELY, IF THE FORCE VARIES, SO DOES THE ACCn.
- IF THE ACCn IS ZERO, THE RESULTANT FORCE IS ZERO- IN OTHER WORDS NEWTON'S FIRST LAW FOLLOWS FROM THE SECOND.

We exert a force on the ground due to our mass – what is it?

If your mass is 50kg, the force you exert

F = m x a

= 50 x acceleration due to gravity ($10 m/s^2$)

= 50 x 10

= 500N (your weight!)

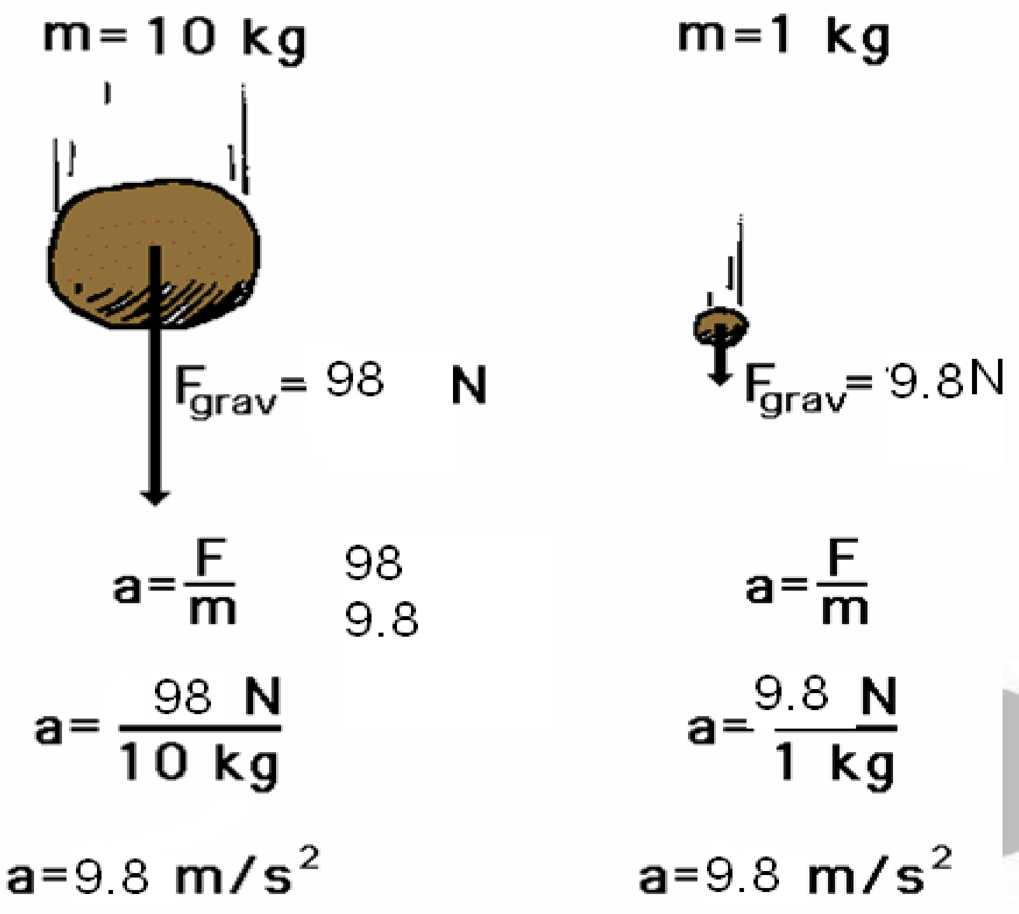
Mass (kg) is just the amount of “stuff” in an object and does not change with gravity!!

Free Fall Motion

As learned in an earlier unit, free fall is a special type of motion in which the only force acting upon an object is gravity. Objects that are said to be undergoing free fall, are not encountering a significant force of air resistance; they are falling under the sole influence of gravity. Under such conditions, all objects will fall with the same rate of acceleration, regardless of their mass. But why? Consider the free-falling motion of a 1000-kg baby elephant and a 1-kg overgrown mouse.

Newton's 2nd Law proves that different masses accelerate to the earth at the same rate, but with different forces.

- We know that objects with different masses accelerate to the ground at the same rate.
- However, because of the 2nd Law we know that they don't hit the ground with the same force.



F = ma

98 N = 10 kg x 9.8 m/s/s

F = ma

9.8 N = 1 kg x 9.8 m/s/s

- 1. What acceleration will result when a 12 N net force applied to a 3 kg object?
- 2. A net force of 16 N causes a mass to accelerate at a rate of 5 m/s^2. Determine the mass.
- 3. How much force is needed to accelerate a 66 kg skier 1 m/sec/sec?
- 4. What is the force on a 1000 kg elevator that is falling freely at 9.8 m/sec/sec?

1. What acceleration will result when a 12 N net force applied to a 3 kg object?

12 N = 3 kg x 4 m/s/s

2. A net force of 16 N causes a mass to accelerate at a rate of 5 m/s^2. Determine the mass.

16 N = 3.2 kg x 5 m/s/s

3. How much force is needed to accelerate a 66 kg skier 1 m/sec/sec?

66 kg-m/sec/sec or 66 N

4. What is the force on a 1000 kg elevator that is falling freely at 9.8 m/sec/sec?

9800 kg-m/sec/sec or 9800 N

What is the function of the hand glove of this baseball player?

Force is inversely proportional to time

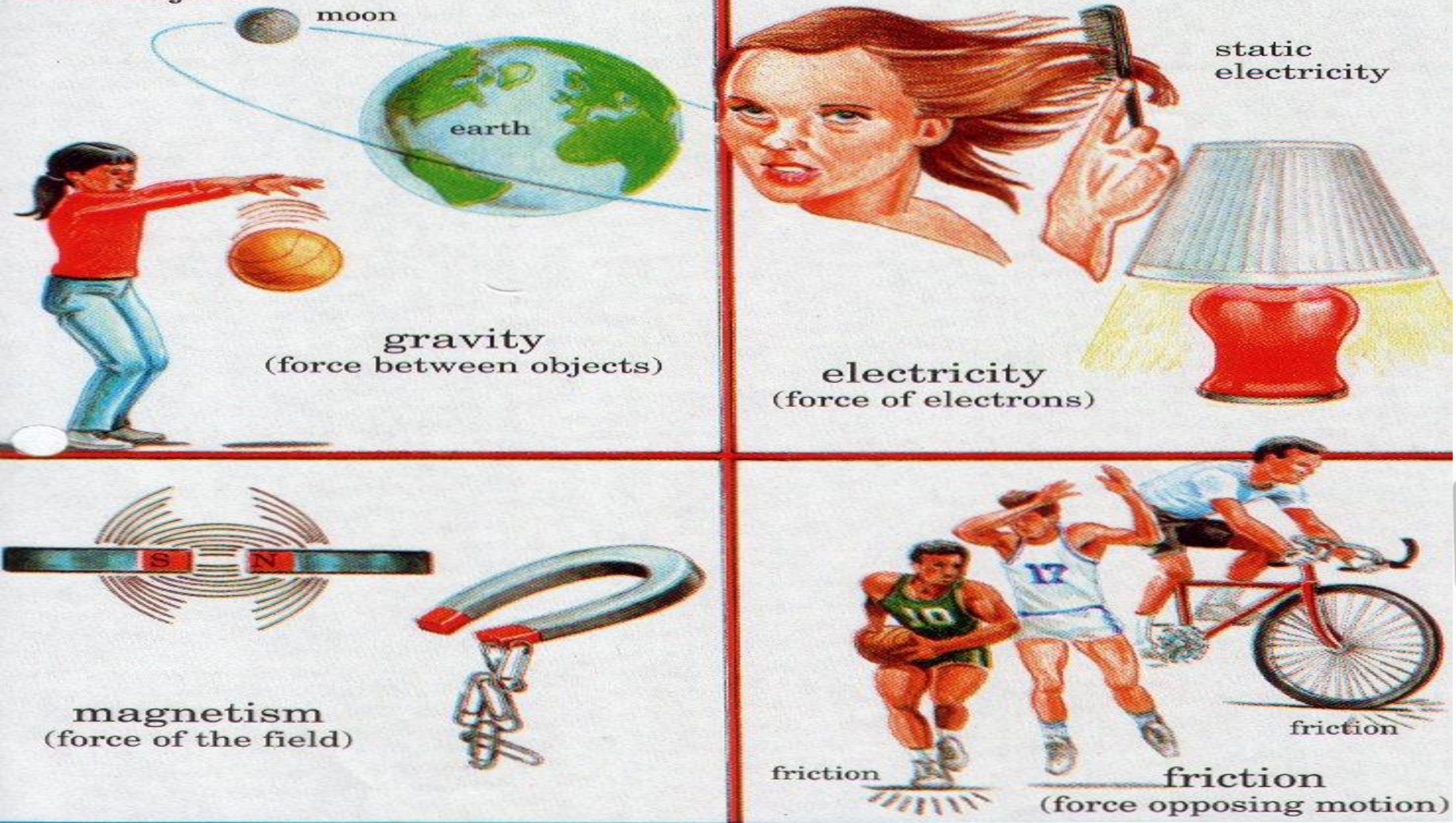
$$F = ma$$

$$= m\frac{(v-u)}{t}$$

The hand glove increases the time of the collision, thereby reducing the force.

Force

Force is the push or pull that causes a change in the motion of an object.



The 3rd Law of Motion

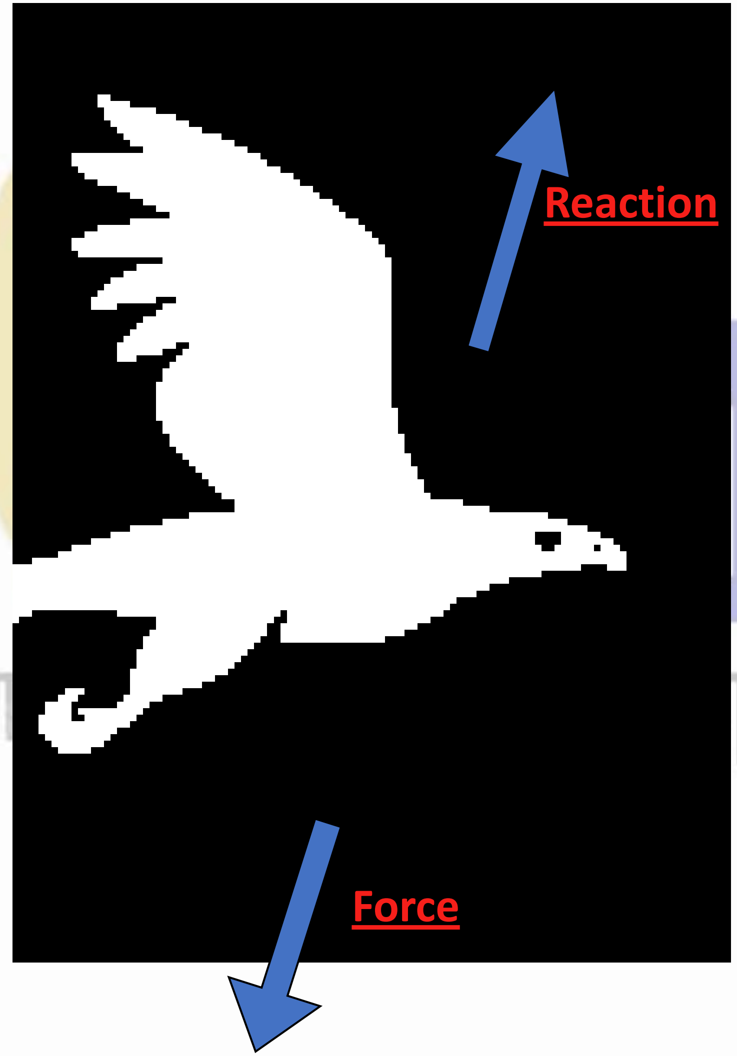
For every action, there is an equal and opposite reaction.

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. These two forces are called *action* and *reaction* forces

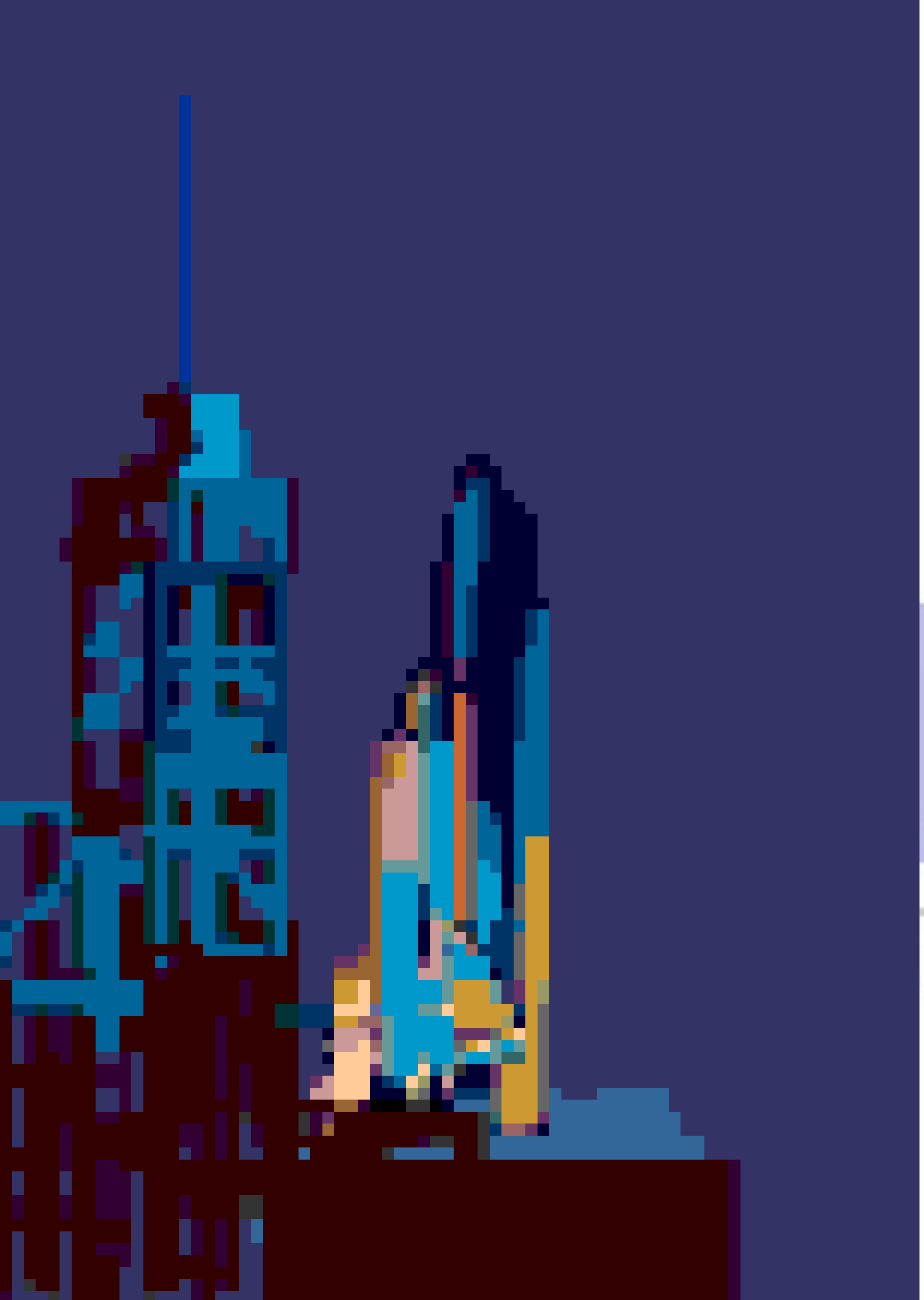
What happens if you are standing on a skateboard or a slippery floor and push against a wall? You slide in the opposite direction (away from the wall), because you pushed on the wall but the wall pushed back on you with equal and opposite force.

Newton's 3rd Law in Nature

- Consider the propulsion of a fish through the water. A fish uses its fins to push water backwards. In turn, the water *reacts* by pushing the fish forwards, propelling the fish through the water.
- The force on the water equals the force on the fish; the direction of the force on the water (backwards) is opposite the direction of the force on the fish (forwards).



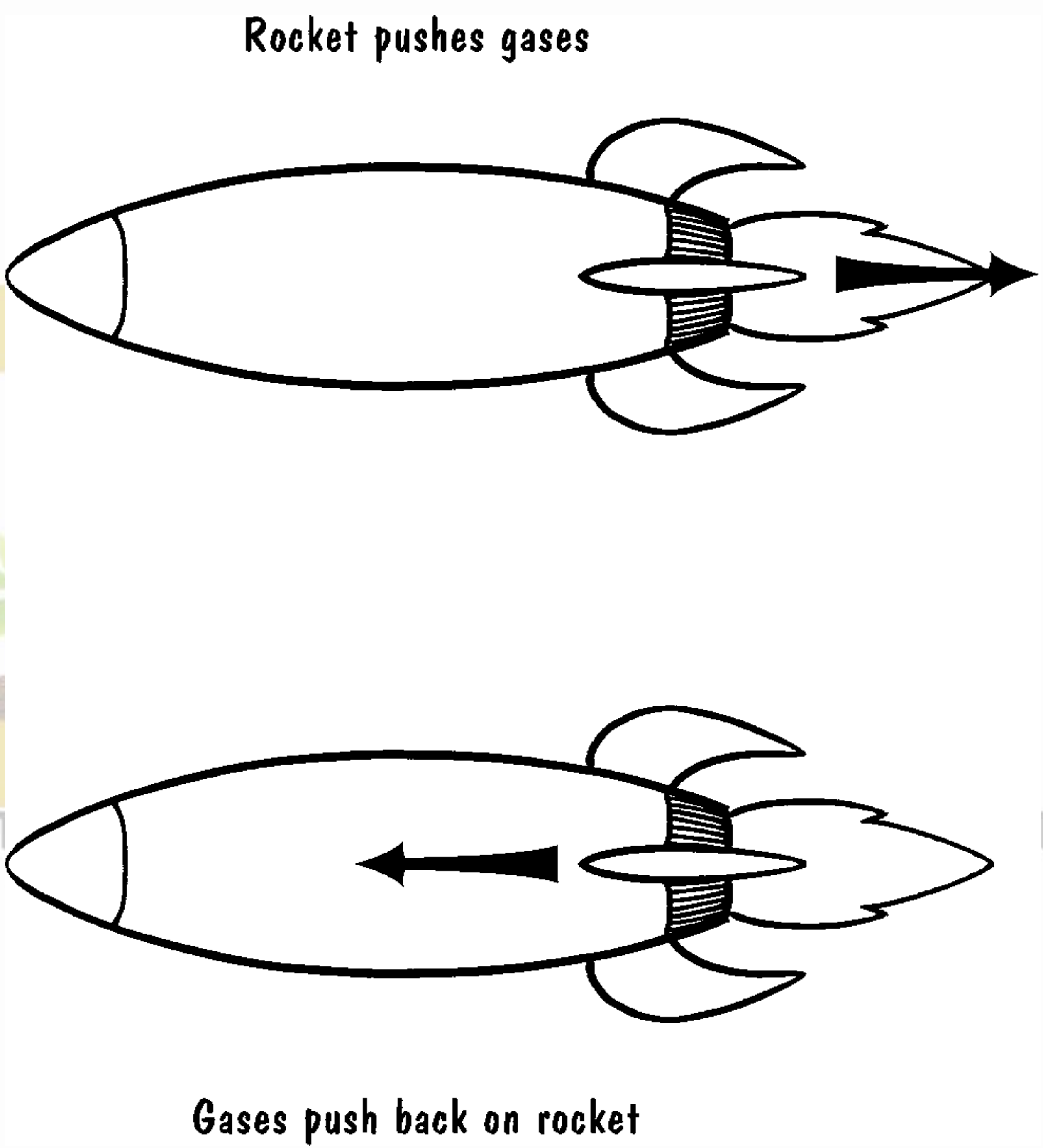
Flying gracefully through the air, birds depend on Newton’s third law of motion. As the birds push down on the air with their wings, the air pushes their wings up and gives them lift.



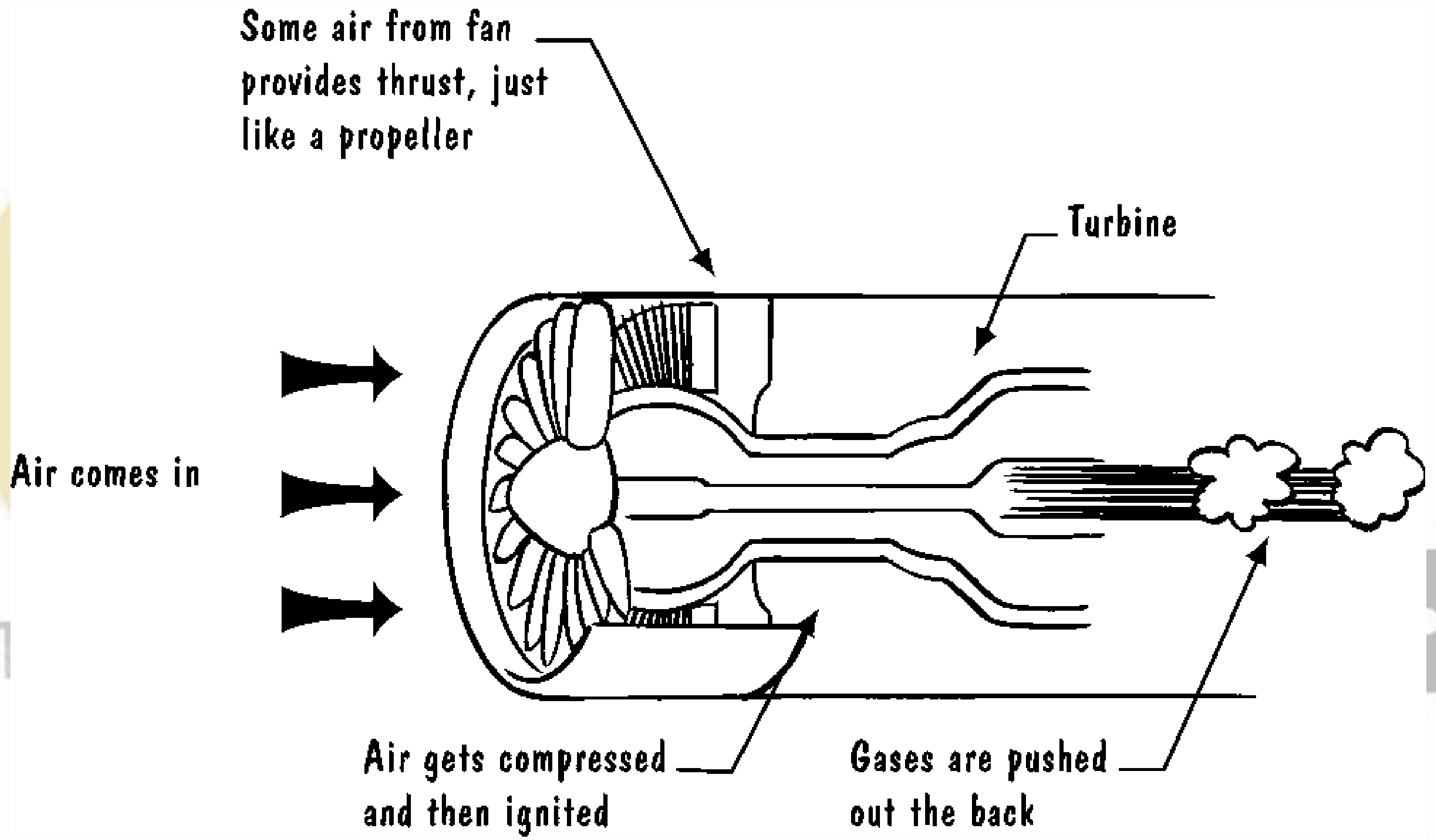
The reaction of a rocket is an application of the third law of motion. Various fuels are burned in the engine, producing hot gases.

The hot gases push against the inside tube of the rocket and escape out the bottom of the tube. As the gases move downward, the rocket moves in the opposite direction.

How does a rocket work?

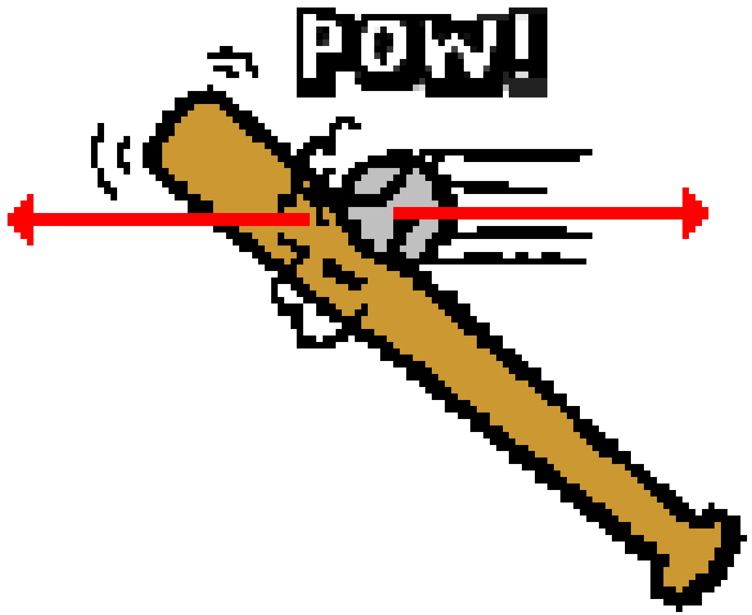

Rocket pushes gases
Gases push back on rocket

How does a jet plane work?



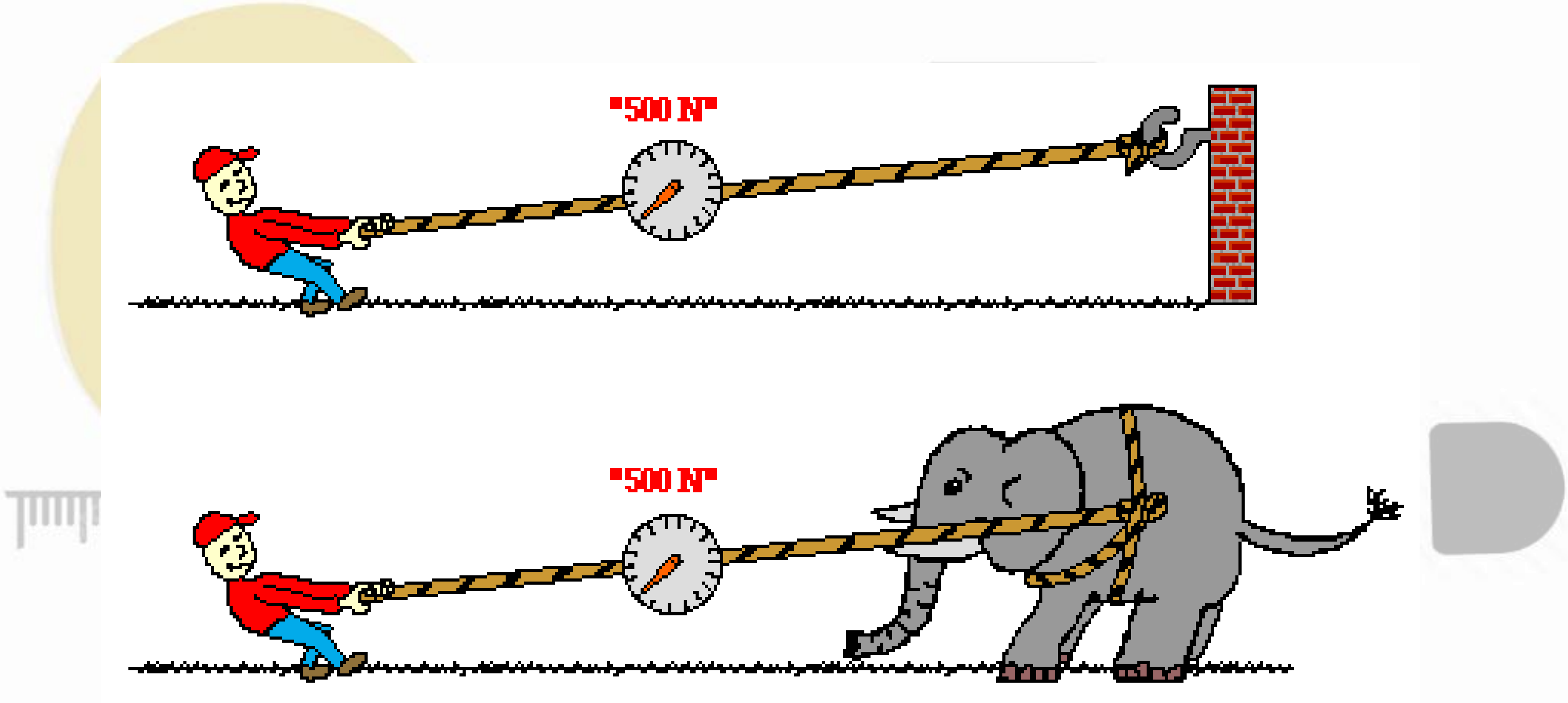
Other examples of Newton's Third Law

- The baseball forces the bat to the left (an action); the bat forces the ball to the right (the reaction).

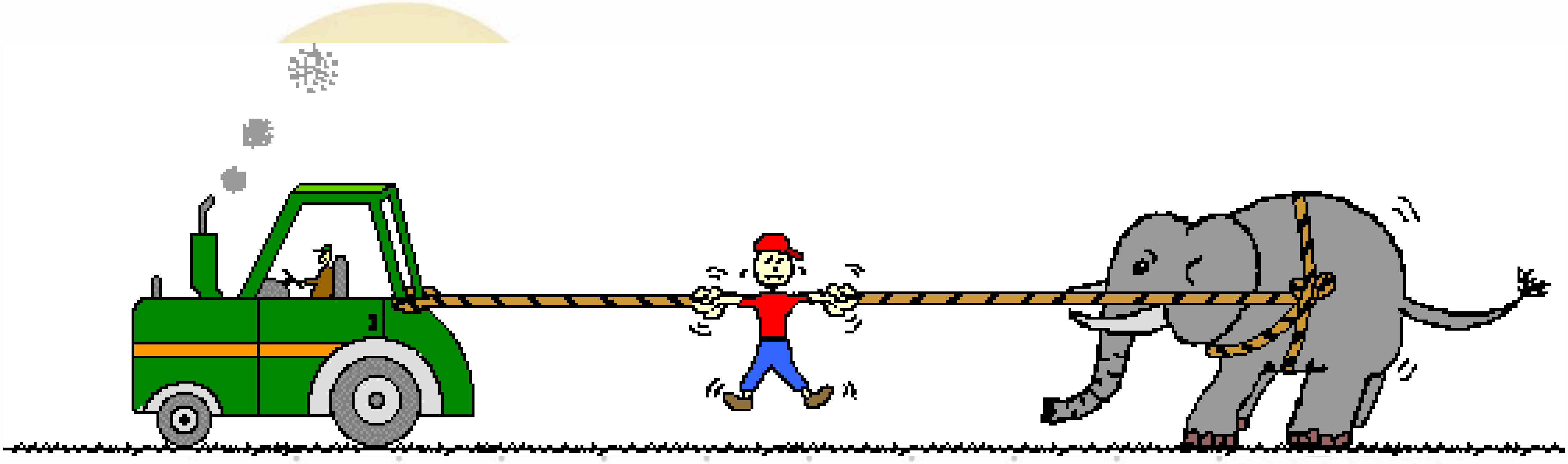


Formally stated, Newton's third law is:

For every action, there is an equal and opposite reaction.



Identify at least six pairs of action-reaction force pairs in the following diagram.



The elephant's feet push backward on the ground; the ground pushes forward on its feet. The right end of the right rope pulls leftward on the elephant's body; its body pulls rightward on the right end of the right rope. The left end of the right rope pulls rightward on the man; the man pulls leftward on the left end of the right rope. The right end of the left rope pulls leftward on the man; the man pulls rightward on the right end of the left rope. The tractor pulls leftward on the left end of the left rope; the left end of the left rope pulls rightward on the tractor.