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1. Let X be a column vector of dimension $n > 1$ with at least one non-zero entry. The number of non-zero eigenvalues of the matrix $M = XX^T$ is

   (a) 0
   (b) n
   (c) 1
   (d) $n - 1$

2. J^π for the ground state of the ${}^{13}_{6}C$ nucleus is

   (a) 1^+
   (b) $\frac{3^-}{2}$
   (c) $\frac{3^+}{2}$
   (d) $\frac{1^-}{2}$

3. A uniform solid cylinder is released on a horizontal surface with speed $5\frac{m}{s}$ without any rotation. The cylinder eventually starts rolling without slipping. If the mass and radius of the cylinder are 10 gm and 1 cm respectively, the final linear velocity of the cylinder is .

4. The energy density and pressure of a photon gas are given by $u = aT^4$ and $P = \frac{u}{3}$, where T is the temperature and a is the radiation constant. The entropy per unit volume is given by aT^3. The value of a is.

5. Which one of the following gases of diatomic molecules is *Raman*, infrared, and NMR active?

   (a) ${}^1H - H$
   (b) ${}^{12}C -^{16} O$
   (c) ${}^1H -^{35} Cl$
   (d) ${}^{16}O -^{16} O$

6. The π^+ decays at rest to μ^+ and ν_μ. Assuming the neutrino to be massless, the momentum of the neutrino is.

7. Using Hund's rule, the total angular momentum quantum number J for the electronic ground state of the nitrogen atom is

   (a) $\frac{1}{2}$
   (b) $\frac{3}{2}$
   (c) 0
   (d) 1

8. Which one of the following operators is Hermitian?

   (a) $\frac{i(p_x x^2 - x^2 p_x)}{2}$
   (b) $\frac{i(p_x x^2 + x^2 p_x)}{2}$
   (c) $e^{ip_x a}$
   (d) $e^{-ip_x a}$

9. The real space primitive lattice vectors are $\vec{a}_1 = a\hat{x}$ and $\vec{a}_2 = \frac{a}{2}\left(\hat{x} + \sqrt{3}\hat{y}\right)$. The reciprocal space unit vectors $\vec{b}_1$ and $\vec{b}_2$ for this lattice are, respectively

   (a) $\frac{2\pi}{a}\left(\hat{x} - \frac{\hat{y}}{\sqrt{3}}\right)$ and $\frac{4\pi}{a\sqrt{3}}\hat{y}$
   (b) $\frac{2\pi}{a}\left(\hat{x} + \frac{\hat{y}}{\sqrt{3}}\right)$ and $\frac{4\pi}{a\sqrt{3}}\hat{y}$
   (c) $\frac{2\pi}{a\sqrt{3}}\hat{x}$ and $\frac{4\pi}{a}\left(\frac{\hat{x}}{\sqrt{3}} + \hat{y}\right)$
   (d) $\frac{2\pi}{a\sqrt{3}}\hat{x}$ and $\frac{4\pi}{a}\left(\frac{\hat{x}}{\sqrt{3}} - \hat{y}\right)$

10. Consider two particles and two non-degenerate quantum levels 1 and 2. Level 1 always contains a particle. Hence, what is the probability that level 2 also contains a particle for each of the two cases:

    a: when the two particles are distinguishable and B: when the two particles are bosons?

    (a) $\frac{1}{2}$ and $\frac{1}{3}$
    (b) $\frac{1}{2}$ and $\frac{1}{2}$
    (c) $\frac{2}{3}$ and $\frac{1}{2}$
    (d) 1 and 0

11. A person weighs W_p at Earth's north pole and W_e at the equator. Treating the Earth as a perfect sphere of radius 6400 km, the value $100 \times \frac{(W_p - W_e)}{W_p}$ is

12. The geometric cross-section of two colliding protons at large energies is very well estimated by the product of the effective sizes of each particle. This is closest to

    (a) 10 b

    (b) 10 mb

    (c) 10 μb

    (d) 10 pb

13. For the transistor amplifier circuit shown below with $R_1 = 10$ kΩ, $R_2 = 10$ kΩ, $R_3 = 1$ kΩ, and $\beta = 99$. Neglecting the emitter diode resistance, the input impedance of the amplifier looking into the base for small ac signal is .