SISSA ISAS
SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI - INTERNATIONAL SCHOOL FOR ADVANCED STUDIES
I-34014 Trieste ITALY - Via Beirut 4 - Tel. [+]39-40-37871 - Telex:460269 SISSA I - Fax: [+]39-40-3787528

October 2008 - Entrance Examination: Condensed Matter
Multiple choice quizzes

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1. Consider the $1s \mapsto 2p$ and $2s \mapsto 2p$ transition in atomic H (hydrogen) and Li (lithium), respectively. When the atomic gas is subject to a homogeneous electric field, the line splits into:

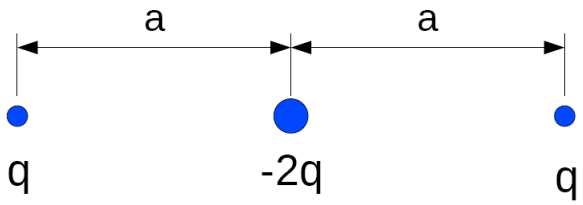
   A. Two lines in Li and three lines in H. The magnitude of the splitting is linear with the intensity of the field for H, and quadratic for Li.

   B. Two lines in both cases. The magnitude of the splitting is quadratic with the intensity of the field.

   C. Three lines in both cases. The magnitude of the splitting is linear with the intensity of the field.

   D. Two lines in H and three lines in Li. The magnitude of the splitting is linear with the intensity of the field for H and quadratic for Li.

2. Consider the electric charges shown in the figure.



   Away from the axis, the potential created by these charges decreases with the distance r from the center as:

   A. $\approx 1/r$.

   B. $\approx a/r^2$.

   C. $\approx a^2/r^3$.

   D. $\approx a^3/r^4$.

3. The low temperature specific heat of an insulating crystal such as diamond grows like aT^3. Supposing to substitute isotopically all carbon atoms of the diamond crystal from ^{12}C to ^{14}C, what would happen to the specific heat?

   A. It would not change, assuming one could neglect the small change of interatomic distance.

B. It would still grow like aT^3, with a replaced by $a(14/12)^{-3/2}$.

C. It would still grow like aT^3, with a replaced by $a(14/12)^{3/2}$.

D. It would not exist, because such a crystal would be mechanically unstable.

4. A free proton with mass m_p and a free electron with mass m_e have the same energy E. The quantum mechanical wavelengths of these two particles are λ_p and λ_e. Which one of the following expressions is true?

A. $\lambda_p = \sqrt{\frac{m_e}{m_p}}\lambda_e$.

B. $\lambda_p = \lambda_e$.

C. $\lambda_p = \sqrt{\frac{m_p}{m_e}}\lambda_e$.

D. $\lambda_p = \frac{m_e}{m_p}\lambda_e$.

5. There are 230 space groups, 32 points groups, 14 Bravais lattices but only 7 crystal systems. Which is the difference between different crystal systems?

A. This is not true, there are 32 crystal systems, one for each point group.

B. The crystal system determines the symmetry of the macroscopic properties of a solid. There are only seven possibilities.

C. The Bravais lattice can have only one out of seven different point groups. This point group determines the crystal system.

D. This is not true, there are 14 crystal systems, one for each Bravais lattice.

6. Solid (S), liquid (L) and gas (G) phases of the same substance differ in more than one way.

A. S and L differ in density, L and G differ in symmetry too. Because of that, S and L merge at a critical point, whereas L and G do not.

B. S and L differ in density and symmetry, L ans G differ in density alone. Because of that, S and L never merge at a critical point, whereas L and G do.

C. Owing to differences of density and symmetry, neither S and L, nor L and G ever merge at a critical point.

D. Owing to differences of density and symmetry, both S and L, and L and G merge at two separate critical points.

7. The Nitrogen (N) atom has 7 electrons and by the Hund's rule has spin $S = 3/2$. In the N_2 dimer, $2p$ electrons form σ and π orbitals. What is the spin of the N_2 dimer?

   A. The Hund's rule is general so the N_2 dimer has spin $S = 3$.

   B. By the standard rules for the sum of two $S = 3/2$ spins, the N_2 dimer in its ground state can allow any spin between 0 and 3.

   C. The total spin is not defined in the N_2 dimer because the system is not fully rotationally invariant as the N atom.

   D. The ground state of the N_2 dimer is a singlet.

8. Two identical non-interacting particles with spin $S = 3/2$ are confined in a harmonic potential well. The ground state is:

   A. non-degenerate.

   B. 6-fold degenerate.

   C. 16-fold degenerate.

   D. 12-fold degenerate.

9. The ground state electronic configuration of a cobalt atom is $[Ar]3d^7 4s^2$ where $[Ar]$ is the electronic configuration of the Argon atom. According to Hund's rules which are its orbital (L) and spin (S) angular momenta?

   A. $L = 3$, $S = 3/2$.

   B. $L = 2$, $S = 1/2$.

   C. $L = 2$, $S = 3/2$.

   D. $L = 1$, $S = 1/2$.

10. The boiling point of water (H_2O) is 100° C. The one of hydrogen sulfide (H_2S) is −60° C. Why?

    A. The mass of S is much larger than the mass of O.

    B. The dipole moment of H_2O is larger than the dipole moment of H_2S so dipole-dipole interactions are much stronger.

    C. In H_2O the H atoms form hydrogen bonds which are much stronger than in H_2S.

    D. This is due to the van der Waals interactions, much stronger in H_2O than in H_2S.

11. The tunneling probability of a quantum particle across a barrier of fixed height and width depends on the particle mass M. When M is large,

A. It decreases like $1/M^{\alpha}$, where α depends on the barrier.

B. It increases like M^{α}, where α depends on the barrier.

C. It decreases like $exp(-M^{1/2})$.

D. It increases like $exp(M^{1/2})$.

12. Which one of the following sentences is false for a crystal with a cubic unit cell? (isotropic means equal in all directions)

A. Its refractive index is isotropic.

B. If it is metallic, its resistivity is isotropic.

C. Its elastic properties are isotropic.

D. Its thermal conductivity is isotropic.

13. Assume the ground state wave function of an isolated system (e.g. one atom) is a singlet. What is the behavior of the spin density $\sigma_z(\vec{R}) = \rho_{\uparrow}(\vec{R}) - \rho_{\downarrow}(\vec{R})$, where $\vec{R}$ is an arbitrary position, and $\rho_{\uparrow}(\vec{R})$ ($\rho_{\downarrow}(\vec{R})$) is the corresponding density of the spin $\uparrow$ ($\downarrow$) electrons?

A. It is very small because the total spin is the minimum possible in a singlet.

B. Only the integral $\int dR^3 \sigma_z(\vec{R})$ vanishes, but the spin density can have arbitrary values at any position $\vec{R}$.

C. As in [B.], but the spin density has to vanish at infinity (far from the atom).

D. The spin density vanishes identically for any $\vec{R}$.

14. The electronic state of an atom can be indicated with the symbol ^{2S+1}L where L, and S indicate the orbital and spin angular momenta respectively. This symbol indicates states that are usually degenerate. Spin-orbit coupling splits this degeneracy and gives terms indicated by $^{2S+1}L_J$ where J is the total angular momentum. How many different J are there for given L and S?

A. $2L + 1$.

B. $2S + 1$.

C. $2L + 1$ if $L \geq S$, $2S + 1$ if $L \leq S$.

D. $2L + 1$ if $L \leq S$, $2S + 1$ if $L \geq S$.

15. Passing from air to water light is refracted. Which one of the following sentences is false?

    A. The velocities of the incident and transmitted waves differ.

    B. The wavelengths of the incident and transmitted waves differ.

    C. The intensities of the incident and transmitted waves differ.

    D. The frequencies of the incident and transmitted waves differ.

16. The emission spectrum of Na atoms is characterized by a strong doublet of yellow lines with wavelengths 5890 Å and 5896 Å. These lines are split because:

    A. The effect is due to spin-orbit coupling which splits the $3p$ levels of Na into $3p_{1/2}$ and $3p_{3/2}$.

    B. This is not true. There is a single line.

    C. The $3p$ and $3d$ levels of Na are split because the effective potential due to the nucleus and core electrons is not equivalent to a Coulomb $\approx -1/r$ potential.

    D. The effect is due to spin-orbit coupling which splits the $3s$ levels of Na into $3s_{1/2}$ and $3s_{-1/2}$.

17. According to the Bloch theorem, in a crystalline solid the electronic states are classified with a wavevector $\mathbf{k}$ inside the first Brillouin zone and a band index i. Which one of the following sentences is valid for a nonmagnetic solid and a non degenerate band?

    A. $\psi_{-\mathbf{k},i}(\mathbf{r}) = \psi_{\mathbf{k},i}(\mathbf{r})$ is always true.

    B. $\psi_{-\mathbf{k},i}(\mathbf{r}) = \psi^*_{\mathbf{k},i}(\mathbf{r})$ is always true.

    C. $\psi_{-\mathbf{k},i}(\mathbf{r}) = \psi^*_{\mathbf{k},i}(\mathbf{r})$ is true only for solids with inversion symmetry.

    D. $\psi_{-\mathbf{k},i}(\mathbf{r}) = \psi_{\mathbf{k},i}(\mathbf{r})$ is true only for solids with inversion symmetry.

18. The metal handle of a wooden door feels cooler than the door itself. This is so because:

    A. Metals do not absorb infrared radiation, whereas wood does.

    B. Metals have a larger thermal conductivity than wood, due to the effect of free carriers, thus subtracting heat more efficiently from the hand that touches it.

    C. The specific heat of wood is larger than any metal's, thus making more difficult to heat it.

D. Metal surfaces are usually way flatter than wood's, thus making heat transfer more efficient upon contact.

19. Iron is magnetic and zinc is not. That is because:

A. Iron is a metal and zinc an insulator.

B. The two s-electrons of zinc neutralize the d-electron spin, while iron has no s-electrons.

C. There are, in the ground state, strong orbital currents that magnetize iron, but not zinc.

D. Zinc's d-electron shell is completely filled, iron's only partly filled.

20. How many nodes are there in the radial $4p$ wavefunction of the H atom?

A. 1.

B. 2.

C. 3.

D. 4.