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Sehr Academy
Plus One Science
25-26 batch

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Chapter 4 : Laws of Motion

What is Motion?

What is Motion?

Motion in simple is tendency to move. An object is said to be in motion when it **changes its position with time**. A body is said to be at **Rest** if it is not moving.

Linear Motion

Circular Motion

Rotational Motion

Periodic Motion

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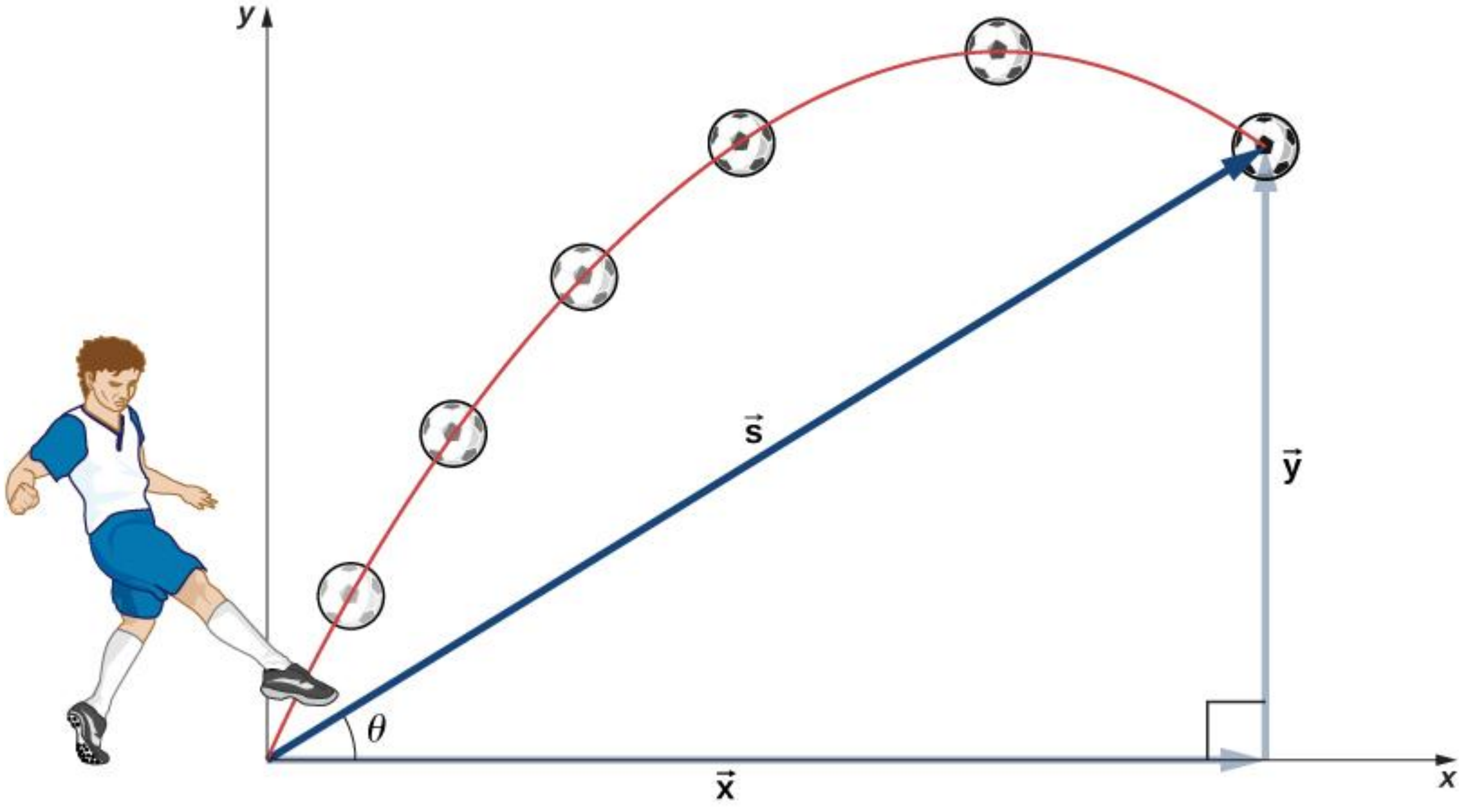

Projectile Motion

Aristotle’s Fallacy

The Greek thinker, Aristotle (384 B.C– 322 B.C.), held the view that if a body is moving, something external is required to keep it moving. According to this view, for example, an arrow shot from a bow keeps flying since the air behind the arrow keeps pushing it. The view was part of an elaborate framework of ideas developed by Aristotle on the motion of bodies in the universe. Most of the Aristotelian ideas on motion are now known to be wrong and need not concern us. For our purpose here, the Aristotelian law of motion may be phrased thus: **An external force is required to keep a body in motion.**

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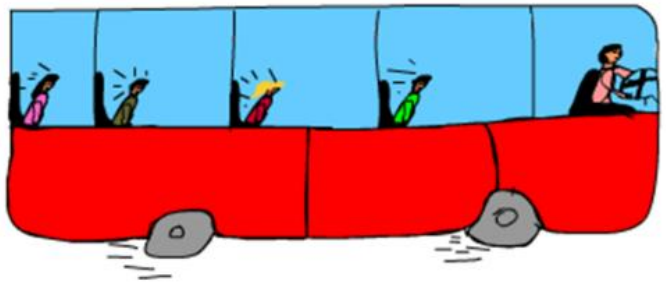
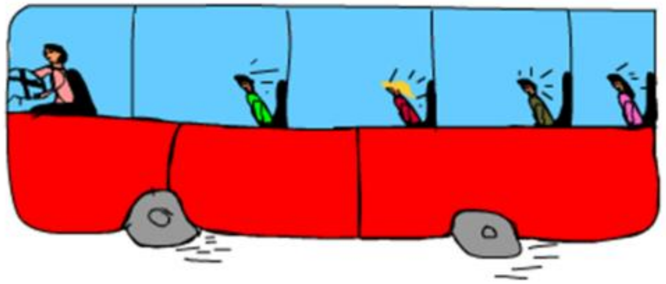
Inertia

Inertia is the tendency of an object to resist any change in its state of motion.
An object at rest tends to remain at rest
An object in motion tends to stay in motion
Have you ever felt a sudden jolt when a vehicle comes to a quick stop?

This happens because both the car and your body are moving together. When the brakes are applied suddenly, the car slows down or stops, but your body wants to keep moving forward due to **inertia**. Since your body resists the change in motion, you experience a sudden forward jerk.

Inertia

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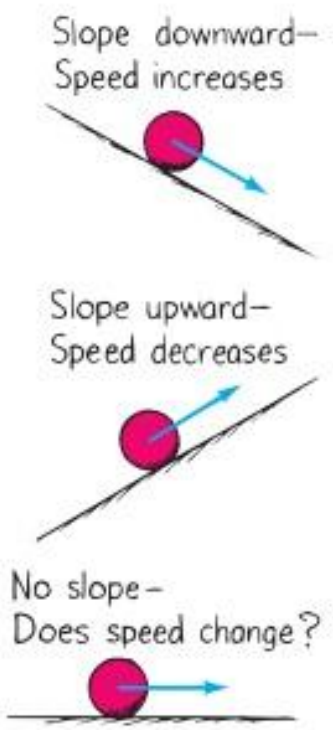
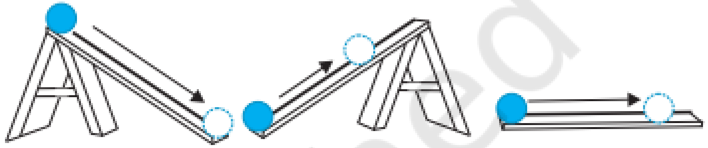
The Law of Inertia



5.3 THE LAW OF INERTIA

Galileo studied motion of objects on an inclined plane. Objects (i) moving down an inclined plane accelerate, while those (ii) moving up retard. (iii) Motion on a horizontal plane is an intermediate situation. Galileo concluded that an object moving on a frictionless horizontal plane must neither have acceleration nor retardation, i.e. it should move with constant velocity (Fig. 5.1(a)).

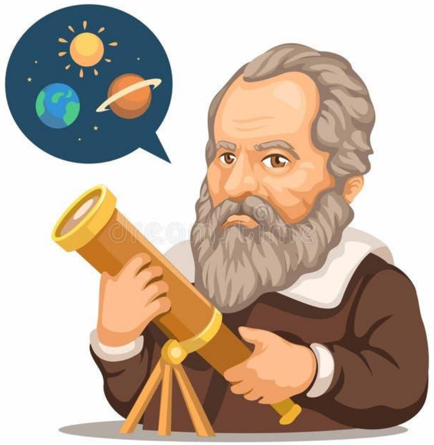


(i) (ii) (iii)

Fig. 5.1(a)

Newton built on Galileo's ideas and laid the foundation of mechanics in terms of three laws of motion that go by his name. Galileo's law of inertia was his starting point which he formulated as the **first law of motion**:

> **Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise.**



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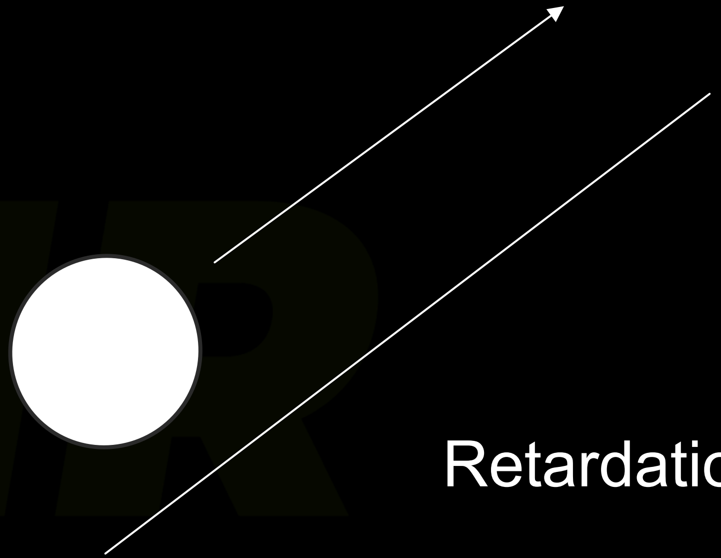
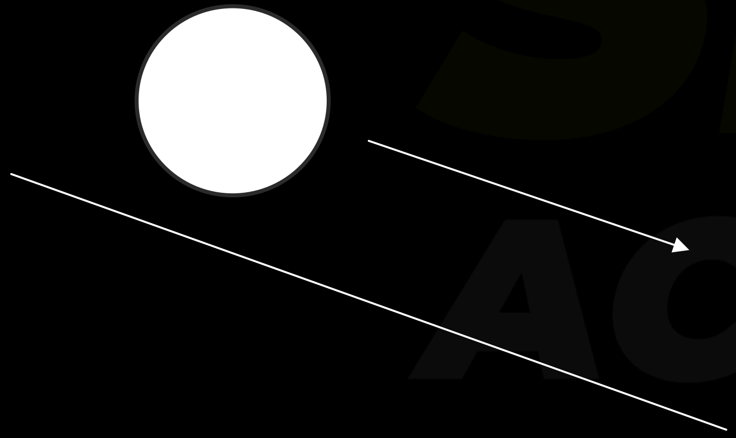
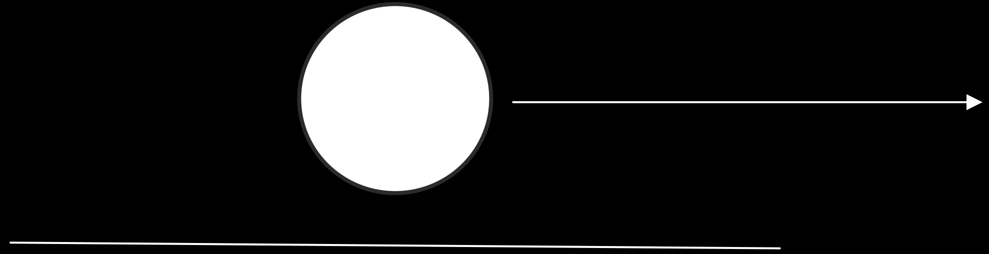


Retardation

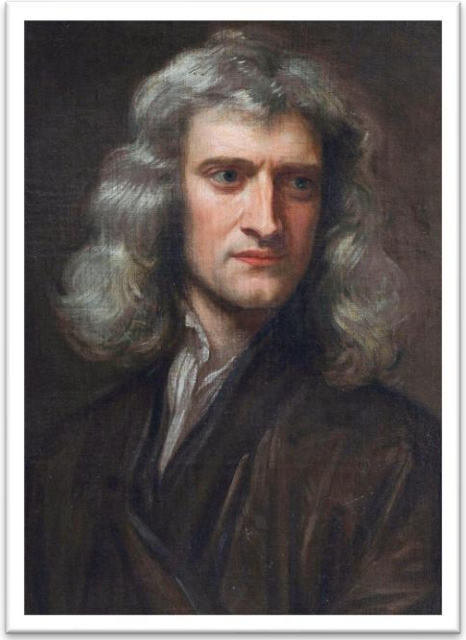


Acceleration

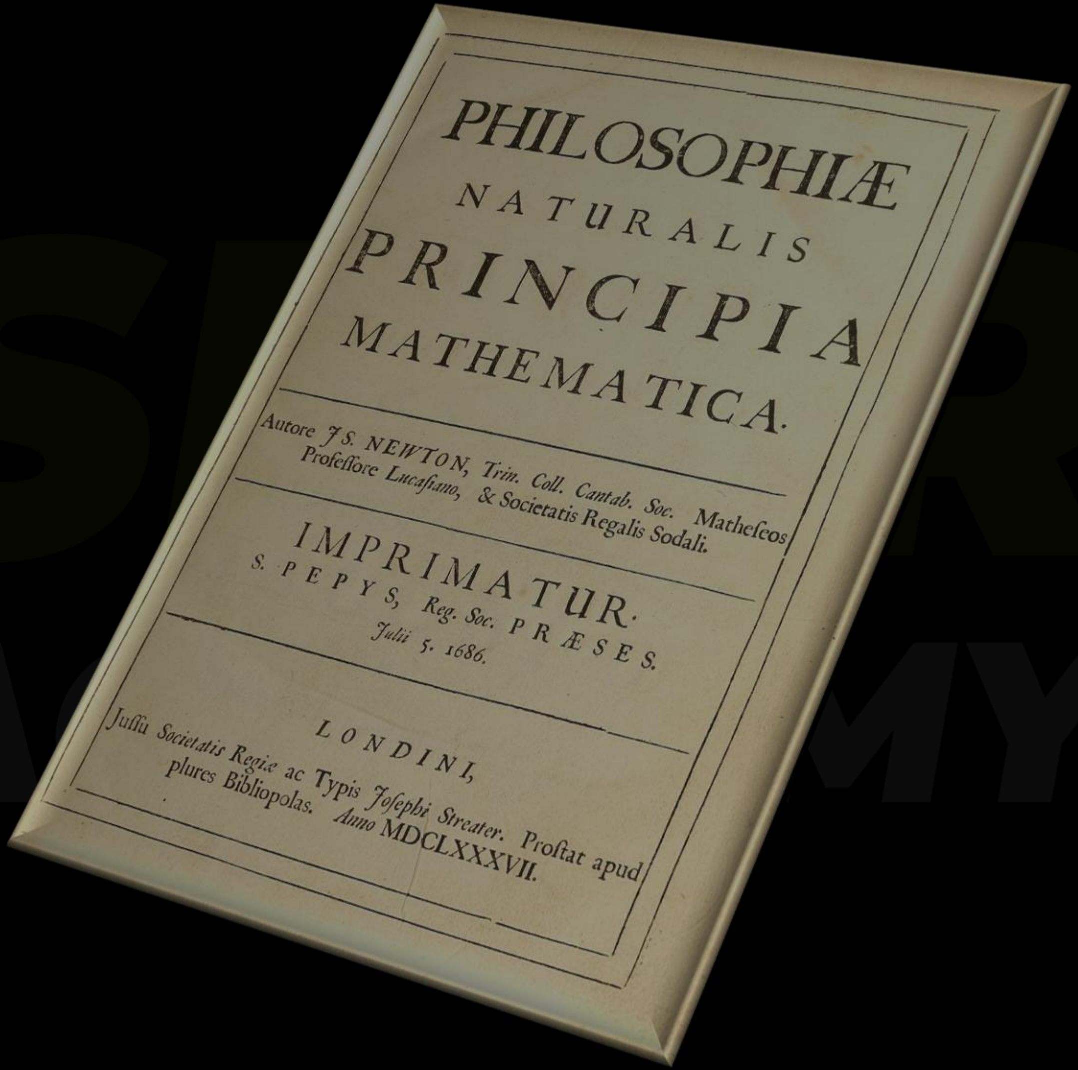


Frictionless Horizontal Plane

Newton’s laws first appeared in his masterpiece, Philosophiae Naturalis Principia Mathematica (1687), commonly known as the Principia. In 1543 Nicolaus Copernicus suggested that the Sun, rather than Earth, might be at the center of the universe. In the intervening years Galileo, Johannes Kepler, and Descartes laid the foundations of a new science that would both replace the Aristotelian worldview, inherited from the ancient Greeks, and explain the workings of a heliocentric universe. In the Principia Newton created that new science. He developed his three laws in order to explain why the orbits of the planets are ellipses rather than circles, at which he succeeded, but it turned out that he explained much more. The series of events from Copernicus to Newton is known collectively as the Scientific Revolution.



In the 20th century Newton’s laws were replaced by quantum mechanics and relativity as the most fundamental laws of physics. Nevertheless, Newton’s laws continue to give an accurate account of nature, except for very small bodies such as electrons or for bodies moving close to the speed of light. Quantum mechanics and relativity reduce to Newton’s laws for larger bodies or for bodies moving more slowly.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

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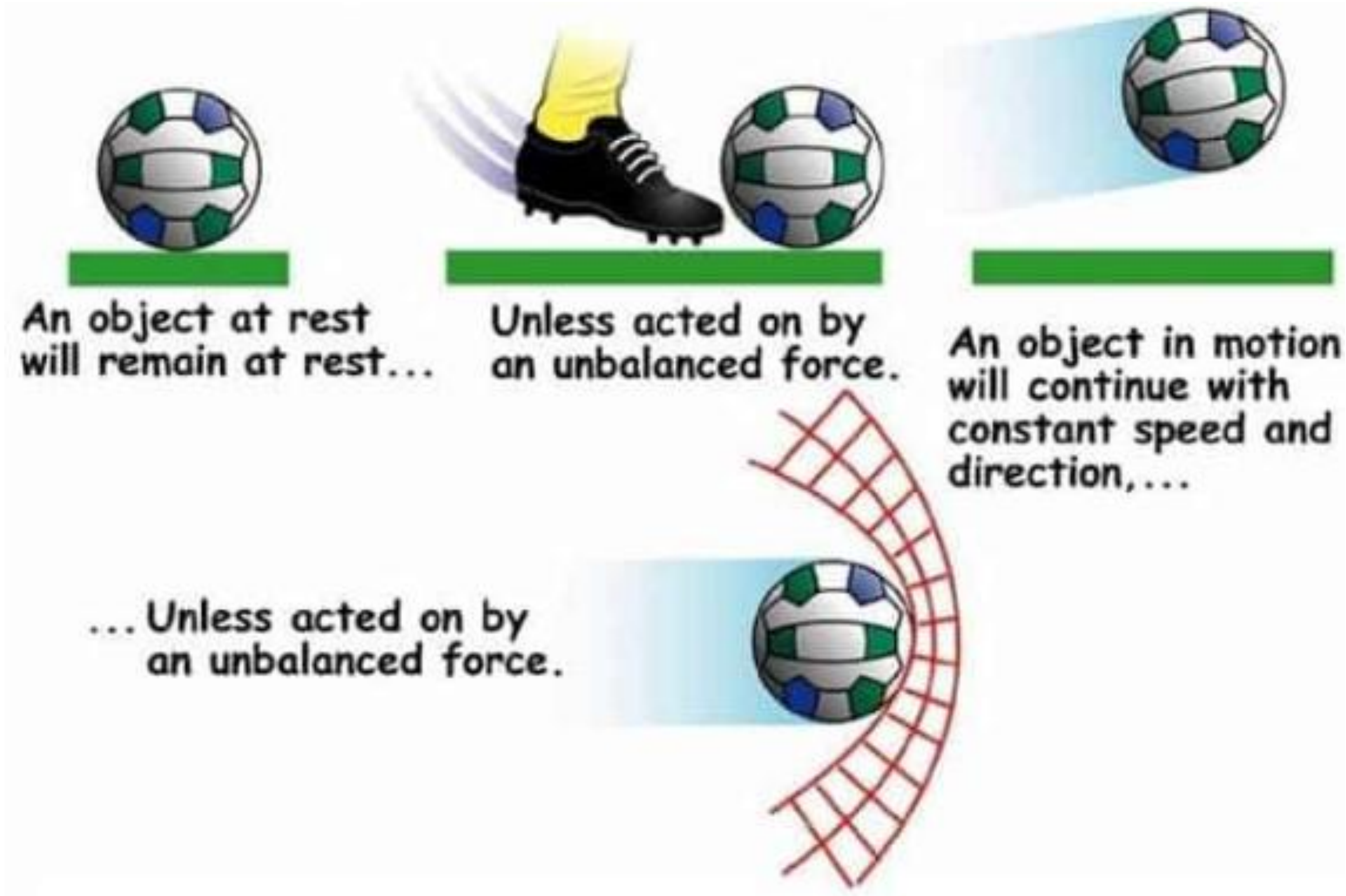


Rest
Velocity v = 10 m/s

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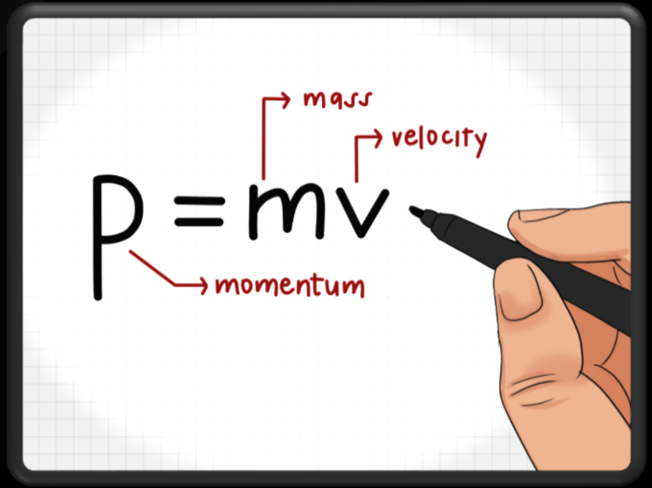
Momentum

Velocity v = 10 m/s

Mass m = 1 kg



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Momentum

Newton's first law was for scenarios where net force = 0. The second law is for scenarios with net force not equal to 0. Momentum plays a crucial role in Second law.

- Momentum is the product of mass of a body & its velocity
- It is a Vector quantity
- It is denoted by $p = mv$

For example, A ball of 1 kg moving with 10m/sec has a momentum 10kg m/sec.

Momentum of a system remains conserved. Therefore,

- Greater force is required to set heavier bodies in motion

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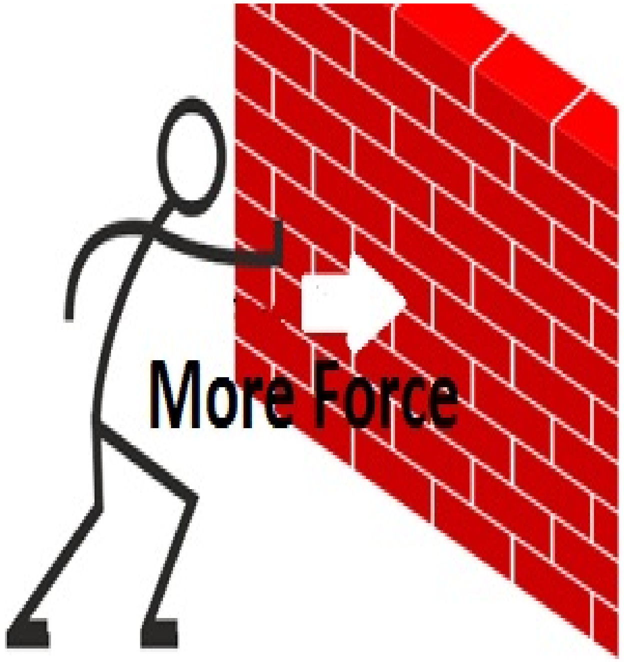
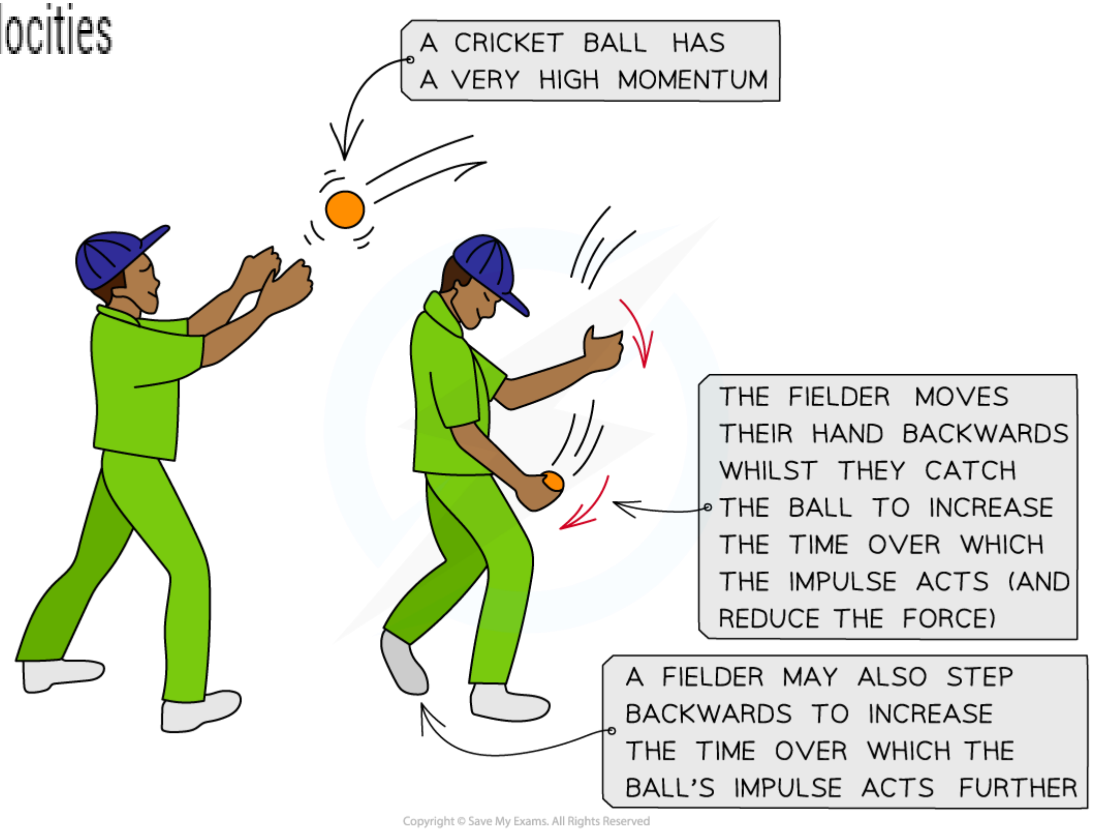
- Greater force is required to stop bodies moving with higher velocities





Conclusion: Greater the change in momentum in a given time, greater is the force that needs to be applied. In other words, greater the change in momentum vector, greater is the force applied.

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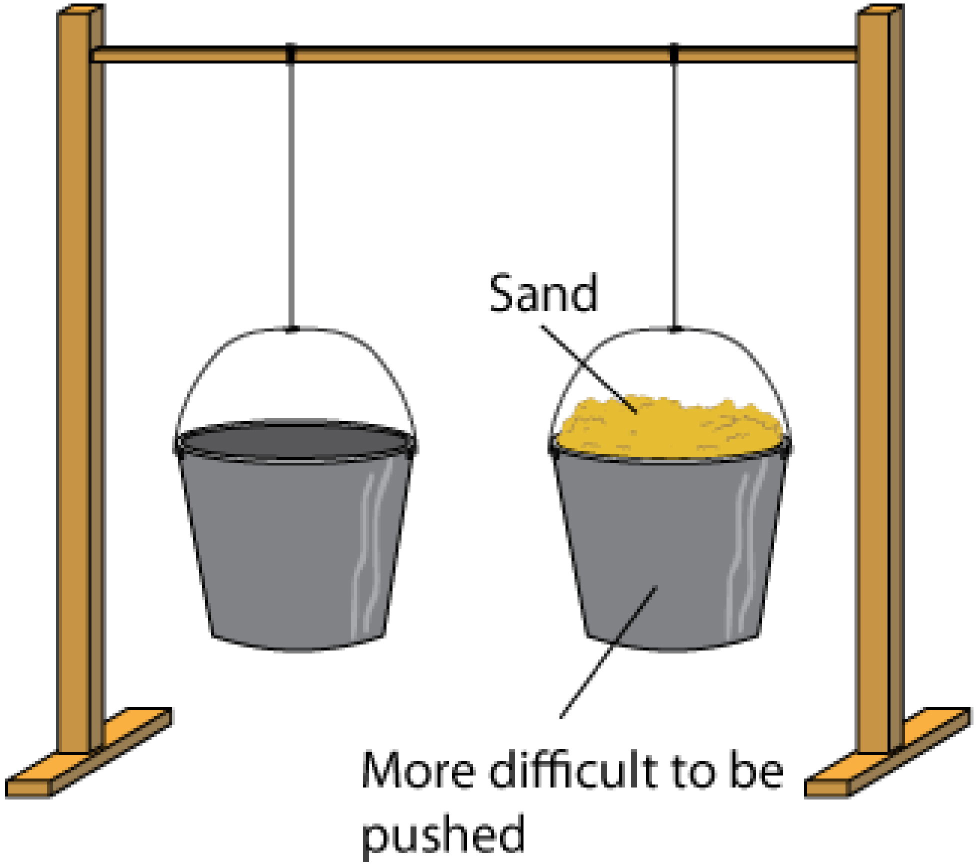

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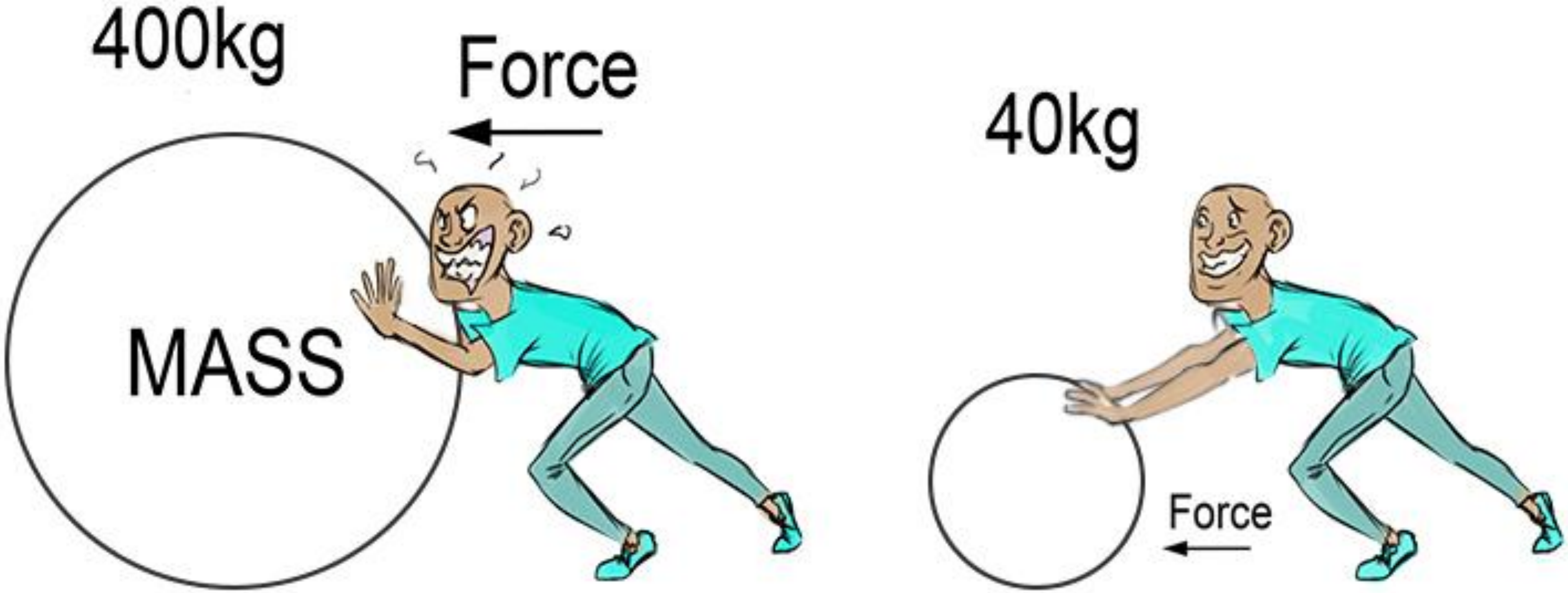

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Newton's Second Law

5 Kg

10 Kg

Velocity

Velocity

Momentum

Momentum

Force Applied

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Newton's Second Law

- The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.
- Alternatively, the relationship between an object's mass ***m***, its acceleration a, and the applied force ***F*** is ***F = ma***; the direction of the force vector is the same as the direction of acceleration vector.

$F \propto dp/dt$ [Greater the change in momentum, greater is force]

$F = k\, dp/dt$

$F = dp/ dt$

$F = d/ dt\, (mv)$

Let, m: mass of the body be constant

$F = m\, dv/dt$

$\mathbf{F = ma}$

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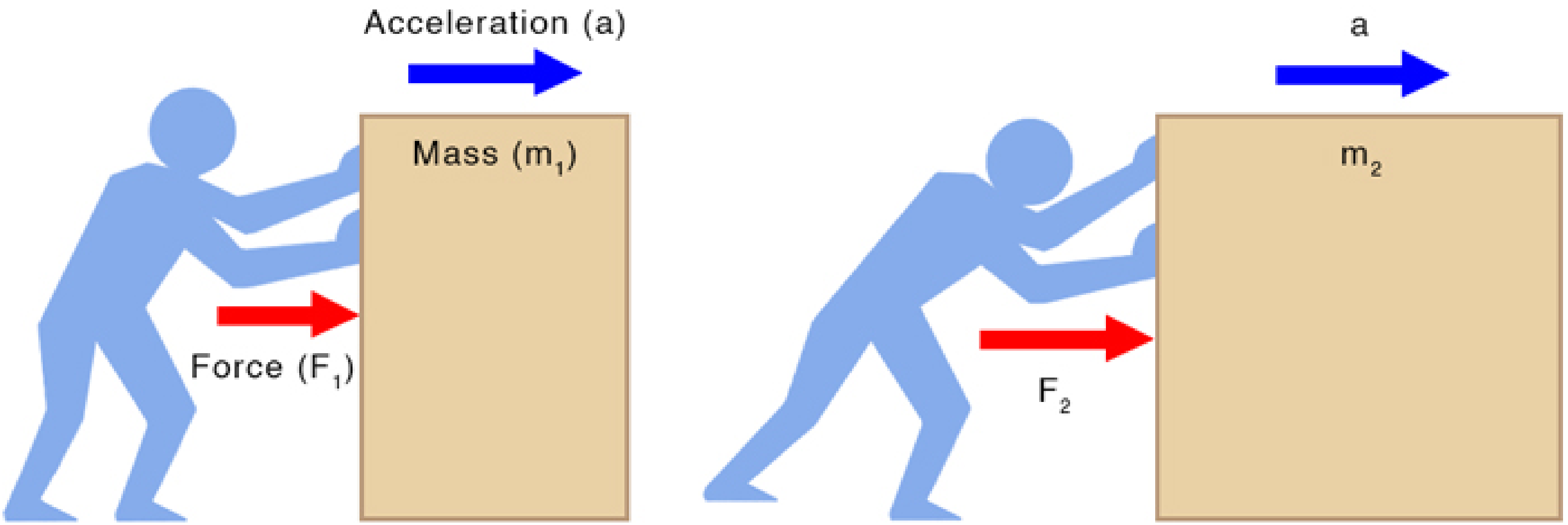
Newton's Second Law

The force (F) acting on a moving object is the product of the mass (m) and acceleration (a)

$$\boxed{F = ma}$$



$F_1 = m_1 a$ $\quad$ $F_2 = m_2 a$

$$m_2 > m_1 \Rightarrow F_2 > F_1$$

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- Newton's Second law is consistent with the First law

$F = ma$

If $F = 0$, then $a = 0$

According to First law, if $a = 0$, Then $F = 0$

Thus, both the laws are in sync.

- Vector form of Newton's Second law

$$\vec{F} = \vec{F_x}i + \vec{F_y}j + \vec{F_z}k$$

$F_x = dp_x/ dt = ma_x$

$F_y = dp_y/ dt = ma_y$

$F_z = dp_z/dt = ma_z$

- Newton's Second Law was defined for point objects. For larger bodies,
  - a: acceleration of the centre of mass of the system.
  - F: total external force on the system.

Problem 1: A car of mass 2×10^3 kg travelling at 36 km/hr. on a horizontal road is brought to rest in a distance of 50m by the action of brakes and frictional forces. Calculate:
(a) average stopping force , (b) time taken to stop the car

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Solution.

$m = 2 * 10^3$

$u = 36$ km/hr = 10m/s

$s = 50m$

$v = 0$

To find: a, F, t

Third equation of motion: $v^2 = u^2 + 2as$

$0 = 100 + 2a * 50$

Or, $\mathbf{a = -1\ m/s^2}$

Therefore, $F = ma = (2 * 10^3) * 1 = \mathbf{2 * 10^3\ N}$

$V = u + at$

$0 = 10 - t$

$\mathbf{t = 10\ sec}$

Problem 2: the only force acting on a 5kg object has components $f_x = 15N$ and $f_y = 25N$. Find the acceleration of the object.

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m= 5kg

$F_x = 15N$, $F_y = 25N$

$F = F_x i + F_y j$

$$|\vec{F}| = \sqrt{F_x^2 + F_y^2}$$

$= \sqrt{225 + 625} = \sqrt{850}$

$F = ma$

Or, $a = F/m = \sqrt{850}/5 = 5\sqrt{34}/5 = \sqrt{34} =$ **$5.83 m/s^2$**

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Impulse

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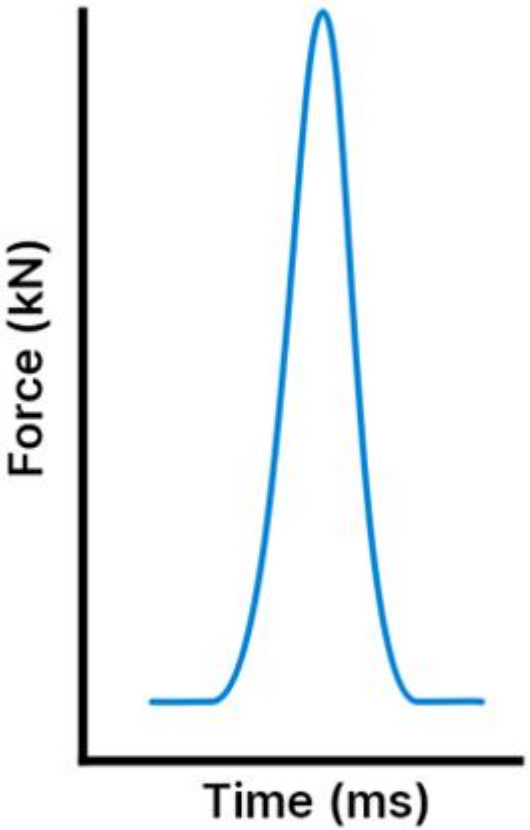

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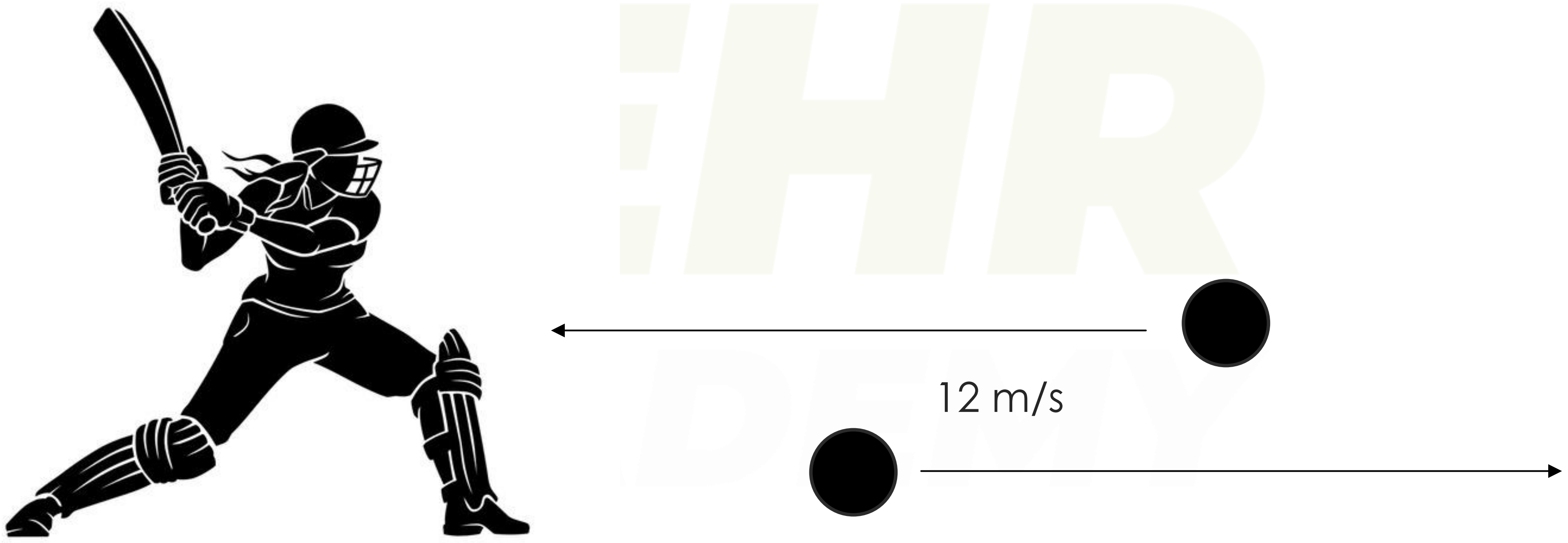
Impulse

- Impulse is defined as a force multiplied by time it acts over.
- For example: Tennis racket strikes a ball, an impulse is applied to the ball. The racket puts a force on the ball for a short time period.

$F \Delta t = \Delta p$

$F = \Delta p / \Delta t$ = Rate of Change of momentum

A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of 12ms−1 . if the mass of the ball is 0.15 kg , determine the impulse imparted to the ball . (assume linear motion of the ball).



12 m/s

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To determine the impulse imparted to the ball when a batsman hits it back towards the bowler, we can follow these steps:

Step 1: Understand the problem
The ball is initially moving towards the batsman with a speed of $12\,\mathrm{m/s}$. After being hit, it moves back towards the bowler with the same speed but in the opposite direction. The mass of the ball is given as $0.15\,\mathrm{kg}$.

Step 2: Define initial and final velocities
- **Initial velocity of the ball (u)**: Since the ball is moving towards the batsman, we can take this velocity as positive:
$u = 12\,\mathrm{m/s}$
- **Final velocity of the ball (v)**: After being hit back towards the bowler, the velocity will be in the opposite direction, so we take it as negative:
$v = -12\,\mathrm{m/s}$

Step 3: Calculate the change in momentum
The change in momentum (Δp) can be calculated using the formula:

$\Delta p = m(v - u)$

Where:
- m is the mass of the ball,
- u is the initial velocity,
- v is the final velocity.

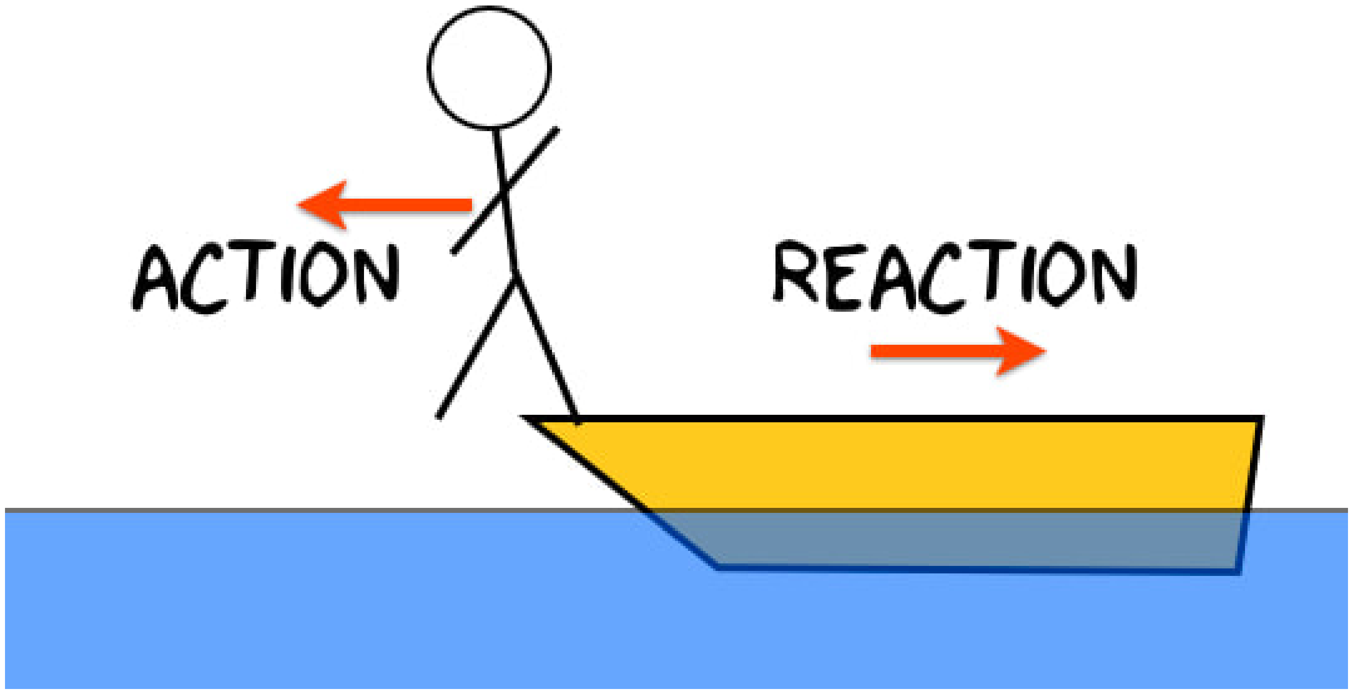
Substituting the values:
$\Delta p = 0.15\,\mathrm{kg} \times (-12\,\mathrm{m/s} - 12\,\mathrm{m/s})$

$\Delta p = 0.15\,\mathrm{kg} \times (-24\,\mathrm{m/s})$

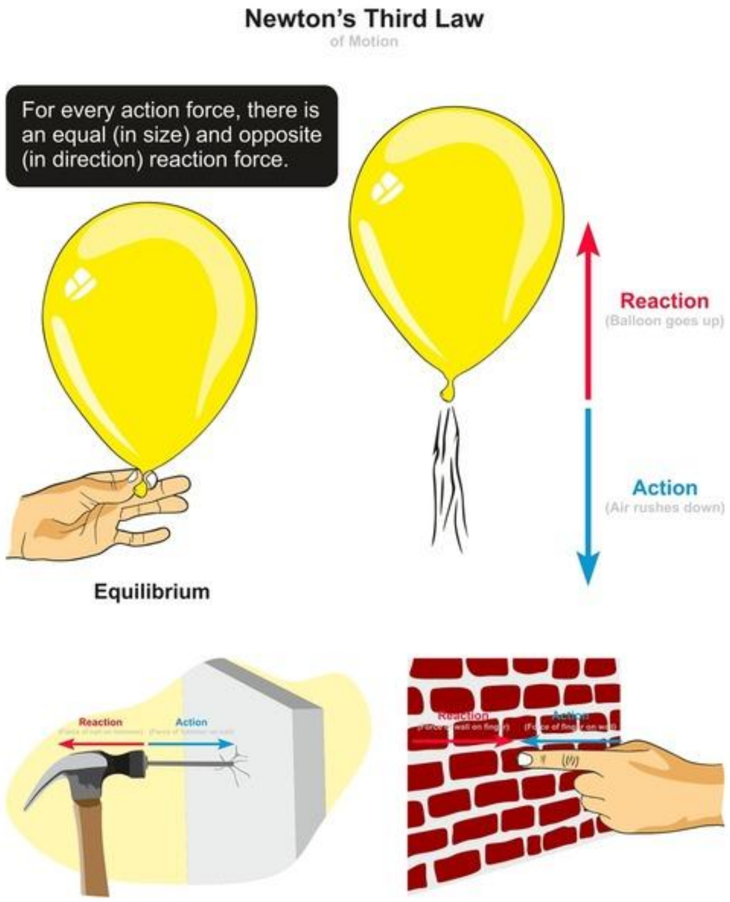
Step 4: Calculate the impulse
Impulse (J) is equal to the change in momentum:
$J = \Delta p$
Calculating:
$J = 0.15\,\mathrm{kg} \times (-24\,\mathrm{m/s}) = -3.6\,\mathrm{kg\ m/s}$
Since impulse is a vector quantity and we are interested in the magnitude:
$|J| = 3.6\,\mathrm{N\ s}$

Step 5: Conclusion
The impulse imparted to the ball is $3.6\,\mathrm{N\ s}$.

Action & Reaction


ACTION
REACTION

Equal and opposite forces



Action & Reaction

Newton's Third Law of Motion

Action and reaction forces

- one force is called the action force; the other force is called the reaction force.
- are co-pairs of a single interaction.
- neither force exists without the other.
- are equal in strength and opposite in direction.
- always act on *different* objects.

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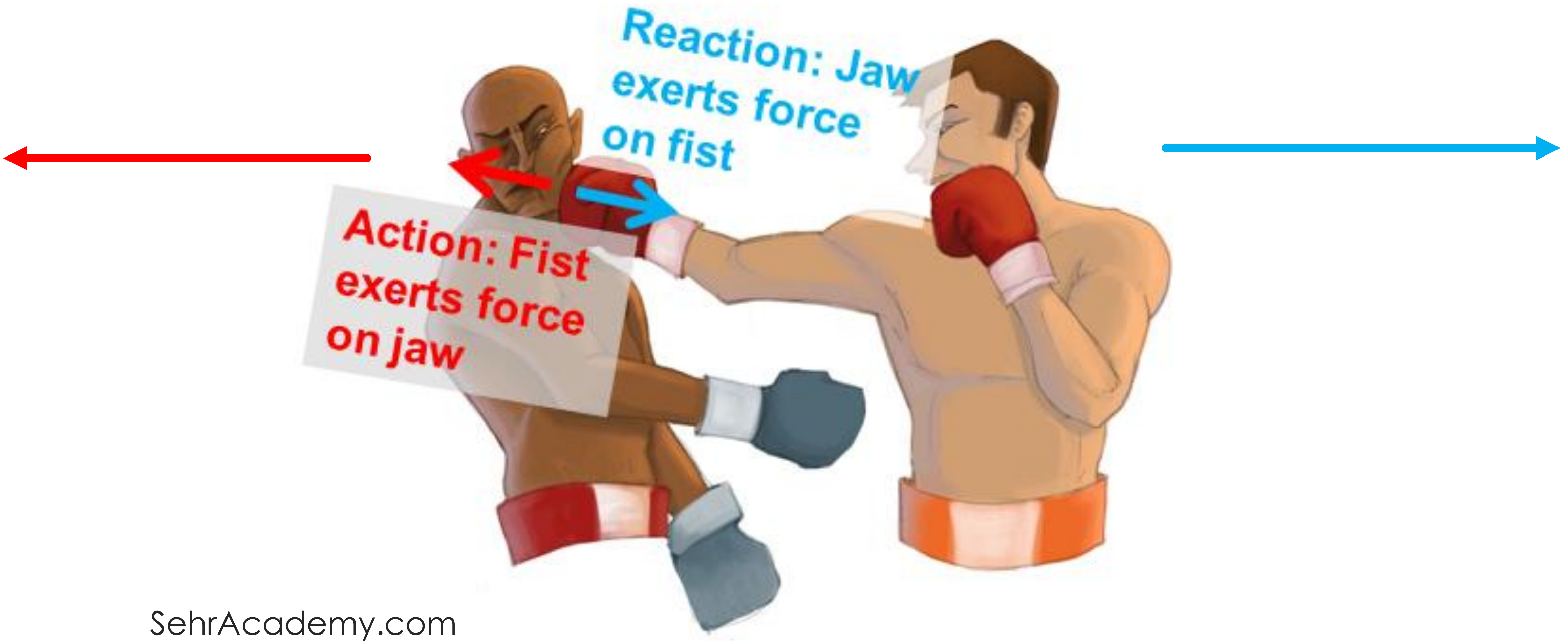
Newton's Third Law

To every action, there is always an equal and opposite reaction.

For example, when you hold the ball, a force acts on the ball (Action), and an equal and opposite force acts on your hand (Reaction).

- Action & Reaction forces always act on different bodies
  - $F_{AB} = F_{BA}$
  - F_{AB}: Force acting on A by B
  - F_{BA}: Force acting on B by A
- Action & Reaction forces occur at the same instant

Equal and opposite forces



Same Instant

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Equal and opposite forces

In physics, normal force is a force that acts perpendicularly to the surface of contact between two objects. It is the force that prevents objects from passing through each other when they are in contact. Essentially, it's the force a surface exerts to support the weight of an object resting on it.

↓

Repulsive force between the electron clouds of two surfaces in contact, preventing them from interpenetrating

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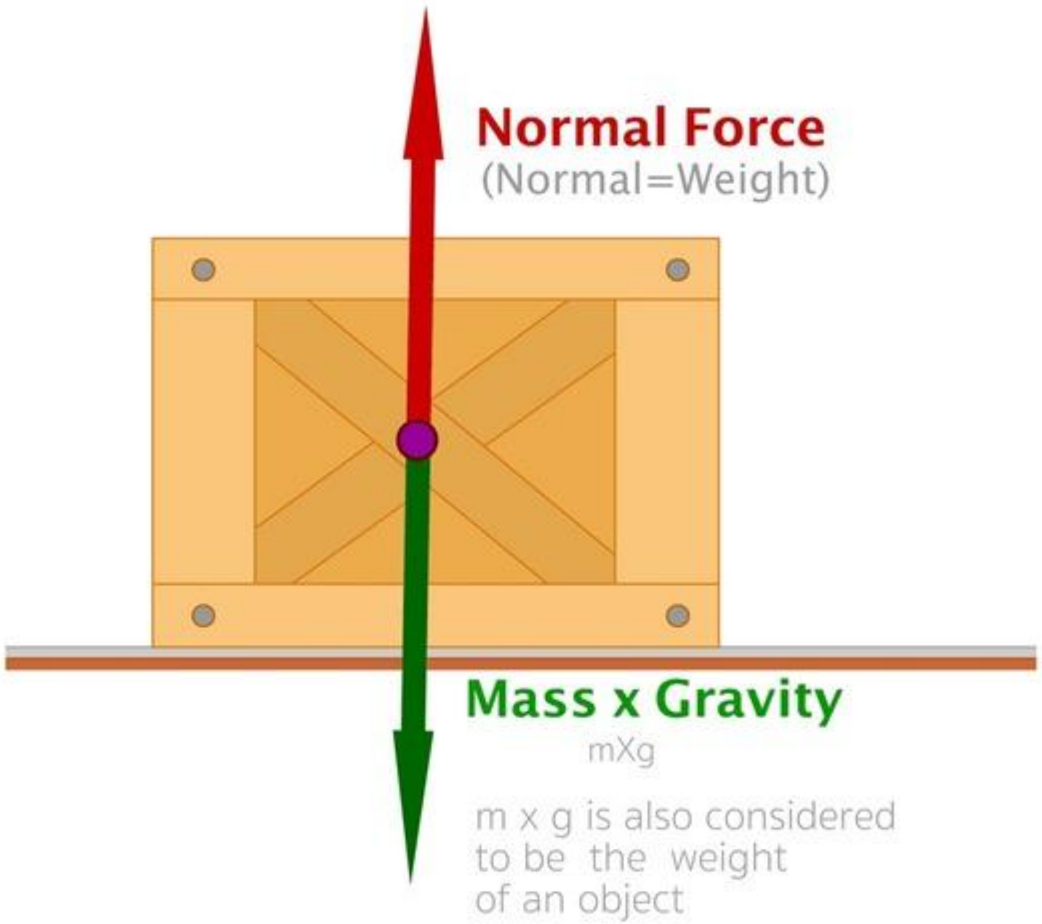

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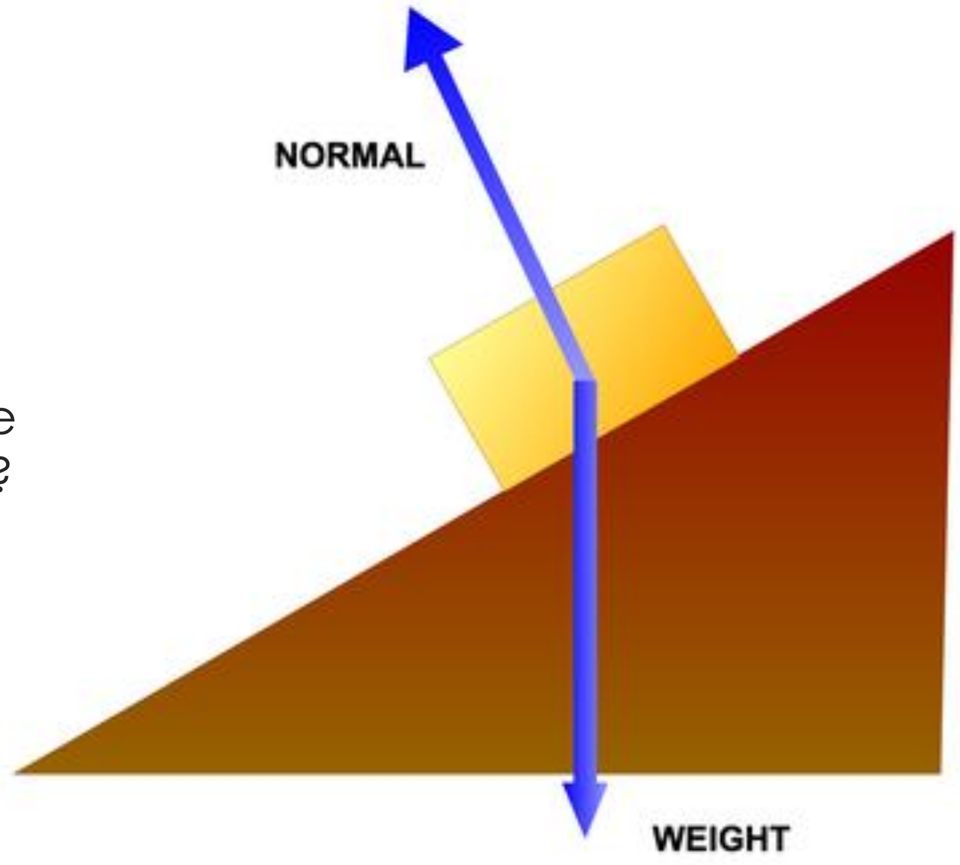
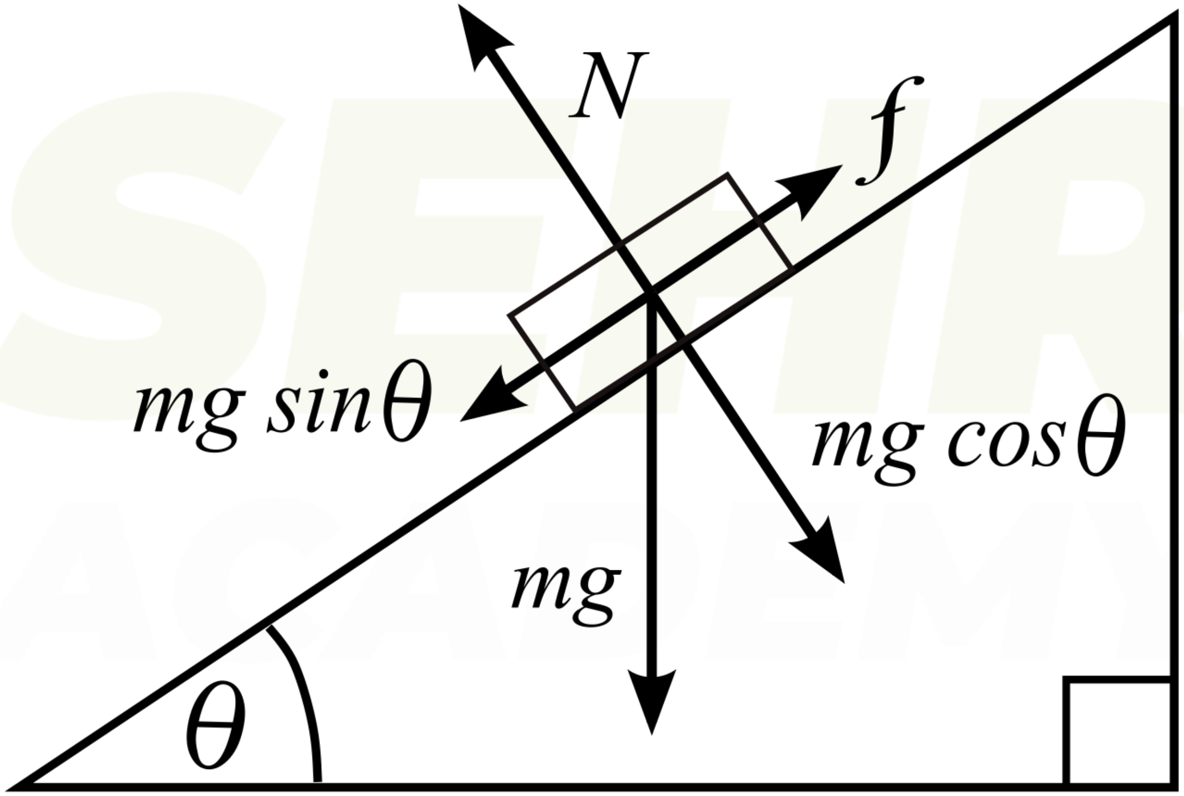
Gravity & Normal force

What happens to the object here?

What is the total force acting on the object?





N
f
mg sinθ
mg cosθ
mg
θ

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Conservation of Momentum

$$F_{\text{net}} = \frac{\Delta p}{\Delta t}$$

$$p = mv$$

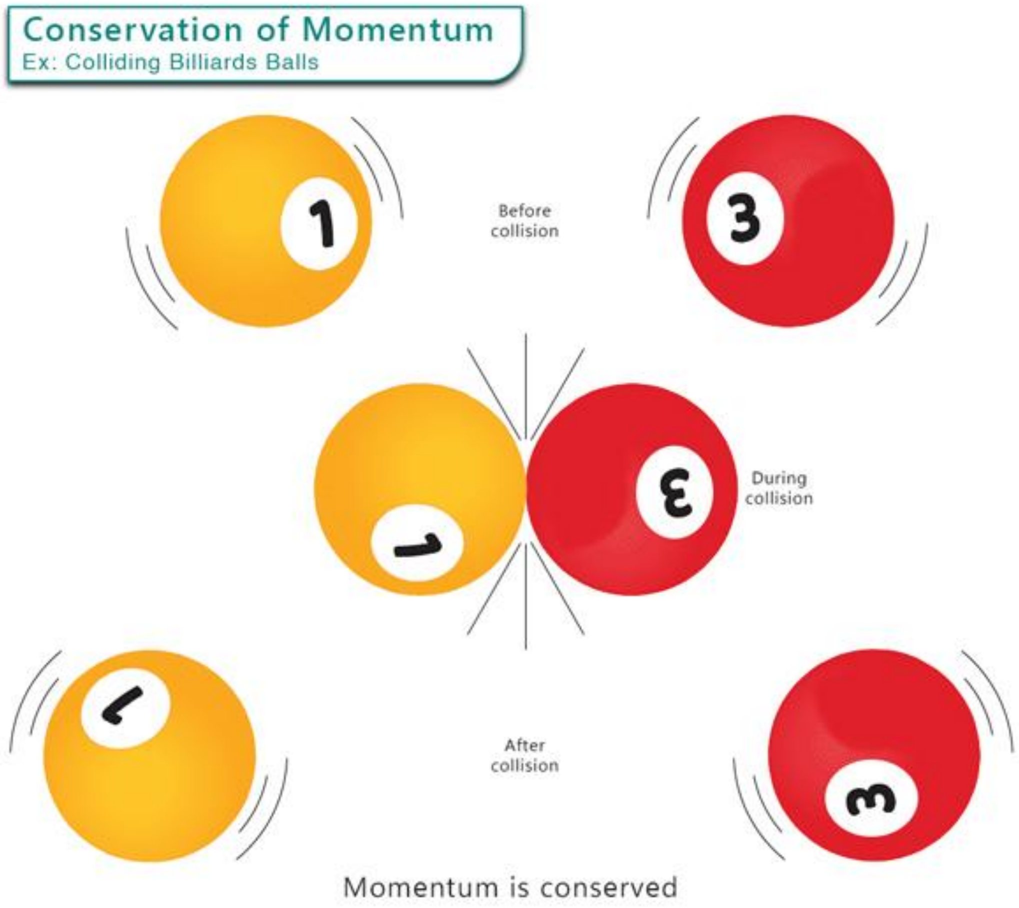
$$\vec{F} = m\vec{a}$$

Net external force = 0?
What happens to rate of change in momentum?

5.7 CONSERVATION OF MOMENTUM

The second and third laws of motion lead to an important consequence: the law of conservation of momentum. Take a familiar example. A bullet is fired from a gun. If the force on the bullet by the gun is **F**, the force on the gun by the bullet is –**F**, according to the third law. The two forces act for a common interval of time Δt. According to the second law, $\mathbf{F}\,\Delta t$ is the change in momentum of the bullet and $-\mathbf{F}\,\Delta t$ is the change in momentum of the gun. Since initially, both are at rest, the change in momentum equals the final momentum for each. Thus if $\mathbf{p}_b$ is the momentum of the bullet after firing and $\mathbf{p}_g$ is the recoil momentum of the gun, $\mathbf{p}_g = -\mathbf{p}_b$ *i.e.* $\mathbf{p}_b + \mathbf{p}_g = 0$. That is, the total momentum of the (bullet + gun) system is conserved.

Thus in an isolated system (i.e. a system with no external force), mutual forces between pairs of particles in the system can cause momentum change in individual particles, but since the mutual forces for each pair are equal and opposite, the momentum changes cancel in pairs and the total momentum remains unchanged. This fact is known as the **law of conservation of momentum** :



Law of Conservation of Momentum

- Now that we've talked about momentum in an isolated system, where no external forces act, we can state that **momentum is always conserved**. Put more simply, **in any closed system, the total momentum of the system remains constant**.
- In the case of a **collision or explosion (an event), if you add up the individual momentum vectors of all of the objects before the event, you'll find they're equal to the sum of the momentum vectors of the objects after the event**. Written mathematically: $p_{initial} = p_{final}$. This is a direct outcome of Newton's 3rd Law.

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Conservation of Momentum

- In an isolated system, the total momentum is conserved.

Example 1. In a Spinning top, total momentum = 0. For every point, there is another point on the opposite side that cancels its momentum.

Example 2. Bullet fired from a Rifle

Initially, momentum = 0

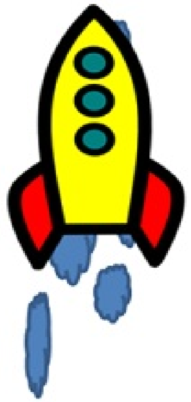
Later, the trigger is pulled, bullet gains momentum in àdirection, but this is cancelled by rifle's ß momentum. Therefore, total momentum = 0

During the process, the chemical energy in gunpowder gets converted into heat, sound and chemical energy.

Example3. Rocket propulsion

Initially, mass of rocket: M. It just started moving with velocity v

Initial momentum = Mv



Later, gases are ejected continuously in opposite direction with a velocity relative to rocket in downward direction giving a forward push to the rocket.

Mass of the rocket becomes (M-m)

Velocity of the rocket becomes (v + v′)

Final momentum = (M − m) (v + v′)

Thus, Mass * velocity = constant

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Recoil of a Gun

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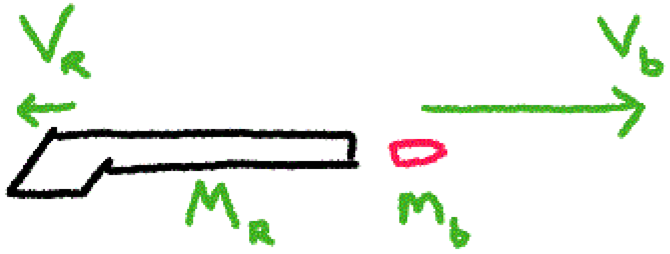
before

$$\Sigma p = 0$$

after



$$\Sigma p = m_b V_b + M_R(-V_R) = 0$$

$$\Rightarrow \quad m_b V_b = M_R V_R$$

$$\frac{V_R}{V_b} = \frac{m_b}{M_R}$$

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What is the recoil velocity of the gun of mass 8 kg when a bullet of mass 10 g is fired from it with a velocity of 400 m/s?

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Given in question,

Mass of the rifle, m_1= 8 kg

Mass of the bullet, m_2= 10g= 0.01 kg

Recoil velocity of the rifle= v_1

Bullet is fired with an initial velocity, v_2= 400 m/s

Initially, the rifle is at rest.

Thus, its initial velocity, v= 0

Initial momentum of the system (rifle and bullet) = (m_1+m_2) v= 0

Total momentum of the system (rifle and bullet) after firing:

$m_1v_1 + m_2v_2$= $8v_g + (0.01)(400)$

Now, apply Conservation of linear momentum:

Initial momentum (rifle and bullet) = Total momentum (rifle and bullet) after firing:

That means: $P_i = P_f$

$\Rightarrow$ 0 = $8v_g + (0.01)(400)$

$\Rightarrow$ v_g= - 0.5 m/s

The negative sign indicates that the rifle recoils backwards with a velocity of 0.5 m/s

$\Rightarrow$ $|v_g|$=0.5 m/s

Therefore, 0.5 m/s is the recoil velocity of the gun of mass 8 kg.

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Net External Force

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Net External Force on the Fridge

50 N

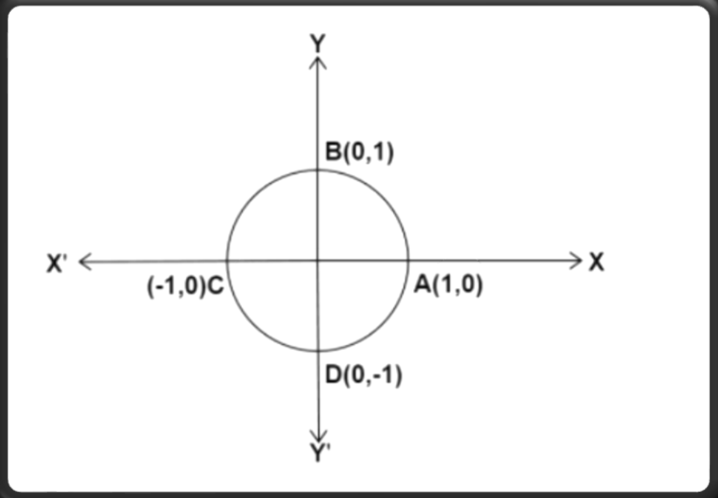
30 N

Resultant Vector Formulas

$F_{1x} = F_1 \cos\theta$ $\quad$ $F_{1y} = F_1 \sin\theta$

$F_x = F_{1x} + F_{2x}$ $\quad$ $F_y = F_{1y} + F_{2y}$

$F = \sqrt{F_x^2 + F_y^2}$ $\quad$ $\theta_{Ref} = \mathrm{Tan}^{-1}\left[\frac{F_y}{F_x}\right]$



The magnitude of the resultant

$$R = \sqrt{(A^2 + B^2 + 2AB\cos\theta)}$$

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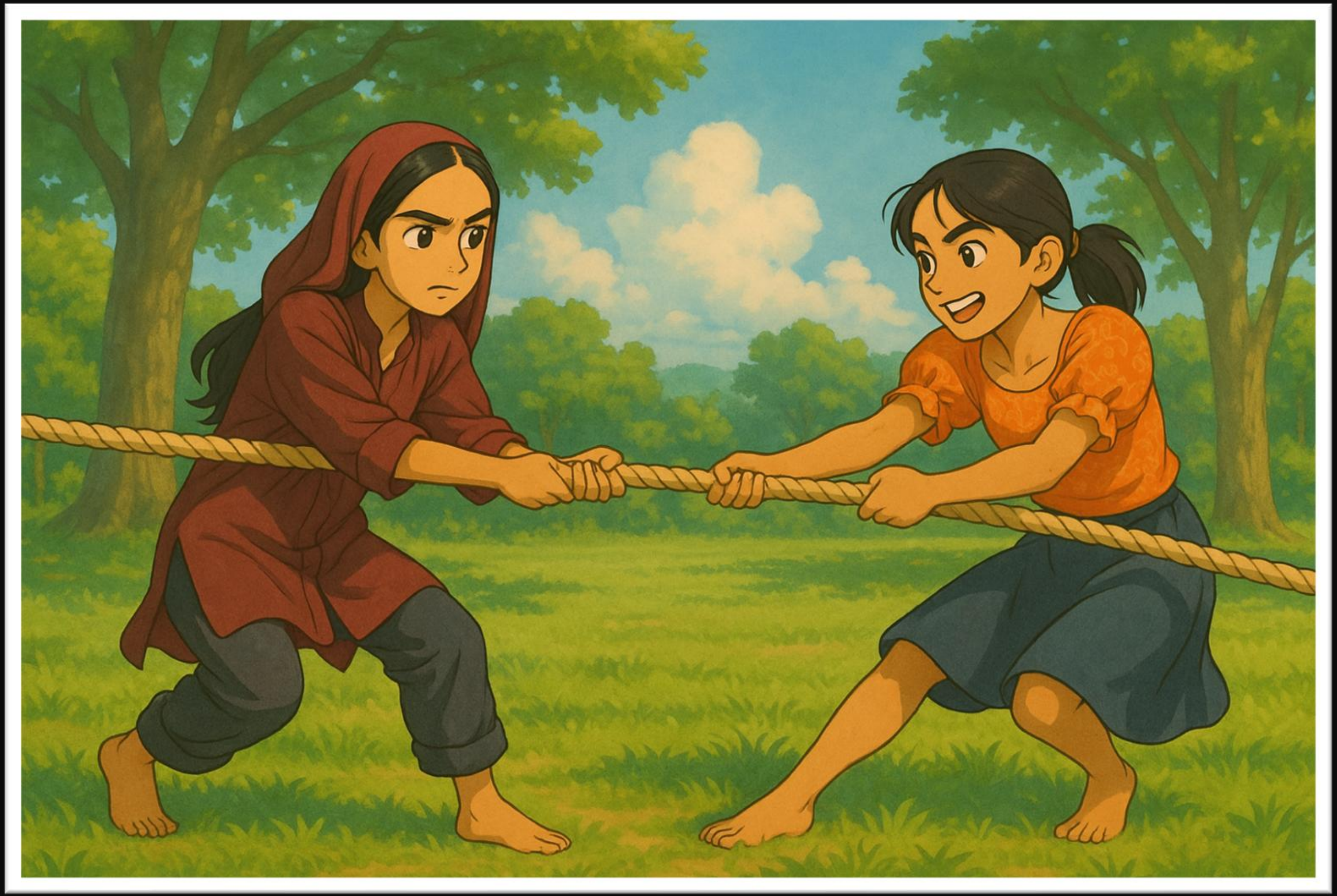
50 N



50 N

Force exerted by Person 1

Force exerted by Person 2

Equilibrium of a particle

A particle is said to be in equilibrium when the net external force acting on it is zero.

$$F_1 + F_2 + F_3 + \text{------} + F_n = 0$$

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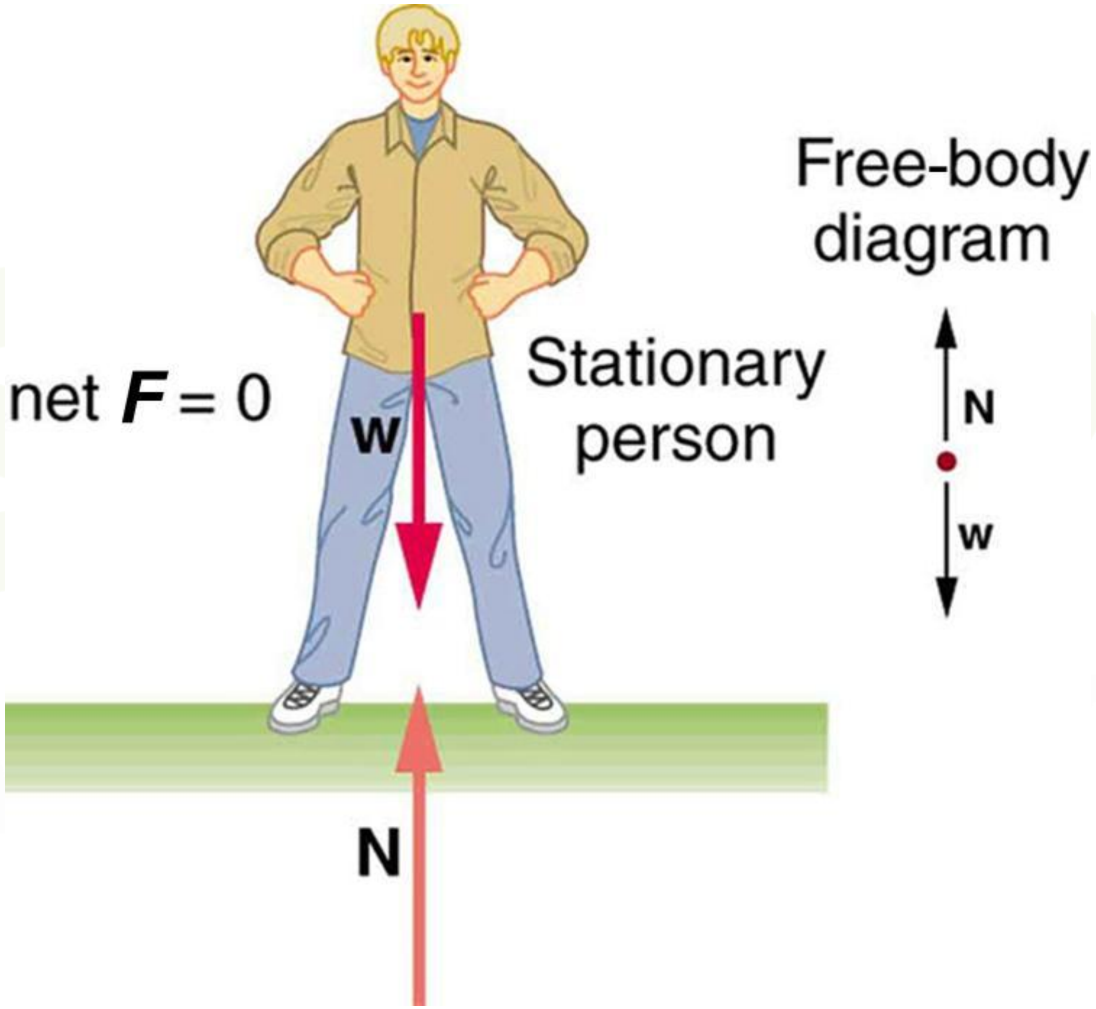

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$$F_1 + F_2 + F_3 + \text{------} + F_n = 0$$

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Friction

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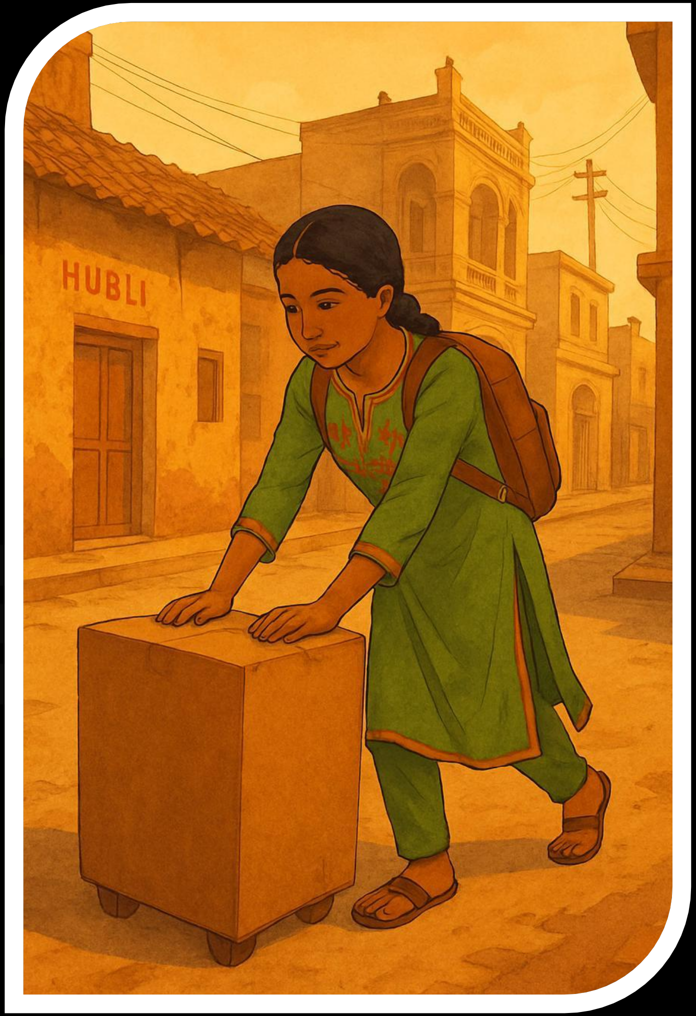

Force F

10 N

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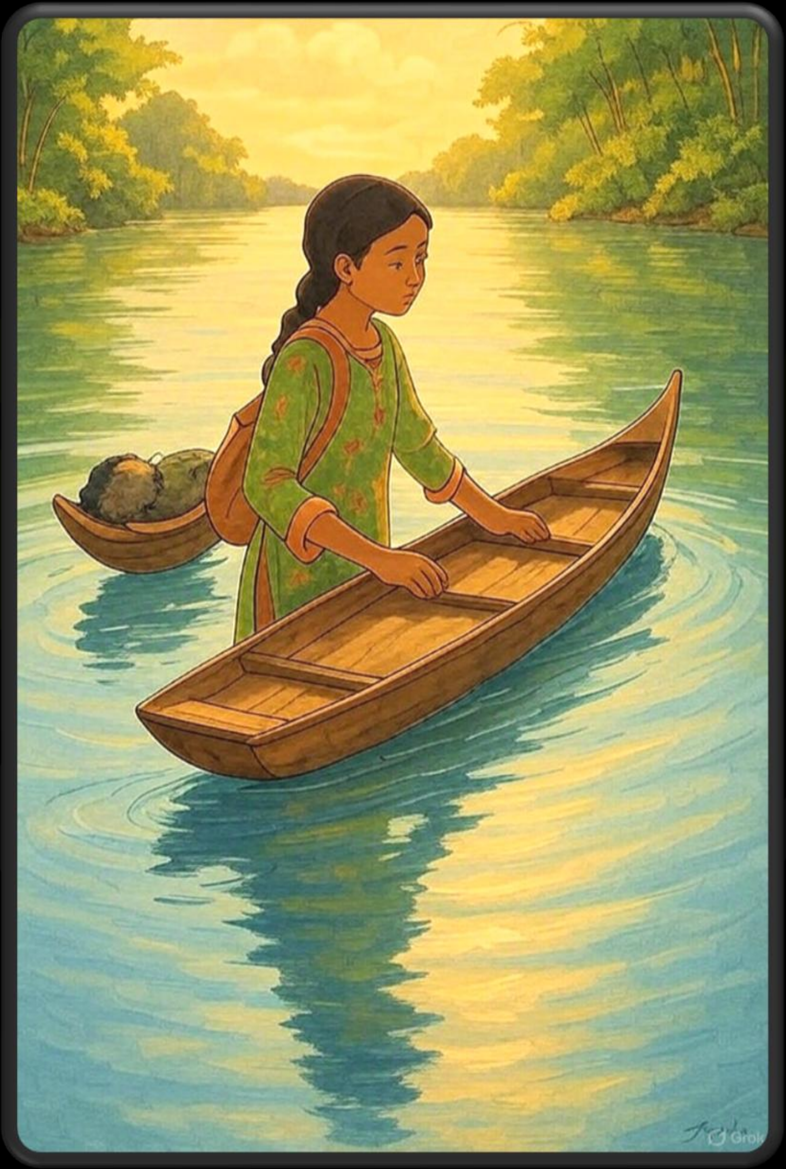
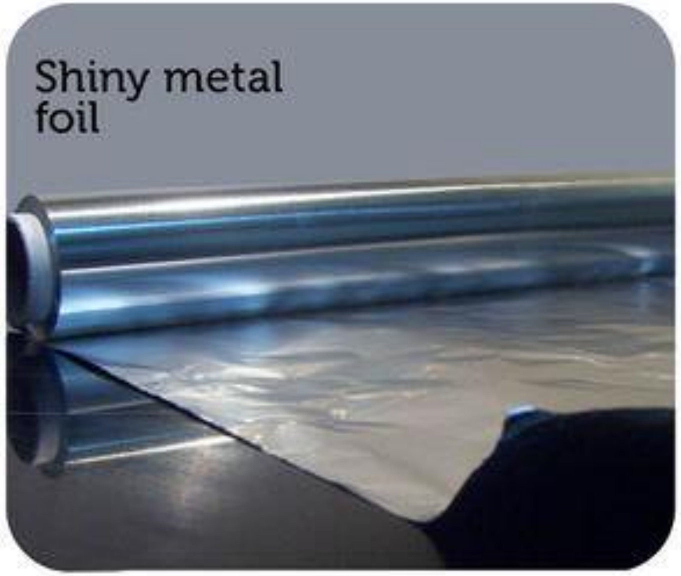
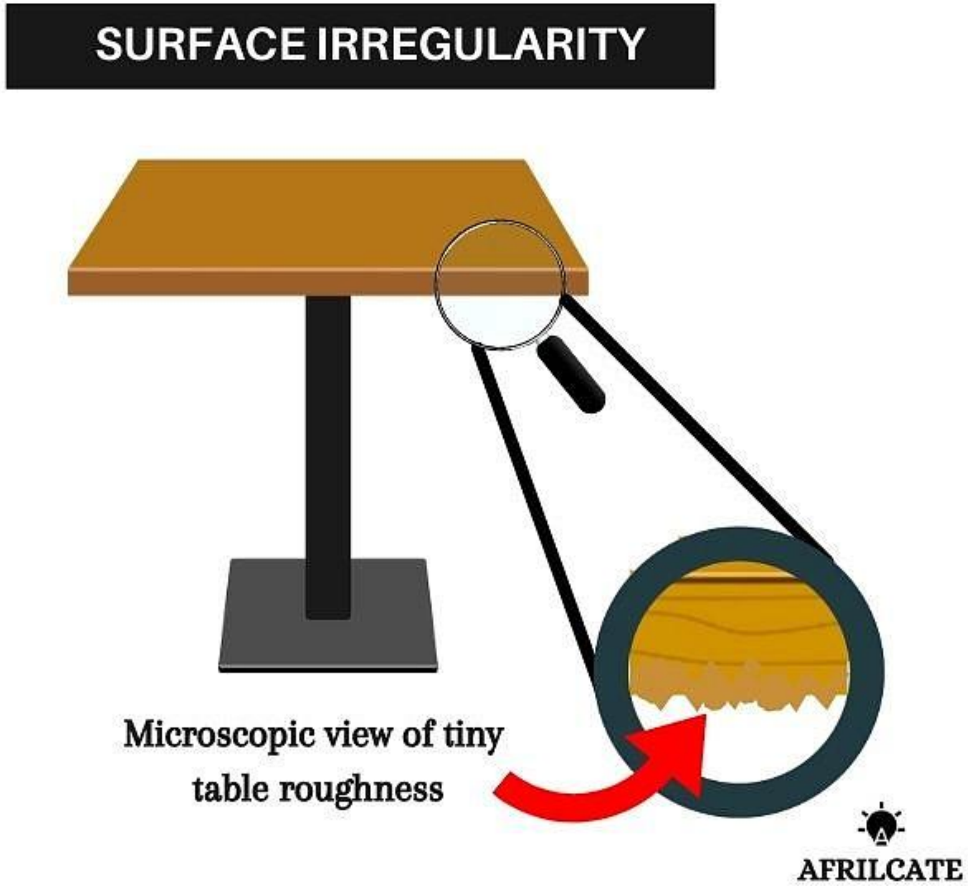


Force F

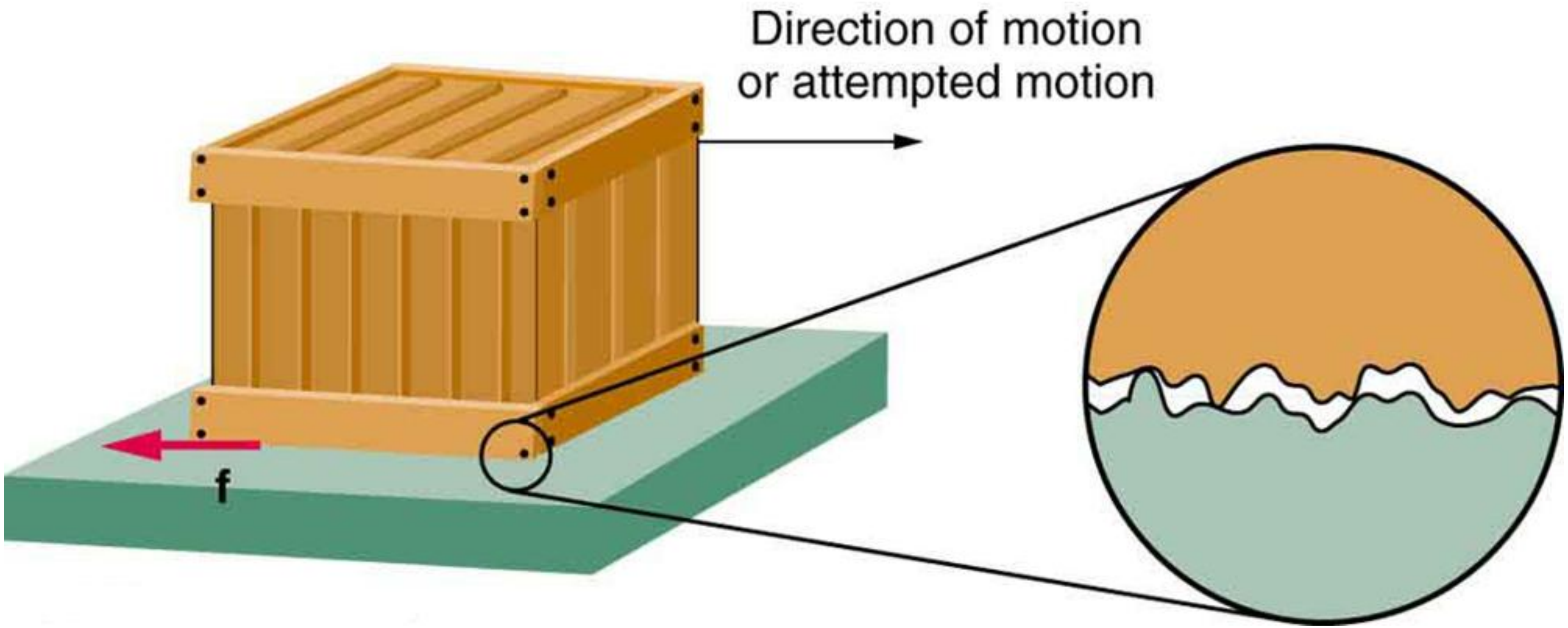
1 N


Shiny metal foil


Surface of metal greatly magnified


SURFACE IRREGULARITY
Microscopic view of tiny table roughness
AFRILCATE

Static $f_s = ? \longrightarrow 0 \longrightarrow ?$



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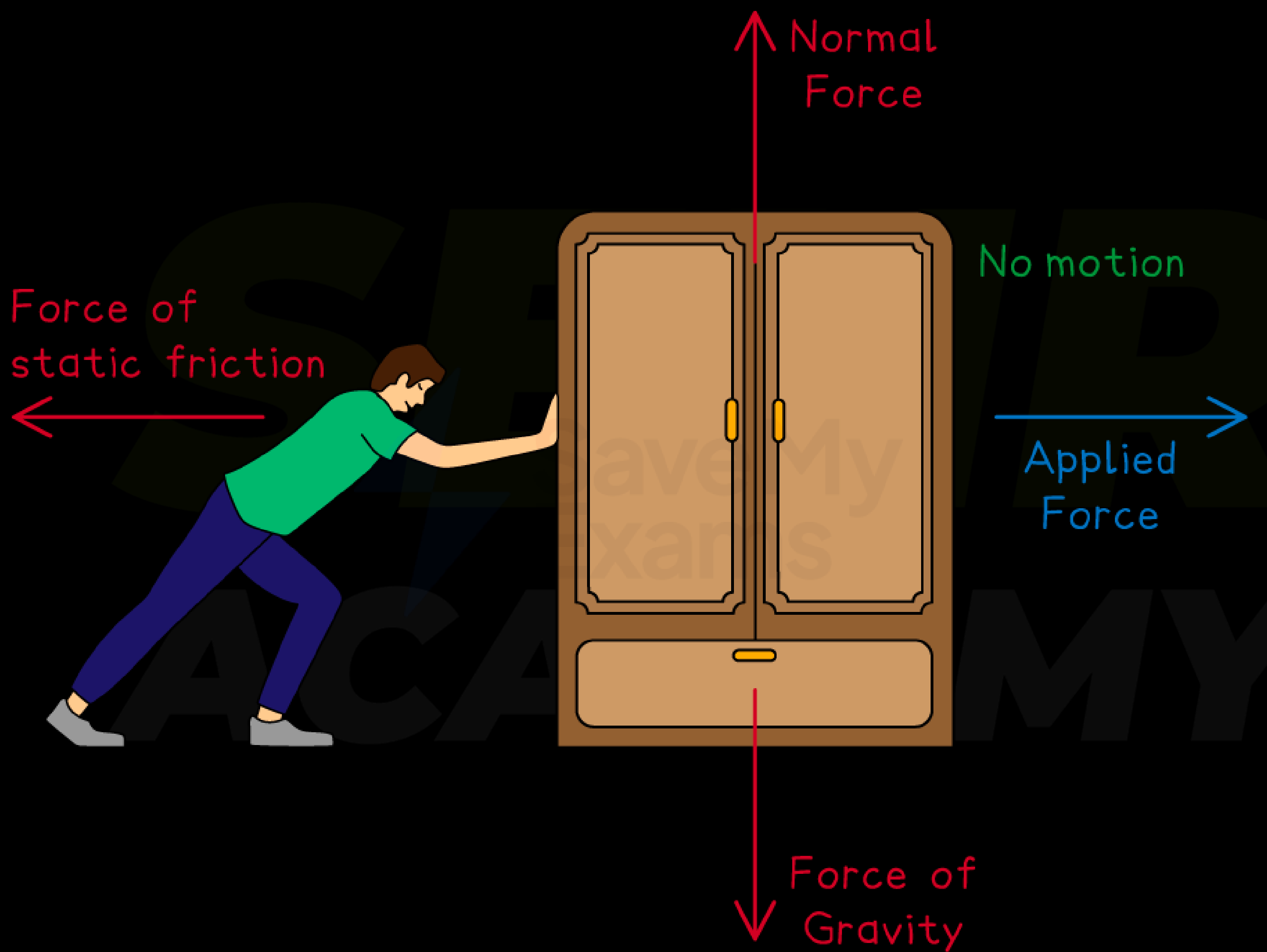
Static Friction

Friction is a contact force that opposes the relative motion between two surfaces; it only exists when an external force is applied.

Static friction specifically resists the initiation of motion between two bodies in contact and opposes impending motion.

Upcoming motion


Normal
Force
No motion
Force of
static friction
Applied
Force
Force of
Gravity

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No Motion

f_k

150N → Women's

Motion ×

$f_s = 0$

f_s

50N Force
+
100N Force

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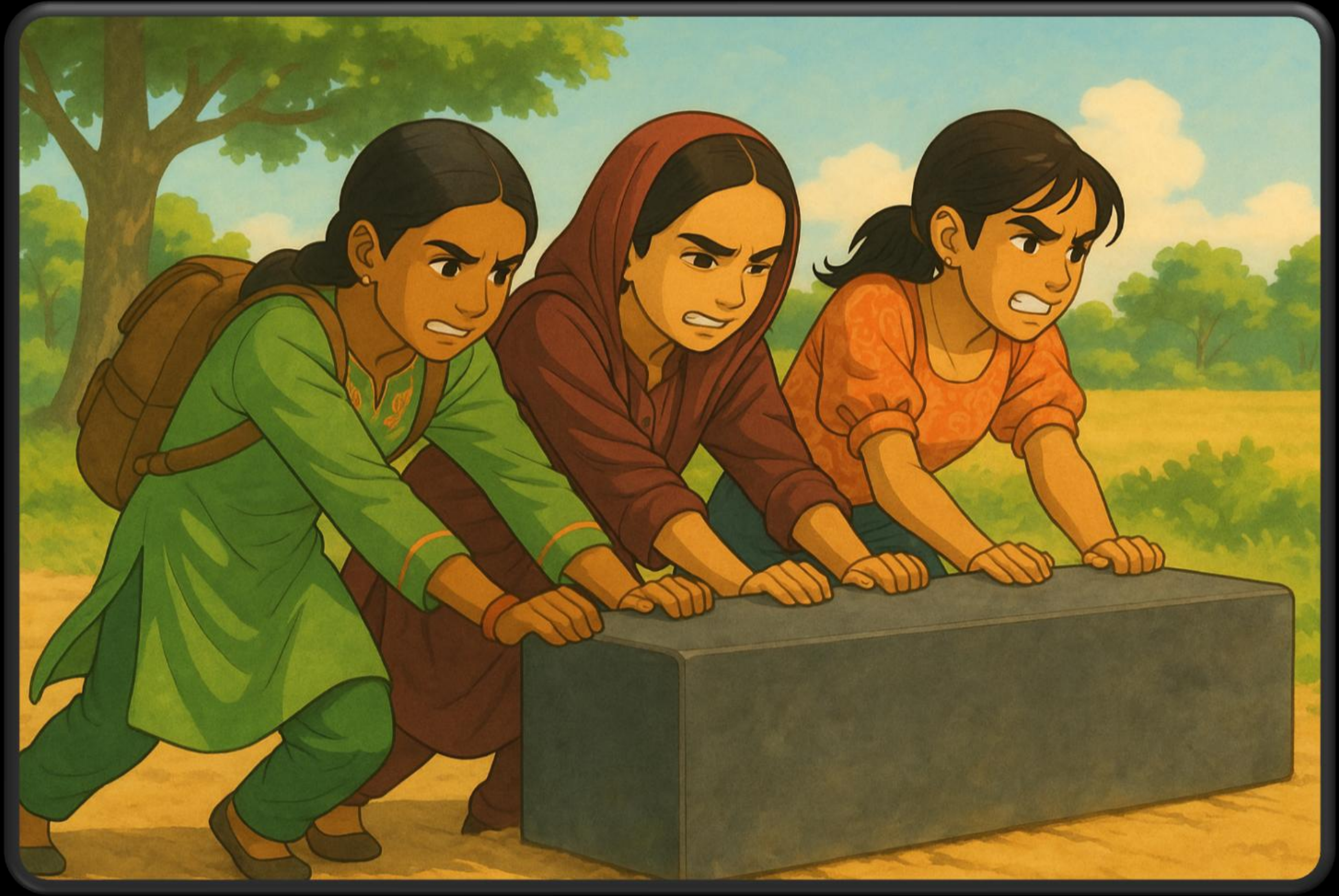
Starts Moving

1N



+ 1N Force

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Static Friction

Static friction opposes Impending Motion

Independent of Area of Contact between bodies

Max value of Static Friction is Limiting Friction

Static friction is proportional to Normal reaction
Law of Static Friction

Limiting Friction

F_s

Static Friction Formula

$$F_s \leq \mu_s \eta \qquad F_s^{max} = \mu_s \eta$$

Where:

F_s - force of static friction

μ_s - coefficient of static friction

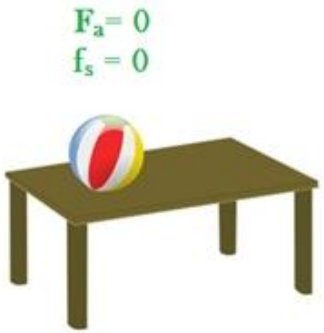
η - normal force

$\leq$ - means "less than or equal to"

F_s^{max} - maximum force of static friction

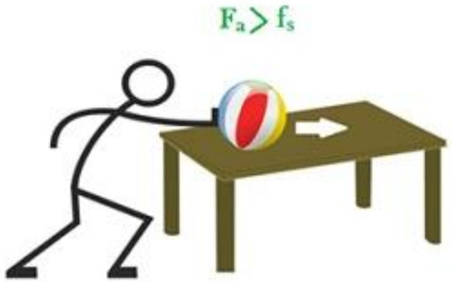
Let the ball be at rest initially

Applied force, $F_a = 0$; Static friction, $f_s = 0$



Ball at Rest

Later, applied force, $F_a = F$, then fs also increases but only up to a certain limit. As soon as F_a becomes greater than fs, the ball starts to move.



Ball Starts Moving

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f_s acts when a body is at rest. Hence called Static friction

- Limiting value of f_s depends on Normal reaction, and is independent of the area of contact

$f_s \max \propto N$

$f_s \max = \text{constant} * N$

$f_s \max = \mu_s N$

where μ_s is the coefficient of static friction

This coefficient depends on the nature of surfaces in contact.

- According to the Law of Static friction, Static friction is always less than or equal to the limiting value of f_s

$f_s =< f_s \max$

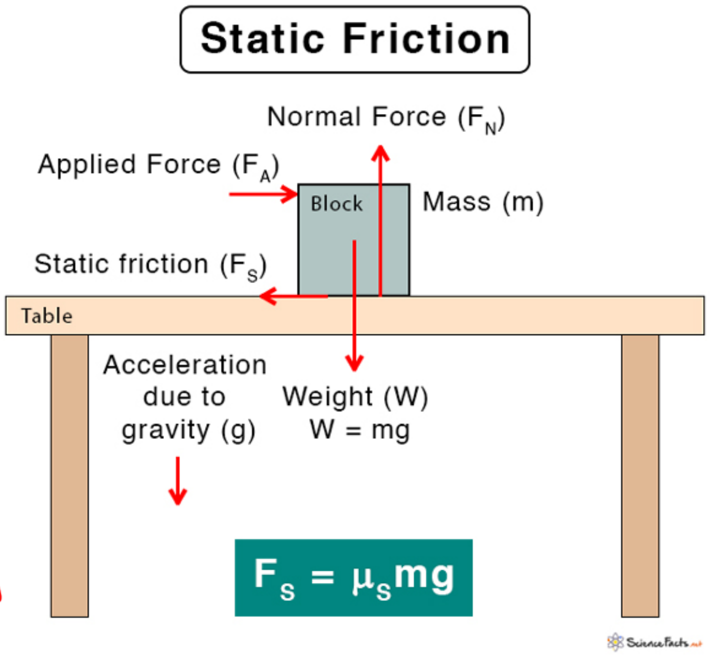
$f_s \max = \mu_s N$

$f_s =< \mu_s N$

f_s

$f_s max \propto N$

$f_s max = \boxed{\mu_s} N$



$f_g = mg$

$N = f_g$

100

N

Wt → gravity

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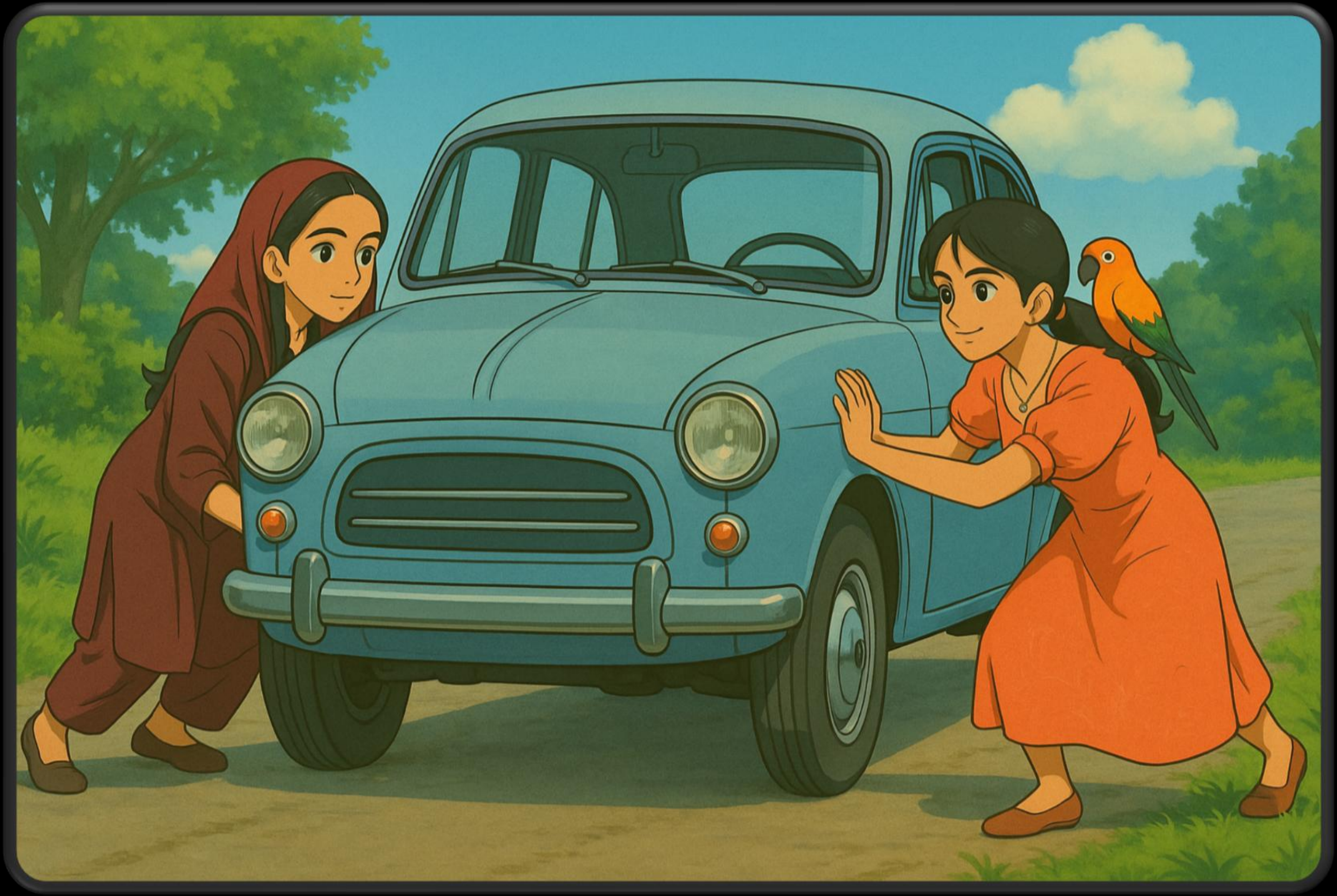
In what direction does friction act?



Force of Person 1

Force of Person 2

Class ended here on July 23 2025

Plus One Science 25-26

24 July 2025

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Coefficient of Friction

Nature of Surface
Mass

Kinetic friction

Static friction

$f_s^{max} = \mu_s N$

mg

μ_s

10N

10N

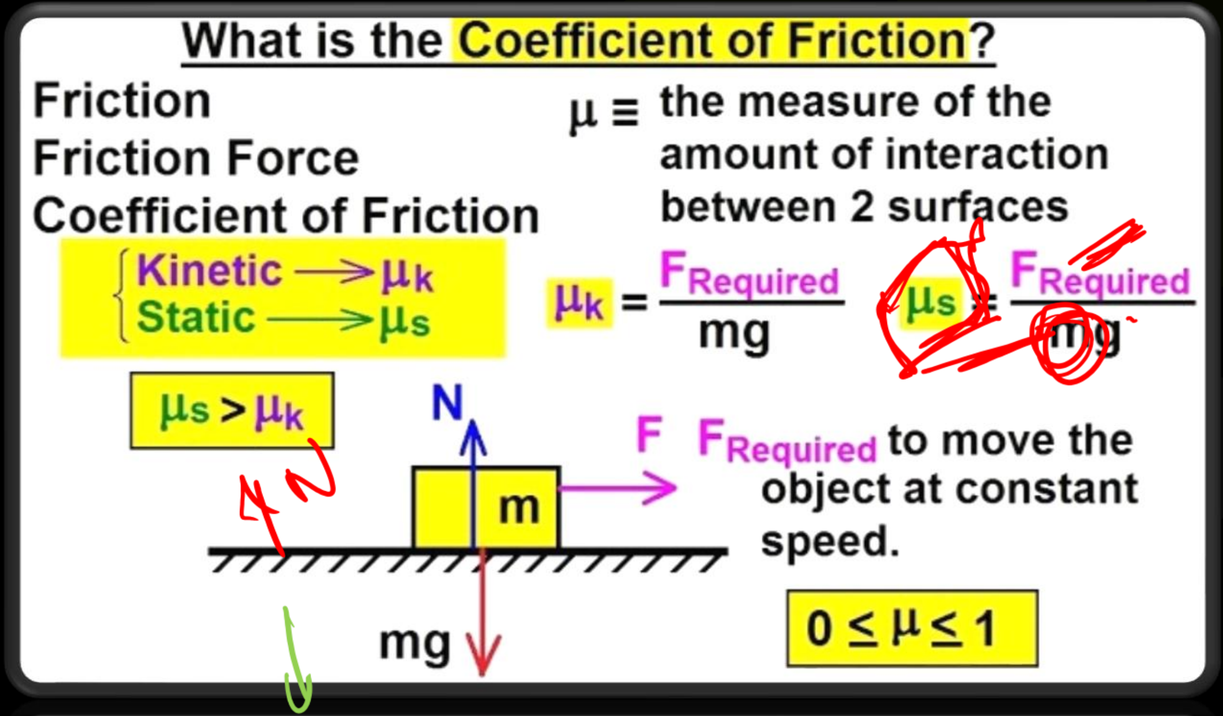
1N

mass

g

$\mu_s \rightarrow$ Surface in contact

Coefficient of Friction



What factors do static friction depend on?

i) Nature of surface

Roughness ↑ μ_s ↑ F_s^{max} ↑

ii) Normal force

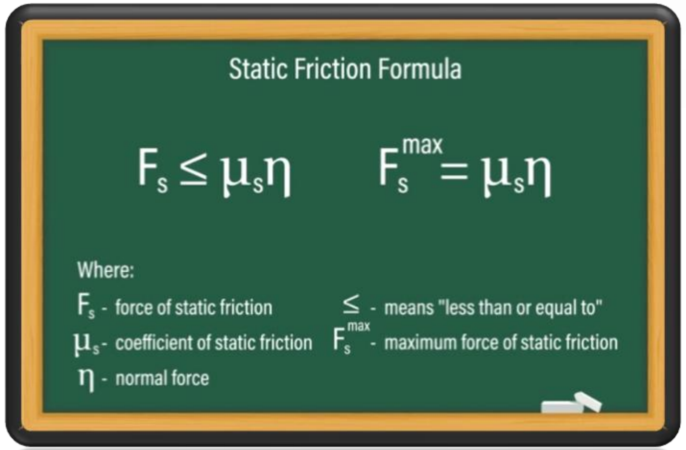
$mg \Rightarrow m \uparrow$ F_s^{max} ↑

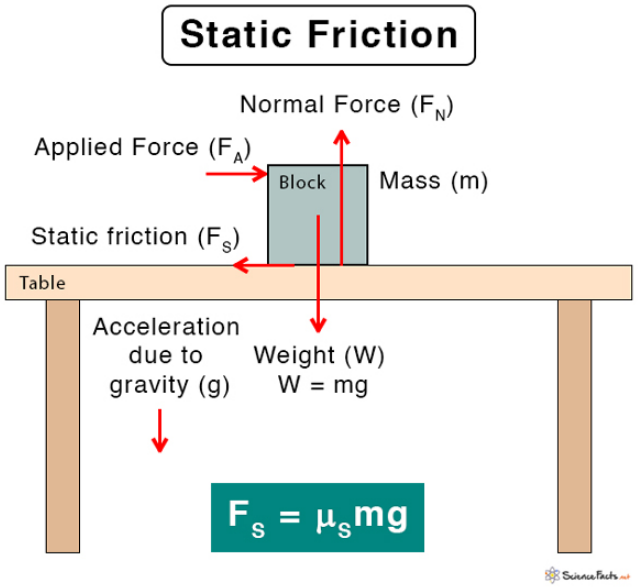
Ice skater

$\boxed{\mu_s} \rightarrow$ Kg

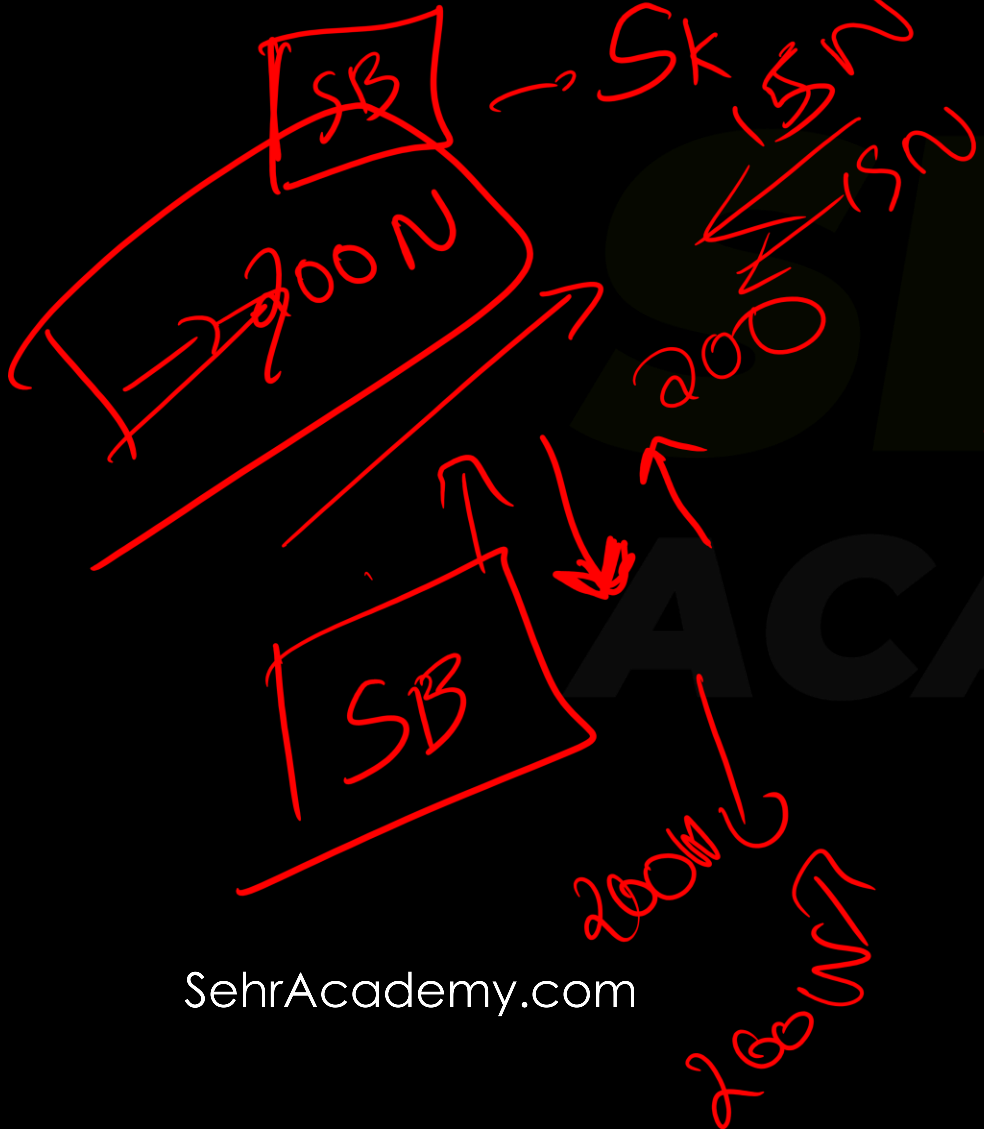
$F_s = \mu_s \cancel{mg}$

$\mu_s = \dfrac{F_s}{F_g}$





A force of ~~200~~ N is exerted ~~on~~ by a snack box of ~~5~~ kg still on the floor. If the coefficient of friction is 0.3, calculate the static friction.



$$f_s^{max} = \mu_s \cancel{N}$$

$$= 0.3 \times \cancel{mg} \quad 200$$

$$= \cancel{0.3 \times 5 \times 10} \quad 200$$

$$= \cancel{50 \times 0.3} = \cancel{15} \quad 60N$$

F_n (Normal force) = 200 N,

μ_s (Coefficient of friction) = 0.3,

Static friction is given by $F_s = \mu_s F_n$

$= 0.3 \times 200$ N

$F_s = 60$ N.

Amy is hauling a toy car of mass 4 kg which was at rest earlier on the floor. If 50 N is the value of the static frictional force, calculate the friction coefficient?

$m = 4\,kg \rightarrow$ rest

$\mu_s = ?$

$f_s = 50N \rightarrow$

$f_s = \mu_s N = \mu_s \times 4 \times 10$

$50 = \mu_s \times 4 \times 10$

$\mu_s = \frac{5\cancel{0}}{4 \times 1\cancel{0}} = 0.25$

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m (Mass) = 4 kg,

F_s (static frictional force) = 50 N,

F_n (Normal force) = mg

= 4 Kg × 9.8 m/s2

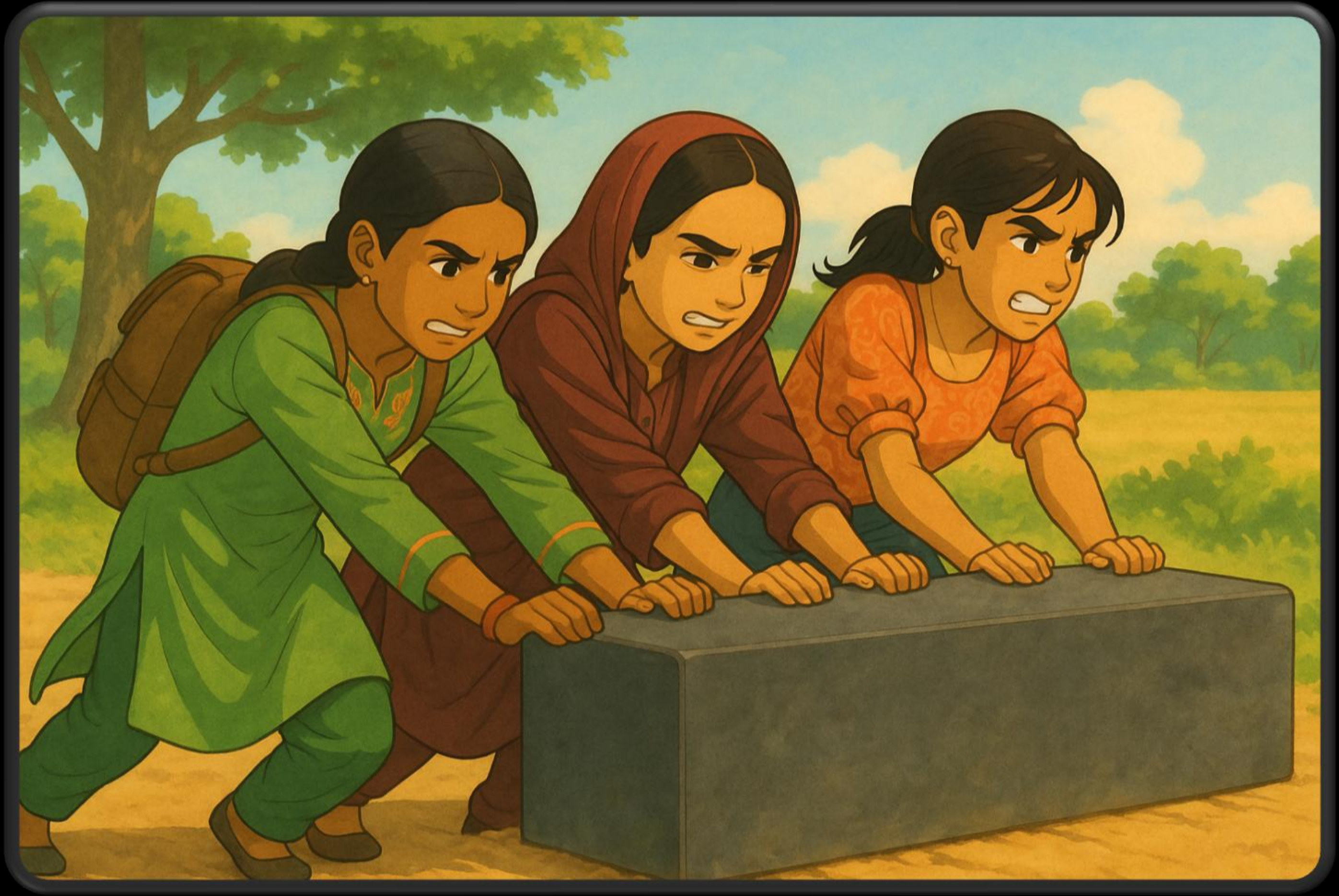
F_n = 39 N

$\mu_s = F_s / F_n$

$\mu_s = 50/39$

$\mu_s = 1.282$

What happens after object starts moving?



f_k

move

$f_s = 0$

We know, once object moves static friction = 0,

we still experience friction as object moves.

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Kinetic Friction

Static → Not moving

Moving → Kinetic friction (f_k)

Proportional to normal reaction

$$\boxed{f_k = \mu_k N}$$ → Constant friction

Coeff of kin. friction

$$f_k = \mu_k N$$

$$f_k \propto N$$

$$f_k = \mu_k N$$

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Kinetic Friction

Kinetic friction opposes Relative Motion

Kinetic friction is independent of Area of Contact between bodies

Kinetic friction is independent of Velocity

Kinetic friction is Proportional to Normal reaction

Law of Kinetic Friction

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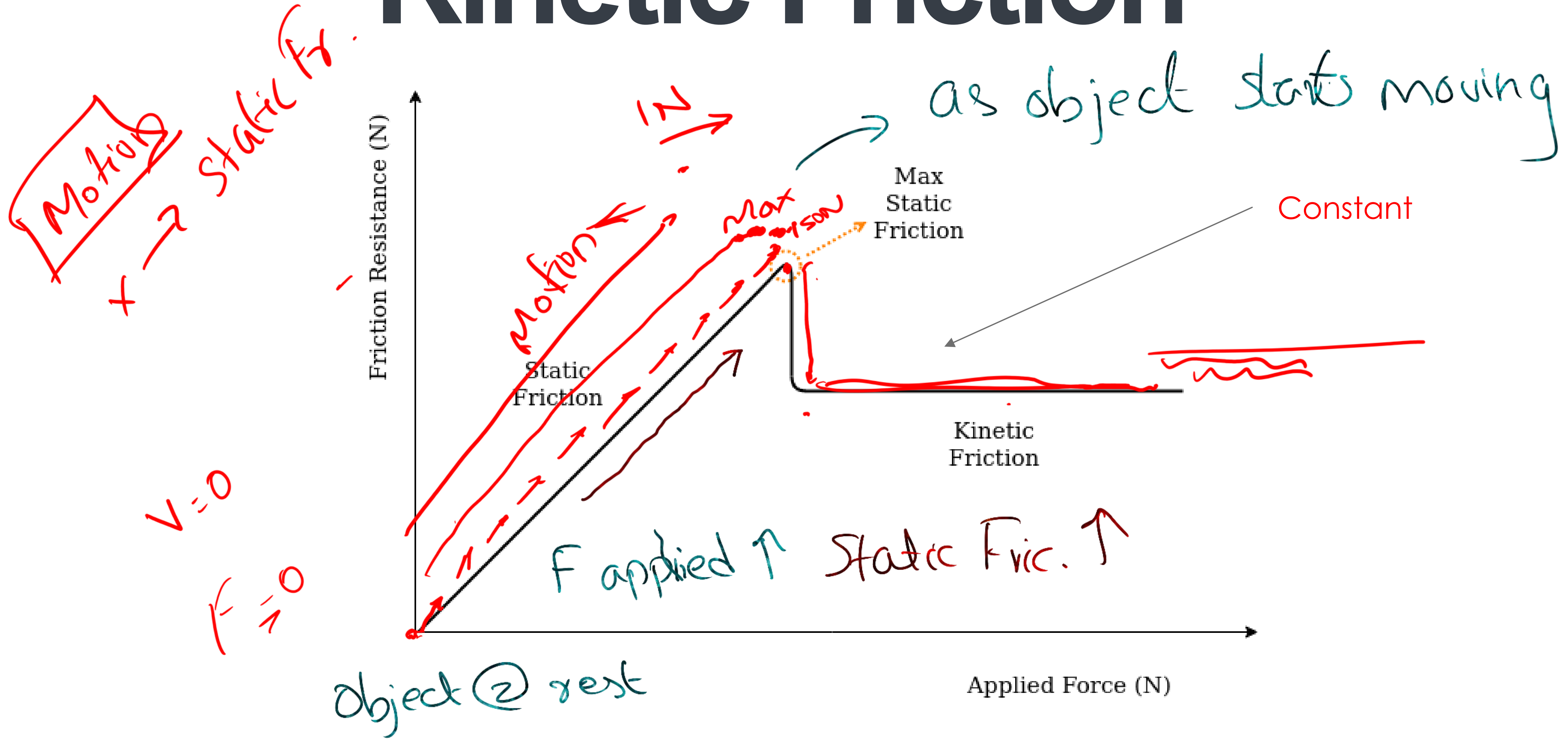
Kinetic Friction



Kinetic friction

- Force that resists motion of one body over another with which it is in contact.
- Denoted by f_k
- As motion starts, f_s vanishes and f_k appears

$f_s \to 0$

f_k : ↑ Constant

- Kinetic friction is Independent of the area of contact and velocity of the body
- It varies with Normal reaction, N

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$f_k \propto N$

f_k = constant * N

$f_k = \mu_k N$; μ_k is the coefficient of kinetic friction

Three scenarios can arise in a body's motion

When applied force > f_k

$F_a > f_k$

$(F_a - f_k) = ma$

$a = (F_a - f_k)/m$

When applied force = f_k

$F_a = f_k$

Therefore, a = 0 i.e. the body moves with uniform velocity

When applied force = 0

$F_a = 0$

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Circular Motion

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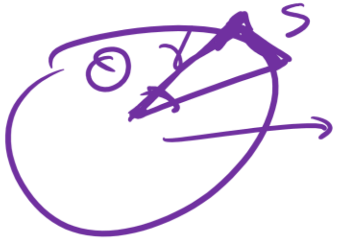
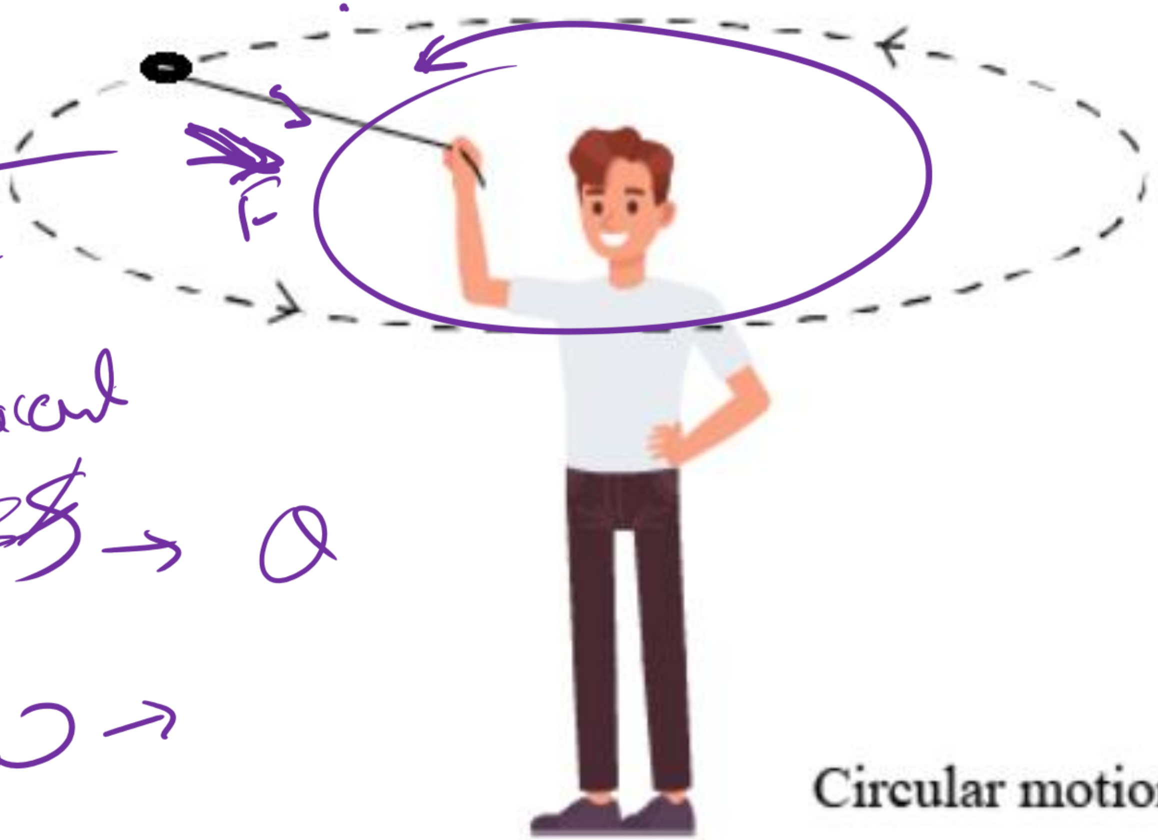
Uniform Circular Motion



$s \rightarrow s/t \rightarrow \theta = \frac{l}{r}$

θ/t

$l = r\theta$



Ma → cent

Linear Disp

Lin Velo

Line Acce

displacement

Angular ~~RBS~~ $\rightarrow \theta$

Ang Vel $\rightarrow \omega \rightarrow$

Circular motion

$S = r\theta \longrightarrow S/t \Rightarrow V = \frac{r\theta}{t} \Rightarrow V = r\omega$

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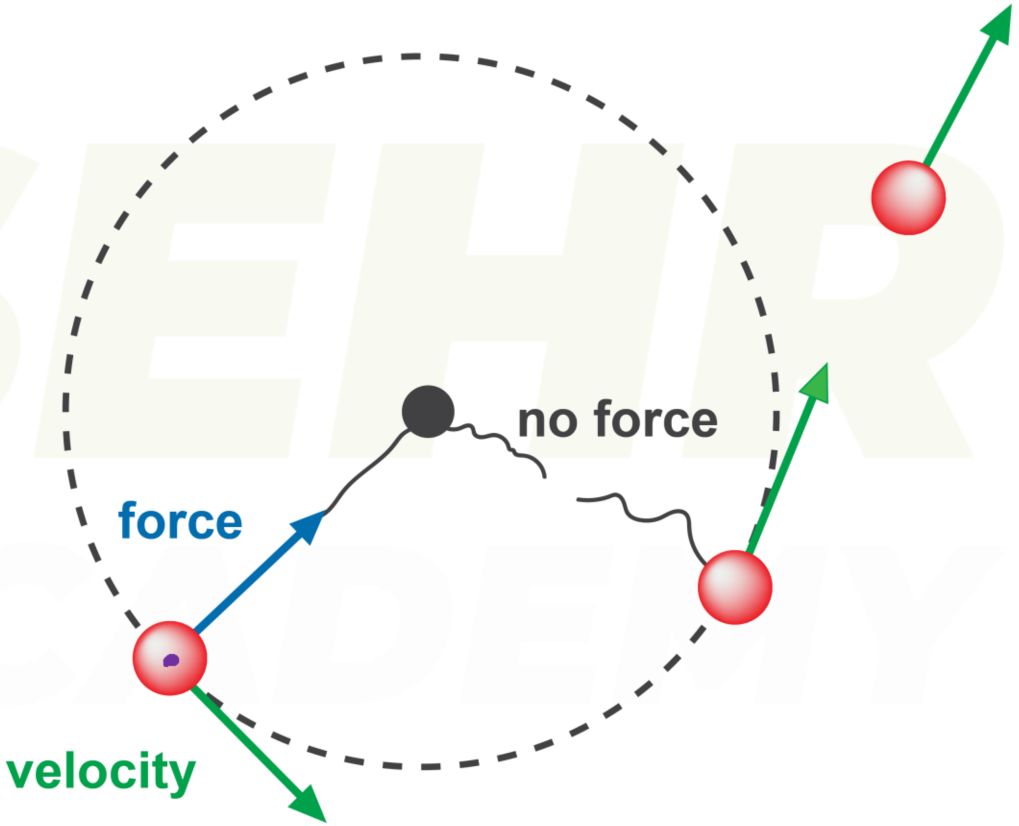
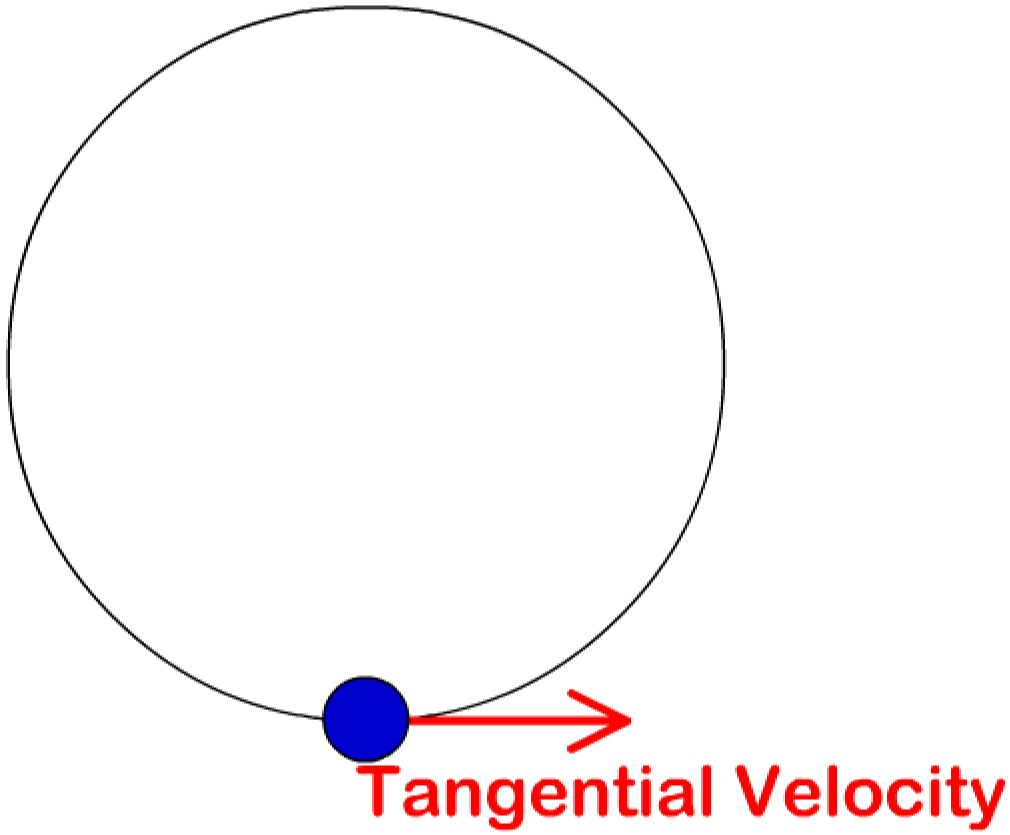



Tangential Velocity

2nd law ~~1st law~~

A Centripetal Acce

$$\boxed{a_c = \frac{v^2}{r}}$$

v_c

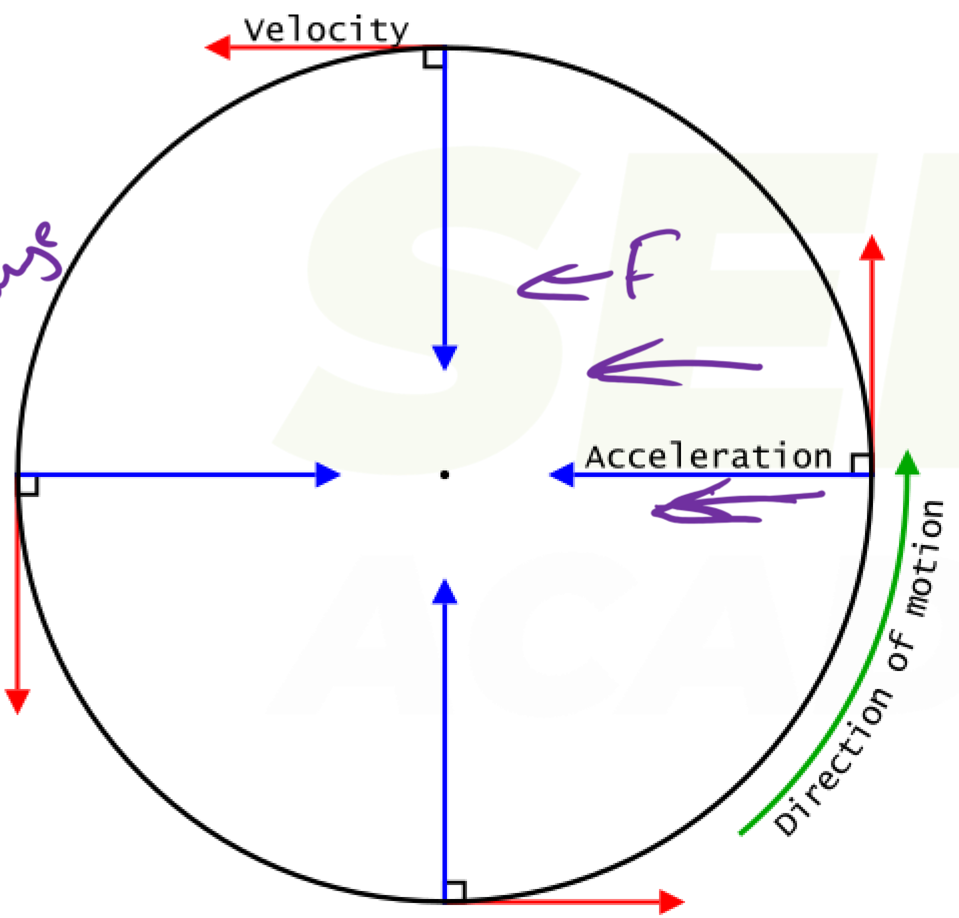
F×

v change

F↓

a

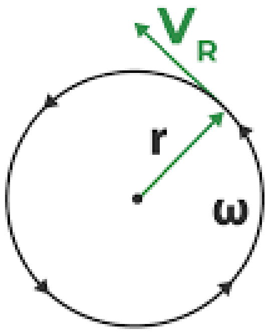
←F



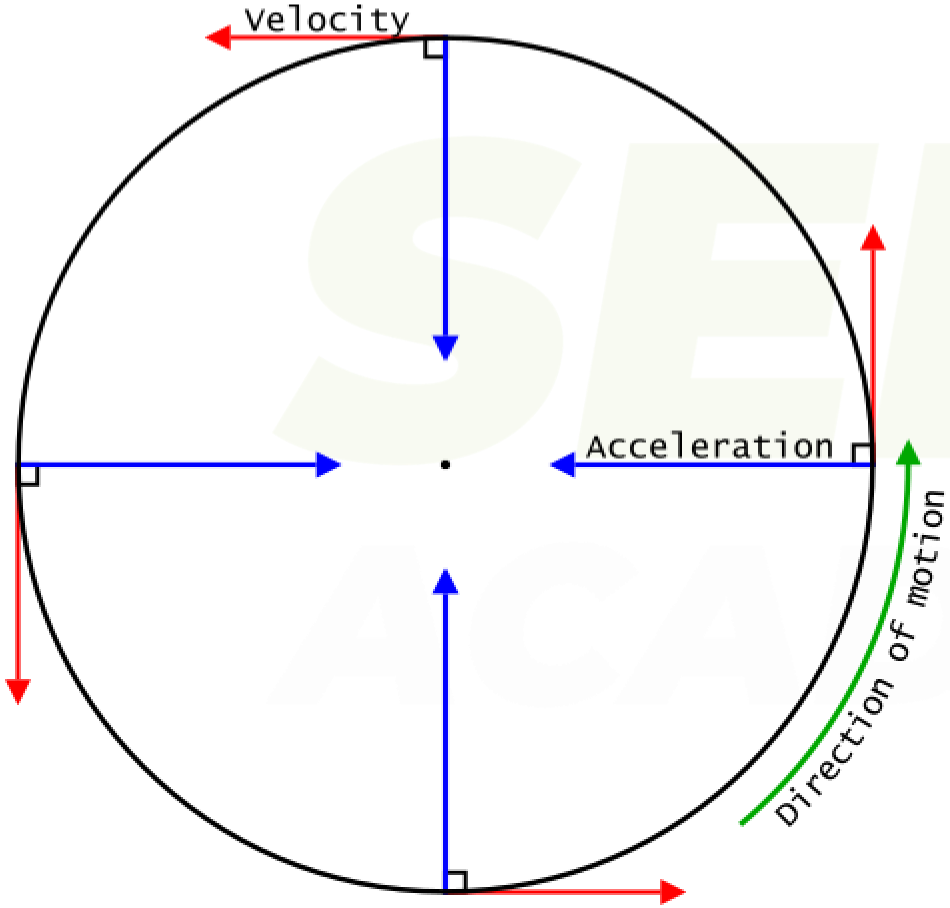
Centripetal Force

$$= ma_c = \frac{mv^2}{r}$$

$$V_r = r \times \omega$$



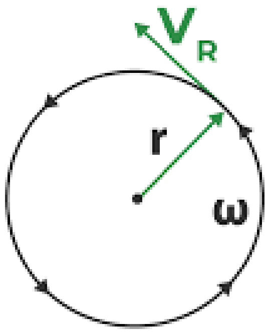
Centripetal Acceleration $\rightarrow a_c = \dfrac{v^2}{r}$

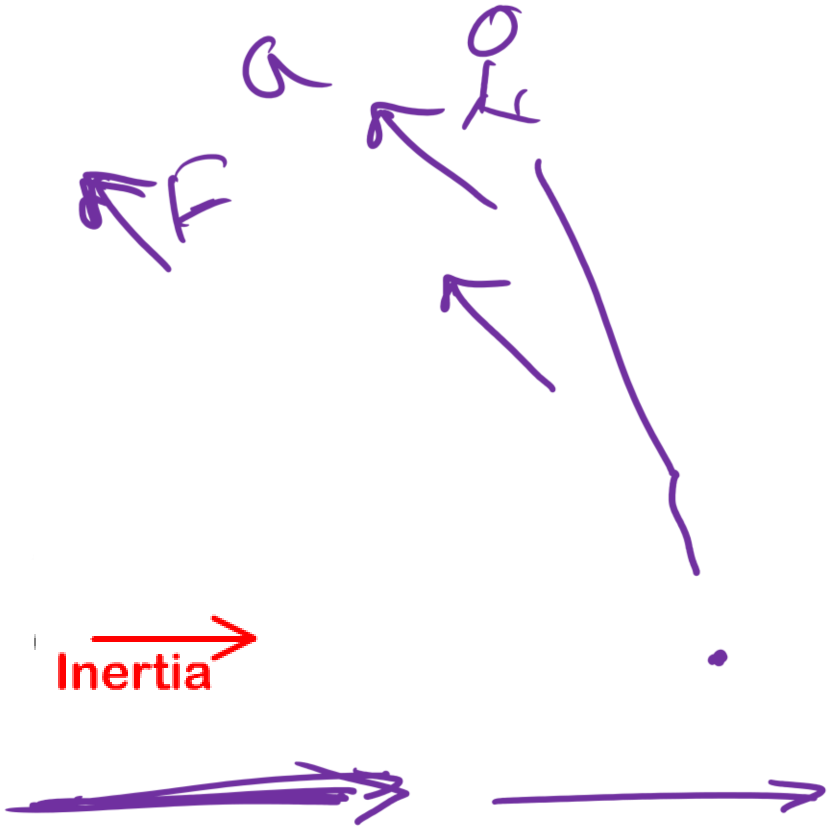


$F = ma_c \rightarrow \dfrac{mv^2}{r}$

$\rightarrow$ Centripetal Force

$V_r = r \times \omega$




a
F
Inertia

Tension

Friction

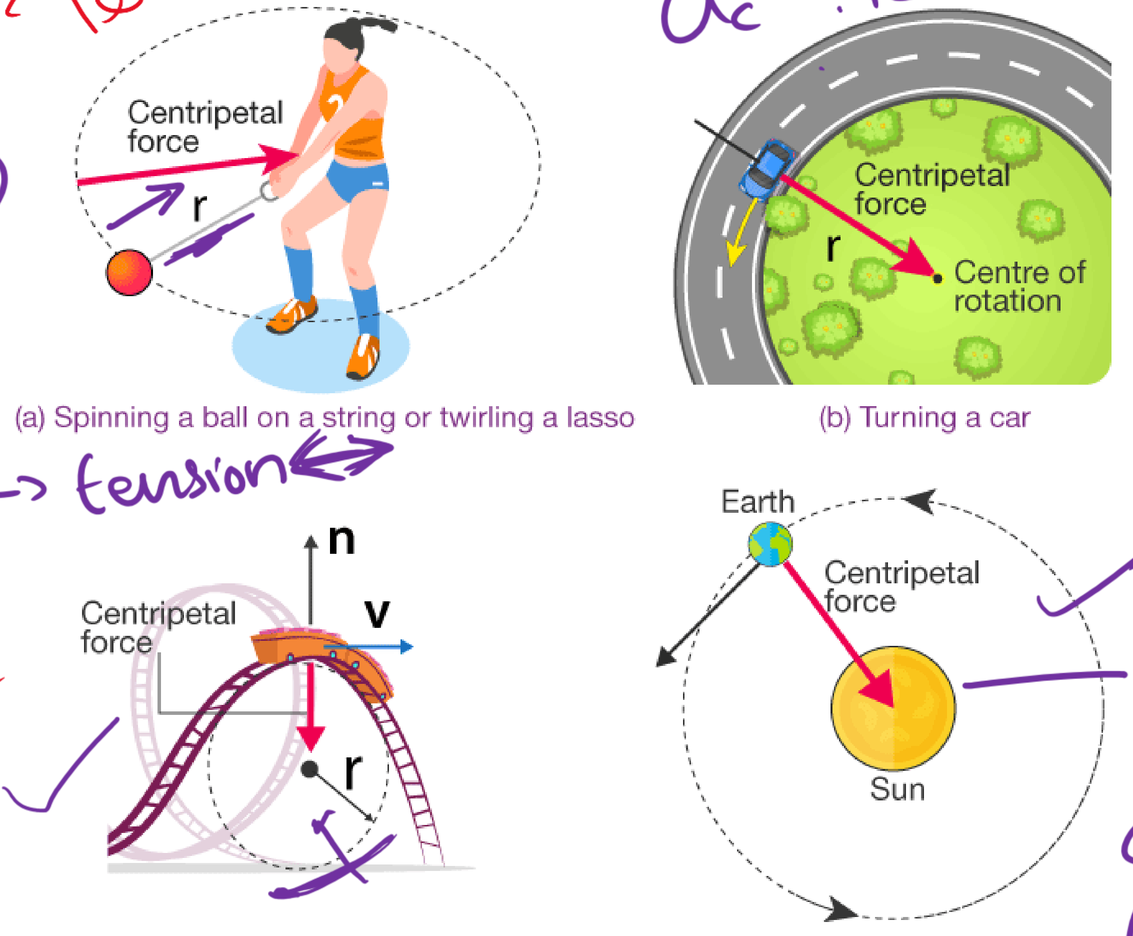
a_c F_c

$a \rightarrow F$

F - ?

$F \rightarrow$ tension

Friction prevents skidding



(a) Spinning a ball on a string or twirling a lasso

(b) Turning a car

(c) Going through a loop on a roller coaster

(d) Planets orbiting around the Sun

Normal

Gravity

F_c

Tension

Tension

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$$a_c = \frac{v^2}{r}$$

$$F_c = m a_c = \boxed{\frac{mv^2}{r}}$$

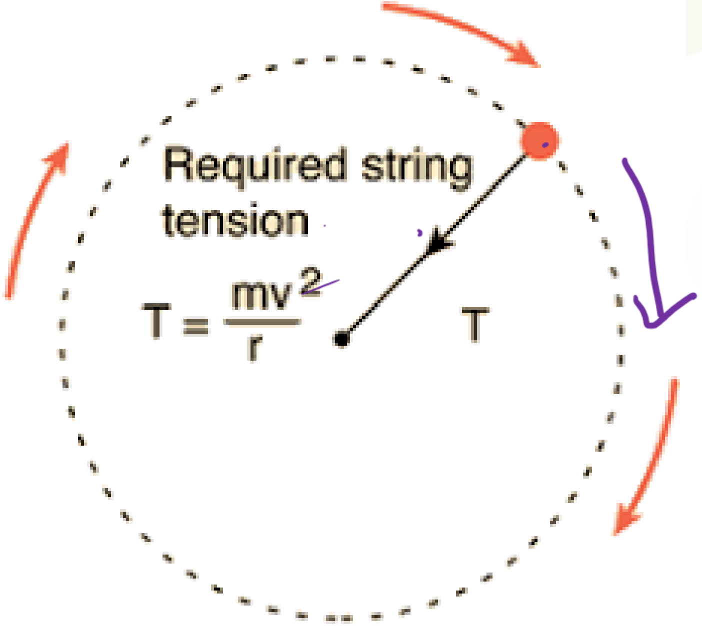
$F_c \leftrightarrow$ Tension

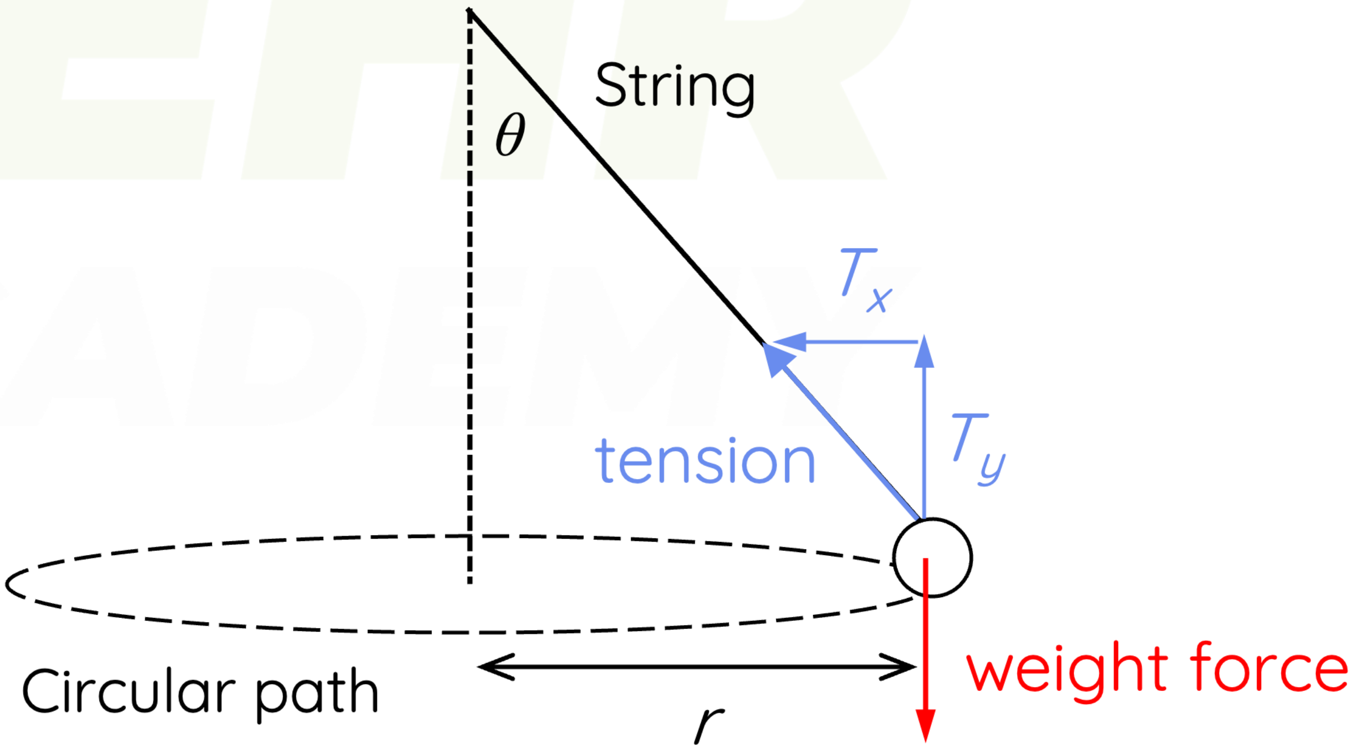
v

m

r

$$\boxed{\frac{m \times v^2}{r}} \rightarrow F$$





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$\theta = \frac{l}{r}$

Plus One State Board

SEE

F

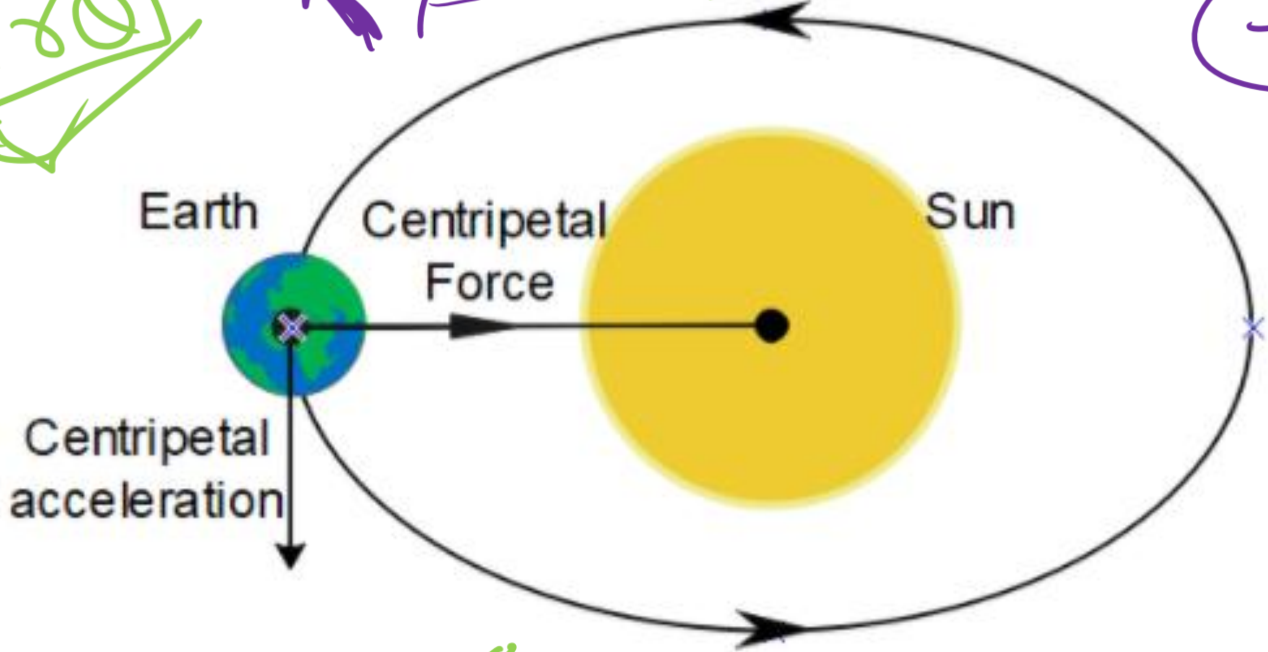
θ

$l = r\theta$

a

Sun

Jupt



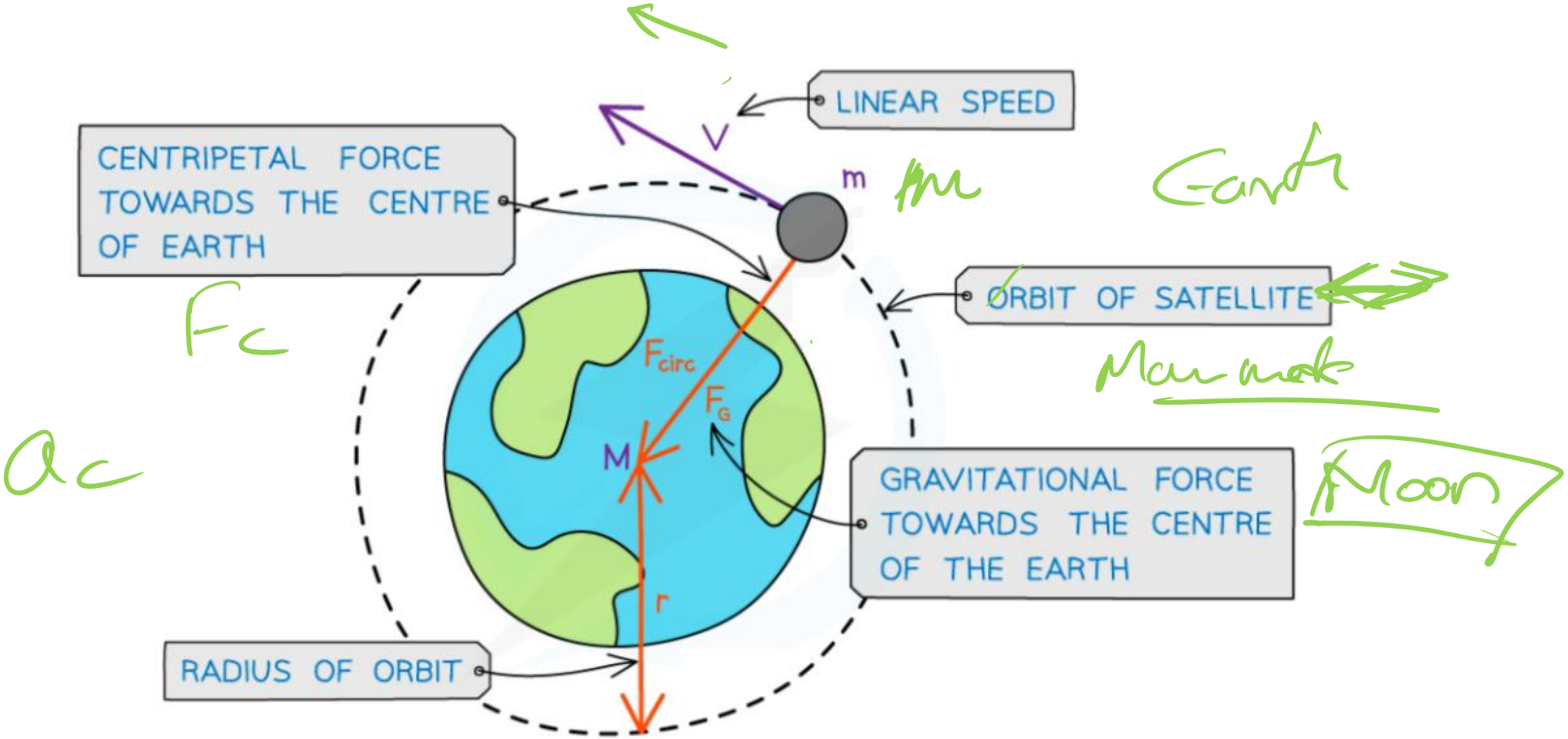
Parallax

Earth V

Const m

dist r

Sun Fg


LINEAR SPEED
V
m
CENTRIPETAL FORCE TOWARDS THE CENTRE OF EARTH
ORBIT OF SATELLITE
F_{circ}
F_G
M
r
GRAVITATIONAL FORCE TOWARDS THE CENTRE OF THE EARTH
RADIUS OF ORBIT
m
Earth
Man made
Moon
Fc
ac

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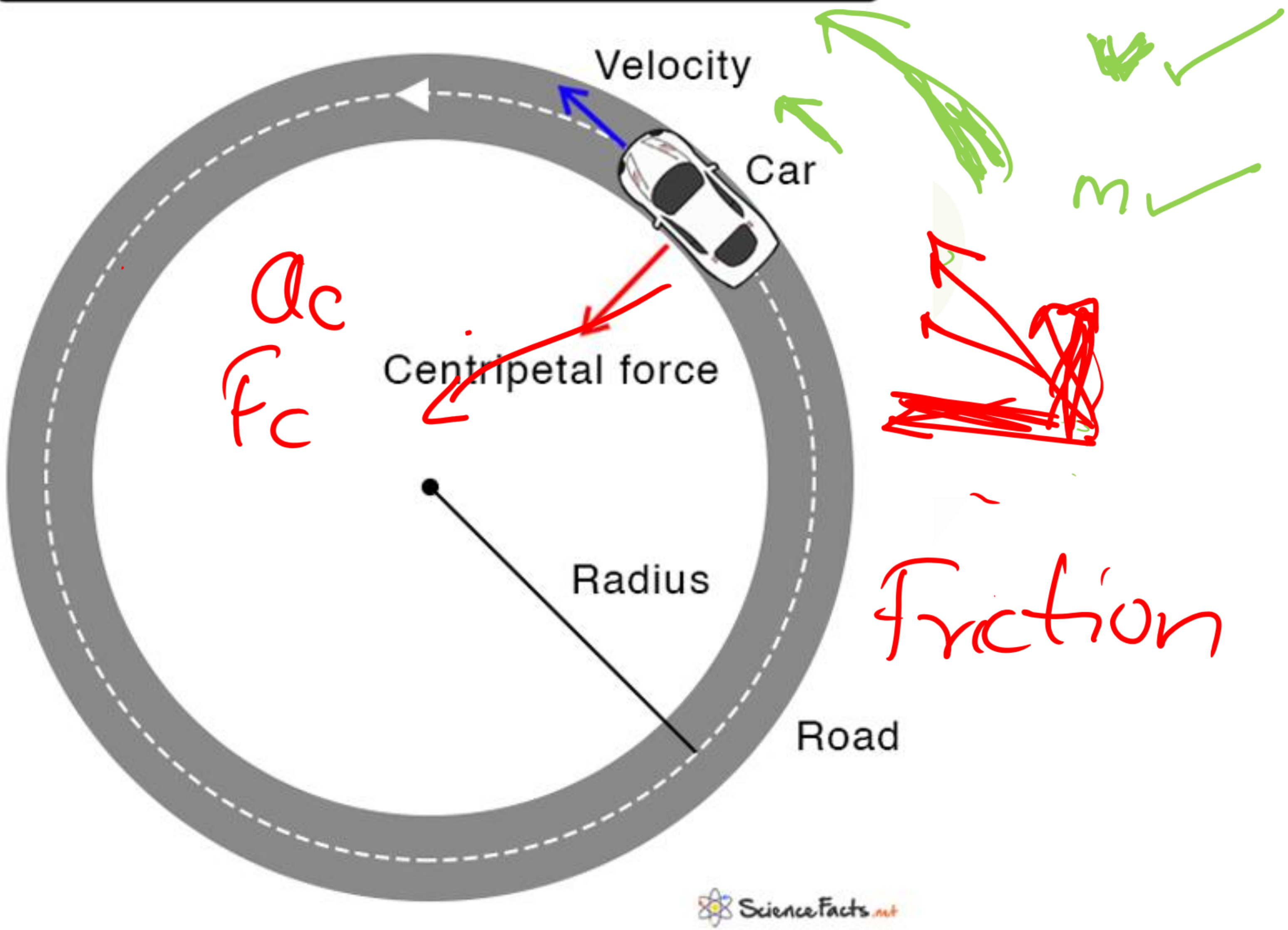
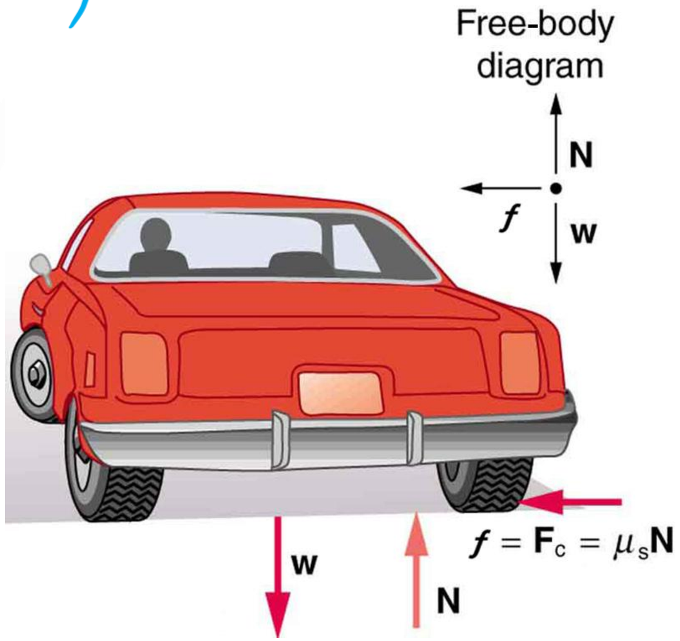
Centripetal Force Example

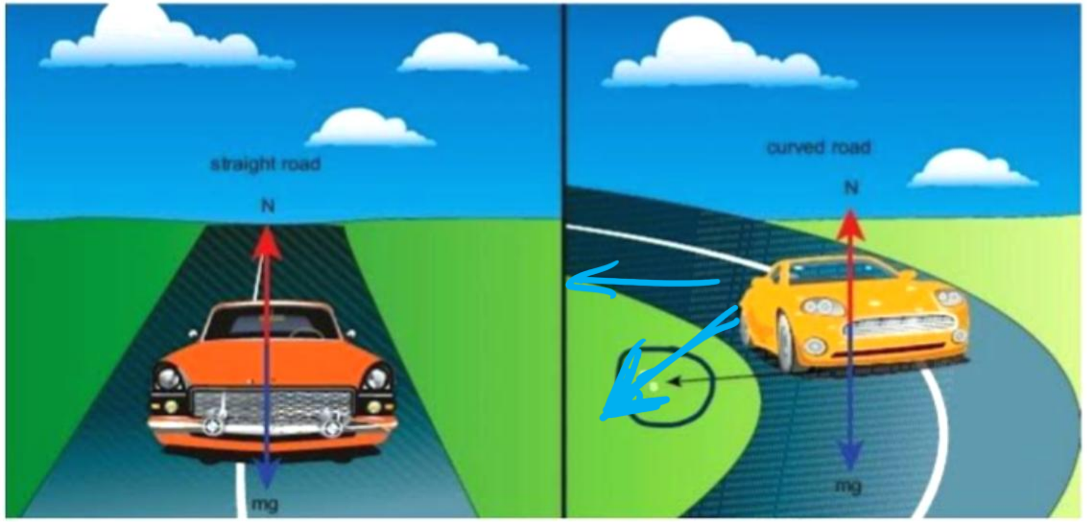
angular
linear



Maximum speed with which a car can safely turn on a bend without skidding.



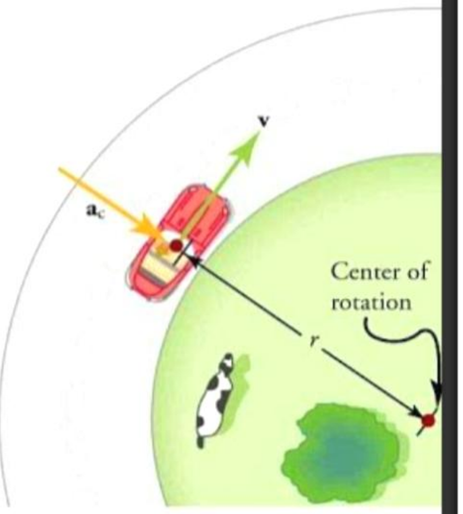
Maximum Turning Velocity on a Level Road



$$f_r \leq \mu_s N$$

$$N = mg$$

$$f_r \leq \mu_s mg$$



Car around corner

$$f_r = \frac{mv^2}{r}$$

$$\frac{mv^2}{r} \leq \mu_s mg$$

$$v^2 \leq \mu_s r g$$

$$\boxed{v \leq \sqrt{\mu_s r g}}$$

$$V_{max} = \sqrt{\mu_s r g}$$

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$N = mg$

$f_s \max = F_c$

$\mu_s N = \dfrac{\cancel{m} v^2}{r} = \mu_s \cancel{m} g$

$$\boxed{v^2 = \mu_s r g \rightarrow \sqrt{\mu_s r g}}$$

$\Rightarrow$ max safe speed

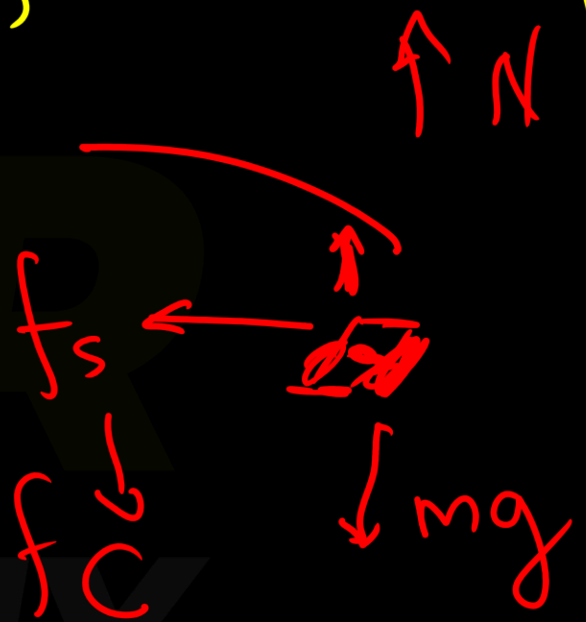
$$N = mg \quad (1)$$

$$f_c = f_s \quad (2)$$

$$\frac{mv^2}{r} = \mu_s N \quad \text{from } (1) \; mg$$

$$\frac{\cancel{m}v^2}{r} = \mu_s \cancel{m}g \rightarrow v^2 = \mu_s r g$$

$$\boxed{v = \sqrt{\mu_s r g}}$$



$\boxed{30}$ $\boxed{20}$ $\boxed{30}$

$\boxed{40 \; 50}$

50

$f_s \uparrow f$

Find the maximum speed with which a car can turn on a bend without skidding, if the radius of the bend is 20 m and the coefficient of friction between the road and the tires is 0.4.

$V = \sqrt{\mu_s r g} \longrightarrow r \to$ curve radius

$m_s \to \boxed{V}$

f_s

$\mu_s \to 0.4$

$r \to 20m$

$V_{max} = \sqrt{\mu_s r g} = \sqrt{0.4 \times 20 \times \cancel{9.8}^{10}}$

$= \sqrt{80} = \boxed{8.94 \ m/s}$

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Radius of the bend, $R = 20$ m
Coefficient of friction, mu = 0.4
Acceleration due to gravity, $g = 9.8\ m/s^2$

Frictional force provides the required centripetal force:
$$mu \times m \times g = m \times v^2 / R$$

Cancel out mass (m) from both sides:
$$mu \times g = v^2 / R$$

Express v^2:
$$v^2 = mu \times g \times R$$

Take square root for v:
v = square root of (mu × g × R)

Substitute the given values:
v = square root of (0.4 × 9.8 × 20)
v = square root of (0.4 × 196)
v = square root of 78.4
$v \approx 8.86$ m/s

Final Answer
Maximum speed = 8.86 m/s

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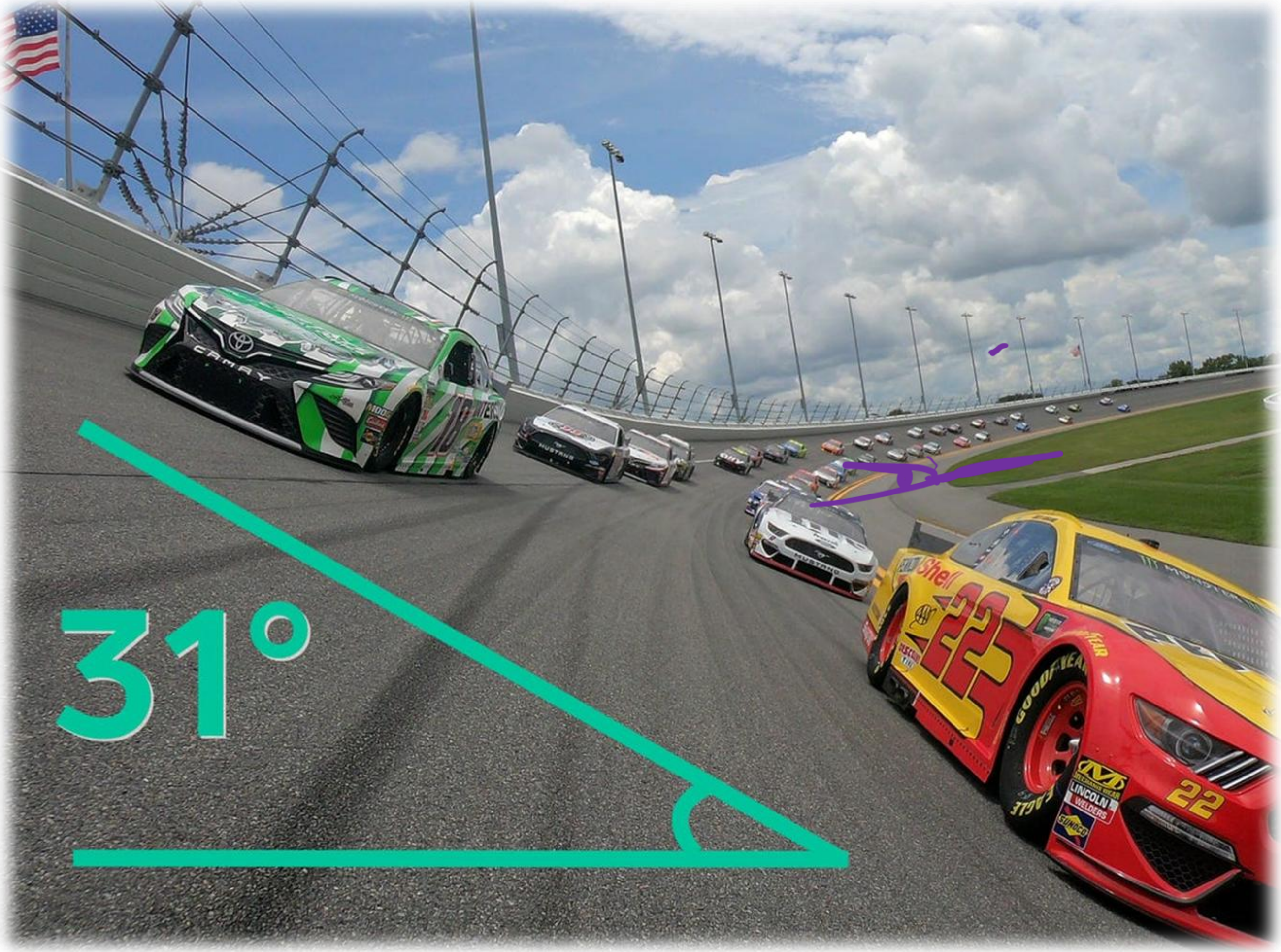
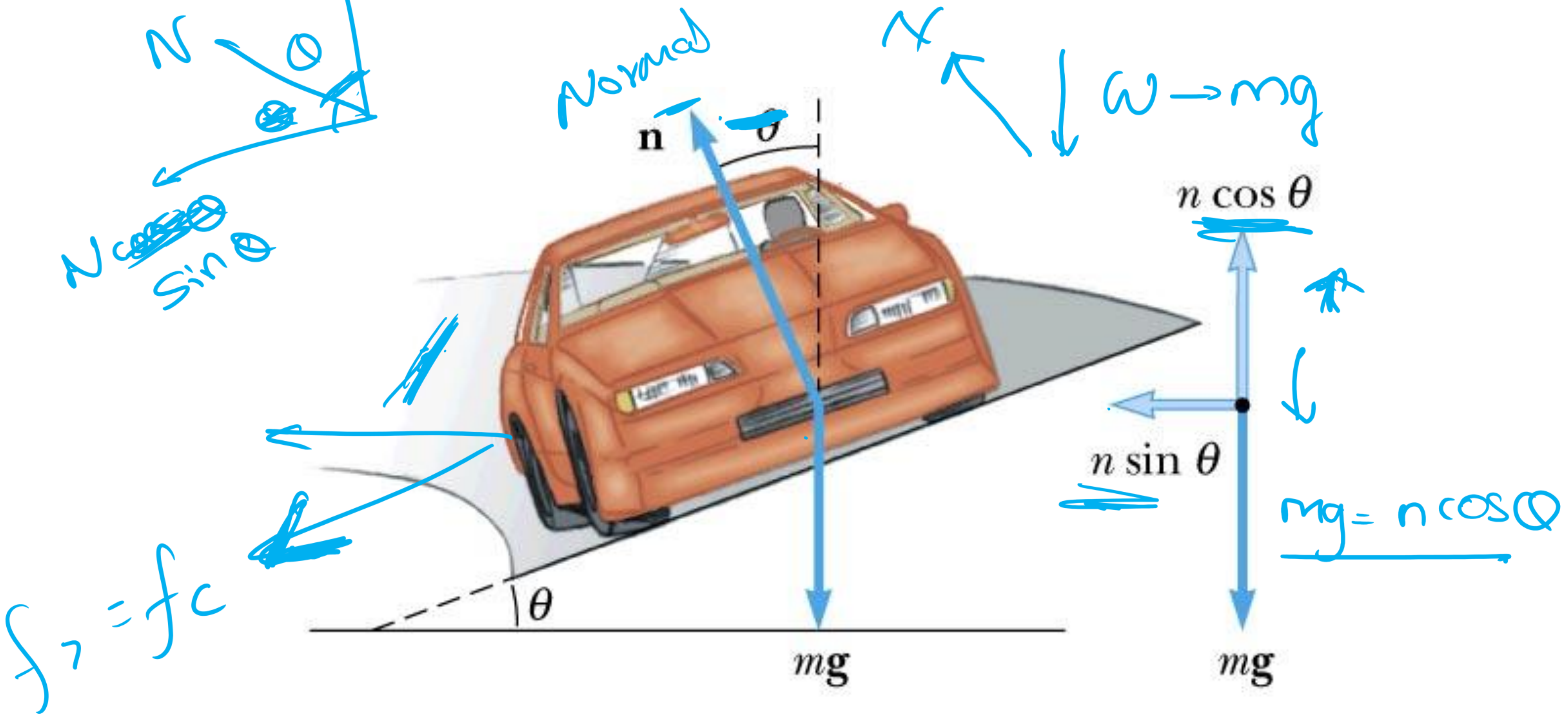


NASCAR tracks are banked to help cars turn faster and safer by using the slope to counteract outward forces.

Car On A Banked Road



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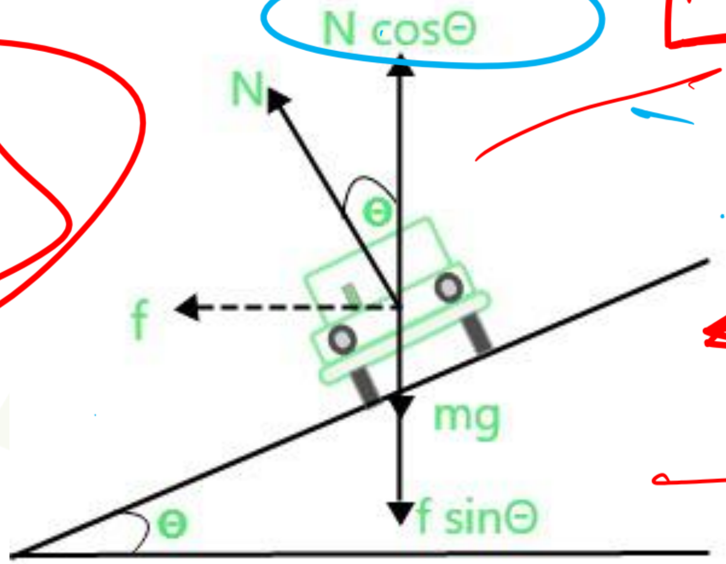
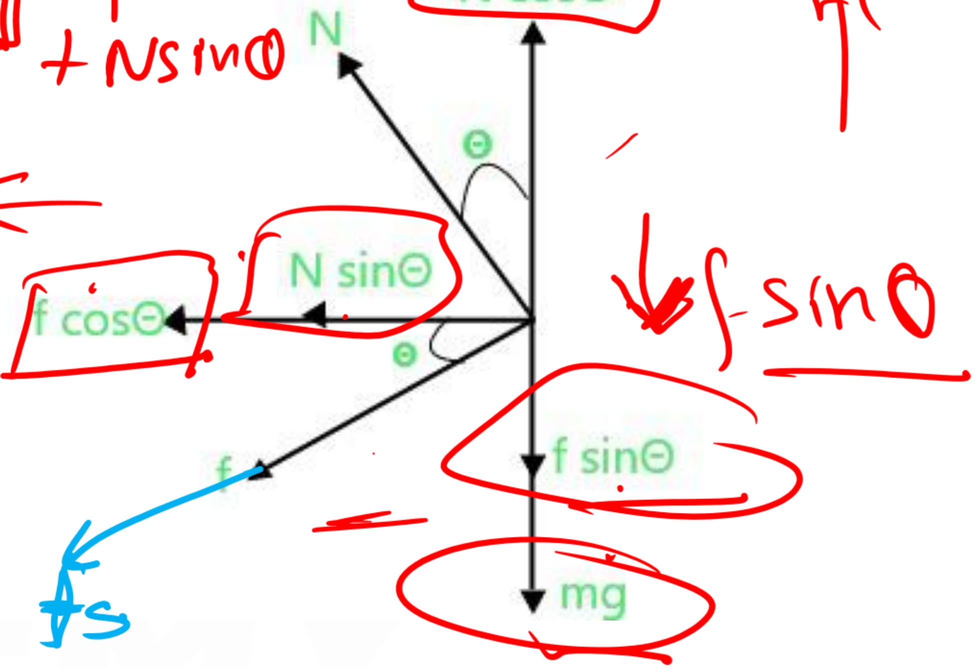
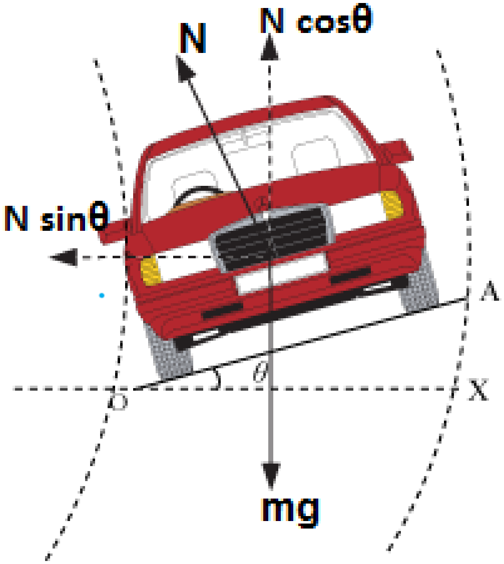
Car On A Banked Road

$N\cos\theta = mg + f\sin\theta$



$\boxed{f_c} = f\cos\theta + N\sin\theta$





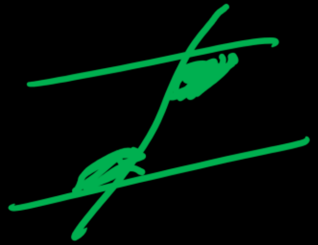
$f_c \rightarrow f_s$

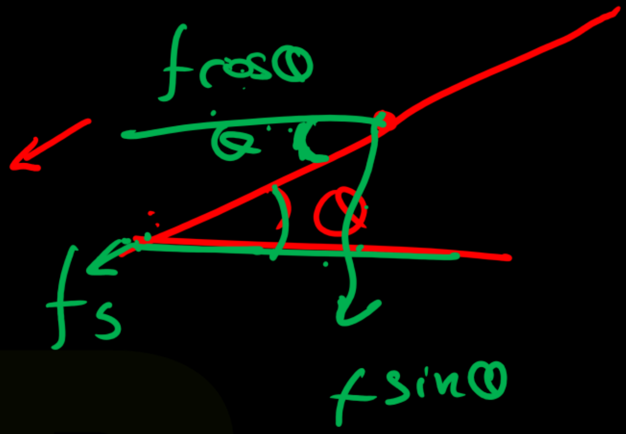
$f\cos\theta$

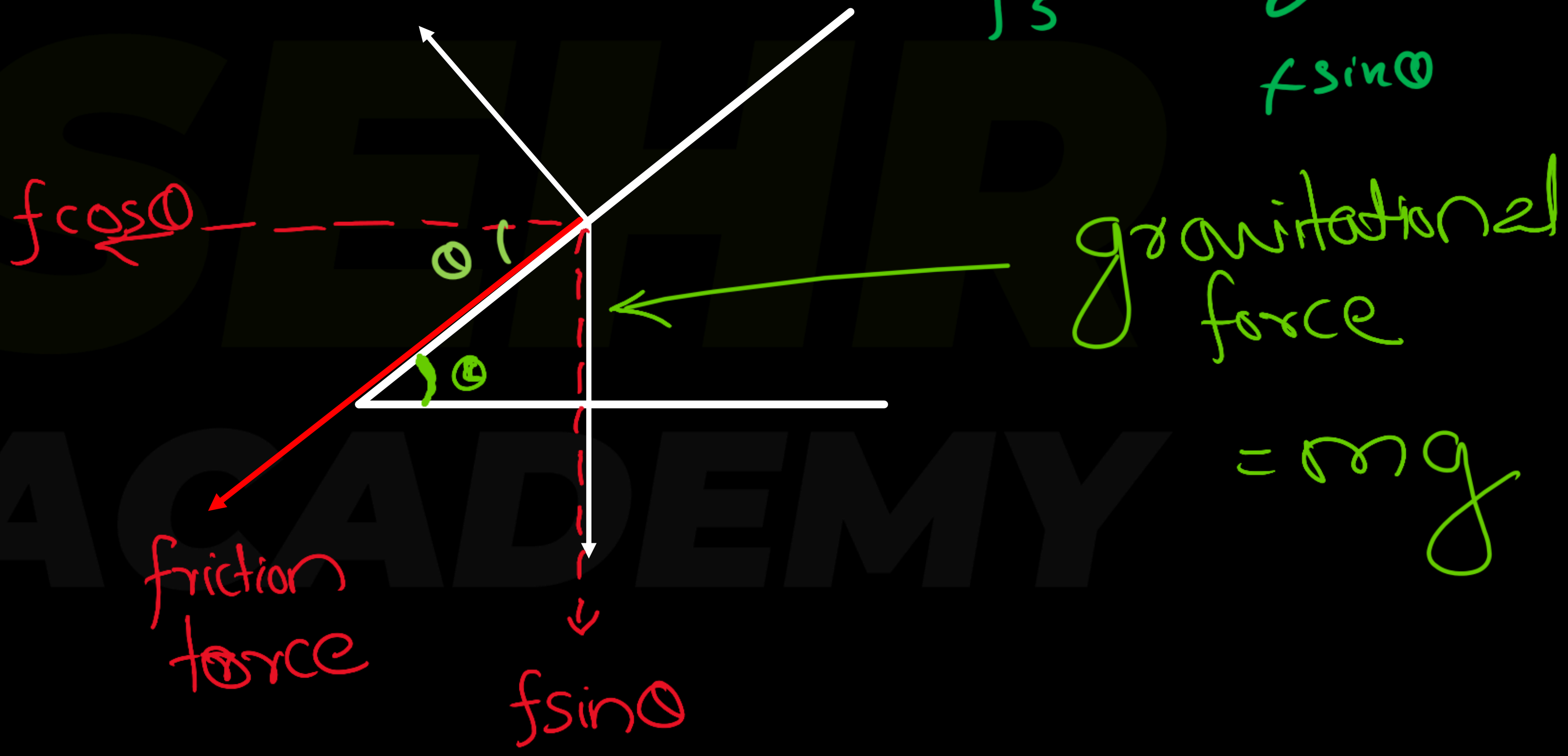
$f\sin\theta$

$\cos\theta = \frac{B}{V}$

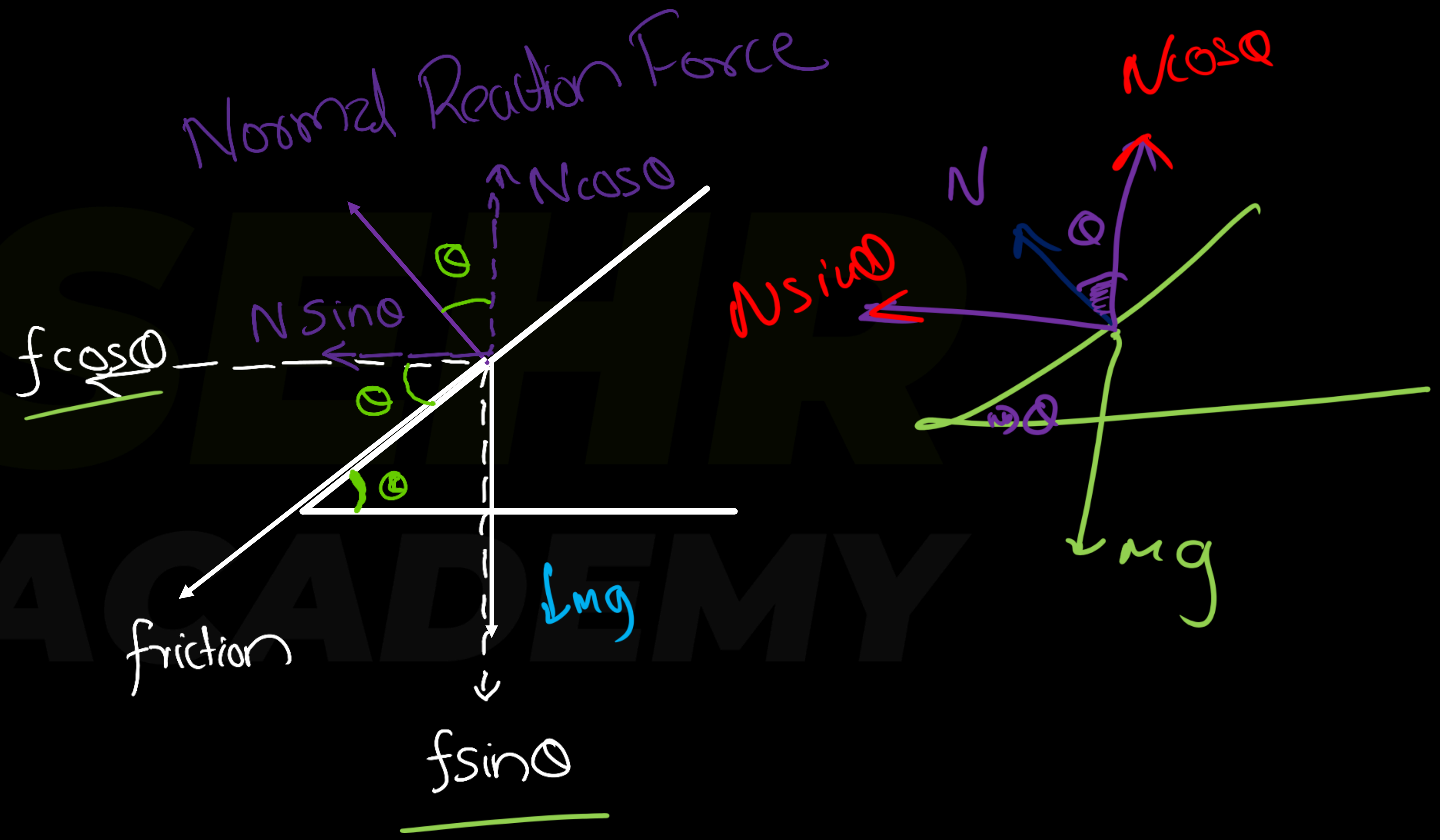
$B = V\cos\theta$




fcosθ
θ
θ
fs
fsinθ

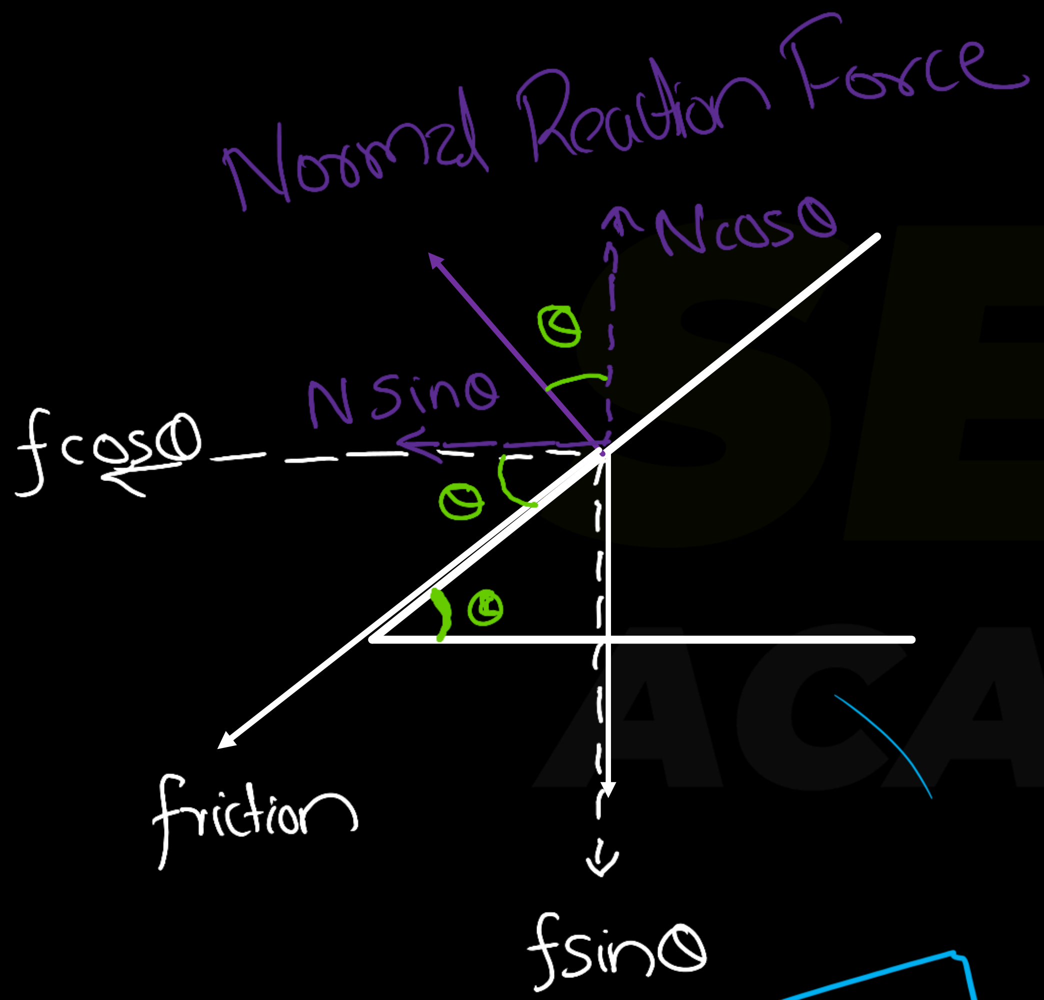

fcosθ
θ
θ
friction force
fsinθ
gravitational force
= mg

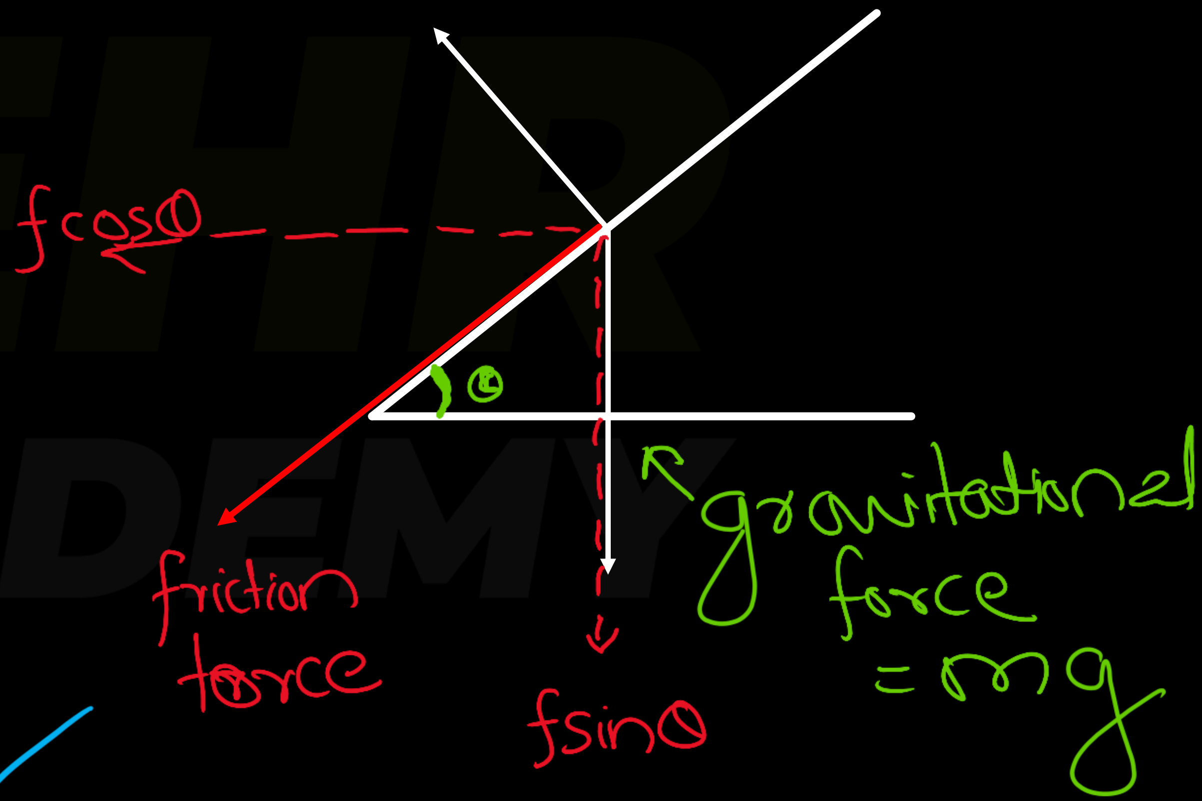
Diagram


Normal Reaction Force
Ncosθ
θ
Nsinθ
fcosθ
θ
θ
friction
mg
fsinθ
N
Ncosθ
θ
Nsinθ
θ
mg

$f_c = f\cos\theta + N\sin\theta$

$N\cos\theta = mg + f\sin\theta$





$f \propto N$

$f = \mu_s N$

$\boxed{f_s^{max}} = \mu_s N$

$\downarrow mg$

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Centripetal force $\longrightarrow$ Towards the center

$a_c = \frac{v^2}{r}$

$\boxed{f_c = \frac{mv^2}{r}}$

$$\boxed{\frac{mv^2}{r}} = f\cos\theta + N\sin\theta \quad \text{---} (1)$$

Vertically $\uparrow$ force $=$ $\downarrow$ force

$\uparrow \downarrow$

$$mg + f\sin\theta = N\cos\theta$$

$$mg = N\cos\theta - f\sin\theta \quad \text{---} (2)$$

$(1) \div (2) \Rightarrow$

$$\frac{v^2}{rg} = \frac{f\cos\theta + N\sin\theta}{N\cos\theta - f\sin\theta}$$

$$\frac{v^2}{rg} = \frac{f\cos\theta + N\sin\theta}{N\cos\theta - f\sin\theta}$$

Limiting friction

$$f_s^{max} = \mu_s N$$

$$= \frac{\mu_s N\cos\theta + N\sin\theta}{N\cos\theta - \mu_s N\sin\theta}$$

N is common $\Rightarrow$ $\div$ by N

$$= \frac{\mu_s\cos\theta + \sin\theta}{\cos\theta - \mu_s\sin\theta}$$

3 times

Ezhuthanam

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$$\frac{v^2}{rg} = \frac{\mu_s \cos\theta + \sin\theta}{\cos\theta - \mu_s \sin\theta}$$

$\div$ by $\cos\theta$

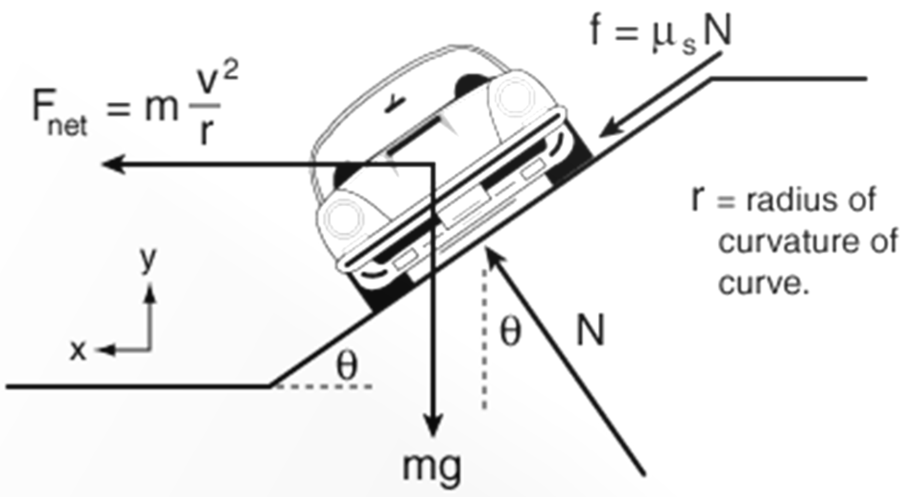
Now divide by $\cos\theta$ all terms RHS

$$\Rightarrow \boxed{\frac{v^2}{rg}} = \frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}$$

Most most most Important

$$\Rightarrow v^2 = rg\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)$$

$$\Rightarrow \boxed{v = \sqrt{rg\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)}}$$



Force equations at maximum speed v, at threshold of sliding up incline.

$$\Sigma F_x = m\frac{v^2}{r} = N \sin\theta + \mu_s N \cos\theta$$

$$\Sigma F_y = 0 = N\cos\theta - \mu_s N \sin\theta - mg$$

Solving this pair of equations for the maximum speed v gives:

$$v_{max} = \sqrt{\frac{rg(\sin\theta + \mu_s \cos\theta)}{\cos\theta - \mu_s \sin\theta}}$$

The limiting cases are:

$$v_{max} = \sqrt{rg\tan\theta}$$

Frictionless case

$$v_{max} = \sqrt{rg\,\mu_s}$$

Flat roadway

Special Cases $\longrightarrow$

flat $\rightarrow$ $\theta = 0$

$\tan\theta = 0$

If no friction $\rightarrow$ $\mu_s = 0$

$$V_{max} = \sqrt{rg\tan\theta}$$

If flat road,

$$\boxed{V_{max} = \sqrt{\mu_s r g}}$$

$$\frac{\sin\theta}{\cos\theta} = \frac{0}{1} = 0$$

$$v\uparrow = \sqrt{rg\left(\mu_s + \tan\theta\right)} \uparrow\uparrow \quad \tan\theta \uparrow$$

arc

$$\frac{s}{t} = \frac{r\theta}{t} \rightarrow v = r\omega$$

Chapter Theeernnn!!
Now some questions

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Newton's First Law describes:

a) Energy

b) Momentum

c) Inertia

d) Work

Inertia

resist → chng of motion

The rate of change of total momentum of a system is proportional to:

a) Work done

b) Internal forces

c) External force

d) Displacement

$\Delta p \propto$

momentum

$C_F \propto \Delta p$ = $C_F = ma$

$0 \to a \to 0$

$V=0 \to V=0 \to x$

$V - x \to x$

$V \to$ constant

The optimum speed of a car on a banked road (without friction) is given by:

$\mu_s = 0$

a) $\sqrt{(Rg \tan\theta)}$ ✓

b) $\sqrt{(Rg \cot\theta)}$

c) $\sqrt{(Rg \sin\theta)}$

d) $\sqrt{(Rg \cos\theta)}$

What is the SI unit of impulse?

a) Newton

b) Joule

c) Newton-second ✓

d) Pascal

$F \times t = N.S$

The force required to produce an acceleration of 2 m/s² on a mass of 2 kg is:

a) 4 N ✓

b) 10 N

c) 12 N

d) 18 N

$a \rightarrow 2\ m/s^2$

$m \rightarrow 2\ kg$

$F = ma$

$= 2 \times 2 \longrightarrow 4N$

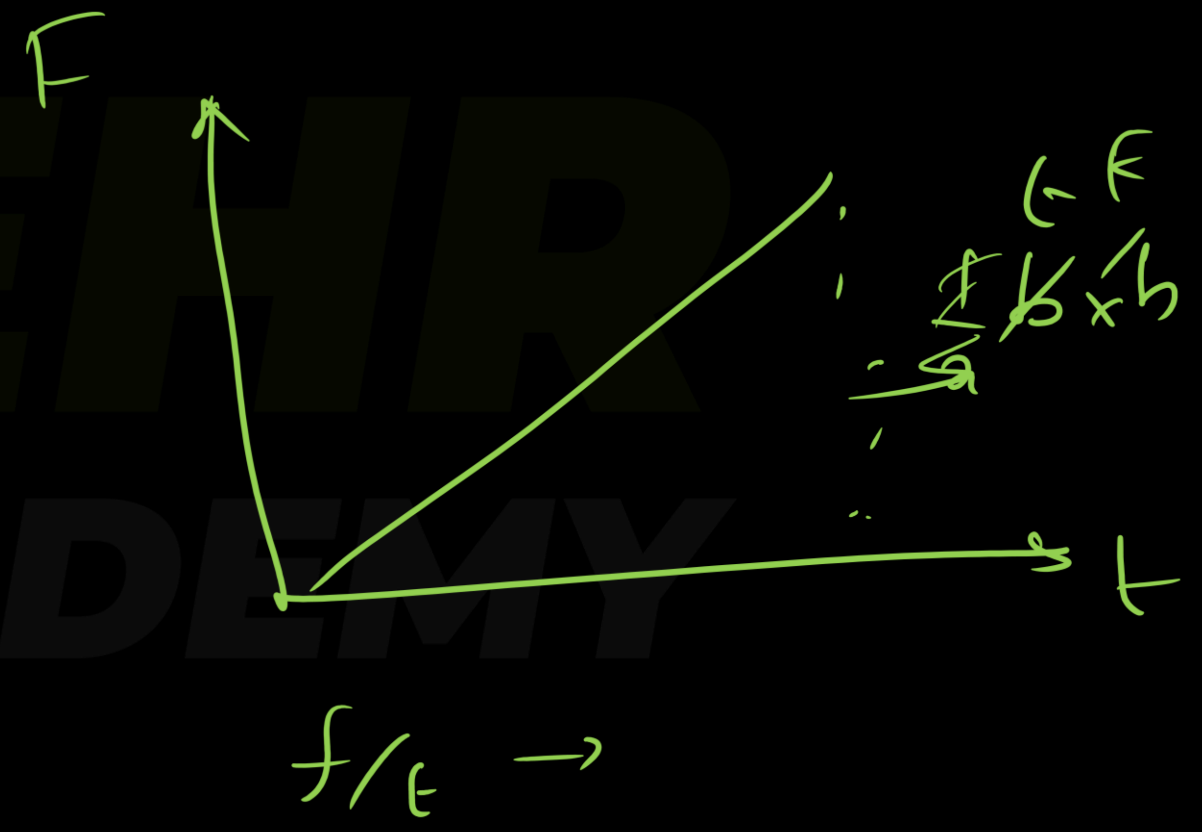
The area under a Force-Time graph represents:

a) Energy

b) Velocity

c) Impulse

d) Mass



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Prev Year Questions

Using Newton's second law of motion, derive the equation F = ma

$$f \propto \frac{\Delta p}{\Delta t} \longrightarrow f \propto \frac{dp}{dt} \longrightarrow p = mv$$

$$f \propto \frac{d}{dt} mv \longrightarrow f \propto m\frac{dv}{dt} \longrightarrow f \propto ma$$

$$\longrightarrow f = kma \longrightarrow k = 1$$

$$\Longrightarrow f = ma$$

A large force acting for a short interval of time is called impulsive force.

(a)What is the SI unit of impulse ?

(b)Two billiard balls each of mass 0.05 kg moving in opposite direction with speed 6 m

$F\Delta t \rightarrow I \longrightarrow SI \longrightarrow Ns \longrightarrow kg\,m/s^2 \times s$

$\longrightarrow kg\,m/s$

$kg\,m/s$

$I = F \times \Delta t$

$\longrightarrow$ change

$F = \frac{\Delta p}{\Delta t} \longrightarrow \boxed{F\Delta t} = \Delta p$

I

$mv \rightarrow kg\,m/s$

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A large force acting for a short interval of time is called impulsive force.

(a)What is the SI unit of impulse ?

(b)Two billiard balls each of mass 0.05 kg moving in opposite direction with speed 6 m

→ Change in momentum

$I = \Delta p$

$m(v-u)$

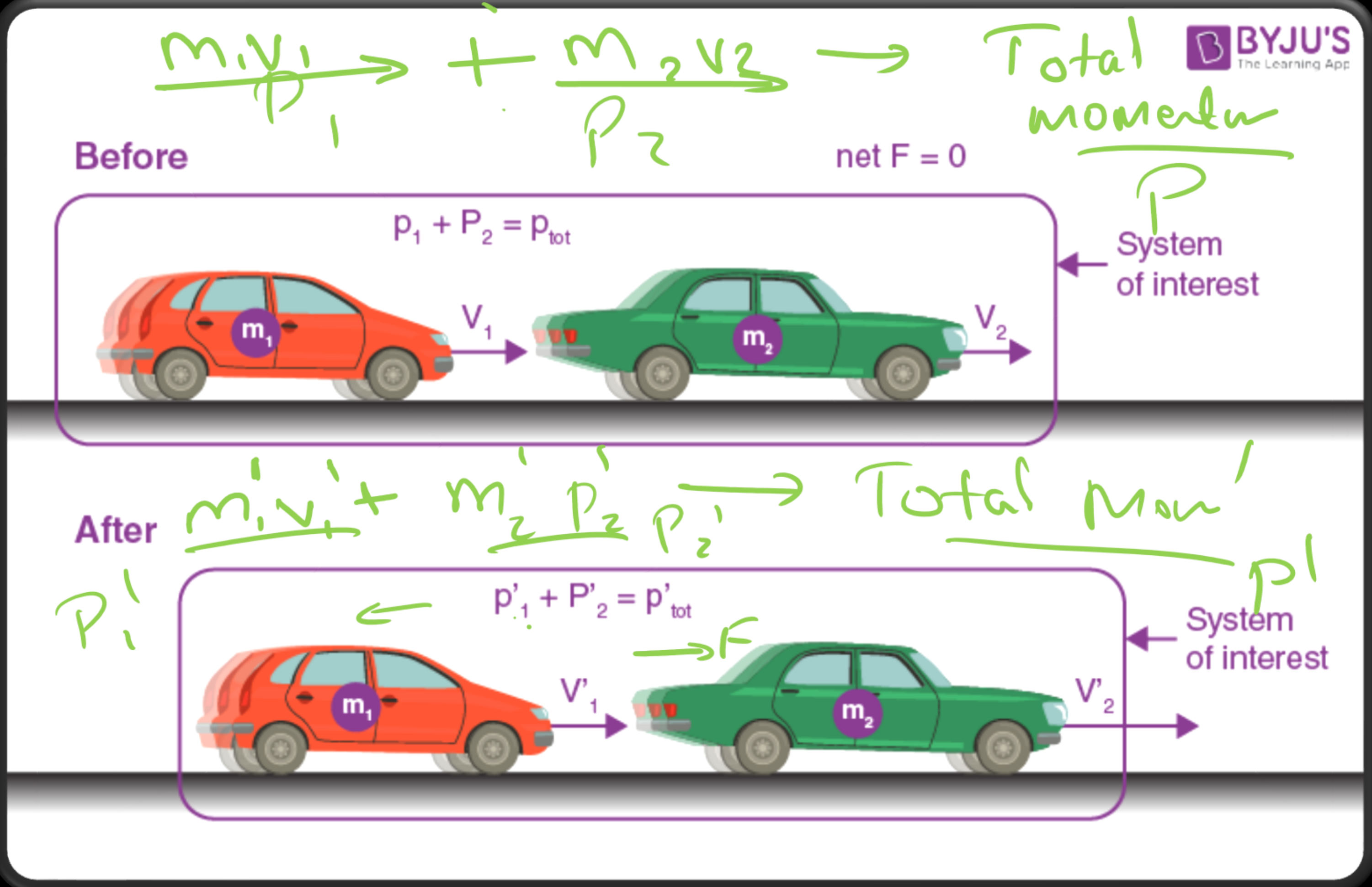
$$I = \Delta p = mv - mu$$
$$= m(v-u)$$
$$= \overset{0.05}{\cancel{m}}(6-(-6))$$
$$= 0.05 \times 12 = \frac{12 \times 5}{100} = \frac{60}{100} = 0.6\ Ns$$

State the law of conservation of linear momentum and prove it on the basis of second law of motion.

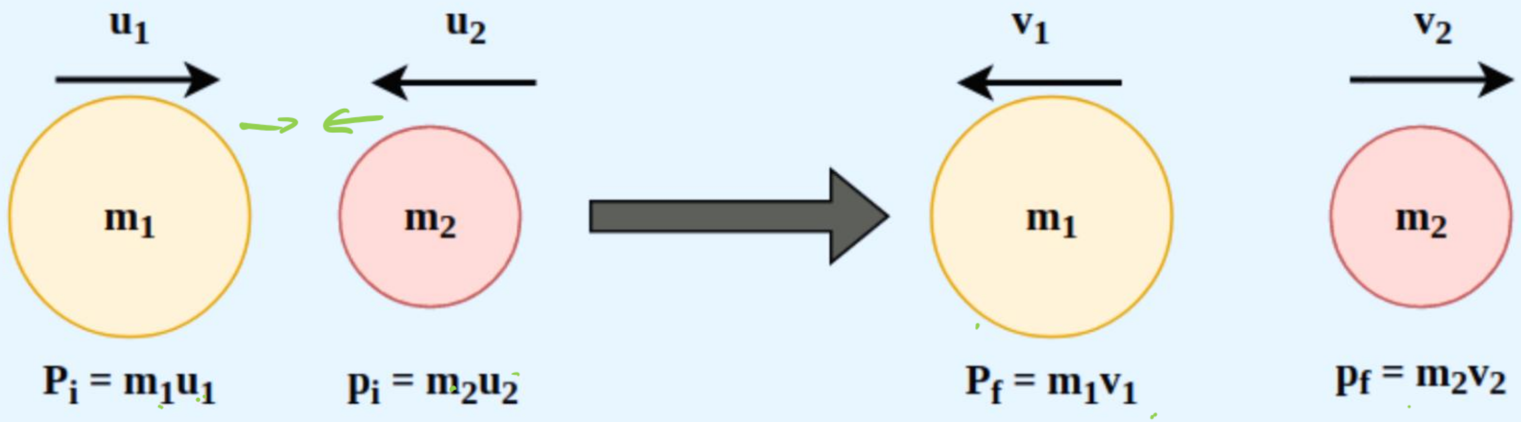
→ Law of cons. of momentum

P after collision

= P before collision


$m_1v_1 + m_2v_2 \rightarrow$ Total momentum
p_1 p_2 P
BYJU'S
The Learning App
Before
net F = 0
$p_1 + P_2 = p_{tot}$
System of interest
m_1 V_1 m_2 V_2
After
$m_1'v_1' + m_2'p_2' \rightarrow$ Total Mom'
p_1' p_2' p'
$p'_1 + P'_2 = p'_{tot}$
F
System of interest
m_1 V'_1 m_2 V'_2

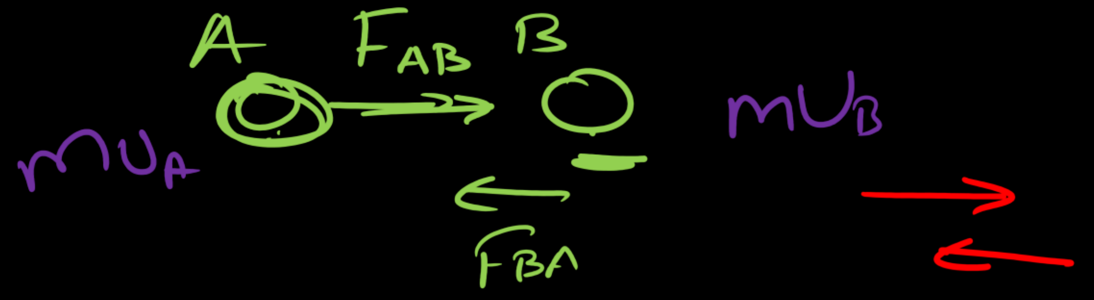
Conservation of Momentum



$$m_1u_1+m_2u_2 = m_1v_1 + m_2v_2$$

State the law of conservation of linear momentum and prove it on the basis of second law of motion.

N's 2nd law



$$F_{AB} = \Delta p_B = mu_B - mv_B$$

Before - After

$$F_{BA} = \Delta P_A = mu_A - mv_A$$

mv_A $m.v_B$

N's 3rd law

$$F_{AB} = -F_{BA}$$

$$mu_B - mv_B = -(mu_A - mv_A)$$

$$mu_B + mu_A = mv_B + mv_A$$

$$\boxed{P_{before} = P_{after}}$$

" Total momentum in an isolated system is conserved "

By Second law,

$$F_{AB}\,\Delta t = P_A' - P_A$$

$$F_{BA}\,\Delta t = P_B' - P_B$$

By third law, $F_{AB} = -F_{BA}$

$$(P_A' - P_A) = -(P_B' - P_B)$$

$$\boxed{P_A' + P_B' = P_A + P_B}$$

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A shell at rest explodes into three equal masses. 2 fragment fly off at right angles to each other with a speed of 9 m/s and 12m/s, calculate the Speed of third fragment

TM = 0 — Initial

$v = ?$

9 m/s

12 m/s

Law of C. of Mom

Bef = Aft. Same

$T = M_T \cdot V_T = 0$

$P_1 \; P_2 \; P_3 \rightarrow$ Total Mom after

$P_1 + P_2 + P_3 = 0$

$P_3 = -(P_2 + P_1)$

$|\vec{P_3}| = |\vec{P_1} + \vec{P_2}| = \sqrt{P_1^2 + P^2}$

$= \sqrt{81 + 144} = \sqrt{225} = 15 \text{ m/s}$

A shell at rest explodes into three equal masses. 2 fragment fly off at right angles to each other with a speed of 9 m/s and 12m/s, calculate the Speed of third fragment

Before explosion $\vec{p}_i = 0$

After Explosion $\vec{P} = 0$

$$\vec{P}_1 + \vec{P}_2 + \vec{P}_3 = 0$$

$$\vec{P}_3 = -(\vec{P}_1 + \vec{P}_2)$$

$$|\vec{P}_3| = |\vec{P}_1 + \vec{P}_2|$$

$$mv_3 = \sqrt{P_1^2 + P_2^2}$$

$$mv_3 = \sqrt{(mv_1)^2 + (mv_2)^2}$$

$$v_3 = \sqrt{v_1^2 + v_2^2}$$

$$v_3 = \sqrt{9^2 + 12^2}$$

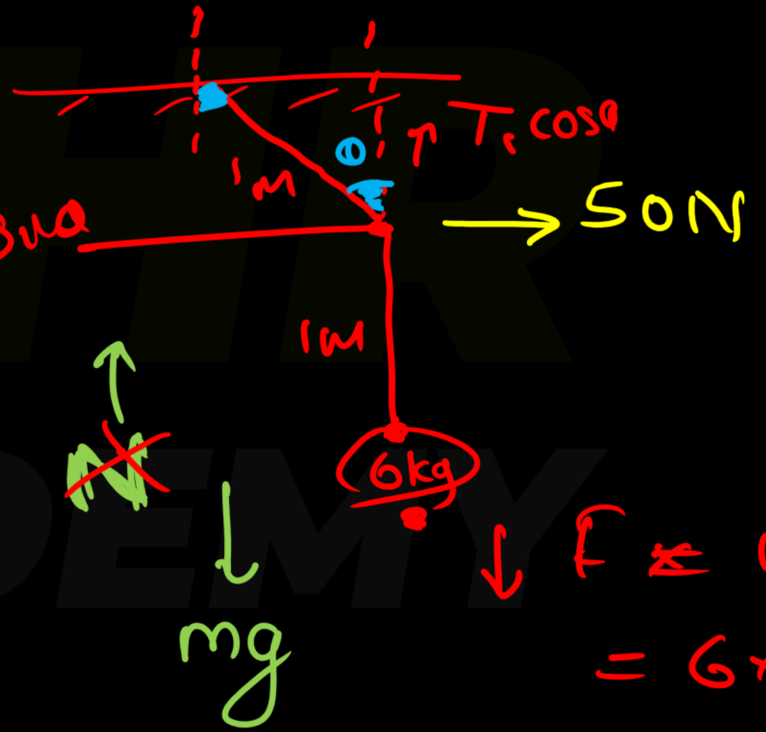
$$v_3 = \sqrt{225} \qquad v_3 = 15\,m/s$$

A mass of 6 kg is suspended by a rope of length 2 m from the ceiling. A force of 50 N in the horizontal direction is applied at the mid - point P of the rope as shown . What is the angle the rope makes with the vertical in equilibrium ? Take g = 10m/s^2. Neglect mass of the rope.

$T_1 \sin\theta = 50\,N$ — (1)

$F_g \rightarrow W = mg = 60\,N$

$T_1 \cos\theta = 60\,N$ — (2)

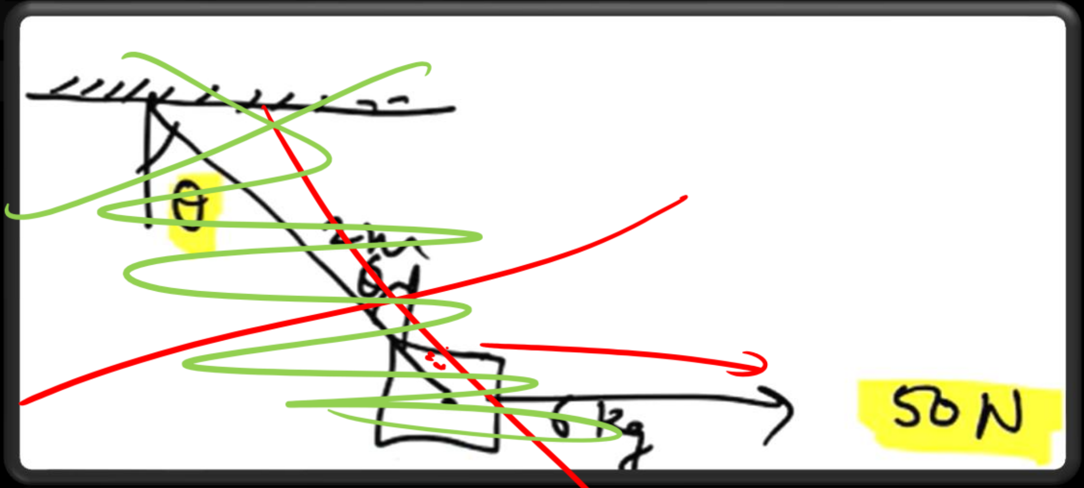


$F = mg$
$= 6\times10 = 60\,N$

$\frac{T_1 \sin\theta}{T_1 \cos\theta} = \frac{50}{60}$

$\tan\theta = \frac{5}{6} \rightarrow \theta = \tan^{-1}\frac{5}{6}$

$\approx 40^\circ$


θ
50 N

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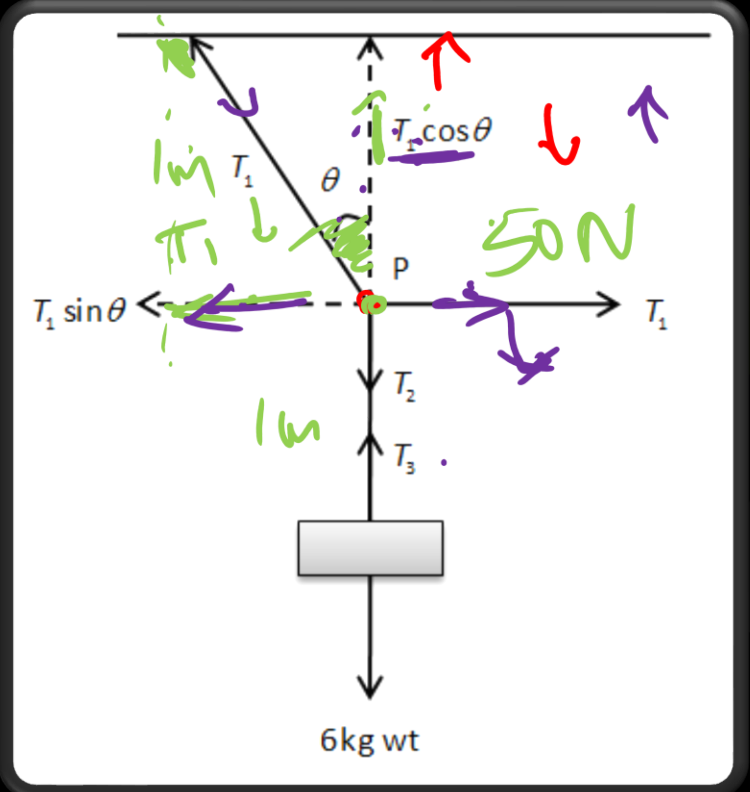

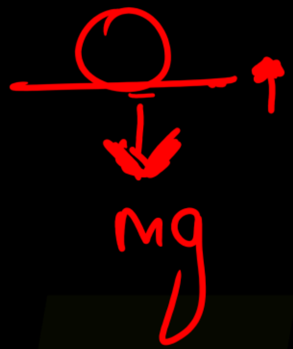

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To solve the problem of finding the angle the rope makes with the vertical in equilibrium when a horizontal force is applied, we can follow these steps:

Step 1: Identify the forces acting on the mass
The forces acting on the mass are:
1. The weight of the mass (W) acting downwards, which is given by:
$W = mg$

where $m = 6\,\mathrm{kg}$ and $g = 10\,\mathrm{m/s}^2$.

2. The tension (T) in the rope acting at an angle θ with the vertical.

3. The horizontal force (F) of 50 N acting at the midpoint of the rope.

Step 2: Calculate the weight of the mass
Substituting the values into the weight formula:
$W = mg = 6\,\mathrm{kg} \times 10\,\mathrm{m/s}^2 = 60\,\mathrm{N}$

Step 3: Set up the equilibrium conditions
In equilibrium, the vertical and horizontal components of the forces must balance out.

- **Vertical forces**:

The vertical component of the tension must balance the weight of the mass:

$$T\cos(\theta) = W$$

Substituting the weight:

$$T\cos(\theta) = 60\,\mathrm{N} \quad (1)$$

- **Horizontal forces**:

The horizontal component of the tension must balance the applied horizontal force:

$$T\sin(\theta) = F$$

Substituting the horizontal force:

$$T\sin(\theta) = 50\,\mathrm{N} \quad (2)$$

Step 4: Divide the equations to eliminate T

Dividing equation (2) by equation (1):

$$\frac{T\sin(\theta)}{T\cos(\theta)} = \frac{50}{60}$$

This simplifies to:

$$\tan(\theta) = \frac{50}{60} = \frac{5}{6}$$

Step 5: Calculate the angle θ

To find θ, take the arctangent:

$$\theta = \tan^{-1}\left(\frac{5}{6}\right)$$

Using a calculator or trigonometric tables:

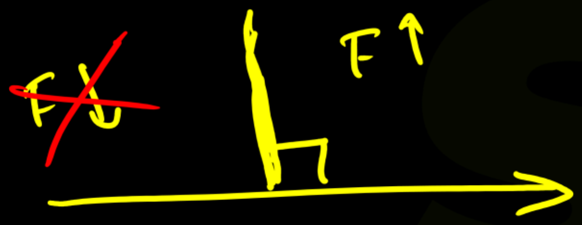
$$\theta \approx 40.0^\circ$$

$\boxed{40^\circ}$

Conclusion

The angle the rope makes with the vertical in equilibrium is approximately 40°.

If force is acting on a moving body perpendicular to the direction of motion, then what will be its effect on the speed and direction of the body?



If force is acting on a moving body perpendicular to the direction of motion, then what will be its effect on the speed and direction of the body?

Parallelogram

a

$|\vec{v}| \rightarrow$ constant

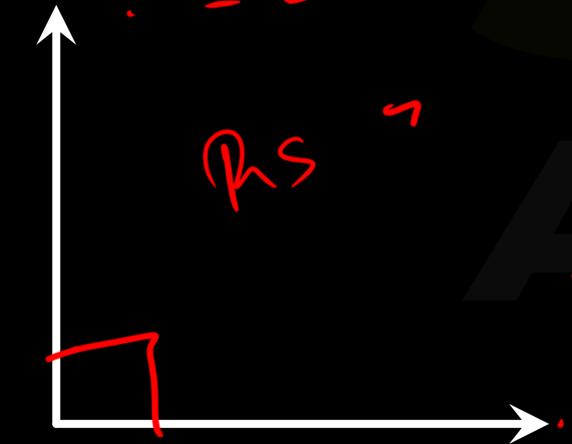
V_y

$V_x = ?$

v

B

Rs



$F_g \rightarrow g$

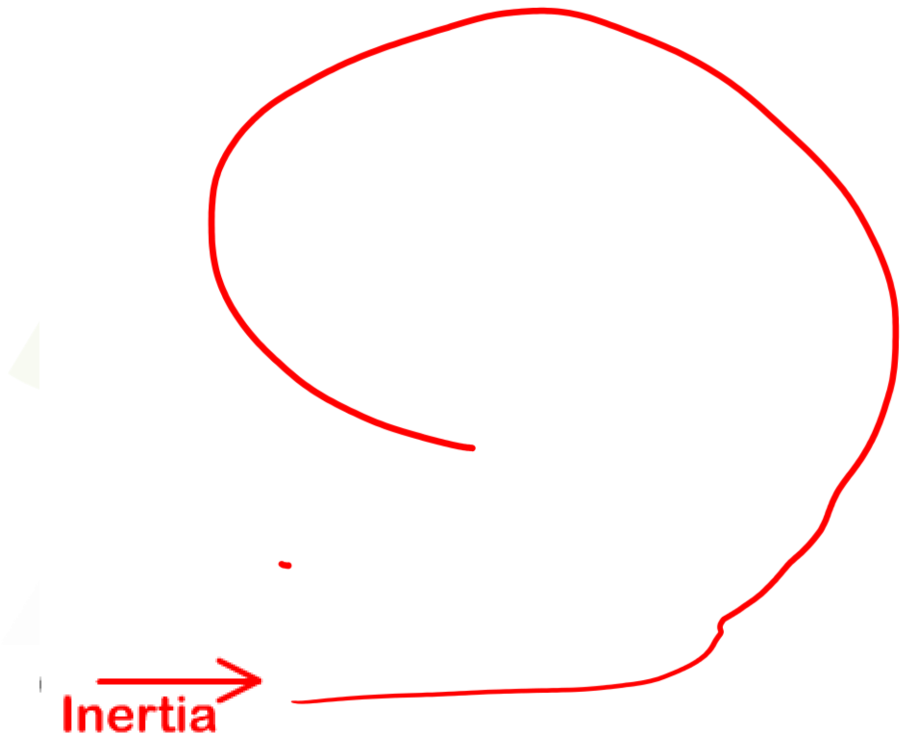
Resultant Vector Formulas

$F_{1x} = F_1 \cos\theta$ $\quad$ $F_{1y} = F_1 \sin\theta$

$F_x = F_{1x} + F_{2x}$ $\quad$ $F_y = F_{1y} + F_{2y}$

$F = \sqrt{F_x^2 + F_y^2}$ $\quad$ $\theta_{Ref} = \tan^{-1}\left[\frac{F_y}{F_x}\right]$

Example of this motion



A light bullet is fired from a heavy gun.

(a)Choose the correct statement

(i) Speed of the gun and the bullet are equal. ✗

(ii)Momenta of the bullet and gun are equal in magnitude and opposite direction. ✓

(iii)Momenta of the bullet and gun are equal in magnitude and in the same direction. ✗

(iv)Velocity of gun and bullet are equal. ✗

(b)By using a suitable conservation law in Physics prove your above answer

Before $T_p = 0$ ← Law of cons.

After

$P_G = -P_B \rightarrow P_G + P_B = 0$ Mom

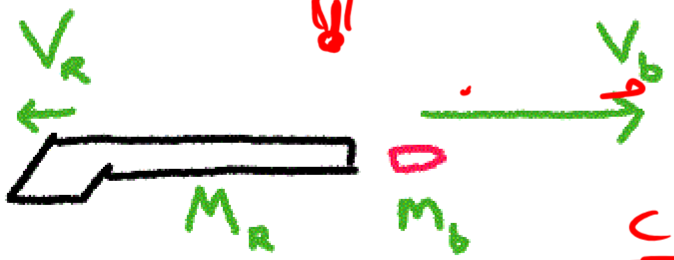
$T_p' = 0$

Momenta of the bullet and gun are equal in magnitude and opposite direction

before

Sum $\boxed{\Sigma p = 0}$

after



$F_B \rightleftarrows F_A$

Δp

$m.v.$

$$\Sigma p = m_b V_b + M_R(-V_R) = 0$$

$$\Rightarrow m_b V_b = M_R V_R$$

$$\frac{V_R}{V_b} = \frac{m_b}{M_R}$$

$m \uparrow v$

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A shell of mass 0.020 kg is fired by a gun of mass 100 kg. If the muzzle speed of the shell is 80 m/s, what is the recoil speed of the gun?

$P_{from} = 0$

$V \rightarrow$ Recoils

$P_i = 0$

$$\underline{m_B V_B} = \underline{M_G V_G}$$

($m_B = 0.02$, $V_B = 80$, $M_G = 100$)

$$\frac{2}{100} \times \frac{8}{10} \qquad \underline{0.02} \times \cancel{80}^{\,0.8} = 10\cancel{0} \times V_G$$

$$V_G = 16 \times \frac{1}{1000} = \underline{0.016} \text{ m/s}$$

A person drives a car along a circular track on a level ground.
(a) Derive an expression for the maximum safe speed of the car.
(b) Why do we give banking to curved roads?

To increase max safe speed

↓ wear tear

$N = mg$

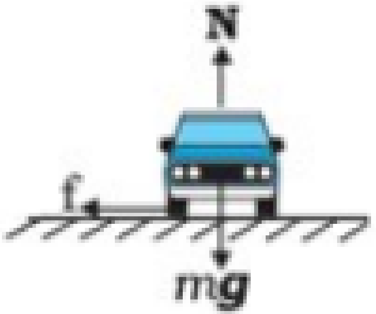
$f_c = f_s = \frac{mv^2}{r}$

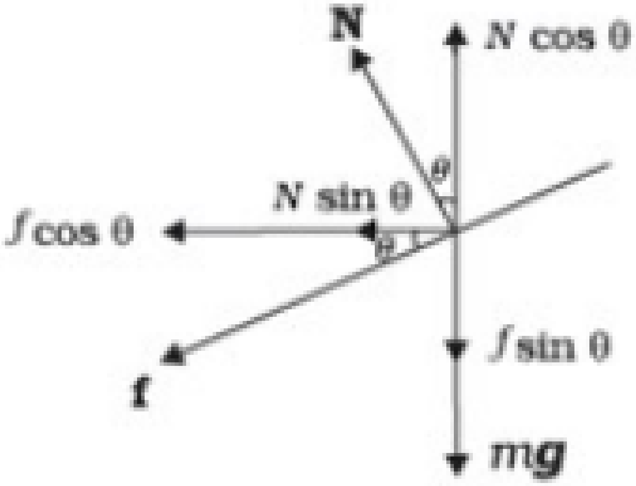
μ, N

$\mu_s mg = \frac{mv^2}{r}$

$f_s = \frac{mv^2}{r}$

$v^2 = \mu_s r g \rightarrow v = \sqrt{\mu_s r g}$





From the Diagram, to avoid skidding of the car, the maximum force of friction must be equal to or greater than centripetal force.

ie $\quad \mu_S N \geq F_C$

But $\quad$ N=mg and $\quad F_C = \dfrac{mv^2}{r}$

Therefore $\quad \mu_S mg \geq \dfrac{mv^2}{r}$

$$v^2 \leq \mu_s r g$$

Thus the maximum safe speed is $\quad v = \sqrt{\mu_S r g}$

(b)To avoid the risk of skidding as well as to reduce the wear and tear of the car tyres.

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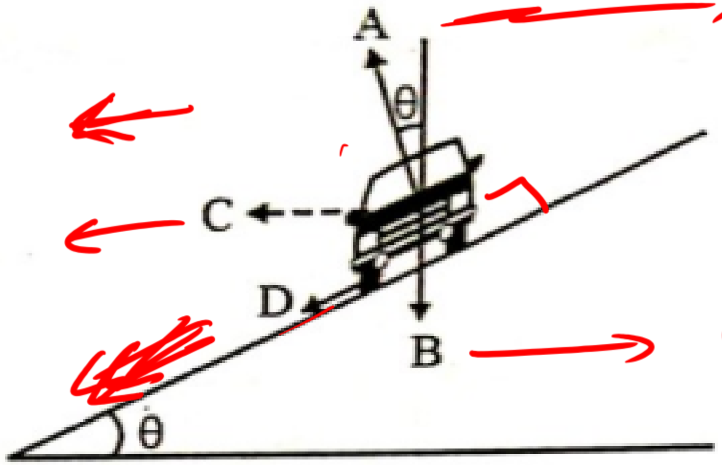
Circular motion of a car on a banked road is shown in figure.



Normal

Centrip

Gravitation

Friction

(a) Write the names of the forces A,B,C and D in figure.
(b) Write the equation which equate forces on the car along horizontal and vertical direction.

(c) State the Laws of static friction.

(a) A--> Normal Reaction (N).

B--> Weight (mg).

C--> Centripetal force ($\dfrac{mv^2}{R}$)

D--> Frictional force.(f_s)

(b)On the Vertical direction

$$N\cos\theta = mg + f_s \sin\theta$$

and

On the horizontal direction

$$N\sin\theta + f_s\cos\theta = \frac{mv^2}{R}$$

(c)The law of static friction may be written as

$$f_s \leq \mu_s N$$

Chapter 4 : Laws of Motion Completed