Spring 2007 - Entrance Examination: Condensed Matter
Multiple choice quizzes

1. Consider a neutral inert object, such as a closed-shell atom, or an insulating tip, being gradually brought into contact with a solid surface, and eventually implanted into the surface. The force exerted by the surface on the tip (and by the tip on the surface) is as a function of their distance:

   A. Always attractive.

   B. Weakly attractive at large distance, strongly attractive before contact, repulsive after contact.

   C. Weakly repulsive at large distance, strongly repulsive before contact, attractive after contact.

   D. Always repulsive.

2. A certain quantum mechanical system contains tunneling, in the form of two eigenstates whose energy levels "cross" as a function of a parameter. For two levels with the same symmetry, exact crossing is forbidden, but is replaced here by a small energy gap, which signifies tunneling. If the system is initially prepared in the lowest level, and subsequently the parameter is varied slowly as a function of time, so as to cause the levels to cross:

   A. The system will instantaneously tunnel at crossing, and always follow whatever level is the lowest.

   B. The system will tunnel at crossing, and follow whatever level is the lowest, only if the level crossing occurs sufficiently fast.

   C. The system will tunnel at crossing, and follow whatever level is the lowest, only if the level crossing occurs sufficiently slow.

   D. The system will never tunnel at crossing, and always stick to the initial level.

3. Metals and insulators are clear concepts at zero temperature, where the latter have zero conductivity and the former nonzero. At finite temperature T:

   A. Everything is a metal.

   B. It is impossible to define metals and insulators, as everything conducts.

   C. As T increases, metals conduct better, insulators conduct worse.

   D. As T increases, insulators conduct better, metals conduct worse.

4. Let us consider a neutral atom with nuclear charge Z and an isolated electron at a large distance D from the atom. Initially the neutral atom polarizes and attracts the electron. Which is the final ground state of the system?

   A. This is not true. The atom is neutral and does not interact with the electron.

   B. In the ground state the electron binds to the neutral atom forming a negative ion.

   C. The atom initially attracts the electron but no bound state is possible. Negative ions do not exist.

   D. It depends on the charge Z. For some atoms point [B] is true, for others point [C].

5. A noble gas in a magnetic field behaves as:

   A. A diamagnetic system with a small negative magnetic susceptibility.

   B. A paramagnetic system with a small positive magnetic susceptibility.

   C. A ferromagnetic system with a large positive magnetic susceptibility.

   D. A non magnetic system.

6. The frequency dependent dielectric constant of a solid has a real and an imaginary part. Why is there an imaginary part?

   A. Because the frequency of the electromagnetic radiation changes when it passes through a solid.

   B. Only the dielectric constant of a metal has an imaginary part because the radiation is totally reflected by the metal.

   C. Because the solid absorbs part of the radiation that passes through it.

   D. Because inside solids the speed of the electromagnetic radiation depends on the frequency.

7. The carbon atom has 6 electrons in a configuration Helium + $2s^2 2p^2$. In agreement with standard Hund's and Lande's rules, its ground state has the following total spin S, orbital angular momentum L and total angular momentum J:

   A. $S = 1,\ L = 1,\ J = 0$.

   B. $S = 1,\ L = 0,\ J = 1$.

   C. $S = 0,\ L = 2,\ J = 2$.

   D. $S = 2,\ L = 2,\ J = 0$.

8. In a periodic solid the eigenstates of the Schrödinger equation can be written in the Bloch form $\psi_{\mathbf{k},n}(\mathbf{r}) = e^{i\mathbf{k}\cdot\mathbf{r}} u_{\mathbf{k},n}(\mathbf{r})$, where $u_{\mathbf{k},n}(\mathbf{r})$ is a periodic function, $\mathbf{k}$ is the wave vector and n is the band index. $\mathbf{k}$ is a real vector because:

   A. The Bloch condition $\psi_{\mathbf{k},n}(\mathbf{r} + \mathbf{R}) = e^{i\mathbf{k}\cdot\mathbf{R}} \psi_{\mathbf{k},n}(\mathbf{r})$ is valid only for real $\mathbf{k}$ vectors.

   B. The function $u_{\mathbf{k},n}(\mathbf{r})$ is periodic only for real $\mathbf{k}$ vectors.

   C. It is due to the Born-von Karman periodic boundary conditions.

   D. $\mathbf{k}$ is a vector inside the first Brillouin zone so it must be real.

9. A cm^3 of gold (Au) is heavier than a cm^3 of sodium (Na) because:

   A. The crystal structure of Au is FCC which is more close-packed than Na's (BCC).

   B. The nucleus of Au has more nucleons than Na's.

   C. Au has a filled $5d$-electron shell whose effective mass is much larger than Na $3s$ electrons'.

   D. The electronic configuration of Au has many more core electrons than Na's, and core electrons are known to have a very large effective mass.

10. Let ω and E be the fundamental vibrational frequency and dissociation energy of a diatomic molecule, respectively, and let us consider H_2 and D_2 ('H'=hydrogen, 'D'=deuterium). Which one of the following statements is true:

   A. $\omega_{D_2} < \omega_{H_2}$; $E_{D_2} > E_{H_2}$.

   B. $\omega_{D_2} < \omega_{H_2}$; $E_{D_2} = E_{H_2}$.

   C. $\omega_{D_2} = \omega_{H_2}$; $E_{D_2} = E_{H_2}$.

   D. $\omega_{D_2} > \omega_{H_2}$; $E_{D_2} < E_{H_2}$.

11. Consider an Ising model with classical spins $\sigma_i = \pm 1/2$ and nearest neighbor ferromagnetic interaction $J < 0$ between sites labeled by the index i. What is the average magnetic moment $\langle \sigma_i \rangle$ at finite temperature in a two dimensional lattice with a *finite* number of sites?

    A. The average magnetic moment is non zero for a temperature below the transition temperature T_c of the 2D Ising model.

    B. The average magnetic moment is zero at finite temperature due to the Mermin-Wagner theorem, implying no magnetic order in two dimensions.

    C. The average magnetic moment is non zero only for a temperature sizably smaller than the transition temperature T_c of the 2D Ising model, due to finite size effects.

    D. The average magnetic moment is always zero because in a finite system no magnetic transition is possible.

12. The electronic wave function of a diatomic molecule has vanishing angular momentum for rotations around the molecular axis. What is the symmetry for a mirror reflection about a plane passing through this axis?

    A. The wave function is always even under reflection because the rotational symmetry implies the mirror reflection symmetry.

    B. The wave function may have either even or odd reflection symmetry, because it may contain an even or odd number of odd-reflection molecular orbitals.

    C. The ground state of a diatomic molecule with vanishing angular momentum is always a singlet. Therefore the odd-reflection molecular orbitals are always doubly occupied by opposite spin electrons, implying even reflection symmetry in the total wave function.

    D. The wave function is always odd under reflection symmetry in order to satisfy the antisymmetry of the total electronic wave function.

13. The static dielectric constant of ice is about 3 while the one of liquid water is about 80. Why?

    A. Because the density of water is higher than the density of ice.
    B. It is an entropic effect. The dielectric constant of liquids is always much larger than the dielectric constant of solids.
    C. This cannot be true. Ice and water are formed by the same molecules so their dielectric constants must be similar.
    D. It is due to the fact that in liquid water molecules can rotate, in ice this is not possible.

14. Let us consider a planar, non linear, molecule with N atoms. In the normal modes of the molecule, the atoms oscillate either in the molecular plane or perpendicularly to it. How many modes with non zero frequency are parallel and how many are perpendicular?

    A. $2N-4$ are parallel, $N-2$ are perpendicular.
    B. $2N-3$ are parallel, $N-3$ are perpendicular.
    C. $2N-2$ are parallel, $N-4$ are perpendicular.
    D. $2N$ are parallel, N are perpendicular.