# INDIAN ASSOCIATION OF PHYSICS TEACHERS
# NATIONAL STANDARD EXAMINATION IN PHYSICS 2014-15
# ANSWERS / SOLUTIONS
# Q. P. Code 160

## A 1

1. **(c)** Use the definition of dB scale: 120 = 10 $\log_{10}\left(\frac{I}{I_0}\right)$, which gives $\left(\frac{I_0}{I}\right)$ = $10^{-12}$.
2. **(b)** Use Gauss law where $E = \frac{\varphi}{A} = \frac{1}{A}\frac{Q}{\epsilon_0}$ so that $\epsilon_0 E = \frac{Q}{A}$ and $\frac{dQ}{dt} = I$.
3. **(d)** Let the distances of the stars with masses $m_1$ and $m_2$ from their centre of mass be $r_1$ and $r_2$ respectively so that $(r_1 + r_2) = r$, say. The necessary centripetal force is provided by the gravitational force between them, so that $G\frac{m_1 m_2}{r^2} = m_1 r_1 \omega^2 = m_2 r_2 \omega^2$. This gives $\omega^2 = \frac{Gm_2}{r^2 r_1} = \frac{Gm_1}{r^2 r_2} = \frac{G(m_1+m_2)}{r^2(r_1+r_2)} = \frac{G(m_1+m_2)}{r^3}$. From this one can write the expression for $T$.
4. **(c)** Effective acceleration $\boldsymbol{g'}$ is the vector sum of $\boldsymbol{g}$ and acceleration due to rotation of the earth $\boldsymbol{r\omega^2}$ where $r$ is the distance from the axis of rotation. Also one can neglect $r\omega^2$compared to $g$ while determining the magnitude $g'$. Therefore, $g' = (g^2 - 2gr\omega^2 cos\lambda)^{\frac{1}{2}}$ . Also $r$ can be written as $Rcos\lambda$ where $\lambda$ is the latitude.
5. **(b)** The direction along which the particle moves is the direction of velocity which in turn, is the slope of the trajectory. This is $\left[\frac{dy}{dx}\right]_{(0,-4)} = \tan(\theta) = 3$ and hence the answer.
6. **(c)** If the particle A is at $(x, y)$, particle B will be at $(x, 0)$. The speed of B is given to be $\frac{dx}{dt} = v_x = 3$ m/s which is also the $x$ component of the velocity of A. Since for particle B, the equation of trajectory is $y = x$, $v_y = \frac{dy}{dt} = \frac{dx}{dt} = v_x = 3$ m/s. Therefore, speed of A is $\sqrt{{v_x}^2 + {v_x}^2} = 3\sqrt{2}$.
7. **(c)** Moment of inertia = $4\left[\left\{\frac{ma^2}{12} + \frac{ma^2}{4}\right\} + \left\{\frac{\pi m}{2}\frac{a^2}{4} + \frac{\pi m}{2}\frac{a^2}{4}\right\}\right] = ma^2\left(\frac{4+3\pi}{3}\right)$
8. **(c)** One can write the series 100 = 36 + $2 \times 36(e^2 + e^4 + e^6 + \cdots)$ giving $e^2 = \frac{8}{17}$ where $e$ is the coefficient of restitution. Now, the percentage loss of kinetic energy = $\frac{change\ in\ kinetic\ energy}{original\ kinetic\ energy} \times 100$. Note that the speed after impact is $e$ times the initial speed. This gives the percentage loss as 52.94 which is almost 53%.
9. **(a)** The magnetic force exerted and hence the corresponding acceleration is proportional to the current. Consider the expression for the period of a simple pendulum in which the effective acceleration due to gravity can be written as $g' = g + ai$ where $a$ is a constant. Then, $T = 2\pi\sqrt{\frac{l}{g+ai}} = 2\pi\sqrt{\frac{l}{g\left(1+\frac{ai}{g}\right)}} =$

$2\pi\sqrt{\frac{l}{g}}\left(1+\frac{ai}{g}\right)^{-\frac{1}{2}} = T_0\left(1-\frac{1}{2}\frac{ai}{g}\right)$ where $T_0$ is the original period. Therefore, the change in period $|\Delta T|$ is linearly proportional to the current $i$.

**10. (b)** The beat frequency is the difference in frequencies which is the reciprocal of the beat period $T$ which is given to be 10 s.

**11. (b)** Thrust on the curved surface $= 2\pi Rh\left(P_0+\frac{h}{2}\right) = 300\pi R$ whereas the thrust on the bottom $= \ \pi R^2(P_0+h) = 20\pi R^2$. The atmospheric pressure in terms of column of water is 10 m. equating the two thrusts gives $R$ = 15 m.

**12. (b)** Moment of inertia of annular disc about the axis under consideration can be written as $\frac{m}{2}(R_1^2+R_2^2)+mR_2^2$. Comparing the expression for the periodic time of this oscillating disc as a compound pendulum with that of a simple pendulum, we get the equivalent length.

**13. (d)** For aluminum one can write $L_{Al} = L_0[1+\alpha_{Al}t] = R_2\theta$ where $R_2$ is the radius of the arc of aluminum strip and $t$ is the temperature. Note that $\theta$ is the angular width of the strips. A similar expression can be written for iron strip. The difference between the radii, say $d$, for aluminum and iron is the distance between the central planes of the two strips. The expression for $d$ can be obtained from the above two expressions as $= \frac{L_0t[\alpha_{Al}-\alpha_{Fe}]}{d}$. Also ($R_1$ + $R_2$) can be approximated as 2i and the value of $R$ can be determined.

**14. (d)** In this case $\frac{\sqrt{T}}{\lambda}$ is constant. If wavelength is λ (when the cylinder is in air), that when the cylinder is immersed in water will be $\frac{\lambda}{2.2}$.

**15. (a)** As per road design, the rated speed is $\sqrt{gRtan\theta} = 20$ m/s. Now, the speed is to be 40 m/s which will be helped by friction. With the help of free body diagram, one can write $mg+\mu_s Nsin\theta = Ncos\theta$ and $Nsin\theta+\mu_s Ncos\theta = \frac{mv^2}{R}$. Simplifying this one gets $\mu_s = \frac{v^2cos\theta-gRsin\theta}{gRcos\theta+v^2sin\theta}$. Using tanθ = 0.2, one gets $\mu_s = 0.517 = 0.52$ approximately.

**16. (a)** Each of the coils acts as a magnetic dipole. The force of interaction between them varies inversely as the fourth power of the distance of separation. When the coils are placed vertically only the weight $mg$ of the coil balances this force. However, when they are placed horizontally a force equal to $\mu mg$ balances this force. Thus, $\frac{\mu mg}{mg} = \frac{(0.04)^4}{(0.05)^4} = 0.4096$ which is almost 0.41.

**17. (b)** The electric field at a distance $x$ from the wire is $E = \frac{\lambda}{2\pi\epsilon_0 x}$ so that the force on a charge $q$ would be $\frac{q\lambda}{2\pi\epsilon_0 x}$. Writing the force as $\frac{dv}{dx}$, the speed can be determined by integrating the expression.

**18. (b)** Let $w_1$ be the weight of the body in air and $w_2$ be its weight in water. Using law of moments, one gets $w_1 = 3mg$ and $w_2 = 2.5\ mg$ where mg is the weight of the meter scale. The specific gravity is then $\frac{w_1}{w_1-w_2} = 6$.

**19. (a)** Let $s_1$ be the specific heat of sand and $s$ be that of the liquid. Using the principle of calorimetry, one gets 4200 = 2 $s_1$ and $s_1$ = 2 $s$ and hence the answer.

**20.** **(d)** Consider the expressions for the different speeds, $v_{avg} = \sqrt{\frac{8RT}{\pi M}}$ , $v_{rms} = \sqrt{\frac{3RT}{M}}$ and $v_p = \sqrt{\frac{2RT}{M}}$, where symbols carry their usual meanings. Now determine their inter-relation.

**21.** **(a)** Ideal efficiency is 40% whereas the actual efficiency is 40 × 0.8 = 32%. In a year the number of units required is 10 × 365 = 3650 units. One unit corresponds to 3600 kJ of energy, so that in a year the actual output is required to be 36000 × 365 kJ, which is (equivalent of 1 kg of coal) × 365. With 32% efficiency this gives the amount of coal required throughout a year is 1140.625 kg of coal.

**22.** **(a)** The thermoemf $e$ = 40 (50 – 0) = 2000 μV. If G is the resistance of the galvanometer, the current through it is $\frac{2000}{G}$ μA which produces full scale deflection of 30 divisions. Therefore, $\frac{2000}{G} = 30C$ where $C$ is the figure of merit of the galvanometer. After connecting 100 ohm resistance in series with the galvanometer, the equation becomes $\frac{2000}{G+100} = 10C$. Solving these equations one gets G = 50 ohm and $C = 1.33$ μA/div.

**23.** **(d)** Let the resistance of the voltmeter be $R$ (in kΩ, for convenience). Considering the voltage drops, one gets $R$ = 10 kΩ. Initial current is then obviously 150 μA. The time required for the voltage across the capacitor to fall from $V_0$ to $V$ is given by $t = RC\ ln\left(\frac{V_0}{V}\right)$. Using this one gets $t$ = 11 s.

**24.** **(c)** A charge – 2 μC is non-uniformly distributed on the inner surface of the spherical shell whereas an equal positive charge is uniformly distributed on the outer surface.

**25.** **(c)** If $T_1$ and $T_2$ are the periodic times of the two pendulums, $\frac{T_1}{T_2} = 1.001$ and hence the ratio of lengths is $\frac{L_1}{L_2} = \left(\frac{T_1}{L_2}\right)^2 = 1.002$. This gives $L_1 = 1.002\ L_2$. Now, one can write the expressions for the increased lengths after the temperature is raised by $t^0$ C and equate the two. Solving this one gets the temperature $t$.

**26.** **(b)** Ultrasonic has to do with the frequency and not the speed.

**27.** **(b)** Clearly the neutral point is on the equator of the magnet and the magnetic field at that point is $B_H = \frac{\mu_0 M}{4\pi r^3}$ . Writing a similar expression for the field at a point on the axis, the ratio can be taken to give the answer.

**28.** **(d)** Knowing the direction ratios, one can write the unit vector in the direction in which the object is moving. Therefore, the velocity of the object can be written as $v = \sqrt{2}\left(\frac{3}{5\sqrt{2}}\hat{\imath} + \frac{4}{5\sqrt{2}}\hat{\jmath} + \frac{5}{5\sqrt{2}}\hat{k}\right)$. Since, the mirror is along the plane $x$ = 3, the velocity will have its $x$ component only inverted.

**29.** **(b)** If $I_0$ is the initial intensity of light entering the first polarizing sheet, the intensity after this sheet is $I_1 = \frac{I_0}{2}$. The intensity of light after the second sheet is $I_2 = I_1 cos^2\ 60^o$ and similarly that after the third sheet is $I_3 = I_2 cos^2\ 30^o$. Finally expressing $I_3$ in terms of $I_0$ one gets the result.

**30.** **(b)** Note that if the rays reflected from the two interfaces (air-film and film-glass) interfere destructively, the reflection will be eliminated. For this the total path difference must be an odd multiple of half the wavelength. If $L$ is the film thickness, $2L = (2n+1)\frac{1}{2}\left(\frac{\lambda}{1.38}\right)$ where the wavelength in $MgF_2$ is $\left(\frac{\lambda}{1.38}\right)$. Now for $L$ to be minimum $n$ should be zero. Substituting the values one gets the result.

**31. (c)** The capacitance $C$ corresponds to $\frac{1}{k}$ and NOT $k$.

**32. (c)** Current through the circuit is obviously 2 mA. Therefore, the capacitive reactance is $\frac{5\ volt}{2\ mA} = 2.5$ kΩ. From this the capacitance turns out to be 1.27 μF. The peak value of the source voltage is $\sqrt{2}$ times the net RMS voltage which is $\sqrt{2} \times \sqrt{5^2 + 2^2} = 7.62$ volt.

**33. (a)** The charging time constant is 220 ms. Since the contact is more than five time constants the capacitor gets fully charged, that is the voltage across the capacitor is 10 volt. Now, the discharging time constant is 330 ms. Therefore, after 330 ms, the voltage across the capacitor and hence across the two resistors together is 3.678 volt. Out of this the voltage across the 5 kΩ resistor is 1.226 volt.

**34. (c)** The variation of $B$ with the distance is linear inside the wire.

**35. (a)** The voltage across coil B is $v_2 = M\frac{dI}{dt}$ where $I = I_0 sin\ \omega t$ is the current in coil A. This gives $v_2 = \omega M I_0 cos\ \omega t$. Taking into account the rms values of current and voltage, $M$ comes out to be 159 mH. Initial current in coil A is, say $I_1$ = 0.1 A. Therefore, if $V$ is the voltage across it, the impedance of coil A is $10V$. After coil B is shorted, the current in coil A increases to 0.102 A, hence its impedance is $\frac{V}{0.102} = 9.804\,V$. Then the percentage change in impedance is 1.96% or about 2%.

**36. (d)** Due to the emf's induced being in phase opposition the net current is small. Also since the number of turns is not the same the current does not drop to zero and hence the bulb glows feebly.

**37. (c)** Let $N_2$ be the number of atoms of stable isotopes and $N_1$ be that of radioactive isotopes. If $N_0$ is the initial number then, $N_2 = N_0 - N_1$. Now, $N_1 = N_0\ e^{-\lambda t} = (N_1 + N_2)\ e^{-\lambda t}$. This gives $t = \frac{ln\left[1+\frac{N_2}{N_1}\right]}{\lambda}$. Writing $\lambda = \frac{ln\ 2}{T_{1/2}}$ one gets the answer.

**38. (c)** With the help of truth table for NAND gate write the output at every stage for all possible cases of the input.

**39. (c)** The minimum wavelength $\lambda_{min}$ corresponds to $v_{max}$ where all the energy carried by the electron is totally transferred to X ray photon. Writing $\lambda_{min} = \frac{hc}{E}$ where $E$ is the energy of the electron, one gets the answer.

**40. (c)** Particularly when the cells assist each other (sum), the driving cell must have an emf $E$ greater than the sum of the emf's [ > (1.40 + 1.08)] of the cells under test.

**41. (d)** Electrical conductivity of brass is the greatest among the materials given. Due to plating the strips are free from corrosion.

**42. (c)** Due to stretching the resistance of the potentiometer wire is 40 + 2% = 40.8 ohm. Potential gradient $v$ can be written as $v = \frac{1}{L}\frac{Er}{R+r}$ where $r$ is the resistance of the wire and $R$ is the resistance connected in the circuit. Solving for $R$ gives the answer.

**43. (b)** Determining the end point is more important than keeping the wire in place.

**44. (c)** The metal strip S has a very small resistance (close to zero, but NOT zero).

**45. (b)** Note that point $P_1$ is closer to the common point (where the positive terminal of E and that of the cell under test are connected) than the point $P_2$ and the emf is proportional to the balancing length.

**46. (c)** If $e < e'$, the emf under test will be negative and the current will always pass through the galvanometer. If key is open, current is only due to the emf under test which never becomes zero. If $R$ is too large, the potential difference across the total length of wire may be smaller than the emf under test.

**47. (c)** The potential difference across 1 cm wire is 6mV and hence the current through the galvanometer is 6 µA.

**48. (b)** Obviously the amplitude is a maximum for one particular frequency at which a pendulum resonates with the driver pendulum.

**49. (c)** The pendulum which has the same natural frequency of oscillation as that of the driver pendulum has maximum amplitude.

**50. (b)** The frequency of the resonating pendulum is obviously the same as $f_0$ the frequency of the driver pendulum.

**51. (a)** When one of the coupled pendulums stops, its energy is completely transferred to the driver pendulum. If $A$ and $A'$ are respectively the amplitudes of the coupled pendulum and the driver pendulum, $\frac{1}{2}\omega^2 MA'^2 = \frac{1}{2}\omega^2 mA^2$. This gives $M = 1.5\ m$.

**52. (c)** Considering the expression for the periodic time $T$ of a simple pendulum, $\Delta T$ is proportional to $\frac{1}{T}$.

**53. (b)** The amplitude of a simple pendulum exponentially decreases with time.

**54. (a)** The graph of log $A$ against $t$ is a straight line as $A$ varies exponentially with $t$.

**55. (b)** The decrease of amplitude is due to a damping force that is proportional to velocity $v$.

**56. (d)** Considering the object distance $u$ and the magnification $m$, the image distance $v$ comes out to be 20 cm and the focal length $f$ to be 12 cm. Now, the object has to be moved closer to the lens so as to get a magnified image. Taking $u' = 10$ cm, image distance comes out to be 60 cm.

**57. (a)** Focal length of the combination is + 24 cm. With $u = 30$ cm, image distance is 120 cm and the magnification is 4, that is the image is real and magnified.

**58. (d)** Convex lens forms a real inverted image at 20 cm from the lens. This acts as the virtual object for the concave lens forming a final image at $\frac{120}{7}$ or approximately 17 cm from the concave lens. Note that this is a real image of the virtual object formed by the concave lens. Therefore, from the object the final image is at a distance of 57 cm.

**59. (d)** At first consider the convex lens made of material of refractive index 1.2 and placed in air ($\mu = 1$) and then immersed in a medium of refractive index $\mu = 1.5$. The focal length happens to be numerically $5k$ where $k$ is a factor decided by the radii of curvature. It is seen that the focal length numerically remains the same. The same argument can be made for the concave lens. Therefore, when the two lenses are in contact, the effective focal length remains numerically the same.

**60. (d)** Use the formula for refraction at a spherical surface. Since the media on the two sides of the lens are different, consider the formation of image by one surface at a time. Consider parallel rays from air and $n_1 = 1$, $n_2 = \frac{3}{2}$, image distance by the first surface is 36 cm. For the second surface $n_1 = \frac{3}{2}$ and $n_2 = \frac{4}{3}$, final image is formed at 24 cm. Thus, $a$ = 24 cm. Using a similar procedure and considering parallel rays incident from water, the final image is formed at $b$ = 18 cm.

## A 2

**61. (a), (c)** After displacement of mass $2m$, there is no change in $y$ coordinate of centre of mass. This indicates that the displacement is along X axis. Using the expression for the X coordinate of centre of mass, initially the X coordinate of mass $2m$ comes out to be 1.5 whereas it is 4 when the mass is displaced. Therefore, the displacement is of magnitude 2.5 or $\frac{5}{2}$ units.

**62. (a), (d)** Deceleration due to the frictional force is 2 m/s$^2$, so that block B collides with a velocity of 0.6 m/s. Using conservation of momentum, $2v_1 + v_2 = 0.6$ where $v_1$ and $v_2$ are the velocities of blocks A and B after collision. Also since the collision is elastic (coefficient of restitution = 1), $v_1 - v_2 = 0.6$. This gives $v_1 = 0.4$ m/s and $v_2 = -0.2$ m/s. The negative sign for $v_2$ indicates that block B rebounds. Displacement of block A after collision is 4 cm to the right whereas that of block B is 1 cm to the left, so that the final separation is 5 cm.

**63. (a), (c), (d)** The net force upward is $Mg$ so that the acceleration is $g$ upwards. The net torque is anticlockwise and is of magnitude $MgR$ which is also the same as the rate of change of angular momentum. Since the moment of inertia is $\frac{MR^2}{2}$, the angular acceleration is $\frac{2g}{R}$.

**64. (a), (c), (d)** Using the expression for the magnetic induction due to a long straight wire and the right hand rule, the magnetic inductions at the origin due to the wires at A, B, C and D are $2 \times 10^{-8}$ T along OY', $4 \times 10^{-8}$ T along OX, $2 \times 10^{-8}$ T along OY and $2 \times 10^{-8}$ T along OX' respectively. Therefore, the inductions due to wires at A and C cancel out. Using the vector addition, the induction due to wires at A and D is $2\sqrt{2} \times 10^{-8}$ T and that due to all wires is $2 \times 10^{-8}$ T.

**65. (c), (d)** Using the equation of continuity, a relation can be written as $\pi(25)^2 \times 0.4 = n \times \pi(2)^2 \times 0.02$ where $n$ is the number of plants. This gives $n$ = 3125. Further the flow of water is 0.25 ml per second so that in 2 hours each plant gets 1.8 litre of water.

**66. (a), (c), (d)** During the positive half cycle, the diode remains open and the output is the same as the input and hence 2.5 volt. Since the negative half cycle is clipped, the circuit acts as a rectifier. If the diode happens to be non-ideal the output is 2.5 + 0.7 = 3.2 volt above minimum.

**67. (a), (c)** At constant volume, pressure is directly proportional to temperature. Using this the temperature at which liquid nitrogen boils comes out to be 74.6 K. Also since at this temperature oxygen is not in gaseous state (boiling point of $O_2$ is 90 K), it cannot be used in gas thermometer.

**68.** **(a), (c)** On cooling of water, deviation increases indicating that the refractive index of water increases. Considering the expression for refractive index in terms of speed of light, the speed of light decreases with decrease of temperature.

**69.** **(a), (b), (c), (d)** Knowing the wavelength diameter of wire can always be determined. Obviously in experiments on diffraction light does not follow rectilinear paths. This is a case of Fraunhoffer diffraction. Diffraction is essentially a case of interference of a large number of wavelets.

**70.** **(c), (d)** The kinetic energy is obviously maximum when the element passes through the mean position. In the mean position the string element happens to be in its maximum stretched and hence its elastic potential energy is also maximum.

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