Module 5: Newton’s Laws of Motion

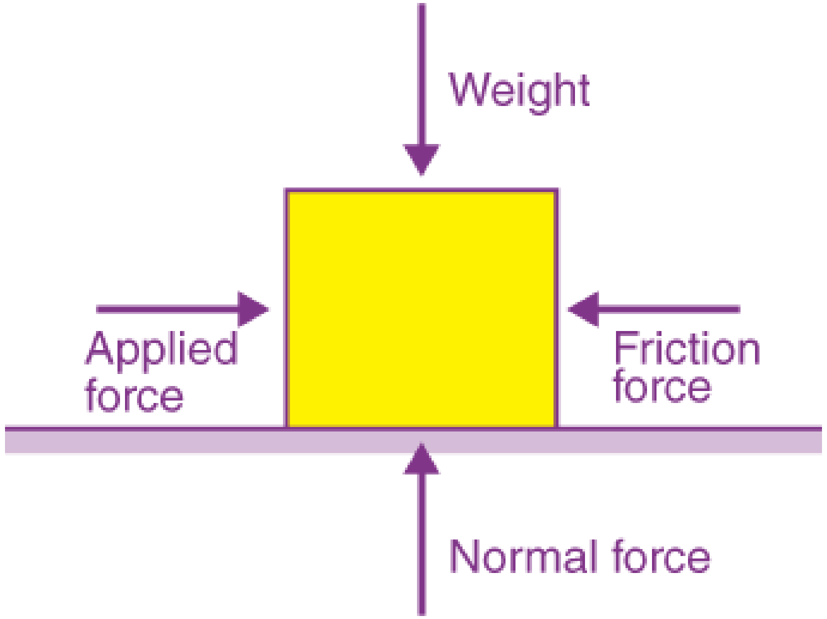
5.1 Law of Inertia

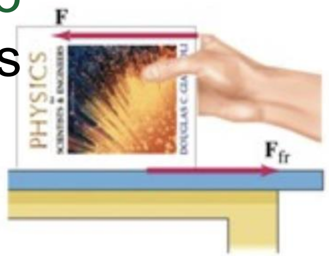
OBJECTIVES:

1. Explain forces and its types
2. Determine and illustrate forces acting on a system
3. Draw free body diagrams of systems
4. Define Newton’s 1st Law
5. Apply Newton’s 1st law of motion in problem solving

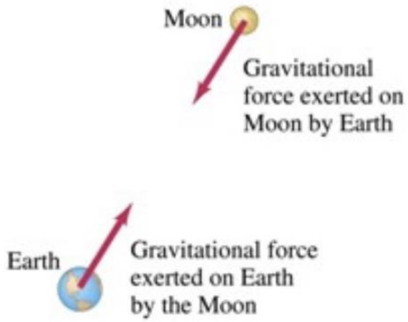
Forces

- **Force** is the capacity to cause physical change in the motion of an object.
- **Force** is an interaction between two bodies or between a body and its environment.
- **Force** is a vector quantity.

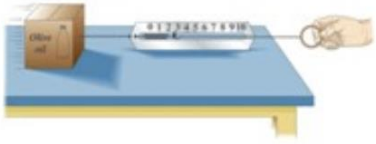




Forces

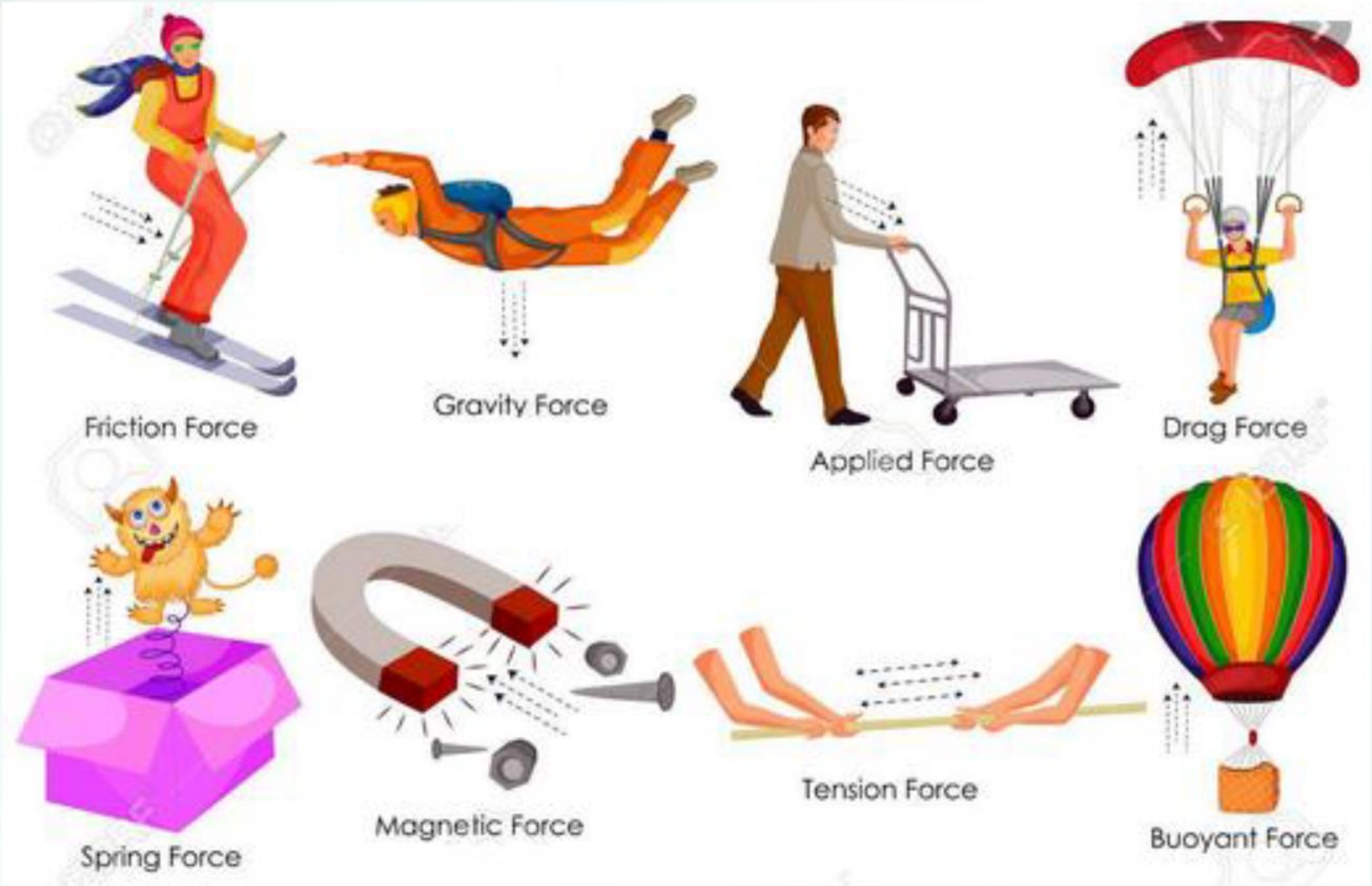


- Contact Forces - those resulting from physical contact between objects
  - Normal Force
  - Friction
  - Tension (spring/rope)
  - Compression



- Action at a Distance Force - Field Forces
  - Gravity
  - Electromagnetic
  - Strong Nuclear Force
    - Holds Nucleus Together
  - Weak Nuclear Force
    - Decay Process

Common Types of Forces

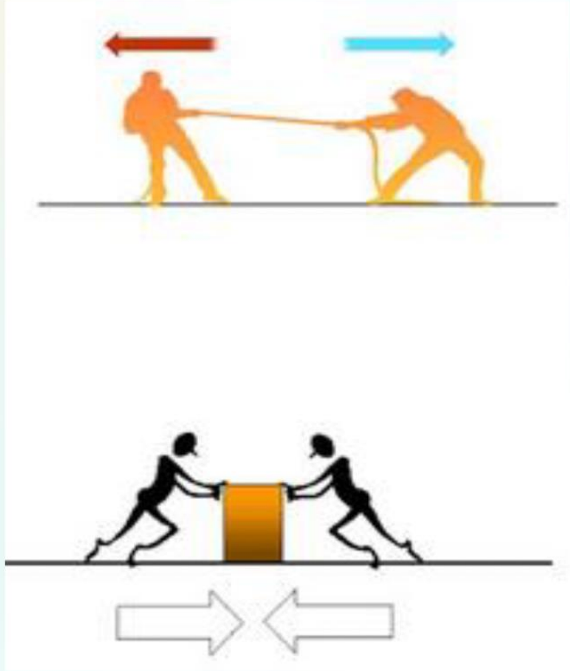


https://sp.depositphotos.com/vector-images/law-energy.html?sorting=undiscovered

Applied Force

- An applied force is a contact force that is applied to an object by external mean

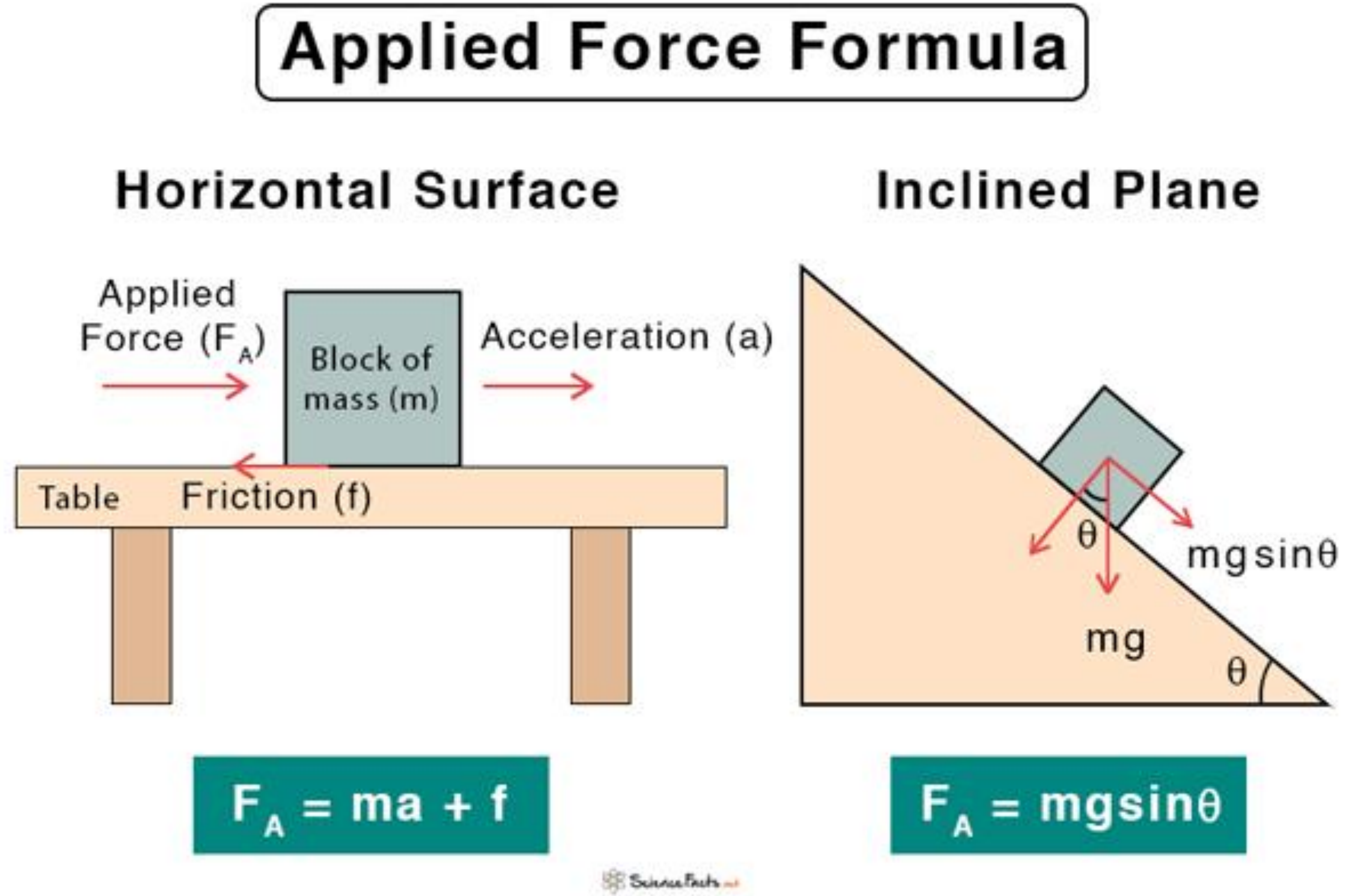
- A contact force exerted on an object; a push or a pull



Push Force:
a type of force that separates objects

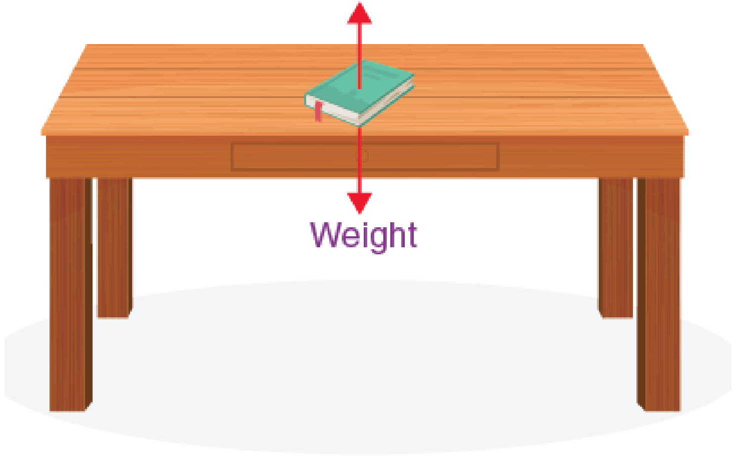
Pull Force:
a type of force that moves objects together

https://quizlet.com/25066526/conceptual-physics-ch-4-newtons-laws-of-motion-flash-cards/

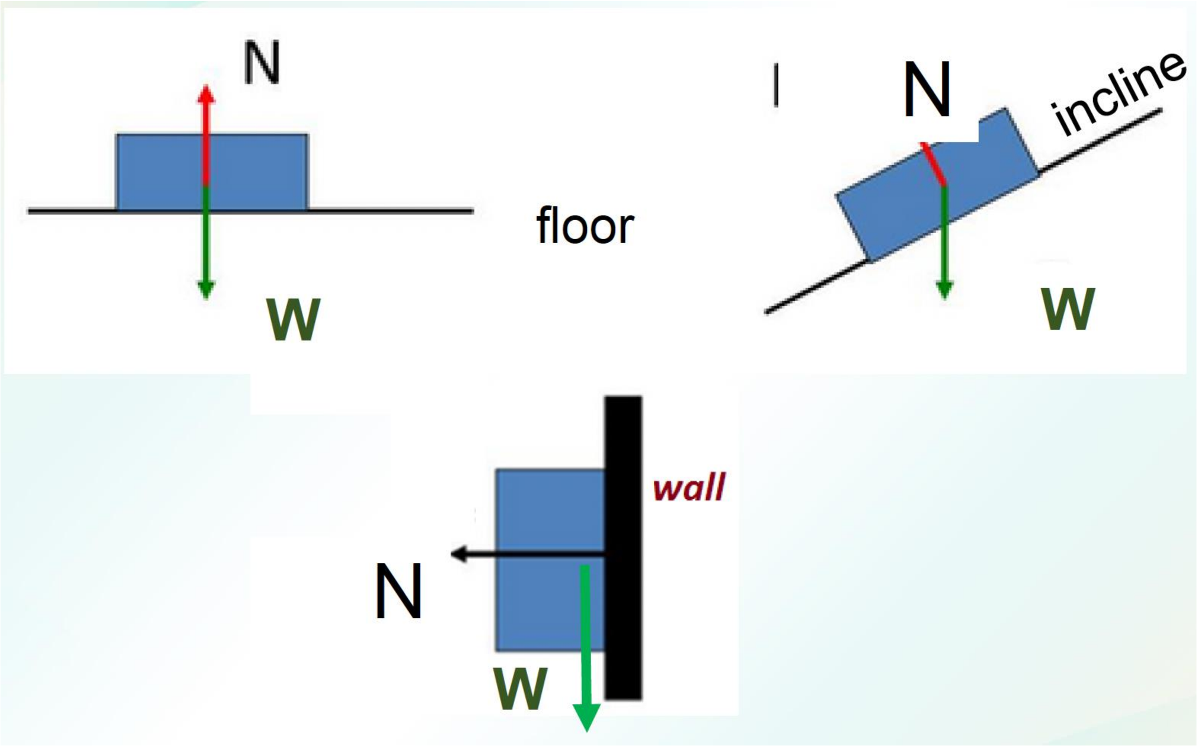

Applied Force Formula
Horizontal Surface
Inclined Plane
Applied Force (F_A)
Block of mass (m)
Acceleration (a)
Table
Friction (f)
θ
mgsinθ
mg
θ
$F_A = ma + f$
$F_A = mgsin\theta$

Normal Force

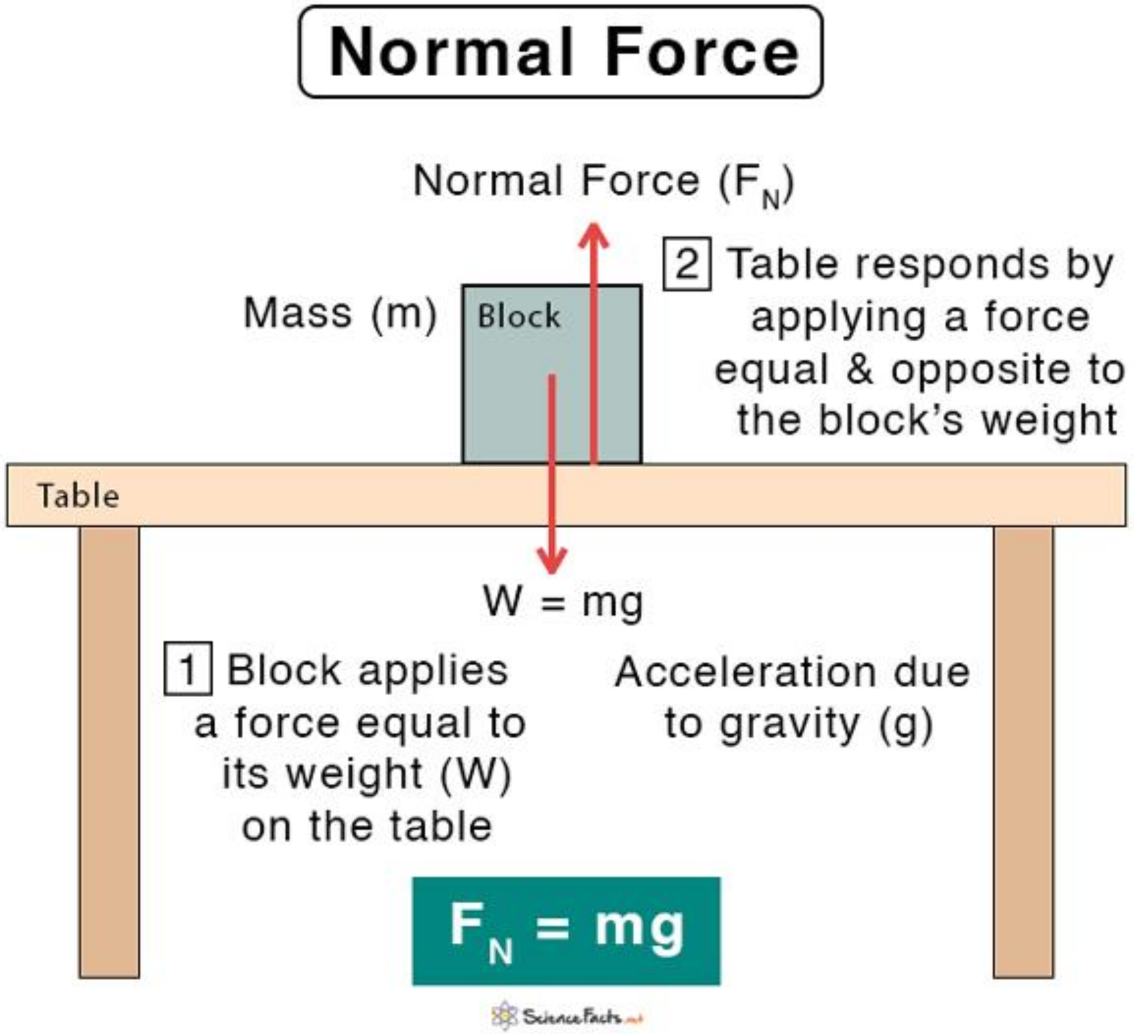
- A force of surface pushing back on an object
- It prevents the object from falling; it balances the weight of the object
- Always perpendicular to the surface
- Not always equal to weight
- No contact, no normal force
- Denoted by the symbol $\mathbf{F_N}$ or **N**

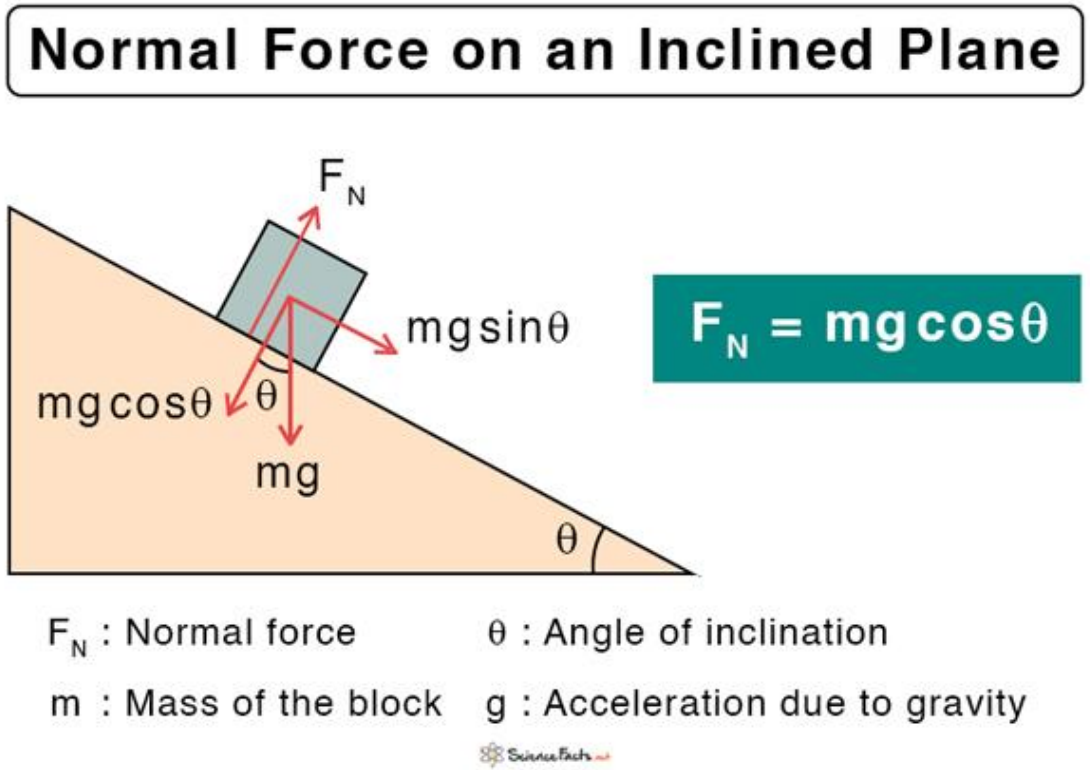


Normal force example



Normal Force





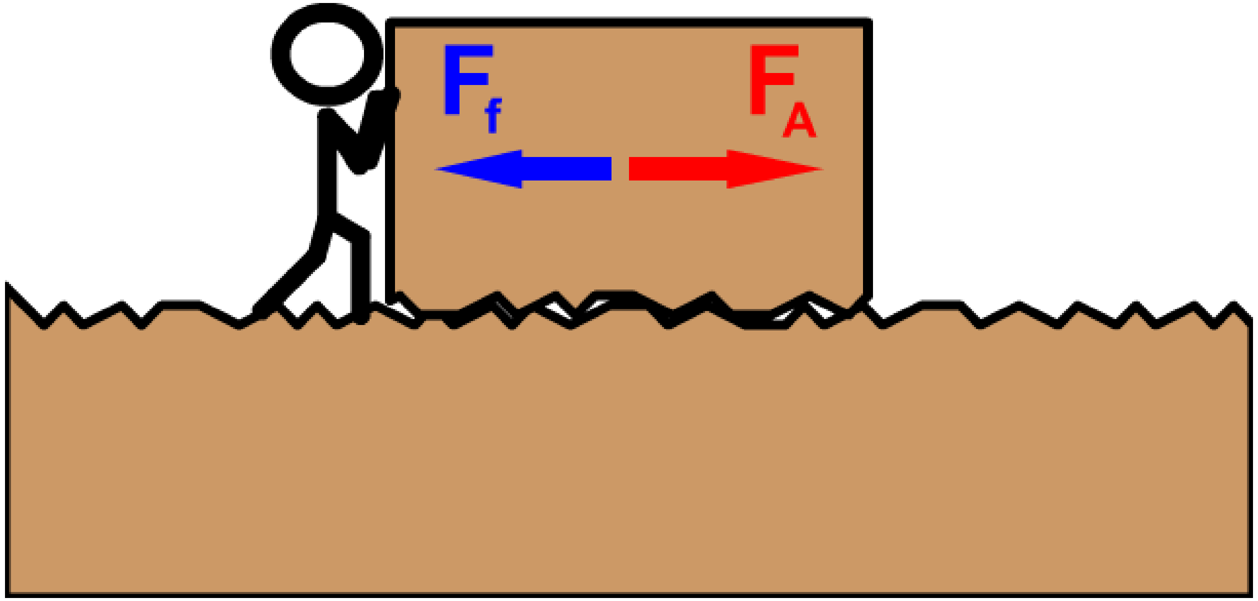
Frictional Force

- A contact force that opposes motion
- Usually proportional to the velocity
- Dependent upon the normal force; Dependent upon the two surfaces in contact, through the coefficient of friction μ

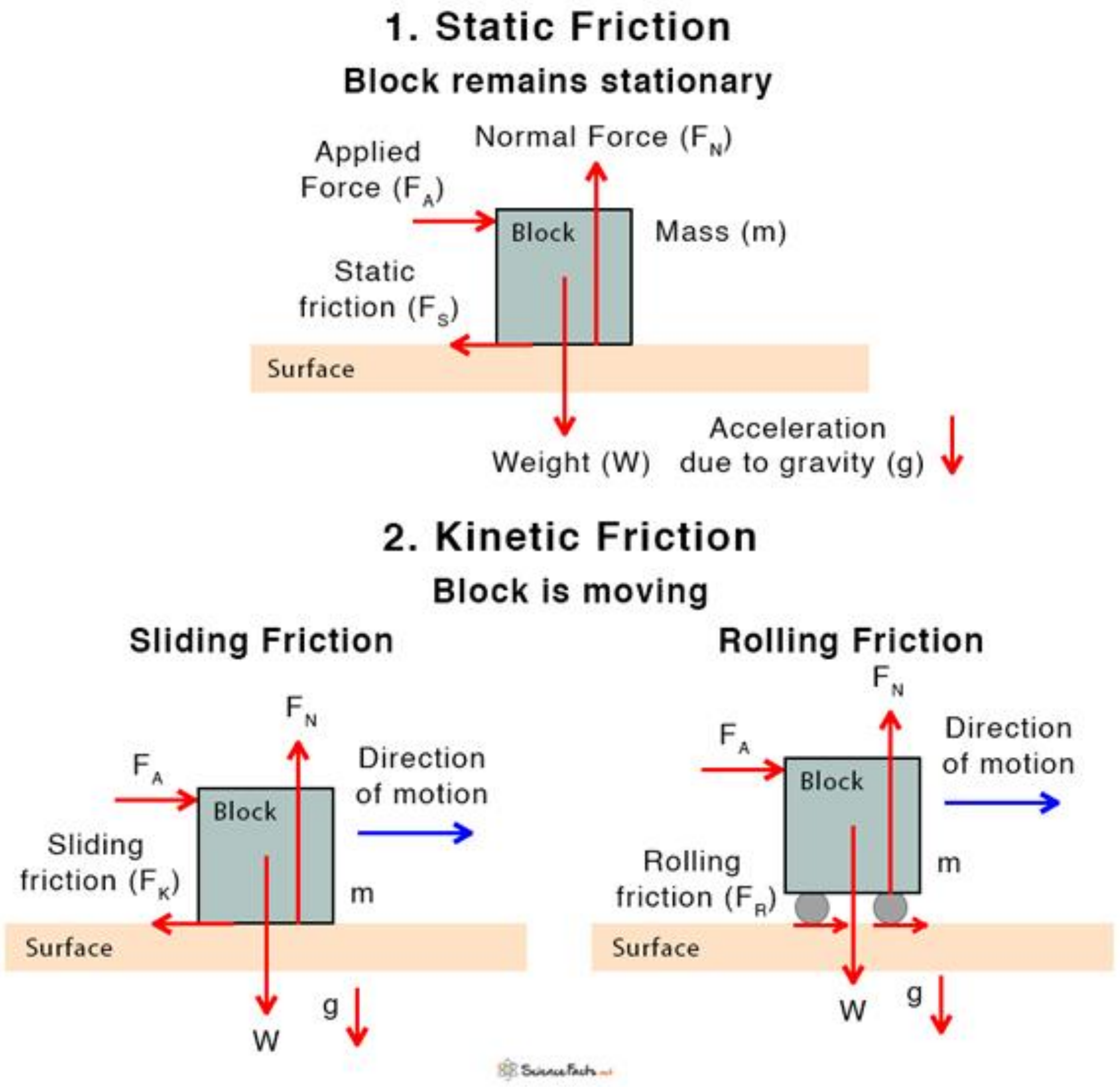
$$\mathbf{F_f = \mu\, F_N}$$

- Represented by an arrow parallel to the surface, opposite to the direction of motion
- No contact, no frictional force
- Denoted by the symbol $\mathbf{F_r}$ or $\mathbf{F_f}$ or **f**

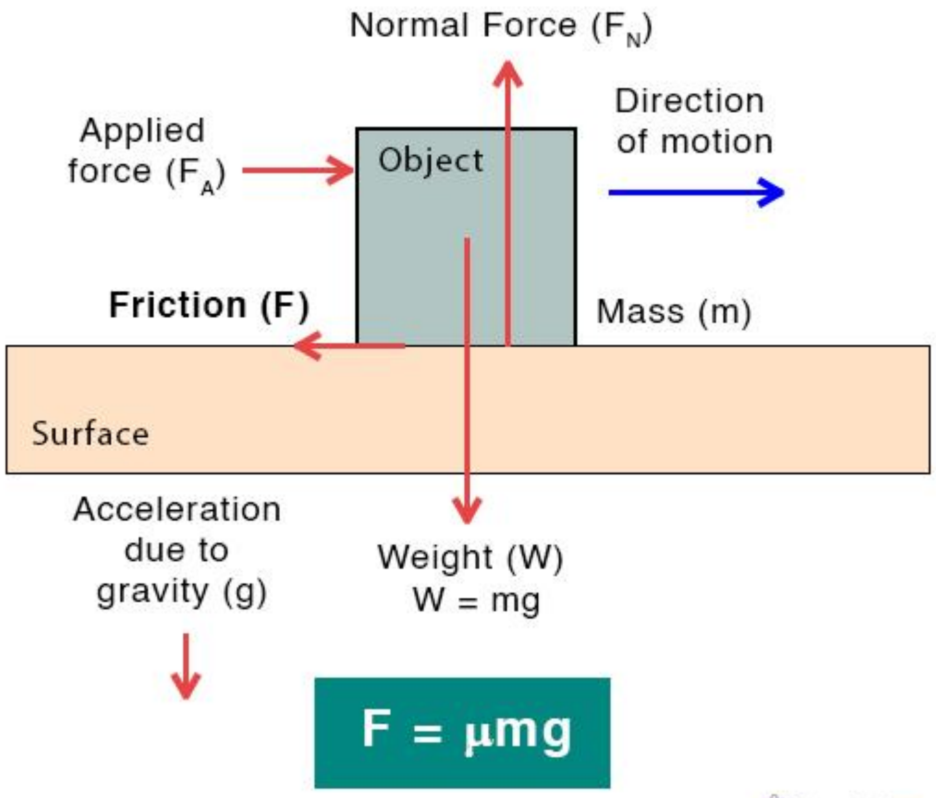
Coefficient of friction, μ		
Surfaces	μ_s	μ_k
Glass on glass	0.94	0.40
Steel on steel	0.74	0.57
Copper on steel	0.53	0.36
Ice on ice	0.10	0.03
Teflon on ice	0.04	0.04

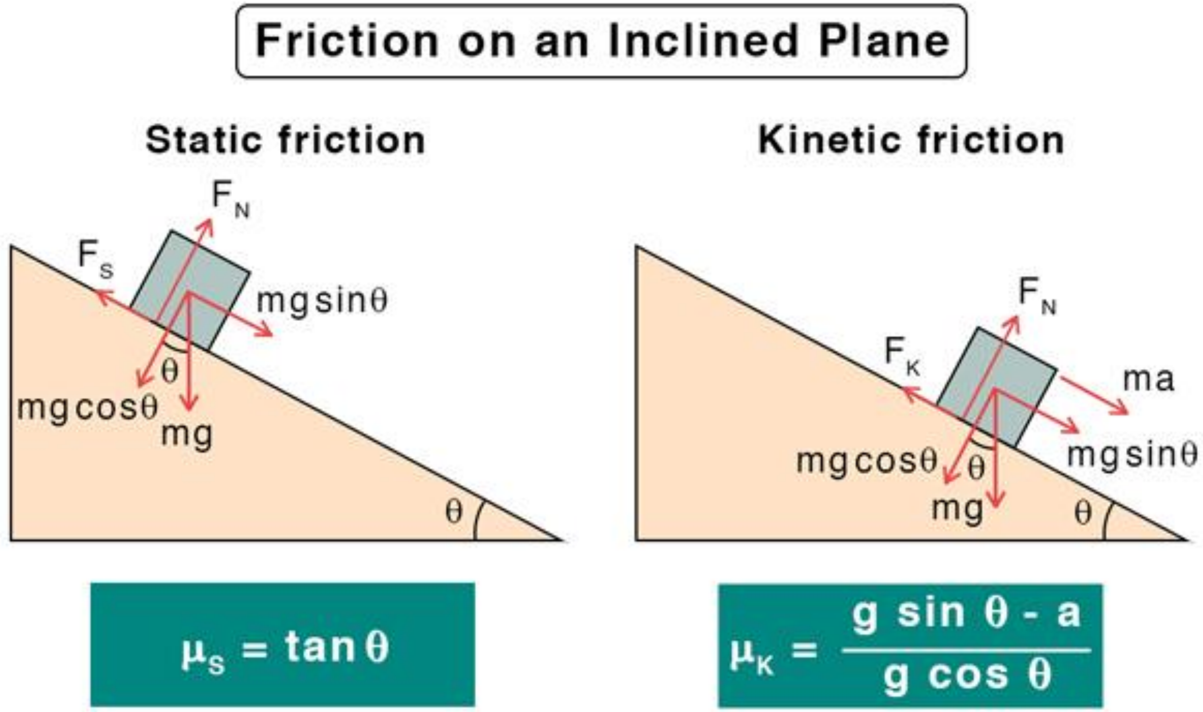


Types of Frictional Force



Frictional Force Formula

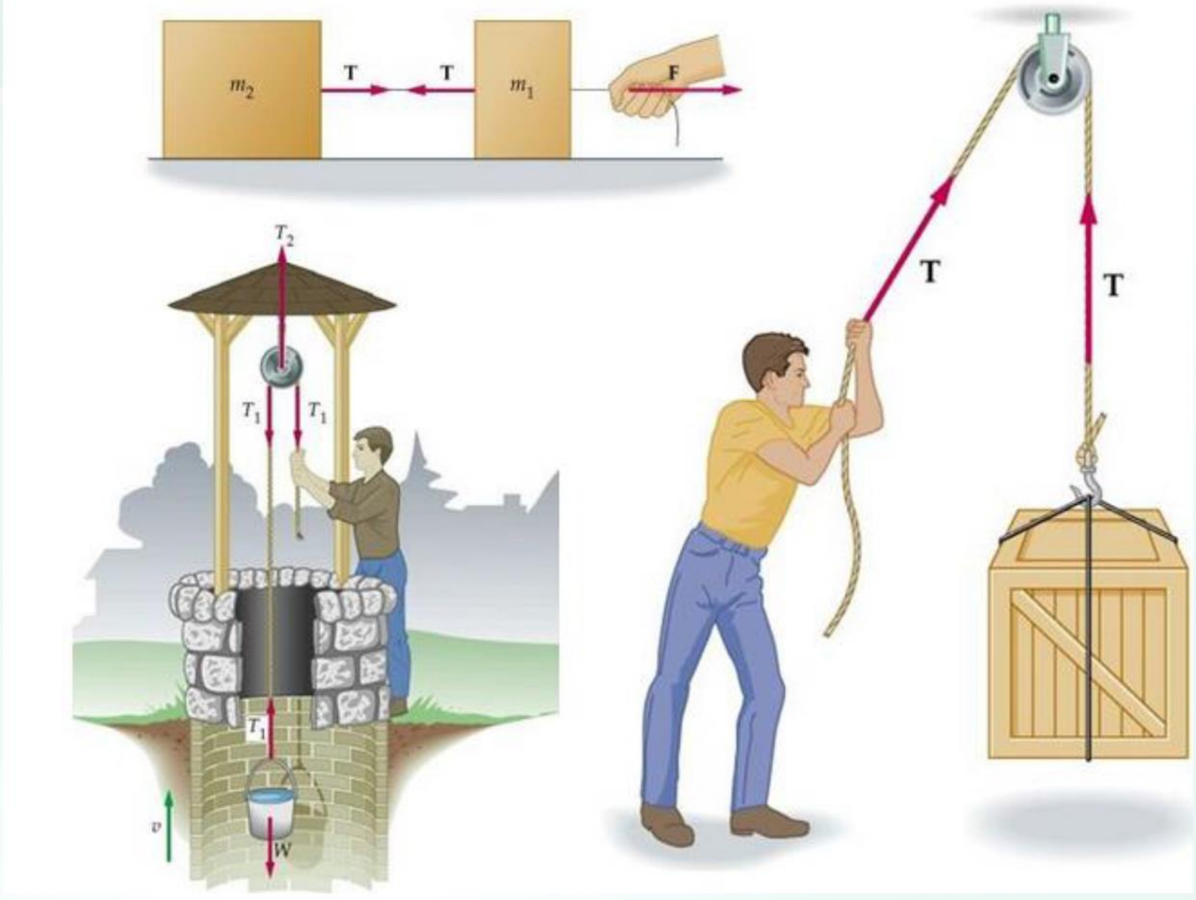


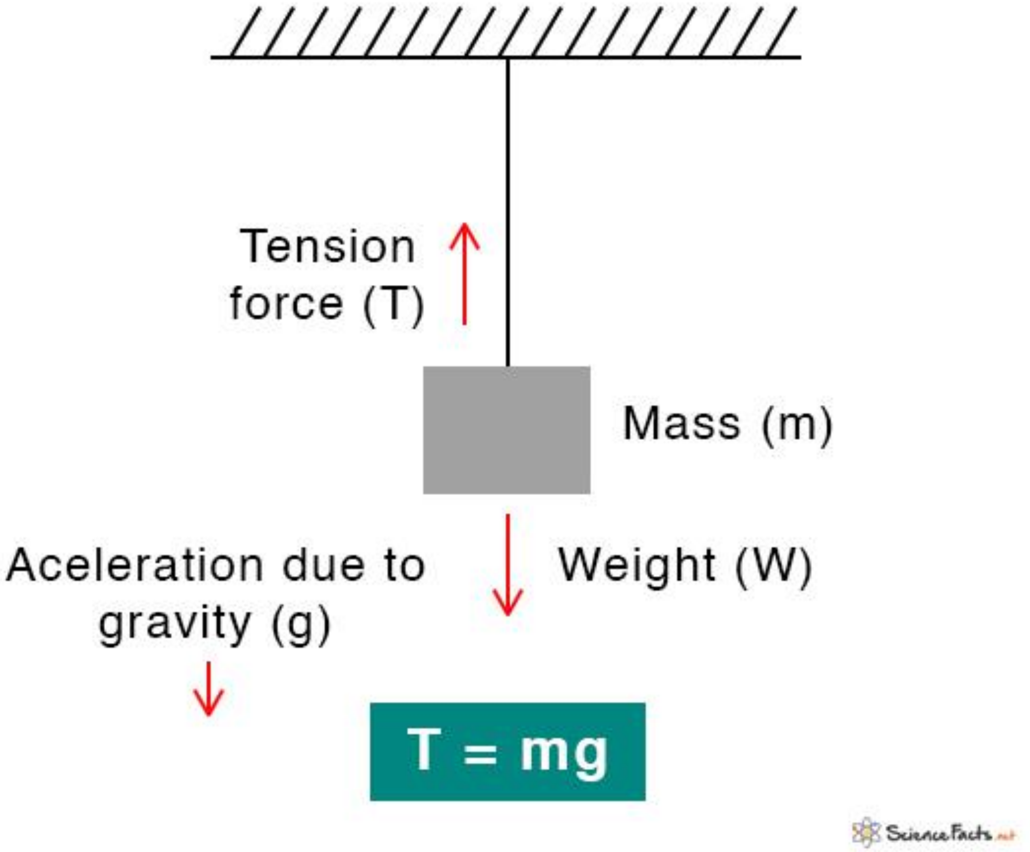


F_N : Normal force
F_S : Static friction
F_K : Kinetic friction
μ_S : Coefficient of static friction
μ_K : Coefficient of kinetic friction
m : Mass of the block
a : Acceleration of the block
θ : Angle of inclination
g : Acceleration due to gravity

Tension Force

- ❑ The force exerted by a rope, wire, cable, chain, cord, etc. is called the force of tension
- ❑ Represented by an arrow along the rope, directed away from the object
- ❑ Denoted by the symbol $\mathbf{F_T}$ or **T**





Tension Force

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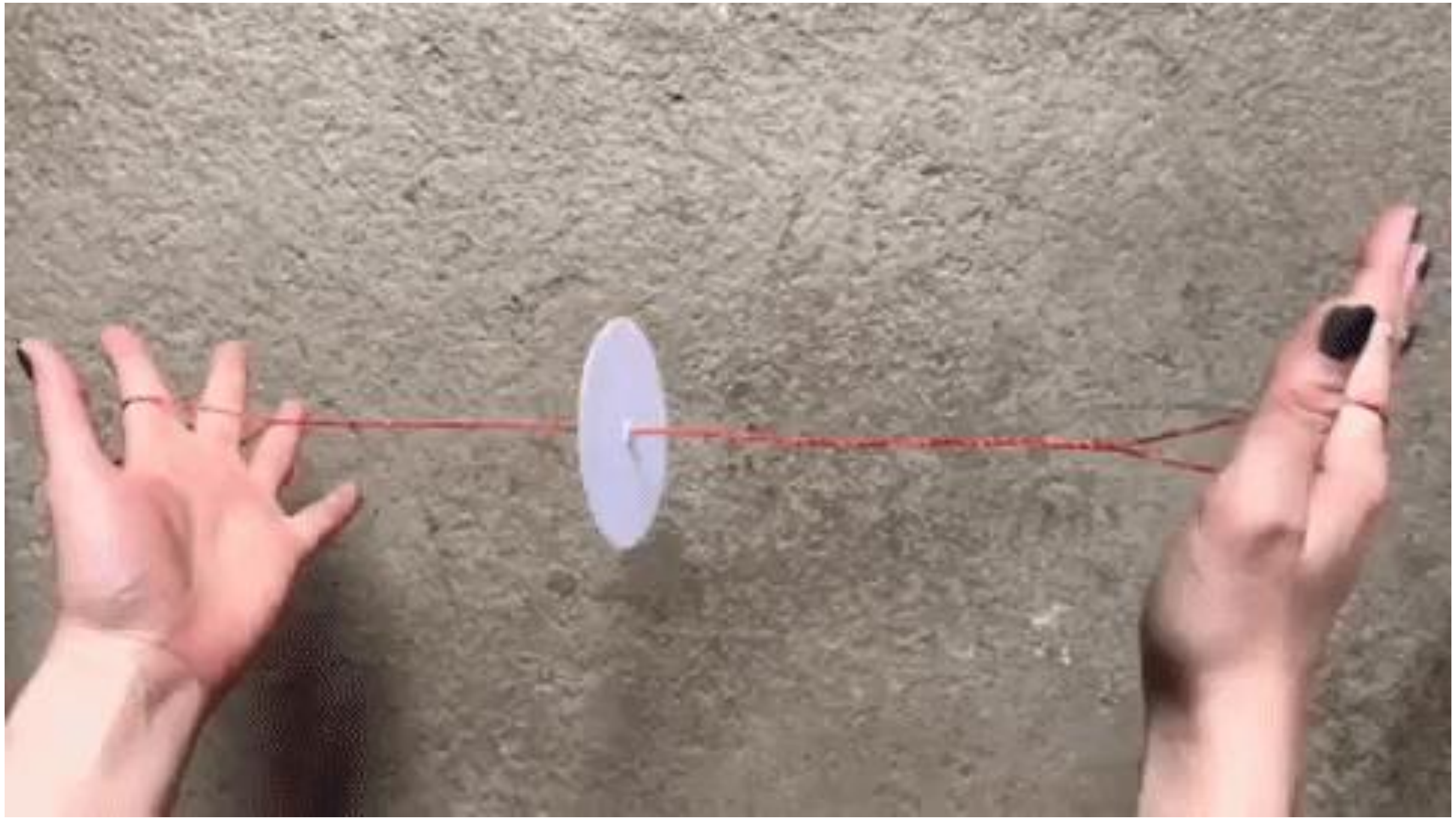
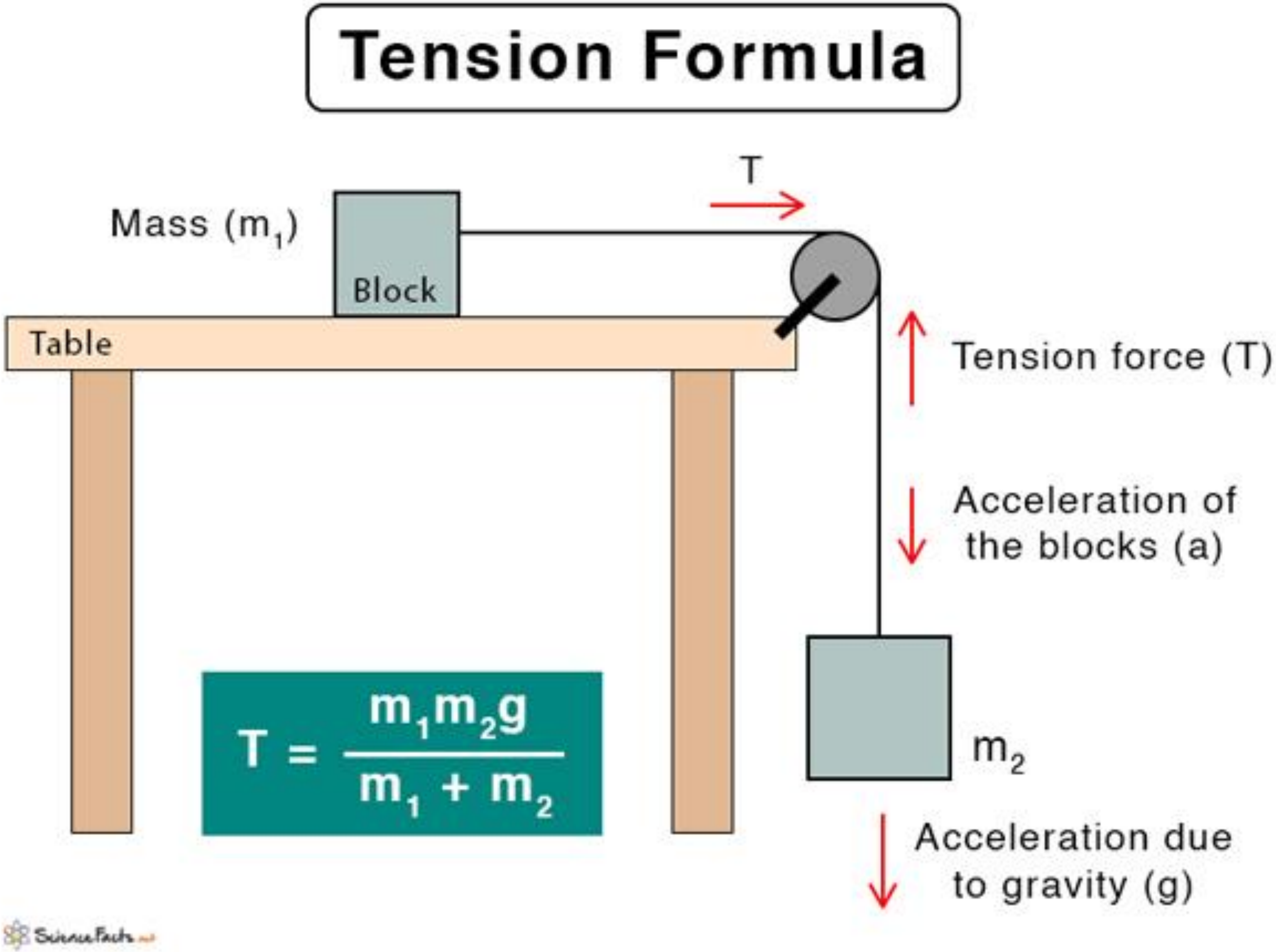
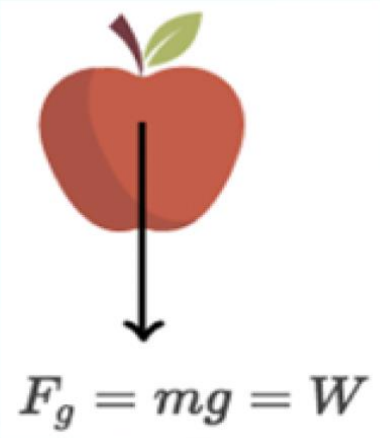


Tension Force



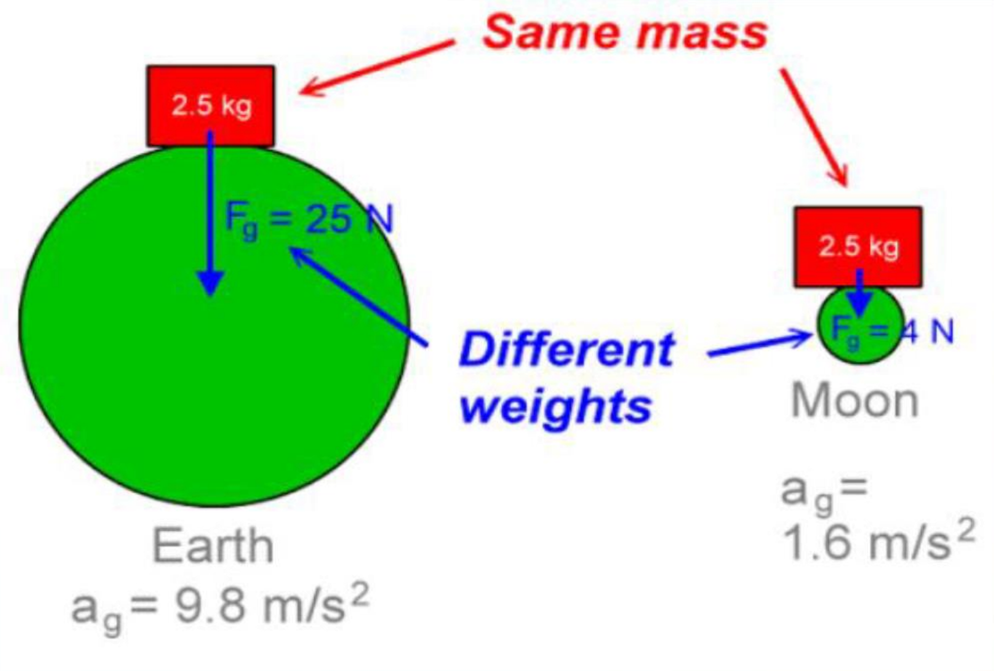
Weight / Gravitational Force

- ❑ Weight is another word for the force of gravity
- ❑ Represented by an arrow pointing downward toward the center of the earth
- ❑ Denoted by the symbol **W**



https://www.khanacademy.org/science/physics/forces-newtons-laws#normal-contact-force

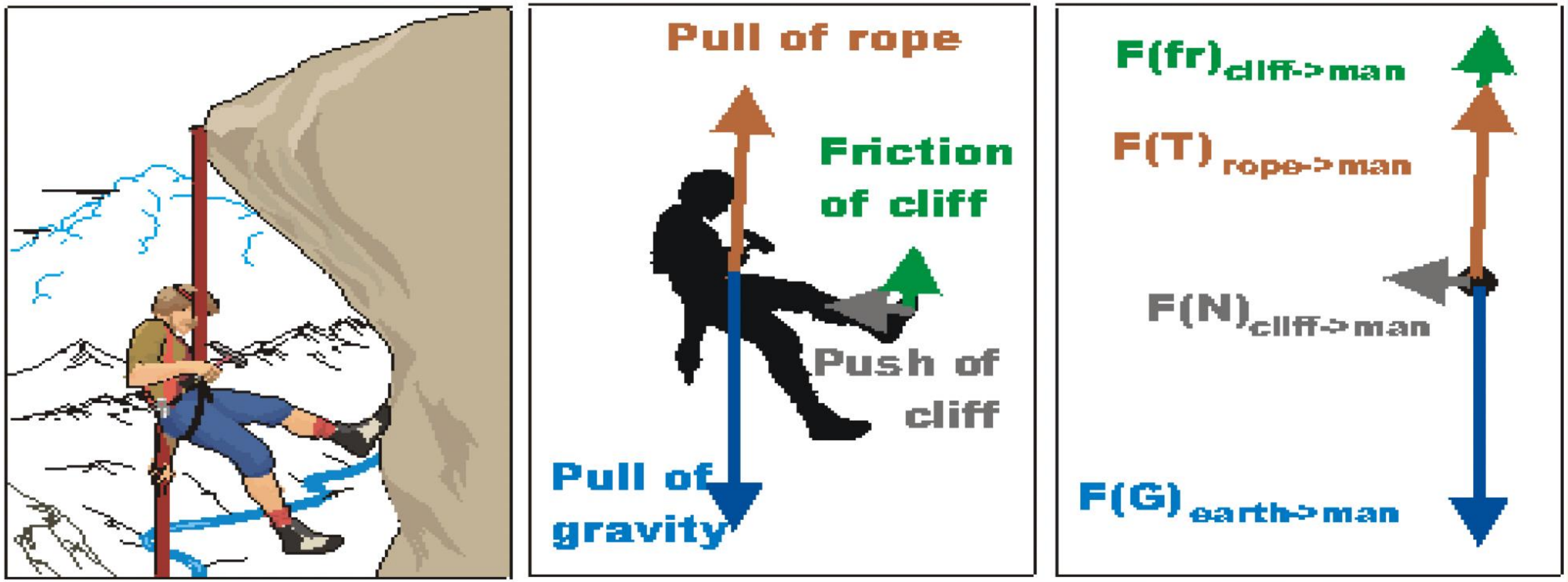
$$W = mg$$



http://zonalandeducation.com/mstm/physics/mechanics/forces/weight/weight.html

Free Body Diagram (FBD)

- a graphical illustration used to visualize the size and direction of forces acting on an object
- to calculate the resulting reactions in many types of mechanics problems.



http://physics.wku.edu/phys201/Information/ProblemSolving/ForceDiagrams.html

Free Body Diagram (FBD)

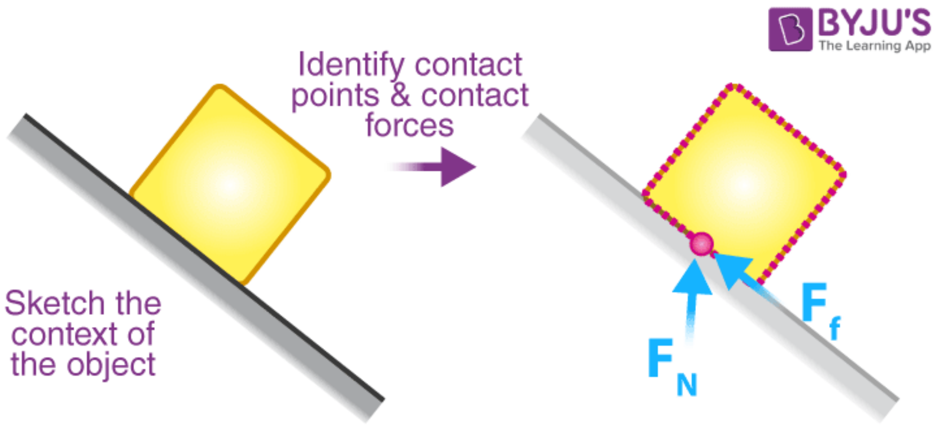
- ✓ A free body diagram is a diagram that is modified as the problem is solved
- ✓ Typically, a free body diagram consists of the following components:
  - A simplified version of the body (most commonly a box)
  - A coordinate system
  - Forces are represented as arrows pointing in the direction they act on the body
  - Moments showed as curved arrows pointing in the direction they act on the body
- ✓ The number of forces acting on a body depends on the specific problem and the assumptions made. Commonly, air resistance and friction are neglected.

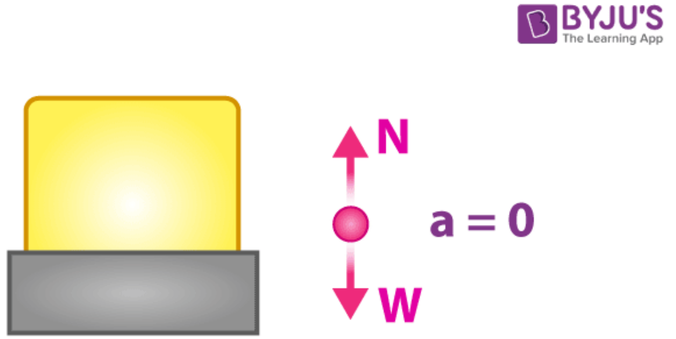
Exclusions in a Free Body Diagram

- Some of the things that a free body diagram excludes are as follows:
  - ❖ Bodies other than the free body diagram
  - ❖ Constraints
  - ❖ Internal forces
  - ❖ Velocity and acceleration vectors

How To Make a Free Body Diagram?

1. Identify the Contact Forces.
2. After identifying the contact forces, draw a dot to represent the object that we are interested in. Here, we are only interested in determining the forces acting on our object.
3. Draw a coordinate system and label positive directions.
4. Draw the contact forces on the dot with an arrow pointing away from the dot. The arrow lengths should be relatively proportional to each other. Label all forces.
5. Draw and label the long-range forces. This will usually be weight unless there is an electric charge or magnetism involved.
6. If there is acceleration in the system, then draw and label the acceleration vector.





Free Body Diagram (FBD)

Common Mistakes Made While Drawing a Free Body Diagram

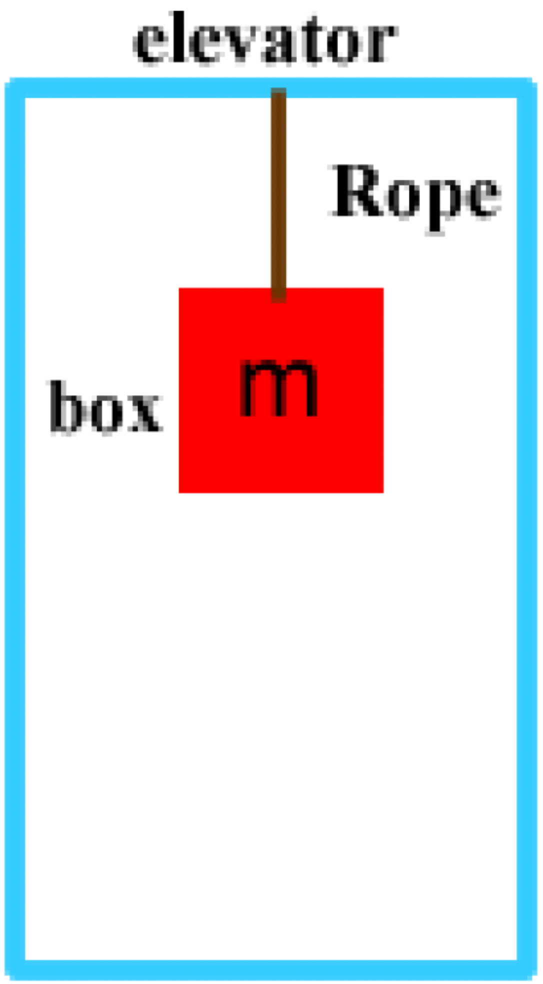
- Avoid drawing forces of the object acting on other objects
- The direction of the different types of forces is denoted wrong

The direction of different forces:

1. Weight is always down
2. Friction is always parallel to the contact surface
3. The normal force is always perpendicular to the contact surface, and tension only pulls

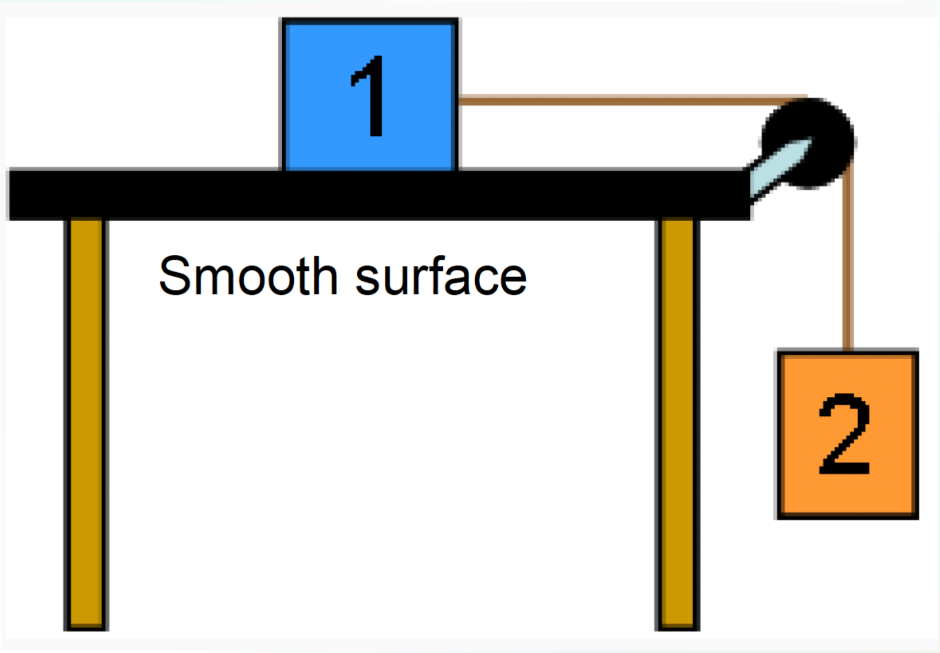
Example:

a) Draw the FBD.

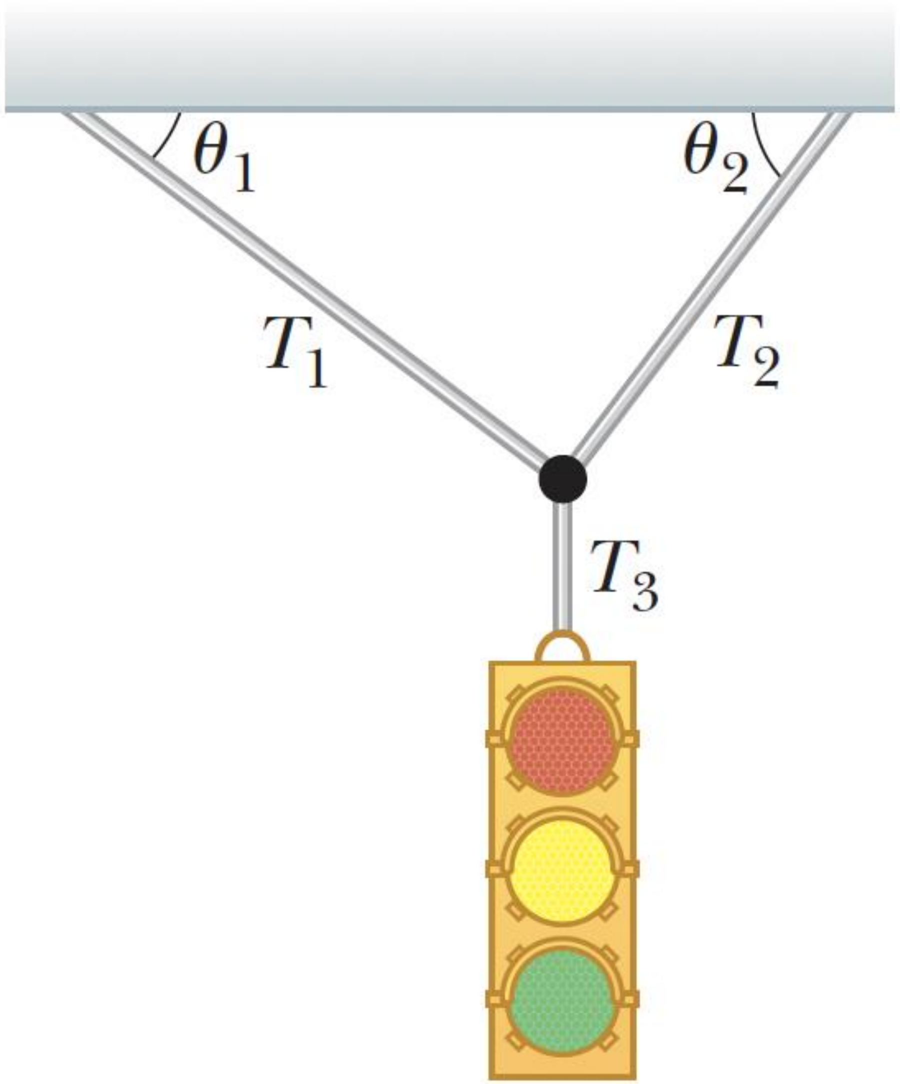


Example:

a) Draw the FBD.



Example:



Example:

A 10 kg box is pulled across the table to the right at a constant speed with a force of 50 N. Suppose the box is now pulled at an angle of 30° above the horizontal with the constant speed (a) calculate the Force of friction and (b) calculate the Normal Force.

Example:

An object of 12 kg mass is suspended by light and an inextensible string at one end. If the string is attached firmly to a hook at the other end, calculate the force of tension.

Answer: F_T = 117.6 N

An object of 8 kg mass is pulled by a rope over a pulley. It is accelerating upward with an acceleration of 6 m/s^2. Calculate the force of tension on the rope.

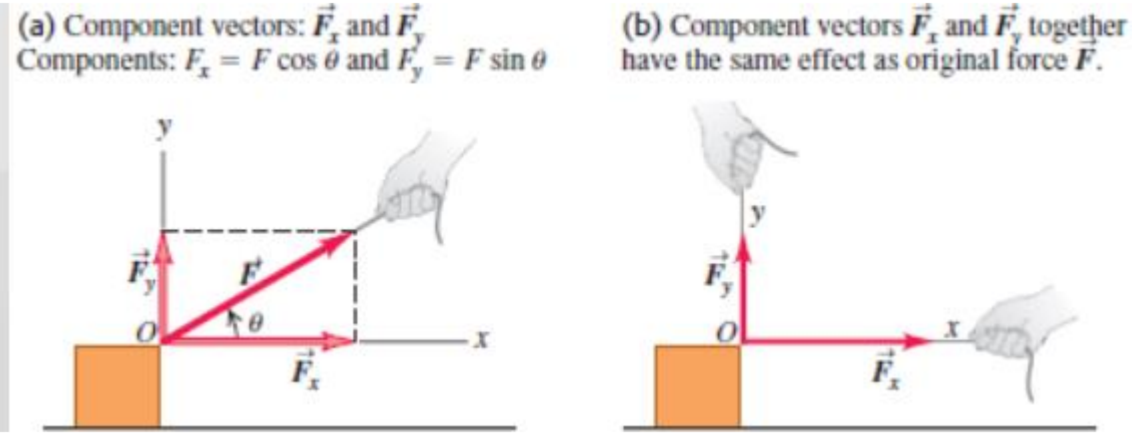
Answer: F_T = 126.4 N

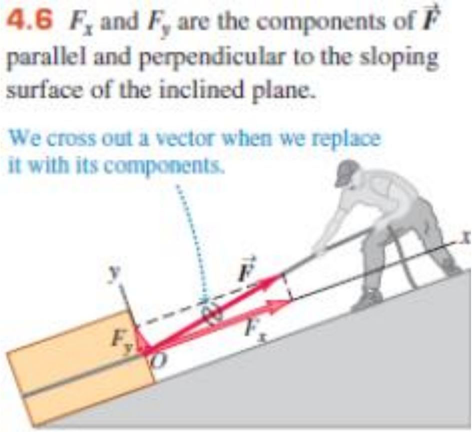
Superposition of Forces

- When you throw a ball, there are at least two forces acting on it: the push of your hand and the downward pull of gravity.
- If you want the resultant force of the system, get the summation of all the forces existing.
- “Any number of forces applied at a point on a body have the same effect as a single force equal to the vector sum of the forces.”
- In general, $\vec{F}_T = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots + \vec{F}_N$

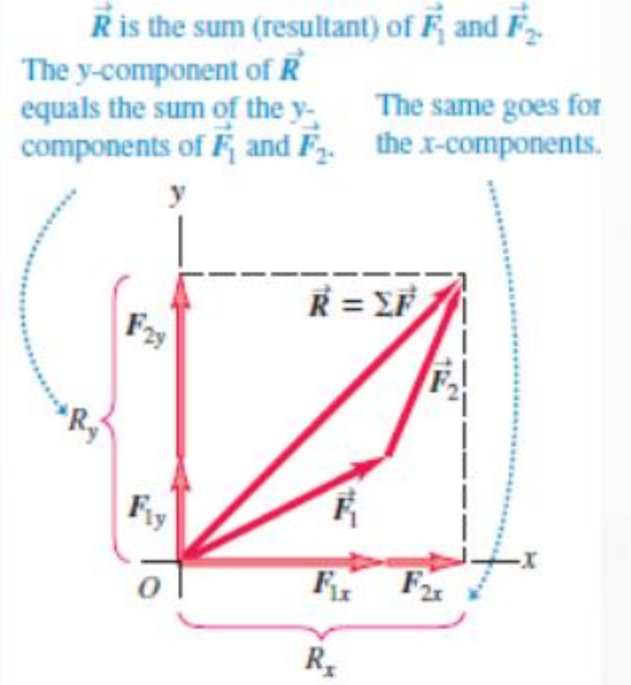
Components of Forces

- Since forces are vector quantities, they can be represented by their components. For instance, a force on a 2D plane has both x and y components written as F_x *and* F_y





Young, H. D., Freedman, R. A., Sandin, T. R., & Ford, A. L. (1996). *University physics* (Vol. 9). Reading, MA: Addison-Wesley.



Applying superposition principle, $\boldsymbol{R_x} = \sum \boldsymbol{F_x}$ *and* $\boldsymbol{R_y} = \sum \boldsymbol{F_y}$

The magnitude of R is calculated as: $|\vec{R}| = \sqrt{R_x^2 + R_y^2}$

Young, H. D., Freedman, R. A., Sandin, T. R., & Ford, A. L. (1996). *University physics* (Vol. 9). Reading, MA: Addison-Wesley.

Newton's Laws of Motion

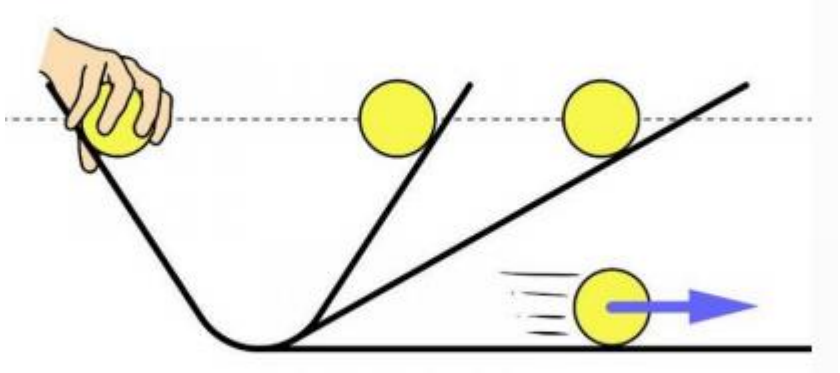
- Newton's laws of motion are three physical laws that, together, laid the foundation for classical mechanics.
- They describe the relationship between a body and the forces acting upon it, and its motion in response to those forces.
- THE THREE LAWS ARE THE FOLLOWING:

1. Law of Inertia
2. Law of Acceleration
3. Law of Action and Reaction

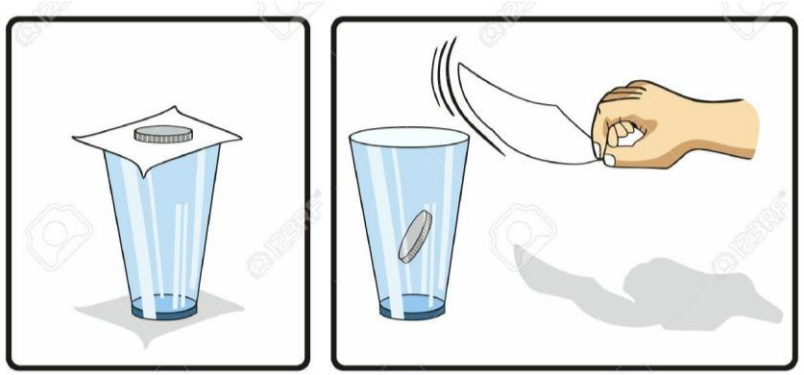
https://www.alamy.com/stock-photo-cartoon-illustration-of-albert-einstein-89903767.html

Law of Inertia

- Inertia is the tendency of a body to resist moving.
- It is the resistance of any physical object to any change in its velocity.
- Inertia, being a passive property, does not enable a body to do anything except oppose such active agents as forces.
- *First Law: "A body at rest will remain at rest, and a body in motion will remain in motion, unless it is acted upon by an unbalanced external force."*



https://studiousguy.com/inertia-examples/



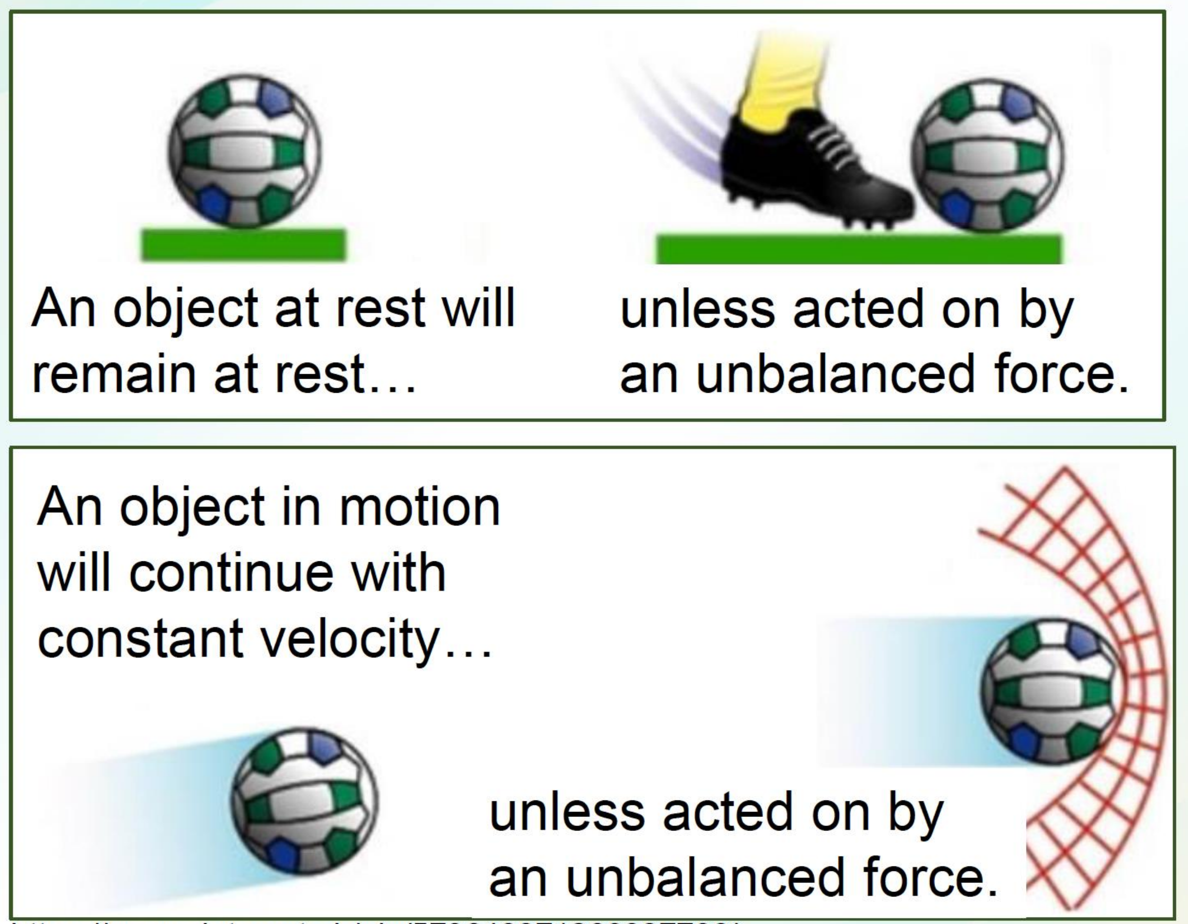
When the cardboard is pulled, the coin falls into the glass. This is because the inertia of the coin maintains its state at rest and it falls into the glass due to gravity.
https://studiousguy.com/inertia-examples/

Law of Inertia

Newton's first law of motion states that:

<u>**"A body continues its state of rest or of uniform motion in a straight line provided no net force acts on it."**</u>

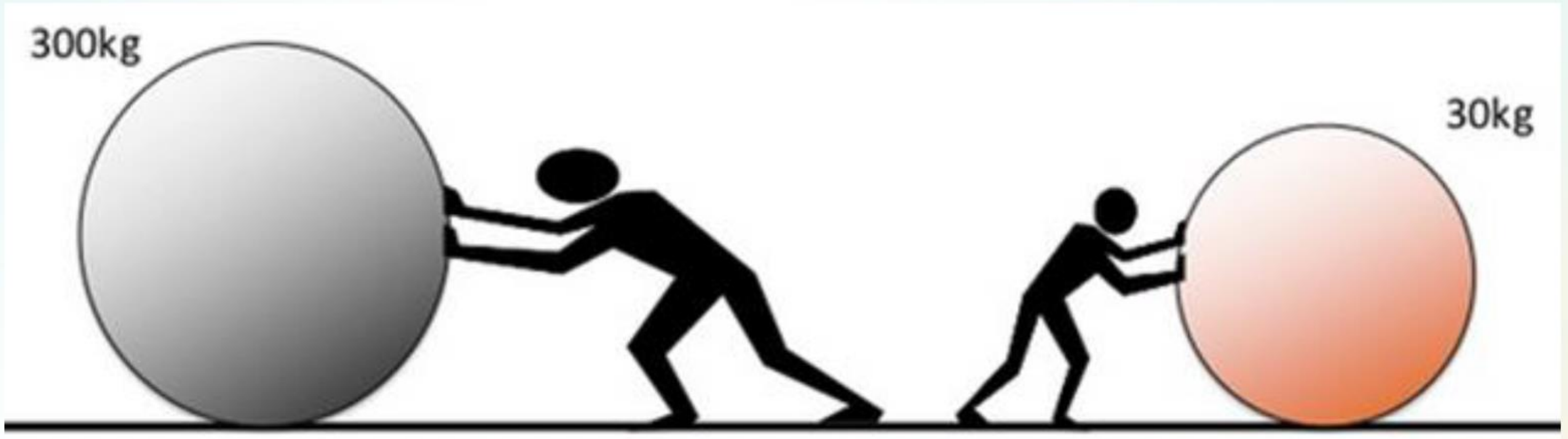
- "No net force" means the body is at equilibrium



https://www.pinterest.ph/pin/573646071266387796/

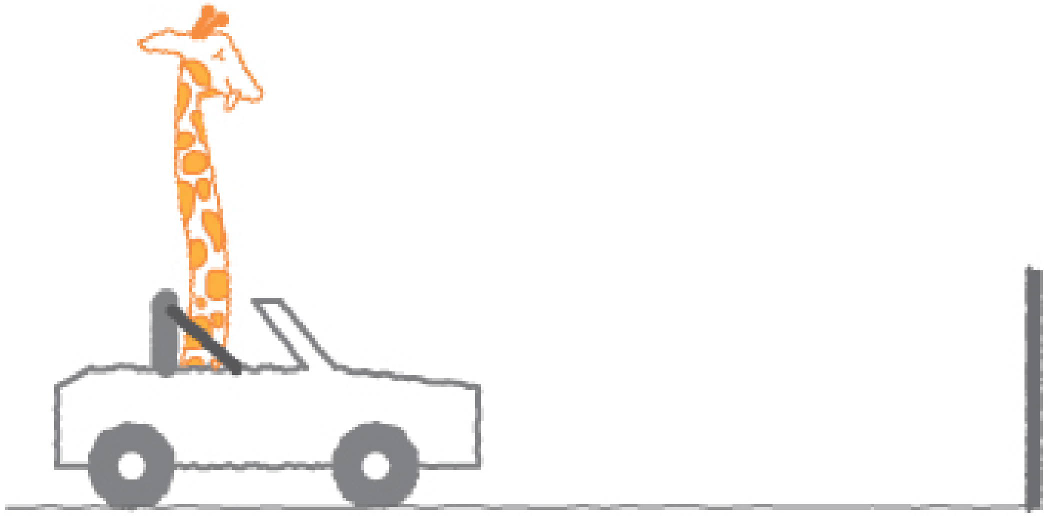
Law of Inertia

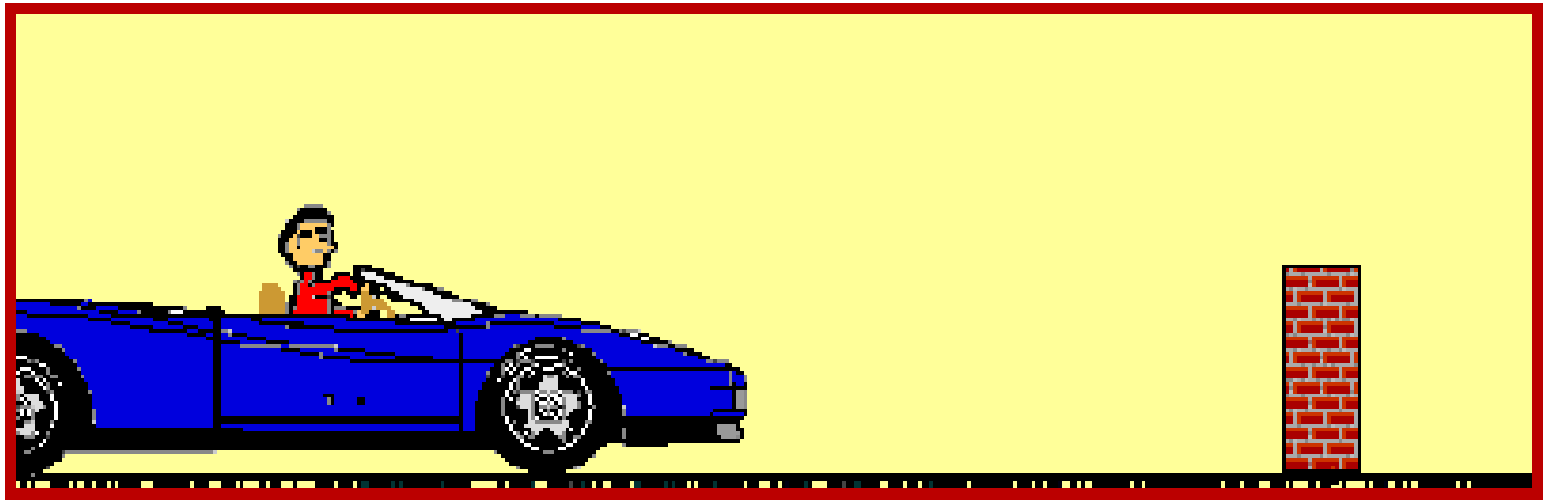
- **Inertia** is the resistance of an object to a change in its state of motion or rest.
- Objects with greater mass have more inertia.
- It takes more power to change their motion.



https://socratic.org/physics/forces-and-newtons-laws/newtons-first-law

Law of Inertia





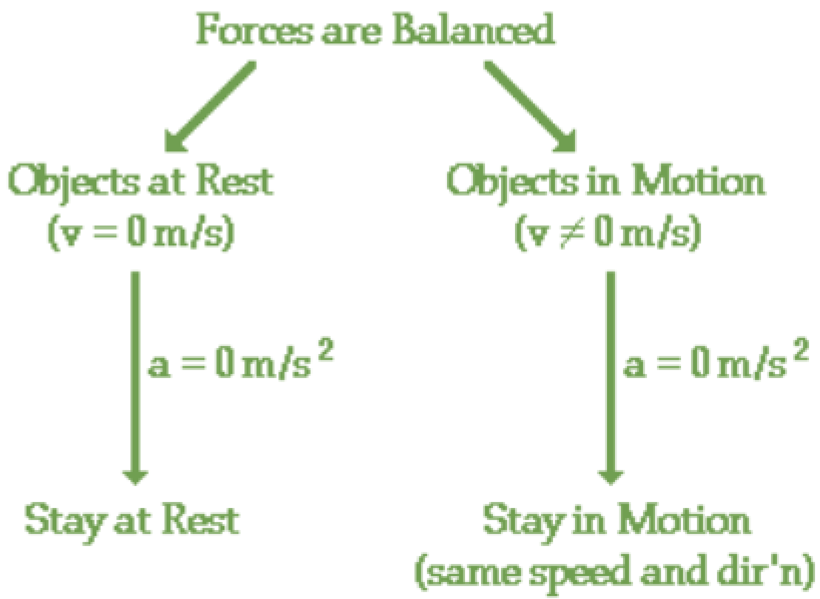
Law of Inertia

- There are two parts - one that predicts the behavior of stationary objects and the other that predicts the behavior of moving objects.

- The two parts are summarized in the following diagram.

- The condition is described by the phrase "... unless acted upon by an unbalanced force." As long as the forces are balanced - the first law of motion applies.

$$\sum F = 0$$



https://www.physicsclassroom.com/class/newtlaws/Lesson-1/Newton-s-First-Law

Inertia of Rest

- Inertia of Rest can be defined as the inability of an object or body to change its state of rest by itself.
- For example, when a car is suddenly started, the passengers in it fall backward.
- Another example is a coin on a piece of cardboard shown by the image beside.
- What do you think will happen if you suddenly pull the cardboard horizontally?

https://studiousguy.com/inertia-examples/

Inertia of Motion

- Inertia of motion can be defined as the inability of an object or body to change its state of motion by itself.
- For example, if we reverse the first example, we will understand the inertia of motion.
- Let’s say that you are in a moving car, and when it suddenly stops, all the passengers fall forward.
- That’s because the lower part of the body, which is in contact with the car is at rest, whereas the upper part tends to remain in motion due to inertia of motion.
- STIRRING OF MILK AND SATELLITES THAT ORBIT THE PLANET.

Inertia of Direction

- Inertia of direction can be defined as the inability of any physical object to change its direction of motion by itself.
- For example, when a car moves along a round curve, the passengers sitting inside are thrown outwards.
- It happens due to the inertia of direction in order to maintain the direction of motion.

https://studiousguy.com/inertia-examples/

Module 5: Newton's Laws of Motion

5.2 Law of Acceleration

OBJECTIVES:

1. Explain forces and its types
2. Determine and illustrate forces acting on a system
3. Draw free body diagrams of systems
4. Define Newton's 2nd Law
5. Apply Newton's 2nd law of motion in problem solving

Law of Acceleration

- Newton's second law of motion pertains to the behavior of objects for which all existing forces are not balanced.

- *"The second law states that the acceleration of an object is dependent upon two variables - the net force acting upon the object and the mass of the object."*

- BUT WHAT EXACTLY ARE THEIR MATHEMATICAL RELATIONSHIPS?

- ACCELERATION IS DIRECTLY PROPORTIONAL TO THE FORCE ACTING UPON THE OBJECT AND INVERSELY PROPORTIONAL TO THE MASS OF THE OBJECT.

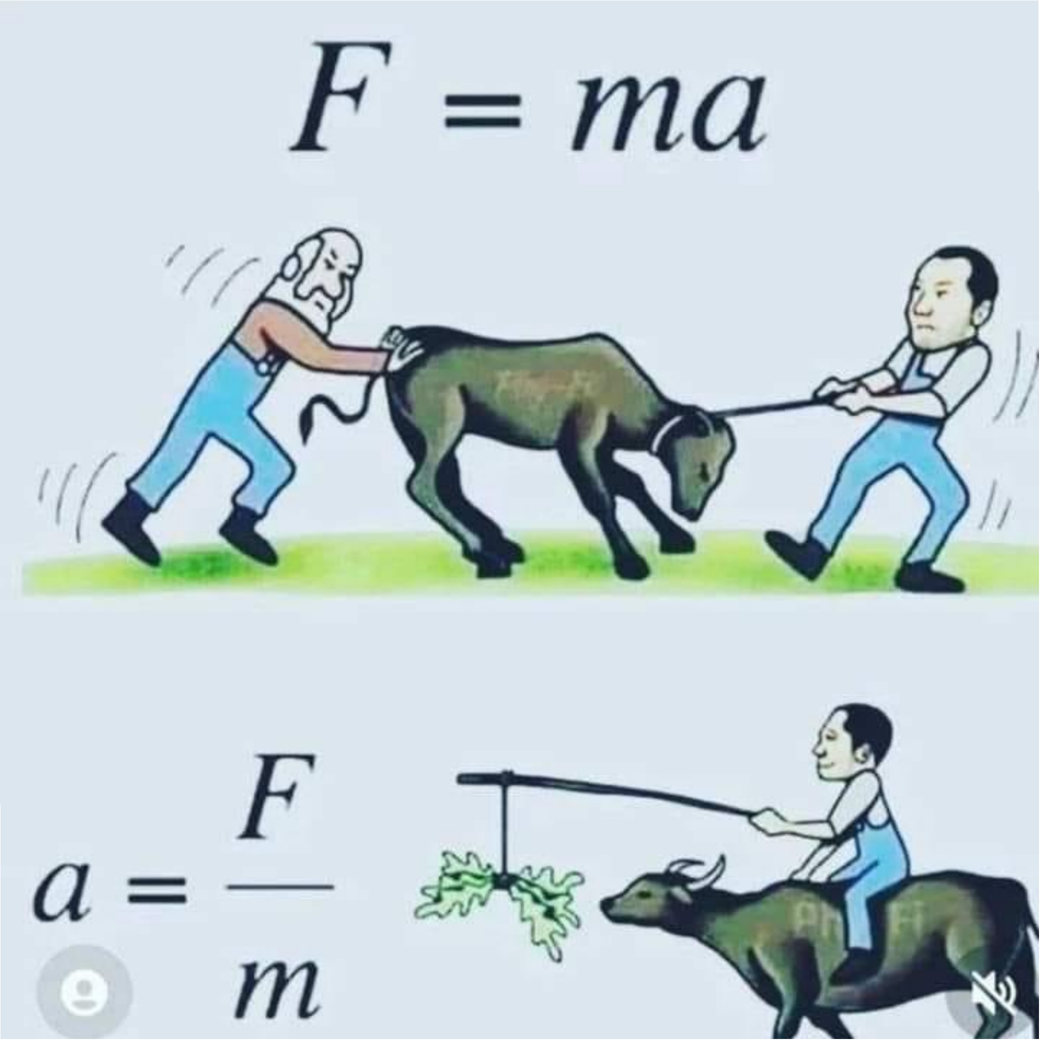
$$\boxed{\vec{a} = \frac{\vec{F}}{m} \rightarrow \vec{F} = m\vec{a}}$$

"When a net force acts on a body, it produces an acceleration in the body in the direction of the net force."

- The magnitude of this acceleration is directly proportional to the net force acting on the body and inversely proportional to its mass."

Newton's Second Law of Motion

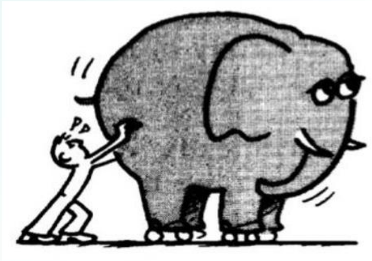
If you know the **acceleration** of an object, you can determine the **net force** on it.



If you know the **force** on an object, you can predict **changes** in its **motion**.

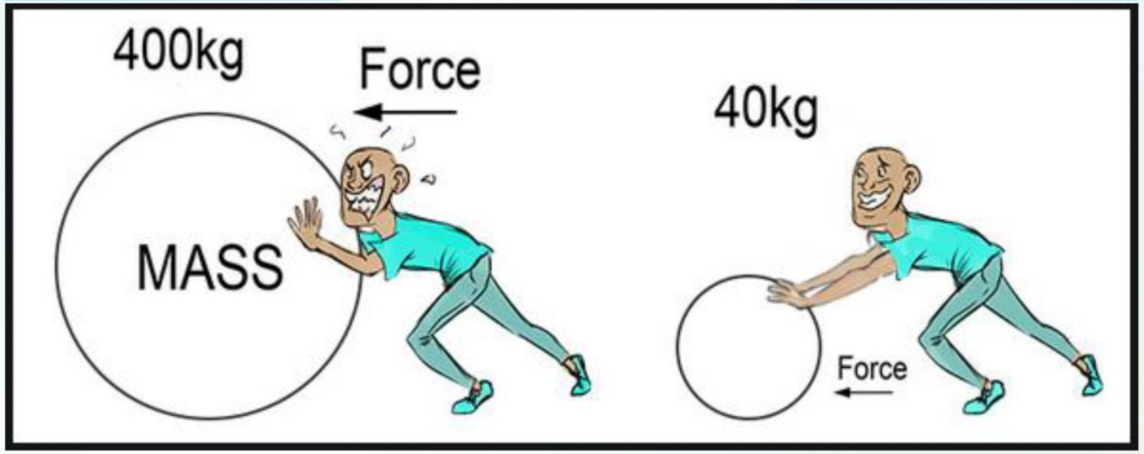
Newton's Second Law of Motion

$m \propto F$



$m\uparrow \quad F\uparrow$

$m\downarrow \quad F\downarrow$

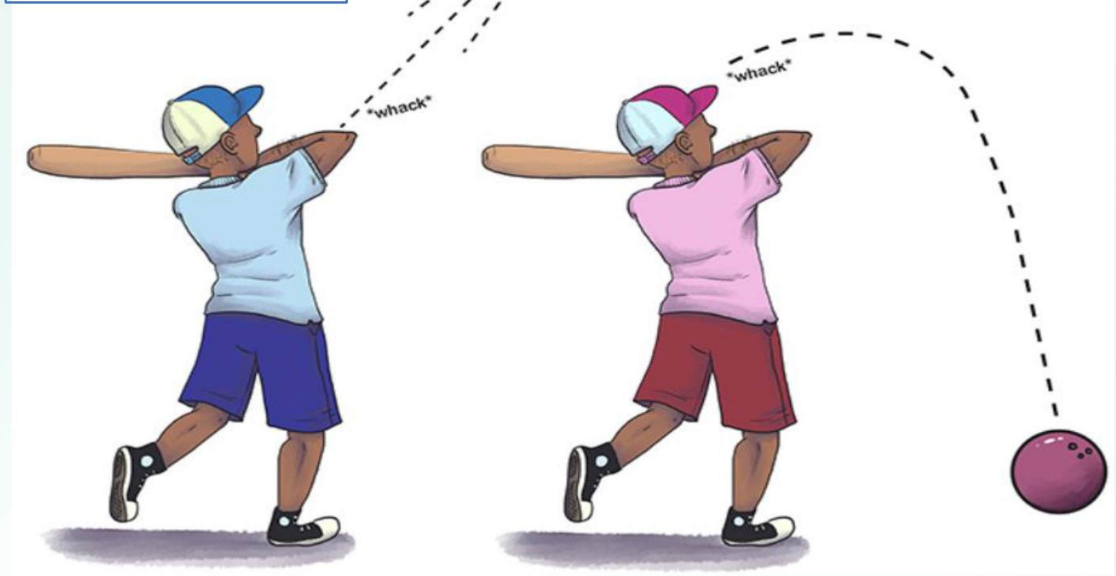


https://mammothmemory.net/physics/newtons-laws-of-motion/newtons-second-law--examples/newtons-second-law-examples.html

$a \propto 1/m$

$m\downarrow \quad a\uparrow$

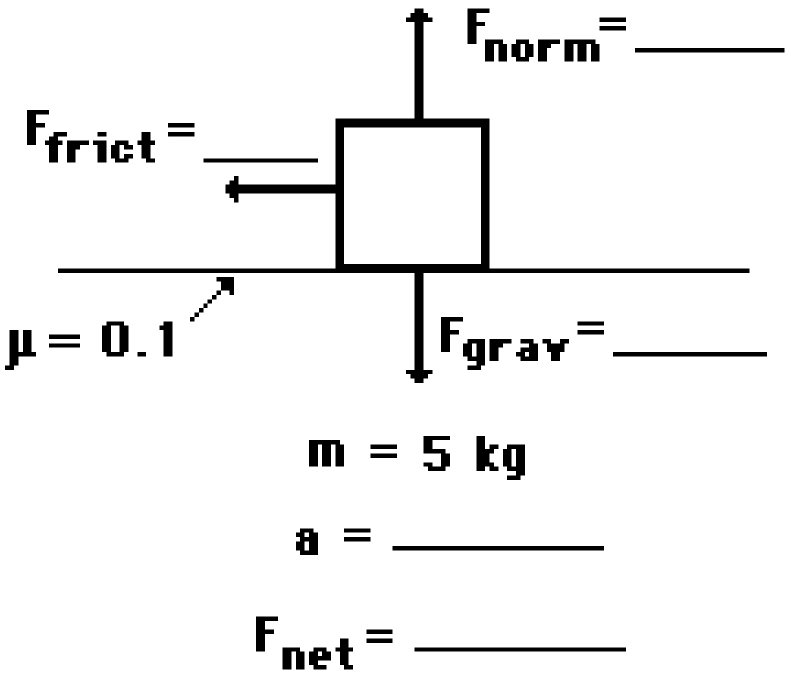
$m\uparrow \quad a\downarrow$



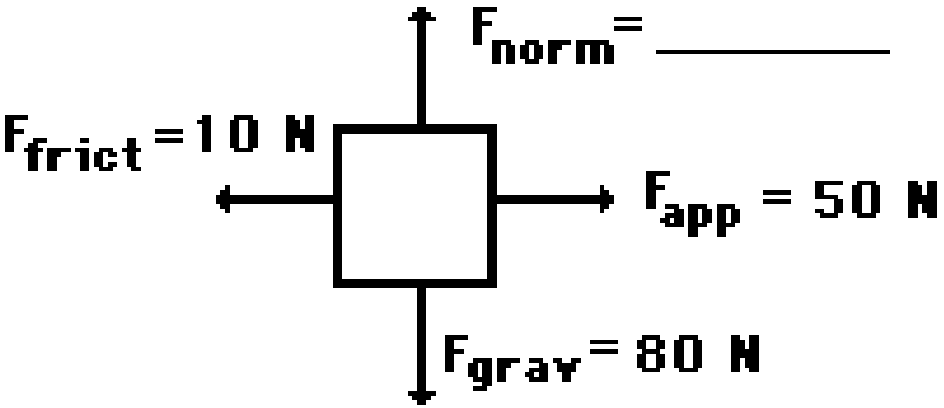
https://mammothmemory.net/physics/newtons-laws-of-motion/newtons-second-law--examples/newtons-second-law-examples.html

Example

A 5-kg object is sliding to the right and encountering a friction force that slows it down. The coefficient of friction (μ) between the object and the surface is 0.1. Determine the force of gravity, the normal force, the force of friction, the net force, and the acceleration. (Neglect air resistance.)



An applied force of 50 N is used to accelerate an object to the right across a frictional surface. The object encounters 10 N of friction. Use the diagram to determine the normal force, the net force, the mass, and the acceleration of the object. (Neglect air resistance.)

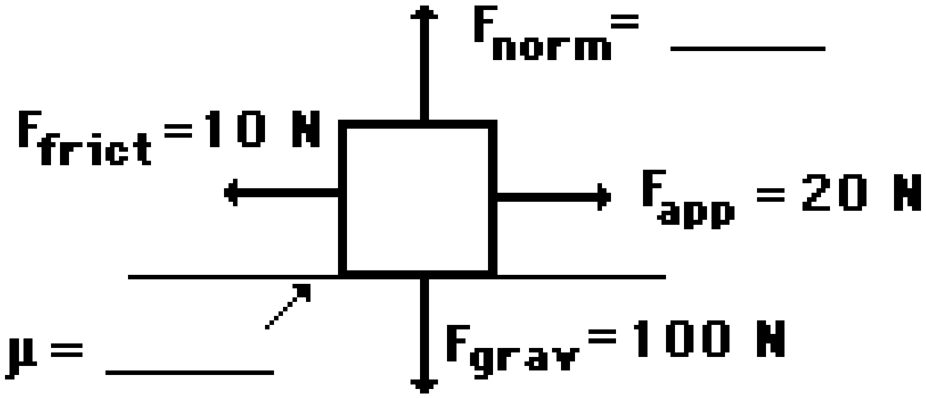


m = ________

a = ________

F_{net} = ________

An applied force of 20 N is used to accelerate an object to the right across a frictional surface. The object encounters 10 N of friction. Use the diagram to determine the normal force, the net force, the coefficient of friction (μ) between the object and the surface, the mass, and the acceleration of the object. (Neglect air resistance.)



m = ________

a = ________

F_{net} = ________

Example

Pedro applies a 4.25-N rightward force to a 0.765-kg book to accelerate it across a tabletop. The coefficient of friction between the book and the tabletop is 0.410. Determine the acceleration of the book.

Newton's Second Law of Motion — Example

In a physics lab, Maria and Teresa use a hanging mass and pulley system to exert a 2.45 N rightward force on a 0.500-kg cart to accelerate it across a low-friction track. If the total resistance force to the motion of the cart is 0.72 N, then what is the cart's acceleration?

A block with a mass of 20 kg rests on an earthbound plane elevated 35° off the horizontal. If the coefficient of kinetic friction for this surface is 0.54, what is the acceleration of the block?

$$F_N = mg\cos\theta = (20\text{ kg})(9.8\text{ m/s}^2)\cos 35°$$

$$F_N = 160.6\text{ N}$$

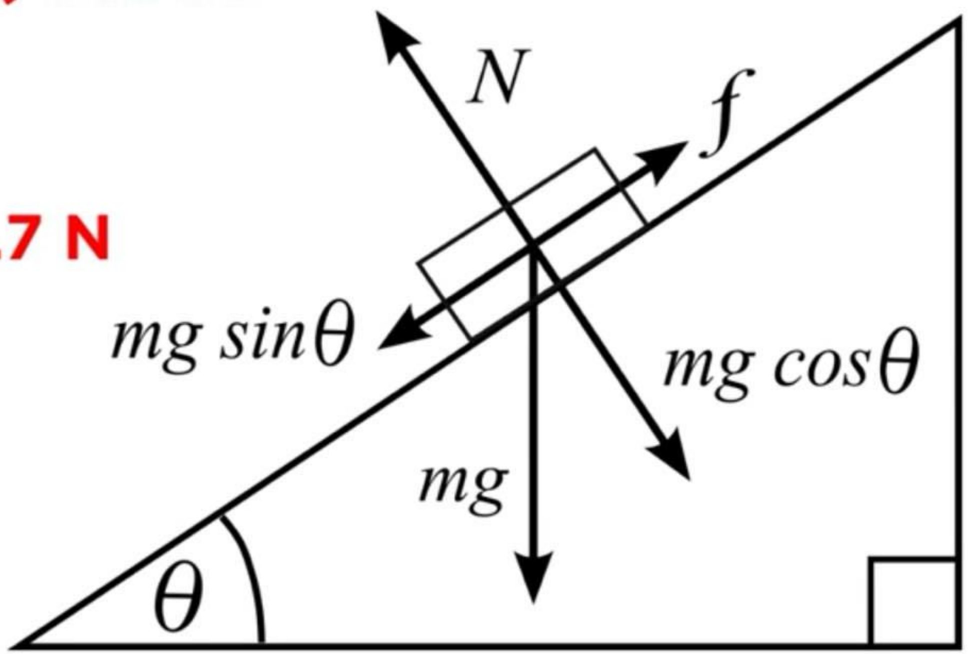
$$F_f = (0.54)(160.6\text{ N}) = 86.7\text{ N}$$

$$F_{net} = mg\sin\theta - F_f = 112.4\text{ N} - 86.7\text{ N}$$

$$F_{net} = 25.7\text{ N} \qquad F_{net} = ma$$

$$25.7\text{ N} = (20\text{ kg})a$$

$$a = 1.3\text{ m/s}^2$$



Example

A block of mass 10kg is placed on a frictionless inclined plane that makes an angle of $\theta = 30 \circ$ with the horizontal. What is the acceleration of the block down the incline?

Example

A 2 kg box is put on the surface of an inclined plane at 27° with the horizontal. The surface of the inclined plane is assumed to be frictionless

a) Draw a free body diagram of the box on the inclined plane and label all forces acting on the box
b) Determine the acceleration a of the box down the plane
c) Determine the magnitude of the force exerted by the inclined plane on the box.

Example

An elevator has a mass of 500 kg. Inside the elevator, there is a person with a mass of 70kg. The elevator is accelerating upward at 2 m/s^2. What is the apparent weight of the person inside the elevator?

Atwood Machine

Example

An Atwood machine consists of two masses, $m_1 = 5\,kg$ and $m_2 = 8\,kg$, connected by a light, inextensible string passing over a pulley. The pulley is frictionless. Calculate the acceleration of the system and the tension in the string.

Circular Motion — Example

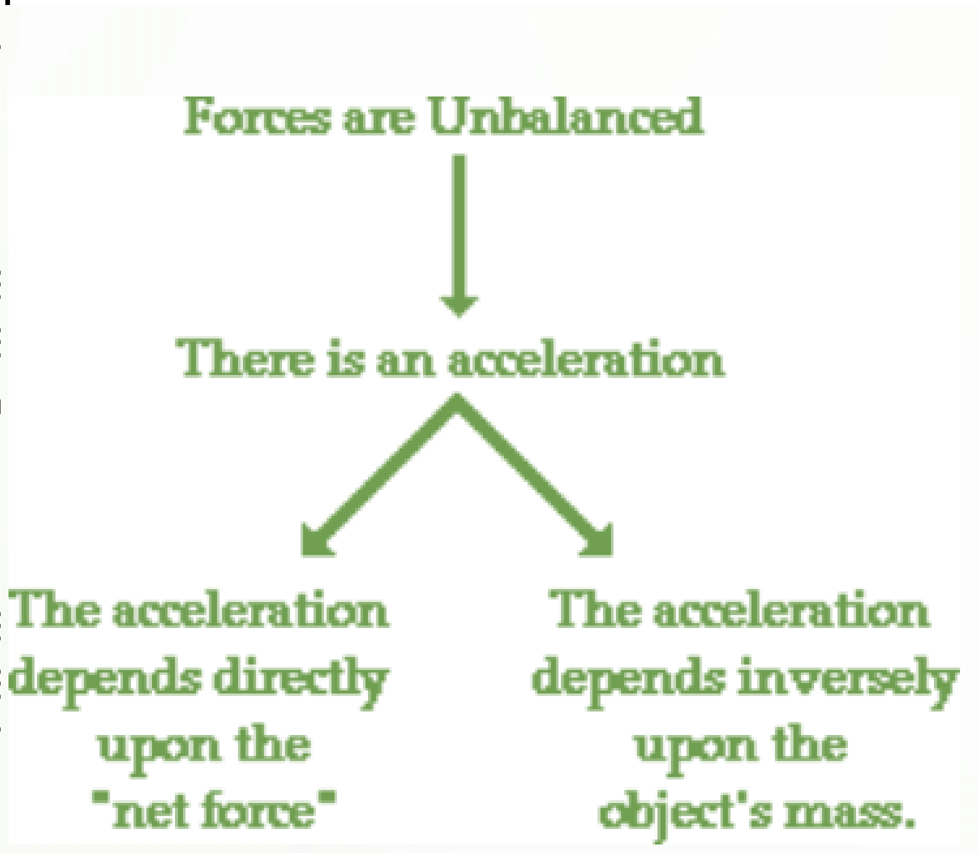
A car of mass $m = 1000kg$ is moving in a circular track of radius $r = 50\,m$ with a constant speed of $v = 20\,m/s$. Determine (a) the centripetal acceleration of the car, (b) the net force required to keep the car in circular motion and the (c) the minimum coefficient of friction required if friction provides the necessary force. (Take $g = 9.8\,m/s^2$)

Practice Problem

- Example: A net force of 15 N is exerted on an encyclopedia to cause it to accelerate at a rate o 5 m/s^2 . Determine the mass of the encyclopedia.

- Example: Suppose that a sled is accelerating at a rate of 2 m/s^2 . If the net force is tripled and the mass is doubled, then what is the new acceleration of the sled?

- Example: Suppose that a sled is accelerating at a rate of 2 m/s^2 . If the net force is tripled and the mass is halved, then what is the new acceleratio of the sled?



https://www.physicsclassroom.com/class/newtlaws/Lesson-1/Newton-s-First-Law

Module 5: Newton's Laws of Motion

5.3 Law of Interaction

OBJECTIVES:

1. Explain forces and its types
2. Determine and illustrate forces acting on a system
3. Draw free body diagrams of systems
4. Define Newton's 3^{rd} Law
5. Apply Newton's 3^{rd} law of motion in problem solving

Law of Interaction

- Also known as “Law of Action / Reaction”.
- The third law states that “for every action, there is an equal and opposite reaction.”
- The size of the forces on the first object equals the size of the force on the second object.
- The direction of the force on the first object is opposite to the direction of the force on the second object.

$$\overrightarrow{F_{12}} = -\overrightarrow{F_{21}}$$

Jumping from a chair

https://www.physicsclassroom.com/class/newtlaws/Lesson-1/Newton-s-Third-Law

- Suppose these kids wanted to know what will happen if they jump from their initial state to the right.

- Draw the FBD of the person and the chair before jumping.
- Draw the FBD of the person and the chair right after jumping.
- What happens to the chair? Explain.

Law of Interaction

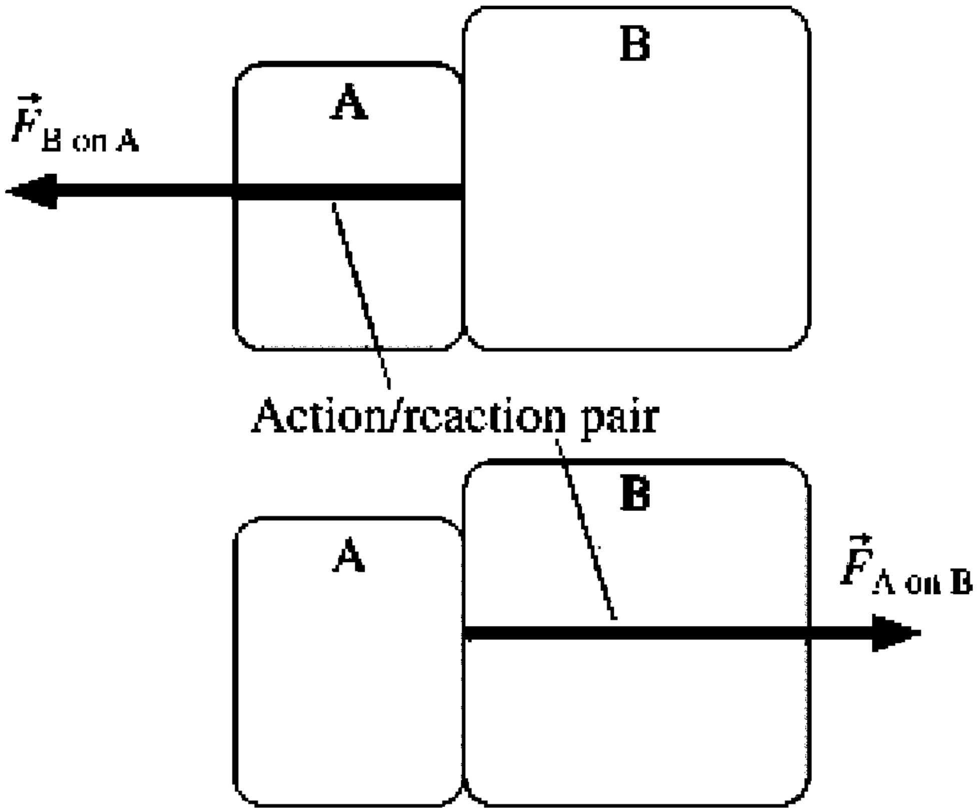
"For every action, there is an equal and opposite reaction."

According to Newton's third law:

- Forces always come in pairs. That is, there are no isolated forces in the universe.
- The forces in pairs are equal in magnitude and opposite in direction.
- The forces in pairs act on different objects.

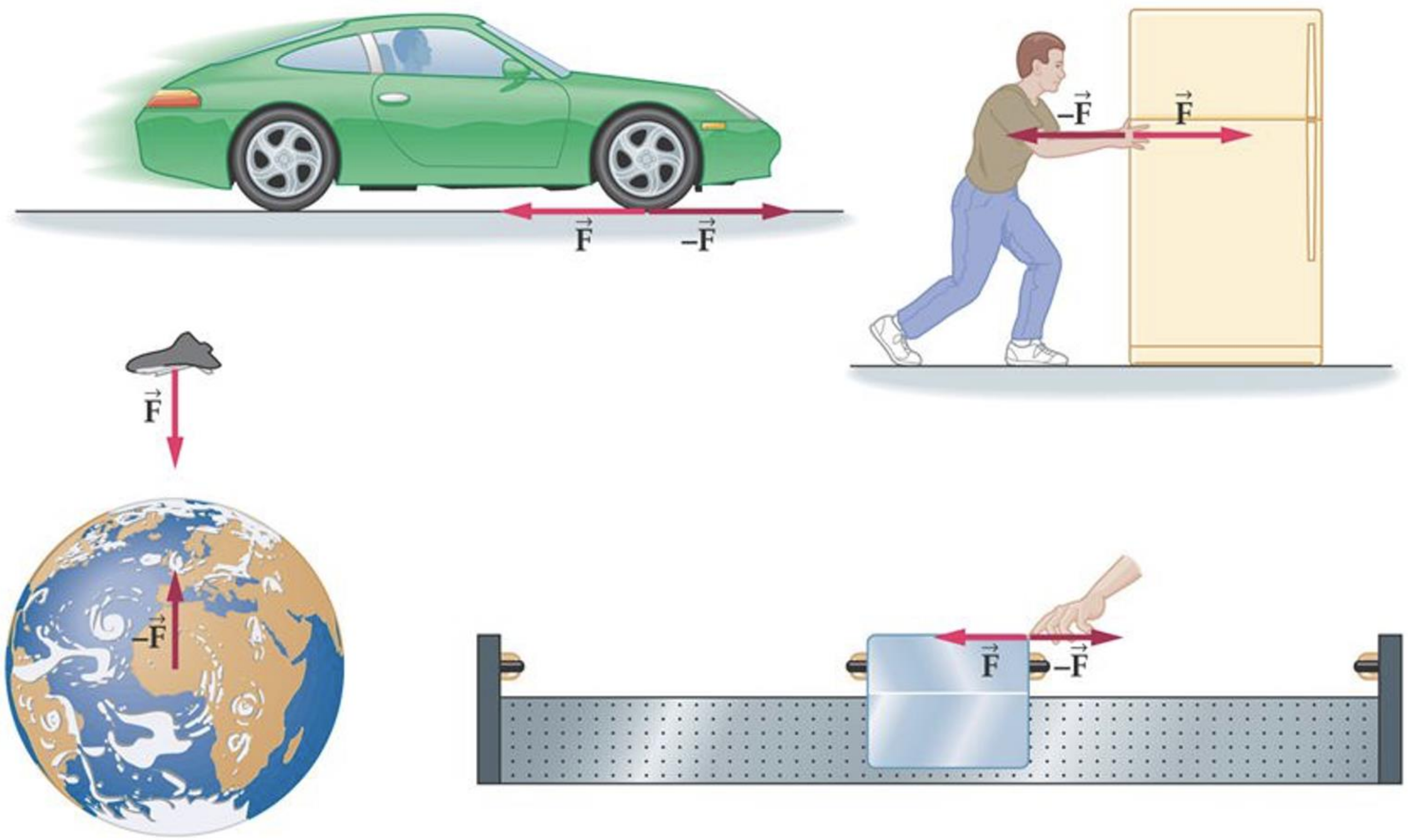
Interacting Objects

- An interaction is the mutual influence of two objects on each other.
- The pair of forces shown in the figure is called an action/reaction pair.
- An action/reaction pair of forces exists as a pair, or not at all



http://www.physics.gsu.edu/dhamala/Phys1111/chap4.pdf

Some action-reaction pairs:



Check you understanding:

An action/reaction pair of forces

A. Points in the same direction.
B. Acts on the same object.
C. Are always long-range forces.
D. Acts on two different object

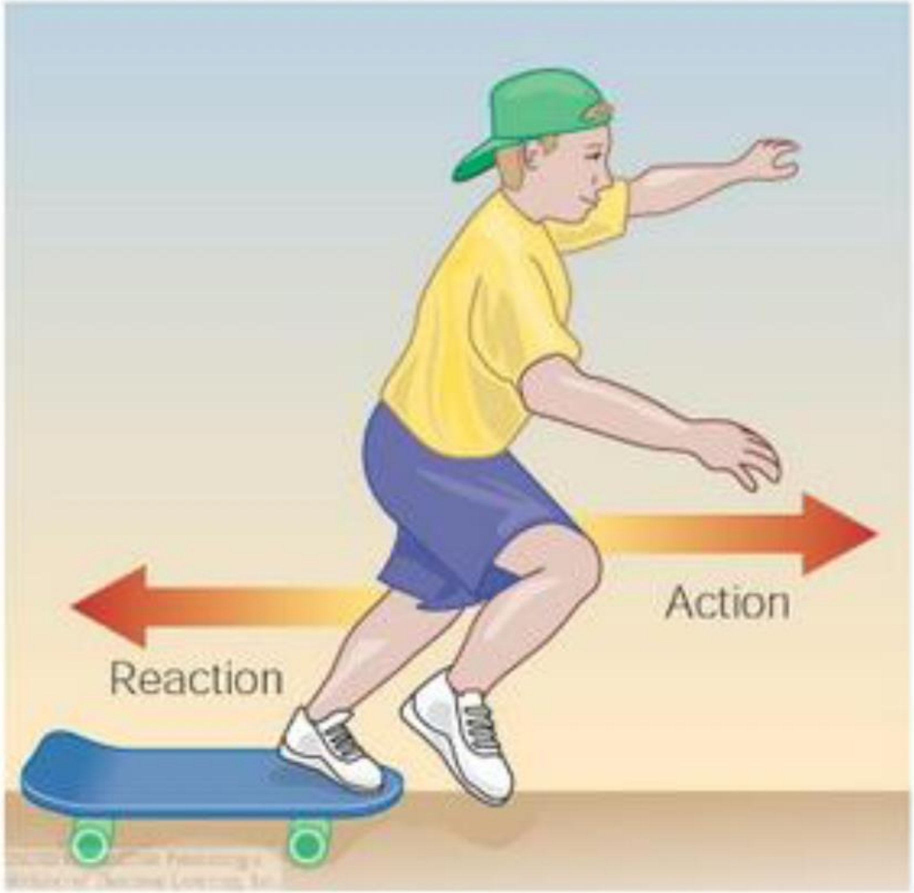
Newton's Third Law of Motion

Check you understanding:

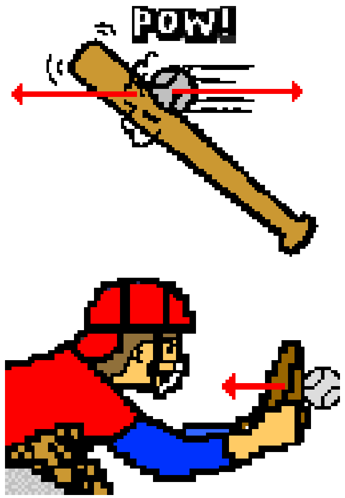
A mosquito runs head-on into a truck. Splat! Which is true during the collision?

A. The mosquito exerts more force on the truck than the truck exerts on the mosquito.
B. The truck exerts more force on the mosquito than the mosquito exerts on the truck.
C. The mosquito exerts the same force on the truck as the truck exerts on the mosquito.
D. The truck exerts a force on the mosquito but the mosquito does not exert a force on the truck.
E. The mosquito exerts a force on the truck but the truck does not exert a force on the mosquito.

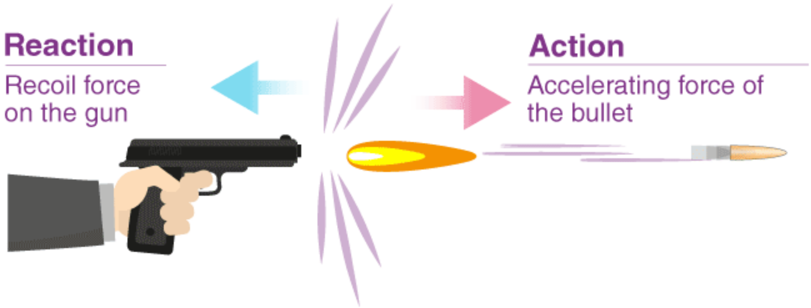
Newton's Third Law of Motion

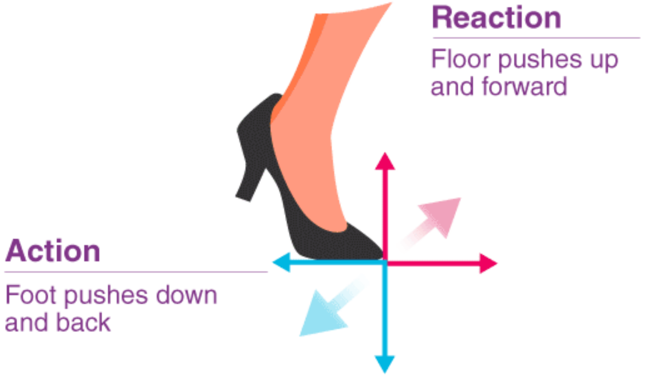


www.assignmentpoint.com



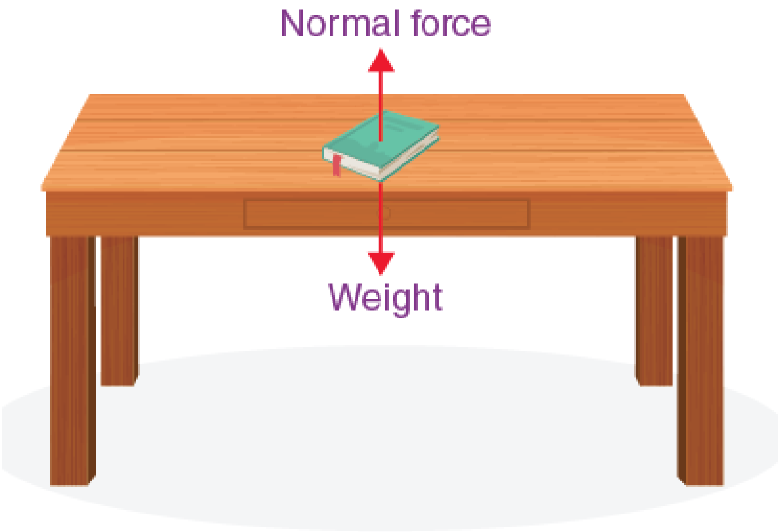
For every action, there is an equal and opposite reaction

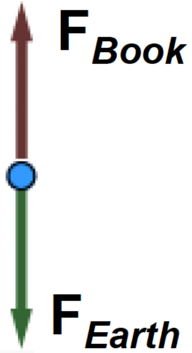


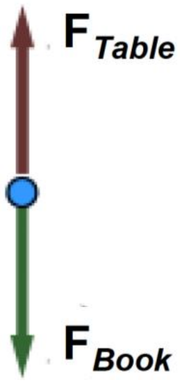


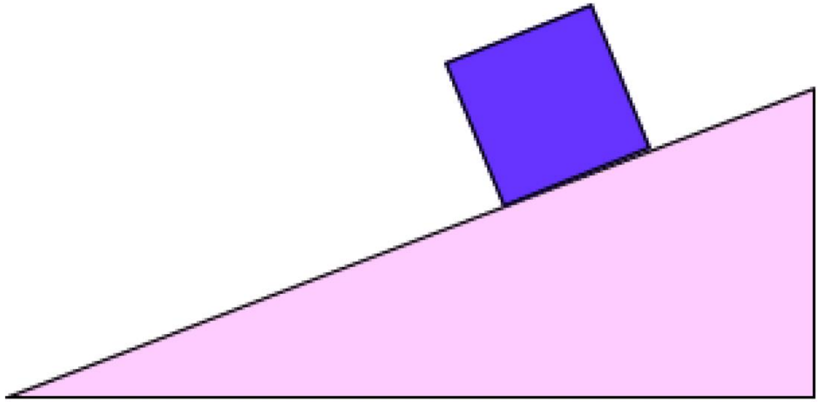
The same force that is accelerating the boy forward, is accelerating the skateboard backward.

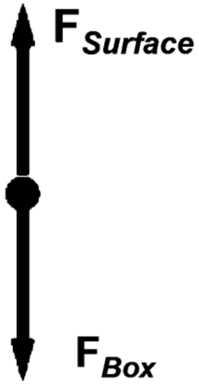
There can be one or more "Third Law" pairs of forces in a system:











Newton’s Third Law of Motion

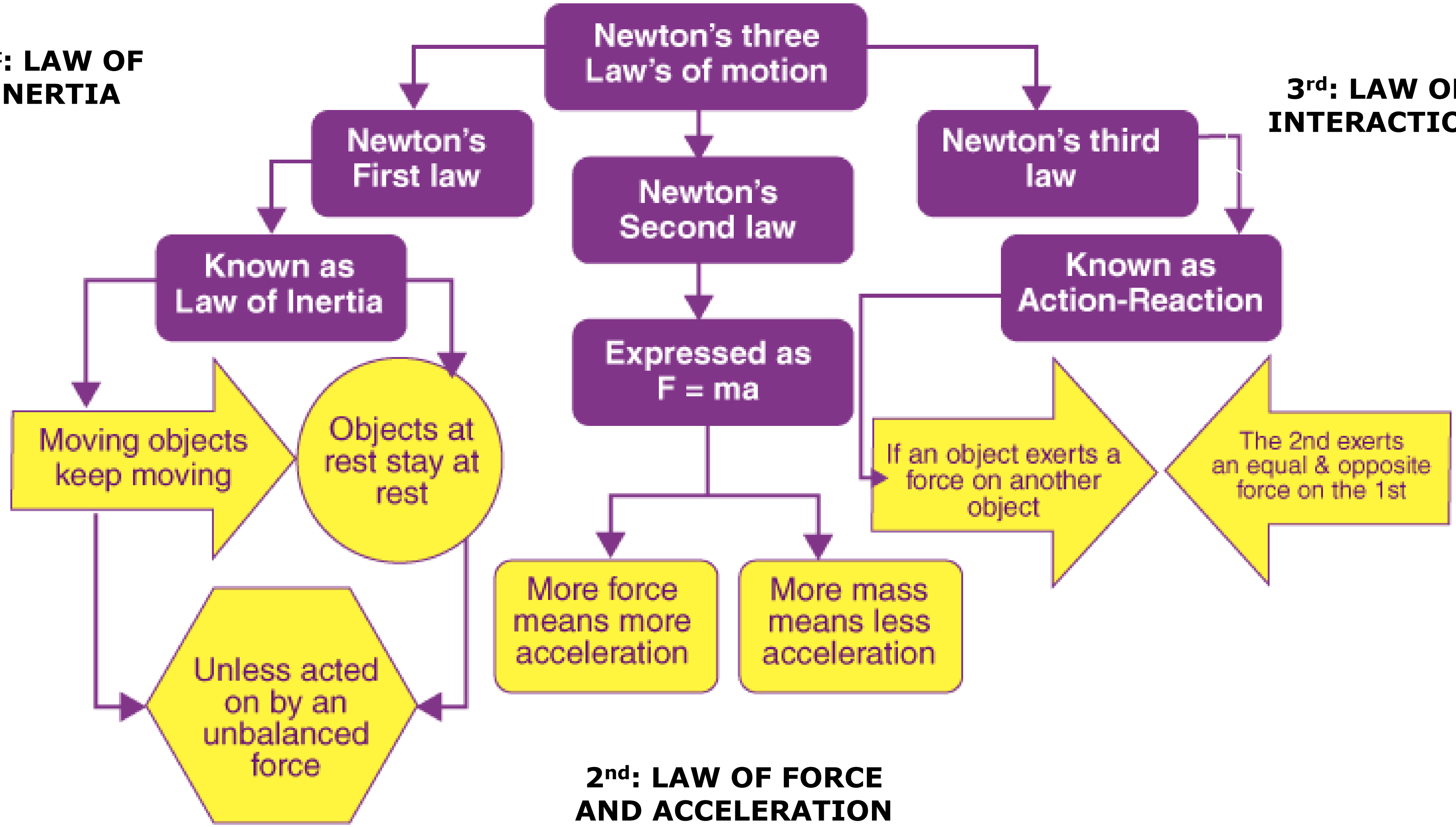
Other examples of Newton’s third law:

- ❑ If one billiard ball hits another, the second will move with the same force as the first.
- ❑ A child wants to jump to climb a tree (he must push the ground to propel himself).
- ❑ A man deflates a balloon the force with which the air comes out causes the balloon to move from one side to the other.
- ❑ A fish makes use of its fins to push water backwards. The direction of the force on the fish is forward.
- ❑ The wings of the bird push the air downwards. The air pushes the air upwards.
- ❑ A swimmer pushes against the water, while the water pushes back on the swimmer.
- ❑ Rock climbers pulling their vertical rope downwards so as to push themselves upwards.

Summary:

1st: LAW OF INERTIA

3rd: LAW OF INTERACTION



2nd: LAW OF FORCE AND ACCELERATION

Module 5: Newton's Laws of Motion

Got any questions???

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The Physics Classroom (2020). Accessed at https://www.physicsclassroom.com