Chapter-5

Laws of Motion

1. What is **Aristotle's Fallacy**?

Ans: According to the Greek thinker Aristotle (384 B.C – 322.B.C), an external force is required to keep a body in uniform motion.

2. What is the **Modern concept about uniform motion**?

Later Galileo (1564 -1642) proved that the above concept was wrong. According to Galileo "**no external force is required to keep a body in uniform motion**".

State of rest and state of uniform linear motion are equivalent. In both cases, there is no external force acting on the body.

3. Define **Inertia**. Which are the three types of inertia? Give examples.

Ans: Inertia is the tendency of a body to continue in its state of rest or state of uniform motion along a straight line.

The word inertia means **resistance to change**.

Different types of inertia

i. Inertia of rest

The tendency of a body to remain in its state of rest is called inertia of rest.

Eg: -

a) A person standing in a bus tends to fall backwards when the bus suddenly starts moving forward.

b) When a horse suddenly starts running, the rider falls backward.

c) Dust is removed from a hanging carpet by beating it with a stick.

d) When we shake the branch of a tree, its fruits and dry leaves fall down.

ii. Inertia of motion

The tendency of a body to remain in its state of uniform motion in a straight line is called inertia of motion

Eg: -

a) When a moving bus suddenly stops, a person standing in it tends to fall forward.

b) When a horse running fast suddenly stops, the rider is thrown forward.

c) A person getting out of a moving bus or train falls in the forward direction.

d) An athlete runs for a certain distance, before taking a long jump.

e) A ball thrown upward in a moving train comes back into the thrower's hands.

iii. Inertia of Direction

The tendency of a body to continue its direction of motion is called inertia of direction.

Eg: -

a) When a bus takes a sharp turn, a person sitting in the bus experiences a force acting away from the centre of the curved path.

b) When a stone executing circular motion is released, it flies off tangentially.

c) During the sharpening of a knife, the sparks coming from the grind stone fly off tangentially to the rim of the rotating stone.

d) When a vehicle moves, the mud sticking to its wheels flies off tangentially.

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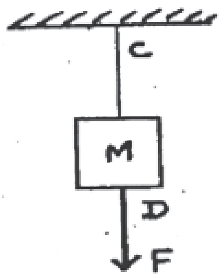
4. Explain the relation between mass and inertia. Give an example.

Ans: Mass of a body is the measure of its inertia. If a body has more mass, it has more inertia.

Eg: When a dog chases a hare, the hare runs along a zigzag path.

Reason: -When the hare runs in a zigzag path, it becomes difficult for the dog to catch the hare. This is because the dog has more mass and hence has more inertia of direction than the hare.

5. A block of mass is suspended by a light cord C from the ceiling and another strong cord D is attached to the bottom of the block as shown.



The cord D is pulled by a force F. Which of these cords will break, if

a) the force is increased steadily?
b) The force is increased suddenly?

Ans:

6. State Newton's 1st Law of motion (Law of Inertia).

Ans: Newton's first law states that "everybody continues in its state of rest or of uniform motion in a straight line unless compelled by some external unbalanced force to change that state".

7. Define linear momentum (p) of a body.

Ans: Momentum of a body is defined as the product of its mass (m) and velocity (v).

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

Momentum is a vector quantity.
S. I unit of momentum is kg m/s.

8. State Newton's second law of motion (Law of force).

Ans: Newton's second law of states that "the rate of change of momentum of a body is directly proportional to the applied force and the change in momentum takes place in the direction of force"

$$\vec{F} \propto \frac{d\vec{p}}{dt}$$

9. Obtain the expression for force $\vec{F} = m\vec{a}$ from second law.

Ans: According to second law,

$$\vec{F} \propto \frac{d\vec{p}}{dt}$$

$$\vec{F} = k\frac{d\vec{p}}{dt},$$ where k is the proportionality constant

But k = 1,

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

$$\vec{F} = m\frac{d\vec{v}}{dt} \quad [\because \text{ m is a constant}]$$

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

10P. A machine gun fires bullets of mass **40 g** each with a speed **1200m/s**. The person can hold the gun with a maximum force of **144N**. What is the maximum number of bullets that can be fired per second from the gun?

Ans:

11P. A constant retarding force of 50N is applied to a body of mass 20kg moving initially with a speed of 15m/s. How long does the body take to stop?

Ans:

12P. A bullet of mass **0.04 kg** moving with a speed of **90m/s** enters a heavy wooden block and is stopped after a distance of **60cm**. What is the average resistive force exerted by the block on the bullet?

Ans:

13P. The driver of a three wheeler, moving with a speed of **36km/hr** sees a child standing at the middle of the road and brings his vehicle to rest in **4 seconds**, just in time to save the child. What is the average retarding force on the vehicle? The mass of the three wheeler is **400kg** and the mass of the driver is **65kg**.

Ans.

14P. A horizontal force of **500N** pulls two masses **10kg** and **20kg** (lying on a friction less table) connected by a light string. What is the tension in the string? Does the answer depend on which mass the pull is applied?

Ans:

15. What is impulsive force? Define impulse.

Ans: Large force acting for a short time is called impulsive force.

Eg: (i) Hitting a nail with a hammer,

(ii) Hitting a cricket ball with a bat.

(iii) Kicking a football.

Impulse of a force is the product of force and time.

$$I = F \times \Delta t$$

S.I unit of impulse is N.S (Newton second). Impulse is a vector quantity.

16. State and prove impulse-momentum theory.

Ans: According to impulse momentum theory, impulse is equal to change in momentum.

<u>Proof</u>

According to Newton's second law,

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

$$\Rightarrow F\,dt = dp$$

i.e., $\boxed{I=dp}$

i.e., Impulse = change in momentum

17P. A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of **12m/s**. If the mass of the ball is **0.15kg**, determine the impulse imparted to the ball.

Ans:

18. Give some applications of the concept of impulse

Ans:

(i) While catching a ball a cricketer lowers his hands.

<u>Reason</u>: By moving the hands backwards, the cricketer increases the time of catch. Then, the force $\left(\downarrow F = \frac{I}{\Delta t \uparrow}\right)$ exerted by the ball on his hands becomes much smaller and it does not hurt him.

(ii) A person falling from a certain height receives more injuries when he falls on a cemented floor than when he falls on a heap of sand.

<u>Reason:</u> When the person falls on a heap of sand, sand gets depressed under his weight. The person **takes longer time** to stop. This decreases the force $\left(\downarrow F = \frac{I}{\Delta t \uparrow}\right)$ exerted by the floor on the person.

(iii) Automobiles are provided with shockers.

<u>Reason</u>: When a vehicle moves on an uneven road, it receives a jerk. The

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shock absorbers increases the time of jerk and hence reduces its force.

(iv) Buffers are provided between the bogies of train.

Reason: Buffers increase the time of jerk. This decreases the force of impact between the bogies. The bogies are thus prevented from receiving severe jerks.

(v) China wares are packed in straw paper before packing.

Reason: The straw paper between the china wares increases the time of experiencing the jerk during the transportation.

19. State Newton's third law of motion (Law of Action and Reaction)

Ans: The law state that "**To every action, there is an equal and opposite reaction**."

Examples:

(i) During walking, a man pushes the ground (**action**). As a **reaction**, the ground exerts an equal but opposite reaction force to the person.

(ii) While swimming, a person pushes water backward. The water then exerts an equal and opposite reaction to the person in the forward direction.

(iii) When a person jumps out of a boat, he pushes the boat in the backward direction. The forward reaction force exerted by the boat on the person helps him to jump out of the boat.

20. Even though action and reaction are equal and opposite, they do not cancel each other. Why?

Ans: Action and reaction are acting on different bodies. So they do not cancel each other.

21. A horse cannot pull a cart and run in empty space. Why?

Ans: In empty space, horse cannot apply action. So it will not get any reaction to run.

22. State the law of conservation of linear momentum.

Ans: The law states that "If no external force acts on a system of several particles, the total linear momentum of the system remains constant."

23. Prove the law of conservation of linear momentum from Newton's second law.

Ans: According to second law, $F = \frac{dp}{dt}$

If there is no external force,

$$F = 0$$

$$\Rightarrow \frac{dp}{dt} = 0$$

$$\Rightarrow p = \text{constant}$$

Thus total linear momentum of a system remains constant in the absence of external force.

24. Prove the law of conservation of linear momentum from Newton's third law.

Ans: Consider two bodies A and B of masses m_1 and m_2 moving with velocities u_1 and u_2 collide with each other. Let v_1 and v_2 be their velocities after collision.

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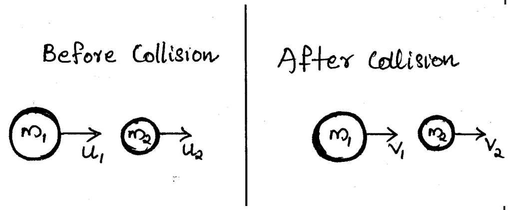


The force exerted by A on B (**action**),

$$F_1 = m_2 a_2$$

$$F_1 = m_2 \left(\frac{v_2 - u_2}{t}\right)$$

Similarly, the force exerted by

B on A (**reaction**),

$$F_2 = m_1 a_1$$

$$F_2 = m_1 \left(\frac{v_1 - u_1}{t}\right)$$

By Newton's third law,

$$\mathbf{F_1 = -F_2}$$

$$\Rightarrow m_2 \left(\frac{v_2 - u_2}{t}\right) = m_1 \left(\frac{v_1 - u_1}{t}\right)$$

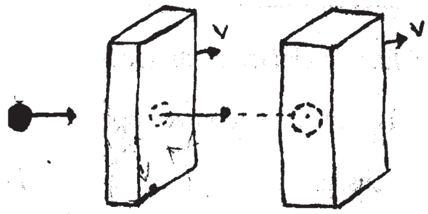
$$\Rightarrow m_2v_2 - m_2u_2 = m_1v_1 - m_1u_1$$

$$\Rightarrow m_2v_2 + m_1v_1 = m_1u_1 + m_2u_2$$

$$\Rightarrow \boxed{\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}}$$

i.e., total linear momentum before collision is equal to total momentum after collision.

25P. A bullet of mass **20g** pierces through a plate of mass **1kg** and then comes to rest inside a second plate of mass **2.98 kg** as shown in figure.



It is found that the two plates, initially at rest, now move with equal velocity. Find the percentage loss of the initial velocity of the bullet when it is between the plates.

Ans:

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26. Give an application of law of conservation of momentum.

Ans: Recoil of gun is an application of law of conservation of angular momentum.

When the gun powder explodes, the shot moves with a large forward momentum. The gun moves backward with the same momentum. This is called recoil of gun. The velocity of gun just after firing is called **recoil velocity**. The velocity of the bullet just after firing is called **muzzle velocity**.

Before firing both the gun and bullet are at rest. There total linear momentum is zero before collision.

Let M → mass of gun

V → velocity of gun

m → mass of bullet

v → velocity of bullet

We know, by the law of conservation of linear momentum,

Total momentum before firing = Total momentum after firing.

$$O = MV + mv$$

$$\Rightarrow -MV = mv$$

$$\Rightarrow \boxed{V = \frac{-mv}{M}}$$

This is the expression for recoil velocity.

Note: To reduce recoil velocity, the mass of the gun is to be increased. Negative sign indicates that the recoil velocity is opposite to the muzzle velocity.

27. Distinguish between mass and weight.

Ans: Mass is the amount of substance contained in a body. It is a scalar quantity its SI unit is **kg.**

Mass is a scalar quantity.

Weight is the gravitational force acting on a body. S.I unit is Newton (**N**).

$$W = mg$$

Weight is a vector quantity.

28. Define **inertial mass** and **Gravitational Mass**.

Ans: From Newton's Second law,

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

That is the acceleration of an object is inversely proportional to its mass. Thus the mass is a measure of inertia of a body. So it is called inertial mass.

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

"Inertial mass is the ratio of force applied on an object to the acceleration produced".

We know, W = mg

$$\therefore m = \frac{W}{g}$$

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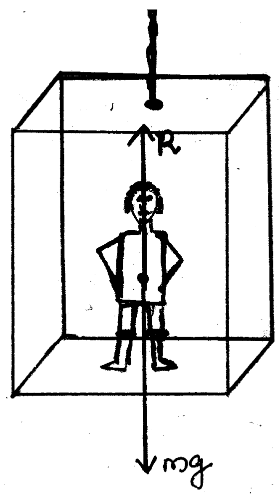
Gravitational mass is the ratio of weight of an object to the acceleration due to gravity. As the mass of an object increases, the gravitational force on it increases.

Gravitational mass can be measured using common balance.

29. Explain the different cases of apparent weight of a body in a lift.

Ans:



Consider a body of mass **m** placed in a lift at rest. The forces acting on the body are

(i) The weight of the body acting vertically downwards (**W = mg**)
(ii) The normal reaction (**R**) acting vertically upwards.

<u>Case–1</u> The lift is stationary or moving up or down with uniform velocity.

$a = 0$

Then the resultant force acting on the body,

$F = ma$
$R - mg = m \times 0$
$\therefore R = mg$

Apparent weight of the body is equal to actual weight.

<u>Case–2</u> The lift is moving upwards with uniform acceleration 'a'.

Here,

$F = ma$
$R - mg = ma$
$\Rightarrow R = ma + mg$
$\Rightarrow R = m(a + g)$,

Apparent weight of the body is greater than the actual weight.

<u>Case–3</u> The lift is moving down with uniform acceleration 'a'.

$F = ma$
$mg - R = ma$
$mg - ma = R$
$R = m(g - a)$, Apparent weight of the body decreases.

<u>Case–4</u> The lift is in free fall (Suppose the lift cable breaks)

Here $\mathbf{a = g}$

$R = m(g - a)$
$= m(g - g) = m(0) = 0$

The apparent weight is zero. The body feels weightlessness.

30P. A child weighing **20 kg** is in a lift that is moving down with an acceleration of **$5 m/s^2$**, what will be the apparent weight of the child?(**$g=10 m/s^2$**)

Ans:

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31P. A monkey of mass 40kg climbs on rope which can withstand a maximum tension of 600N. In which of the following cases will the rope break? The monkey

(a) Climbs up with an acceleration of $6m/s^2$.

(b) Climbs down with an acceleration of $4m/s^2$.

Ans:

Friction

32. Define friction

Ans: Friction is the force which opposes the relative motion between two surfaces in contact.

33. What is the cause of friction?

Ans: Friction is due to the force of attraction between the molecules of the two surfaces in contact.

34. Give the classification of friction

Ans: There are two types of friction (i) **Static friction** and (ii) **Kinetic friction**

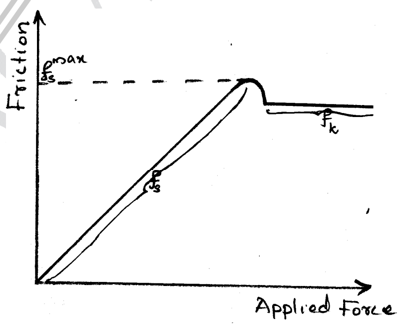
Kinetic friction is again divided in to (a) **Sliding friction** and **Rolling friction.**

35. Define Static Friction (f_s)

Ans: It is the frictional force between two surfaces in contact before there is relative motion between the surfaces.

36. Plot the variation in the value of static friction with the applied force.

Ans:



When we push or pull a body the static friction develops in the opposite direction. If we increase the external force, more and more static friction is developed. But the static friction has a maximum value called the limiting friction. If we apply more force than the limiting friction, the body will move. When the body once starts motion, the friction slightly decreases and thereafter it has a constant value called kinetic friction.

37. Define limiting friction (f_s^{max}).

Ans: The maximum value of static friction is called limiting friction.

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38. State the laws of static friction.

Ans: The laws of static friction are:

- **i.** The magnitude of the limiting friction is independent of the area of contact.
- **ii.** The limiting friction is directly proportional to normal reaction.

$$f_s^{max} \propto R$$

$$f_s^{max} = \mu_s \times R$$

μ_s is called the coefficient of the static friction.

39. Define kinetic friction.

Ans: It is the force of friction between two surfaces in contact when there is relative motion between the surfaces.

Kinetic friction is always less than limiting friction.

40. What are the two types of kinetic friction?

Ans: Kinetic friction is of two types

(a) Sliding friction

(b) Rolling friction

Note: - Rolling friction is less than Sliding friction.

41. State the laws of kinetic friction.

Ans:

- **(i)** The kinetic friction has a constant value depending on the nature of the two surfaces in contact.
- **(ii)** The kinetic friction (**f_k**) is directly proportional to the normal reaction **R**.

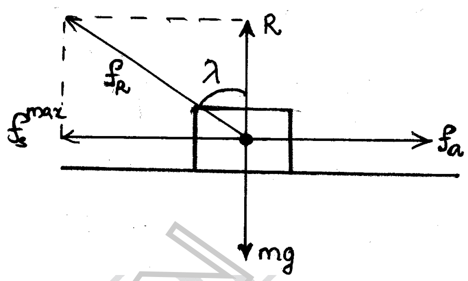
$$f_k \propto R$$

$$\Rightarrow f_k = \mu_k \times R$$

μ_k is called the coefficient of kinetic friction.

42. Define the angle of friction.

Ans:



$f_a \rightarrow$ Applied force

$f_s^{max} \rightarrow$ Limiting friction

$R \rightarrow$ Normal reaction

$mg \rightarrow$ weight of the body

"The angle which the resultant (f_R) of the limiting friction and normal reaction makes with the normal reaction (R) is called the angle of friction (λ)".

$$\tan \lambda = \frac{f_s}{R} = \frac{\mu_s \cancel{R}}{\cancel{R}} = \mu_s$$

$$\boxed{\tan \lambda = \mu_s}$$

$$\lambda = \tan^{-1}(\mu_s)$$

43. Define angle of repose.

Ans: "The angle of inclination of the inclined plane when the body just slides down is called angle of repose"

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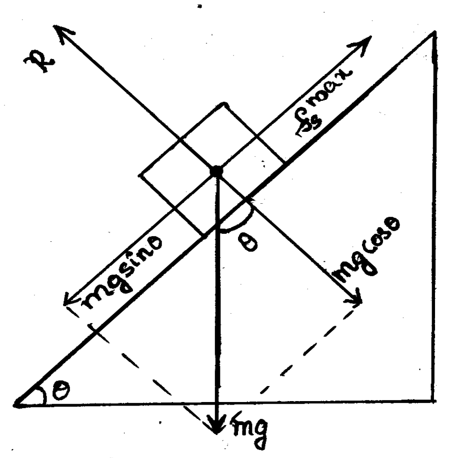

Here,

$$mg\sin\theta = f_s^{max} \cdots\cdots\cdots(1)$$

$$mg\cos\theta = R \cdots\cdots\cdots(2)$$

$$\frac{(1)}{(2)} \rightarrow \tan\theta = \frac{f_s^{max}}{R} = \frac{\mu_s R}{R} = \mu_s$$

$$\boxed{\tan\theta = \mu_s}$$

$$\therefore\ \theta = \tan^{-1}(\mu_s) \cdots\cdots\cdots(3)$$

Also we have, the angle of friction

$$\lambda = \tan^{-1}(\mu_s) \cdots\cdots\cdots(4)$$

$\therefore$ From (3) and (4)

$$\theta = \lambda$$

Angle of Repose = Angle of friction

44. What is the principle behind the use of ball bearings?

Ans: Rolling friction is less than sliding friction. This is the principle behind the use of ball bearings.

45. Friction is a necessary evil. Explain.

Ans: Friction has many advantages and some disadvantages. So friction is called a necessary evil.

Advantages of friction

i. We are able to walk on the ground due to friction.
ii. We can hold an object in hand due to friction.
iii. Meteors burn in air due to atmospheric friction.

Disadvantages of friction

i. When a vehicle moves, a lot of energy is lost to overcome the friction.
ii. Friction causes the wear and tear of moving parts of machines.
iii. Friction offered by atmospheric air is disadvantageous to rockets and satellites.

46. Give some methods to reduce friction.

Ans:

i. **Use ball-bearings** between two moving parts of a machine.
ii. **Use lubricants**: - Lubricants form a layer between the two solid surfaces and thus prevent them coming into direct contact. Grease, oil, wax etc. are used as lubricants.

Circular Motion and Friction

47. Define centripetal force. Give examples.

Ans: Centripetal force is that force experienced by a body, when it moves along a curved path. The direction of the force is towards the centre of the curved path.

$$\text{Centripetal force} = \frac{m v^2}{r}$$

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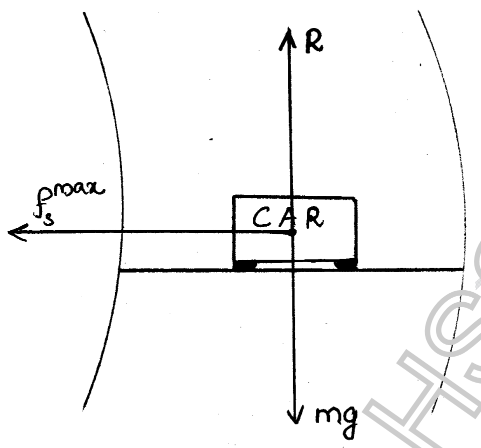
Eg: i) When a stone tied to a string is whirled, the centripetal force is provided by the tension in the string.

ii) When a satellite moves around the earth, centripetal force is provided by the gravitational attraction of earth on the satellite.

iii) For a car taking a circular turn on a horizontal road, the centripetal force is the force of friction.

48. A car is moving on a circular level road. Derive the expression for **maximum speed for safe turning** of the car.

Ans:



The forces acting on the car are:
(i) the weight of the car, **mg**

(ii) Normal reaction, **R**
(iii)Frictional force, **f**

The centripetal force required for the motion of the car = $\frac{mv^2}{r}$, where r is the radius of curvature of the road. This is provided by the force of friction between the tyres and the road.
The maximum frictional force

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

$= \mu_s mg$ [Since R = mg]
The condition for the safe turning of the car is,

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

$$\frac{m v_{max}^2}{r} = \mu_s mg$$

$$v_{max}^2 \leq \frac{\mu_s mgr}{m} = \mu_s gr$$

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

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

This is the **maximum speed** for the vehicle **to avoid skidding**.

49P. A cyclist speeding at **18km/hr** on a level road takes a sharp circular turn of radius **3m** without reducing the speed. The coefficient of static friction between the tyres and the road is **0.1**. Will the cyclist slip while taking the turn?
Ans:

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Banking of Road

50. What is meant by banking of road?

Ans: At a curve the road is made in such a way that the outer edge of the road is raised above the inner edge. This is called banking of roads.

51. What is the advantage of banked road?

Ans: On a banked road, a vehicle gets more centripetal force.

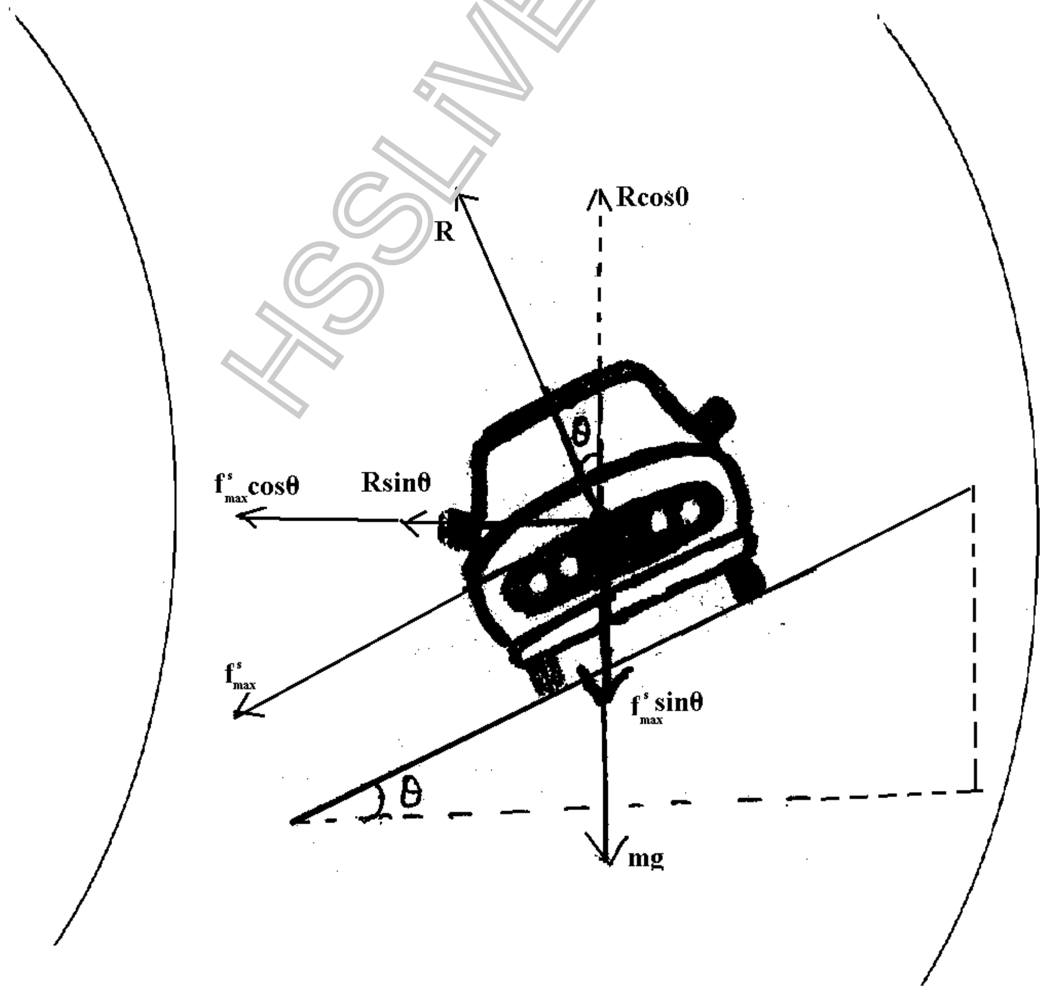
Explanation

On a **level road**, friction is the only available centripetal force.

On a **banked road**, both friction and a component of normal reaction are available as centripetal force.

52. Derive an expression for the maximum speed for safe turning on a banked road.

Ans:



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At equilibrium, we have

$$R\cos\theta = mg + f_s^{max}\sin\theta \cdots\cdots\cdots(1)$$

$$\frac{m\,v_{max}^2}{r} = f_s^{max}\cos\theta + R\sin\theta \cdots(2)$$

$$\text{Eqn }(2) \rightarrow \frac{m\,v_{max}^2}{r} = \mu_s R\cos\theta + R\sin\theta$$

$$\Rightarrow \frac{m\,v_{max}^2}{r} = R\left(\mu_s\cos\theta + \sin\theta\right) \cdots(3)$$

$$\text{Eqn }(1) \rightarrow R\cos\theta = mg + \mu_s R\sin\theta$$

$$\Rightarrow R\cos\theta - \mu_s R\sin\theta = mg$$

$$\Rightarrow R\left(\cos\theta - \mu_s\sin\theta\right) = mg$$

$$\Rightarrow R = \frac{m\,g}{\cos\theta - \mu_s\sin\theta} \cdots\cdots\cdots\cdots\cdots\cdots(4)$$

Substituting eqn (4) in eqn (3),we get

$$\frac{m v_{max}^2}{r} = \frac{m\,g}{\cos\theta - \mu_s\sin\theta}\left(\mu_s\cos\theta + \sin\theta\right)$$

$$v_{max}^2 = \frac{rg\left(\mu_s\cos\theta + \sin\theta\right)}{\cos\theta - \mu_s\sin\theta}$$

Dividing both Nr. & Dr. of RHS by $\cos\theta$

$$v_{max}^2 = \frac{\left[\dfrac{rg\left(\mu_s\cos\theta + \sin\theta\right)}{\cos\theta}\right]}{\left[\dfrac{\cos\theta - \mu_s\sin\theta}{\cos\theta}\right]}$$

$$\boxed{v_{max} = \sqrt{\frac{r\,g\,(\mu_s + \tan\theta)}{1 - \mu_s\tan\theta}}} \cdots\cdots\cdots(5)$$

This is the **maximum speed to avoid skidding** of the vehicle.

<u>Without considering friction</u>,
put $\mu_s = 0$ in eqn (5)

$$\therefore \boxed{v'_{max} = \sqrt{r\,g\tan\theta}}$$

This is the **maximum speed to avoid wear and tear** of tyres.

53P. A circular racetrack of radius **300m** is banked at an angle of 15^0. If the coefficient of static friction between the wheel of a race car and the road is 0.2, what is the (a) optimum speed of the race car to avoid wear and tear of its tyres, and (b) maximum permissible speed to avoid slipping?

Ans:

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