Dynamics (गतिकी)

SAFALTA CLASS™

An Initiative by अमर उजाला

cause of motion

Newton's Laws of Motion

I. Law of Inertia

II. F=ma

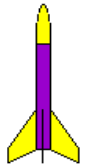
III. Action-Reaction

While most people know what Newton's laws say, many people do not know what they mean (or simply do not believe what they mean).

Force and mass

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

- Vector – show magnitude and direction



Force

- The push or pull on an object with mass that causes it to change its velocity.
- द्रव्यमान के साथ किसी वस्तु पर धक्का या खिंचाव जिससे उसका वेग बदल जाता है।

$1N = 10^5 D$

$\vec{F}$

Common symbols:	F⟶, F
SI unit:	Newton
In SI base units:	kg·m/s^2
Other units:	dyne, poundal, pound-force, kip, kilo pond
Derivations from other quantities:	F = m a
Dimension:	LMT^{-2}

Four Forces Known in the Universe

विद्युत चुम्बकीय

- **Electromagnetic**- caused from electric and magnetic interactions

Range = ∞

- **Strong Nuclear-** Responsible for holding nucleus together in the atom; strongest force; acts over the shortest distance

नाभिक

1 Fermi = 10^{-15} m

- **Gravitation**- weakest force; acts over the longest distance

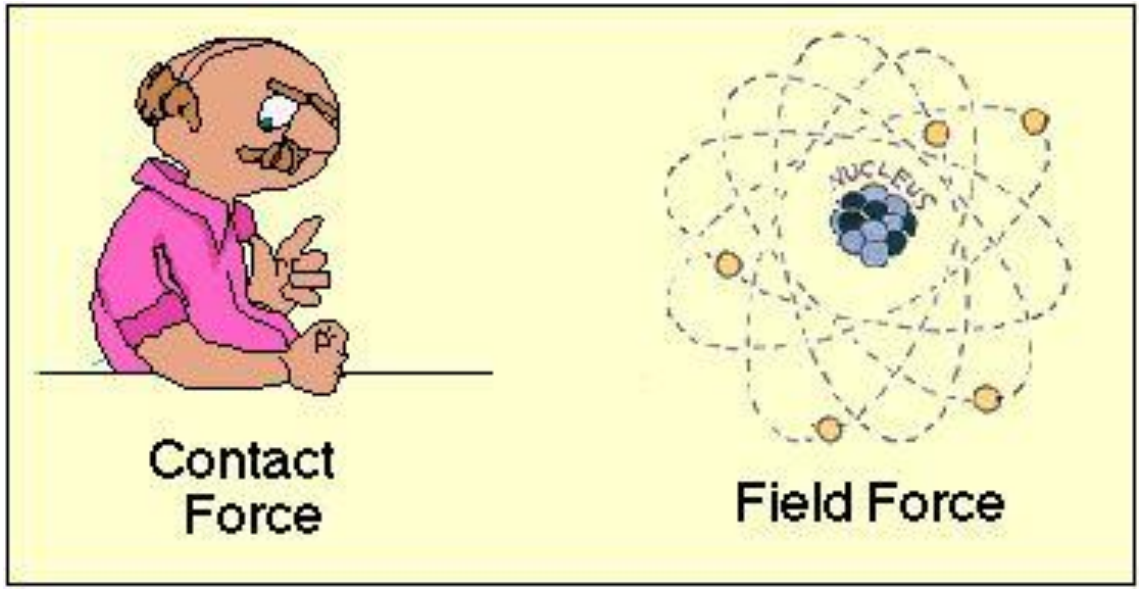
गुरुत्वाकर्षण

Range = ∞

- **Weak Nuclear-** Responsible for radioactivity in atoms

Types of Forces

- There are two main types of forces
  - Contact संपर्क
  - Field / Non-Contant असंपर्क



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

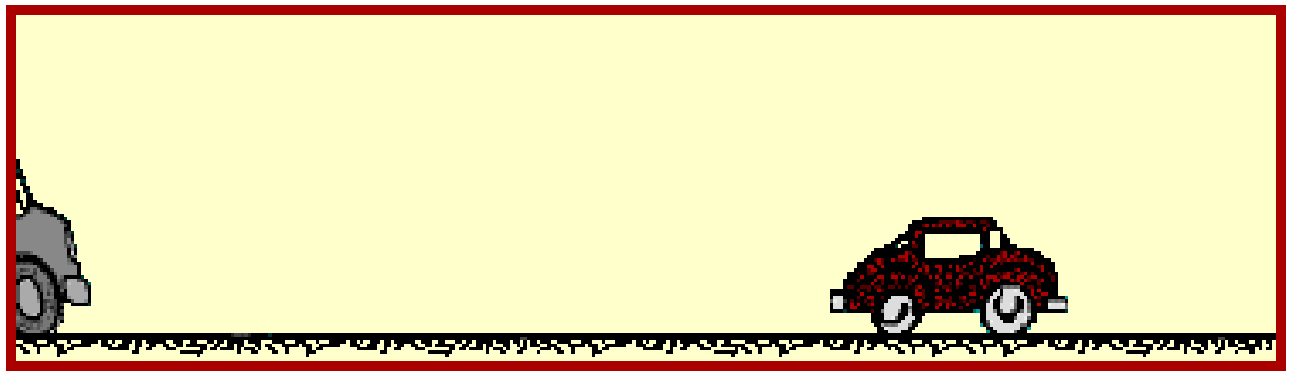
- Example of Contact Forces
- Friction
- Tension

- 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



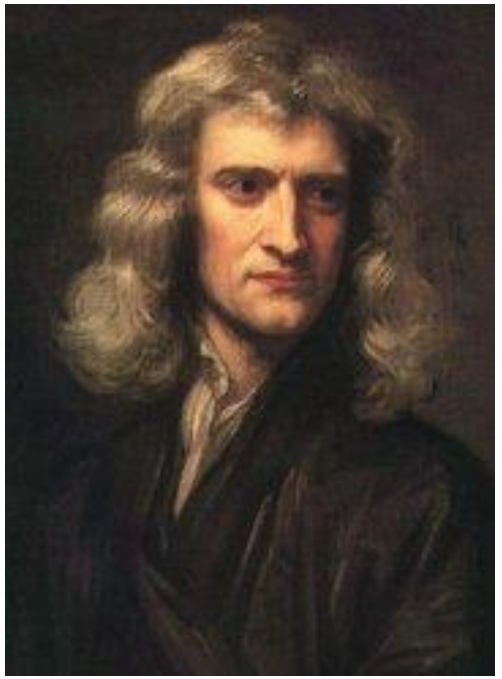
Newton's Laws

① Inertia of Rest (स्थिर) ✓

② " " motion (गति)

③ " " Direction (दिशा)

Background



Sir Isaac Newton (1643-1727)

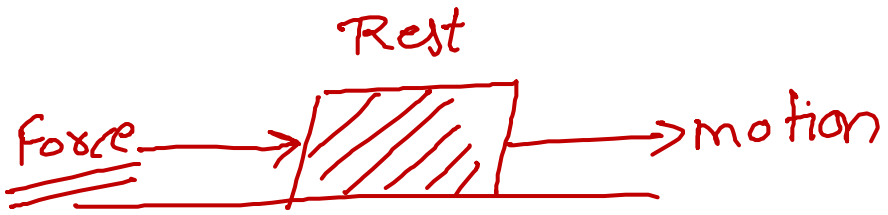
an English scientist and mathematician famous for his discovery of the law of gravity also discovered the three *laws of motion*.

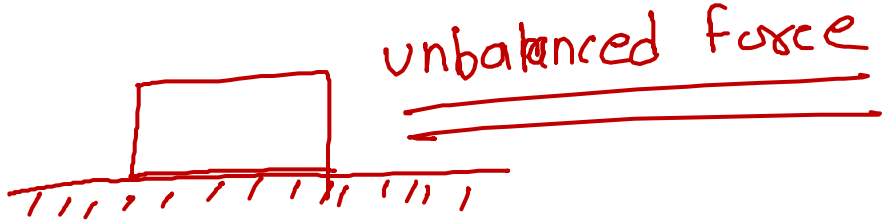
Today these laws are known as *Newton's Laws of Motion* and describe the motion of all objects on the scale we experience in our everyday lives.

NEWTON'S LAWS OF MOTION

- **Newton's first law (law of inertia) :** Newton's 1st law states that a body at rest or uniform motion will continue to be at rest or uniform motion until and unless a net external force acts on it.

वस्तु अपनी विरामावास्था या एक सीध में एकरूप गत्यावस्था में तब तक रहती है, जब तक बाह्य बल (external force) द्वारा उसकी विरामावस्था या गत्याव्स्था में कोई परिवर्तन न लाया जाए. वस्तु के विराम की अवस्था (Inertia) का बोध होता है. अतः इस नियम को विराम का नियम भी कहते हैं.





1st Law

- *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.

1st Law

- Once airborne, unless acted on by an unbalanced force (gravity and air – fluid friction), it would never stop!

1st Law

- Unless acted upon by an unbalanced force, this golf ball would sit on the tee forever.

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

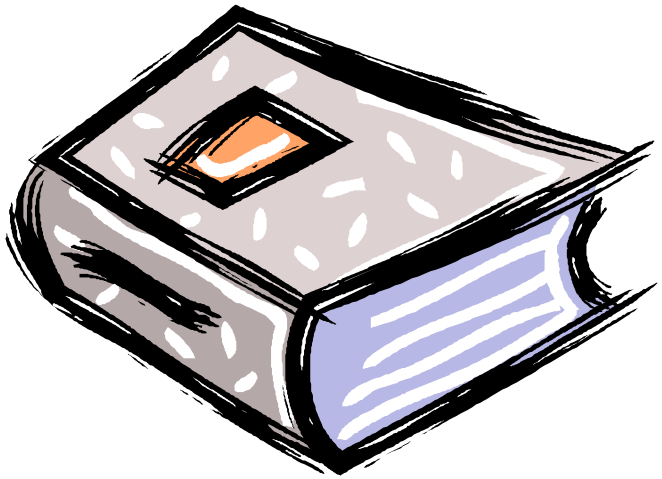
It's a force we sometimes cannot see – friction.

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

Friction!

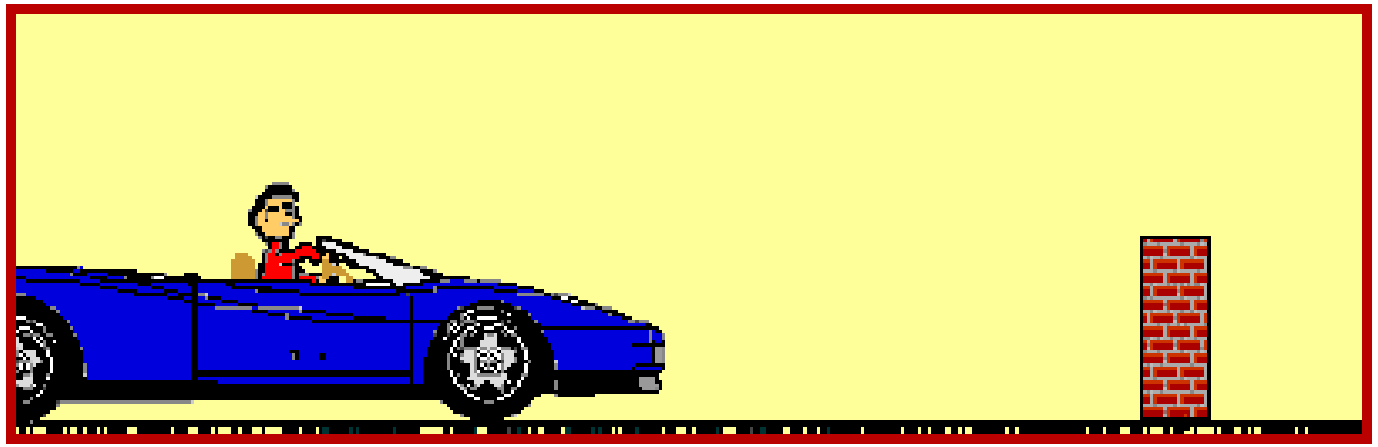
- There are four main types of friction:
  - Sliding friction: ice skating
  - Rolling friction: bowling
  - Fluid friction (air or liquid): air or water resistance
  - Static friction: initial friction when moving an object

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.)

Newtons's 1st Law and You



Don't let this be you. Wear seat belts.

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.

Newton's Second Law

Force equals mass times acceleration.

$$F = ma$$

Acceleration: a measurement of how quickly an object is changing speed.

MOMENTUM (संवेग) :-

$\vec{p} = m\vec{v}$

$F \propto p$

① गतिशीय रूप,

(i) $F \propto \frac{dp}{dt}$ (ii) $F \propto ma$

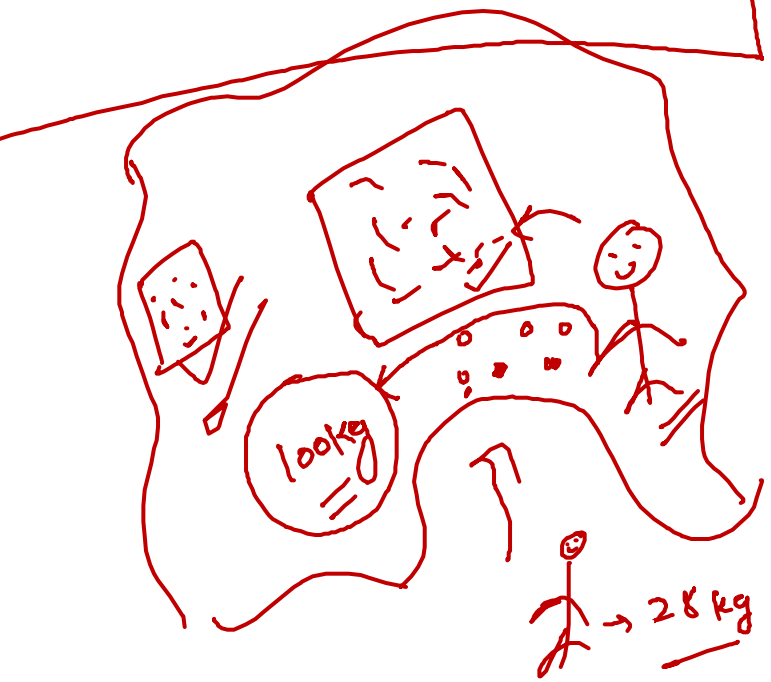
(iii) $F = \frac{dp}{dt}$ (iv) $F = ma$ ~~$= ma$~~

object की Property गुण)

$\vec{p} = m\vec{v}$

Unit = Kg-m/s

D.F. = $[MLT^{-1}]$



$\vec{F} \propto \frac{\Delta p}{\Delta t}$

$\vec{F} \propto \frac{dp}{dt}$

$\vec{F} = K\frac{dp}{dt}$

$\vec{F} = K\frac{d(m\vec{v})}{dt}$

$\vec{F} = Km\frac{d\vec{v}}{dt}$

$\vec{F} = m\vec{a}$

$p\uparrow \quad F\uparrow$

$p\uparrow \quad F\uparrow$

~~K~~ $K \neq 1$

$K = 1$

Acceleration

$\vec{F} = m\vec{a}$

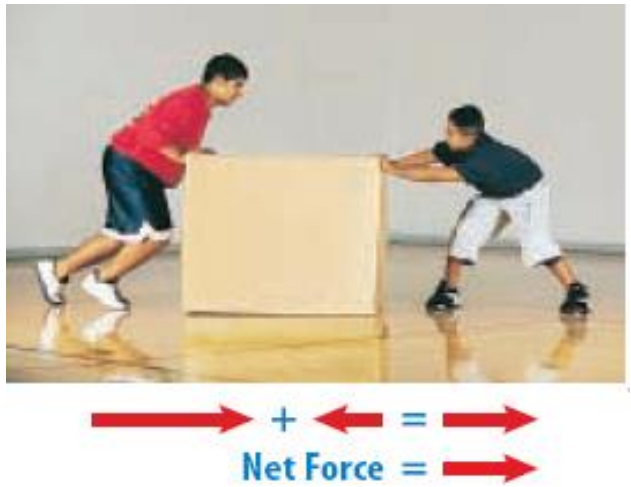
$\vec{F}_{net} = 0$

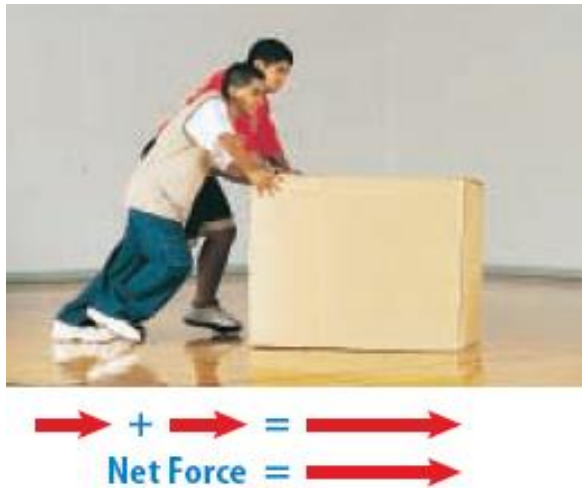
- An ***unbalanced force*** causes something to accelerate.
- A force can cause motion only if it is met with an ***unbalanced force***.
- Forces can be balanced or unbalanced.
- Depends on the **net force** acting on the object
- **Net force (F_{net}):** The sum total and direction of all forces acting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

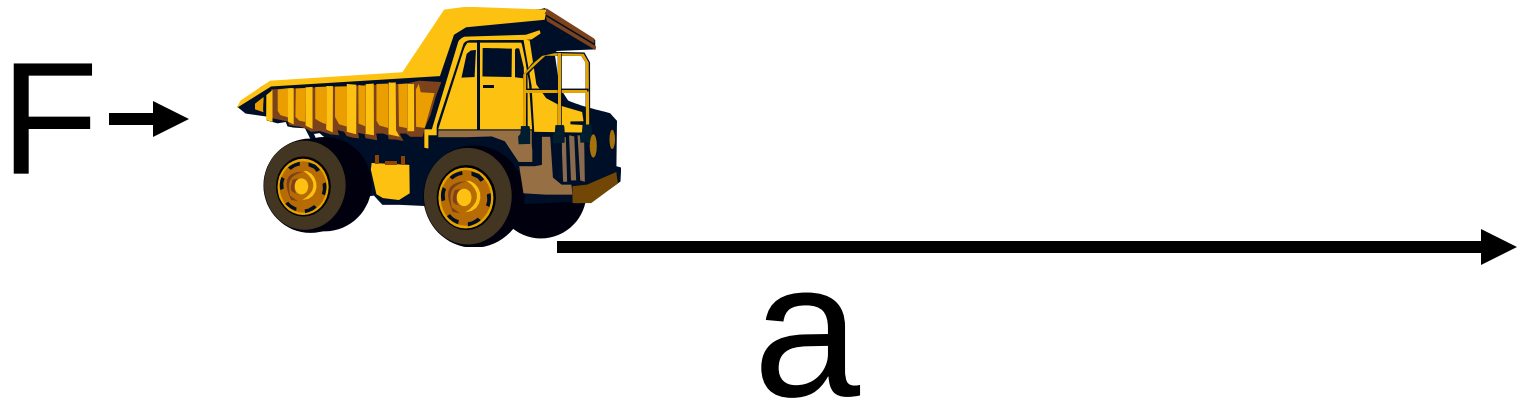
In Other Words…

Small Force = Small Acceleration

$\Rightarrow \vec{F} = m\vec{a}$

In Other Words…

Large Force = Large Acceleration



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

But there is a twist....

$\vec{F} \propto \vec{a}$

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

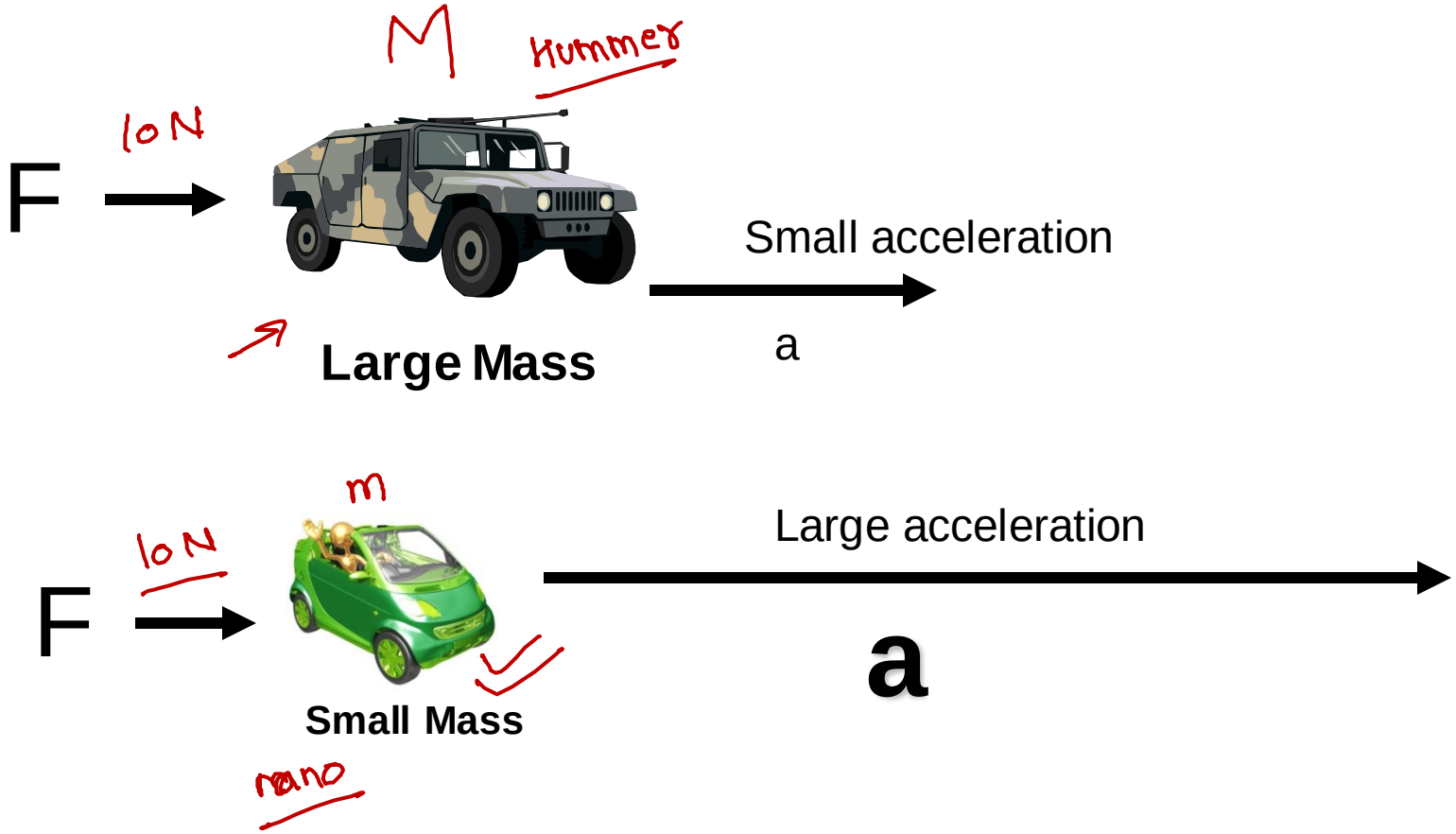
$\vec{a} \propto \frac{1}{m}$

$F = ma$

$ma = \text{Constant}$

$a \propto \frac{1}{m}$

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

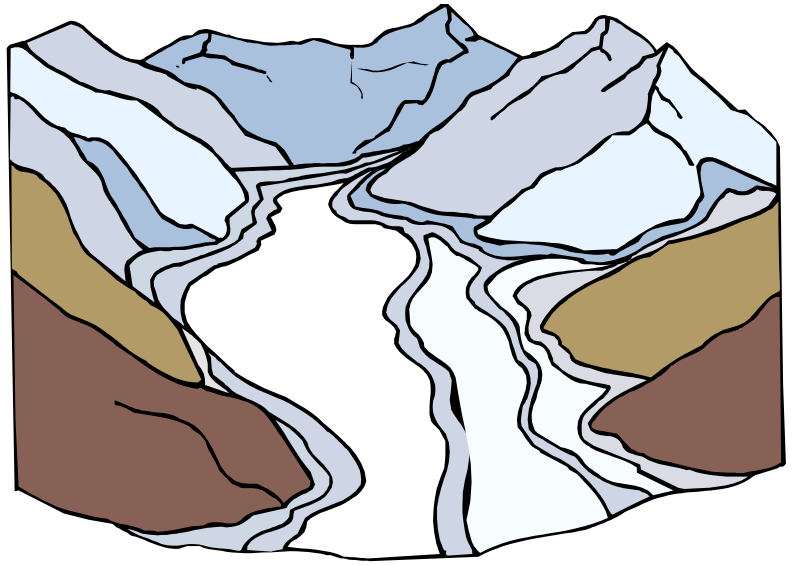
kg m/s^2

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

High Mass

$$F \propto \frac{dp}{dt}$$

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

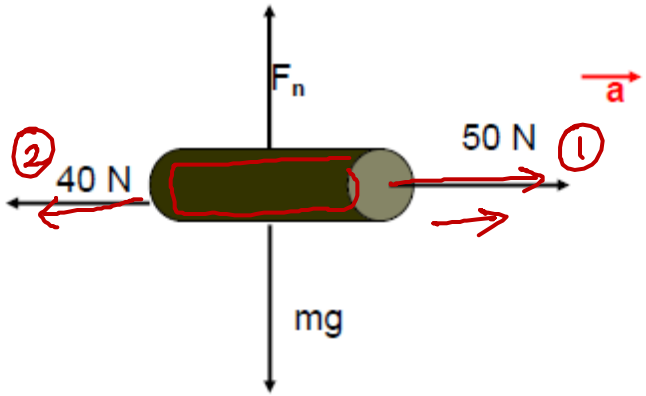
Example

$F = ma$

- 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?

$F_{net} = 50 - 40$

$= 10\ N$



$$F_{NET} = ma$$

$$F_a - F_f = ma$$

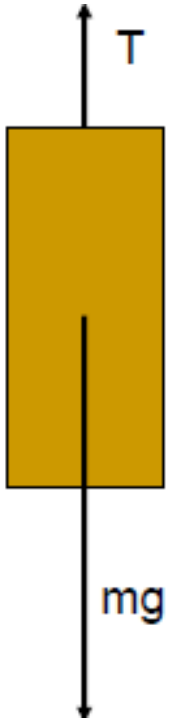
$$50 - 40 = 8.16a$$

$$10 = 8.16a$$

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

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

$$F_{NET} = ma$$

$$T - mg = ma$$

$$T = ma + mg$$

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

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

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

$$\sum F = 0$$

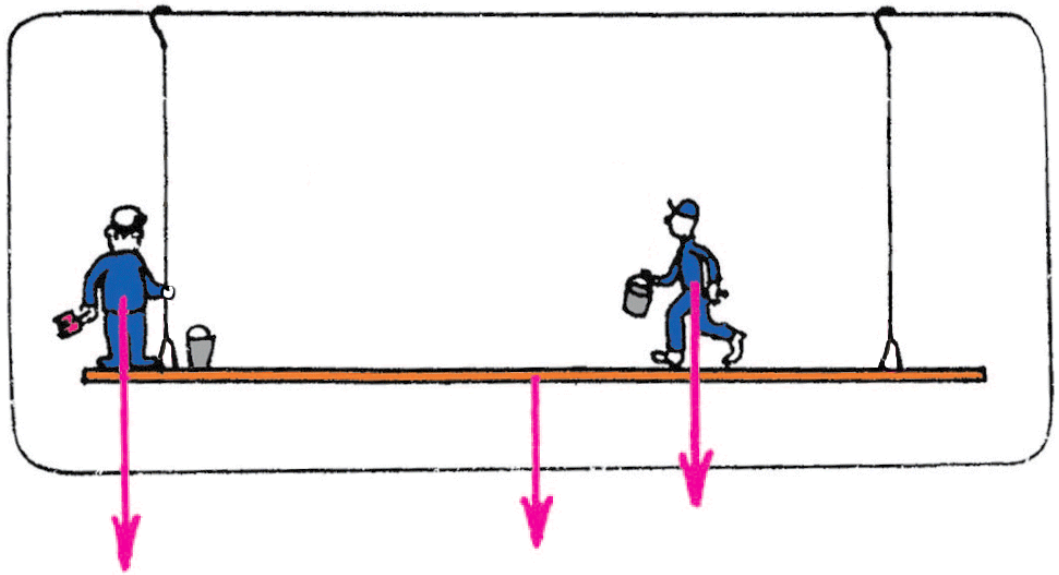
The Σ symbol stands for “the sum of.”
F stands for “forces.”

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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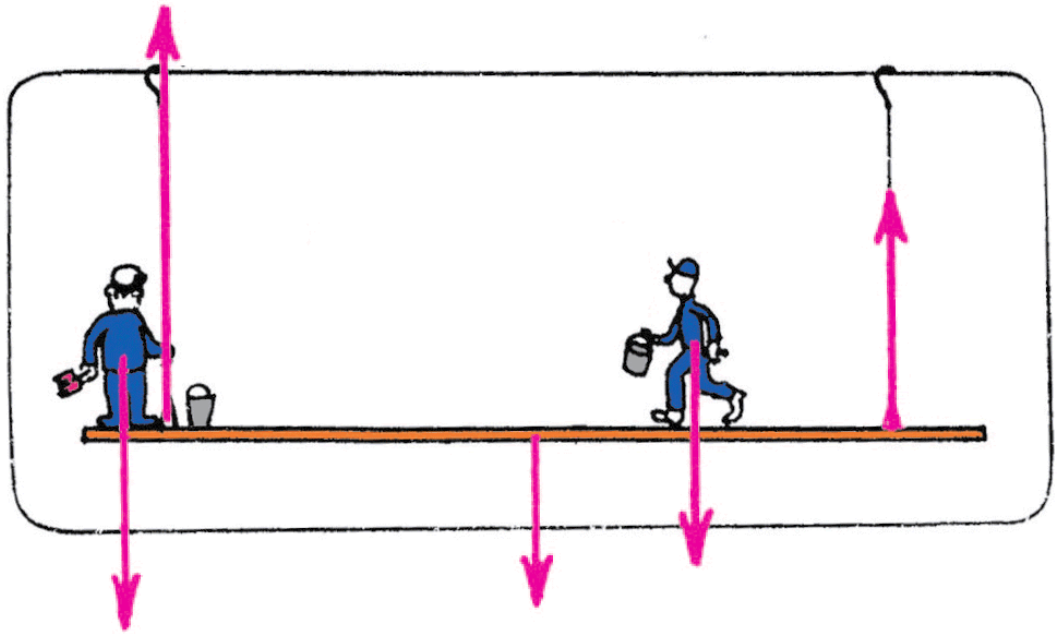

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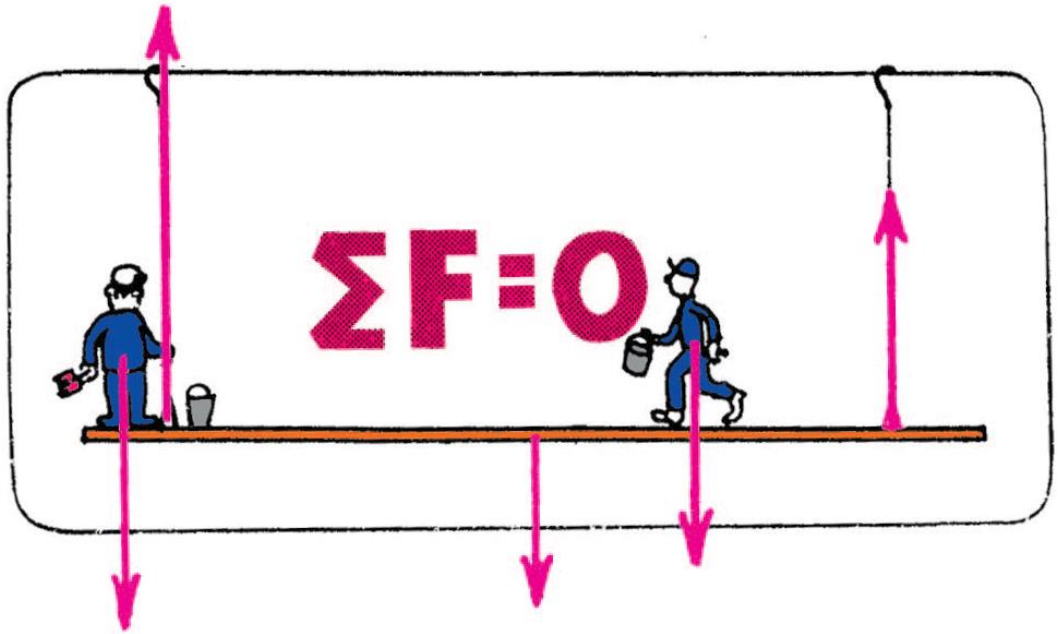


Equilibrium for stationary objects

- 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.

- **Newton's 2nd law of motion :**

Newton's 2nd law states that the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force.

वस्तु के संवेग (Momentum) में परिवर्तन की दर उस पर लगाये गये बल के अनुक्रमानुपाती (Directly proportional) होती है |

2nd Law

2nd Law (F = m x a)

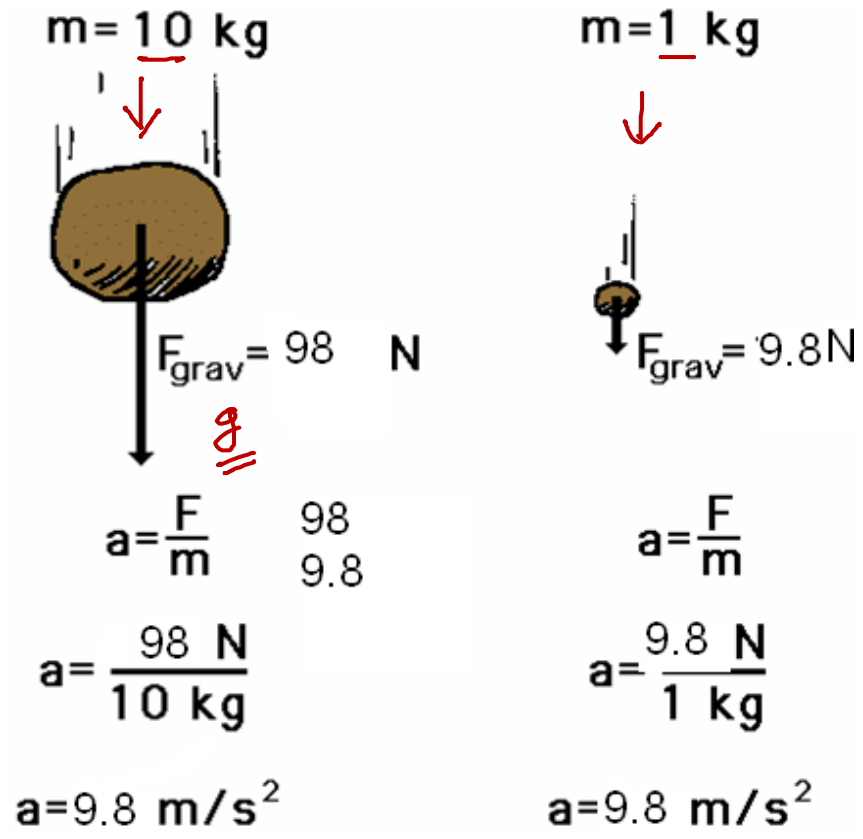
- How much force is needed to accelerate a 1400 kilogram car 2 meters per second/per second?
- Write the formula
- F = m x a
- Fill in given numbers and units
- F = 1400 kg x 2 meters per second/second
- Solve for the unknown
- 2800 kg-meters/second/second or **2800 N**

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.

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.

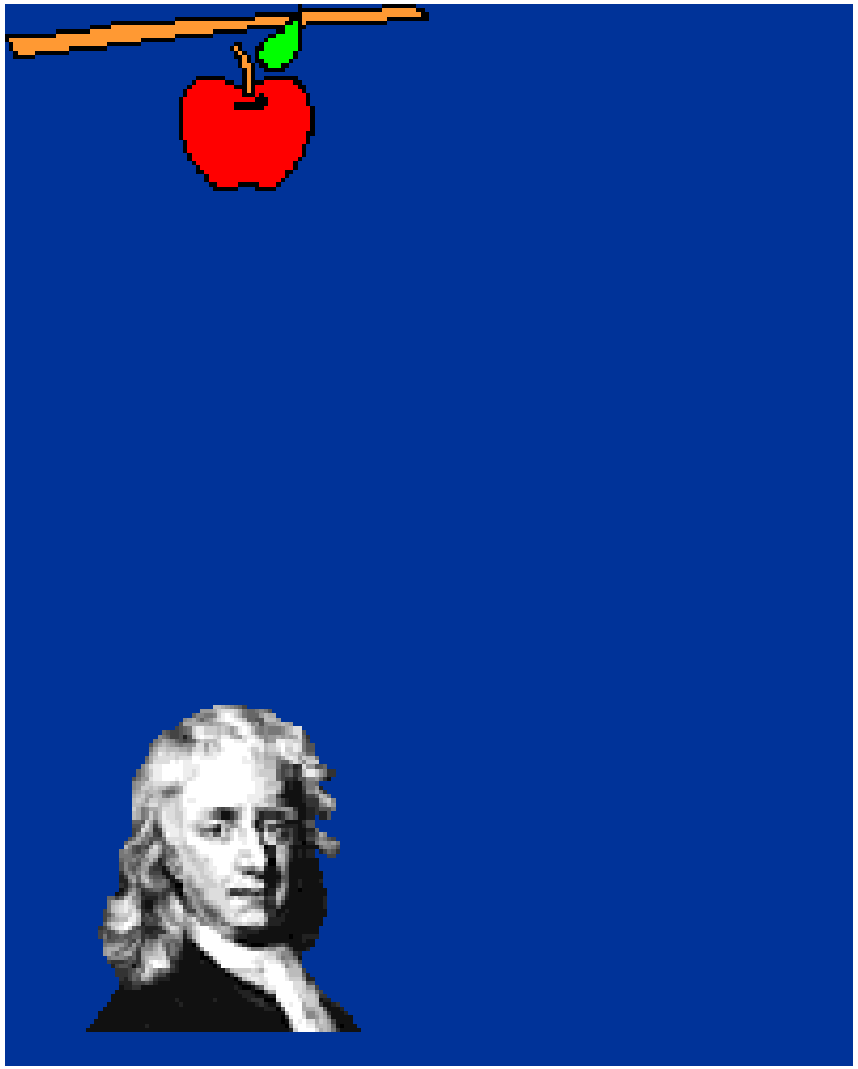


F = ma

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

F = ma

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



Check Your Understanding

- 1. What acceleration will result when a 12 N net force applied to a 3 kg object? A 6 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?

Check Your Understanding

- 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?

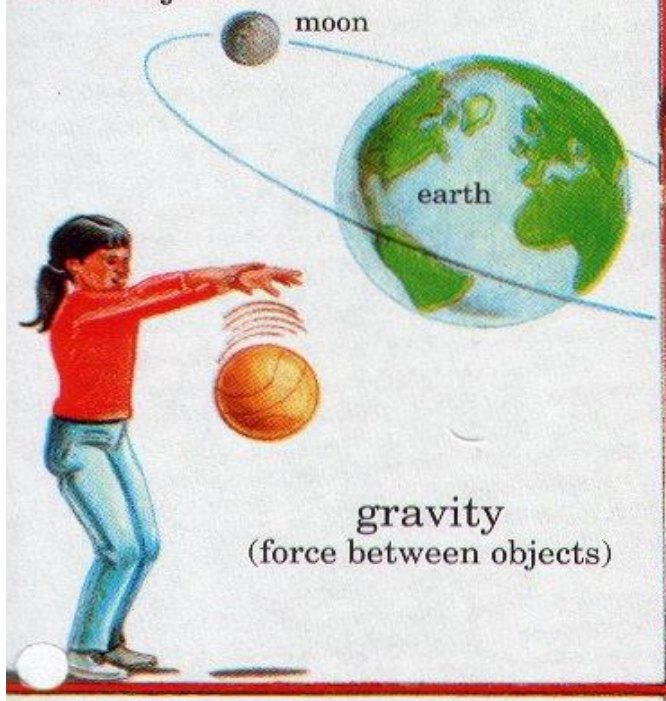
66 kg-m/sec/sec or 66 N

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

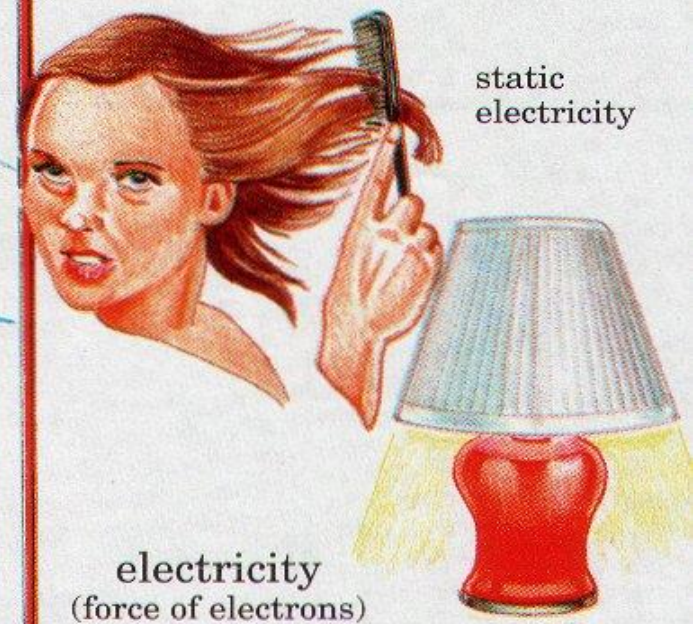
- **9800 kg-m/sec/sec or 9800 N**

Force

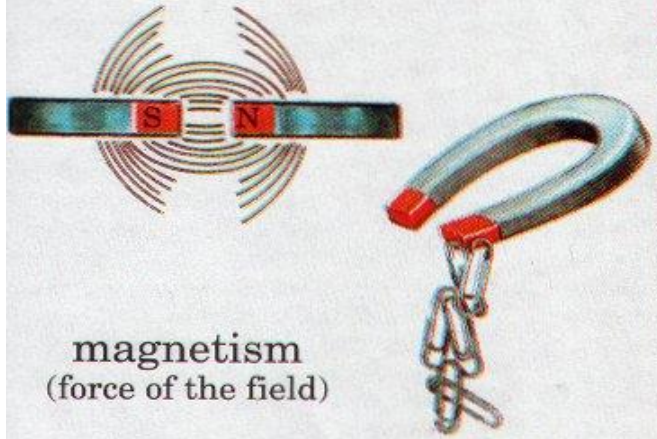
Force is the push or pull that causes a change in the motion of an object.



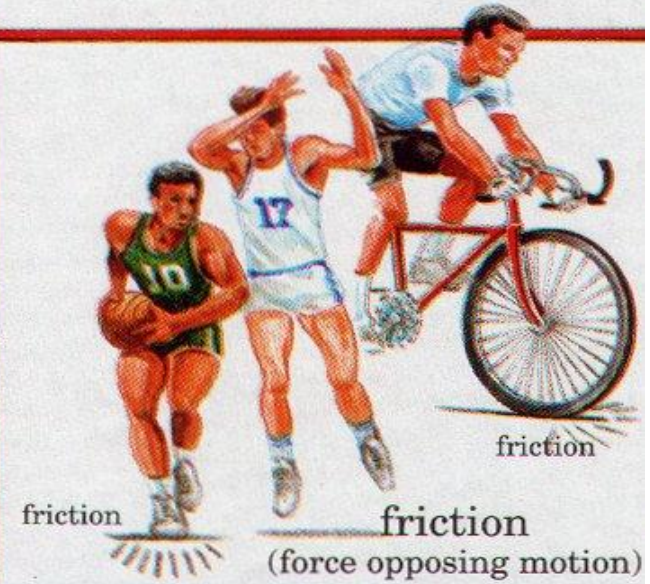
gravity
(force between objects)



electricity
(force of electrons)

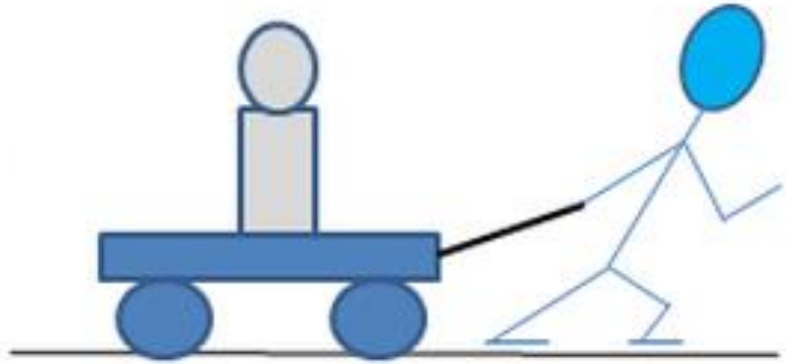


magnetism
(force of the field)

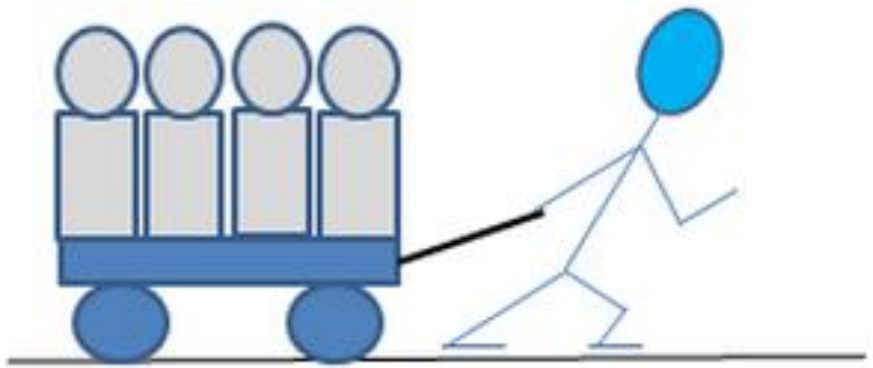


friction
(force opposing motion)

To get the wagon to *accelerate*, you have to apply a PULL (Force).



If the MASS of the wagon increases, a greater PULL is necessary to accelerate it.



Newton's Third Law

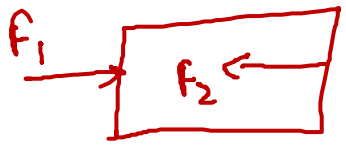
For every action there is an equal and opposite reaction.

• Newton's Third Law of Motion :

The Newton's 3rd law states that for every action there is an equal and opposite reaction.

प्रत्येक क्रिया (Action) की उसके बराबर तथा उसके विरुद्ध दिशा में प्रतिक्रिया (Reaction) होती है. इस

नियम को क्रिया-प्रतिक्रिया (Law of action and reaction) का नियम कहा जाता है.



$$F_1 = F_2$$

$$|\vec{F}_1| = |\vec{F}_2|$$

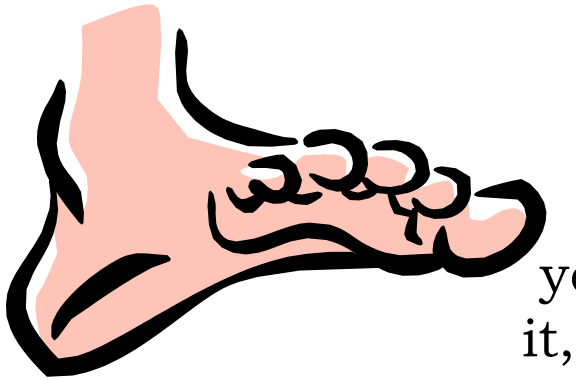
$$\Rightarrow \boxed{\vec{F}_1 = -\vec{F}_2}$$

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 . . .

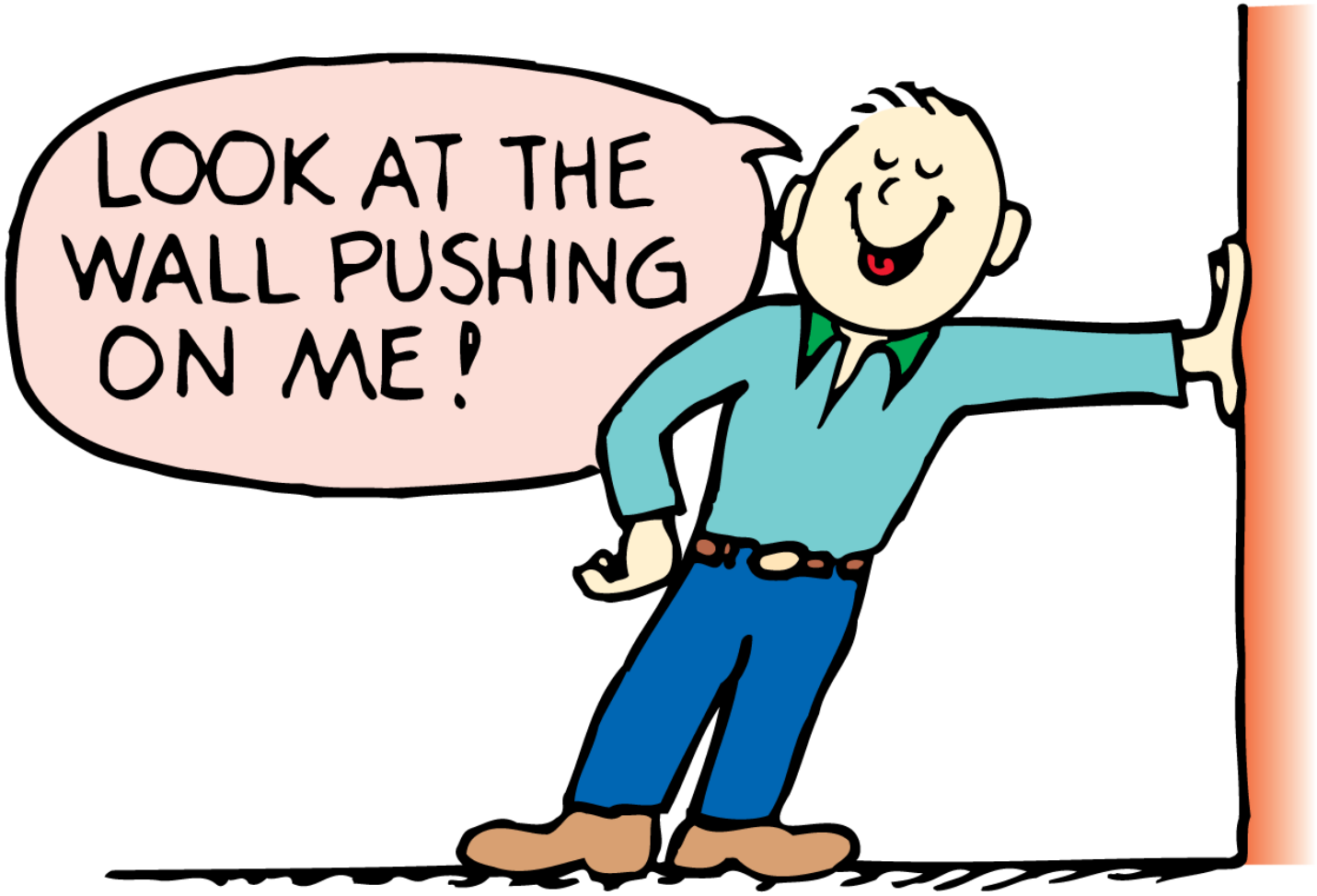
What happens if you are standing on a skateboard or a slippery floor and push against a wall? You slide in the opposite direction (away from the wall), because you pushed on the wall but the wall pushed back on you with equal and opposite force.



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

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

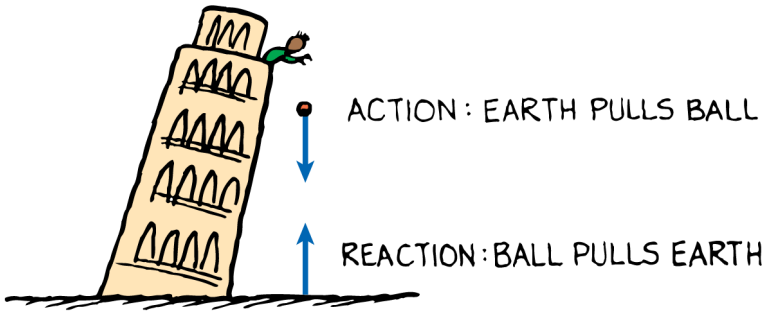
3rd Law

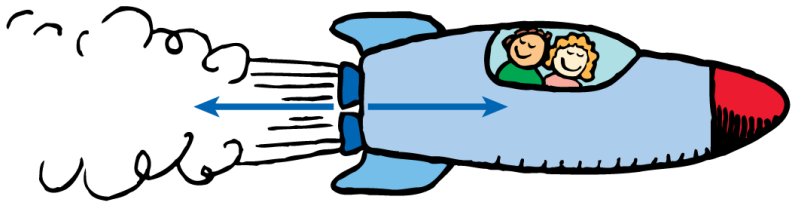
Flying gracefully through the air, birds depend on Newton's third law of motion. As the birds push down on the air with their wings, the air pushes their wings up and gives them lift.

Identifying Action and Reaction Pairs

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

ACTION : TIRE PUSHES ROAD REACTION : ROAD PUSHES TIRE

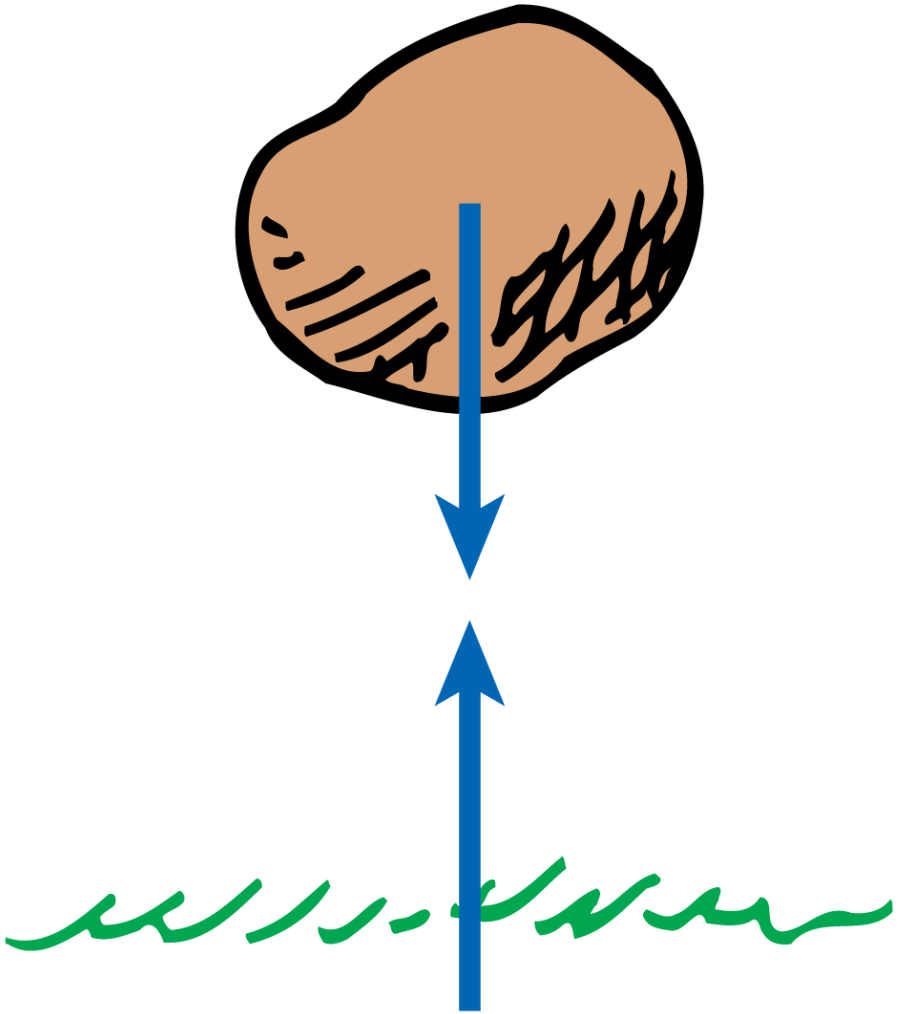




ACTION : ROCKET PUSHES GAS REACTION : GAS PUSHES ROCKET

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.



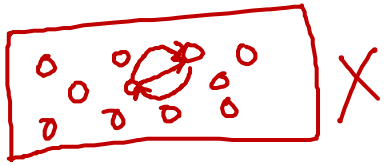
Question

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



दो अलग - अलग वस्तु पर

- 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.

- Consider the flying motion of birds. A bird flies by use of its wings. The wings of a bird push air downwards. In turn, the air reacts by pushing the bird upwards.
- The size of the force on the air equals the size of the force on the bird; the direction of the force on the air (downwards) is opposite the direction of the force on the bird (upwards).
- Action-reaction force pairs make it possible for birds to fly.

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