Fall 2005 – Entrance Examination: Condensed Matter
Multiple choice quizzes

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1. There are, in nature, different types of conductors. Very common are degenerate electron conductors (EC), where essentially free electrons can be excited above their Fermi level, and ionic conductors (IC), where electrons are bound but ions as a whole can drift.

   (A) Water is an EC, copper an IC.

   (B) Water is an IC, copper an EC.

   (C) Both water and copper are ECs.

   (D) Both water and copper are ICs.

2. The basic importance of semiconductors for electronics is due to the fact that:

   (A) They conduct not too much, not too little.

   (B) They are cheap and abundant in nature.

   (C) They conduct current only in one direction, i.e., they rectify.

   (D) Thanks to doping, their conductance can be controlled by an external voltage.

3. Two atoms will always weakly attract when at large distance. A certain experiment needs to identify the two atoms, equal or unequal between them, whose attraction will be the smallest. The answer is:

   (A) Two He atoms.

   (B) Two H atoms.

   (C) One H and one He.

   (D) One He and one Rn (radon).

4. Iron is magnetic because:

   (A) The collective alignment of orbital magnetic moments of individual Fe ions lowers the total energy.

   (B) Collective macroscopic currents set up spontaneously inside metallic Fe, giving rise to a magnetization through Ampère's law.

   (C) The collective alignment of spin moments of individual Fe ions lowers the total energy.

   (D) Magnetic dipoles (North and South) form at the surfaces, giving rise to magnetic domains and permanent flux lines.

5. Consider the ground state of a hypothetical hydrogen molecule H_2 where the distance a between the two protons could be changed arbitrarily. As a changes from very small to very large, the ground state

   (A) is always a singlet, but crosses over from basically a single Slater determinant, to a sum of two Slater determinants.

   (B) is always a spin triplet.

   (C) switches from singlet to triplet.

   (D) is always a single Slater determinant, but switches from triplet to singlet.

6. Helium, ^4He, remains liquid down to absolute zero because the atoms are so light that their zero-point motion is sufficient to destabilize the solid. Molecular hydrogem, H_2, is about twice as light, and yet it solidifies upon cooling below $14K$. That is because:

   (A) H_2 is not a boson.

   (B) Unlike ^4He, H_2 has a non zero spin.

   (C) H_2 is more polarizable, causing a much larger intermolecular attraction.

   (D) The quadrupolar forces induce a static angle between the H_2 molecules.

7. All solids possess gapless, low-frequency vibrational excitations (acoustical phonons) due to motion of their ions, but not all solids possess gapless, low-energy electronic exitations.

   (A) This is due to the electronic excitations having a short wavelength, whereas the phonons can have indefinitely long wavelengths.

   (B) This is not fully correct, and acoustical phonons can also have a gap, such as in ionic crystals.

   (C) This is not fully correct, since electronic gaps are never really complete, and electrons can flow – even if very slowly – even in insulators.

   (D) Electrons in insulators are bound to the ions and can develop a gap, but the ions themselves are free to move and cannot have a gap.

8. The energy of a non-relativistic electron of momentum $\hbar k$ in vacuum grows monotonically as $\hbar^2 k^2/2m$. The energy of the same electron in a periodic solid is a periodic function of the quasi-momentum $k = 2\pi/\lambda$ (a so-called energy band). What happens of very high-energy electronic states?

   (A) The are eliminated by scattering by the ions.

   (B) There are many periodic bands, covering all energies, including the higher ones.

   (C) The high energy states actually decay in presence of a lattice, so that only one periodic energy band is stable.

   (D) The statement is false, and energy is not strictly periodic, since an electron in a periodic potential is in reality a wavepacket, whose energy is still the same as in vacuum.

9. Neglecting spin-orbit, is the ground state of a carbon atom degenerate?

   (A) Yes, nine-fold degenerate.

   (B) No. It is non degenerate.

   (C) Yes, six-fold degenerate.

(D) Yes, three-fold degenerate.

10. Let's consider a gas of Xe atoms and a gas of Na atoms in a magnetic field. Which one among the following statements is true?

    (A) Both gases are paramagnetic.
    (B) Both gases are diamagnetic.
    (C) Xe is paramagnetic and Na is diamagnetic.
    (D) Na is paramagnetic and Xe is diamagnetic.

11. Let's consider an electron in the $2p$ levels of a Boron atom inside a very strong magnetic field. The field is so strong that spin-orbit coupling can be neglected, and the $2p$ levels are split into distinct levels. How many (assume $g = 2$)?

    (A) 3.
    (B) 4.
    (C) 5.
    (D) 6.

12. The wavefunction of many electrons, in a uniform system without disorder, is initially prepared in a state with finite total current. Then the wavefunction is evolved in time by using, in the Schroedinger equation, the standard Hamiltonian with the usual kinetic energy of free electrons and the two body electron-electron interaction. What happens to the expectation value of the total current?

    (A) It oscillates around a mean value because there is no dissipation and only quantum interference between different energy levels.
    (B) The expectation value of the current remains constant because the Hamiltonian considered commutes with the total current operator.
    (C) It decays to zero due to electron-electron interaction.
    (D) The current will continuously increase with time because, as well known, the resistivity is zero in a clean system.

13. The sky is blue because:

    (A) Air contains 22% of oxygen which does not absorb electromagnetic radiation at wavelengths larger than 6000 $\AA$.
    (B) The main constituent of air is nitrogen whose molecule is held together by a very stable triple bond responsible for strong absorption in the blue.
    (C) The same reason why colors shift to blue deep in the ocean: air, like water, slightly absorbs electromagnetic radiation, and the absorbtion coefficient is larger the larger the wavelength.
    (D) Because the cross section for elastic scattering of photons by atoms and molecules decreases when the wavelength of the light increases.

14. Ice floats on water. This indicates that:

    (A) The melting temperature of ice increases with increasing pressure.

(B) The entropy of water is larger in the solid phase than in the liquid phase due to disorder in the hydrogen sublattice.

(C) The melting temperature of ice decreases with increasing pressure.

(D) Ice is lighter than water because of an anomalous lattice expansion due to zero-point motion of hydrogen atoms.