SISSA ISAS

SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI - INTERNATIONAL SCHOOL FOR ADVANCED STUDIES
I-34136 Trieste ITALY - Via Bonomea 265 - Tel. [+]39-40-37871 - Telex:460269 SISSA I - Fax: [+]39-40-3787528

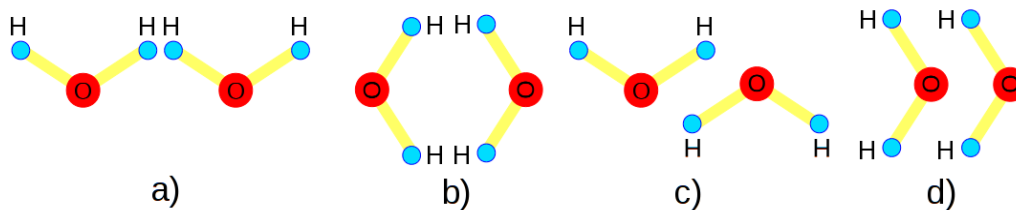# April 2011 - Entrance Examination: Condensed Matter
Multiple choice quizzes

1. Consider a charged quantum harmonic oscillator interacting with an external electric field. Which one of the following sentences is true:

   A. The excitation energies of the system are independent of the strength of the field.

   B. To leading order, the excitation energies of the system depend linearly on the strength of the field.

   C. To leading order, the excitation energies of the system depend quadratically on the strength of the field.

   D. To leading order, the excitation energies of the system depend linearly or quadratically on the strength of the field, according to whether the final state has odd or even parity.

2. Let us consider the FeH molecule. Which orbitals of Fe can form a bonding orbital with the $1s$ orbital of H? (assume that the molecule is along z)

   A. Only the $4s$.

   B. The $4s$ and the $3d_{3z^2-r^2}$.

   C. The $4s$, the $3d_{xy}$, and the $3d_{x^2-y^2}$.
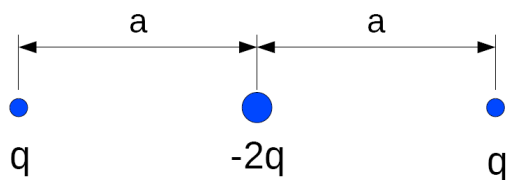
   D. The $4s$, the $3d_{xz}$, and the $3d_{yz}$.

3. Spin-orbit coupling can split the atomic energy levels. Among the following orbitals, identify those with the largest splitting.

   A. The $1s$ orbitals of Uranium ($Z = 92$ where Z is the atomic number).

   B. The $3d$ orbitals of Gold ($Z = 79$).

   C. The $3d$ orbitals of Iron ($Z = 26$).

   D. The $3p$ orbitals of Gold.

4. Four possible configurations of the water dimer are shown in the figure. Modeling the two water molecules as two interacting dipoles at fixed distance and assuming only electrostatic interactions, which is the configuration with the lowest energy?

A. a).

B. b).

C. c).

D. d).

5. Consider the three molecules: (1) acetylene (C_2H_2), (2) ethylene (C_2H_4), and (3) ethane (C_2H_6), and the vibrational frequencies corresponding to the stretching of the CC bond, ν_1, ν_2, and ν_3. Which one of the following statements is true:

A. $\nu_1 > \nu_2 > \nu_3$.

B. $\nu_1 < \nu_2 < \nu_3$.

C. $\nu_1 \approx \nu_2 \approx \nu_3$.

D. $\nu_1 > \nu_2 \approx \nu_3$.

6. Let us consider the total energy of a Fe atom and that of a Fe^+ ion. Which one of the following sentences is false.

A. The ground state energy of the Fe atom is always lower than the ground state energy of the Fe^+ ion.

B. Any excited state of the Fe^+ ion has energy higher than any excited state of the Fe atom.

C. Any excited state of the Fe^+ ion has energy higher than the ground state energy of the Fe atom.

D. There are excited states of the Fe atom with energy higher than the ground state energy of the Fe^+ ion.

7. Consider He and H⁻ atoms, which one of the following statements is correct?

    A. There is an infinite number of bound states in both cases.

    B. There is just one bound state for both atoms.

    C. There are more bound states for H⁻ than for He.

    D. There are more bound states for He than for H⁻.

8. Among the following four solids, identify the one with the highest speed of sound.

    A. Diamond.

    B. Sodium metal.

    C. Gold metal.

    D. Silicon.

9. The specific heat C_V of a non-interacting Fermi gas in a d-dimensional hyper-cubic box behaves at low temperature T as

    A. $C_V \sim T^{d-2}$.

    B. $C_V \sim T^{d/3}$.

    C. $C_V \sim T$.

    D. $C_V \sim T^{3/d}$.

10. The following charges:

have

    A. Dipole moment $2qa$.

    B. Dipole moment $2qa^2$.

    C. Quadrupole moment $2qa$.

    D. Quadrupole moment $2qa^2$.

11. Which is the relationship between the point group and the space group of a solid?

    A. The space group contains all the symmetry operations of the point group and their combinations with the translations of a Bravais lattice vector.

    B. The point group contains only rotations, while the space group contains only translations.

    C. The point group contains all the symmetry operations that can be obtained from the symmetry operations of the space group by setting all translations to zero.

    D. The point group is a subgroup of the space group that can be obtained by taking only the symmetry operations of the space group that have zero translation.

12. Many atoms have a finite magnetic moment in their ground state. Among the following, can you identify the one with the largest spin magnetic moment? In parenthesis the ground state electronic configuration.

    A. Rh ($4d^85s$).

    B. Cr ($3d^54s$).

    C. Er ($4f^{12}6s^2$).

    D. Re ($5d^56s^2$).

13. The constant volume specific heat (C_V) and the constant pressure specific heat of a solid (C_P) are usually different. Which one of the following sentences is true for a nonmagnetic solid.

    A. C_P is always larger than C_V.

    B. They do not differ appreciably in solids.

    C. C_P is always smaller than C_V.

    D. At temperatures (T) sufficiently high, C_V is constant independent of T while C_P is not.

14. An fcc crystal can be described by the conventional cubic unit cell or by a primitive fcc unit cell. Let us consider the volumes of the Brillouin zones of the cubic lattice Ω_c and of the fcc lattice Ω_f. Which is the relationship between Ω_c and Ω_f?

    A. $\Omega_c = 2\Omega_f$.

    B. $\Omega_f = 2\Omega_c$.

    C. $\Omega_f = 4\Omega_c$.

    D. $\Omega_c = 4\Omega_f$.

15. Pyroelectric solids have a permanent macroscopic polarization. Therefore they ...

    A. ... cannot be piezoelectric.

    B. ... cannot have a cubic Bravais lattice.

    C. ... cannot be insulators.

    D. ... cannot remain polarized at zero temperature.

16. It is found that the low-temperature specific heat of a system of bosons behaves as $C_V \approx \alpha T^n$, where α is a constant. Which one of the following statements is true:

    A. The system is gapless and, at low energy, the density of states of the system behaves as: $g(\epsilon) \propto \epsilon^{n-1}$;

    B. The system is gapless and, at low energy, the density of states of the system behaves as: $g(\epsilon) \propto \epsilon^{n}$;

    C. The system is gapless and, at low energy, the density of states of the system behaves as: $g(\epsilon) \propto \epsilon^{n+1}$;

    D. The system has a finite gap.

17. A d_{xy} orbital vanishes on the planes:

    A. $z = 0$, $x = 0$.

    B. $x = y$, $y = 0$.

    C. $x = 0$, $y = 0$.

    D. $x = y$, $z = 0$.

18. Consider atoms with two electrons and different atomic numbers, like H$^-$, He, Li$^+$, Be^{2+}, etc., which one of the following statements is correct?

    A. By increasing the atomic number, the Hartree-Fock approach will be less and less accurate.

    B. By increasing the atomic number, the Hartree-Fock approach will be more and more accurate.

    C. The accuracy of the Hartree-Fock approach does not depend upon the atomic number.

    D. In order to answer this question, I need to do a full numerical calculation.

19. Consider a generic quantum state $|\Psi\rangle$ for a system with a finite number N of interacting spins. Take the time evolution of this state and consider the expectation value of any observable O, namely $O(t) = \langle\Psi| \exp(iHt)O \exp(-itH)|\Psi\rangle$:

    A. $O(t)$ will converge exponentially to some value.

    B. $O(t)$ will converge to some value, but the rate of convergence depends upon the details of the model.

    C. $O(t)$ will never converge.

    D. The convergence at large times depends upon the actual form of the operator O.

20. The work function of a transition metal (i.e. the energy necessary to extract an electron from the metal) is observed to decrease as the metal surface is exposed to an alkaline vapor. One can guess that:

    A. Alkaline atoms donate electrons to the metallic substrate upon adsorption.

    B. The metal substrate donates electrons to the alkaline atoms upon adsorption.

    C. The work function change is not related to the charge transfer.

    D. This cannot be true because the work function is a bulk property of the transition metal substrate.