INDIAN ASSOCIATION OF PHYSICS TEACHERS

National Graduate Physics Examination 2022

Day and Date of Examination : Sunday, January 23, 2022

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 1.2.2022.
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 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 — 25x6 = 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. In a certain region of space the field is expressed as $\vec{E} = 3x\hat{i} + 2y\hat{j} + z\hat{k}$. The value of the surface integral $\oiint \vec{E}.d\vec{S}$ over a closed surface bounded by $x = 0$ to $x = 3$, $y = 0$ to $y = 2$ and $z = -1$ to $z = 2$ is
   (a) 108 units
   (b) 36 units
   (c) 18 units
   (d) 6 units

2. In a dispersive medium the angular frequency (ω) of the wave is related with its wave vector ($\vec{K}$) as $\omega^2 = \omega_0^2 + c^2K^2$ where ω_0 and c are constant. The product of Phase velocity (v_p) and the group velocity (v_g) is expressed as
   (a) $0.25c^2$
   (b) $0.5c^2$
   (c) c^2
   (d) data insufficient to calculate

3. In a simple circuit for charging of a capacitor of 100 μF through a resistance of 10 kΩ in series by a battery of 6 volt in your laboratory, the displacement current i_d between the capacitor plates after 500 millisecond shall be
   (a) 240 μA
   (b) 364 μA
   (c) 480 μA
   (d) 600 μA

4. A well-known differential equation for forced oscillation is

   $$\frac{d^2x}{dt^2} + 2b\frac{dx}{dt} + \omega^2 x = f_0 \sin pt$$

   where b , $\frac{\omega}{2\pi}$ and $\frac{p}{2\pi}$ are respectively

   damping factor, the natural frequency of the oscillating system and the frequency of the applied periodic force $F = F_0 \sin pt$. Under the conditions of low damping, the solution can be expressed as

   $$x(t) = \frac{f_0}{\sqrt{(\omega^2 - p^2)^2 + 4b^2p^2}} \sin(pt - \theta)$$

   The phase angle θ for $p >> \omega$, when the damping factor b tends to zero is

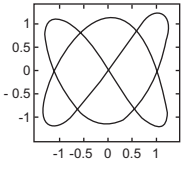
   (a) Zero
   (b) $\frac{\pi}{4}$
   (c) $\frac{\pi}{2}$
   (d) π

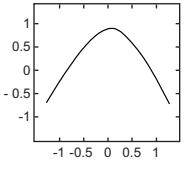
5. A thin long wire of mass M and length 4L is folded into a square and is now rotated about an axis passing through its centre and perpendicular to the plane of the square with an angular speed ω rad/sec. Its angular momentum is

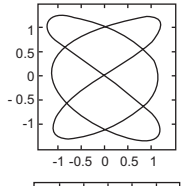
   (a) $\frac{4ML^2\omega}{3}$ (b) $\frac{ML^2\omega}{3}$
   (c) $\frac{ML^2\omega}{4}$ (d) $\frac{ML^2\omega}{12}$

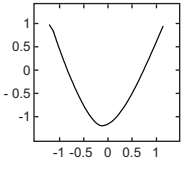
6. In an experiment with Michelson's interferometer using monochromatic light of wave length $\lambda = 600$ nm and adjusted for circular fringes, a thin transparent sheet of thickness t and refractive index $\mu = 1.54$ is introduced between the mirror M_1 and the beam splitter. In doing so, 180 circular fringes are observed to disappear. The thickness t of the transparent plate is
   (a) 27.0 μm
   (b) 54.0 μm
   (c) 100.0 μm
   (d) 200.0 μm

7. Two simple harmonic motions executed along mutually perpendicular directions (x-axis and y-axis) $x = a\sin 2\omega t$ and $y = a\cos 3\omega t$ are superimposed. Identify the resulting Lissajous figure

   (a) 

   (b) 

   (c) 

   (d) 

8. If the charge density $\rho(r, t)$ in a poorly conducting dielectric medium of conductivity σ and permitivity ε is $\rho_0(r)$ at time t = 0. At a later time t the charge density $\rho(r, t)$ is expressed as
   (a) $\rho(r,t) = \rho_0(r)$
   (b) $\rho(r,t) = \rho_0(r)\,\frac{\sigma t}{\varepsilon}$
   (c) $\rho(r,t) = \rho_0(r)\,\exp\left[-\frac{\sigma t}{\varepsilon}\right]$
   (d) $\rho(r,t) = \rho_0(r)\exp\left[\frac{\sigma t}{\varepsilon}\right]$

9. The magnetic flux density B for a Ferro-magnetic substance is expressed as
   $B = \frac{H}{3} + H^2$. The magnetic energy density stored in the spacemen when H increases from $H = 0$ to $H = 180\ Am^{-1}$ is
   (a) $5.84\ MJ\,m^{-3}$
   (b) $3.89\ MJ\,m^{-3}$
   (c) $32.4\ kJ\,m^{-3}$
   (d) data insufficient

10. Which of the statements below express Gauss's divergence theorem.
   (a) $\oiint \vec{E}.d\vec{S} = \frac{1}{\varepsilon_0}\Sigma q$
   (b) $\vec{\nabla}.\vec{E} = \frac{\rho}{\varepsilon_0}$
   (c) $\vec{\nabla}.\vec{g} = 4\pi G\rho$
   (d) $\oiint \vec{g}.d\vec{S} = 4\pi G\,\Sigma m$

11. The free electron density of conduction electrons is $2.42 \times 10^{27}\ m^{-3}$ in Beryllium and $9.1 \times 10^{27}\ m^{-3}$ in Cesium. If the Fermi energy of the conduction electrons in Be is 14.44 eV, the Fermi energy for free electrons in Cesium is
   (a) 16.0 eV
   (b) 1.62 eV
   (c) 3.20 eV
   (d) None of these values

12. If $\phi = 3x^2 + y^4 + 6x^2z^2$ then
div grad $\phi = [\vec{\nabla}.(\vec{\nabla}\phi)]$ is
(a) $6 + 12y^2 + 12x^2$
(b) $12r^2$
(c) $6 + 12r^2$
(d) zero
[Given that $r^2 = x^2 + y^2 + z^2$].

13. Claussius Mossotti equation is valid for
(a) gases
(b) liquids
(c) crystalline solids
(d) polar dielectrics

14. Annihilation of an electron by a positron of negligible initial kinetic energy produces two identical photons. The minimum frequency of such a photon may be
(a) 3.0×10^8 Hz
(b) 1.2×10^{20} Hz
(c) 6.6×10^{20} Hz
(d) 1.6×10^{19} Hz

15. The electric susceptibility of a dielectric material is $\chi = 3.54 \times 10^{-11} \ \frac{\text{Coul}^2}{\text{Nm}^2}$. The dielectric constant K of this material is
(use $\varepsilon_0 = 8.85 \times 10^{-12}$ SI unit)
(a) 1
(b) 3
(c) 4
(d) 5

16. The total heat content of a substance is often known as its
(a) internal energy
(b) enthalpy
(c) entropy
(d) thermal capacity

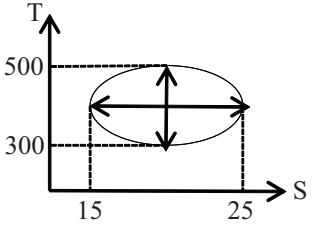
17. Ultrasonic waves are the mechanical waves
(a) of frequency greater than the audible range of sound
(b) which can be produced using piezo electric generator
(c) which are used to detect flaws in diamond and other precious stones
(d) which travel faster than sound

18. Choose the correct statement/s:
(a) Varactor diode is used for high frequency tuning circuits.
(b) Tunnel diode is used for high frequency switching circuits.
(c) Photo diode is used to charge auxiliary storage batteries.
(d) Zener diode is used for reference voltage.

19. A gold wire, 0.32 mm in diameter, elongates by 1 mm when stretched by a force of 330 gmwt and twists through 1 radian, when equal and opposite torques of the value $\tau = 1.45 \times 10^{-5}$ N × m are applied at its ends. The value of Poisson's ratio (σ) of gold is
(a) 0.192
(b) 0.229
(c) 0.429
(d) 0.492

20 For which of the following energy states, the Lande's g factor for LS coupling is zero ?
(a) $^5F_1$
(b) $^4D_{\frac{1}{2}}$
(c) $^3P_0$
(d) $^6G_{\frac{3}{2}}$

21. The thermodynamic cycle of a heat engine is shown in figure below. The shape of the closed cycle is an ellipse with major axis extending from 15 J/K to 25 J/K parallel to entropy (S) axis and the minor axis being from 300 K to 500 K parallel to temperature axis.



The cycle is executed by the engine 20 times per second. The power output of the engine is approximately

(a) 12.5 KW
(b) 16.0 KW
(c) 31.5 KW
(d) 63.0 KW

22. Which of the following statement/s is/are Correct for a LASER.
    (a) Spontaneous emission occurs in a LASER system.
    (b) Stimulated emission occurs in a LASER system.
    (c) The active medium consists of metastable state.
    (d) The LASER system does not require any external energy source.

23. Langvin theory explains the behaviour of a Paramagnetic substance in terms of a function known as Langvin function L(α).

$\left(\text{here } \alpha = \frac{\mu B}{kT}\right)$ The Langvin function is

(a) $L(\alpha) = \cosh\alpha - \frac{1}{\alpha}$
(b) $L(\alpha) = \coth\alpha + \frac{1}{\alpha}$
(c) $L(\alpha) = \coth\alpha - \frac{1}{\alpha}$
(d) $L(\alpha) = \tanh\alpha + \frac{1}{\alpha}$

24. According to the nuclear shell model, the spin and parity of the two nuclei $^{125}_{51}Sb$ and $^{89}_{38}Sr$ are respectively

(a) $\left(\frac{5}{2}\right)^+$ and $\left(\frac{5}{2}\right)^+$ (b) $\left(\frac{7}{2}\right)^+$ and $\left(\frac{7}{2}\right)^+$
(c) $\left(\frac{5}{2}\right)^+$ and $\left(\frac{7}{2}\right)^+$ (d) $\left(\frac{7}{2}\right)^+$ and $\left(\frac{5}{2}\right)^+$

25. A message signal 12 KHz and peak voltage 20 volt is modulated (Amplitude modulation) by a carrier wave of frequency 12 MHz and peak voltage of 30 volt. The value of the modulation index (m_a) and the side band frequencies produced are

(a) $m_a = 1.5$ and LSB = 11988 KHz, HSB = 12012 KHz
(b) $m_a = 0.67$ and LSB = 11.88 KHz, HSB = 12.12 KHz
(c) $m_a = 0.67$ and LSB = 11988 KHz, HSB = 12012 KHz
(d) $m_a = 1.5$ and LSB = 11.88 KHz, HSB = 12.12 KHz

Part B1 — 10x5 = 50

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

B1. In a longitudinal wave the displacement node is pressure antinode. Defend or refute.

B2. A boy standing close to a wall (behind him) cannot touch his toe on bending forward, however he can do so if he stands in an open ground and bends forward. Explain why?

B3. In a negative crystal the speed of an extraordinary ray of light is less along the optic axis as compared to that in a direction perpendicular to the optic axis. Defend or refute.

B4. The energy produced by fusion of one kilogram of Hydrogen in the deep interior of the Sun is about eight times more than the energy produced by one kilogram of Uranium in a nuclear reactor. Defend or refute.

B5. A maximum of 20 orders of diffraction are observed in a diffraction grating having 2620 line per inch when monochromatic light of the wavelength 500 nm is used. Defend or refute.

B6. A Gypsy car has a canvas top. When the car runs at a highway the top bulges out. Explain why?

B7. One of your friends argues that he has studied that there exists no electric field inside a conductor hence there cannot be any current through the conductor. What is the fallacy in this argument? Explain.

B8. In a three dimensional cubical box of side L, a maximum number of 19 electrons can occupy the discrete energy level $E = \frac{33h^2}{4mL^2}$

Defend or refute.

B9. The resolution of a 4–bit counting ADC (analogue to digital converter) is 0.5 volt. For an analog input of 6.6 volt, the digital output of the ADC is 1110. Defend or refute.

B10. The circuit in which two transistors are connected in series in emitter follower configuration is known as Darlington Pair. Defend or refute.

Part B2 — 10x10 = 100

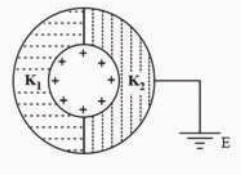
Solve all the 10 problems. Each carries 10 marks.

P1. Show that $\vec{\nabla}.\left\{ r\,\vec{\nabla}\left(\frac{1}{r^3}\right)\right\} = \frac{3}{r^4}$.

P2. An elliptical plate of mass M and semi major axis 'a' and semi minor axis 'b' is suspended at one of its foci with its plane vertical. This plate, of uniform thickness, is made to oscillate about the horizontal axis, with its plane remaining vertical, as a compound pendulum. Obtain an expression for its moment of inertia about the axis of rotation.

Also show that the centre of oscillation lies at a distance $z = \frac{a^2+b^2}{4ea}$ from the CG of the plate on its major axis. Here e being the eccentricity of the ellipse.

P3. Two metallic spherical shell of radii $r_1 = a$ and $r_2 = b$ (b>>a) are kept coaxially. The inner shell is given a charge +q distributed uniformly on its surface while the outer shell is earthed. The space between the two shells is now uniformly filled half by a dielectric medium of dielectric constant K_1 and the other half of K_2. Calculate the potential difference between the two shells and the capacitance of the system.



P4. (a) The wave function of a particle is given by $\psi(x) = \frac{1}{\sqrt{a}} e^{-\frac{x}{a}}$. Find the probability of locating particle in the range $-a \le x \le a$

(b) A particle in an infinite potential step $V(x) = \begin{cases} 0; \text{ for } 0 \le x \le a \\ \infty; \text{ otherwise} \end{cases}$ is in a state represented by a wave function

$$\psi(x) = \begin{cases} A \sin^3\left(\frac{\pi x}{a}\right); 0 \le x \le a \\ 0 \quad\quad\quad ; \text{otherwise} \end{cases}$$

Obtain the expectation value of the energy of the particle.

P5. (a) Write an expression for

(i) Lande's g factor g_j for one valence electron system in weak magnetic field.

(ii) Lande's g factor g_j in LS coupling for the atomic systems containing two valence electrons and

(iii) Lande's g factor g_j in case of JJ coupling

(b) What does Pauli's g sum rule state? Show the calculations of g factor by illustrating g sum rule for ps electron configuration for both JJ coupling and LS coupling schemes.

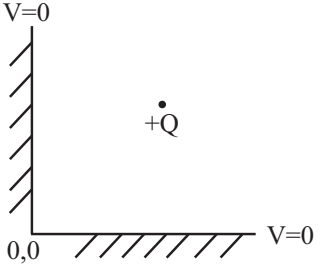
P6. Distinguish between negative and positive crystals producing double refraction. Show explicitly how would you draw the wave-front for an O-ray and E-ray in a doubly refracting negative crystal in the following cases.

(a) The optic axis lies in the plane of incidence and subtends an angle of 30 degree with the crystal surface both for oblique incidence and normal incidence.

(b) The optic axis lies in the plane of incidence and is parallel to the crystal surface both for oblique incidence and normal incidence.

P7. (a) An aluminum block scatters a beam of photons of energy 50 keV. Considering Compton scattering, obtain the energy of photons detected at an angle of 30 degrees with respect to the direction of incidence.

(b) Two semi-infinite grounded conducting plates meet at right angle at (0, 0).



A point positive charge +Q is located at (a, a) as shown. Find the expression for the force experienced by the charge +Q.

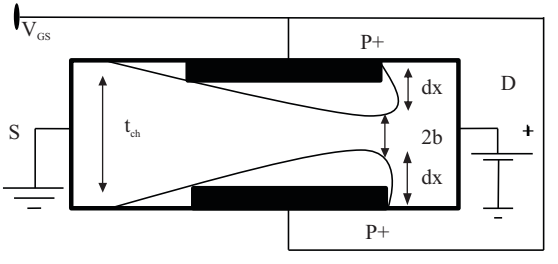
P8. (a) Knowing that the specific volume of steam is 1.671 m^3Kg^{-1} and at normal atmospheric pressure water boils at 100°C, estimate the temperature at which water will be boiling in a pressure cooker where the pressure has increased to 2 atmosphere. The latent heat of vaporisation of water is 540 cal/gm.

(b) The surface area of the filament of a 100 W Lamp which emits as a black body, is $6.25\times10^{-2}cm^2$ Estimate the wavelength of radiation for which the maximum emission takes place from this lamp. Given that the Wien's constant b = 0.288 cmK and Stefan's constant $\sigma = 6.67\times10^{-8} Wm^{-2}K^{-4}$

P9. The adiabatic lapse rate is defined as the variation of temperature with height in the atmosphere. This may be explained by adiabatic expansion. The air near the surface of earth is heated by the radiations received from the sun as well as those reflected from earth. The hot air from the lower region rises upwards to the region of low pressure hence expands. The air being a poor conductor of heat, the expansion may be considered as adiabatic. Find the temperature gradient considering $\gamma = 1.4$ and molar mass as 0.029 kg/mole for air.

P10. The channel resistance,

$$R = \frac{\rho L}{[t_{ch} - 2dx] \times W}$$, of n channel JFET shown in figure is 600 Ω when the full channel thickness of 10 μm is available for conduction.



The built-in voltage of the gate $P^+ - N$ junction is 1 volt. When V_{GS} is 0 volt, the channel is depleted by 1 μm on each side due to build-in voltage. Calculate the channel resistance when (i) $V_{GS} = 0V$ and (ii) $V_{GS} = -3V$ respectively.