A force can be a **push or a pull.** Force acting on a body tends to produce a change in velocity or acceleration of the body.

- SI unit of force is the newton (N). It is a vector quantity.
- We can add/subtract forces. (More about this at Addition of forces)
- Whenever we are pushing, pulling, lifting, bending, twisting, tearing, stretching or squeezing, we are exerting a force.

Force can:

- make a stationary body move
- change the speed of a body
- change the direction of motion of a body (It is possible to change the direction of motion of a body without changing its speed.)
- change the size or shape of the body

Here are some forces which you are familiar with:

- **Gravitational force** – force due to gravitational pull
- **Frictional force** – force which opposes motion
- **Electrical force** – force of attraction or repulsion between electrical charges
- **Magnetic force** – force of attraction or repulsion between the poles of magnets
- **Contact force** – force of repulsion when two objects are pressed together (Caused by the repulsion between surface atoms)

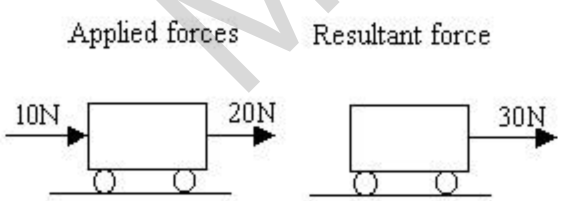
Since <u>force</u> is a <u>vector quantity</u>, forces can be represented by an arrow diagram.

- The magnitude of the force is represented by the length of the arrow
- The direction of the force is represented by the direction in which the arrow is pointed.

Resultant force is the combination of 2 or more forces.

- The effect on a body produced by 2 or more forces acting on it will be the **same** as that produced by their resultant force.
- Hence, resultant force is used to simplify force diagrams – it is easier to deal with one resultant force than multiple forces.

Forces are in the same direction

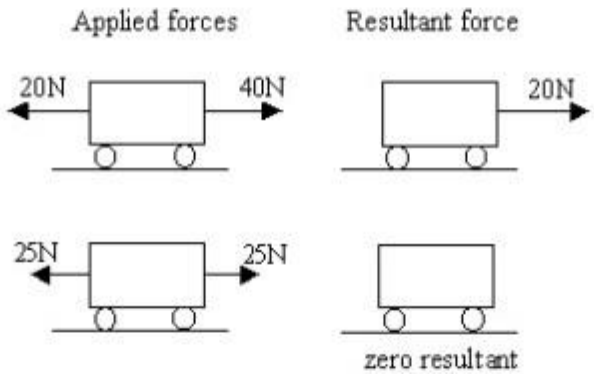


The above figure shows two forces – 10 N and 20 N acting on a car. The resultant force will be 30 N to the right, which is obtained by adding the two forces numerically.

In the general case, where there is F1 to Fn acting on an object in the same direction,

$$F_{resultant} = F1+F2+\ldots+Fn$$

Forces are in opposite direction



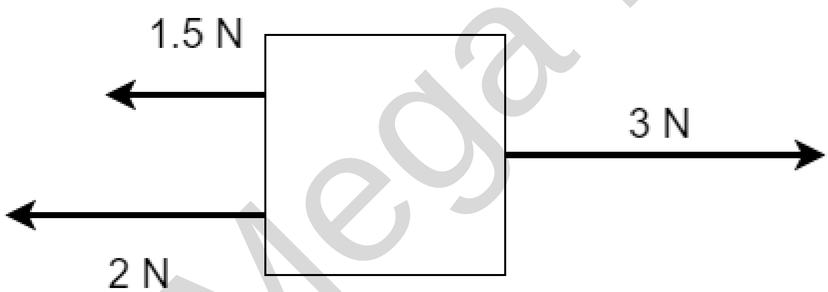
When the applied forces are in the opposite direction, the resultant force is dependent on the magnitude of the forces. Using the first car in the above figure, there are two forces 20 N and 40 N acting on it. The resultant force will be 20 N as $F_{resultant}$= 40–20 = 20N to the right.
When the two forces are same in magnitude but different in direction, the resultant force will be 0 (as seen above)

Slightly more advanced trick:
Taking rightward as positive, the forces acting on the car will be -20 N (Negative because the force is to the left) and + 40 N.

Using the addition of forces, $F_{resultant}$=(–20)+40 =+20N, which is 20 N to the right.

__Worked Example__

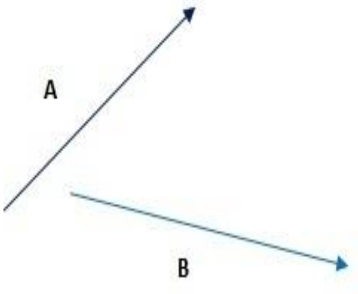
Q. Three forces of 3 N, 1.5 N and 2 N are acting on an object, as shown in the picture below.



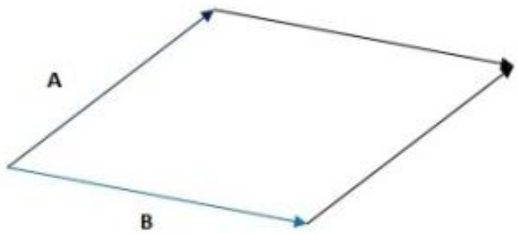
What is the resultant due to the three forces?
From the diagram above and taking rightward as positive, the resultant force is given by:

$$\mathbf{F}_{resultant}=3-1.5-2=-0.5\ \text{N}$$

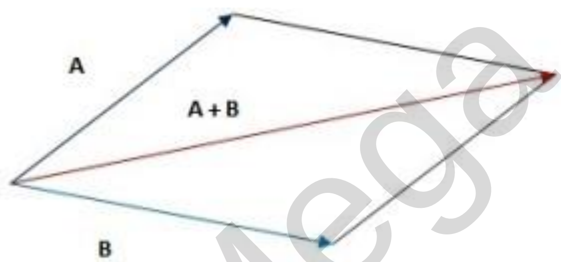
Forces at an angle to each other (Drawing force diagrams)
This will be more complicated than the previous two cases. We can use the parallelogram law of vector addition to find the resultant force.



Consider the above diagram, we are given two forces – A and B. We will shift B to match up with A as seen below.

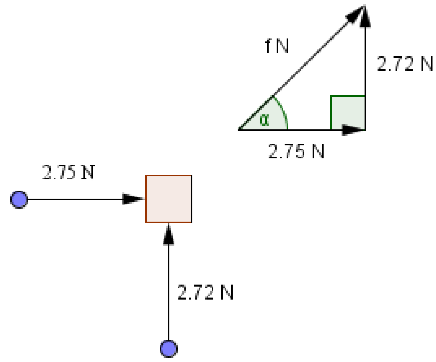


After shifting B, we draw two more lines to make it a parallelogram. The resultant force will just be the red line in the diagram below:

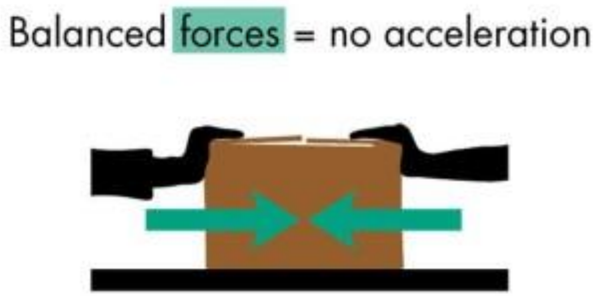


Bonus: Can you work out what happens if the two forces are at 90° **to each other?**

Ans: The parallelogram is now a square and you can just use Pythagoras' Theorem to find the magnitude of the resultant force. E.g.



Newton's First Law of Motion



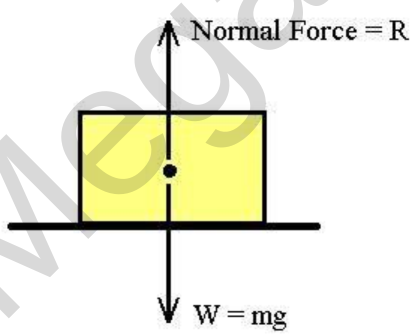
When two or more external forces acting on a body produce no net **resultant force**, i.e., vector sum of forces is zero, we say that the forces are balanced. The lack of **resultant** force produces no net **acceleration** and hence, the body will remain at rest or moves at its original constant **velocity** in a straight line.

- This is Newton's First Law of Motion
- An external force is one whose source lies outside of the body being considered. e.g. weight of a body and friction
- The resultant force is the vector sum of all external forces exerted on a body.

Newton's First Law of Motion is also known as the law of inertia. **Inertia** is a property of mass resisting any change from its original state of rest or motion. The greater the mass of a body, the greater will be its inertia and the greater will be its resistance to changes to its state of rest or motion.

A body at rest implies that the net resultant force exerted on the body is **zero**.

1. However, it is **not** necessarily that there is **no** forces acting on the body.



b. For instance, a box resting on a table has zero net resultant force. But there are two forces acting on the box! One of the force is the gravitational force due to the weight of the box, while the other is the normal force.

2. **Normal force** (or reaction force) is an external force exerted perpendicularly by the surface in reaction to any body placed against it.

Other Laws of motion

Newton's 3 laws of motion are:

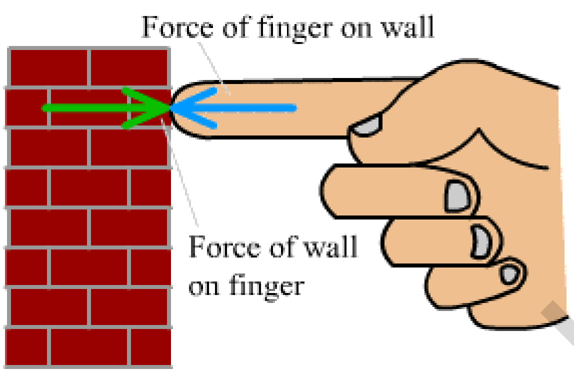
1st law: Newton's first law of motion states that a body will continue in its state of rest or uniform motion in a straight line unless an external resultant force acts on it.

2nd law: Newton's second law states that the rate of change of momentum of a body is proportional to the resultant force acting on it and the change takes place in the direction of the force.

3rd law: Newton's third law states that: If body A exerts a force on body B, then body B exerts a force of equal magnitude but in the opposite direction on body A.

We will explore the 2nd law of motion in greater details in the subsequent posts.

Newton's Third Law of Motion



Newton's third law states that: If body A exerts a force on body B, then body B exerts a force of equal magnitude but in the opposite direction on body A.

Forces always occur in pairs – **Action force** and **reaction force**.

Action and Reaction Forces

Some properties of the action and reaction forces are as follows:

- The action and reaction forces are equal in magnitude.
- The action and reaction forces act opposite to one another.
- The action and reaction forces act on different bodies.

When two or more external forces acting on a body produce a net resultant force, i.e, the vector sum of forces is not zero, the forces are unbalanced.

- **Newton's Second Law of Motion** says that the resultant force acting on a body produces a net acceleration and causes the body to accelerate in the direction of the resultant force.
- If the net resultant force is in the direction of the motion, the body will accelerate.
- If the net resultant force is against the direction of motion, the body will decelerate.
- For a body of constant mass, Newton's Second Law of Motion can be expressed as: **F = ma**,
  where F = force
  m = mass
  a = acceleration

- Since mass (m) is scalar quantity, the direction of acceleration (a) is thus in the same direction as the applied force (F).
- To calculate the acceleration of a body, one should use the net resultant force exerted on it.

Note:
All forces observed in nature can be explained in terms of four basic interactions that occur between elementary particles:

- Gravitational force
- Electromagnetic force
- Strong nuclear force
- Weak nuclear force

Examples
Q. A box of mass 20 kg is pushed with a force of 50 N. What is the acceleration of the box? Neglect the effects of friction.

From Newton's Second Law,

$$F=ma$$
$$a=\frac{F}{m}$$
$$a=\frac{50}{20}$$

$$\mathbf{=2.5\ m\ s^{-1}}$$

Q. A car of mass 1000 kg accelerates from rest to 20 m s^{-1} in 5 s. Calculate the driving force of the engine. (Neglect the effects of friction)

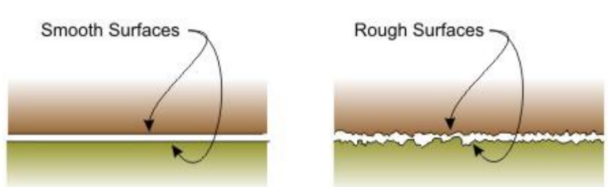
Friction

Friction is the force that resists the motion of one surface relative to another with which it is in contact. It is parallel to the contact surfaces and opposite to the direction of motion or impeding motion.

- SI unit of friction is newton (N). It is a vector quantity.
- Viscous force is the equivalence of friction in fluids that resists the relative motion of a body through the fluid.

Body in Motion
When a body is in **motion**, friction will tend to **slow** it down.

- *Example:* Pushing a box along the table. The box will eventually come to rest.



Friction Force is affected by the smoothness of the surfaces

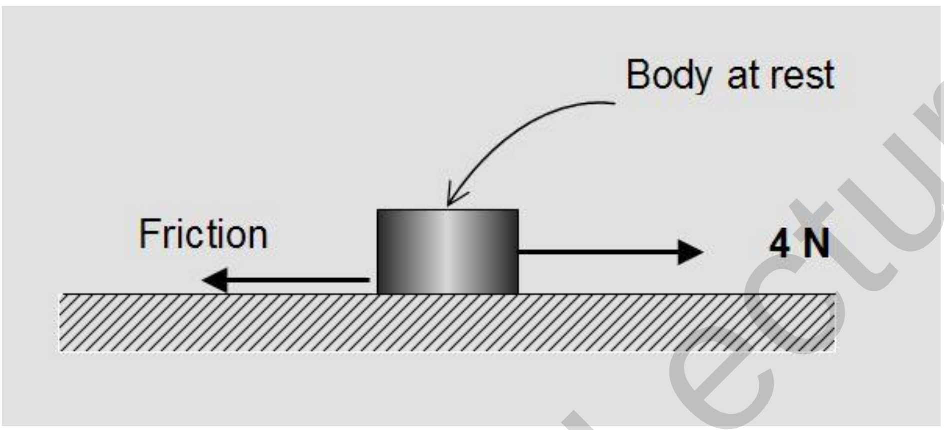
- The friction comes from the microscopic surface irregularities of the two surfaces (of the box and the table). The surface irregularities catch onto each other and resist motion.

Body in Motion (With pushing force)

When the magnitude of the pushing force is equal to the magnitude of frictional force on the object, the object will travel at a constant speed.

- *Why?* Since the magnitude of the pushing force is equal to the magnitude of the frictional force on the object, there will be **zero resultant force**. From **Newton's 2nd law of motion** (F=maF=ma), there will be zero **acceleration** (i.e. constant speed).

Body at Rest



When a body is at rest, friction will have to be overcome before the body can start to move.

- *Why?* For a body to embark on a state of motion, there needs to be acceleration.
  From Newton's 2nd law of motion (F=maF=ma), we will require a non-zero resultant force to be acting on the body. Hence, the pushing force (or driving force) must be greater than the frictional force.
- In the picture above, the pushing force of 4N is not enough to overcome the frictional force. Hence the body is at rest.

Advantages and Disadvantages of friction

ADVANTAGES OF FRICTION	DISADVANTAGES OF FRICTION
Able to start of stop motion (Used in braking pads to slow down cars)	Reduces speed of motion (A box sliding along the floor gradually comes to a stop)
Prevents slipping when walking	Causes wear and tear (Gears get worn out and require replacements)
Essential for rolling motion (You cannot roll a ball if there is no friction!)	Energy is wasted as work done to overcome friction

Methods to reduce friction:

- Lubricate the surfaces in contact
- Smoothen the surfaces in contact (E.g. By polishing)
- Place ball bearings, rollers between surfaces
- Use an air cushion between surfaces (E.g. Hovercraft)

Example:

A man pushes a trolley forward with a force of 10 N. The floor exerts a frictional force of 7 N on the trolley. Find the acceleration of the trolley, given that the mass is 10 kg. If there is no friction, what would be the new acceleration?

Solution:

Net resultant force: $F_{res}=F_{man}-F_{fric}$

$=10-7$

$=3$ N

Net resultant acceleration is given by Newton's 2nd law of motion**,**

$$a=\frac{Fres}{m}$$

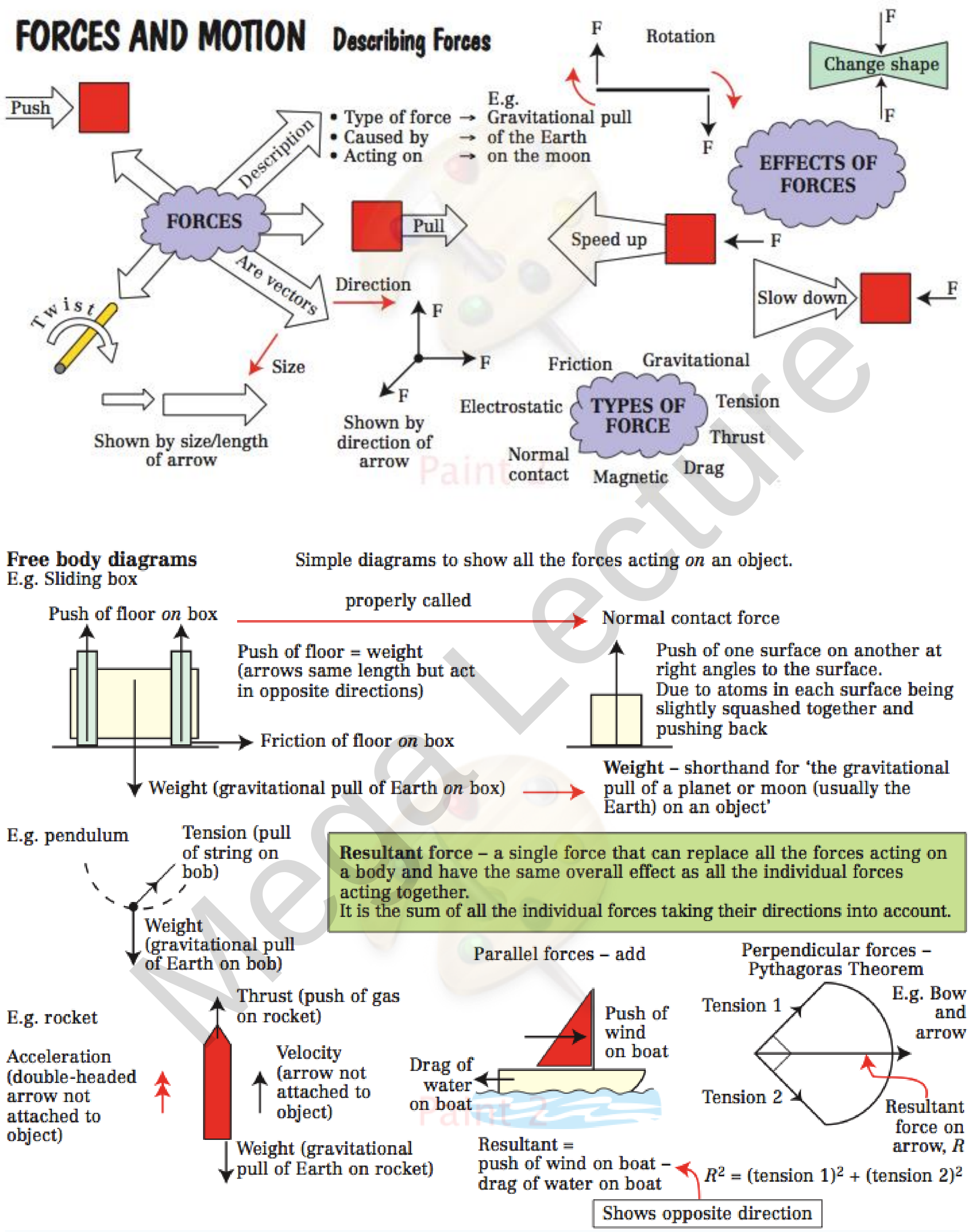
$$==\frac{3}{10}$$

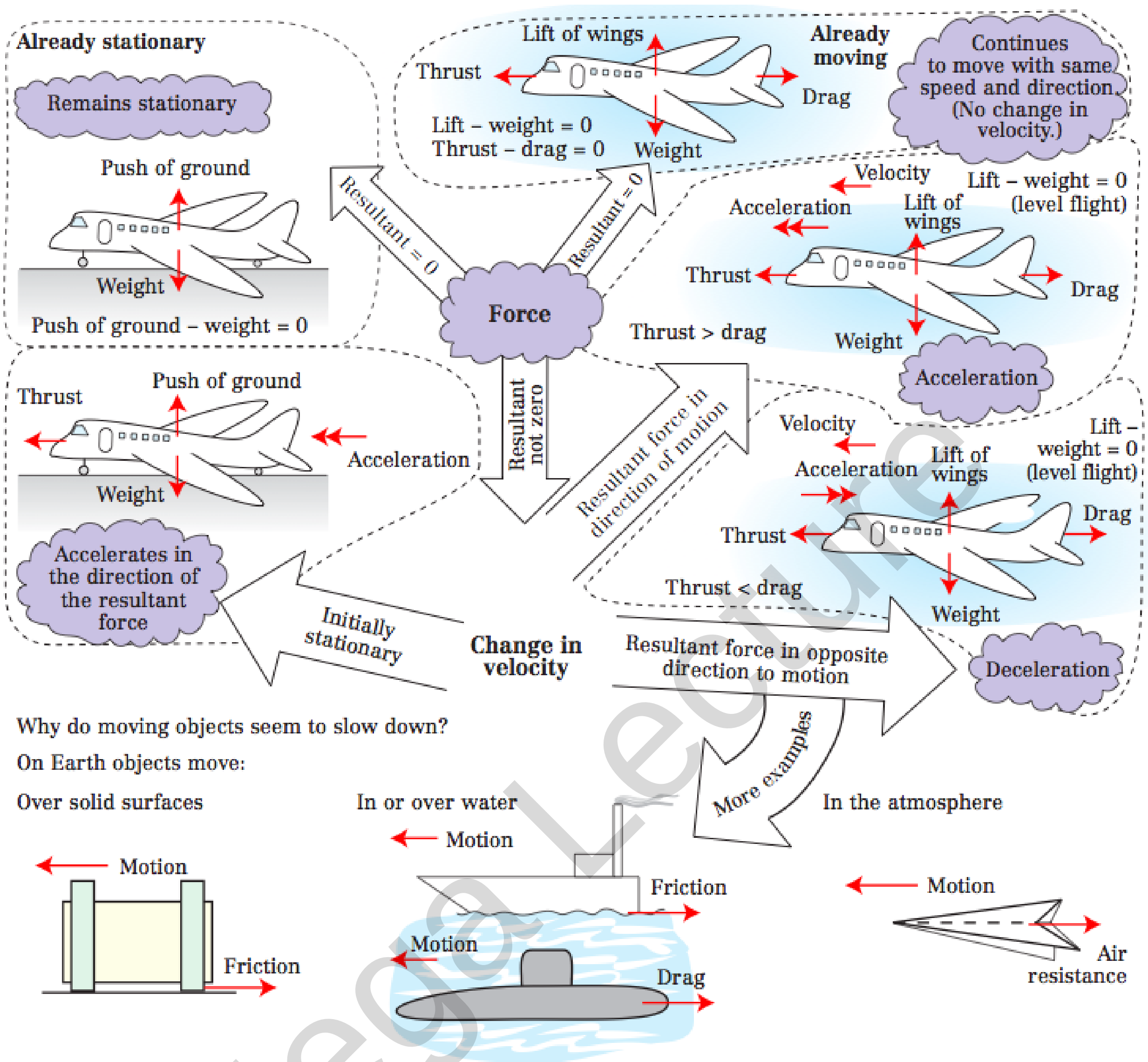
$$=\mathbf{0.3\ ms^{-2}}$$

Additional Notes:

- The major cause of friction between solids appears to be the forces of attraction, known as adhesion (electromagnetic forces), between the contact regions of the surfaces, which are always microscopically irregular. Friction arises from shearing these "welded" junctions and from the actions of the irregularities of the harder surface plowing across the softer surface.
- Sliding friction arises because of relative motion between surfaces. There are two kinds of sliding friction: static and kinetic. Static sliding friction refers to the amount of force that needs to be overcome to start motion. On the other hand, kinetic sliding friction is the force that needs to be overcome in order to maintain relative motion between the surfaces.
- The force required to start motion, or to overcome static friction, is always greater than the force required to continue the motion, or to overcome kinetic friction.
- From experiments, sliding friction is found to be proportional to the load or weight of the body in contact with a surface and is nearly independent of the area of contact.
- Rolling friction occurs when a wheel, ball, or cylinder rolls freely over a surface. (Not possible to roll without friction!)
- Sliding friction is generally 100 to 1,000 times greater than rolling friction. Thus, a body on a sledge is harder to pull than the same body on wheels.

Summary

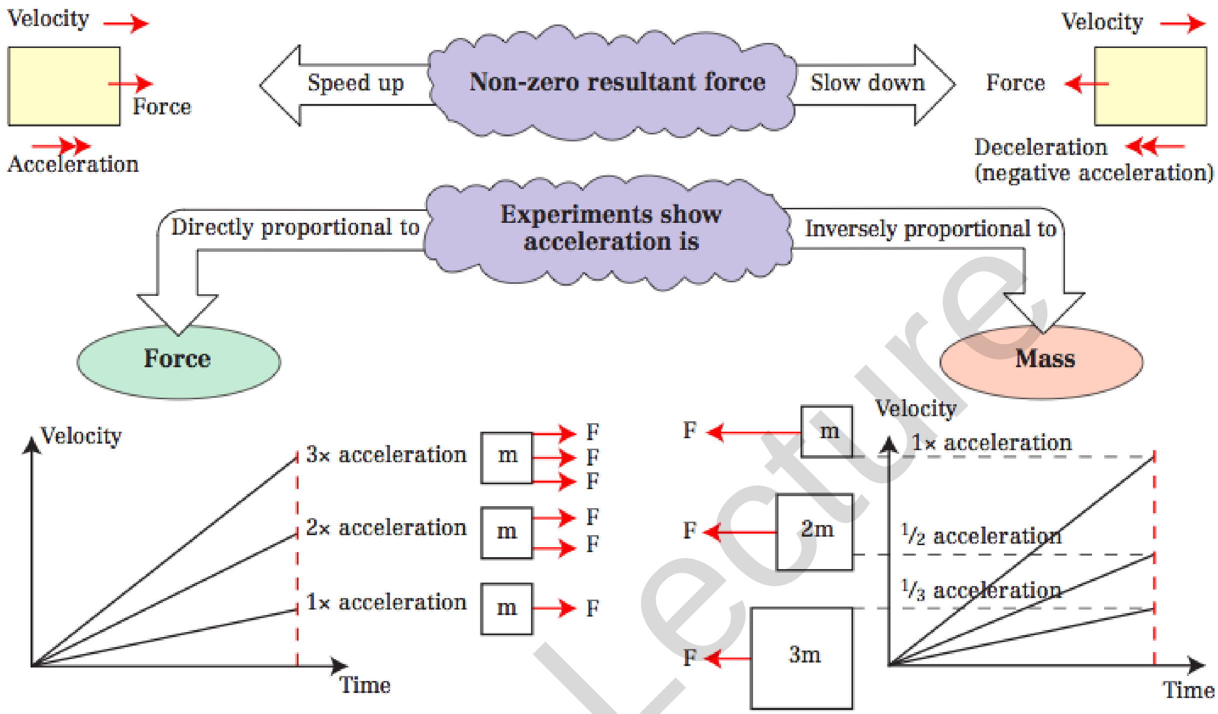

FORCES AND MOTION
Describing Forces
Push
FORCES
Description
• Type of force → E.g. Gravitational pull
• Caused by → of the Earth
• Acting on → on the moon
Pull
Are vectors
Direction
Twist
Size
Shown by size/length of arrow
F
F
F
Shown by direction of arrow
Rotation
F
F
Change shape
F
F
EFFECTS OF FORCES
Speed up
F
Slow down
F
Friction
Gravitational
Electrostatic
TYPES OF FORCE
Tension
Thrust
Normal contact
Magnetic
Drag
Free body diagrams
E.g. Sliding box
Simple diagrams to show all the forces acting on an object.
Push of floor on box
properly called
Normal contact force
Push of floor = weight (arrows same length but act in opposite directions)
Push of one surface on another at right angles to the surface.
Due to atoms in each surface being slightly squashed together and pushing back
Friction of floor on box
Weight (gravitational pull of Earth on box)
Weight – shorthand for 'the gravitational pull of a planet or moon (usually the Earth) on an object'
E.g. pendulum
Tension (pull of string on bob)
Weight (gravitational pull of Earth on bob)
Resultant force – a single force that can replace all the forces acting on a body and have the same overall effect as all the individual forces acting together.
It is the sum of all the individual forces taking their directions into account.
Parallel forces – add
Perpendicular forces – Pythagoras Theorem
E.g. rocket
Thrust (push of gas on rocket)
Acceleration (double-headed arrow not attached to object)
Velocity (arrow not attached to object)
Weight (gravitational pull of Earth on rocket)
Push of wind on boat
Drag of water on boat
Resultant = push of wind on boat – drag of water on boat
Tension 1
Tension 2
E.g. Bow and arrow
Resultant force on arrow, R
R² = (tension 1)² + (tension 2)²
Shows opposite direction



In all cases, resistive forces act to oppose motion. Therefore, unless a force is applied to balance the resistive force the object will slow down. In space, there are no resistive forces and objects will move at constant speed in a straight line unless another force acts.

Newton's First Law of Motion:

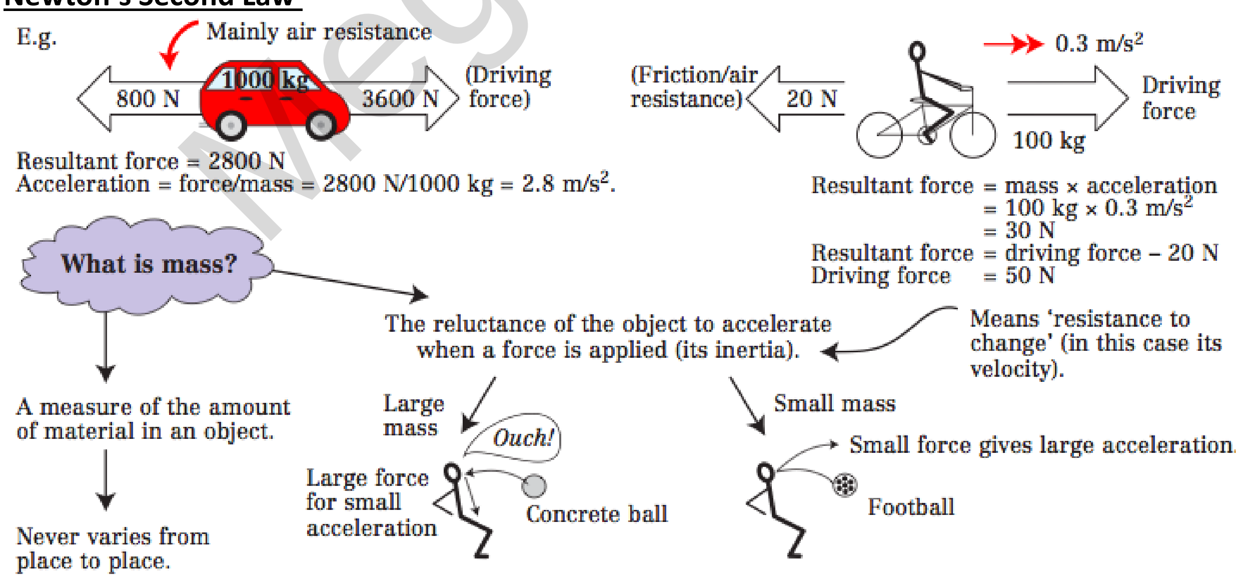
- If the resultant force acting on a body is zero, it will remain at rest or continue to move at the same speed in the same direction.
- If the resultant force acting on a body is not zero, it will accelerate in the direction of the resultant force.



We define the Newton as the force needed to accelerate a 1 kg mass at 1 m/s^2. Therefore, we can write:

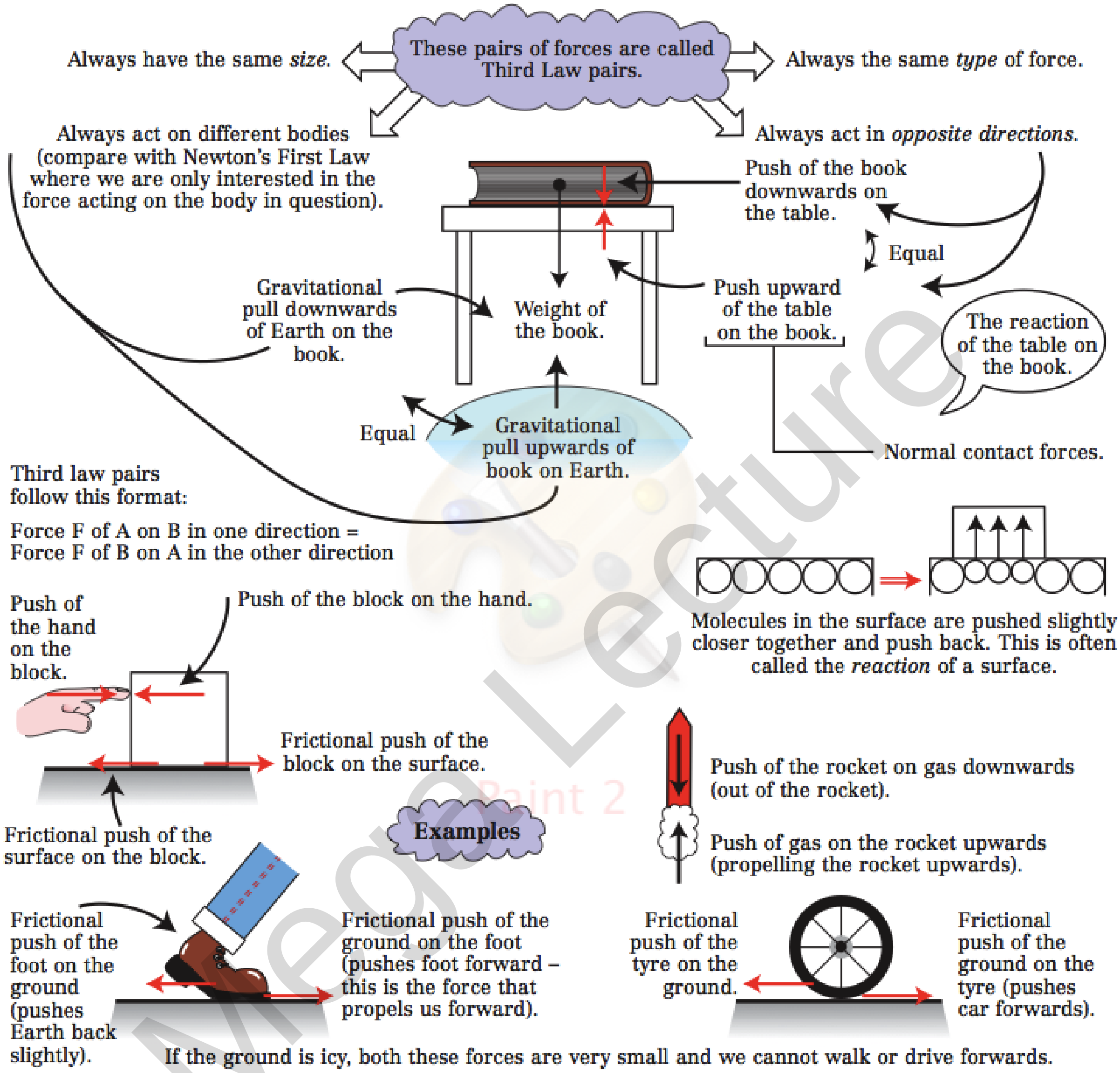
Force (N) = mass (kg) × acceleration (m/s^2)

Newton's Second Law

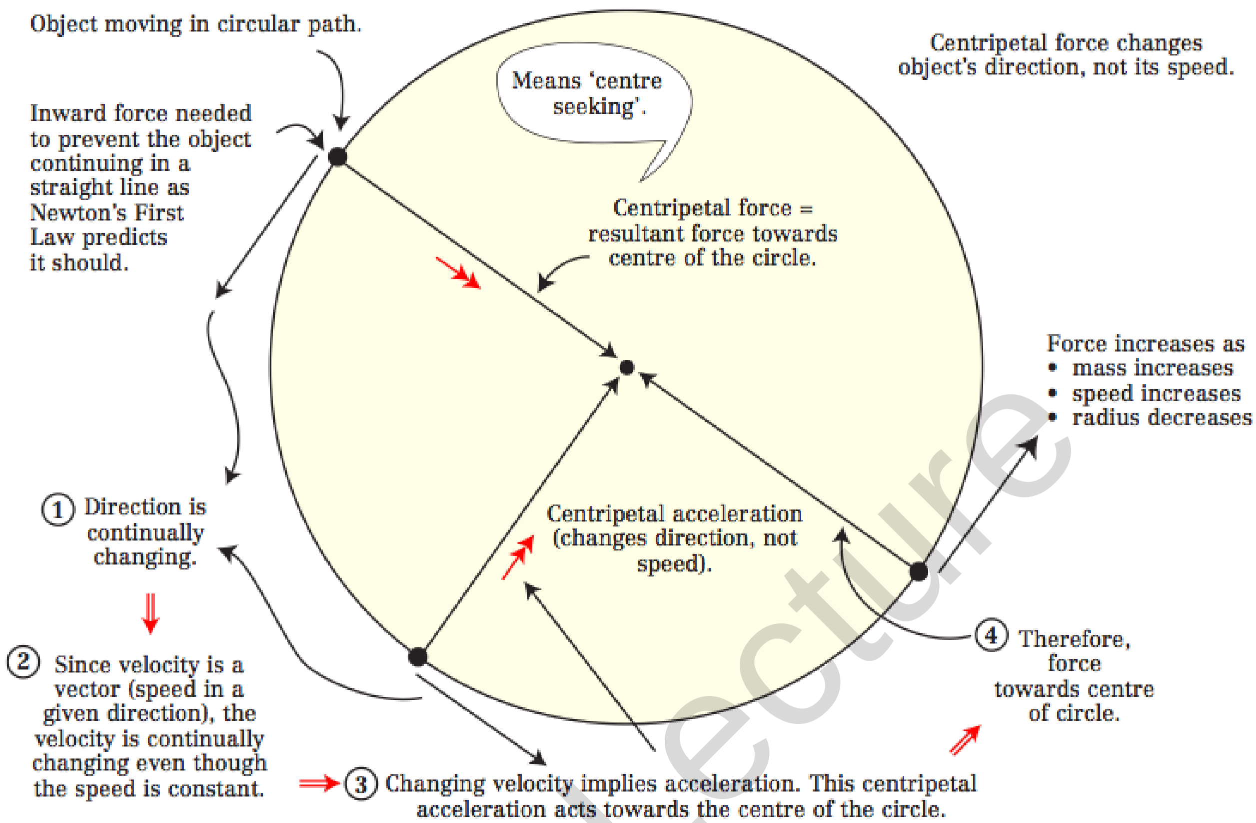


Newton's Third Law

Whenever an object experiences a force it always exerts an equal . . . . . and . . . . . opposite force on the object causing the force.



Motion in Circles and Centripetal Forces



Centripetal acceleration (m/s²) = $\frac{\text{[velocity (m/s)]}^2}{\text{radius (m)}}$

$a = v^2/r$

Centripetal force = mass (kg) × acceleration (m/s²)

$F = mv^2/r$ = $\frac{\text{mass (kg)} \times \text{[velocity (m/s)]}^2}{\text{radius (m)}}$

Centripetal force is not a force in its own right – it must be *provided* by another type of force.