GLOBAL INSTITUTE OF TECHNOLOGY,
JAIPUR

RTU Paper Solution

Branch – Mechanical Engineering

Subject Name – Engineering Mechanics

Paper Code – 3ME3-04

Roll No. ____________ Total No of Pages: 3

3E1116

3E1116

B. Tech. III - Sem. (Main / Back) Exam., Dec. 2019
ESC Mechanical Engineering
3ME3-04 Engineering Mechanics
Common For AE, ME

Time: 2 Hours **Maximum Marks: 80**

Instructions to Candidates:

Attempt all five questions from Part A, four questions out of six questions from Part B and two questions out of three from Part C.

Schematic diagrams must be shown wherever necessary. Any data you feel missing may suitably be assumed and stated clearly. Units of quantities used /calculated must be stated clearly.

Use of following supporting material is permitted during examination. (Mentioned in form No. 205)

1. NIL 2. NIL

PART – A

(Answer should be given up to 25 words only) **[5×2=10]**

All questions are compulsory

Q.1 What is Engineering Mechanics?

Q.2 Explain the principle of virtual work.

Q.3 What is area moment of inertia for disk?

Q.4 Explain the Newton's second law.

Q.5 How couple works?

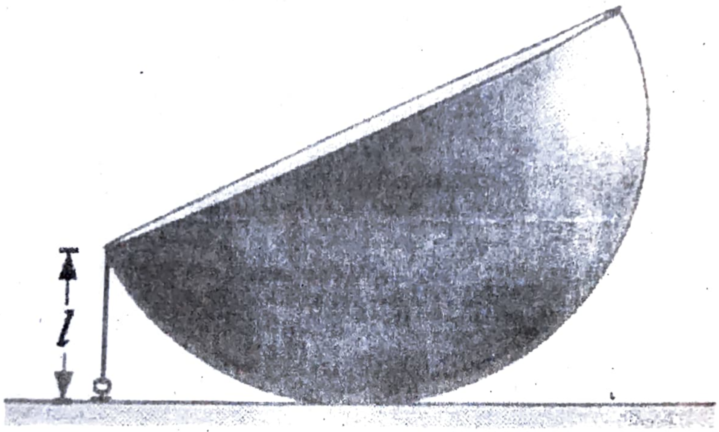
PART – B

(Analytical/Problem solving questions) [4×10=40]

Attempt any four questions

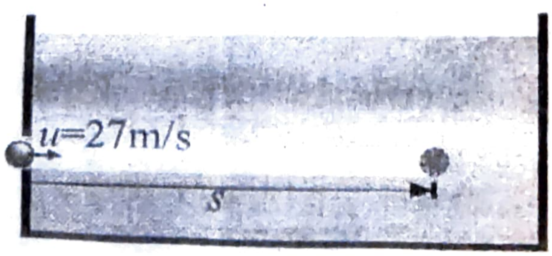
Q.1 State and explain the Varignon's theorem.

Q.2 A hemisphere of radius r and weight W is placed with its curved surface on a smooth table and a string of length l (< r) is attached to a point on its rim and to a point on the table as shown in Figure. Find the tension of the string.



Q.3 Derive an expression for the length of the cross belt.

Q.4 A sphere is fired horizontally into a viscous liquid with an initial velocity of 27 m/s, as shown in Figure. If it experiences a deceleration a = - 6t m/s^2, where t is in seconds, determine the distance travelled before it stops.

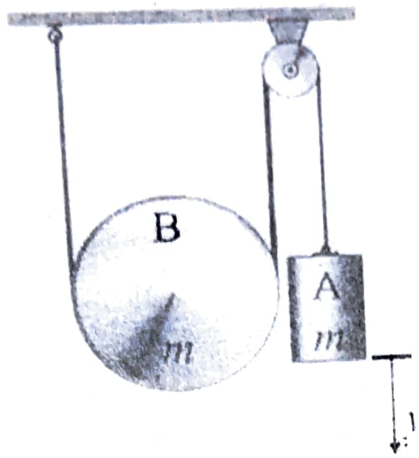


5 Define the angle of friction and angle of repose.

.6 If the system shown in figure is released from rest, find:

(a) velocity v of the falling block A as a function of y.

(b) tensions of the string.



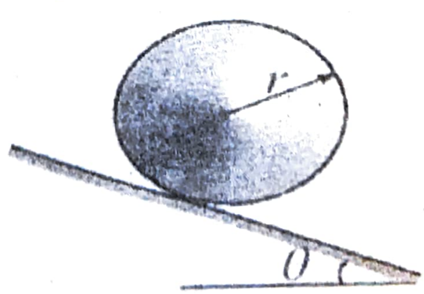
PART – C

(Descriptive/Analytical/Problem Solving/Design Questions) **[2×15=30]**

Attempt any two questions

Q.1 Determine the moment of inertia of a thin elliptical disk of mass m, having axial radius of a and b.

Q.2 Find the minimum value of the coefficient of friction between a body and a plane, so that the body may roll without slipping. As shown in Figure, the radius of gyration and radius of body are k and r, respectively.



Q.3 Write short note on –

(a) Principle of work and energy

(b) Conservation of Energy

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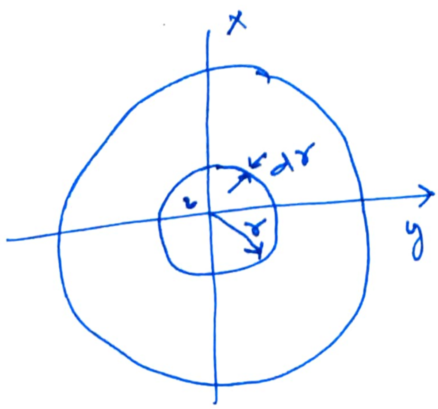
PART-A

Ans-1 Engg. mechanics is the application of mechanics to solve problems involving common engineering elements. The goal of engg. mechanics course is to expose students to problems in mechanics as applied to plausibly real-world scenarios.

Ans-2 Principle of virtual work → If particle is in equilibrium under the action of a number of forces, the work done by the forces for a small arbitary displacement of the particle is zero.

Ans-3 Area moment of inertia for disk:-



In fig, we can see a uniform thin disk with radius r rotating about z-axis passing through the centre

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$$\sigma = \frac{m}{A} \quad or \quad \sigma A = m$$

So, $dm = \sigma(dA)$

$$A = \pi r^2, \quad dA = d(\pi r^2) = \pi dr^2 = 2 r dr$$

$$I = \int_0^R r^2 (\pi r)\, dr$$

$$I = 2\pi\sigma_0 \int_0^R r^3 dr = \frac{2\pi \sigma r^4}{4}$$

$$I = 2\pi \left(m/\pi R^2\right)\left(R^4/4\right)$$

$$\boxed{I = \frac{1}{2} m R^2}$$

Ans-4 Newton's second law:- The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

Ans-5 A couple refers to two parallel forces that are equal in magnitude, opposite in direction and do not share a line of action. A better term is force couple or pure moment. Its effect is to create rotation without translation or, more generally without any acceleration of the centre of mass.

PART-B

Ans-1 Varignon's theorem:- It states that the moment of resultant of all the forces in a plane about any point is equal to the algebric sum of moment of all the forces about the same point.

Proof:- consider a force R acting at a point O. Say P and Q are the resolved components of R. Let R, P & Q form an angle θ, θ_1, θ_2 respectively with x-axis.

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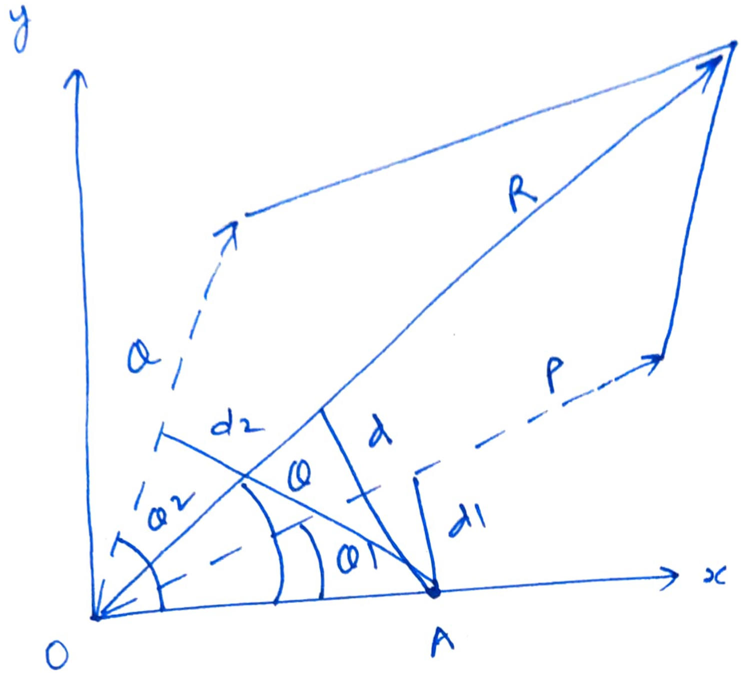

Since R is the resultant of P & Q it follows that the sum $P_y + Q_y$ of the y component of two forces P & Q is equal to the y component R_y of their resultant.

$$R_y = P_y + Q_y$$

$$R_y = R\sin\theta, \quad P_y = P\sin\theta_1 \quad \& \quad Q_y = Q\sin\theta_2$$

$$\therefore R\sin\theta = P\sin\theta_1 + Q\sin\theta_2$$

multiplying both sides by length OA

$$R \times OA\sin\theta = P \times OA\sin\theta_1 + Q \times OA\sin\theta_2$$

But $OA\sin\theta = d$, $OA\sin\theta_1 = d_1$

& $OA\sin\theta_2 = d_2$

$$\therefore \boxed{R \times d = P \times d_1 + Q \times d_2}$$ Hence proved.

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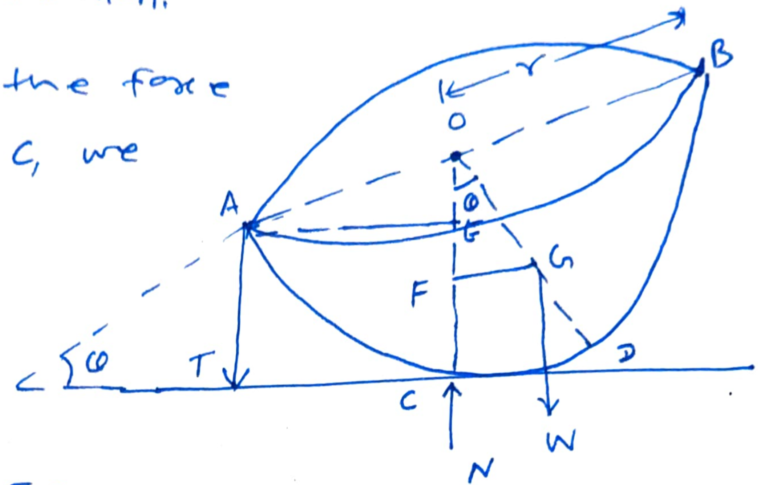
Ans-2

Let the base of the hemisphere be inclined at an angle θ to the horizontal.

taking moment of the force about Contact point C, we have,



$$\Sigma M_C = 0$$

$$\Rightarrow T \times AE - W \times FG = 0$$

$$\Rightarrow T \times r\cos\theta - W \times \frac{3}{8} r\sin\theta = 0$$

$$T = \frac{3W}{8}\tan\theta$$

$$T = \frac{3W}{8} \times \frac{\sin\theta}{\cos\theta} = \frac{3W}{8} = \frac{\sin\theta}{\sqrt{1-\sin^2\theta}}$$

$$T = \frac{3W}{8} \times \frac{[(r-l)/r]}{\sqrt{1-[(r-l)/r]^2}}$$

$$\left\{ \because \sin\theta = \frac{OE}{OA} \quad \sin\theta = \frac{r-l}{r} \right\}$$

$$\boxed{T = \frac{3W}{8} \times \frac{r-l}{\sqrt{2rl-l^2}}}$$

tension of the string $\boxed{T = \frac{3W}{8} \times \frac{r-l}{\sqrt{2rl-l^2}}}$

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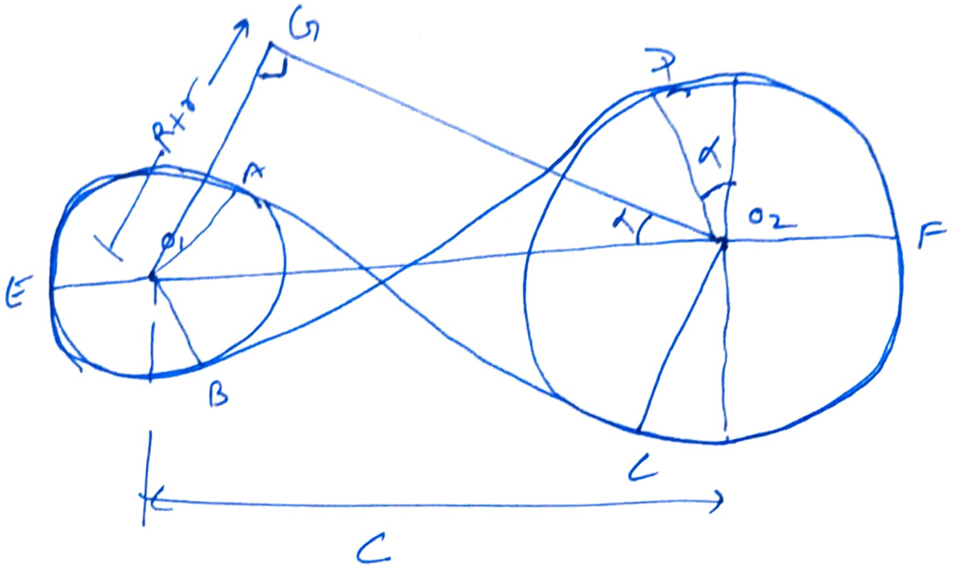
Ans-3 Length of cross belt drive:-

Let r be the radius of smaller pulley, R be the radius of larger pulley, C be the distance between O_1 and O_2, as shown in fig.



total Length of the belt $L =$ Arc $AB + BD +$ Arc $DC + CA$

But Arc $AB = 2$ Arc AE, $BD = AC$ and

Arc $DC = 2$ Arc DF

$\therefore L = 2$ (Arc $AE + AC +$ Arc DF)

Substituting Arc $AE = \left[\left(\frac{\pi}{2}\right) + \alpha\right] r$, Arc $DF = \left[\left(\frac{\pi}{2}\right) + \alpha\right] R$

$AC = C \cos\alpha$ we have

$$L = \pi (R+r) + 2\alpha (R+r) 2C\cos\alpha$$

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Through O_2, draw O_1G parallel to AC From the geometry of the figure, we find O_1G will be perpendicular to O_2D. In ΔO_1O_2G.

$$\sin\alpha = \frac{R+r}{C}$$

Since the angle α is very small,

$$\sin\alpha = \alpha = \frac{R+r}{C}$$

$$AD = O_2G = \sqrt{(O_1O_2)^2 - (GO_1)^2}$$

$$= \sqrt{C^2 - (R+r)^2} = C\left[1 - \left(\frac{R+r}{C}\right)^2\right]^{1/2}$$

Expanding by binomial theorem

$$AD = C\left[1 - \frac{1}{2}\left(\frac{R+r}{C}\right)^2\right] + \text{---}\ ]$$

$$AD = C - \frac{1}{2}\frac{(R+r)^2}{C}$$

$\therefore$ Length of Belt

$$L = 2\left(\frac{\pi}{2}+\alpha\right)r + C - \frac{1}{2}\frac{(R+r)^2}{C} + \left(\frac{\pi}{2}+\alpha\right)R]$$

$$L = \pi(R+r) + 2\alpha(R+r) + 2C - \frac{(R+r)^2}{C}$$

$$\alpha = (R-r)/C$$

$$L = \pi(R+r) + 2\frac{(R+r)^2}{C} + 2C - \frac{(R+r)^2}{C}$$

$$\boxed{L = \pi(R+r) + 2C + \frac{(R+r)^2}{C}}$$

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Ans -4 The acceleration given as a function of time so, that the velocity can be obtained by -

$$a = \frac{dv}{dt} = -6t \Rightarrow dv = -6t\,dt$$

Given → $v = 27$ m/s at $t = 0$

$$\int_{27}^{v} dv = -\int_{0}^{t} 6t\,dt \Rightarrow v - 27 = -3t^2$$

$$\boxed{v = 27 - 3t^2}$$

velocity of sphere becomes zero at $t = \sqrt{(27-0)/3} = 3$

knowing the velocity as a function of time, we can write,

$$v = \frac{ds}{dt} = 27 - 3t^2$$

$$ds = (27 - 3t^2)/dt$$

$$\int_0^s ds = \int_0^3 (27 - 3t^2)\,dt$$

$$s = \left[27t - t^3\right]_0^3$$

$$s = 27(3-0) - (3^3 - 0^3)$$

$$\boxed{s = 54\,m}$$

$\boxed{\text{Distance travelled } s = 54\,m}$

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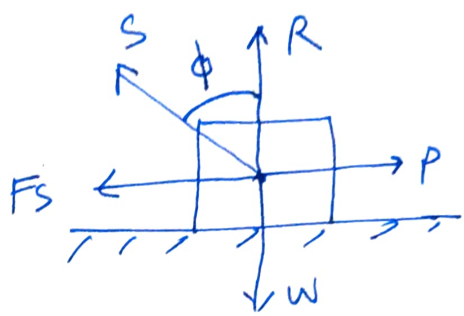
Ans-5 **Angle of Friction:-** It is the angle ϕ which resultant S subtends with the normal to the plane, when the body just starts sliding over the horizontal plane. This angle is also known as limiting angle of friction.

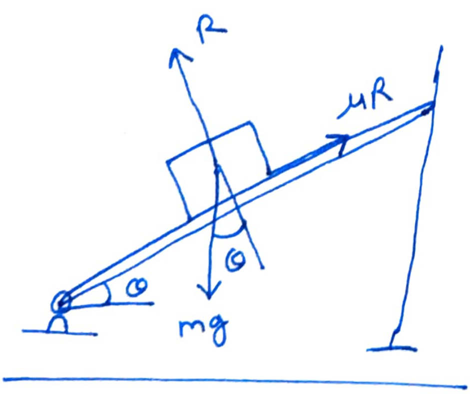
$$\tan\phi = \frac{F_s}{R} = \frac{\mu R}{R}$$

$$\tan\phi = \mu$$

$$\boxed{\phi = \tan^{-1}\mu}$$



Angle of Repose:-



Resolving these forces along the perpendicular to the plane.

$$W\sin\theta - \mu R = 0 \quad \text{——} (1)$$

$$R - W\cos\theta = 0 \quad \text{——} (2)$$

From equations (1) & (2)

$$\mu = \tan\theta$$

In terms of angle of Fr.

$$\tan\phi = \tan\theta$$

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

the maximum angle θ of the inclined plane, at which a block resting on it is about to slide down is called the angle of repose it is equal to the angle of friction.

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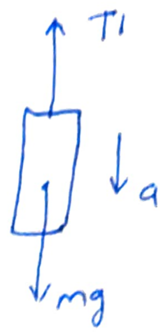
Ans – 6

(a)



(b)

Consider the motion of block A

$$\Sigma F_y = ma_y$$

$$mg - T1 = ma \quad \text{—— (1)}$$

Consider the motion of disk B

$$\Sigma F_y = ma_y \Rightarrow T1 + T2 - mg = \frac{ma}{2} \quad \text{—— (2)}$$

$$\Sigma \tau = I\alpha \Rightarrow (T1 - T2)r = I\alpha = \frac{Ia}{2r}$$

$$\boxed{T1 - T2 = \frac{Ia}{2r^2}} \quad \text{—— (3)}$$

From equation (2) & (3)

$$2T1 = mg + \frac{ma}{2} + \frac{Ia}{2r^2}$$

$$T1 = \frac{mg}{2} + \frac{ma}{4} + \frac{Ia}{4r^2} \quad \text{—— (4)}$$

From eq – (1) & (4)

$$mg = ma + \frac{mg}{2} + \frac{ma}{4} + \frac{Ia}{4r^2}$$

$$\left(m + \frac{m}{4} + \frac{I}{4r^2}\right)a = \frac{mg}{2}$$

$$\left(m + \frac{m}{4} + \frac{mr^2}{2} \times \frac{1}{4r^2}\right)a = \frac{mg}{2}$$

$$\frac{11}{8} ma = \frac{mg}{2}$$

$$a = \frac{4}{11} g$$

velocity of block

$$v = \sqrt{u^2 + 2ay}$$

$$v = \sqrt{\frac{8}{11} gy}$$

Substituting the value of a into eq — (I)

$$T_1 = mg - ma = mg - \frac{4mg}{11} = \frac{7}{11} mg$$

$$\boxed{T_1 = \frac{7}{11} mg}$$

Substituting the value of a & T_1 into Equation (ii)

$$T_2 = \frac{ma}{2} + mg - T_1$$

$$T_2 = \frac{m}{2} \times \frac{7}{11} g + mg - \frac{7}{11} mg$$

$$\boxed{T_2 = \frac{15}{22} mg}$$

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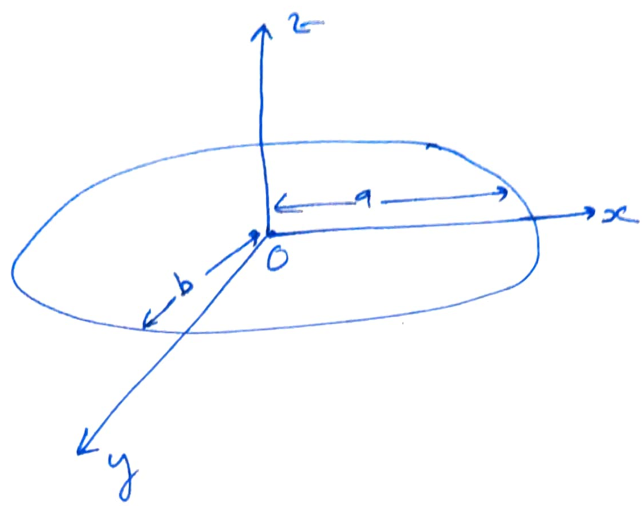
PART-C

Ans 1



$dI_x = y^2 dm$

$dI_x = (r \sin\theta)^2 \rho r \, d\theta \, dr$

$dI_x = \rho t r^3 \sin^2\theta \, d\theta \, dr$

$$I_x = \rho t \int_0^R \int_0^{2\pi} r^3 \sin^2\theta \, d\theta \, dr$$

$$I_x = \rho t \int_0^R \int_0^{2\pi} r^3 \sin^2\theta \, d\theta \, dr = \frac{m}{\pi R^2 t} \times \frac{R^4}{4} \times \frac{2\pi}{2}$$

$$\boxed{I_x = \frac{1}{4} m R^2}$$

Answers are $\rightarrow$ $I_x = \frac{1}{4} m b^2$

$I_y = \frac{1}{4} m a^2$

$I_z = \frac{1}{4} m (a^2 + b^2)$

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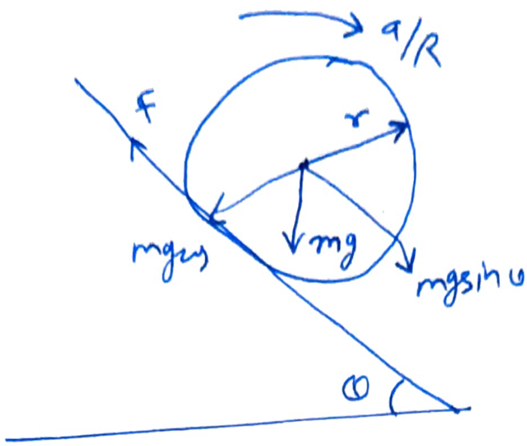
Ans-2



$$mg\sin\theta - f = ma$$

$$fR = I\alpha$$

$$I = mk^2 , \quad a = \alpha R$$

$$mg\sin\theta - \frac{I\alpha}{R} = m\alpha R$$

$$mg\sin\theta = m\alpha R + \frac{I\alpha}{R} \qquad mg\sin\theta R + mk^2\alpha$$

$$mg\sin\theta = ma + \frac{mk^2\alpha}{R} \qquad mg\sin\theta = a\left[\frac{R^2+k^2}{R^2}\right]$$

$$a = \frac{g\sin\theta}{\left[\frac{R^2+k^2}{R^2}\right]} \qquad a = \frac{g\sin\theta}{\left[1+\frac{k^2}{R^2}\right]} \qquad f = \frac{I\alpha}{R}$$

$$f = \frac{mk^2 a}{R^2} \Rightarrow \frac{mgk^2\sin\theta}{R^2+k^2}$$

$$\frac{mk^2}{k^2}a \le \mu \le mg\cos\theta$$

$$R^2\frac{k^2}{R^2} \times \frac{g\sin\theta}{(k^2+R^2)} \qquad f \neq \mu g\cos\theta \geq \frac{\tan\alpha}{1+\frac{R^2}{k^2}}$$

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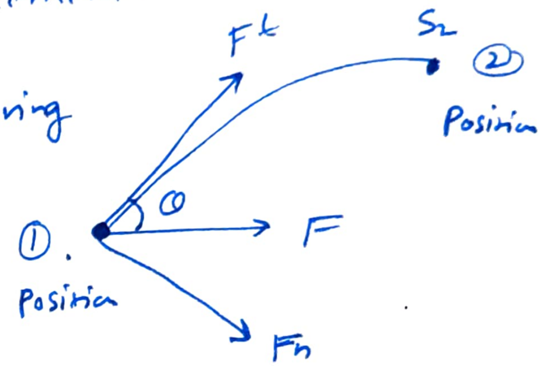
Ans-3 (a) Principle of work and energy →

work done by the forces acting on a particle during some displacement is equal to the change in kinetic energy that displacement.

Proof:- Consider the particle having mass m is acted upon by a force F and moving along a path which can be rectilinear or curvilinear as shown in fig.



$$\Sigma F_t = m a_t$$

$$F\cos\theta = m a_t = m\frac{dv}{dt}$$

$$F\cos\theta = m\frac{dv}{ds} \times \frac{ds}{dt}$$

$$F\cos\theta = mv\frac{dv}{ds}$$

$$F\cos\theta \, ds = mv\,dv$$

Integrating both sides we have

$$\int_{S_1}^{S_2} F\cos\theta \, ds = \int_{v_1}^{v_2} mv\,dv$$

$$\therefore U_{1-2} = \frac{1}{2}mv_1^2 - \frac{1}{2}mv_2^2$$

work done = change in K.E

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Ans-3 (b) Conservation of Energy:-

When a particle moving from position ① to position ② under the action of only conservative forces then by energy conservation principle we say that the total energy remains constant.

total energy = K.E + P.E. + Strain energy

$$\text{total energy} = \frac{1}{2}mv^2 \pm mgh + \frac{1}{2}kx^2$$