PHYSICS INDUCTION
An institute of Science & Mathematics

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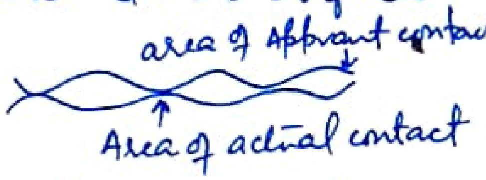
NOTES : CLASS XI : CHAPTER-4 : LAWS OF MOTION (PHY)

FRICTION :- Opposing force that comes into play, when one body moves or even tries to move over the surface of another body. It arises because of the irregularities b/w the surfaces in contact.

Old View :

Modern View :



When bonds are broken, new bonds are formed, local deformation arises. → send vibrations → vibrations finally damp out. & energy increases random motion → bodies heated → F is needed.

f : Non-conservative

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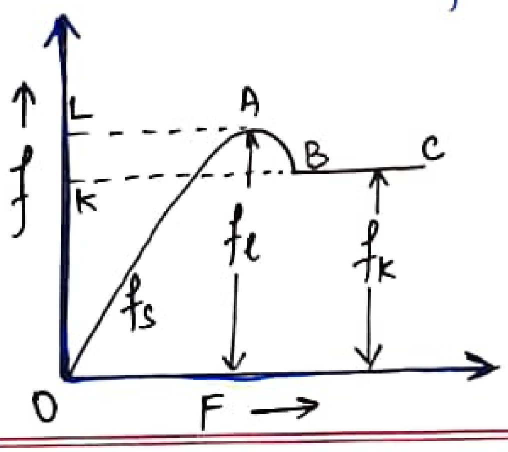
CLASSIFICATION OF FRICTION :-

f
- → Internal f : relative motion b/w any two layers of liq e.g. – viscosity
- → External f : Actual relative motion b/w two bodies in contact
  - static friction (f_s)
  - Limiting friction (f_ℓ)
  - Kinetic friction / Dynamic friction (f_k)
    - Sliding friction
    - Rolling friction



f_k is slightly less than f_ℓ

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f_s :- The opposing force that comes into play, when one body tends to move over the surface of another body, but the actual motion has yet not started is called static friction.

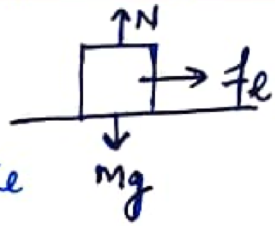
f_s opposes impending motion

f_ℓ :- Limiting friction is the maximum opposing force that comes into play, when one body is just at the verge of moving over the surface of other body.

f_K :- Kinetic friction / Dynamic friction is the opposing force that comes into play when one body is actually moving over the surface of another body.

f_s is a self Adjusting force :- f_s adjusts itself so that its magnitude is equal to the magnitude of the applied force & direction is opposite to that of the applied force. $f_s = F$

Laws of f_e :- (i) $f_e \propto N$

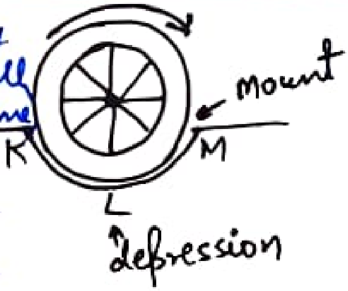


(ii) direction of f_e is opposite to the direction in which the body is at the verge of moving over the other.

(iii) f_e is independent of the apparent area of contact, so long as N b/w 2 bodies remains the same.

(iv) depends upon the nature of material of the surfaces in contact.

Cause of Rolling Friction :- Area of contact: Very small



velocity at the point of contact = 0 (all the time)
wheel constantly pulls out of depression & goes uphill on the mount, detaches itself from KL, which is opposed by the adhesive forces b/w the surfaces in contact.

Coefficient of f :- $f \propto N$ (Ist law)

$\Rightarrow \boxed{f = \mu N}$

coeff. of f

$\mu = \frac{f}{N}$; It has no units.

μ depends :-
- Nature of the surfaces in contact (Dry/wet/polished/rough/smooth)
- Material of the surfaces in contact

Law of static friction : $f_s \leq \mu_s N$

if $F > (f_s)_{max} \rightarrow$ the body begins to slide.

Law of Kinetic friction : $f_K = \mu_K N$

As, $f_K < f_e \Rightarrow \mu_K < \mu_s$

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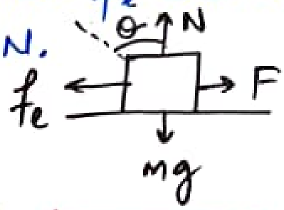
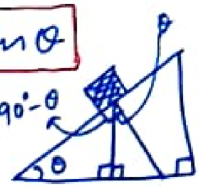
Angle of Friction :- ∠ which the resultant of the f_e and Normal reaction, N makes with the direction of N.



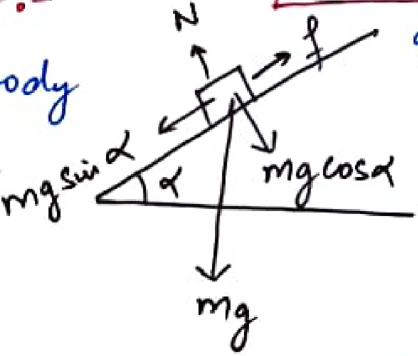
θ depends upon the material & nature of surfaces in contact. $\tan\theta = \frac{f_e}{N} = \mu$

$\Rightarrow \boxed{\mu = \tan\theta}$



Angle of Repose / Angle of sliding :-

Minimum angle so that the body placed on a plane just begins to slide down.



$f = mg\sin\alpha$

$N = mg\cos\alpha$

$\mu = \frac{f}{N} = \frac{mg\sin\alpha}{mg\cos\alpha} = \tan\alpha \Rightarrow \boxed{\mu = \tan\alpha}$

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But, $\mu = \tan\theta \Rightarrow \tan\alpha = \tan\theta \Rightarrow \boxed{\alpha = \theta}$

i.e., Angle of friction is equal to angle of repose.

Acceleration of a body down a rough inclined plane :-

θ > angle of repose

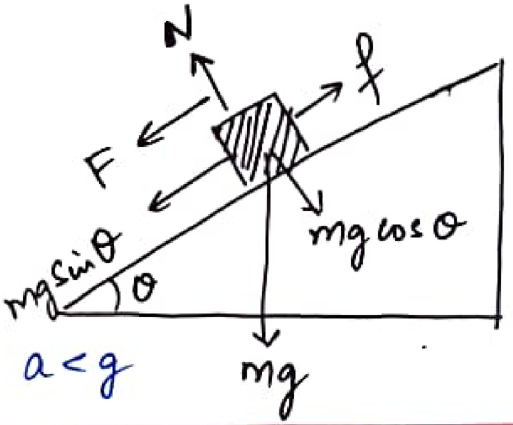
$F = mg\sin\theta - f$

$\Rightarrow ma = mg\sin\theta - \mu N$

$\Rightarrow ma = mg\sin\theta - \mu mg\cos\theta$

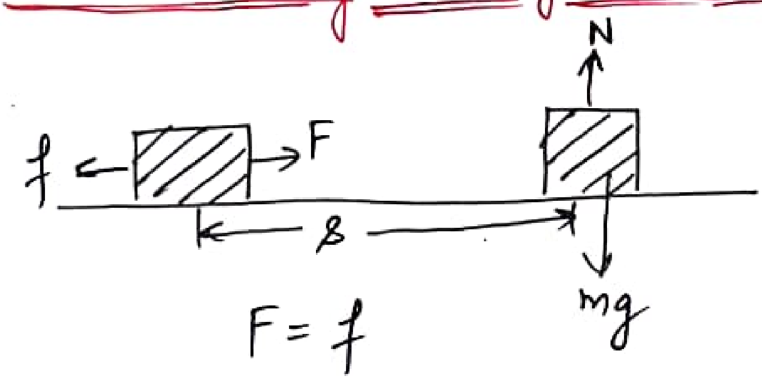
$\Rightarrow a = g\sin\theta - \mu g\cos\theta$

$\Rightarrow \boxed{a = g(\sin\theta - \mu\cos\theta)}$



$a < g$

W.D. in moving a body over a rough horizontal surface :-



$F = f$

$W = F \times s$

$= f \times s$

$= \mu N \times s$

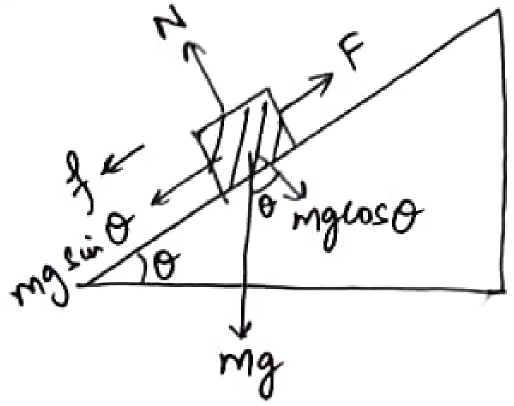
$= \mu mg \times s$

nature weight distance

W.D. in moving a body up a rough inclined plane :

$N = mg\cos\theta$

$F = mg\sin\theta + f$



$$\begin{aligned} \text{W.D.} &= (mg\sin\theta + f)s \\ &= (mg\sin\theta + \mu N)s \\ &= (mg\sin\theta + \mu mg\cos\theta)s \\ &= mg(\sin\theta + \mu\cos\theta)s \end{aligned}$$

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f : Necessary Evil :
- **Necessity :** Walking, writing, working of brakes, cleaning, no sticking, machine parts working
- **Evil :** Energy loss, wear & tear, heat production

Ways to reduce f :- Polishing, lubrication, material selection, streamlining, Using Ball-Bearings, Air cushion

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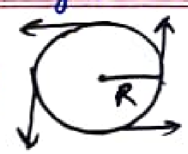
Dynamics of Circular Motion :-

Circular motion is accelerated, direction of motion of the object changes at every point in Circular Motion.



Centripetal Force :- It's required to move a body uniformly in a Circle. It acts along the radius & towards the centre.

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

$$\boxed{a_c = \frac{v^2}{R} = R\omega^2 = \omega v}$$

$$f_c = ma_c$$

As, $\omega = \frac{2\pi}{T}$ & $v = \frac{2\pi R}{T}$

$$\therefore \boxed{a_c = \frac{4\pi^2 r}{T^2} = 4\pi^2 r \nu^2} \qquad \left(\because \frac{1}{T} = \nu\right)$$

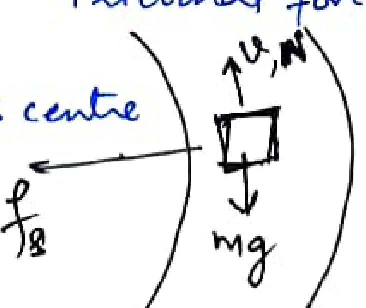
Circular Turnings :-

External forces : Weight (mg), Normal Reaction (N), Frictional force (f).

Case - 1 : Horizontal Road :-

Tyres - tendency to skid outward;

f_s opposes the skidding act; towards centre



$$\begin{aligned} f_s &= \mu_s N \\ &= \mu_s mg \quad (\because N = mg) \end{aligned}$$

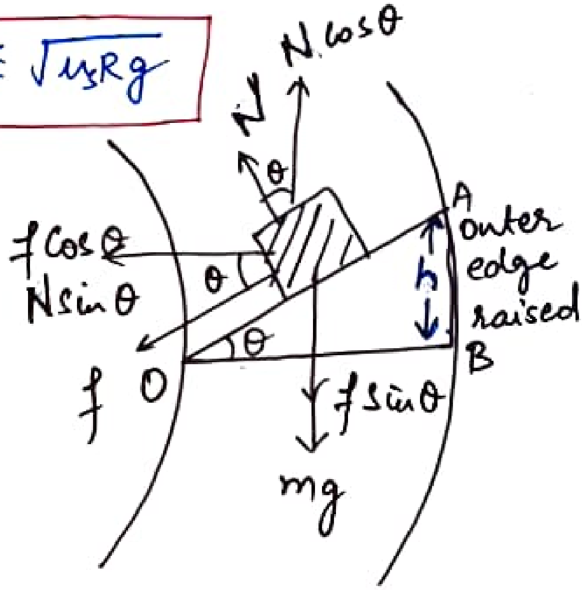
for a safe turn, $\frac{mv^2}{R} = f_s$ ← provides necessary centripetal force.

f_s can't exceed $\mu_s R$: $f_s \leq \mu_s mg$

$$\Rightarrow \frac{mv^2}{R} \leq \mu_s mg$$

$$\Rightarrow \boxed{\mu_s \geq \frac{v^2}{Rg} \Rightarrow v \leq \sqrt{\mu_s Rg}}$$

Case-2: Banked Road :-



$$N\cos\theta = mg + f\sin\theta \quad -①$$

$$\& \quad N\sin\theta + f\cos\theta = \frac{mv^2}{R} \quad -②$$

But, $f \leq \mu_s N$

Thus, to obtain v_{max}, we put

$$f = \mu_s N$$

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∴ Eqⁿ ① & ② become

(i) $N\cos\theta = mg + \mu_s N\sin\theta \Rightarrow N = \frac{mg}{(\cos\theta - \mu_s\sin\theta)}$ $-③$

(ii) $N\sin\theta + \mu_s N\cos\theta = \frac{mv^2}{R}$ $-④$

Substituting N from ③ to ④, we get.

$$\frac{mg(\sin\theta + \mu_s\cos\theta)}{\cos\theta - \mu_s\sin\theta} = \frac{mv_{max}^2}{R}$$

$$\Rightarrow v_{max} = \left(Rg\,\frac{\mu_s + \tan\theta}{1 - \mu_s\tan\theta}\right)^{1/2}$$

* Max^m possible speed on a banked road is greater than that on the flat road.

for $\mu_s = 0$, $v_o = (Rg\tan\theta)^{1/2}$

At this speed, frictional force isn't needed at all to provide the necessary centripetal force.