April 2009 - Entrance Examination: Condensed Matter
Multiple choice quizzes

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1. A crystal is observed to develop a spontaneous electric polarization when the temperature is lowered below a certain critical value. What fundamental symmetry of the high-temperature crystal structure is broken by this transition?

   A. Time-reversal.

   B. Permutation among identical particles.

   C. Gauge.

   D. Parity.

2. A cubic crystal with a substitutional impurity, characterized by an electronic state of p ($l = 1$) angular symmetry is subject to a uniaxial compression along the z axis. Which one of the following statements is true (neglect spin degeneracy)?

   A. The crystal field does not affect the degeneracy of the impurity state before, nor after the compression. The impurity state is therefore always threefold degenerate.

   B. The impurity state is threefold degenerate prior to the uniaxial strain. Upon compression, the degeneracy is lifted, resulting in a doublet and a singlet.

   C. The crystal field completely lifts the degeneracy of the impurity state, which is split into three singlets, irrespective of the applied stress.

   D. The multiplet structure of the impurity state cannot be told without knowing the electronic structure of the crystal host.

3. An atom has total angular momentum $L = 0$ in its ground state. One wants to know what are the possible values of the three components of the angular momentum. Which one of the following statements is true?

   A. A measure of L_z will give 0 with certainty, whereas the outcome of a measure of L_x and L_y cannot be foreseen, because they do not commute with L_z, nor among themselves.

   B. A measure of the three components of the angular momentum will give 0 *on the average*. The outcome of each individual measure cannot be told in advance, because of the probabilistic nature of quantum mechanics.

C. A measure of each one of the three components of the angular momentum will give 0 with certainty.

D. The question is meaningless, because in quantum mechanics one can only think of measuring commuting observables, whereas it is well known that the three components of the angular momentum do not commute among themselves.

4. What is the leading order of the interaction potential between a water molecule and a sodium ion (ionic charge = 1) at large distance, R?

   A. R^{-1}

   B. R^{-6}

   C. R^{-2}

   D. $\mathrm{e}^{-\lambda R}$

5. The ground-state wave-function of a particle moving in 1D under the influence of a local potential, $V(x)$, has the following asymptotic form: $\psi(x) \sim c \times \exp(-\alpha x^3)$, for $x \to +\infty$. What is the large-x asymptotic behavior of the potential?

   A. $V(x) \sim$ constant

   B. $V(x) \sim x^4$

   C. $V(x) \sim x^6$

   D. None of the above.

6. The density of materials usually decreases upon increasing temperature. This fact indicates that:

   A. The harmonic approximation is inadequate to describe lattice vibrations.

   B. The independent-electron approximation is not valid.

   C. The continuum elasticity model for sound propagation breaks down.

   D. Thermal excitations of the electrons have to be taken into account.

7. The dissociation energy of the deuterium dimer, D_2 (D, deuterium is the heavy isotope of hydrogen with $A = 2$) is:

   A. Much smaller than that of H_2.

   B. Slightly larger than that of H_2.

   C. Slightly smaller than that of H_2.

   D. Equal to that of H_2.

8. Consider an H_2 molecule and imagine increasing adiabatically the proton-proton distance. In the large-distance limit:

    A. The bond will break and the two atoms will repel each other because of the residual overlap between the atomic orbitals.

    B. The two atoms will continue to attract each other, but the strength of the bond will decrease exponentially, due to the exponential decay of the electronic charge distribution of the two atoms.

    C. Because the H negative ion is stable, the two product atoms will be ionized with opposite charge and will attract each other with a Coulomb interaction.

    D. The two atoms will attract each other with an interaction which decreases with a power law of the inter-atomic separation, and which is due to correlation effects that cannot be accounted for in the Hartree-Fock approximation.

9. The frictional force between two sliding bodies is proportional to the load force, but surprisingly independent of the apparent contact area (Da Vinci-Amontons law).

    A. The microscopic contact area is much smaller, and determined by load.

    B. The microscopic contact force is much larger, and determined by the area.

    C. The microscopic contact load is much smaller, and determined by the area.

    D. The "surprising" property is just not true: friction does depend on the area.

10. Spin system under the action of an applied magnetic field are known to give rise, under certain circumstances, to negative temperatures.

    A. This is so only on the Celsius or Fahreneit scales. On the absolute Kelvin scale, temperatures are always positive.

    B. This is a consequence of the broken ergodicity, due to the finite number of degrees of freedom.

    C. This is the consequence of the the non-commutative character of the three components of the spin, which break the third principle of thermodinamics.

    D. This is so because of the finite number of available quantum states, which make the entropy a decreasing function of temperature, at high enough temperature.

11. Compare the electrical properties of (ideal, perfect, crystalline) solid ice at very low temperature, and of liquid water at 20 C.

    A. Both are good electronic and ionic conductors.
    B. Water is an ionic conductor and an electronic insulator, ice is an insulator on both accounts.
    C. Water is a electronic conductor and an ionic insulator, ice is a conductor on both accounts.
    D. Both water and ice are good electronic and ionic insulators.

12. Consider simulating the thermal vibrations of a solid, by solving on the computer Newton's equation $F = ma$ for each atom (atoms are treated as classical particles on account of their large mass). At the end of the simulation, you will obtain numerically for each (average) temperature T, an internal energy $\langle E(T) \rangle$ and its derivative the specific heat C_v. For very small T, this calculation will yield

    A. $C_v \sim T$.
    B. $C_v \sim T^3$.
    C. $C_v \sim \ln T$.
    D. $C_v \sim$ constant.

13. The electrical conductivity of a material decreases exponentially decreasing the temperature. The material is:

    A. A superconductor.
    B. A doped semiconductor.
    C. A highly pure insulator.
    D. A normal metal.

14. Consider the (high temperature) thermal conductivities of an insulating crystal or of the same material in glassy form.

    A. Both the crystal and the glass thermal conductivities are negligible because phonons have a gap in an insulator.
    B. The crystal is the worse conductor because order reduces the chance of atoms to exchange heat.
    C. The crystal is the better conductor because phonons have a much longer mean free path.

D. Both are excellent heat conductors, because there are no free electrons to damp the phonon motion.

15. Consider a system of N non-interacting bosons in three dimensions:

    A. The system is condensed (namely all bosons occupy the same quantum state) only at zero temperature, whereas at any finite temperature the number of bosons in any state is finite.

    B. The system is condensed for sufficiently small temperature and the condensate fraction N_0 goes like $N_0 \sim 1 - (T/T_c)^{3/2}$, for $T < T_c$.

    C. The system is condensed for sufficiently small temperature and the condensate fraction N_0 goes like $N_0 \sim 1 - (T/T_c)^{1/2}$, for $T < T_c$.

    D. The system is never condensate, because of quantum fluctuations, and it can form a condensate only within a mean-field approximation.

16. The N atom has seven electrons. Its first ionization energy is 14.5 eV, the second ionization energy is 29.6 eV and the third is 47.5 eV. Estimate the Coulomb repulsion energy U between two $2p$ electrons in N.

    A. 47.0 eV.

    B. 15.0 eV.

    C. 30.0 eV.

    D. 3.0 eV.

17. When a thermally isolated paramagnetic solid is inserted into a magnetic field, its temperature...

    A. increases.

    B. decreases.

    C. does not change.

    D. increases in some materials, decreases in others.

18. The Ca atom has two optically active electrons outside the Ar core. Let us consider an optical transition between two triplets ^3P and ^3D. Accounting for the spin-orbit splitting of these triplets and using the selection rule $\Delta J = 0, \pm 1$ (where J is the total angular momentum), how many lines do you expect to see from this transition?

    A. 1.

    B. 3.

    C. 6.

D. 9.

19. The mass of a cubic meter (m^3) of O_2 gas (at $T = 0$ C temperature and 1 atm pressure) is about:

    A. 1400 g.

    B. 140 g.

    C. 14 g.

    D. 1.4 g.

20. Consider a superconducting material and an external magnetic field. Which one of the following statement is correct:

    A. Inside the bulk there is no magnetic field, provided the field is not too strong.

    B. Inside the bulk, the system is paramagnetic and from the susceptibility it is possible to understand that electrons are paired.

    C. Inside the bulk there is no magnetic field, no matter how strong the magnetic field is.

    D. Even an infinitesimal magnetic field turns the superconductor into a normal metal.