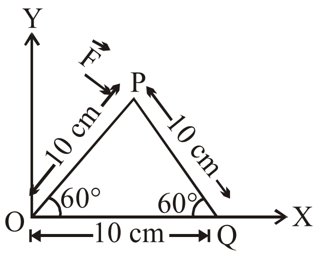
FINAL JEE–MAIN EXAMINATION – MARCH, 2021

(Held On Wednesday 17th March, 2021) TIME : 9 : 00 AM to 12 : 00 NOON

PHYSICS — TEST PAPER WITH ANSWER & SOLUTION

SECTION-A

1. A triangular plate is 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 :



(1) $-15 - 20\sqrt{3}$, $15 - 20\sqrt{3}$

(2) $15 + 20\sqrt{3}$, $15 - 20\sqrt{3}$

(3) $15 - 20\sqrt{3}$, $15 + 20\sqrt{3}$

(4) $-15 + 20\sqrt{3}$, $15 + 20\sqrt{3}$

Official Ans. by NTA (1)

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

$\vec{r}_1 = 5\hat{i} + 5\sqrt{3}\hat{j}$ & $\vec{r}_2 = -5\hat{i} + 5\sqrt{3}\hat{j}$

Torque about 'O'

$$\vec{\tau}_O = \vec{r}_1 \times \vec{F} = \left(-15 - 20\sqrt{3}\right)\hat{k} = \left(15 + 20\sqrt{3}\right)\left(-\hat{k}\right)$$

Torque about 'Q'

$$\vec{\tau}_Q = \vec{r}_2 \times \vec{F} = \left(-15 + 20\sqrt{3}\right)\hat{k} = \left(15 - 20\sqrt{3}\right)\left(-\hat{k}\right)$$

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

(1) $\frac{ab}{b-a}$ (2) $\frac{a+b}{ab}$

(3) $\frac{b-a}{ab}$ (4) $\frac{ab}{a+b}$

Official Ans. by NTA (1)

Sol. Excess pressure at common surface is given by

$$P_{ex} = 4T\left(\frac{1}{a} - \frac{1}{b}\right) = \frac{4T}{r}$$

$$\therefore \frac{1}{r} = \frac{1}{a} - \frac{1}{b}$$

$$r = \frac{ab}{b-a}$$

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

(1) 1.03 (2) 1.30

(3) 1.37 (4) 10.3

Official Ans. by NTA (1)

Sol. Since each vibrational mode has 2 degrees of freedom hence total vibrational degrees of freedom = 48

f = 3 + 3 + 48 = 54

$$\gamma = 1 + \frac{2}{f} = \frac{28}{27} = 1.03$$

4. 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 :

(1) $v_n \propto n$ (2) $v_n \propto \frac{1}{n}$

(3) $v_n \propto n^2$ (4) $v_n \propto \frac{1}{n^2}$

Official Ans. by NTA (2)

Sol. We know velocity of electron in n^{th} shell of hydrogen atom is given by

$$v = \frac{2\pi kZe^2}{nh}$$

$$\therefore v \propto \frac{1}{n}$$

5. 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)

(1) $\frac{1}{c}\left(\frac{2m}{E}\right)^{1/2}$ (2) $\frac{1}{c}\left(\frac{E}{2m}\right)^{1/2}$

(3) $\left(\frac{E}{2m}\right)^{1/2}$ (4) $c\ (2mE)^{1/2}$

Official Ans. by NTA (2)

Sol. $\lambda_1 = \frac{h}{\sqrt{2mE}}$

$\lambda_2 = \frac{hc}{E}$

$\frac{\lambda_1}{\lambda_2} = \frac{1}{c}\left(\frac{E}{2m}\right)^{1/2}$

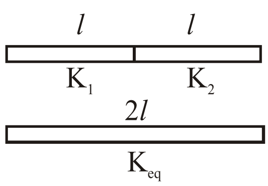
6. Two identical metal wires of thermal conductivities K_1 and K_2 respectively are connected in series. The effective thermal conductivity of the combination is :

(1) $\frac{2K_1K_2}{K_1+K_2}$ (2) $\frac{K_1+K_2}{2K_1K_2}$

(3) $\frac{K_1+K_2}{K_1K_2}$ (4) $\frac{K_1K_2}{K_1+K_2}$

Official Ans. by NTA (1)

Sol.



$R_{eff} = \frac{l}{K_1A} + \frac{l}{K_2A} = \frac{2l}{K_{eq}A}$

$K_{eq} = \frac{2K_1K_2}{K_1+K_2}$

7. The vernier scale used for measurement has a positive zero error of 0.2 mm. If while taking a measurement it was noted that '0' 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)

(1) 8.36 cm (2) 8.54 cm

(3) 8.58 cm (4) 8.56 cm

Official Ans. by NTA (2)

Sol. Positive zero error = 0.2 mm

Main scale reading = 8.5 cm

Vernier scale reading = 6 × 0.01 = 0.06 cm

Final reading = 8.5 + 0.06 – 0.02 = 8.54 cm

8. 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 :

(1) $\sqrt{\frac{I_1^2 - I_2^2}{2}}$ (2) $\sqrt{\frac{I_1^2 + I_2^2}{2}}$

(3) $\frac{I_1 + I_2}{\sqrt{2}}$ (4) $\frac{I_1 + I_2}{2\sqrt{2}}$

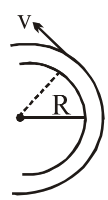
Official Ans. by NTA (2)

Sol. $I = I_1 \sin \omega t + I_2 \cos \omega t$

$\therefore I_0 = \sqrt{I_1^2 + I_2^2}$

$\therefore I_{rms} = \frac{I_0}{\sqrt{2}} = \sqrt{\frac{I_1^2 + I_2^2}{2}}$

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



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

(3) $m\left(g - \frac{v^2}{\mu_s R}\right)$ (4) $-m\left(g + \frac{v^2}{\mu_s R}\right)$

Official Ans. by NTA (2)

Sol. $\mu_s N = \dfrac{mv^2}{R}$

$N = \dfrac{mv^2}{\mu_s R} = mg + F_L$

$F_L = \dfrac{mv^2}{\mu_s R} - mg$

10. 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 :

(1) $\dfrac{4\alpha\beta}{(\alpha+\beta)}t^2$ (2) $\dfrac{2\alpha\beta}{(\alpha+\beta)}t^2$

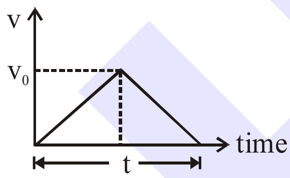
(3) $\dfrac{\alpha\beta}{2(\alpha+\beta)}t^2$ (4) $\dfrac{\alpha\beta}{4(\alpha+\beta)}t^2$

Official Ans. by NTA (3)

Sol. $v_0 = \alpha t_1$ and $0 = v_0 - \beta t_2 \Rightarrow v_0 = \beta t_2$

$t_1 + t_2 = t$

$v_0\left(\dfrac{1}{\alpha}+\dfrac{1}{\beta}\right) = t$



$\Rightarrow v_0 = \dfrac{\alpha\beta t}{\alpha+\beta}$

Distance = area of v-t graph

$= \dfrac{1}{2} \times t \times v_0 = \dfrac{1}{2} \times t \times \dfrac{\alpha\beta t}{\alpha+\beta} = \dfrac{\alpha\beta t^2}{2(\alpha+\beta)}$

11. A solenoid of 1000 turns per metre has a core with relative permeability 500. Insulated windings of the solenoid carry an electric current of 5A. The magnetic flux density produced by the solenoid is :

(permeability of free space = $4\pi \times 10^{-7}$ H/m)

(1) πT (2) 2×10^{-3} πT

(3) $\dfrac{\pi}{5}$T (4) $10^{-4}\pi$T

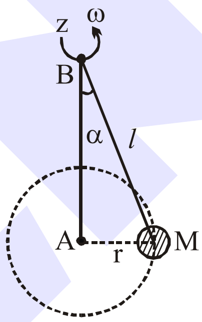
Official Ans. by NTA (1)

Sol. $B = \mu n I = \mu_0 \mu_r n I$

$B = 4\pi \times 10^{-7} \times 500 \times 1000 \times 5$

$B = \pi$ Tesla

12. 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 B is L_B. The correct statement for this system is :



(1) L_A and L_B are both constant in magnitude and direction

(2) L_B is constant in direction with varying magnitude

(3) L_B is constant, both in magnitude and direction

(4) L_A is constant, both in magnitude and direction

Official Ans. by NTA (4)

Sol. We know, $\vec{L} = m(\vec{r} \times \vec{v})$

Now with respect to A, we always get direction of $\vec{L}$ along +ve z-axis and also constant magnitude as mvr. But with respect to B, we get constant magnitude but continuously changing direction.

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

(1) x = 0 (2) x = ± A

(3) $x = \pm \dfrac{A}{\sqrt{2}}$ (4) $x = \dfrac{A}{2}$

Official Ans. by NTA (3)

Sol. KE = PE

$\frac{1}{2} m\omega^2 (A^2 - x^2) = \frac{1}{2} m\omega^2 x^2$

$A^2 - x^2 = x^2$

$2x^2 = A^2$

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

14. 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 :

(1) 3200 J (2) 1800 J

(3) 1600 J (4) 2400 J

Official Ans. by NTA (4)

Sol. $\eta = \frac{T_2}{T_1} = \frac{Q_2}{Q_1} = \frac{Q_1 - W}{Q_1}$ $(\because W = Q_1 - Q_2)$

$\frac{400}{800} = 1 - \frac{W}{Q_1}$

$\frac{W}{Q_1} = 1 - \frac{1}{2} = \frac{1}{2}$

$Q_1 = 2W = 2400$ J

15. 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 2×10^8 ms^{-1}. The focal length of the lens is _____.

(1) 0.30 cm (2) 15 cm

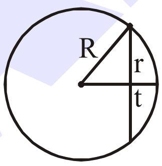
(3) 1.5 cm (4) 30 cm

Official Ans. by NTA (4)

Sol. $R^2 = r^2 + (R - t)^2$

$R^2 = r^2 + R^2 + t^2 - 2Rt$

Neglecting t^2, we get



$R = \frac{r^2}{2t}$

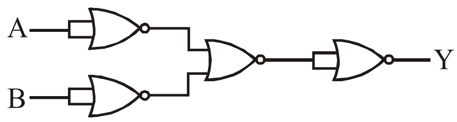
$\therefore \frac{1}{f} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{\mu - 1}{R}$

$f = \frac{R}{\mu - 1} = \frac{r^2}{2t(\mu - 1)} = \frac{(3\times10^{-2})^2}{2\times3\times10^{-3}\times\left(\frac{3}{2}-1\right)}$

$= \frac{9\times10^{-4}}{6\times10^{-3}\times1} \times 2$

f = 0.3 m = 30 cm

16. The output of the given combination gates represents :

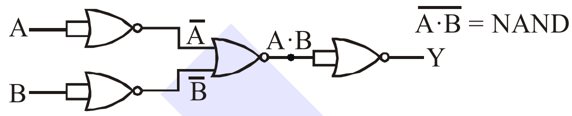


(1) XOR Gate (2) NAND Gate

(3) AND Gate (4) NOR Gate

Official Ans. by NTA (2)

Sol. By De Morgan's theorem, we have



17. A boy is rolling 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 ?

(1) 19.0 ms^{-1} (2) 4.47 ms^{-1}

(3) 14.41 ms^{-1} (4) 1.00 ms^{-1}

Official Ans. by NTA (2)

Sol. Given, m = 0.5 kg and u = 20 m/s

Initial kinetic energy $(k_i) = \frac{1}{2} mu^2$

$= \frac{1}{2} \times 0.5 \times 20 \times 20 = 100$ J

After deflection it moves with 5% of k_i

$\therefore k_f = \frac{5}{100} \times k_i \Rightarrow \frac{5}{100} \times 100$

$\Rightarrow k_f = 5$ J

Now, let the final speed be 'v' m/s, then :

$k_f = 5 = \frac{1}{2} mv^2$

$\Rightarrow v^2 = 20$

$\Rightarrow v = \sqrt{20} = 4.47$ m/s

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

(1) 1 (2) 6

(3) 4 (4) 8

Official Ans. by NTA (2)

Sol. Energy of H-atom is $E = -13.6\ Z^2/n^2$

for H-atom Z = 1 & for ground state, n = 1

$$\Rightarrow E = -13.6 \times \frac{1^2}{1^2} = -13.6\ eV$$

Now for carbon atom (single ionised), Z = 6

$$E = -13.6\ \frac{Z^2}{n^2} = -13.6 \qquad \text{(given)}$$

$\Rightarrow n^2 = 6^2 \Rightarrow n = 6$

19. 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 :

(1) $\frac{n_1T_1+n_2T_2}{n_1+n_2}$ (2) $\frac{n_1F_1T_1+n_2F_2T_2}{n_1F_1+n_2F_2}$

(3) $\frac{n_1F_1T_1+n_2F_2T_2}{F_1+F_2}$ (4) $\frac{n_1F_1T_1+n_2F_2T_2}{n_1+n_2}$

Official Ans. by NTA (2)

Sol. Let the final temperature of the mixture be T.

Since, there is no loss in energy.

$\Delta U = 0$

$$\Rightarrow \frac{F_1}{2} n_1R\ \Delta T + \frac{F_2}{2}\ n_2R\Delta T = 0$$

$$\Rightarrow \frac{F_1}{2} n_1R\ (T_1 - T) + \frac{F_2}{2} n_2R\ (T_2 - T) = 0$$

$$\Rightarrow T = \frac{F_1n_1RT_1+F_2n_2RT_2}{F_1n_1R+F_2n_2R} \Rightarrow \frac{F_1n_1T_1+F_2n_2T_2}{F_1n_1+F_2n_2}$$

20. A current of 10A exists in a wire of crosssectional area of 5 mm² with a drift velocity of $2 \times 10^{-3}\ ms^{-1}$. The number of free electrons in each cubic meter of the wire is ___.

(1) 2×10^6 (2) 625×10^{25}

(3) 2×10^{25} (4) 1×10^{23}

Official Ans. by NTA (2)

Sol. $i = 10A$, $A = 5\ mm^2 = 5 \times 10^{-6}\ m^2$

and $v_d = 2 \times 10^{-3}$ m/s

We know, $i = neAvd$

$\therefore 10 = n \times 1.6 \times 10^{-19} \times 5 \times 10^{-6} \times 2 \times 10^{-3}$

$\Rightarrow n = 0.625 \times 10^{28} = 625 \times 10^{25}$

SECTION-B

1. For VHF signal broadcasting, ____ km² of maximum service area will be covered by an antenna tower of height 30m, 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)

Official Ans. by NTA (1206)

Sol. $d = \sqrt{2Rh}$

$A = \pi d^2$

$A = \pi 2Rh$

$$= 3.14 \times 2 \times 6400 \times \frac{30}{1000}$$

$A = 1205.76\ km^2$

$A \simeq 1206\ km^2$

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

(Assuming the acceleration to be uniform).

Official Ans. by NTA (728)

Sol. We know, $\theta = \left(\frac{\omega_1+\omega_2}{2}\right)t$

Let number of revolutions be N

$$\therefore 2\pi N = 2\pi\left(\frac{900+2460}{60\times 2}\right)\times 26$$

N = 728

3. 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 minimum value for n is ___. (Round off to the Nearest Integer)

Official Ans. by NTA (4)

Sol. $R_1 + R_2 = s$ ... (1)

$$\frac{R_1R_2}{R_1+R_2} = p \quad \text{... (2)}$$

$R_1R_2 = sp$

$R_1R_2 = np^2$

$$R_1 + R_2 = \frac{nR_1R_2}{(R_1+R_2)}$$

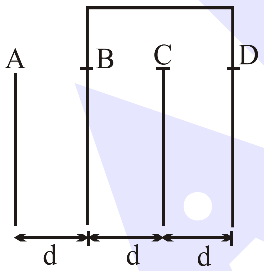
$$\frac{(R_1+R_2)^2}{R_1R_2} = n$$

for minimum value of n

$R_1 = R_2 = R$

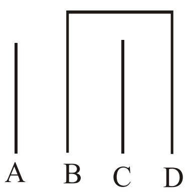
$$\therefore\ n = \frac{(2R)^2}{R^2} = 4$$

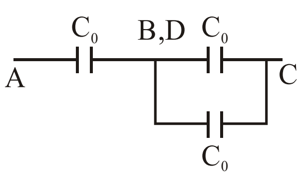
4. Four identical rectangular plates with length, l = 2 cm and breadth, b = $\frac{3}{2}$ cm are arranged as shown in figure. The equivalent capacitance between A and C is $\frac{x\varepsilon_0}{d}$. The value of x is ____. (Round off to the Nearest Integer)



Official Ans. by NTA (2)

Sol.





$$C_{eq} = \frac{2C_0}{3} = \frac{2\in_0 A}{3\ d}$$

$$C_{eq} = \frac{2\in_0}{3d}\times\left(2\times\frac{3}{2}\right) = 2 \quad (\because\ A = lb = 2\times\frac{3}{2})$$

5. 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 time is _______.

Official Ans. by NTA (64)

Sol. $V_e = \sqrt{\frac{2Gm}{R}}$ .... (1)

$$10V_e = \sqrt{\frac{2Gm}{R'}} \quad \text{... (2)}$$

$$\therefore\ 10 = \sqrt{\frac{R}{R'}}$$

$$\Rightarrow\ R' = \frac{R}{100} = \frac{6400}{100} = 64\ \text{km}$$

6. 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 $\frac{T_b}{T_a} = \sqrt{x}$, where value of x is ______. (Round off to the Nearest Integer)

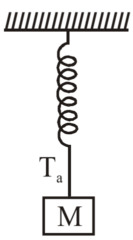


Fig.1

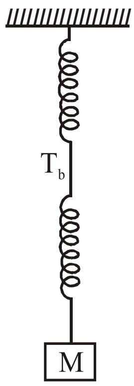


Fig.2

Official Ans. by NTA (2)

Sol. $T_a = 2\pi\sqrt{\frac{M}{K}}$

$T_b = 2\pi\sqrt{\frac{M}{K/2}}$

$\frac{T_b}{T_a} = \sqrt{2} = \sqrt{x}$

$\Rightarrow x = 2$

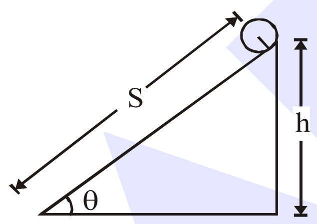
7. The following bodies,

(1) a ring (2) a disc

(3) a solid cylinder (4) 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]



Official Ans. by NTA (4)

Sol. Mg sinθ R = (mk² + mR²) α

$\alpha = \frac{Rg\sin\theta}{k^2+R^2} \Rightarrow a = \frac{g\sin\theta}{1+\frac{k^2}{R^2}}$

$t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2s}{g\sin\theta}\left(1+\frac{k^2}{R^2}\right)}$

for least time, k should be least & we know k is least for solid sphere.

8. A parallel plate capacitor whose capacitance C is 14 pF is charged by a battery to a potential difference V = 12V 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)

Official Ans. by NTA (864)

Sol. $U_i = \frac{1}{2} \times 14 \times 12 \times 12$ pJ $(\because U = \frac{1}{2}CV^2)$

= 1008 pJ

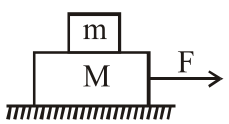
$U_f = \frac{1008}{7}$ pJ = 144 pJ $(\because C_m = kC_0)$

Mechanical energy = ΔU

= 1008 – 144

= 864 pJ

9. 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 $\frac{3}{7}$. 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]



Official Ans. by NTA (21)

Sol. $a_{max} = \mu g = \frac{3}{7} \times 9.8$

$F = (M + m)\, a_{max} = 5\, a_{max}$

= 21 Newton

10. If 2.5×10^{-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)

Official Ans. by NTA (25)

Sol. $F = \frac{IA}{C}$

$$I = \frac{FC}{A} = \frac{2.5\times10^{-6}\times3\times10^{8}}{30} = 25\ W/cm^2$$