CLASS TEST

S.No.: 01SPME_ABCDE_14032024

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ENGINEERING MECHANICS

CIVIL ENGINEERING

Date of Test : 14/03/2024

ANSWER KEY

1.	(d)	7.	(d)	13.	(b)	19.	(b)	25.	(d)
2.	(b)	8.	(b)	14.	(a)	20.	(c)	26.	(b)
3.	(c)	9.	(a)	15.	(c)	21.	(b)	27.	(c)
4.	(a)	10.	(c)	16.	(d)	22.	(c)	28.	(a)
5.	(b)	11.	(a)	17.	(c)	23.	(b)	29.	(b)
6.	(b)	12.	(d)	18.	(a)	24.	(a)	30.	(b)

DETAILED EXPLANATIONS

1. **(d)**

Without slipping, maximum acceleration provided by friction is given as

$$a = \mu g = 0.75 \times 9.81 = 7.36 \text{ m/s}^2$$

Using second equation of kinematics as the car is starting from rest,

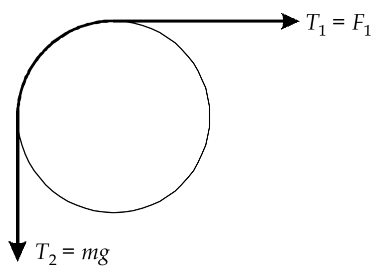
$$s = ut + \frac{1}{2}at^2$$

$$\therefore \quad s = \frac{1}{2}at^2 \qquad (u = 0)$$

$$\therefore \quad t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2\times 700}{7.36}} = \sqrt{100.217}$$

$$= 13.79 \text{ seconds}$$

2. **(b)**



The angle of contact between the cable and the round support is $\theta = \frac{\pi}{2}$ radians.

$$\therefore \quad T_2 = T_1 e^{\mu_s \theta}$$

$$T_2 = T_1 e^{0.4\times\frac{\pi}{2}}$$

$$T_2 = T_1 e^{0.628} = 1.874 T_1$$

$$T_1 = \frac{T_2}{1.874} = \frac{50\times 9.81}{1.874} = 261.74 \text{ N}$$

3. **(c)**

The work done in a small displacement dx is given as,

$$dw = \vec{F}\cdot\vec{dx} = Fdx$$

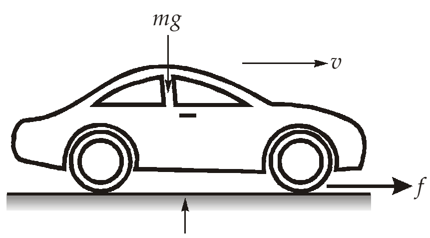
$$w = \int dw = \int_0^3 (10 + x)dx$$

$$w = 10[x]_0^3 + \frac{1}{2}\left[x^2\right]_0^3 = 10(3-0) + 0.5(9-0)$$

$$= 30 + 4.5 = 34.5 \text{ Joules}$$

4. (a)

Using impulse-momentum theorem,



F.B.D.

$$mu + \int F dt = mv$$

$$mu + \int_0^6 600t^2 dt = mv$$

$$2500 \times 20 + 600\left(\frac{t^3}{3}\right)_0^6 = 2500 \times v$$

$$50000 + 600 \times \frac{216}{3} = 2500 \times v$$

$$v = \frac{93200}{2500} = 37.28 \text{ m/s}$$

5. (b)

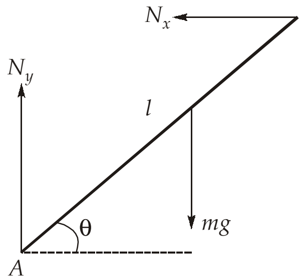
Given u = 8 m/s, a = 2.4 m/s^2, t = 10s

Using,
$$S = ut + \frac{1}{2}at^2$$

$$S = 8 \times 10 + \frac{1}{2} \times 2.4 \times 10^2$$

$$S = 80 + 120 = 200 \text{ m}$$

6. (b)



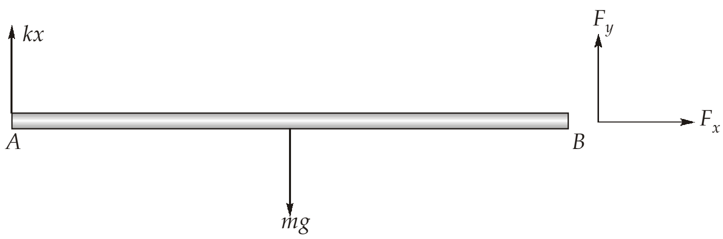
The free body diagram of the rod is shown. From the equilibrium of the rod and taking moment about the end A, we get,

$$mg \times \frac{l}{2}\cos\theta = N_x \times l \sin\theta$$

$$N_x = \frac{mg}{2\tan\theta}$$

7. (d)

Free body diagram of rod is given as



Taking moment about B.

$$mg \times \frac{l}{2} = kx \times l$$

$$\therefore \quad x = \frac{mg}{2k}$$

Since, there is no external horizontal force on the rod, so $F_x = 0$ and $F_y + kx = mg$

$$F_y + \frac{mg}{2k} \times k = mg$$

$$F_y = \frac{mg}{2}$$

8. (b)

As the block is at rest, the net horizontal force acting on it should be zero. Therefore, friction force is equal to 20 N.

9. (a)

$$\text{Acceleration of particle, } a = \frac{F}{m} = \frac{7.5}{30 \times 10^{-3}} = 250 \text{ m/s}^2$$

Time taken to cover 2.5 meters distance is

$$t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \times 2.5}{250}} = 0.141 \text{ seconds}$$

Velocity after this displacement,

$$v = \sqrt{2as} = \sqrt{2 \times 250 \times 2.5} = 35.35 \text{ m/s}$$

$$P_{av} = \frac{\text{Total work done}}{\text{Time}} = \frac{\text{Change in KE}}{\text{Time}}$$

$$= \frac{\frac{1}{2}mv^2}{t} = \frac{\frac{1}{2} \times 30 \times 10^{-3} \times 35.35^2}{0.141}$$

$$= 133 \text{ Watts}$$

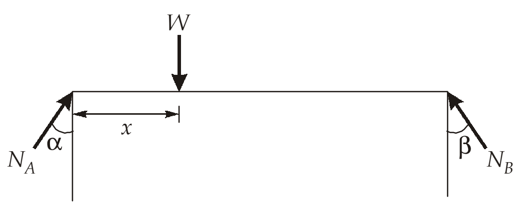
10. (c)

Acceleration is defined as the rate of change of velocity with respect to time. So, a change in either the speed or the direction of motion or both results into acceleration. Statement I is correct.

For a particle moving in circular motion with a constant speed, the direction of velocity is changing at every instant. Therefore, the particle is having an acceleration. So, statement II is false.

11. (a)

Free-body diagram of the beam is drawn as,



From equilibrium equation,

$$N_A \cos\alpha + N_B \cos\beta = W \quad \text{...(i)}$$

$$N_A \sin\alpha = N_B \sin\beta \quad \text{...(ii)}$$

Moment about A is given by,

$$W \times x = N_B \cos\beta \times l \quad \text{...(iii)}$$

Solving these equations,

$$N_B = \frac{Wx}{l\cos\beta}$$

Putting this value of N_B in equation (ii),

$$N_A = \frac{Wx}{l\cos\beta}\frac{\sin\beta}{\sin\alpha} = \frac{Wx}{l}\frac{\tan\beta}{\sin\alpha}$$

Now, putting the values N_A and N_B in equation (i)

$$\frac{Wx}{l}\frac{\tan\beta}{\sin\alpha}\times\cos\alpha + \frac{Wx}{l\cos\beta}\times\cos\beta = W$$

$$\frac{Wx}{l}\frac{\tan\beta}{\tan\alpha} + \frac{Wx}{l} = W$$

$$\frac{x}{l}\left(\frac{\tan\beta}{\tan\alpha} + 1\right) = 1$$

$$x = \frac{l}{1 + \dfrac{\tan\beta}{\tan\alpha}}$$

12. (d)

The angles between the pillar ED and three cables are

$$\alpha_A = \tan^{-1}\left(\frac{4}{6}\right) = 33.7°$$

$$\alpha_B = \tan^{-1}\left(\frac{8}{6}\right) = 53.1°$$

$$\alpha_C = \tan^{-1}\left(\frac{12}{6}\right) = 63.4°$$

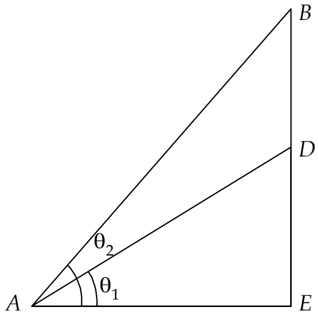
The vertical components of each force at point D exert no moment about E. Noting that $F_A = F_B = F_C$, the magnitude of the moment about E due to the horizontal components is

$$\Sigma M_E = F_A(\sin\alpha_A + \sin\alpha_B + \sin\alpha_C)\times 6 = 2700$$

$$F_A = \frac{2700}{6\times(\sin\alpha_A + \sin\alpha_B + \sin\alpha_C)} = \frac{2700}{6\times(0.55 + 0.8 + 0.89)}$$

$$F_A = 200.89 \text{ kN}$$

13. (b)



$$\tan\theta_1 = \frac{DE}{AE} = \frac{\frac{1}{4}a}{a} = \frac{1}{4} = 0.25$$

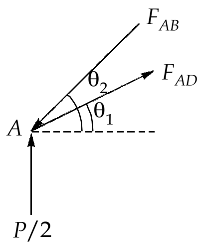
$$\theta_1 = \tan^{-1}(0.25) = 14.04°$$

$$\tan\theta_2 = \frac{BE}{AE} = \frac{a}{a} = 1$$

$$\theta_2 = \tan^{-1}(1) = 45°$$

Given: F_{AB} = 800 N (C)

Joint A:



$\Sigma F_x = 0;$

$$F_{AD}\cos\theta_1 = 800\cos\theta_2$$

$$F_{AD} = 800\frac{\cos 45°}{\cos 14.04°}$$

$$F_{AD} = 583.01 \text{ N} < 2000 \text{ N}$$

$\Sigma F_y = 0;$

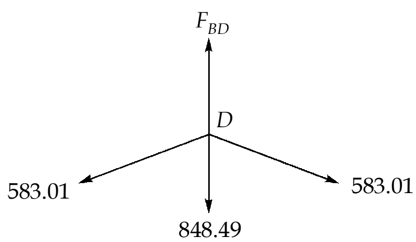
$$\frac{P}{2} + F_{AD}\sin\theta_1 = F_{AB}\sin\theta_2$$

$$P = (2)\ (800 \sin 45° - 583.01 \sin 14.04°)$$

$$P = 2\ (565.68 - 141.44)$$

$$P = 848.49 \text{ N}$$

Joint *D*,



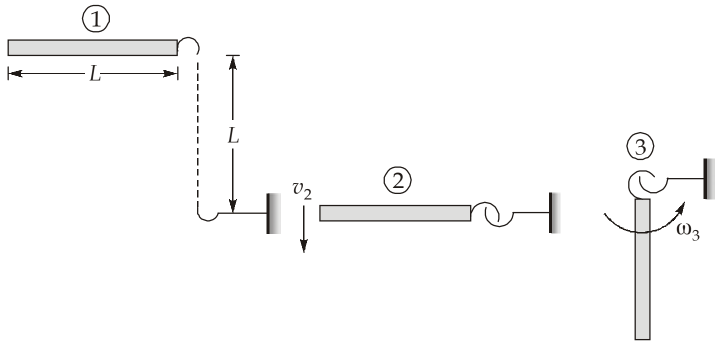
$\Sigma F_y = 0;$

$$F_{DB} = 848.49 + 2 \times 583.01 \times \sin 14.04$$
$$= 1131.29 \text{ N} < 2000 \text{ N}$$

Therefore, $$P_{max} = 848.49 \text{ N}$$

14. (a)

The three different situations of motion of rod is shown as :



Using energy conservation between (1) and (2),

$$U_1 + K_1 = U_2 + K_2$$

$$\Rightarrow \quad mgL + 0 = 0 + \frac{1}{2}mv_2^2$$

$$\Rightarrow \quad v_2 = \sqrt{2gL}$$

From momentum conservation before and after striking the hook

$$\therefore \quad P_1 = P_2$$

$$\Rightarrow \quad mv_2 r = I\omega_2$$

$$\Rightarrow \quad m\sqrt{2gL} \times \frac{L}{2} = \left(\frac{mL^2}{3}\right)\omega_2$$

$$\Rightarrow \quad \omega_2 = \frac{3}{2}\sqrt{\frac{2g}{L}}$$

Energy conservation between (2) and (3),

$$U_2 + K_2 = U_3 + K_3$$

$$0 + \frac{1}{2}\left(\frac{1}{3}ML^2\right) \times \frac{9}{4} \times \frac{2g}{L} = \frac{1}{2}\left(\frac{1}{3}ML^2\right)\omega_3^2 - Mg\frac{L}{2}$$

$$\frac{3}{4}gL = \frac{1}{6}L^2\omega_3^2 - g\left(\frac{L}{2}\right)$$

$$\omega_3 = \sqrt{\frac{7.5g}{L}} = \sqrt{\frac{7.5 \times 9.81}{1}} = \sqrt{73.575}$$

$$\omega_3 = 8.57 \text{ rad/sec}$$

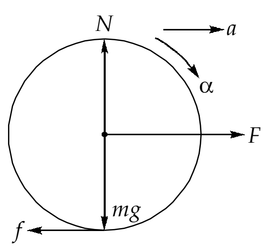
15. (c)

Free body diagram of the disc is given as

$$F - f = ma \quad \text{...(i)}$$

$$fR = I\alpha = \frac{1}{2}mR^2\alpha = \frac{1}{2}mR^2\frac{a}{R}$$

$$fR = \frac{mRa}{2}$$



$$f = \frac{ma}{2} \quad \text{...(ii)}$$

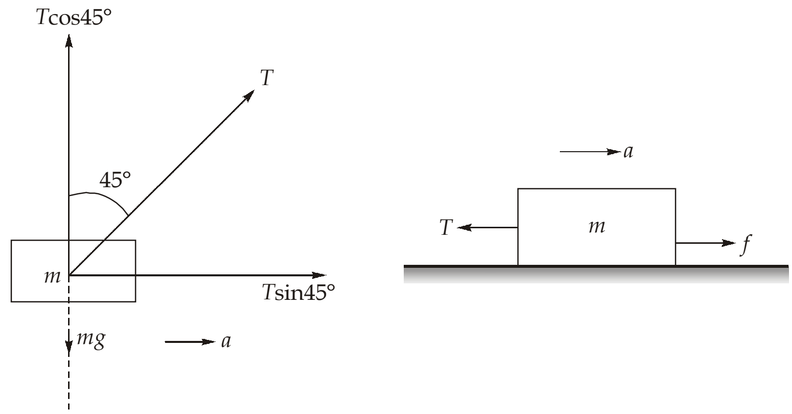
From equation (i) and (ii),

$$F = \frac{3ma}{2}$$

$$\Rightarrow \quad a = \frac{2F}{3m} = \frac{2 \times 10}{3 \times 12} = 0.55 \text{ m/s}^2$$

16. **(d)**

Free body diagram of the blocks are:



$$T\sin45° = ma \quad \text{... (i)}$$

$$T\cos45° = mg \quad \text{... (ii)}$$

Dividing equation (i) by (i),

$$\frac{T\sin 45°}{T\cos 45°} = \frac{ma}{mg}$$

$$\Rightarrow \quad a = g$$

From equation (ii), $T = \dfrac{mg}{\cos 45°} = \sqrt{2}\, mg$.

Applying Newton's law equation for the block placed on the cart.

$$f - T = ma$$

$$\mu mg - T = ma$$

$$\mu mg = T + ma = \sqrt{2}\, mg + mg$$

$$\mu mg = mg\left(\sqrt{2} + 1\right)$$

$$\mu = \sqrt{2} + 1$$

17. (c)

$$v\frac{dv}{ds} = a$$

$$-6s^{-3} = v\frac{dv}{ds}$$

$$\left[a = \frac{dv}{dt}, dt = \frac{dS}{v}\right.$$
$$\left. a = \frac{dv}{\left(\frac{dS}{v}\right)} = v\left(\frac{dv}{dS}\right)\right]$$

$$\int_{\infty}^{6} -6s^{-3}ds = \int_{0}^{v} vdv$$

$$\left[-\frac{6}{-2}s^{-2}\right]_{\infty}^{6} = \frac{v^2}{2}$$

$$\left[\frac{3}{s^2}\right]_{\infty}^{6} = \frac{v^2}{2}$$

$$v^2 = \left[\frac{6}{s^2}\right]_{\infty}^{6}$$

$$\Rightarrow \quad v^2 = \frac{6}{6\times 6} = \frac{1}{6}$$

$$v = 0.408 \text{ m/s}$$

18. (a)

Given data: m = 8.4 kg, ω = 6.9 rad/s, F = 6.6 N, M = 59 Nm, L = 4 m, $\omega_{\theta = 90°}$ = ?

Moment of Inertia of rod about hinge O,

$$I_O = \frac{mL^2}{12} + m\times\left(\frac{L}{2}\right)^2 = \frac{mL^2}{3} = \frac{8.4\times 4\times 4}{3} = 44.8 \text{ kg m}^2.$$

By conservation of energy:

$$mgh_{cm} + (M + F \times L)\Delta\theta = \frac{1}{2}I_0\left(\omega_1^2 - \omega_0^2\right)$$

$$\text{For } \theta = 90°, h_{cm} = 2 \text{ m}$$

$$(8.4\times 9.81\times 2) + (59 + 6.6\times 4)\times\frac{\pi}{2} = \frac{1}{2}\times(44.8)\left[\omega_1^2 - 6.9^2\right]$$

$$\frac{298.954\times 2}{44.8} = \omega_1^2 - 6.9^2$$

$$\omega_1^2 = 60.9562$$

$$\omega_1 = 7.807 \text{ rad/s}$$

19. (b)

Given: Pitch (P) = 12 mm, Mean radius (r) = $\frac{80}{2} = 40$ mm, Coefficient of static friction (μ_s) = 0.15,

Coefficient of kinetic friction (μ_k) = 0.10, Lever length (a) = 600 mm, Weight to be lifted (W) = 25 kN.
Since, the screw is single threaded, lead (C) = Pitch(P) = 12 mm.
Determination of helix angle,

$$\tan\theta = \frac{L}{2\pi r} = \frac{12}{2\pi\times 40} = 0.0477$$

$$\theta = \tan^{-1}(0.0477) = 2.733°$$

Force required to just lift a weight of 25 kN.

$$\tan\phi_s = \mu_s$$
$$\phi_s = \tan^{-1}(\mu_s) = \tan^{-1}(0.15)$$
$$\phi_s = 8.53°$$
$$\phi_s + \theta = 8.53° + 2.733° = 11.263°$$
$$\tan(\phi_s + \theta) = \tan(11.263) = 0.199$$

Therefore, the force required to just raise the load is given as:

$$P = \frac{Wr}{a}\tan(\phi_s + \theta)$$
$$= \frac{25000 \times 0.04}{0.6} \times 0.199 = 331.67 \text{ N}$$

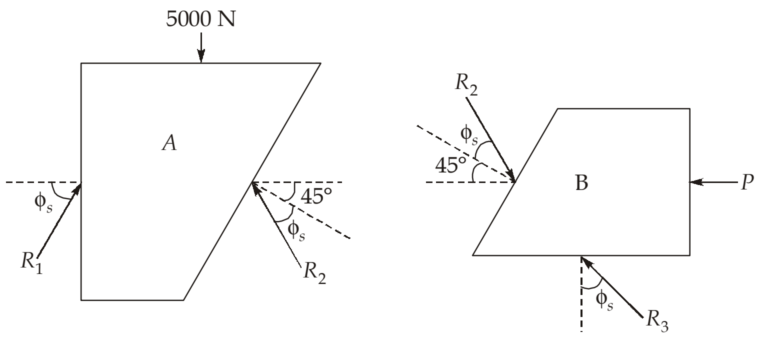
20. (c)

Coefficient of friction, $\mu_s = 0.2$.

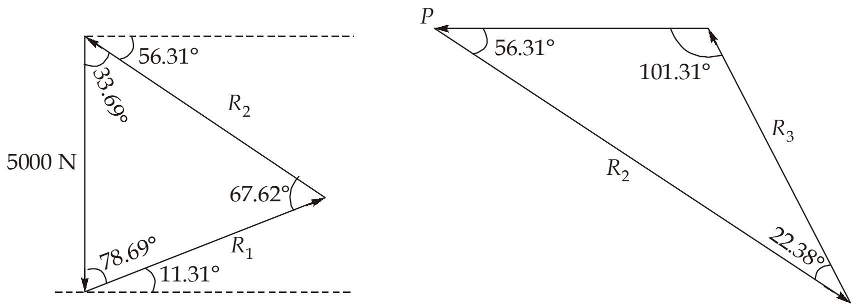
Here the force P is required to maintain the equilibrium. The direction of impending motion of the block A is downwards and that of block B is rightwards.

The free body-diagrams of the block are:

[Angle of friction: $\phi_s = \tan^{-1}\mu$, $\phi_s = \tan^{-1}(0.2)$, $\phi_s = 11.31°$]



Making force triangles for A and B



Applying Lami's theorem for block A

$$\frac{5000}{\sin(67.62°)} = \frac{R_1}{\sin(33.69°)} = \frac{R_2}{\sin(78.69°)}$$

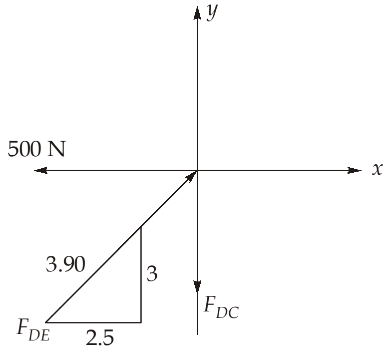
$$\therefore \quad R_2 = 5000 \times \frac{\sin(78.69°)}{\sin(67.62°)} = 5302.27 \text{ N}$$

From Lami's theorem for block B

$$\frac{P}{\sin(22.38°)} = \frac{R_2}{\sin(101.31°)} = \frac{R_3}{\sin(56.31°)}$$

$$\therefore \quad P = R_2 \times \frac{\sin(22.38°)}{\sin(101.31°)}$$

$$P = 5302.27 \times \frac{\sin(22.38°)}{\sin(101.31°)} = 2058.81 \text{ N}$$



21. **(b)**

Beginning by analyzing the equilibrium of joint D.

$\Sigma F_x = 0$

$$F_{DE} \cos\theta - 500 = 0$$

$$F_{DE} = \frac{500}{\cos\theta} = \frac{500}{\left(\frac{2.5}{3.90}\right)} = 780 \text{ N}$$

F_{DE} is compressive in nature.

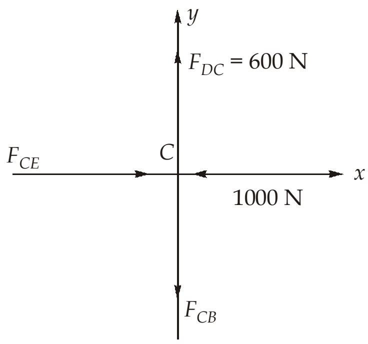
$\Sigma F_y = 0$

$$F_{DC} = F_{DE} \sin\theta$$

$$F_{DC} = 780 \times \frac{3}{3.90} = 600 \text{ N}$$

F_{DC} is tensile in nature.

Free-body diagram of the joint C,



$\Sigma F_x = 0$

$$F_{CE} = 1000 \text{ N}$$

F_{CE} is compressive in nature,

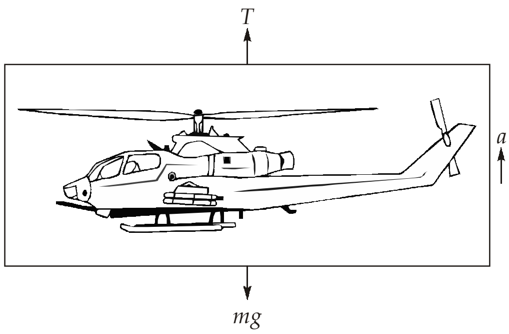
$\Sigma F_y = 0,$ $\quad 600 - F_{CB} = 0$

$$F_{CB} = 600 \text{ N}$$

F_{CB} is tensile in nature.

22. **(c)**

Free-body diagram of the helicopter is given by:



Net force on the helicopter is given as,

$$F_{\text{net}} = T - mg = (200 + 2t^3 - 100) \text{ kN}$$

Impulse of the net force is given as

$$I = \int_0^4 F_{net}\, dt = \int_0^4 \left(200 + 2t^3 - 100\right) dt$$

$$= \int_0^4 \left(2t^3 + 100\right) dt = 2\left[\frac{t^4}{4}\right]_0^4 + 100[t]_0^4$$

$$= \frac{2}{4}\left[4^4 - 0\right] + 100[4 - 0]$$

$$= 128 + 400 = 528 \text{ kN-s}$$

23. (b)

The area under the force displacement curve will give the net work done by the force on the particle.

$$W_{net} = 10\times 2 - \frac{1}{2}\times 10\times 2 = 20 - 10 = 10\text{ J}$$

Using work energy theorem,

$$W_{net} = \text{Change in kinetic energy}$$

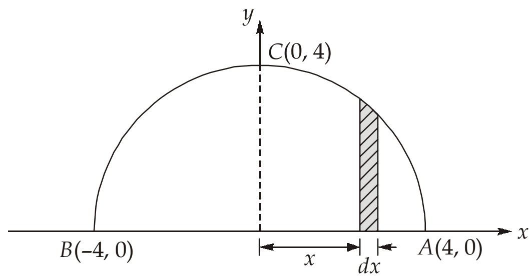
$$10 = (KE)_f - (KE)_i$$

$$10 = \frac{1}{2}Mv^2 - 0$$

$$v = \sqrt{\frac{20}{M}} = \sqrt{\frac{20}{5}} = \sqrt{4} = 2\text{ m/s}$$

24. (a)

The co-ordinates of the plate on the axis are:



Let ρ be the area density of the plate,

$$\rho = \frac{m}{A} = \frac{W}{gA}$$

The mass of an element ydx at a distance x from the y-axis is,

$$dm = \frac{W}{gA}ydx$$

Using the formula for moment of inertia,

$$I_{y\text{-axis}} = \int r^2 dm = \int x^2 \frac{W}{gA} ydx$$

$$= \frac{W}{gA}\int_{-4}^{4} x^2\left(4 - \frac{x^2}{4}\right)dx = \frac{W}{gA}\int_{-4}^{4}\left(4x^2 - \frac{x^4}{4}\right)dx$$

$$= \frac{W}{gA}\left[\frac{4x^3}{3} - \frac{x^5}{20}\right]_{-4}^{4} = \frac{W}{gA}(68.26) \qquad \text{... (i)}$$

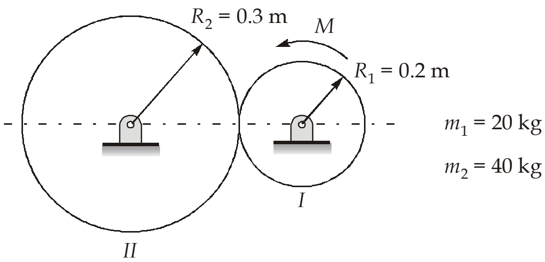
Area of the plate is $A = \int\left(4 - \frac{x^2}{4}\right)dx = \left[4x - \frac{x^3}{12}\right]_{-4}^{4}$

$$A = 21.33\text{ m}^2$$

Putting this value of area in equation (i)

$$I_{y\text{-axis}} = \frac{W}{g\times 21.33}\times(68.26) = \frac{20}{(9.81\times 21.33)}\times(68.26) = 6.5458\text{ kg–m}^2 \simeq 6.55\text{ kg–m}^2$$

25. (d)



$$\text{Moment of inertia, } I_1 = \frac{m_1 R_1^2}{2} = \frac{20 \times 0.2^2}{2} = 0.4 \text{ kgm}^2$$

$$I_2 = \frac{m_2 R_2^2}{2} = \frac{40 \times 0.3^2}{2} = 1.8 \text{ kgm}^2$$

A force of friction F acts between disc I and II which drives disc II.

$$F \times R_2 = I_2 \alpha_2 \quad \text{...(1)}$$

$$R_1 \alpha_1 = R_2 \alpha_2$$

$\Rightarrow$ $$0.2 \times 8.33 = 0.3 \times \alpha_2$$

$$\alpha_2 = 5.55 \text{ m/s}^2$$

Put α_2 value in equation (1),

We get $$F = 33.32 \text{ N}$$

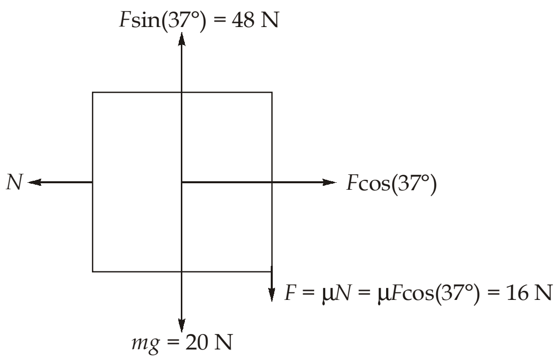
$$M - FR_1 = I_1 \alpha_1$$

$\Rightarrow$ $$M - 33.32 \times 0.2 = 0.4 \times 8.33$$

$$M = 9.996 \simeq 10 \text{ Nm}$$

26. (b)

Free-body diagram of the block is given as:



As the upward force [$F\sin(37°)$ = 48 N] is greater than the total downward force (20 + 16 = 36 N) hence, it has an upward acceleration,

$$F_{\text{net}, y} = ma$$

$$[48 - (20 + 16)] = 2a$$

$$48 - 36 = 2a$$

$$a = \frac{12}{2} = 6 \text{ m/s}^2$$

27. (c)

Given: N_1 = 100 rev/min, N_2 = 200 rev/min, N = 130 rev/min, I_1 = 1 kg-m^2.

Since the external torque acting on the two wheels system is zero, the angular momentum will be conserved.

$$L_i = L_f$$
$$I_1N_1 + I_2N_2 = (I_1 + I_2)N$$
$$1 \times 100 + I_2 \times 200 = (I_1 + I_2) \times 130$$
$$100 + 200I_2 = 130 + 130I_2$$
$$70I_2 = 30$$
$$I_2 = 0.4286 \text{ kg-m}^2 \simeq 0.43 \text{ kg-m}^2$$

28. (a)

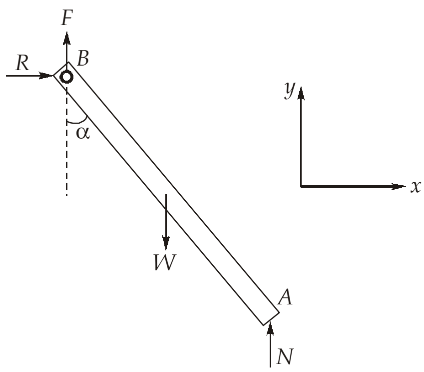
Mass of bar, $m = 4$ kg

Length of bar, $L = 6$ m

The elongation in the spring,

$$x = L - L\cos\alpha \quad \text{... (i)}$$

Free-body diagram of the bar is given as:



From equilibrium equations,

$\Sigma F_x = 0,\quad R = 0$

$\Sigma F_y = 0,\quad F + N = W$

$$\Sigma M_A = 0,\ W\left(\frac{L}{2}\sin\alpha\right) - R(L\cos\alpha) - F(L\sin\alpha) = 0$$

as $R = 0$

$$W\left(\frac{L}{2}\sin\alpha\right) = F(L\sin\alpha)$$

$$\therefore \quad F = \frac{W}{2} = \frac{4\times 10}{2} = 20\text{ N}$$

$\therefore$ Putting this value of F in equation (i),

$$F = k(L)\,(1 - \cos\alpha)$$

$$k = \frac{F}{L(1-\cos\alpha)} = \frac{20}{6(1-\cos 30°)}$$

$$k = 24.88 \text{ N/m}$$

29. (b)

The initial extension of the spring,

$$x_0 = \frac{mg}{k}$$

Using conservation of linear momentum to find the combined speed of A and B.

$$P_i = P_t$$
$$2\,m \times u + 0 = (3\,m) \times v$$

$$\Rightarrow \qquad v = \frac{2mu}{3m} = \frac{2u}{3}$$

For the spring to just attain its natural length, the combined blocks must rise by $\frac{mg}{k}$. Therefore, using conservation of mechanical energy:

$$E_i = E_f$$

$$\Rightarrow \frac{1}{2}\times 3m\left(\frac{2u}{3}\right)^2 + \frac{1}{2}k\left(\frac{mg}{k}\right)^2 = (3mg)\left(\frac{mg}{k}\right)$$

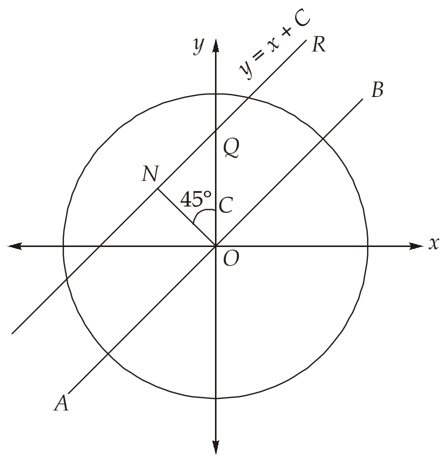
$$\Rightarrow \qquad \frac{2mu^2}{3} + \frac{m^2g^2}{2k} = \frac{3m^2g^2}{k}$$

$$\Rightarrow \qquad \frac{2mu^2}{3} = \left(\frac{m^2g^2}{k}\right)\left(\frac{5}{2}\right)$$

$$\Rightarrow \qquad u^2 = \frac{15mg^2}{4k}$$

$$\Rightarrow \qquad u = \sqrt{\frac{15mg^2}{4k}}$$

30. (b)



$$I_{PQR} = I_{AOB} + m(ON)^2$$

$$I_{PQR} = \frac{mR^2}{4} + m\left(\frac{C}{\sqrt{2}}\right)^2 \qquad \left[ON : C\cos(45°) = \frac{C}{\sqrt{2}}\right]$$

$$= \frac{mR^2}{4} + \frac{mC^2}{2}$$

$$I_z = I_{PQR}$$

$$\frac{mR^2}{2} = \frac{mR^2}{4} + \frac{mC^2}{2}$$

$$\frac{mR^2}{4} = \frac{mC^2}{2}$$

$$C = \pm\frac{R}{\sqrt{2}}$$

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