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- 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
  - 0
  - $n$
  - 1
  - $n - 1$
- $J^\pi$  for the ground state of the  ${}^{13}_6C$  nucleus is
  - $1^+$
  - $\frac{3^-}{2}$
  - $\frac{3^+}{2}$
  - $\frac{1^-}{2}$
- 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 .
- 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.
- Which one of the following gases of diatomic molecules is *Raman*, infrared, and *NMR* active?
  - ${}^1H - H$
  - ${}^{12}C - {}^{16}O$
  - ${}^1H - {}^{35}Cl$
  - ${}^{16}O - {}^{16}O$

6. The  $\pi^+$  decays at rest to  $\mu^+$  and  $\nu_\mu$ . 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
- $\frac{1}{2}$
  - $\frac{3}{2}$
  - 0
  - 1
8. Which one of the following operators is Hermitian?
- $\frac{i(p_x x^2 - x^2 p_x)}{2}$
  - $\frac{i(p_x x^2 + x^2 p_x)}{2}$
  - $e^{ip_x a}$
  - $e^{-ip_x a}$
9. The real space primitive lattice vectors are  $\vec{a}_1 = a\hat{x}$  and  $\vec{a}_2 = \frac{a}{2}(\hat{x} + \sqrt{3}\hat{y})$ . The reciprocal space unit vectors  $\vec{b}_1$  and  $\vec{b}_2$  for this lattice are, respectively
- $\frac{2\pi}{a}(\hat{x} - \frac{\hat{y}}{\sqrt{3}})$  and  $\frac{4\pi}{a\sqrt{3}}\hat{y}$
  - $\frac{2\pi}{a}(\hat{x} + \frac{\hat{y}}{\sqrt{3}})$  and  $\frac{4\pi}{a\sqrt{3}}\hat{y}$
  - $\frac{2\pi}{a\sqrt{3}}\hat{x}$  and  $\frac{4\pi}{a}(\frac{\hat{x}}{\sqrt{3}} + \hat{y})$
  - $\frac{2\pi}{a\sqrt{3}}\hat{x}$  and  $\frac{4\pi}{a}(\frac{\hat{x}}{\sqrt{3}} - \hat{y})$
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?
- 1/2 and 1/3
  - 1/2 and 1/2
  - 2/3 and 1/2
  - 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  $\mu\text{b}$
  - (d) 10 pb
13. For the transistor amplifier circuit shown below with  $R_1 = 10\text{ k}\Omega$ ,  $R_2 = 10\text{ k}\Omega$ ,  $R_3 = 1\text{ k}\Omega$ , and  $\beta = 99$ . Neglecting the emitter diode resistance, the input impedance of the amplifier looking into the base for small ac signal is .

