October 2009 - Entrance Examination: Condensed Matter
Multiple choice quizzes

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1. The ionization potential of the Hydrogen atom is 13.6 eV. What is the ionization potential of the Be^{3+} ion? (the atomic charge of Be is Z= 4).

   A. 54.4 eV.

   B. 217.6 eV.

   C. 3.4 eV.

   D. 870.4 eV.

2. Let us consider the hydrogen molecule H_2 and the ionized hydrogen molecule H_2^+. Which one of the following sentences is true? (Here E_b is the binding energy in eV and d is the equilibrium distance in Å).

   A. For H_2: $E_b = 4.7$, $d = 0.74$. For H_2^+: $E_b = 2.8$, $d = 1.06$.

   B. For H_2: $E_b = 2.8$, $d = 1.06$. For H_2^+: $E_b = 4.7$, $d = 0.74$.

   C. For H_2: $E_b = 4.7$, $d = 1.06$. For H_2^+: $E_b = 2.8$, $d = 0.74$.

   D. For H_2: $E_b = 2.8$, $d = 0.74$. For H_2^+: $E_b = 4.7$, $d = 1.06$.

3. A chemical reaction cannot occur spontaneously if:

   A. It is exothermic and the entropy of the products is larger than the entropy of the reactants.

   B. It is exothermic and the entropy of the products is smaller than the entropy of the reactants.

   C. It is endothermic and the entropy of the products is larger than the entropy of the reactants.

   D. It is endothermic and the entropy of the products is smaller than the entropy of the reactants.

4. Consider the Bloch functions $\psi_{\mathbf{k},v}(\mathbf{r}) = e^{i\mathbf{kr}} u_{\mathbf{k},v}(\mathbf{r})$ eigenstates of the Hamiltonian of a periodic solid. Here $\mathbf{k}$ is a vector in the first Brillouin zone and $u_{\mathbf{k},v}(\mathbf{r})$ has the same periodicity of the Bravais lattice. Which one of the following sentences is true:

   A. As a function of $\mathbf{k}$, both $\psi_{\mathbf{k},v}(\mathbf{r})$ and $u_{\mathbf{k},v}(\mathbf{r})$ can be chosen periodic with the periodicity of the reciprocal lattice.

B. As a function of $\mathbf{k}$, only $\psi_{\mathbf{k},v}(\mathbf{r})$ can be chosen periodic with the periodicity of the reciprocal lattice.

C. As a function of $\mathbf{k}$, only $u_{\mathbf{k},v}(\mathbf{r})$ can be chosen periodic with the periodicity of the reciprocal lattice.

D. As a function of $\mathbf{k}$, neither $\psi_{\mathbf{k},v}(\mathbf{r})$ nor $u_{\mathbf{k},v}(\mathbf{r})$ can be periodic.

5. The thermal conductivity in metals is usually larger than in insulators. This is so because:

   A. Phonon-phonon interactions are larger in insulators than they are in metals.

   B. The electron-phonon interaction is larger in metals than it is in insulators.

   C. In metals free carriers, which are absent in insulators at low temperature, also conduce heat.

   D. The electron-electron interaction is totally screened in metals, thus enhancing transport processes, whereas it is only partially screened in insulators.

6. The spin and orbital total angular momenta of a carbon atom in its ground state (electronic configuration $(1s)^2(2s)^2(2p)^2$) are:

   A. $S = 1$ and $L = 1$.

   B. $S = 1$ and $L = 0$.

   C. $S = 0$ and $L = 2$.

   D. $S = 0$ and $L = 1$.

7. The low-temperature heat capacity of a solid goes to zero with temperature as $C_V \approx \alpha T^3$. How does the α coefficient depend on the nuclear mass(es) M of the constituents of the solid?

   A. $\alpha \propto M^{\frac{3}{2}}$

   B. $\alpha \propto M^{-\frac{3}{2}}$

   C. α is independent of M

   D. $\alpha \propto \log M$

8. Water is known to conduct electricity, yet it is transparent. How is this possible?

   A. So what? Many conductors, known as *glassy metals*, are actually transparent.

B. Water is not an electronic conductor but rather an ionic conductor, enhanced by the solvation of foreign molecules which dissociate into ions that act as charge carriers.
C. False. Water is an insulator, it does not conduct.
D. It is the sunlight that excites electrons and makes water conduct. In the dark, water insulates.

9. Among these linear molecules: O_2, CO, CO_2, which ones do have a static dipole moment, and which don't?

   A. None has a dipole moment.
   B. Only CO does, the others don't.
   C. CO and CO_2 do, O_2 doesn't.
   D. All have a dipole moment

10. Magnetism is a collective phenomenon: the magnetic moment of a magnetic object results from the coherent addition of moments around all atoms. Where does this coherence between even very distant atoms come from?

    A. Magnetic interactions are extremely long ranged,reaching essentially infinite distance.
    B. It is a phenomenon typical of metals. Magnetism resides in the electron spins, and the electrons travel eveywhere in a metal, carrying magnetism with them.
    C. It is not really collective. Most spins in a magnet point in random directions: but the random deviation from zero magnetization is still macroscopic in a macroscopic sample.
    D. Coherence results from long-range correlations typical of the broken symmetry phases in phase transitions, irrespective of the range of the interactions.

11. The color of an object is given by those frequencies that are not absorbed. What color would you choose your car, so as to avoid its getting too hot in the sunlight (roughly a Planckian spectrum, centered on green)?

    A. Green.
    B. Black.
    C. White.
    D. No difference expected.

12. Consider a one dimensional array of N spins of magnitude S that are coupled among each other ferromagnetically. Which of the following sentences is correct:

    A. The ground state is a spin singlet because in one-dimension the continuous spin-rotational symmetry can not be spontaneously broken.

    B. The ground state has a finite total spin that tends to $S\,N$ only in the limit $N \to \infty$.

    C. The ground state has total spin $S\,N$ for any N.

    D. Spin symmetry is broken and the ground state is not eigenstate of the total spin.

13. The conduction electron density of states of a metal is finite at the chemical potential. It follows that

    A. The conduction electron contribution to the specific heat is finite at zero temperature $T = 0$ and increases linearly with T.

    B. The conduction electron contribution to the specific heat is zero at $T = 0$ and increases linearly.

    C. The conduction electron contribution to the specific heat is zero at $T = 0$ and increases as a power law dictated by the slope and curvature of the density of states around the chemical potential.

    D. The conduction electron contribution to the specific heat is constant at zero temperature $T = 0$ and decreases linearly with T.

14. $2N$ electrons must be distributed into $M \geq N$ different orbitals. The maximum total spin S of all allowed $2N$-electron wavefunctions are:

    A. $S = N$ if $2N \leq M$, $S = M - N$ if $M \leq 2N \leq 2M$.

    B. $S = N$.

    C. $S = M - N$.

    D. $S = 2N - M$ if $N \leq M/2$, $S = 0$ otherwise.

15. At low temperature hydrogen fluoride and deuterium fluoride are polar liquids. Their static dielectric constants ϵ_{HF} and ϵ_{DF} obey the relations:

   A. $\epsilon_{DF} > \epsilon_{HF}$.

   B. $\epsilon_{DF} < \epsilon_{HF}$.

   C. $\epsilon_{DF} = \epsilon_{HF}$.

   D. $\epsilon_{DF} > \epsilon_{HF}$ near the melting temperature, but $\epsilon_{DF} < \epsilon_{HF}$ near the boiling temperature.

16. Ruby and sapphire are insulators with the same chemical composition (Al_2O_3), but ruby looks red to the human eye, while sapphire looks blue. This is because of:

   A. The optical phonons; in sapphire, they have a higher energy than in ruby.

   B. The value of the band gap; in ruby, it is smaller than in sapphire.

   C. Impurities in the band gap.

   D. Surface effects; the surface is slightly conducting and therefore these materials are not transparent.

17. Why is the Earth core largely made of iron? What is so special about iron in the universe?

   A. It is not known.

   B. It is a metal, and the metallic state is favored at high pressures.

   C. Iron is heavy, and heavy elements dominate

   D. Nucleons in iron have maximum binding energy, so all nuclear reactions end up producing iron.

18. Which one of the following is an acceptable form for the entropy of a system as a function of its energy, E, number of particles, N, and volume V? (R, v_0, and θ are positive constants)

   A. $S = \left(\frac{R^2\theta}{v_0^3}\right)\frac{V^3}{NE}$

   B. $S = \left(\frac{R^2}{v_0\theta}\right)^{\frac{1}{3}}(NVE)^{\frac{1}{3}}$

   C. $S = NR\log\left(\frac{VE}{N^2R\theta v_0}\right)$

   D. $S = \left(\frac{R^2}{v_0\theta}\right)^{\frac{1}{3}}(N^2VE)^{\frac{1}{3}}$

19. A sample of pure silicon was claimed to display a negative expansion coefficient at very low temperature.

A. And so what? this is the regular behavior observed in any insulating material.

B. This is so because, due to anharmonic effects, the frequencies of some acoustic phonons increase with increasing volume.

C. This is so because, due to anharmonic effects, the frequencies of some optic phonons increase with increasing volume.

D. This behavior is not possible in any pure insulating material, and can only be due to the presence of impurities (donors and acceptors) that release charge carriers in the conduction and valence bands upon heating.

20. A gambler plays *heads or tails*. Let $P(N)$ be the probability that after N coin tosses the gambler has exactly the same sum he started with, and assume that the gambler gets unlimited credit in case of loss. Which of the following statements is true for large N?

A. $P(N) \propto \frac{1}{N}$.

B. $P(N) \propto \frac{1}{N^2}$.

C. $P(N) \propto \frac{1}{\sqrt{N}}$.

D. $P(N) \propto \mathrm{e}^{-\frac{N}{2}}$.