JEE Main 2021 Paper

Date: 17^{th} March 2021 (Shift-1)

Subject: Physics

Section - A

1. **The vernier scale used for measurement has a positive zero error of $0.2\ mm$. If while taking a measurement it was noted that 'o' on the vernier scale lies between $8.5\ cm$ and $8.6\ cm$, vernier coincidence is 6, then the correct value of measurement is ……………………. cm. (least count = $0.01\ cm$)**

a. 8.36 cm
b. 8.56
c. 8.58 cm
d. 8.54 cm

Answer. (d)

Sol. Reading = MSR + VSD × LC – zero error

Reading = $8.5 + \frac{(6.1)\times 6}{10} - \frac{0.2}{10} = 8.54$ cm

2. **For what value of displacement do the kinetic energy and potential energy of a simple harmonic oscillation become equal ?**

a. $x = \frac{A}{2}$
b. $x = 0$
c. $x = \pm A$
d. $x = \pm \frac{A}{\sqrt{2}}$

Answer. (d)

Sol. KE = PE

$\frac{1}{2}k(A^2 - X^2) = \frac{1}{2}kX^2$

Here, k = spring constant

A = amplitude

x = displacement

$A^2 - X^2 = X^2$

$2X^2 = A^2$

$X^2 = \frac{A^2}{2}$

$X = \pm \frac{A}{\sqrt{2}}$

3. **An electron of mass m and a photon have same energy E. The ratio of wavelength of electron to that of photon is : (c being the velocity of light)**

a. $\left(\frac{E}{2m}\right)^{1/2}$
b. $\frac{1}{c}\left(\frac{E}{2m}\right)^{1/2}$
c. $c(2mE)^{1/2}$
d. $\frac{1}{c}\left(\frac{2m}{E}\right)^{1/2}$

Answer. (b)

Sol. For photon $E = \frac{hc}{\lambda_P}$

$\lambda_p = \frac{hc}{E}$...(i)

For electron $\lambda_e = \frac{h}{\sqrt{2mE}}$...(ii)

$\frac{\lambda_e}{\lambda_p} = \frac{\frac{h}{\sqrt{2mE}}}{\frac{hc}{E}} = \sqrt{\frac{E}{2mc^2}} = \frac{1}{c}\left(\frac{E}{2m}\right)^{1/2}$

4. **A car accelerates from rest at a constant rate α for some time after which it decelerates at a constant rate β to come to rest. If the total time elapsed is t seconds, the total distance travelled is :**

a. $\frac{\alpha\beta}{2(\alpha+\beta)}t^2$

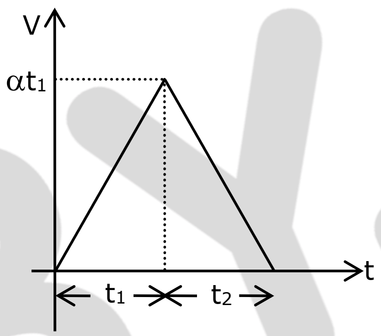
b. $\frac{\alpha\beta}{4(\alpha+\beta)}t^2$

c. $\frac{4\alpha\beta}{(\alpha+\beta)}t^2$

d. $\frac{2\alpha\beta}{(\alpha+\beta)}t^2$

Answer. (a)

Sol.



Let t be total time travelled

v′ →velocity after time t_1

then, $t_1 + t_2 = t$, $V' = 0 + \alpha t_1$(for Ist part of motion)

V = u + at (for IInd part of motion)

$0 = \alpha t_1 - \alpha t_2$

$t_2 = \frac{\alpha}{\beta} t_1$

$t_1 + \frac{\alpha}{\beta}t_1 = t$

$t_1 = \left(\frac{\beta}{\alpha+\beta}\right)t$

Distance $= \frac{1}{2}(t_1 + t_2) \times \alpha t_1$ area of triangle

$= \frac{1}{2}\, t \times \left(\frac{\beta}{\alpha+\beta}\right)t$

$= \frac{\alpha\beta}{2(\alpha+\beta)}\, t^2$

JEE Main 2021 Paper

5. **A Carnot's engine working between 400 K and 800 K has a work output of 1200 J per cycle. The amount of heat energy supplied to the engine from the source in each cycle is :**

a. 1800 J
b. 3200 J
c. 2400
d. 1600 J

Answer. (c)

Sol. $\eta = 1 - \frac{T_2}{T_1}$

T_1 = source's temperature
T_2 = sink's temperature
η = efficiency of engine
W = work output
Q_1= heat supplied to engine

$= 1 - \frac{400}{800} = 0.5$

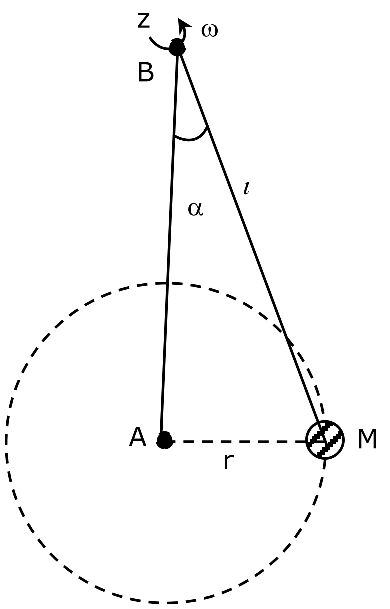
$\eta = \frac{1}{2}$

$\frac{W}{Q_1} = \eta$

$\frac{1200}{Q_1} = \frac{1}{2}$

$Q_1 = 2400$ J

6. **A mass M hangs on a massless rod of length l which rotates at a constant angular frequency. The mass M moves with steady speed in a circular path of constant radius. Assume that the system is in steady circular motion with constant angular velocity ω. The angular momentum of M about point A is L_A which lies in the positive z direction and the angular momentum of M about point B is L_B. The correct statement for this system is :**



a. L_A and L_B are both constant in magnitude and direction

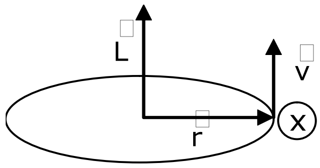
b. L_B is constant, both in magnitude and direction

c. L_A is contant, both in magnitude and direction

d. L_B is constant in direction with varying magnitude

Answer. (c)

Sol.



Angular momentum, $\vec{L} = \vec{r} \times \vec{p} = m\left(\vec{r} \times \vec{v}\right)$

Direction of $\vec{L}_A$ is along + Z axis and is constant in magnitude (= mvr).But$\vec{L}_B$ magnitude is constant and direction is varying with respect to time.

7. **Two ideal polyatomic gases at temperatures T_1 and T_2 are mixed so that there is no loss of energy. If F_1 and F_2 , m_1 and m_2, n_1 and n_2 be the degrees of freedom, masses, number of molecules of the first and second gas respectively, the temperature of mixture of these two gases is :**

a. $\frac{n_1F_1T_1+n_2F_2T_2}{n_1F_1+n_2F_2}$

b. $\frac{n_1F_1T_1+n_2F_2T_2}{F_1+F_2}$

c. $\frac{n_1F_1T_1+n_2F_2T_2}{n_1+n_2}$

d. $\frac{n_1T_1+n_2T_2}{n_1+n_2}$

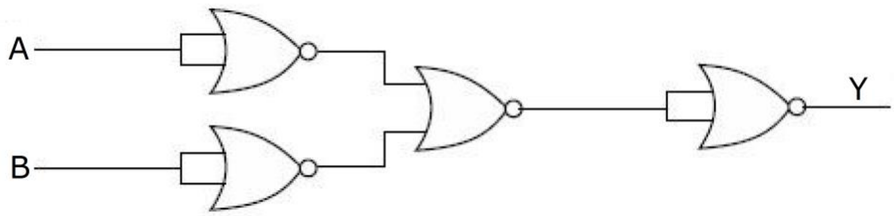
Answer. (a)

Sol. initial internal energy = final internal energy (assuming no internal energy loss)

$\frac{F_1}{2}n_1RT_1 + \frac{F_2}{2}n_2RT_2 = \frac{F_1}{2}n_1RT + \frac{F_2}{2}n_2RT$

$T = \frac{F_1n_1T_1+F_2n_2T_2}{F_1n_1+F_2n_2}$

8. **The output of the given combination gates represents :**



a. XOR Gate

b. NOR Gate

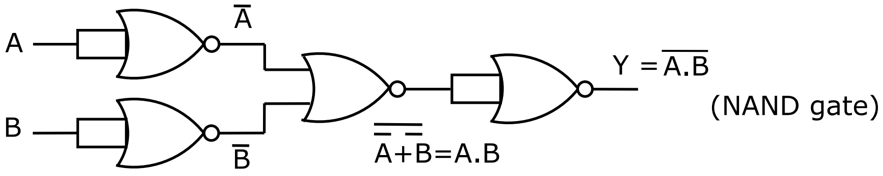
c. NAND Gate

d. AND Gate

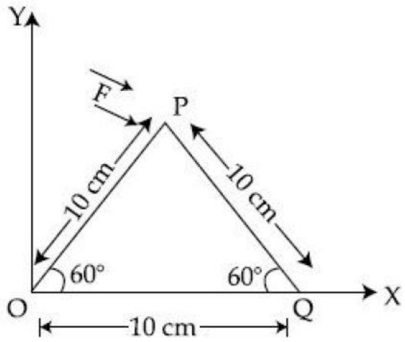
Answer. (c)

Sol.

Apply De Morgan's theorem to evaluate output at each gate. We get,



9. **A triangular plate is as shown. A force $\vec{F} = 4\hat{i} - 3\hat{j}$ is applied at point *P*. The torque at point *P* with respect to point '*O*' and '*Q*' are :**



a. $15 - 20\sqrt{3}, 15 + 20\sqrt{3}$

b. $15 + 20\sqrt{3}, 15 - 20\sqrt{3}$

c. $-15 + 20\sqrt{3}, 15 + 20\sqrt{3}$

d. $-15 - 20\sqrt{3}, 15 - 20\sqrt{3}$

Answer. (d)

Sol. Given : $\vec{F} = 4\hat{i} - 3\hat{j}$

$\vec{\tau}_o = \vec{r}_1 \times \vec{F}$

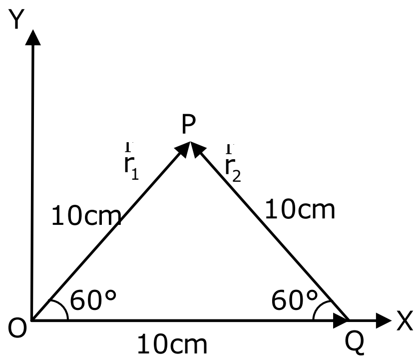
Torque about O, $\vec{\tau}_o = \vec{r}_1 \times \vec{F}$

$(5\hat{i} + 5\sqrt{3}\hat{j}) \times (4\hat{i} - 3\hat{j})$

$= -15\hat{k} - 20\sqrt{3}\hat{k}$

$\vec{r}_2 = 5\hat{i} + 5\sqrt{3}\hat{j} - 10\hat{i}$

$= -5\hat{i} + 5\sqrt{3}\hat{j}$



Torque about Q, $\vec{\tau}_Q = \vec{r}_2 \times \vec{F}$

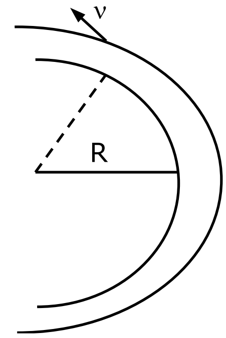
$= (5\hat{i} + 5\sqrt{3}\hat{j}) \times (4\hat{i} - 3\hat{j})$

$= 15\hat{k} - 20\sqrt{3}\hat{k}$

$= (15 - 20\sqrt{3})\hat{k}$

10. **A modern grand-prix racing car of mass m is travelling on a flat track in a circular arc of radius *R* with a speed *v*. If the coefficient of static friction between the tyres and the track is μ_s, then the magnitude of negative lift**

F_1 acting downwards on the car is : (Assume forces on the four tyres are identical and g = acceleration due to gravity)



a. $m\left(\frac{v^2}{\mu_s R} - g\right)$

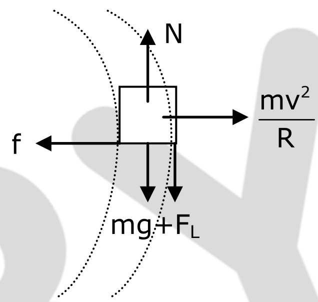
b. $m\left(\frac{v^2}{\mu_s R} + g\right)$

c. $m\left(g - \frac{v^2}{\mu_s R}\right)$

d. $-m\left(g + \frac{v^2}{\mu_s R}\right)$

Answer. (a)

Sol.



Static friction = f = $\frac{mv^2}{R}$ from force balance along radial direction,

Normal reaction = N = $\frac{mv^2}{R}$ from force balance along vertical,

$\mu(mg + F_L) = \frac{mv^2}{R}$

$mg + F_L = \frac{mv^2}{R\mu}$

$F_L = \frac{mv^2}{\mu R} - mg$

$= m\left(\frac{v^2}{\mu R} - g\right)$

11. **The thickness at the centre of a plano convex lens is 3 mm and the diameter is 6 cm. If the speed of light in the material of the lens is $2 \times 108\ mm^{-1}$. The focal length of the lens kept in air is ____.**

a. 0.30 cm

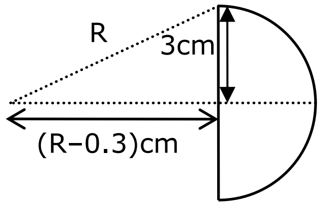
b. 1.5 cm

c. 15 cm

d. 30 cm

Answer. (d)

Sol.



$R^2 = 3^2 + (R - 0.3)^2$

$R^2 = 9 + R^2 + 0.09 - 2 \times 0.3R$

$2 \times 0.3\ R = 9.09$

$R = 15.15$ cm

$\mu = \frac{c}{v} = 1.5$

$\frac{1}{f} = (1.5 - 1)\left(\frac{1}{R}\right)$

f ; 30cm

12. If an electron is moving in the n^{th} orbit of the hydrogen atom, then its velocity (v_n) for the n^{th} orbit is given as :

a. $v_n \propto n$

b. $v_n \propto \frac{1}{n}$

c. $v_n \propto n^2$

d. $v_n \propto \frac{1}{n^2}$

Answer. (d)

Sol.

Velocity of electron of the hydrogen atom in n^{th} orbit is,

$v_n = \frac{e^2 z}{2n\varepsilon_0 h}$

$v_n \propto \frac{1}{n}$

$\therefore\ v \propto \frac{1}{n}$ (as z = 1)

13. An AC current is given by $I = I_1\ sin\omega t\ +\ I_2\ cos\omega t$. A hot wire ammeter will give a reading :

a. $\frac{I_1 + I_2}{\sqrt{2}}$

b. $\sqrt{\frac{I_1^2 + I_2^2}{2}}$

c. $\sqrt{\frac{I_1^2 - I_2^2}{2}}$

d. $\frac{I_1 + I_2}{2\sqrt{2}}$

Answer. (b)

Sol.

$I_{RMS} = \sqrt{\frac{\int I^2 dt}{\int dt}}$

$I^2_{RMS} = \int_0^T \frac{(I_1 \sin\omega t + I_2 \cos\omega t)^2 dt}{T} \int_0^T \frac{(I_1 \sin\omega t + I_2 \cos\omega t)^2 dt}{T}$

$= \frac{1}{T}\int_0^T (I_1^2 \sin^2\omega t + I_2^2 \cos^2\omega t + 2I_1 I_2 \sin\omega t \cos\omega t)$

$= \frac{I_1^2}{2} + \frac{I_2^2}{2} + 0$

$I_{RMS} = \sqrt{\frac{I_1^2 + I_2^2}{2}}$

14. Two identical metal wires of thermal conductivities K_1 and K_2 respectively are connected in series. The effective thermal conductivity of the combination is :

a. $\frac{2K_1 K_2}{K_1+K_2}$

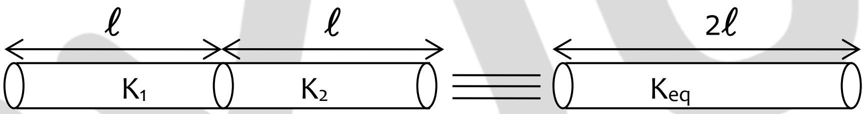
b. $\frac{K_1+K_2}{K_1 K_2}$

c. $\frac{K_1+K_2}{2K_1 K_2}$

d. $\frac{K_1 K_2}{K_1+K_2}$

Answer. (a)

Sol.



Consider equivalent thermal resistance $R_{eq.}$

$R_{eq} = R_1 + R_2$

$\frac{1}{K_{eq}}\frac{2\ell}{A} = \frac{\ell}{K_1 A} + \frac{\ell}{K_2 A}$

$\frac{2}{K_{eq}} = \frac{1}{K_1} + \frac{1}{K_2}$

$\frac{2}{K_{eq}} = \frac{K_1+K_2}{K_1 K_2}$

$K_{eq} = \frac{2K_1 K_2}{K_1+K_2}$

15. A boy releases a $0.5\,kg$ ball on the frictionless floor with the speed of $20\,ms^{-1}$. The ball gets deflected by an obstacle on the way. After deflection it moves with 5% of its initial kinetic energy. What is the speed of the ball now ?

a. $14.41\ ms^{-1}$

b. $1.00\ ms^{-1}$

c. $19.0\ ms^{-1}$

d. $4.47\ ms^{-1}$

Answer. (d)

Sol.

$K.E._f$ = 5% KE_i(since it is a frictionless floor, rolling will not take place)

$\frac{1}{2} mv^2 = \frac{5}{100} \times \frac{1}{2} \times m \times 20^2$

$v^2 = \frac{1}{20} \times 20^2 = 20$

$v = \sqrt{20} = 2\sqrt{5}$ m/s

= 4.47 m/s

16. A polyatomic ideal gas has 24 vibrational modes. What is the value of γ ?

a. 1.03
b. 1.30
c. 10.3
d. 1.37

Answer. (a)

Sol.

f = 3T + 3R + 24×2V

= 54

$\gamma = 1 + \frac{2}{f}$

f = number of degrees of freedom due to translation, rotation, vibration

$\gamma = 1 + \frac{2}{54} = 1\ \frac{1}{27} + = \frac{28}{27}$

= 1.03

17. A current of 10 A exists in a wire of crosssectional area of 5 mm^2 with a drift velocity of $2 \times 10^{-3}\ ms^{-1}$. The number of free electrons in each cubic meter of the wire is _______

a. 1×10^{23}
b. 2×10^{6}
c. 2×10^{25}
d. 625×10^{25}

Answer. (d)

Sol.

Current through a wire is given by,

$I = neAV_d$

$n = \frac{I}{eAV_d}$ (n→ free electron density)

$= \frac{10}{1.6\times10^{-19}\times5\times10^{-6}\times2\times10^{-3}}$

$= 6.25\times10^{27} = 625 \times 10^{25}$

18. A solenoid of 1000 turns per metre has a core with relative permeability 500. Insulated windings of the solenoid carry an electric current of 5 A. The magnetic flux density produced by the solenoid is : (Permeability of free space = $4\pi \times 10^{-7}\ H/m$)

a. $2 \times 10^{-3}\pi$T
b. $\frac{\pi}{5}$
c. $10^{-4}\pi$T
d. πT

Answer. (d)

Sol.

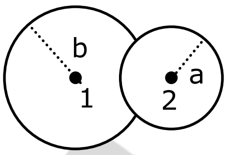
Magnetic flux density (B) will be,
$B = \mu n\, i$
$B = \mu_r \mu_0\, ni$
$B = 500 \times 4\pi \times 10^{-7} \times 10^3 \times 5$
$B = \pi \times 10^{-3} \times 10^3$
$B = \pi$ T

19. When two soap bubbles of radii a and b $(b > a)$ coalesce, the radius of curvature of common surface is -

a. $\frac{b-a}{ab}$
b. $\frac{ab}{b-a}$
c. $\frac{ab}{a+b}$
d. $\frac{a+b}{ab}$

Answer. (b)

Sol.



$P_1 - P_0 = \frac{4S}{b}$
$P_2 - P_0 = \frac{4S}{a}$
$P_2 - P_1 = \frac{4S}{R} \rightarrow$ excess pressure at common surface
equation (2)−equation(1) = equation(3)
$\frac{1}{a} - \frac{1}{b} = \frac{1}{R}$
$\therefore R = \frac{ab}{b-a}$

20. Which level of the single ionized carbon has the same energy as the ground state energy of hydrogen atom ?

a. 8
b. 1
c. 6
d. 4

Answer. (c)

Sol.

$E_n = -13.6\frac{Z^2}{n^2}$ (energy in n^{th} state for hydrogen-like atom)
E_n^{th} of Carbon = $E_{1^{st}}$ of Hydrogen
$-13.6 \times \frac{6^2}{n^2} = -13.6 \times \frac{1^2}{1^2}$
$n = 6$

Section – B

1. **A parallel plate capacitor whose capacitance C is $14pF$ is charged by a battery to a potential difference $V = 12\ V$ between its plates. The charging battery is now disconnected and a porcelin plate with $k = 7$ is inserted between the plates, then the plate would oscillate back and forth between the plates, with a constant mechanical energy of ____ pJ.(Assume no friction)**

Answer. (864)

Sol.

Initial energy stored in capacitor is,

$U_i = \frac{1}{2} cv^2$

$= \frac{1}{2} \times 14 \times (12)^2$ pJ

= 1008 pJ

Final energy stored in capacitor is,

$U_f = \frac{Q^2}{2kC}$

$= \frac{(14\times12)^2}{2\times7\times14}$

= 144 pJ

oscillating energy = $U_i - U_f$

= 1008 – 144

= 864 pJ

2. **If $2.5 \times 10^{-6}\ N$ average force is exerted by a light wave on a non-reflecting surface of $30\ cm^2$ area during 40 minutes of time span, the energy flux of light just before it falls on the surface is ______ W/cm^2. (Round off to the nearest integer)**
(Assume complete absorption and normal incidence conditions are there)

Answer.(25)

Sol.

Radiation pressure $= \frac{\text{Intensity}}{C}$ (for absorbing surface)

I = P × C

$I = \frac{2.5\times10^{-6}}{30cm^2} N \times 3 \times 10^8$ m/s

$I = 25\ W/cm^2$

3. **The following bodies**

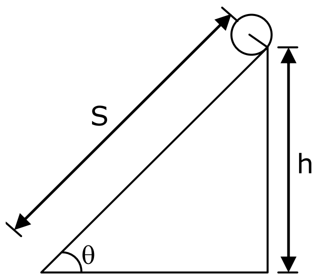
a. **a ring**

b. **a disc**

c. **a solid cylinder**

d. **a solid sphere**

of same mass 'm' and radius 'R' are allowed to roll down without slipping simultaneously from the top of the inclined plane. The body which will reach first at the bottom of the inclined plane is_______.
[Mark the body as per their respective numbering given in the question]



Answer. (4)

Sol.

Acceleration of a body rolling down an inclined plane is,

$a = \frac{g\sin\theta}{(1+\frac{I}{mR^2})}$

$I_R = mR^2$, $a_R = g\sin\theta/2$

$I_D = \frac{mR^2}{2}$, $a_D = \frac{2}{3}$ g sin θ

$I_{SC} = \frac{mR^2}{2}$, $a_{sc} = \frac{2}{3}$ g sin θ

$I_{SC} = \frac{2}{5}mR^2$, $a_{ss} = \frac{5}{7}g\sin\theta$

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

$t = \sqrt{\frac{2S}{a}}$

$\therefore\ t \propto \frac{1}{\sqrt{a}}$ For least time, a should be highest

$\Rightarrow$ solid sphere will take minimum time.

4. **For VHF signal broadcasting,______ km^2 of maximum service area will be covered by an antenna tower of height 30 m, if the receiving antenna is placed at ground. Let radius of the earth be 6400 km. (Round off to the nearest integer) (Take π as 3.14)**

Answer. (1206)

Sol.

$r = \sqrt{2hR}$

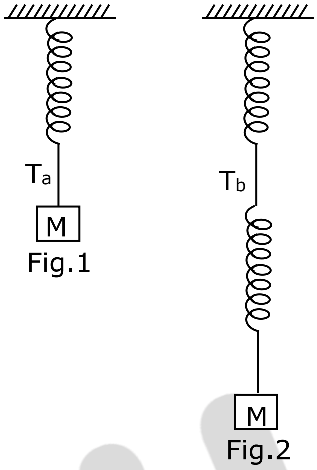
area = πr^2(consider ‘r’ to be maximum line of sight distance)

Area = $\pi(2hR) = 3.14\times2\times30\times6400\times10^3$. m^2

$= 1205.76\ km^2$

$\approx 1206\ km^2$

5. **Consider two identical springs each of spring constant k and negligible mass compared to the mass M as shown. Fig.1 shows one of them and Fig. 2 shows their series combination. The ratios of time period of oscillation of the two SHM is $T_b/T_a = \sqrt{x}$, where value of x is _____. (Round off to the nearest integer)**



Answer. (2)

Sol.

$T_a = 2\pi\sqrt{\frac{M}{k}}$

$k_{eq_{series}} = \frac{k_1 k_2}{k_1+k_2} = \frac{k}{2}$

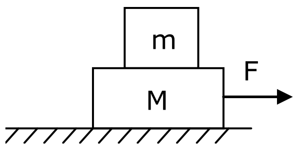
$T_B = 2\pi\sqrt{\frac{M}{k/2}} = 2\pi\sqrt{\frac{2M}{k}}$

$T_B = \sqrt{2}T_B$

$\frac{T_B}{T_A} = \sqrt{2}$

$\therefore x = 2$

6. **Two blocks ($m = 0.5\,kg$ and $M = 4.5\,kg$) are arranged on a horizontal frictionless table as shown in figure. The coefficient of static friction between the two blocks is $3/7$. Then the maximum horizontal force that can be applied on the larger block so that the blocks move together is ______ N. (Round off to the nearest integer) [Take g as $9.8\,ms^{-2}$]**



Answer. (21)

Sol.

Maximum acceleration, a_{max} of m (i.e. 0.5 kg) for both blocks to move together

$= \mu g$

$= \frac{3}{7} \times 9.8$

$= 4.2\ m/s^2$

Now, considering both blocks moving together with $4.2\ m/s^2$

$F_{max} = (M + m)\ a_{max}$

$= 4.2 \times 5 = 21$ N

7. The radius in kilometer to which the present radius of earth ($R = 6400\ km$) to be compressed so that the escape velocity is increased 10 times is _____.

Answer. (64)

Sol.

$V_{es} = \sqrt{\frac{2GM}{R}}$

$V_{es}\sqrt{R}$= constant

$V_{es}\sqrt{R}10V_{es}\sqrt{R'}$

$R' = \frac{R}{100} = 64$ KM

8. The equivalent resistance of series combination of two resistors is 's'. When they are connected in parallel, the equivalent resistance is 'p'. If $s = np$, then the maximum value for n is _____. (Round off to the nearest integer)

Answer. (4)

Sol.

s = np

$R_1 + R_2 = n\left[\frac{R_1R_2}{R_1+R_2}\right]$

$R_1^2 + R_2^2 + 2R_2R_2 = nR_1R_2$

$R_1^2 + (2-n)R_1R_2 + R_1^2 = 0$

(Considering this quadratic equation, for real roots)

$b^2 - 4ac \geq 0$

$[(2-n)R_2]^2 - 4 \times 1 \times R_2^2 = 0$

$(2-n)^2R_2^2 = 4R_2^2$

$2-n = \pm 2$

So n = 4

9. The angular speed of truck wheel is increased from 900 rpm to 2460 rpm in 26 seconds. The number of revolutions by the truck wheel during this time is _____.

(Assuming the acceleration to be uniform).

Answer. (728)

Sol.

$\omega_f = 2460 \times \frac{2\pi}{60}$

$= 82\pi$ rad/second

$\omega_i = \frac{900 \times 2\pi}{60} = 30\pi$ rad/second

$\alpha = \frac{\omega_f - \omega_i}{t}$

$= \frac{82\pi - 30\pi}{26}$

$= 2\pi$ rad/s^2

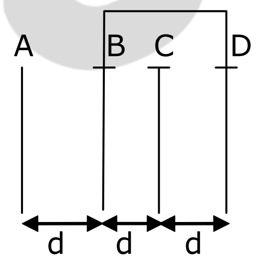
$\theta = \frac{\omega_f^2 - \omega_i^2}{2\alpha}$

$= \frac{(82\pi + 30\pi)(82\pi - 30\pi)}{2 \times 2\pi}$

$= \frac{(112 \times 52)\pi^2}{4\pi}$

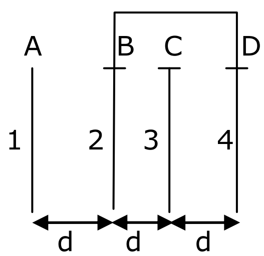
$\frac{\theta}{2\pi}$ = no. of revolution $= \frac{(112 \times 13)\pi}{2\pi} = 728$

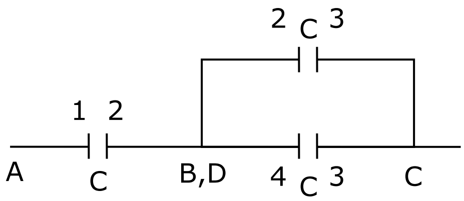
10. **Four identical rectangular plates with length, $l = 2\ cm$ and breadth, $b = 3/2\ cm$ are arranged as shown in figure. The equivalent capacitance between A and C is $\frac{x\varepsilon_0}{d}$. The value of x is _____. (Round off to the nearest integer)**



Answer. (2)

Sol.





$C = \frac{\epsilon_0 A}{d}$

$C_{eq} = \frac{2C \times C}{2C + C} = \frac{2C}{3} = \frac{2}{3} = \frac{\epsilon_0 A}{d} = \frac{2}{3} \times \frac{\epsilon_0}{d} \times \left(2 \times \frac{3}{2}\right) = \frac{2\varepsilon_0}{d}$