Summerschool 2012

Nanophysics exam

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For numerical applications we will (crudely) assume the following values:
mass(electron)=10^{-30} kg.
Reduced Planck constant hbar=h/2π=10^{-34} S.I.
Electron charge e=10^{-19} C
Boltzmann constant $k_B=10^{-23}$ J/K
Gravitational acceleration on earth g=10 m.s^{-2}
$\pi^2=10$

1. De Broglie's relation states a quantum mechanical correspondence between the wave vector and
   a.) energy
   b.) position
   c.) momentum
   d.) frequency

2. What are the standard international units of the Planck constant h?
   a.) kg. m^2. s^{-2}
   b.) kg^2. m. s^{-1}
   c.) kg. m. s^{-2}
   d.) kg. m^2. s^{-1}

3. May the absolute value of the wave function ψ exceed 1 at a given position?
   a.) yes, no problem
   b.) impossible
   c.) yes, as long its square value doesn't exceed 1.

4. The van der Waals force between an infinite plane and a sphere of radius R_1, that are separated by R is given by

$$F = -\frac{HR_1}{6R^2}$$

   We assume R=10 nm and that all materials are silver (density=10 g/cm3, H = 1 eV). What is the maximum radius of a silver sphere that can « hang on the ceiling », i.e. that is subject to a van der Waals force greater or equal to it's weight ? R_1 is
   a.) less than 5 nm
   b.) comprized between 5 and 50 nm
   c.) comprized between 50 and 500 nm
   d.) more than 500 nm

4. Around the Fermi energy E_F, the electronic density of states of a metal
   a.) has a gap
   b.) is non zero and varies slowly
   c.) is made of sharp discrete states
   d.) is nearly equal to 1 below E_F and nearly equal to 0 above.

5. A quantum system which has equally spaced energy levels is of the type of
   a.) the hydrogen atom
   b.) the square well with infinite boundaries
   c.) the harmonic oscillator
   d.) the tunnel junction

6. Consider a normal metal N connected to a superconductor S via a tunnel junction. The junction is biased with a voltage V, a current I flows across the barrier. At sufficiently low temperatures, the differential conductance of the tunnel junction dI/dV is proportional to
   a.) the Fermi-Dirac distribution in N
   b.) the Fermi-Dirac distribution in S
   c.) the density of states in N
   d.) the density of states in S

7. An STM tip is placed 0.3 nm above a conductive surface, at a given bias voltage. The tunnel current is 1 nA. The tip is then moved to a distance of 0.5 nm to the surface; the current drops to 250 pA. At what distance will the current go below 1 pA?
   a.) 1.7 nm
   b.) 1.5 nm
   c.) 1.3 nm
   d.) 1.1 nm

8. Every classical degree of freedom appearing as a quadratic term in the energy carries an average thermal energy $k_BT/2$. Further, the heat conduction of a gas scales like its energy. By how much does one reduce the heat conduction through the gas of a double-glass window by replacing the air (assume 100% N_2) in between the two glass plates by noble gas argon?
   a.) 40 %
   b.) 50 %
   c.) 60 %
   d.) 80 %

9. We note FD, Bo and BE the Fermi-Dirac, Boltzmann and Bose-Einstein distributions respectively. At fixed energy and at sufficiently high temperatures
   a.) FD tends to 1 while BE goes to infinity.
   b.) FD tends to 1 while BE goes to 0.
   c.) All three distributions go to zero.
   d.) BE can be smaller than FD.

10. Only one of the consequences listed below of downscaling the size of a mechanical resonator is **not** an advantage for single molecular mass sensing applications:
   a.) lower resonator mass
   b.) less dissipation
   c.) higher surface to volume ratio
   d.) higher resonance frequency

11. A single electron device is incorporating a small island of charging energy 10 meV. The temperature at which Coulomb blockade effects will become negligible is

a.) below 100 mK
b.) between 0.1 K and 1 K
c.) between 1 and 10 K
d.) higher than 10 K.

12. The resistance of a nanoelectronic device fluctuates between 50 and 50.5 Ohms. How much of a variation of the conductance does this correspond to?
a.) 39 μS
b.) 50 μS
c.) 100 μS
d.) 200 μS

13. Which of the four lengthscales below increases significantly at low temperatures in a nanoelectronics device?
a.) the Fermi wavelength
b.) the momentum mean free path
c.) the phase relaxation length
d.) the sample size

14. The possible energies of a particle in a 1 dimensional infinite square well are given by

$$E_n = \frac{\hbar^2}{2m}\left(\frac{n\pi}{L}\right)^2$$

where n=(1, 2, 3, …), L=1 nm and each energy state is doubly degenerate (i.e. can contain two electrons) because of spin. Assume that the Fermi energy E_F is 2 eV. How many particles are there in the well at zero temperature (at energies equal or below E_F)? (We neglect charging energies here).
a.) 4
b.) 2
c.) 1
d.) none

15. Why are superconducting quantum interference devices (SQUIDS) better magnetometers than Aharonov-Bohm rings?
a.) because their resistance is low, therefore the relative changes in conductance are easier to monitor.
b.) because superconductivity expels the magnetic field, which allows for a non-invasive measurement of magnetism at a local scale.
c.) because superconducting transport is described by a single phase along a given path, therefore the visibility of interferences is higher.
d.) because in superconductors the ions of the lattice cannot vibrate, therefore the energy of the superconducting electrons cannot decrease by scattering from vibrations.

16. What is the most notable change in the dynamics of a driven mechanical resonator if exposed to a small time-independent force field?
a.) its resonance frequency
b.) its vibration amplitude
c.) its phase
d.) its dissipation

17. Which force does the gecko exploit for sticking to extremely low roughness surfaces?
    a.) the Casimir force
    b.) the Coulomb force
    c.) the capillary force
    d.) the van der Waals force