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Sprint 2003 – Entrance Examination: Condensed Matter
Multiple choice quizzes

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1. The fact that many atoms and ions have ground states with largest possible value of the total spin is:

   (a) false. He, for instance, has $S = 0$ and the same applies over all of the periodic table.

   (b) due to the fact that electrons keep more effectively apart in higher spin states, hence minimizing Coulomb repulsions.

   (c) due to the dipole-dipole interactions between the spins which are ferromagnetic at short distances.

   (d) it is due to Quantum Electrodynamics effects, and is beyond any non-relativistic theory.

2. Zero-point energy, proportional to the phonon frequencies, is a part of the total energy of all solids at zero temperature.

   (a) Its sign is negative, and quantitatively much larger in Neon than in diamond

   (b) Its sign is positive, and quantitatively much larger in Neon than in diamond

   (c) Its sign is positive, and quantitatively much smaller in Neon than in diamond

   (d) Its sign is negative, and quantitatively much smaller in Neon than in diamond

3. Most pure elements in the periodic table are metals at 1 bar pressure and $300K^o$ temperature.

   (a) This is false

   (b) This is because $300K^o$ is a relatively large temperature, and metals possess a higher heat capacity

   (c) This is because all matter is metallic at large pressures, and 1 bar is enough to drive many elements metallic.

   (d) This is because a gap at the Fermi level does require a specific mechanism, absent in most cases.

4. The molecule NH_3 has the form of a triangular pyramid, with the Nitrogen atom as the vertex, on top, say, of the plane containing the H_3 triangle. A totally equivalent configuration is a specular one, with the Nitrogen vertex now positioned "below" the plane containing the H_3 triangle. At $T = 0$, beginning with one of these two configurations, and ignoring all global rotations (i.e., keeping the H_3 triangle fixed):

(a) the nitrogen will simply remain in the initial asymmetric configuration forever. Full symmetry will however be restored by even an infinitesimal temperature T.

(b) the nitrogen will tunnel and oscillate quantum mechanically between the initial and the specular configuration, thus restoring reflection symmetry.

(c) the nitrogen will move to the center of the H_3 triangle, so as to restore reflection symmetry, even if that has a higher energy.

(d) the question makes no sense, and the configuration of NH_3 must be different.

5. A primitive (but intelligent) man could guess even without such tools as X rays, etc. that some piece of mineral is crystalline and ordered inside, rather than glassy and disordered inside, because:

(a) it sounds much better when hit

(b) it has shiny flat facets

(c) it is transparent rather than opaque

(d) it will decompose light into its spectrum when hit by a sunbeam

6. Among many other things, magnetism of matter would disappear from the universe if:

(a) Planck's constant went to zero

(b) the electron charge doubled

(c) the electrom mass halved

(d) the speed of light went down by a factor $\hbar/e$.

7. Consider the two-electron ground state of an H_2 molecule as a function of the interatomic distance. At the equilibrium distance the ground state is a singlet. What happens at large finite distances ?

(a) The ground state is no longer a singlet, and the electrons prefer to have parallel spins, recovering Hund's rule.

(b) The ground state is 4-fold degenerate, since the spins $\sigma = \pm 1/2$ of the two electrons are mutually independent.

(c) The ground state is always a singlet because the orbital wavefunction of the two electrons has to be node-less and symmetric.

(d) This is false. The ground state cannot be a singlet for any distance, because that would violate Hund's first rule.

8. The Clausius-Mossotti model links the dielectric constant of a molecular solid to the polarizability of its molecules. A local electric field acts on each molecule. Which one of the following statements is valid for a solid with a cubic lattice?

(a) The local electric field is higher than the total electric field inside the sample.

(b) The local electric field is lower than the total electric field inside the sample.

(c) The local electric field is equal to the total electric field inside the sample.

(d) The local electric field is equal to the external field applied to the sample.

9. In a carbon atom, the energies of the many-electron multiplets depend on the total spin S, the total orbital angular momentum L, the total angular momentum J. Neglecting the small splitting between states which differ only for J, the multiplet which lie lowest in energy is that with:

   (a) The lowest S and the lowest L compatible with the Pauli principle.

   (b) The lowest S and the highest L compatible with the Pauli principle.

   (c) The highest S and the lowest L compatible with the Pauli principle.

   (d) The highest S and the highest L compatible with the Pauli principle.

10. The frequency of the bending vibrational mode of (H_2O), which essentially involves only the two hydrogens, is close to 1600 cm^{-1}. [1 cm^{-1} is a frequency unit equal to 0.03×10^{12} Hz.] Which frequency do you expect for the bending mode of heavy water (D_2O)? [Recall that $m_D \approx 2m_H$.]

   (a) A frequency close to 1600 cm^{-1} but slightly higher.

   (b) A frequency close to 800 cm^{-1}.

   (c) A frequency close to 1100 cm^{-1}.

   (d) A frequency close to 1600 cm^{-1} but slightly lower.