Spring 2004 – Entrance Examination: Condensed Matter
Multiple choice quizzes

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1. The heat capacity of a metal is made up of an electron and of a phonon contribution.

   (A) The phonon contribution dominates at very low temperature, the electron contribution at room and higher temperature.

   (B) The electron and the phonon contribution remain comparable at all temperatures.

   (C) The electron contribution dominates at very low temperature, the phonon contribution at room and higher temperature.

   (D) Both contributions are and remain negligible even at room temperature.

2. Two non relativistic electrons collide in vacuum. Owing to their spin, there are two possible channels for this process: triplet (S=1), and singlet (S=0). The cross sections of the two channels are:

   (A) Identical, since the Coulomb force between the electrons is spin independent.

   (B) Vanishing, because it is impossible to conserve energy and momentum in a nontrivial collision in vacuum.

   (C) Larger in the triplet, because exchange between electrons is ferromagnetic.

   (D) Larger in the singlet, because the Pauli principle keeps parallel spin electrons apart.

3. Molecules and solids are made up of electrons and nuclei. Electrons are commonly treated as fermions delocalized on the whole system; ions as classical particles that are localized and fixed. Why is that?

   (A) Ions are heavier, and because of that even if treated quantum mechanically they would not strongly delocalize.

   (B) Ions are not fermions like the electrons, and because of that even if treated quantum mechanically they would not strongly delocalize.

   (C) Simply a matter of formalism. Electrons too are in reality also localized, in the so-called Wannier functions.

   (D) Simply not true. Ions are delocalized too, even though this is not often emphasized. This is treated in the so-called configuration interaction.

4. Consider a one dimensional potential V(x) with two identical minima, separated by a barrier of height U and width d. Given an electron initially in the first minimum, compare the probabilities to jump to the second minimum, neglecting prefactors, either (i) classically, due to a finite temperature T, ignoring quantum effects; or (ii) at T=0, by pure quantum mechanical tunneling. The two probabilities

(A) Both are dependent on U but independent on d

(B) Both are dependent on U and on d

(C) The classical probability depends on U and d, the quantum mechanical only on U

(D) The classical probability depends only on U, the quantum mechanical on both U and d.

5. The two electrons of Helium form a singlet spin state, while the two 2p-electrons of Carbon form a triplet state. The difference is due to:

(A) The first Hund's rule, favoring high spin states, applies only in case of degenerate orbitals not completely filled.

(B) Carbon represents an exceptional case. Most of the atoms with an even number of electrons are in singlet states, due to Pauli principle.

(C) Magnetism for Carbon is due to spin-orbit effects which vanish exactly for the s-states of Helium.

(D) The two 2p-electrons of Carbon have an effective ferromagnetic interaction, due to polarization effects of the lower 1s-shell, an effect which is lacking in Helium.

6. Positronium is a bound system of a positron e^+ (which has the same mass as an electron but positive charge) and an electron. It can be seen as an hydrogen atom where the proton has been substituted by a positron. Which is the ionization potential of positronium?

(A) 13.6 eV

(B) 6.8 eV

(C) 27.2 eV

(D) 13.6 $\times$ 1836 = 24969.6 eV

7. The electronic configuration of the ground state of the Cr atom is $[Ar]3d^5 4s^1$. Which is the ground state term of the Cr atom. (A term is defined by the total orbital angular momentum L, by the total spin S, and by the total angular momentum J. We use the notation ${}^{2S+1}L_J$.)

(A) ${}^7S_3$

(B) ${}^7S_2$

(C) ${}^5S_2$

(D) ${}^5D_0$

8. Why does the spin-orbit splittings increase from lighter to heavier atoms?

(A) It is not true, spin-orbit splittings are larger in lighter atoms.

(B) Because the spin-orbit splittings are proportional to Z^4, where Z is the nuclear charge.

(C) Because the spin-orbit splittings are proportional to the number of electrons.

(D) Because the spin-orbit splittings are proportional to Z^2, where Z is the nuclear charge.

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

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

(B) The model is always paramagnetic in 2D, ordered magnetic phases appear only in three 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 at finite temperature.

10. A piece of crystal is placed in a clamp whose jaws are connected to each other by a conducting wire. When the clamp is tightened, electric current is observed to flow through the wire. One can conclude that:

(A) The work function of the crystal is smaller that that of the material of which the clamp is made.

(B) The crystal Hamiltonian is not time-reversal invariant.

(C) The crystal is a superconductor.

(D) The crystal lattice is not invariant under parity.

11. A bottle of sodium vapor, placed in a uniform electric field $\mathbf{E}$, displays optical absorption at a frequency close to the energy difference between the 4s and 3s energy levels. Let $\boldsymbol{\epsilon}$ be the polarization versor of the incoming light. When the strength of $\mathbf{E}$ is small the absorption intensity is:

(A) Finite and roughly independent of the strength of $\mathbf{E}$ and of the direction of $\boldsymbol{\epsilon}$.

(B) Always zero.

(C) Quadratic in $|\mathbf{E}|$ for $\boldsymbol{\epsilon} \parallel \mathbf{E}$ and zero for $\boldsymbol{\epsilon} \perp \mathbf{E}$.

(D) Linear in $|\mathbf{E}|$ for $\boldsymbol{\epsilon} \parallel \mathbf{E}$ and quadratic for $\boldsymbol{\epsilon} \perp \mathbf{E}$.

12. A system can stay in any of two states, A and B with energies E_A and E_B, and jump back and forth from one to the other with probabilities per unit time $W_{A\to B}$ and $W_{B\to A}$. Tell which one of the following expressions for the transition probabilities is compatible with thermal equilibrium (k is the Boltzmann constant and T the absolute temperature):

(A) $W_{A\to B} = c\left(\frac{kT}{|E_A - E_B|}\right)^{\frac{1}{2}}$; $\qquad W_{B\to A} = (W_{A\to B})^{-1}$

(B) $W_{A\to B} = f(T)\mathrm{e}^{-\frac{(E^\star - E_A)}{kT}}$; $\qquad W_{B\to A} = f(T)\mathrm{e}^{-\frac{(E^\star - E_B)}{kT}}$

(C) $W_{A\to B} = f(T)\mathrm{e}^{-\left(\frac{E_A}{kT}\right)^2}$; $\qquad W_{B\to A} = f(T)\mathrm{e}^{-\left(\frac{E_B}{kT}\right)^2}$

(D) None of the above: no simple expressions for the transition rates can be found, based on the energetics of the system, for they depend very sensitively on the kinetics of the thermal bath.

13. The dipole moment of a CO molecule is small (of the order of 0.2 Debye) because:

(A) The carbon-oxygen bond is non polar, since the two atoms have similar electronic affinity.

(B) Although the electronic affinity of the two atoms is very different, relativistic quantum effects reduce the dipole moment to the experimental value.

(C) The spatial distribution of the carbon doublet of electrons not involved in the bond with oxygen compensates the strong dipole moment of the carbon-oxygen bond.

(D) All the bi-atomic molecules containing oxygen have a small dipole moment.

14. Van der Waals dimers are held together by very small forces i.e. by forces that are on the order of very few meV. A beam of deuterium molecular dimers (i.e. $[D_2]_2$) is made to impinge on a crystal surface at an energy of approximately 15 meV. What is the fate of the dimers?

(A) Because deuterium is a very reactive molecule most dimers will react with the surface irrespective of its nature.

(B) Since the energy of the collisions is much larger than their binding energy, all dimers break up at the surface.

(C) The question is ill posed because a beam of deuterium dimers cannot be prepared since the mass of a deuterium molecule is too small and the van der Waals potential in this case does not support a bound state.

(D) In spite of their weak binding energy a measurable fraction of the dimers is reflected elastically by the surface because the quantum mechanical probability for specular reflection is never zero, this being particularly true for light mass particles.