

## PHYSICS

Joint Entrance Screening Test (JEST - 2019)

(Booklet Series-A)

### PLEASE READ THE INSTRUCTIONS CAREFULLY

1. This paper contains three parts: Part A, Part B and Part C
2. Part A and Part C contains multiple choice questions and only one of the four options in each question is correct. Questions in Part B has integers between 0 and 9999 as answers.
3. Part A contains 25 questions, and each carries 1 (one) mark for the correct answer and  $-\frac{1}{3}$  (negative one third) mark for incorrect answer. Part B contains 15 questions and carry 3 (three) marks each for correct answer and  $-1$  (negative one) mark for incorrect answer. Part C contains 10 questions and each carries 3 (three marks). The answer to these questions must be answered by integers of 4 digits each. Note that if the answer is, e.g. 5, you must fill in 0005. If it is 0, you must fill in 0000. If the zeros are not filled in (where required), the answer will not be credited. There are **NO NEGATIVE MARKS** for these questions.
4. Only non-programmable scientific calculator is allowed and exchange of calculators among the candidates is not permitted. Use of other items like electronic diary, writing pads, pencil box, beeper, cameras, mobile phones, palmtops, laptops, pagers etc. are not permitted inside the examination hall.

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**Part-A: 1-Mark Questions**

- Q1. Let  $r$  be the position vector of a point on a closed contour  $C$ . What is the value of the line integral  $\int_C \mathbf{r} \cdot d\mathbf{r}$  ?
- (a) 0                      (b)  $\frac{1}{2}$                       (c) 1                      (d)  $-\frac{1}{2}$
- Q2. A dc voltage of 80 Volt is switched on across a circuit containing a resistance of 5  $\Omega$  in series with an inductance of 20 H. What is the rate of change of current at the instant when the current is 12 A ?
- (a) 0 A / s                      (b) 1 A / s                      (c) 5 A / s                      (d) 80 A / s
- Q3. Consider the function  $f(x, y) = |x| + i|y|$ . In which domain of the complex plane is this function analytic?
- (a) First and second quadrants                      (b) Second and third quadrants  
(c) Second and fourth quadrants                      (d) Nowhere
- Q4. Consider the following transformation of the phase space coordinates  $q, p \rightarrow Q, P$
- $$Q = q^a \cos bp \quad P = q^a \sin bp$$
- For what values of  $a$  and  $b$  will the transformation be canonical?
- (a) 1,1                      (b)  $\frac{1}{2}, \frac{1}{2}$                       (c) 2,  $\frac{1}{2}$                       (d)  $\frac{1}{2}, 2$
- Q5. What is the binding energy of an electron in the ground state of a  $He^+$  ion?
- (a) 6.8 eV                      (b) 13.6 eV                      (c) 27.2 eV                      (d) 54.4 eV
- Q6. A collimated white light source illuminates the slits of a double slit interference setup and forms the interference pattern on a screen. If one slit is covered with a blue filter, which one of the following statements is correct?
- (a) No interference pattern is observed after the slit is covered with the blue filter  
(b) Interference pattern remains unchanged with and without the blue filter  
(c) A blue interference pattern is observed  
(d) The central maximum is blue with coloured higher order maxima
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Q7. Consider a system of  $N$  distinguishable particles with two energy levels for each particle, a ground state with energy zero and an excited state with energy  $\epsilon$ . What is the average energy per particle as the system temperature  $T$ ?

- (a) 0                      (b)  $\frac{\epsilon}{2}$                       (c)  $\frac{\epsilon}{e^{\epsilon/k_B T} + 1}$                       (d)  $\frac{\epsilon}{e^{\epsilon/k_B T} - 1}$

Q8. Consider a diatomic molecule with an infinite number of equally spaced non-degenerate energy levels. The spacing between any two adjacent levels is  $\epsilon$  and the ground state energy is zero. What is the single particle partition function  $Z$ ?

(a)  $Z = \frac{1}{1 - e^{-\epsilon/k_B T}}$                       (b)  $Z = \frac{1}{1 + e^{-\epsilon/k_B T}}$

(c)  $Z = \frac{1}{2 - e^{-\epsilon/k_B T}}$                       (d)  $Z = \frac{1 - e^{-\epsilon/k_B T}}{1 - e^{-2\epsilon/k_B T}}$

Q9. A very long solenoid (axis along  $z$  direction) of  $n$  turns per unit length carries a current which increases linearly with time,  $i = Kt$ . What is the magnetic field inside the solenoid at a given time  $t$ ?

- (a)  $B = \mu_0 n K t \hat{z}$                       (b)  $B = \mu_0 n K z \hat{z}$   
 (c)  $B = \mu_0 n K t x \hat{y}$                       (d)  $B = \mu_0 c n K t \hat{z}$

Q10. Suppose  $\vec{A}$  is a conservative vector,  $\vec{B}$  is a non-conservative vector and  $\phi$  is non-zero scalar everywhere. Which one of the following is true?

- (a)  $\nabla \cdot \vec{A} = 0$                       (b)  $\nabla \cdot \vec{B} = 0$   
 (c)  $\nabla \phi = 0$                       (d)  $\nabla \cdot \vec{A} = \nabla \cdot \vec{B} = 0$

Q11. Consider two  $n \times n$  matrices,  $A$  and  $B$  such that  $A + B$  is invertible. Define two matrices,  $C = A(A + B)^{-1}B$  and  $D = B(A + B)^{-1}A$ . Which of the following relations always hold true?

- (a)  $C = D$                       (b)  $C^{-1} = D$                       (c)  $BCA = ADB$                       (d)  $C = D^{-1}$
-



Q12. The refractive index  $n$  of the entire environment around a double slit interference setup is changed from  $n_1$  to  $n_2$ . Which one of the following statements is correct about the change in the interference pattern?

- (a) The fringe pattern disappears
- (b) The central bright maximum turns dark, i.e. becomes a minimum
- (c) Fringe width of the pattern increases by a factor 2
- (d) Fringe width of the pattern decreases by a factor 2

Q13. A cyclotron can accelerate deuteron to  $16 \text{ MeV}$ . If the cyclotron is used to accelerate  $\alpha$  particles, what will be their energy? Take the mass of deuteron to be twice the mass of proton and mass of alpha particles to be four times the mass of protons.

- (a)  $8 \text{ MeV}$
- (b)  $16 \text{ MeV}$
- (c)  $32 \text{ MeV}$
- (d)  $64 \text{ MeV}$

Q14. Consider a hypothetical world in which the electron has spin  $\frac{3}{2}$  instead of  $\frac{1}{2}$ . What will be the electronic configuration for an element with atomic number  $Z = 5$ ?

- (a)  $1s^4, 2s^1$
- (b)  $1s^4, 2s^2, 2p^1$
- (c)  $1s^5$
- (d)  $1s^3, 2s^1, 2p^1$

Q15. Two objects of unit mass are thrown up vertically with a velocity of  $1 \text{ ms}^{-1}$  at latitudes  $45^\circ \text{ N}$  and  $45^\circ \text{ S}$ , respectively. The angular velocity of the rotation of Earth is given to be  $7.29 \times 10^{-5} \text{ s}^{-1}$ . In which direction will the objects deflect when they reach their highest point (due to Coriolis force)? Assume zero air resistance.

- (a) to the east in Northern hemisphere and west in Southern Hemisphere
- (b) to the west in Northern hemisphere and east in Southern Hemisphere
- (c) to the east in both hemispheres
- (d) to the west in both hemispheres

Q16. Which one of the following vectors lie along the line of intersection of the two planes

$$x - 3y - z = 5 \text{ and } 2x - 2y - 4z = 3$$

- (a)  $10\hat{i} - 2\hat{j} + 5\hat{k}$
  - (b)  $10\hat{i} + 6\hat{j} + 8\hat{k}$
  - (c)  $10\hat{i} + 2\hat{j} - 5\hat{k}$
  - (d)  $10\hat{i} - 2\hat{j} - 5\hat{k}$
-



Q17. What is the value of the integral  $\int_0^{\pi/2} \cos x \, dx$ ?

- (a)  $\frac{1}{2}$  (b)  $\frac{1}{2}$  (c)  $\frac{1}{2}$  (d) 0

Q18. Two joggers A and B are running at a steady pace around a circular track. A takes  $T_A$  minutes whereas B takes  $T_B$  minutes to complete one round. Assuming that they have started together, what will be time taken by A to overtake B for the first time?

- (a)  $\frac{2}{T_A T_B}$  (b)  $\frac{1}{T_A} - \frac{1}{T_B}$  (c)  $\frac{1}{T_A + T_B}$  (d)  $\frac{1}{T_A} + \frac{1}{T_B}$

Q19. The magnetic field (Gaussian units) in an empty space is described by

$$\vec{B} = B_0 \exp(ax \sin ky - t) \hat{z}$$

What is the y - component of the electric field?

- (a)  $\frac{ac}{B_0} \sin ky - t$  (b)  $\frac{ac}{B_0} \exp(ax \cos ky - t)$   
 (c)  $B_0 \sin ky - t$  (d) 0

Q20. Let A be a hermitian matrix, and C and D be the unitary matrices. Which one of the following matrices is unitary?

- (a)  $C^{-1}AC$  (b)  $C^{-1}DC$  (c)  $C^{-1}AD$  (d)  $A^{-1}CD$

Q21. The wave function  $\psi(x) = A \exp\left(\frac{b^2 x^2}{2}\right)$  (for real constants A and b) is a normalized eigen-

function of the Schrodinger equation for a particle of mass m and energy E in a one dimensional potential V(x) such that  $V(x) = 0$  at  $x = 0$ . Which of the following is correct?

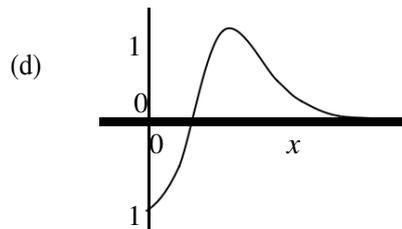
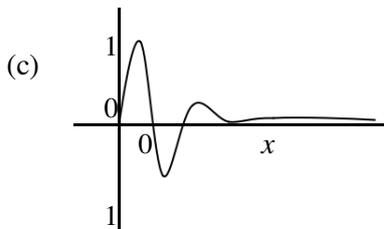
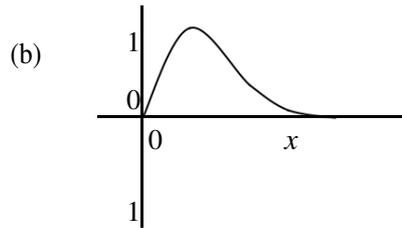
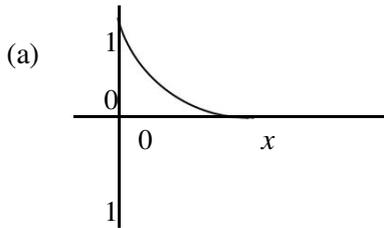
- (a)  $V = \frac{2b^4 x^2}{m}$  (b)  $V = \frac{2b^4 x^2}{2m}$  (c)  $E = \frac{2b^2}{4m}$  (d)  $E = \frac{2b^2}{m}$
-



Q22. A quantum particle of mass  $m$  is in a one dimensional potential of the form

$$V(x) = \begin{cases} \frac{1}{2} m \omega^2 x^2, & \text{if } x \geq 0 \\ 0, & \text{if } x < 0 \end{cases}$$

where  $\omega$  is a constant. Which one of the following represents the possible ground state wave function of the particle?



Q23. Consider a  $2 \times 2$  matrix  $A = \begin{pmatrix} 1 & 13 \\ 0 & 0 \end{pmatrix}$  what is  $A^{27}$ ?

- (a)  $\begin{pmatrix} 1 & 13 \\ 0 & 0 \end{pmatrix}$  (b)  $\begin{pmatrix} 1 & 13^{27} \\ 0 & 0 \end{pmatrix}$  (c)  $\begin{pmatrix} 1 & 27 \\ 0 & 0 \end{pmatrix}$  (d)  $\begin{pmatrix} 1 & 351 \\ 0 & 0 \end{pmatrix}$

Q24. Consider a grand ensemble of a system of one dimensional non-interacting classical harmonic oscillators (each of frequency  $\omega$ ). Which one of the following equations is correct? Here the angular bracket  $\langle \rangle$  indicate the ensemble average.  $N$ ,  $E$  and  $T$  represent the number of particles, energy and temperature, respectively.  $k_B$  is the Boltzmann constant.

- (a)  $\langle E \rangle N = \frac{k_B T}{2}$  (b)  $\langle EN \rangle = \langle \frac{k_B T}{2} \rangle$   
 (c)  $\langle E \rangle N = k_B T$  (d)  $\langle E \rangle N = k_B T$
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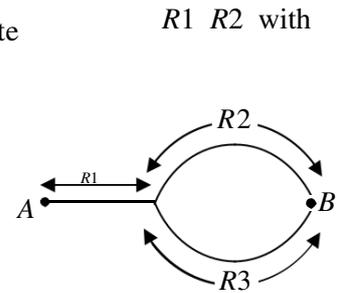


Q25. A bullet with initial speed  $v_0$  is fired at a log of wood. The resistive force by wood on the bullet is given by  $\nu$ , where  $\nu = kv$ . What is the time taken to stop the bullet inside the wood log?

- (a)  $\frac{m v_0}{k}$                       (b)  $\frac{m v_0^2}{k}$                       (c)  $\frac{m v_0^3}{k}$                       (d)  $\frac{v_0^3}{k}$

**PART- B: 3 Mark-Questions**

Q1. A person plans to go from town A to town B by taking either the route with probability  $\frac{1}{2}$  or the route R1 R3 with probability  $\frac{1}{2}$  (see figure). Further, there is a probability  $\frac{1}{3}$  that R1 is blocked, a probability  $\frac{1}{3}$  that R2 is blocked, and a probability  $\frac{1}{3}$  that R3 is blocked. What is the probability that he/she would reach town B?

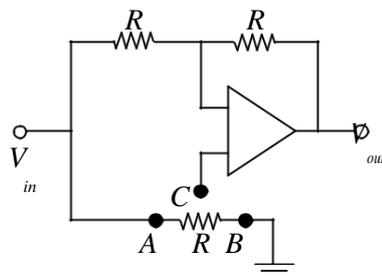


- (a)  $\frac{8}{9}$                       (b)  $\frac{1}{3}$                       (c)  $\frac{4}{9}$                       (d)  $\frac{2}{3}$

Q2. What is the change in the kinetic energy of rotation of the earth if its radius shrinks by 1%? Assume that the mass remains the same and the density is uniform.

- (a) increases by 1%                      (b) increases by 2%  
 (c) decreases by 1%                      (d) decreases by 2%

Q3. Analysis the ideal op-amp circuit in the figure. Which one of the following statements is true about the output voltage  $V_{out}$ , when terminal 'C' is connected to point 'A' and then to point 'B'?



- (a)  $V_{out} = V_{in}$  and  $V_{out} = V_{in}$  when 'C' is connected to 'A' and 'B', respectively  
 (b)  $V_{out} = V_{in}$  and  $V_{out} = V_{in}$  when 'C' is connected to 'A' and 'B', respectively  
 (c)  $V_{out} = V_{in}$  when 'C' is connected to either 'A' or 'B'  
 (d)  $V_{out} = V_{in}$  when 'C' is connected to either 'A' or 'B'



Q4. White light of intensity  $I_0$  is incident normally on a filter plate of thickness  $d$ . The plate has a wavelength dependent absorption coefficient  $\mu_0$  per unit length. The band pass edge of the filter is defined as the wavelength at which the intensity, after passing through the filter, is  $I_0 e^{-\mu_0 d}$  and are constants. The reflection coefficient of the plate may be assumed to be independent of  $\lambda$ . Which one of the following statements is true about the bandwidth of the filter?

(a) The bandwidth is linearly dependent on  $\mu_0$

(b) The bandwidth is independent of the plate thickness  $d$

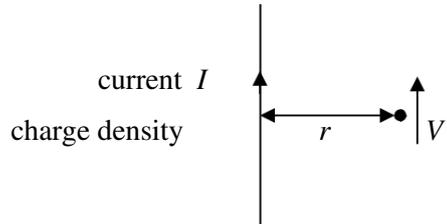
(c) The bandwidth is linearly dependent on  $\mu_0 d$

(d) The bandwidth is dependent on the ratio  $\frac{\mu_0}{d}$

Q5. Consider two concentric spherical metal shells of radii  $r_1$  and  $r_2$  ( $r_2 > r_1$ ). The outer shell has a charge  $q$  and the inner shell is grounded. What is the charge on the inner shell?

- (a)  $\frac{r_1}{r_2} q$                       (b)  $\frac{r_1}{r_2} q$                       (c) 0                                      (d)  $\frac{r_2}{r_1} q$

Q6. A wire with uniform line charge density  $\lambda$  per unit length carries a current  $I$  as shown in the figure. Take the permittivity and permeability of the medium to be  $\epsilon_0$  and  $\mu_0$ . A particle of charge  $q$  is at a distance  $r$  and is travelling along a trajectory parallel to the wire. What is the speed of the charge?



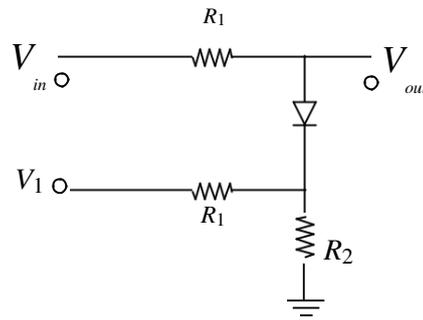
- (a)  $\frac{I}{\mu_0}$                       (b)  $\frac{I}{2\mu_0}$                       (c)  $\frac{I}{3\mu_0}$                       (d)  $\frac{4I}{\mu_0}$



Q7. Consider a non-relativistic two-dimensional gas of  $N$  electrons with the Fermi energy  $E_F$ . What is the average energy per particle at temperature  $T = 0$ ?

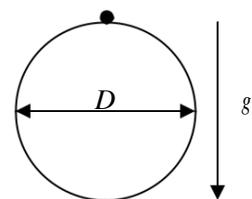
- (a)  $\frac{3}{5} E_F$       (b)  $\frac{2}{5} E_F$       (c)  $\frac{1}{2} E_F$       (d)  $E_F$

Q8. The circuit given below is fed by a sinusoidal voltage  $V_{in} = V_0 \sin t$ . Assume that the cut-in voltage of the diode is 0.7 volts and  $V_1$  is a positive dc voltage smaller than  $V_0$ . Which one of the following statements is true about  $V_{out}$ ?



- (a) Positive part of  $V_{out}$  is restricted to a maximum voltage of  $0.7 + \frac{R_2}{R_1 + R_2} V_1$
- (b) Negative part of  $V_{out}$  is restricted to a maximum voltage of  $0.7 - \frac{R_2}{R_1 + R_2} V_1$
- (c) Positive part of  $V_{out}$  is restricted to a maximum voltage of  $0.7 + \frac{R_1}{R_1 + R_2} V_1$
- (d) Negative part of  $V_{out}$  is restricted to a maximum voltage of  $0.7 - \frac{R_1}{R_1 + R_2} V_1$

Q9. A hoop of diameter  $D$  is pivoted at the topmost point on the circumference as shown in the figure. The acceleration due to gravity  $g$  is acting downwards. What is the time period of small oscillations in the plane of the hoop?



- (a)  $2 \sqrt{\frac{D}{2g}}$       (b)  $2 \sqrt{\frac{5D}{6g}}$
- (c)  $2 \sqrt{\frac{D}{g}}$       (d)  $2 \sqrt{\frac{2D}{g}}$



Q10. For a spin  $\frac{1}{2}$  particle placed in a magnetic field  $B$ , the Hamiltonian is  $H = BS_y = S_y$ , where

$S_y$  is the  $y$ -component of the spin operator. The state of the system at time  $t = 0$  is

$|\uparrow\rangle$ , where  $S_z|\uparrow\rangle = \frac{1}{2}|\uparrow\rangle$ . At a later time  $t$ , if  $S_z$  measured then what is the probability to get a

value  $\frac{1}{2}$ ?

- (a)  $\cos^2 t$       (b)  $\sin^2 t$       (c) 0      (d)  $\sin^2 \frac{t}{2}$

Q11. In a fixed target elastic scattering experiment, a projectile of mass  $m$ , having initial velocity  $v_0$ , and impact parameter  $b$ , approaches the scatterer. It experiences a central repulsive force

$f(r) = \frac{k}{r^2}$ . What is the distance of the closest approach  $d$ ?

- (a)  $d = b^2 \frac{k}{mv_0^2}$       (b)  $d = b^2 \frac{k}{mv_0^2}$   
 (c)  $d = b$       (d)  $d = \sqrt{\frac{k}{mv_0^2}}$

Q12. Consider a quantum particle in a one-dimensional box of length  $L$ . The coordinates of the leftmost wall of the box is at  $x = 0$  and that of the rightmost wall is at  $x = L$ . The particle is in the ground state at  $t = 0$ . At  $t = 0$ , we suddenly change the length of the box to  $3L$  by moving the right wall. What is the probability that the particle is in the ground state of the new system immediately after the change?

- (a) 0.36      (b)  $\frac{9}{8}$       (c)  $\frac{81}{64}$       (d)  $\frac{0.5}{L}$

Q13. Consider a function  $f(x) = P_k(x) e^{x^4 - 2x^2}$  in the domain  $x \in \mathbb{R}$ , where  $P_k$  is any polynomial of degree  $k$ . What is the maximum possible number of extrema of the function?

- (a)  $k + 3$       (b)  $k - 3$       (c)  $k + 2$       (d)  $k - 1$
-



Q14. The energy spectrum of a particle consists of four states with energies  $0, 2, 3$ . Let  $Z_B(T), Z_F(T)$  and  $Z_C(T)$  denote the canonical partition functions for four non-interacting particles at temperature  $T$ . The subscripts  $B, F$  and  $C$  corresponds to bosons, fermions and

distinguishable classical particles, respectively. Let  $y = \exp\left(-\frac{k_B T}{\epsilon}\right)$ . Which one of the

following statements is true about  $Z_B(T), Z_F(T)$  and  $Z_C(T)$  ?

- (a) They are polynomials in  $y$  of degree 12,6 and 12, respectively.
- (b) They are polynomials in  $y$  of degree 16,10 and 16, respectively
- (c) They are polynomials in  $y$  of degree 9,6 and 12, respectively.
- (d) They are polynomials in  $y$  of degree 12,10 and 16, respectively.

Q15. Consider a quantum particle of mass  $m$  and a charge  $e$  moving in a two dimensional potential given as:

$$V(x, y) = \frac{k}{2} x^2 y^2 - k x y^2$$

The particle is also subject to an external electric field  $E = E_i \hat{i} + E_j \hat{j}$ , where  $E_i$  and  $E_j$  corresponds to unit vectors along  $x$  and  $y$  directions, respectively. Let  $E_1$  and  $E_0$  be the energies of the first excited state and ground state, respectively. What is the value of  $E_1 - E_0$  ?

- (a)  $\sqrt{\frac{2k}{m}}$
- (b)  $\sqrt{\frac{2k}{m}} e^2$
- (c)  $3 \sqrt{\frac{2k}{m}}$
- (d)  $3 \sqrt{\frac{2k}{m}} e^2$

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**PART C: 3-Mark Numerical Questions**

Q1. A thin uniform steel chain is 10 m long with a linear mass density of  $2 \text{ kg m}^{-1}$ . The chain hangs vertically with one end attached to a horizontal axle, having a negligibly small radius compared to its length. What is the work done (in N m) to slowly wind up the chain on to the axle? The acceleration due to gravity is  $g = 9.81 \text{ ms}^{-2}$ .

Q2. A one-dimensional harmonic oscillator is in the state

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|n\rangle + |n+1\rangle)$$

where  $|n\rangle$  is the normalized energy eigenstate with eigenvalue  $n + \frac{1}{2}$ . Let the expectation

value of the Hamiltonian in the state  $|\psi\rangle$  be expressed as  $\frac{1}{2}(n + \frac{1}{2})$ . What is the value of  $n$ ?

Q3. The Euler polynomials are defined by

$$\frac{2e^{-xs}}{e^x - 1} E_n(s) = \frac{x^n}{n!}$$

What is the value of  $E_5(2) - E_5(3)$ ?

Q4. What is the angle (in degrees) between the surfaces  $y^2 + z^2 = 2$  and  $y^2 + x^2 = 0$  at the point (1, 1, 1)?

Q5. Consider a system of 15 non-interacting spin-polarized electrons. They are trapped in a two-dimensional isotropic harmonic oscillator potential  $V(x, y) = \frac{1}{2}m\omega^2(x^2 + y^2)$ . The angular frequency  $\omega$  is such that  $\hbar\omega = 1$  in some chosen unit. What is the ground state energy of the system in the same units?

Q6. Consider the motion of a particle in two dimensions given by the Lagrangian

$$L = \frac{m}{2}(\dot{x}^2 + \dot{y}^2) - 4xy^2$$

where  $m = 1$ . The initial conditions are given as  $y(0) = 0$ ,  $x(0) = 42$  meters,  $\dot{x}(0) = \dot{y}(0) = 0$ . What is the value of  $x(t) + y(t)$  at  $t = 25$  seconds in meters?

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- Q7. A diatomic ideal gas at room temperature, is expanded at a constant pressure  $P_0$ . If the heat absorbed by the gas is  $Q = 14$  Joules, what is the maximum work in Joules that can be extracted from the system?
- Q8. An optical line of wavelength  $5000 \text{ \AA}$  in the spectrum of light from a star is found to be red-shifted by an amount of  $2 \text{ \AA}$ . Let  $v$  be the velocity at which the star is receding. Ignoring relativistic effects, what is the value of  $\frac{v}{c}$ ?
- Q9. In the Young's double slit experiment (screen distance  $D = 50 \text{ cm}$  and  $d = 0.1 \text{ cm}$ ), a thin mica sheet of refractive index  $n = 1.5$  is introduced in the path of one of the beams. If the central fringe gets shifted by  $0.2 \text{ cm}$ , what is the thickness (in micrometer) of the mica sheet?
- Q10. A circular metal loop of radius  $a = 1 \text{ m}$  spins with a constant angular velocity  $20 \text{ rad/s}$  in a magnetic field  $B = 3 \text{ Tesla}$ , as shown in the figure. The resistance of the loop is  $10 \text{ Ohms}$ . Let  $P$  be the power dissipated in one complete cycle. What is the value of  $\frac{P}{3}$  in Watts?

