INDIAN ASSOCIATION OF PHYSICS TEACHERS

National Graduate Physics Examination 2024

Day and Date of Examination : Sunday, January 21, 2024

Time : 10 AM to 1 PM

Instructions to Candidates

1. In addition to this question paper, you are given **answer sheet (OMR Sheet) for part A** and **answer paper for part B**.
2. On the answer sheet (OMR Sheet) for part A, fill up all the entries carefully in the space provided, **Only in block capital. Do write the name and PIN of your city.**

   Incomplete / incorrect / carelessly filled information may disqualify your candidature
3. On part A answer sheet, use only BLUE or BLACK BALL PEN for making entries and marking answers.
4. In Part A each question has **FOUR** alternatives. Any number of these (4, 3, 2 or 1) may be correct. You have to mark **ALL** correct alternatives and fill a bubble (●) for each, like

Q.No.	a	b	c	d
24	○	●	○	●

   Full marks are 6 for each question, you get them only when ALL correct answers are marked. The answers of part A shall be available on **www.indapt.org** on 1.2.2024.
5. Part A answer sheet will be collected at the end of one hour.
6. Any rough work should be done only on the sheets provided with part B answer paper.
7. Use of non-programmable calculator is allowed.
8. No candidate should leave the examination hall before the completion of the examination. You will take away the question paper with you.
9. Symbols used in the paper have their usual meaning unless specified otherwise.

PLEASE DO NOT MAKE ANY MARK OTHER THAN ● IN THE SPACE PROVIDED ON THE ANSWER SHEET OF PART A MEANS YO HAVE TO DARK THE CIRCLE.

Answer sheets for part A are to be evaluated with the help of a machine. Due to this, **CHANGE OF ENTRY IS NOT ALLOWED**

Scratching or overwriting may result in wrong score

DO NOT WRITE ANYTHING ON BACK SIDE OF ANSWER SHEET FOR PART A

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Part A- Maximum Marks: 150 — Time for Part A : 60 minutes

Part B- Maximum Marks: 150 — Time for Part B : 120 minutes

Part A

$25 \times 6 = 150$

Mark the correct option/options (Any number of options may be correct).
Marks will be awarded only if all the correct options are marked. No negative marking.

1. The work done in moving a point charge $q = -5\mu C$ in an electric field $\vec{E} = \left(8r\sin\theta\ \hat{r} + 4r\cos\theta\ \hat{\theta}\right)\frac{V}{m}$ from a point $A(r, \theta) \equiv A\left(10, \frac{\pi}{6}\right)$ to a point $B(r, \theta) \equiv B\left(10, \frac{\pi}{2}\right)$ is
   (a) $+1mJ$
   (b) $-1mJ$
   (c) $+2mJ$
   (d) $-2mJ$

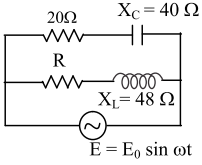
2. The dispersion relation for an electromagnetic wave in a certain medium is given by $\omega^2 = \alpha k$ where α is constant, ω is the angular frequency and k is the magnitude of the wave vector. The velocity of energy propagation in this medium is given by:
   (a) $v = \frac{\alpha}{6\omega}$
   (b) $v = \omega$
   (c) $v = \frac{\alpha}{2\omega}$
   (d) $v = \frac{\omega}{\alpha}$

3. If a^+ and a are creation and annihilation operators for a Linear Harmonic Oscillator, then which of the following is/are Hermitian operator?
   (a) $(a\,a^+ + a^+a)$
   (b) $(a\,a^+ - a^+a)$
   (c) $i(a^+ - a)$
   (d) $i(a^+ + a)$

4. A rectangular solid strip of length ℓ, breadth b and negligible thickness is used as a bar pendulum in the laboratory to measure the value of acceleration due to gravity. When the axis of rotation is horizontal and perpendicular to the ℓ-b plane of the strip at a distance ξ from a parallel axis through its centre of gravity,
   (a) the radius of gyration is $K = \sqrt{\frac{\ell^2 + b^2 + 12\xi^2}{12}}$
   (b) the time period of the pendulum is $T = 2\pi\sqrt{\frac{\ell^2 + b^2 + 12\xi^2}{12\xi g}}$
   (c) the length of an equivalent simple pendulum turns equal to $L = \frac{\ell^2 + b^2 + 12\xi^2}{12\xi}$
   (d) the time period will have to be a minimum when $\xi = \sqrt{\frac{\ell^2 + b^2}{12}}$

5. The divergence of the magnetic vector potential $\vec{A}$, is $\nabla.\vec{A} = -\frac{\mu_0}{4\pi}\frac{Q}{r^2}$, where Q is a constant of appropriate dimension. The corresponding scalar potential $\phi\ (r, t)$ that makes $\vec{A}$ and ϕ a Lorentz Gauge is
   (a) $\phi(r, t) = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$
   (b) $\phi(r, t) = \frac{1}{4\pi\varepsilon_0}\frac{Qt}{r}$
   (c) $\phi(r, t) = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$
   (d) $\phi(r, t) = \frac{1}{4\pi\varepsilon_0}\frac{Qt}{r^2}$

6. In the AC circuit shown, if the total current is in phase with the applied voltage, the value of resistance R is nearly

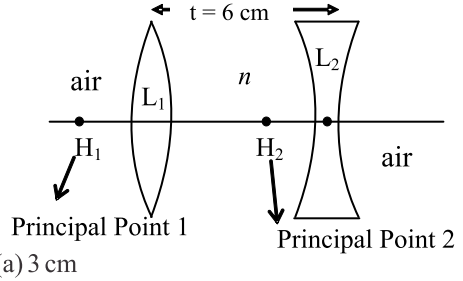


(a) 24 Ω
(b) 8 Ω
(c) 12 Ω
(d) 10 Ω

7. The ratio of the energy of the first excited state E_1, to that of the ground state E_0, of a particle in a three dimensional rectangular box of sides L, L and $\frac{L}{2}$ is

(a) 3 : 2
(b) 2 : 1
(c) 4 : 1
(d) 4 : 3

8. A thin divergent glass lens of focal length 10 cm is placed coaxially 6 cm away from a thin converging glass lens of same focal length 10 cm. When in air, the distance between the two principal planes of the coaxial system is:



(a) 3 cm
(b) 6 cm
(c) 16 cm
(d) zero

9. Which of the following statement/s is/are correct regarding strong nuclear forces?

(a) Nuclear forces are responsible for holding the nucleons (protons and neutrons) together in the nucleus of an atom.
(b) Nuclear forces are predominantly attractive in nature.
(c) Nuclear forces are short-range forces that act between nucleons inside the nucleus.
(d) Nuclear forces play a significant role in chemical reactions.

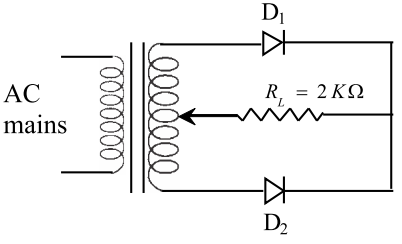
10. If the reverse bias voltage of a silicon varactor diode is increased by a factor of 2, the corresponding transition capacitance

(a) increase by a factor of $\sqrt{2}$
(b) increase by a factor of 2
(c) decrease by a factor of $\sqrt{2}$
(d) decrease by a factor of 2

11. Monochromatic X-rays of wave length $\lambda = a$ are reflected from the (111) plane of a simple cubic lattice of lattice constant a, the corresponding Bragg angle (in radian) is

(a) $\frac{\pi}{6}$
(b) $\frac{\pi}{4}$
(c) $\frac{\pi}{3}$
(d) $\frac{\pi}{8}$

12. The centre tap full-wave single-phase rectifier circuit uses 2 ideal diodes D_1 and D_2 as shown. Given that the rms voltage (V_{rms}) between two ends of the secondary of the transformer is 200 volt.



(a) the rms voltage across each diode is 100 V
(b) the rms voltage across load R_L is 100 V
(c) dc value of load current is 45.0 mA
(d) rms value of the load current is 50.0 mA

13. A typical low-power 7 mW He-Ne LASER tube operates at a voltage of 1500 V and carries a current of 10 mA. The efficiency of the LASER is:

(a) 0.024%
(b) 0.036%
(c) 0.047 %
(d) 0.072%

14. In a Carnot heat engine, which of the following statement/s is/are correct?
    (a) The efficiency of a Carnot engine increases with increasing temperature of the hot reservoir.
    (b) The Carnot cycle is the most efficient heat engine operating between two given temperature reservoirs.
    (c) The Carnot cycle consists of two reversible adiabatic processes and two reversible isothermal processes.
    (d) The Carnot cycle has a higher efficiency when the working substance is an ideal gas compared to a liquid.

15. Two point charges + 2Q and – Q are kept at points, with cartesian coordinates, (1, 0, 0) and (2, 0, 0) respectively in front of an infinite grounded conducting plate located in y-z plane at $x = 0$. The electric potential at point P $(x, 0, 0)$ for $x >> 1$ majorly depends on x as
    (a) $\frac{1}{x^2}$
    (b) $\frac{1}{x^3}$
    (c) $\frac{1}{x^4}$
    (d) $\frac{1}{x^5}$

16. A particle of mass m is confined in the ground state of a one dimensional potential well extending from $x = -2L$ to $x = +2L$. The wave function of the particle in this state is

    $\psi(x) = A \cos \frac{\pi x}{4L}$, where A denotes the normalization constant.

    (a) The normalization constant A of this wave function is $\sqrt{\frac{1}{2L}}$
    (b) The energy Eigen value corresponding to this state is $\frac{\pi^2 \hbar^2}{2mL^2}$
    (c) The energy Eigen value corresponding to this state is $\frac{\pi^2 \hbar^2}{32mL^2}$
    (d) The expectation value of p^2 (p is the momentum operator) in this state is $\frac{\pi^2 \hbar^2}{8L^2}$

17. The physical phenomenon that can be used for memory storage applications is/are the
    (a) large variation in magneto resistance as a function of applied magnetic field.
    (b) variation in magnetization of a ferromagnetic substance as a function of magnetic field.
    (c) variation in polarisation of a ferroelectric as a function of applied electric field.
    (d) variation in resistance of a metal as a function of applied electric field.

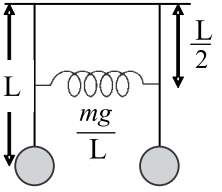
18. In a bipolar junction transistor (BJT), which of the following statements regarding the operation modes is/are correct?
    (a) In saturation mode, both the base-collector and base-emitter junctions are forward-biased.
    (b) In cut-off mode, both the base-collector and base-emitter junctions are reverse-biased.
    (c) In active mode, the base-collector junction is reverse-biased, and the base-emitter junction is forward-biased.
    (d) In breakdown mode, excessive current flows through the base-emitter junction.

19. One mole of nitrogen (M = 28) is contained in a cylinder at a pressure of 2 atm. and temperature of 17°C. Considering the diameter of nitrogen molecule as $\sigma = 2.0$Å, you may estimate the
    (a) mean free path of N_2 as $\lambda = 1.0 \times 10^{-7} m$
    (b) rms speed of N_2 molecules as $v_{rms} = 510\ ms^{-1}$
    (c) collision frequency of nitrogen molecule as $f = 5.1 \times 10^9\ per\ sec$
    (d) molecular density of N_2 in the cylinder as $n = 5 \times 10^{25}\ m^{-3}$

20. An intense laser beam of wavelength of 600 nm having a circular cross-section of radius $r = 10\ mm$, is incident parallel to the principal axis on a convex lens of focal length 10 cm and aperture diameter of 40 mm. The size (diameter) of the focussed spot is approximately
    (a) 0.3 μm
    (b) 0.6 μm
    (c) 3.0 μm
    (d) 6.0 μm

21. In the context of Laplace's equation, which of the following statement/s is/are correct?
    (a) Gauss's law in electrostatics turns into Laplace's equation in the charge free region.
    (b) Laplace's equation describes the behaviour of magnetic field (B) in the presence of time varying electric fields $\left(\frac{\partial E}{\partial t} \neq 0\right)$
    (c) Laplace's equation describes the behaviour of electric and magnetic fields under dynamic situations.
    (d) Laplace's equation can be used to find the electric potential (V) in regions with no charge distribution

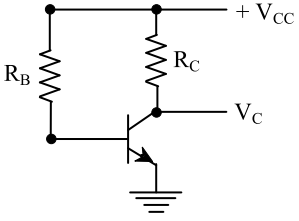
22. Two identical simple pendulum of length L are connected by a spring at a distance $\frac{L}{2}$ from the support as shown. Assume that the spring constant is $K = \frac{mg}{L}$. Here m is the mass of each bob and g is acceleration due to gravity. The ratio of the highest to the lowest eigen frequencies of the system is
    (a) $\sqrt{\frac{3}{2}}$
    (b) 1
    (c) $\sqrt{2}$
    (d) $\sqrt{3}$



23. Gamma ray of energy 2.2 MeV produces an electron-positron pair.
    (a) Only 1.02 MeV is used to produce the pair
    (b) The K.E of each particle is 0.51 MeV
    (c) The sum of the Kinetic Energies of both the electron and the positron is 1.18 MeV
    (d) The electron and the positron gain equal and opposite momenta.

24. Which of the following principles or technologies are likely to have been used in sending Chandrayaan-3, a lunar mission?
    (a) Ion Propulsion
    (b) Nuclear Reactor
    (c) Solar Panels
    (d) Magnetic Levitation

25. During the analysis of the transistor circuit shown, one obtains
    (Given that $\alpha = 0.96$, $V_{BE} = 0.3\ V$, $R_C = 2.2\ k\Omega$, $R_B = 100\ k\Omega$ and $V_{cc} = +10\ V$)



    (a) the value of β is 24
    (b) the collector current I_C is 2.328 mA
    (c) the base current I_B is 97.0 μA
    (d) the collector voltage V_C is 4.88 V

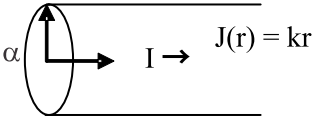
Part B1

10 x 5 = 50

Answer all the following in brief (not more than 10 lines) with appropriate reasoning

B1. In Bohr's model of the atom, the mass of the electron is taken as constant. Defend or refute.

B2. The current density J(r), in a long wire of uniform circular cross section as shown, is proportional to the radial distance r from the axis of the wire, i.e., $\vec{J} = k\vec{r}$ (k is a constant with a value of 100 A/m^3).



The total current (I)flowing through the wire of uniform cross section of radius R = 3.0 mm is approximately I = 5.7 μA. Defend or refute.

B3. Maxwellian velocity distribution law is applicable to non-ideal gases i.e real gases. Defend or refute.

B4. Prior to emerging from a cyclotron deuteron describes a circle of radius r = 0.32 m. If the frequency of the applied AC voltage is 10 MHz, the speed of the deuteron emerging from the cyclotron is $v = 2.01 \times 10^7$ ms^{-1} (when the relativistic correction is ignored) Defend or refute.

B5. In Nuclear fission a heavy nucleus breaks up while two or more lighter nuclides fuse together in Nuclear fusion. The energy is released in both the cases. Explain why?

B6. Silicon and Germanium semiconductors at an ambient temperature of 1000 K are still semiconductor. Defend or refute

B7. The ratio $\gamma = \frac{C_P}{C_V}$ is $\gamma = \frac{9}{7}$ for a diatomic gas. The molecules of the gas are essentially not rigid rotators. Defend or refute.

B8. Three plane harmonic waves
$y_1 = A \sin(\omega t - kx - \phi)$
$y_2 = A \sin(\omega t - kx + \phi)$ and
$y_3 = 3A \sin(\omega t - kx)$ are superimposed.
The resultant intensity is maximum when $\phi = 2n\pi$ with n = 0,1,2,3.. Defend or refute.

B9. Ohm's Law states that for a given conductor, physical conditions remaining the same, the current flowing through the conductor is directly proportional to the potential difference applied across the conductor. What is the significance of "for a given conductor, physical conditions remaining the same?"

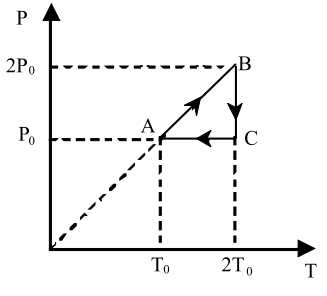
B10. A moving particle of mass *m* describes a circle of radius *r*. The centripetal acceleration of the particle is $\frac{4}{r^2}$. The momentum of the particle is $p = \pm \frac{2m}{\sqrt{r}}$. Defend or refute.

Part B2

$10 \times 10 = 100$ marks

Solve all the 10 problems. Each carries 10 marks.

P1. Pressure temperature variation in a cyclic thermodynamic process ABCA for a diatomic gas is shown. For the given process



(a) Calculate efficiency of the cyclic process
(b) Draw volume – temperature diagram for the process ($\gamma = 1.4$)

P2. In an early experiment to determine Poisson's ratio of rubber, a long rubber tube (a cycle tyre tube) of length L = 1 m and diameter D =5 cm is taken. The tube is completely filled with water, corked tightly at both the ends and is suspended vertically on a support just at the upper cork. The upper cork carries a calibrated vertical capillary of radius $r = 1.0\ mm$ through which the water level remains visible and can be recorded. When the lower end is loaded and pulled down by a mass M = 0.25 kg the tube length increases by $\Delta L = 2.0\ cm$ while the water level in the capillary at the top rises by $h = 3.0\ cm$. Derive an expression for Poisson's ratio (σ) in terms of the relevant parameters and estimate its value from the given data.

P3. A beam of X-rays of frequency υ falls upon a metal sheet and gives rise to photoelectrons. These electrons of rest mass m_0 moving under the influence of the magnetic induction B, describe a circle of radius r. Show that

$$h\left(\upsilon-\upsilon_0\right) = m_0c^2\left[\left(1+\frac{e^2B^2r^2}{m_0^2c^2}\right)^{\frac{1}{2}}-1\right]$$

P4. State and Explain Fourier theorem. You are given a periodic function $f(x)$, with periodicity 2π, such that $f(x)=\begin{cases}c & 0\le x<\pi\\ 0 & \pi\le x<2\pi\end{cases}$

where c is a constant

(a) Expand the given periodic function $f(x)$ in a Fourier series of harmonics

(b) Using the results obtained in (a), show that

$$\frac{\pi}{4}=1+\frac{1}{3}+\frac{1}{5}+\frac{1}{7}+\frac{1}{9}+\ldots\ldots\ldots$$

P5. A Fabry Perot interferometer is used to determine the small difference in wavelength of two components of a radiation of average wavelength 6400Å. It is observed that at a given point, near the centre, the two sets of the fringe coincide for a given distance between the two plates and again when distance is increased by 1.024mm. Find the difference in the two wavelengths.

P6. Explain the concept of displacement current. Write four Maxwell's equations in differential form. Hence derive the equation of an EM wave in free space and justify its transverse nature.

P7. Show explicitly that the time period of a relativistic harmonic oscillator of rest mass m_0 and amplitude a is

$$T=2\pi\sqrt{\frac{m_0}{K}}\left[1+\frac{3Ka^2}{16m_0c^2}+\ldots\ldots\ldots\ldots\right]$$

Note that K is the force constant and c is speed of light in free space.

P8. A simple cubic crystal with lattice parameter a_c undergoes transition into a tetragonal structure with lattice parameters $a_t=b_t=\sqrt{2}a_c$ and $c_t=2a_c$, below a certain temperature. Find out the ratio of the interplanar spacing of (101) planes for the cubic to the tetragonal structure.

P9. Charge q is uniformly distributed over the surface of a spherical shell of mass M and radius R. Estimate the value of the magnetic dipole moment when the sphere rotates about its diameter with an angular velocity ω. Also obtain the ratio of magnetic dipole moment to the mechanical moment (Angular momentum) of the rotating spherical shell.

P10. For the given transistor amplifier, find

(a) the DC bias levels i.e. I_B, I_C, I_E, V_C and V_E

(b) the AC emitter resistance and

(c) the voltage gain

Given that $\beta=100$, $V_{cc}=+15$ V and $V_{BE}=0.7$ V