Question Bank

CHAPTER 5- LAWS OF MOTION

Each question scores One

1 Newton's first law of motion describes the.......................(Energy , Momentum , Inertia, work)

Ans: Inertia.

2 The rate of change of total momentum of a system of many-particles is proportional to the......................on the system.
i. external force
ii. a sum of the internal forces

Ans: (i) external force.

3 The optimum speed of a car on a banked road to avoid wear and tear on its tyres is given by ....

i. $\sqrt{Rg \tan\theta}$ ii. $\sqrt{Rg \cot\theta}$ iii. $\sqrt{Rg \sin\theta}$ iv. $\sqrt{Rg \cos\theta}$

Ans: (i) $\sqrt{Rg \tan\theta}$

4 State true or false.
An iron ball and a wooden ball of the same radius are released from a height in vacuum; the iron ball will reach the ground first.

Ans: False.

5 The mass of a body which is equal to the ratio of the force acting on a body to the acceleration produced in the body is

(a) the gravitational mass (b) the electromagnetic mass
(c) the internal mass (d) the inertial mass

Ans: (d) the inertial mass.

6 The force required to produce an acceleration of 2 m/s^2 on a mass of 2 kg is
(a) 4 N (b) 10 N
(c) 22 N (d) 18 N

Ans: (a) 4N

7 A machine gun fires a bullet of mass 40 g with a velocity of 1200 ms^{-1}. The man holding it can exert a maximum force of 144 N on the gun. How many bullets can he fire per second at the most?
(a) one (b) four
(c) two (d) three

Ans: (d) three

8	A block of wood is placed on a surface. A force is applied parallel to the surface to move the body. The frictional force developed acts (a) normal to the surface upwards (b) normal to the surface downwards (c) along the direction of the applied force (d) opposite to the direction of the applied force Ans: (d) opposite to the direction of the applied force
9	A block of mass M is placed on a flat surface. A force is applied to move it parallel to the surface. The frictional force f developed is proportional to the (a) square of the mass of the body (b) mass of the body (c) reciprocal of the mass of the body (d) reciprocal of the square of the body Ans: (b) mass of the body
10	Two bodies of masses 4 kg and 5 kg are acted upon by the same force. If the acceleration of lighter body is 2 m/s^2, the acceleration of heavier body is (a) 1 m/s^2 (b) 1.2 m/s^2 (c) 1.6 m/s^2 (d) 1.8 m/s^2 Ans: (c) 1.6 m/s^2
11	Newton's second law defines ------------------ Ans: Force
12	A bullet of mass 25 g moving with a velocity of 200 cm/s is stopped within 5 cm of the target. The average resistance offered by the target is (a) 1 N (b) 2 N (c) 3 N (d) 4 N Ans: (a) 1N
13	A block is placed above a table. The frictional force acting on it is.... a) static friction. b) kinetic friction. c) Rolling friction. d)No friction. Ans: No friction
14	Rocket propulsion is based on the principle.........? Ans: Law of conservation of momentum.
15	Maximum value of friction is called....... Ans: Limiting friction.
16	The area under force time graph is....... Ans: Impulse or change in momentum
17	If two highly polished surfaces are placed in contact and tried to move one over the other. Does the friction........ (Increase/decrease) Ans: increase

Each question scores Two

1	State the law of conservation of Linear momentum Ans: The law of conservation of momentum states that "The total momentum of an isolated system is conserved."
2	Using Newton's second law of motion, derive the equation F = ma Ans: By Newton's second law, $\vec{F}=k\frac{d\vec{P}}{dt}$ But $\vec{P}=m\vec{v}$ Therefore $\vec{F}=k\frac{d(m\vec{v})}{dt}$ $\vec{F}=km\frac{d\vec{v}}{dt}$ $\vec{F}=km\vec{a}$ But k=1 Therefore $\vec{F}=m\vec{a}$
3	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/s collide and rebound with same speed. What is the impulse imparted to each ball due to other? Ans: (a)Ns or kg m/s. (b)Impulse = Change in momentum = 0.05 x (6-(-6))= 0.6 Ns.
4	State the law of conservation of linear momentum and prove it on the basis of second law of motion. Ans: The law of conservation of momentum states that "The total momentum of an isolated system is conserved." Consider two bodies A and B, with initial momenta P_A and P_B. And after collision the final momenta P'_A and P'_B respectively. By the Second Law $\mathbf{F}_{AB}\Delta t = \mathbf{p}'_A - \mathbf{p}_A$ and $\mathbf{F}_{BA}\Delta t = \mathbf{p}'_B - \mathbf{p}_B$ Since $\mathbf{F}_{AB} = -\mathbf{F}_{BA}$ by the third law, $\mathbf{p}'_A - \mathbf{p}_A = -(\mathbf{p}'_B - \mathbf{p}_B)$ i.e. $\mathbf{p}'_A + \mathbf{p}'_B = \mathbf{p}_A + \mathbf{p}_B$ which shows that the total final momentum of the isolated system equals its initial momentum.

5 Match the following

Sl No	A	B
1	Newton's first law	Change in momentum
2	Conservation of linear momentum	Action ↔ reaction
3	Newton's third law	Law of inertia
4	Impulse	Momentum before collision= Momentum after collision

Ans:

Sl.No	A	B
1	Newton's First law	Law of inertia
2	Conservation of Linear momentum	Momentum before collision = Momentum after collision
3	Newton's third law	Action <-> Reaction
4	Impulse	Change in momentum.

6 A cricketer moves his hands backwards while holding a catch. Write the reason.

Ans: To reduce the impact of momentum by increasing the time of contact.

7 Friction is a necessary and evil, Justify.

Ans: Frictional force causes a lot of losses in general upkeep and wear and tear of machinery. ... But almost all crucial tasks cannot be carried out without the presence of friction. Basic activities like walking and writing on a surface are possible due to friction. Hence it is considered as a necessary evil

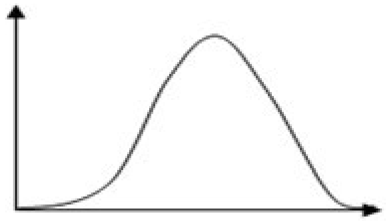
8 Why long jump is done to loose land ?

Ans: Athlete is made to land on the sand after long jump so as to increase the time of impact. This reduces the momentum and force by which he is landing on the ground. Thus, athlete is saved from getting injured.

9 Brittle utensils are packed with straw or paper piece. Why?

Ans: It is to increase the time, so that impulse can be minimised

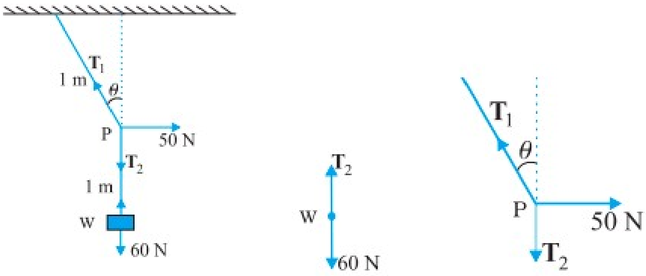
10 The force acting on a particle with time is represented in the graph



a. Area under this curve is called …………..
b. Explain why easily breakable materials are wrapped in paper or straw pieces while packing ?

	Ans: a. Impulse b. In order to increase the time taken for change in momentum and hence decrease the impulsive force acting on it during a jerk.
11	What are the ways to reduce friction between two surfaces? Ans: 1)Apply oil or lubricants. 2) Use ball bearings. 3) Streamlining
12	A man cycling towards east. The direction of friction acting on the front tyre is..... And that of rear wheel is........ Ans: For front tyre friction is towards west. For rear tyre friction is towards east.
13	Why train bogies are connected with buffers Ans: It is use to dump the unwanted vibration produce by running train. Its dump the vibration otherwise these vibration can damage train bogie. All the parts are made from iron , iron shape can be change by these powerful vibration and it will decrease the safety of train
14	Explain why a passenger standing in a moving bus tends to fall forward while the driver applies a sudden brake ? Ans: explanation based on Inertia of motion
15	A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of 12m/s. a. Does it violate the conservation of momentum ? b. Calculate the impulse imparted to the ball and the force applied by the batsman , if the mass of ball is 0.15 kg and it is in contact with the bat for 1 ms
16	A man cycling towards east. The direction of friction acting on the front tyre is..... And that of rear wheel is........ Ans: For front tyre friction is towards west. For rear tyre friction is towards east.
17	Define 1N? Ans: It is the force acting on a mass of 1Kg produce an acceleration of $1 m/s^2$.
18	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 Ans: Before explosion $\vec{p}_i=0$ After Explosion $\vec{P}=0$ $\vec{P}_1+\vec{P}_2+\vec{P}_3=0$ $\vec{P}_3=-(\vec{P}_1+\vec{P}_2)$ $\lvert\vec{P}_3\rvert=\lvert\vec{P}_1+\vec{P}_2\rvert$ $mv_3=\sqrt{P_1^2+P_2^2}$ $mv_3=\sqrt{(mv_1)^2+(mv_2)^2}$ $v_3=\sqrt{v_1^2+v_2^2}$ $v_3=\sqrt{9^2+12^2}$ $v_3=\sqrt{225}$ $v_3=15 m/s$

19	See Fig. 5.8. 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 midpoint P of the rope, as shown. What is the angle the rope makes with the vertical in equilibrium ? (Take g = 10 m s^{-2}). Neglect the mass of the rope.



(a) (b) (c)

Fig. 5.8

Ans: Example 5.6 (NCERT Text book)

Answer Figures 5.8(b) and 5.8(c) are known as free-body diagrams. Figure 5.8(b) is the free-body diagram of W and Fig. 5.8(c) is the free-body diagram of point P.

Consider the equilibrium of the weight W. Clearly, $T_2 = 6 \times 10 = 60$ N.

Consider the equilibrium of the point P under the action of three forces - the tensions T_1 and T_2, and the horizontal force 50 N. The horizontal and vertical components of the resultant force must vanish separately :

$$T_1 \cos\theta = T_2 = 60 \text{ N}$$

$$T_1 \sin\theta = 50 \text{ N}$$

which gives that

$$\tan\theta = \frac{5}{6} \text{ or } \theta = \tan^{-1}\left(\frac{5}{6}\right) = 40^o$$

Note the answer does not depend on the length of the rope (assumed massless) nor on the point at which the horizontal force is applied.

Each question scores Three

1	A light bullet is fired from a heavy gun.

(a)Choose the correct

(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.

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

(b) By the conservation of linear momentum,

Momentum after firing = Momentum before firing

MV +mv =0

MV = -mv

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

2 A gun moves backward when a shot is fired from it.

(a) Choose the correct statement.

(i)The momentum of the gun is greater than that of the shot.

(ii)The momentum acquired by the gun and shot have the same magnitude.

(iii)Gun and shot acquire the same amount of kinetic energy.

(b)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?

Ans: (a)(ii) The momentum acquired by the gun and shot have the same magnitude.

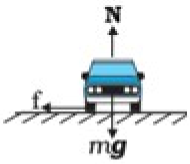
(b) Recoil speed of the gun , $V=\frac{-mv}{M}$

3 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?

Ans: (a)



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

ie $\mu_S N \geq F_C$

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

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

$v^2 \leq \mu_s r g$

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

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

4 A machine gun fires bullets of mass 40 g each with a speed of 1200 ms $^{-1}$.The person can hold the gun with a maximum force of 144 N. What is the maximum number of bullets that can be fired per second from the gun?

Ans:

By Newton’s second law of motion

$$F=\frac{dp}{dt}=\frac{n(mv)}{dt}$$

Where ‘n’ is the number of bullets per second.

Therefore $144=\frac{n(40\,x\,10^{-3}\,x\,1200)}{1}$

$n=\frac{144}{48}$ =3 bullets.

5 A ball of mass 50g is moving with a velocity 20 m/s hit on a wall and bounce back with same speed. The time of contact between ball and wall is 0.1sec. Find the force due to hitting?

F= m(v-u)/t

$$F=\frac{m(v-u)}{t}$$

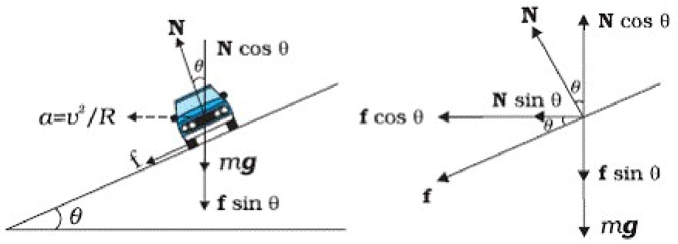
$$F=\frac{0.05(20--20)}{0.1}$$
$$F=\frac{0.05(40)}{0.1}$$
F=20N

Each question scores Four

1 To reduce friction and accident by skidding the roads are banked at curves.
(a)What is meant by banking of roads?
(b)Sketch the schematic diagram of a vehicle on a banked road with friction and mark the various forces.
(c) Derive an expression for maximum safe speed of a vehicle on a banked road with friction.

Ans: (a) The process of raising the outer edge than the inner edge for a curved road is called Banking of road.
The angle through which the outer edge is raised is called **angle of banking**.

(b)



(c)
Let
R--> radius of circular path
θ--> angle of banking
μ_S -->Coefficient of friction.
From the diagram
$$N\cos\theta=mg+f\sin\theta$$
$$N\cos\theta=mg+\mu_S N\sin\theta$$
$$N\cos\theta-\mu_S N\sin\theta=mg$$
$$N(\cos\theta-\mu_S\sin\theta)=mg$$
Therefore $N=\frac{mg}{\cos\theta-\mu_S\sin\theta}$ ------------------(1)

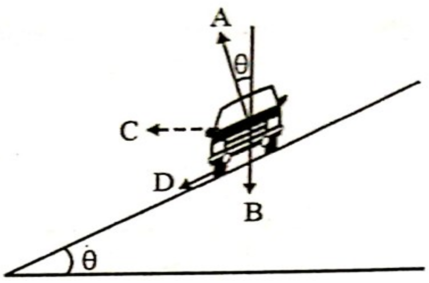
Similarly $\frac{mv^2}{R}=N\sin\theta+f\cos\theta$
$$\frac{mv^2}{R}=N\sin\theta+\mu_S N\cos\theta$$
$$\frac{mv^2}{R}=N(\sin\theta+\mu_S\cos\theta)$$ ----------------(2)

Substituting (1) in (2)
$$\frac{mv^2}{R}=\frac{mg}{\cos\theta-\mu_S\sin\theta}(\sin\theta+\mu_S\cos\theta)$$
$$\frac{v^2}{R}=\frac{g(\sin\theta+\mu_S\cos\theta)}{(\cos\theta-\mu_S\sin\theta)}$$

	$$v^2=\frac{Rg(\sin\theta+\mu_S\cos\theta)}{(\cos\theta-\mu_S\sin\theta)}$$ Therefore $v=\sqrt{\frac{Rg(\sin\theta+\mu_S\cos\theta)}{(\cos\theta-\mu_S\sin\theta)}}$ Dividing by cos θ, $$v=\sqrt{\frac{Rg(\tan\theta+\mu_S)}{(1-\mu_S\tan\theta)}}$$ This is the safe velocity (maximum possible speed) for a vehicle on a banked road.
2	According to Newton's law of motion, the force depends on the rate of change of momentum. a)State whether the force is external or internal? Justify your answer. b)What happens to the linear momentum when the force is absent? c)The motion of a particle of mass m is described y = ut + 1⁄2 gt^2 . find the force acting on the particle. Ans: (a)External force. Because to change the state of body the force must be external. (b) Momentum becomes constant. (c) We have $y=ut+\frac{1}{2}gt^2$ $v=\frac{dy}{dt}=u+gt$ $a=\frac{dv}{dt}=g$ Therefore F=ma =mg
3	Friction is the force which opposes relative motion between two surfaces in contact with each other. (a)What do you mean by limiting static friction ? (b)Obtain the expression for optimum speed of a vehicle on a curved level road. (c)A cyclist speeding at 18 km/h on a level road takes a sharp circular turn of radius 3 m without reducing the speed. The coefficient of static friction between the tyres and the road is 0.1 . Will the cycle slip while taking the turn? Ans: (a). Definition (b). Derivation of V = √μrg (c). For not to slip , $v^2 \le \mu rg$, v^2 = 5 x 5 = 25 μrg = 0.1 x 3 x 9.8 = 2.94. The condition is not obeyed so he will slip.
4	Aristotle had an idea that constant force is required to produce a constant velocity. Hence he concluded that in the absence of forces bodies would come to rest. a. State Newton's first law of motion b. Why a horse cannot pull a cart and run in empty space ? c. The motion of a particle of mass 'm' is described by y = At + Bt^2. Find the force acting on the particle Ans: a. Definition b. In empty space there will not be reaction required for the forward move c. Comparing the equation with s = ut + ½ at^2 , we get a = 2B , so f = ma = 2mB

Each question scores Five

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



(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.

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

B--> Weight (mg).

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

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

$$f_S \leqslant \mu_S N$$

2 A vehicle of mass m is moving on a banked road of radius r.

(a) What are various forces acting on the vehicle ?

(b) Obtain an expression for maximum safe speed of the vehicle on a banked road.

(c) A circular road of radius 300 m is banked at an angle of 15°. If the coefficient of friction between the wheels of a car and the road is 0.2, what is the optimum speed of the car ? (g = 9.8 m/s 2)

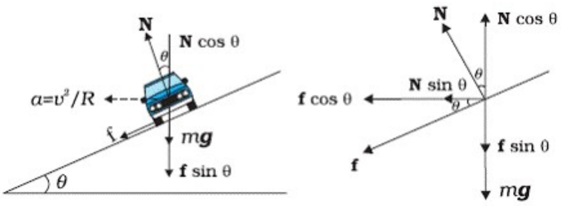
Ans: (a) Normal Reaction (N).

Weight (mg).

Centripetal force ($\frac{mv^2}{R}$)

Frictional force.(f_S)

(b)



Let

R--> radius of circular path

θ--> angle of banking

μS -->Coefficient of friction.

From the diagram

$$N\cos\theta = mg + f\sin\theta$$
$$N\cos\theta = mg + \mu_S N\sin\theta$$
$$N\cos\theta - \mu_S N\sin\theta = mg$$
$$N(\cos\theta - \mu_S\sin\theta) = mg$$

Therefore $N = \dfrac{mg}{\cos\theta - \mu_S\sin\theta}$ ------------------(1)

Similarly $\dfrac{mv^2}{R} = N\sin\theta + f\cos\theta$

$$\frac{mv^2}{R} = N\sin\theta + \mu_S N\cos\theta$$
$$\frac{mv^2}{R} = N(\sin\theta + \mu_S\cos\theta) \quad \text{----------------(2)}$$

Substituting (1) in (2)

$$\frac{mv^2}{R} = \frac{mg}{\cos\theta - \mu_S\sin\theta}(\sin\theta + \mu_S\cos\theta)$$
$$\frac{v^2}{R} = \frac{g(\sin\theta + \mu_S\cos\theta)}{(\cos\theta - \mu_S\sin\theta)}$$
$$v^2 = \frac{Rg(\sin\theta + \mu_S\cos\theta)}{(\cos\theta - \mu_S\sin\theta)}$$

Therefore $v = \sqrt{\dfrac{Rg(\sin\theta + \mu_S\cos\theta)}{(\cos\theta - \mu_S\sin\theta)}}$

Dividing by cos θ,

$$v = \sqrt{\frac{Rg(\tan\theta + \mu_S)}{(1 - \mu_S\tan\theta)}}$$

This is the safe velocity (maximum possible speed) for a vehicle on a banked road.

(c) Optimum speed $v = \sqrt{\dfrac{Rg(\tan\theta + \mu_S)}{(1 - \mu_S\tan\theta)}}$

$$v = \sqrt{\frac{300\,x\,9.8(\tan 15 + 0.2)}{(1 - 0.2\,x\tan 15)}} \quad = 38.1 \text{ m/s}$$

3 Static friction opposes impending motion.

(a)Write the mathematical equation connecting the limiting value of static friction with Normal reaction.

(b)Choose the correct statement.

(i) Both kinetic friction and static friction are independent of area of contact.
(ii) Kinetic friction depends on area of contact but static friction do not.
(iii) static friction depends on area of contact but kinetic friction do not.
(iv) Both kinetic friction and static friction depends on area of contact

(c) A mass rest s on a horizontal plane. The plane is gradually inclined until at an angle θ with the horizontal, the mass just begins to slide. Show that the coefficient of static friction between the block and surface is equal to tanθ.

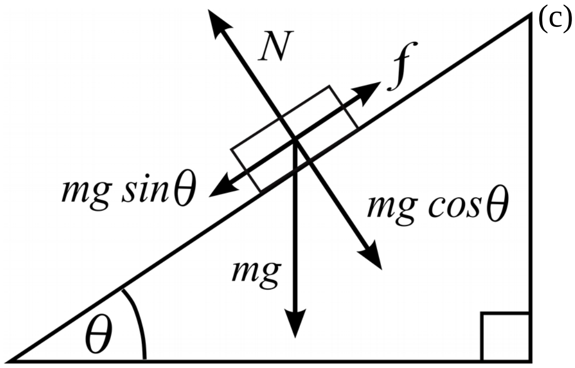
Ans: (a)The limiting static friction varies with the normal force(N) approximately as $f_S^{max} = \mu_S N$

Where μ_S is a constant and is called as coefficient of static friction.

N is the normal reaction.

(b) (i)Both kinetic friction and static friction are independent of area of contact.

(c)



From the diagram, f_S =mg sinθ and N = mg cos θ

μ_S N = mg sinθ ------(1)

N = mg cos θ-------(2)

Dividing (1) by (2) Coefficient of static friction, $\mu_S = \tan\theta$.

4 The static friction comes into play at the moment the force is applied.

(a) Write the relation between static friction and normal reaction.

(b) Determine the maximum acceleration of the train in which a box lying on its floor will remain stationary, given that the coefficient of static friction between the box and the train's floor is 0.15.

(c)State the laws of limiting friction.

Ans:

(a)The limiting static friction varies with the normal force(N) approximately as

$$f_S^{max} = \mu_S N$$

Where μ_S is a constant and is called as coefficient of static friction.

N is the normal reaction.

(b) To be stationary , $f_S^{max} = \mu_S N$ =ma

$$\mu_S mg = ma$$

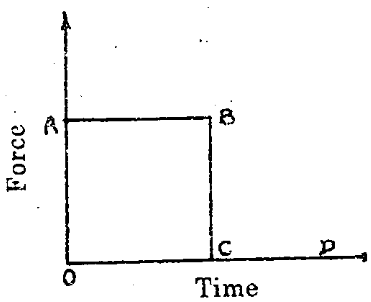
$$a = \mu_S g = 0.15 x 10 = 1.5 ms^{-2}$$

(c)Law of Static Friction:

The law of static friction may be written as

$$f_S \leqslant \mu_S N$$

5 The given graph ABCD shows variation of force with time for a body placed on a smooth horizontal surface.



(a) Using the given graph, state whether the following statements are true or false.
   i) The force acting on a body along AB is constant.
   ii) The force acting on a body along CD is zero.

(b) i) State the law of conservation of linear momentum.
   ii) Find the region on the graph at which the body moves with constant momentum.
   Iii) Draw a momentum time graph for the given graph.

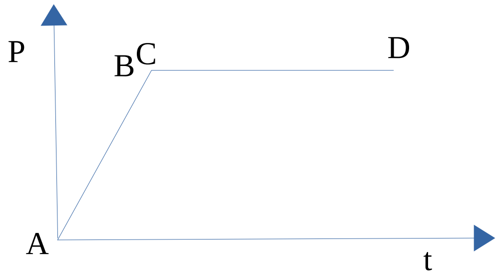
Ans: (a) (i)True

(ii)True.

(b) (i)The law of conservation of momentum states that "The total momentum of an isolated system is conserved."

(ii) CD (If Force is equal to zero , momentum remains constant).

(iii)



6 a) State the following statements are True or False. Correct the statements if false.

i. A spring balance gives the mass of a body while a common balance gives its weight.

ii. If the same force is applied on two bodies of different masses for the same time, then the change in momentum of two bodies is the same.

b) State Newton's second law and arrive at the equation of force.

c) A motorcycle and a bus are moving with same momentum. Which of them has greater kinetic energy? Justify.

Ans: (a) (i) False: Spring balance gives weight but common balance gives mass.

(ii) True: Because F dt =dp.

(b) It states that "The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the applied force."

$$\vec{F}\,\alpha\,\frac{d\vec{P}}{dt} \quad \text{OR} \quad \vec{F}=k\frac{d\vec{P}}{dt}$$

Expression for Force:

By Newton's second law,

$$\vec{F}=k\frac{d\vec{P}}{dt}$$

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

Therefore

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

$$\vec{F}=k\,m\frac{d\vec{v}}{dt}$$

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

But k=1 Therefore $\vec{F}=m\vec{a}$

(c) We have $KE=\frac{P^2}{2m}$

As momentum are equal $KE\,\alpha\frac{1}{m}$

As $m_{bus}>m_{cycle}$ we get $KE_{cycle}>KE_{bus}$

7 Friction is defined as the force which opposes the relative motion between two surfaces in contact.

a) Friction is a necessary evil. Explain.

b) What is meant by banking of roads?

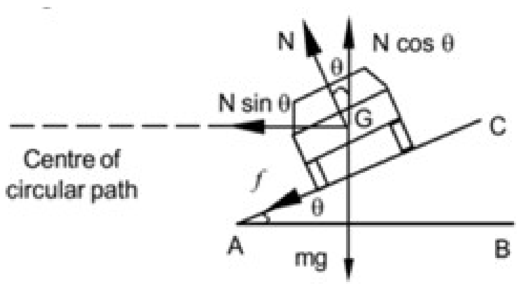
c) Obtain an expression for maximum speed on a banked road without considering friction.

Ans: (a)**Frictional** force causes a lot of losses in general upkeep and wear and tear of machinery. Hence it is considered as a **evil**.. Basic activities like walking and writing on a surface are possible due to **friction**. Hence it is considered as a **necessary evil** .

(b)The process of raising the outer edge than the inner edge for a curved road is called Banking of road.

The angle through which the outer edge is raised is called **angle of banking**.

(c)



From the diagram,

$mg = N\cos\theta$ ----------------(1)

$\frac{mv^2}{r} = N\sin\theta$ ---------------(2)

Dividing (2) by (1)

$\frac{v^2}{rg} = \tan\theta$

$v^2 = rg\tan\theta$

Therefore $v = \sqrt{rg\tan\theta}$

This is the expression for maximum speed on a banked road without considering friction

8 We are familiar with Newton's laws of motion.

a) State Newton's second law of motion.

b) Using the above law, explain:

i. Impulse – momentum principle

ii. Law of conservation of linear momentum

c) A circular racetrack of radius 300 m is banked at an angle of 15 ^{0} . The coefficient of friction between the wheels of a race car and the road is 0.2. Find:

i. The optimum speed of the race car to avoid wear and tear on its tyres.

ii. Maximum permissible speed to avoid slipping.

Ans: (a) It states that "The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the applied force."

$\vec{F}\,\alpha\,\frac{d\vec{P}}{dt}$ OR $\vec{F} = k\frac{d\vec{P}}{dt}$

(b) (i) By Newton's second law of motion, $\vec{F} = \frac{d\vec{P}}{dt}$

Therefore Fdt =dp

That is Impulse = Change in momentum.

This is the impulse – momentum principle.

(ii) The law of conservation of momentum states that "The total momentum of an isolated system is conserved."

By Newton's second law of motion, $\vec{F} = \frac{d\vec{P}}{dt}$

If F=0, dP=0 that is the momentum remains constant.

(c) (i) The optimum speed of the race car to avoid wear and tear on its tyres.

$v=\sqrt{rg\tan\theta}$

$v=\sqrt{300\,x\,9.8\,x\tan 15}=29\,m/s$

(ii) Maximum permissible speed to avoid slipping.

$$v=\sqrt{\frac{Rg(\tan\theta+\mu_S)}{(1-\mu_S\tan\theta)}}$$

$$v=\sqrt{\frac{300\,x\,9.8\,(\tan 15+0.2)}{(1-0.2\,x\tan 15)}}\quad =38.1 \text{ m/s}$$

9 A circular track of radius 400m is kept with outer edge raised to make 5 degrees with the horizontal.

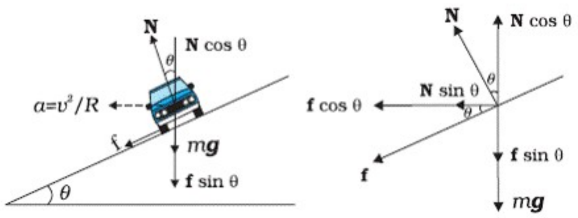
a) What do you call this type of construction of tracks?

b) Obtain an expression for the maximum permissible speed considering the force of friction.

c) Calculate the permissible speed of the car if the coefficient of friction is 0.2.

Ans: (a)Banking of roads.

(b)



Let R--> radius of circular path

θ --> angle of banking

μ_S -->Coefficient of friction.

From the diagram

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

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

$N\cos\theta-\mu_S N\sin\theta=mg$

$N(\cos\theta-\mu_S\sin\theta)=mg$

Therefore $N=\dfrac{mg}{\cos\theta-\mu_S\sin\theta}$ ------------------(1)

Similarly $\dfrac{mv^2}{R}=N\sin\theta+f\cos\theta$

$\dfrac{mv^2}{R}=N\sin\theta+\mu_S N\cos\theta$

$\dfrac{mv^2}{R}=N(\sin\theta+\mu_S\cos\theta)$ ----------------(2)

Substituting (1) in (2)

$$\frac{mv^2}{R}=\frac{mg}{\cos\theta-\mu_S\sin\theta}(\sin\theta+\mu_S\cos\theta)$$

$$\frac{v^2}{R}=\frac{g(\sin\theta+\mu_S\cos\theta)}{(\cos\theta-\mu_S\sin\theta)}$$

$$v^2=\frac{Rg(\sin\theta+\mu_S\cos\theta)}{(\cos\theta-\mu_S\sin\theta)}$$

Therefore $v=\sqrt{\dfrac{Rg(\sin\theta+\mu_S\cos\theta)}{(\cos\theta-\mu_S\sin\theta)}}$

Dividing by cos θ,

$$v=\sqrt{\frac{Rg(\tan\theta+\mu_S)}{(1-\mu_S\tan\theta)}}$$

This is the safe velocity (maximum possible speed) for a vehicle on a banked road.

(c)Maximum permissible speed to avoid slipping.

$$v=\sqrt{\frac{Rg(\tan\theta+\mu_S)}{(1-\mu_S\tan\theta)}}$$

$$v=\sqrt{\frac{400\,x\,9.8(\tan 5+0.2)}{(1-0.2\,x\tan 5)}}$$

$$v=\sqrt{\frac{400\,x\,9.8\,x(0.287)}{(1-0.0174)}}=\sqrt{\frac{1125.04}{0.9826}}=33.84\,m/s$$