Final exam. Introduction to Nanotechnology

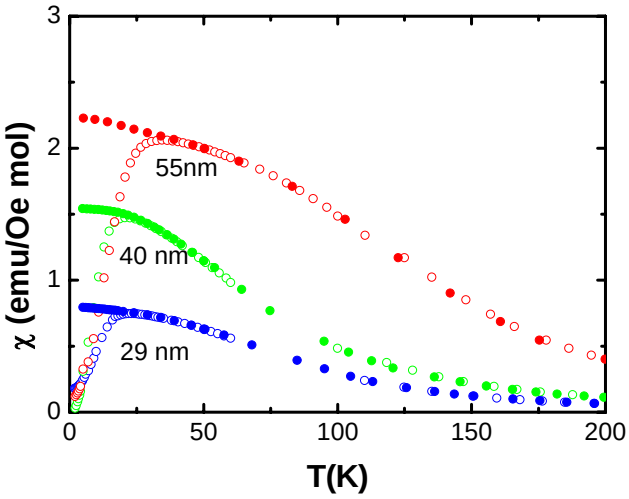
Name:

Student number:

1. (a) What is the definition for a cluster size-wise? (3%) **(b)** Calculate the energy separation near the Fermi surface of a metallic cluster of 5 nm in diameter, which is comprised from a mono-valent metal element of 0.25 nm in dia. Assume the Fermi energy is 8 eV for the bulk material of the same metal. (7%)

2. In terms of optical properties, what are the reasons for shifting the spectrum of a metal cluster toward **(a)** the blue (6%) and **(b)** the red (4%), comparing to its bulk counterpart?

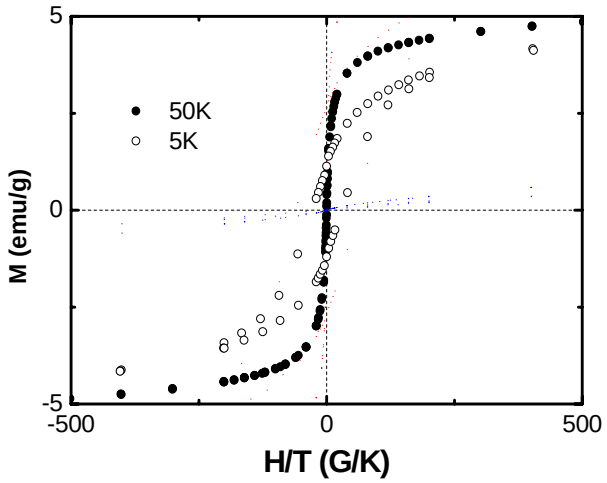
3. **(a)** 5% The plot of χ vs. T for a series of $FeSi_2$ nanoparticles with different sizes is shown below. Please explain the result. (You may use the following terms for explanation: superparamagnetism, blocking temperature T_B, FC and ZFC curves)



(b) 5% T_B is described by the equation below, please illustrate its physical meaning

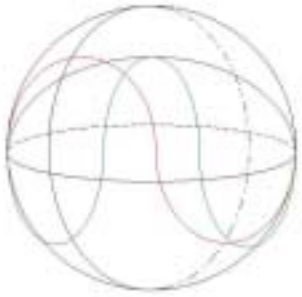
$T_B = KV/25\ K_B$

(c) 5% Please explain the result for 40 nm $FeSi_2$ nanoparticles with T_B=20 K (You may use the following terms for explanation: ferromagnetic order, papramagnetic, blocking temperature and hysteresis for explanation)

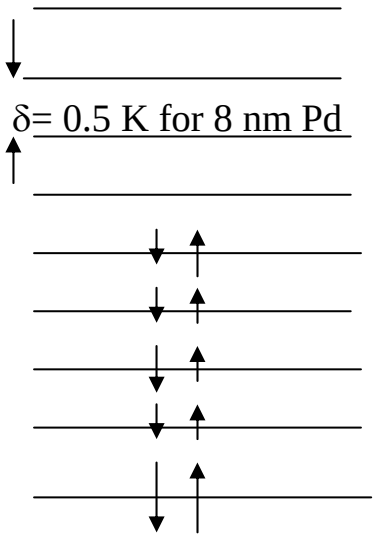


4. Please explain

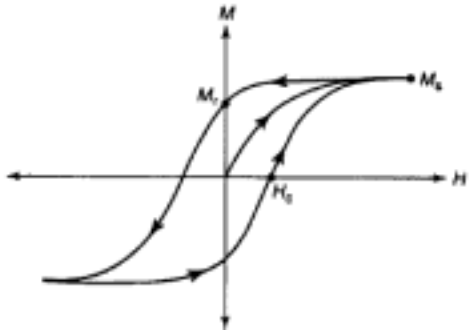
(a) 5% “Phonon quantum size effect” (You may use the terms of degree of freedom, wave modes, finite number of atoms)



(b) 5% “Electronic quantum size effect”



5. **(a)** 5% The plot is the magnetization vs. magnetic field for bulk Fe.
Please explain the terms of “hysteresis loop”, “coercive field”, “remnant magnetization” and “saturation magnetization”



(b) 5% For fabrication of electrical transformer and permanent magnet, how can you use the effect of bulk nanostructuring to modify the magnetic properties of materials.

6. 5% Below is the plot showing the mass spectrum of Pb clusters. Please explain the term of “Magic number of atoms” in nanoparticle and cluster. What is its mechanism?

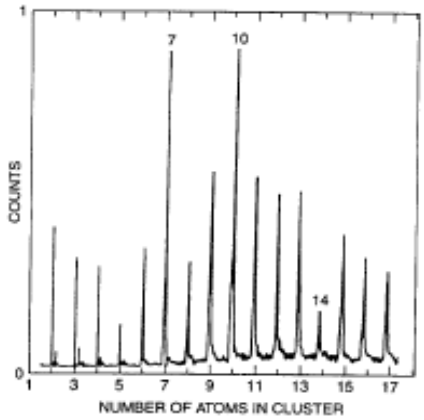


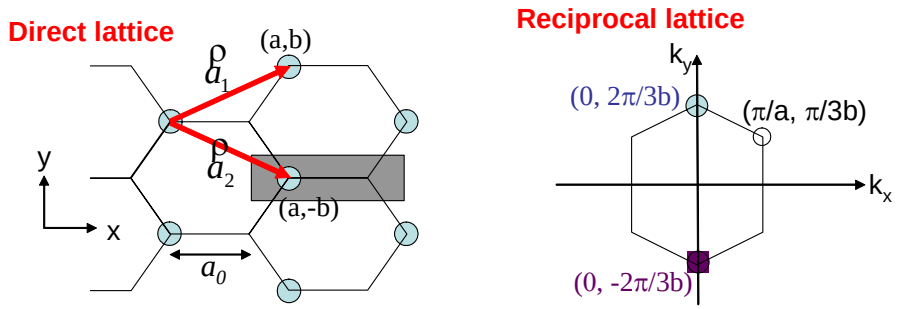
Figure 4.3. Mass spectrum of Pb clusters. [Adapted from M. A. Duncan and D. H. Ro
Am. 110 (Dec. 1989).]

7. (10% + 3% bonus) Sketch and write the wavefunctions for the four lowest energy levels (n=1~4) of a one-dimensional infinite square well with boundary condition $\Psi_n(x=a/2)= \Psi_n(x=-a/2)=0$ and calculate the respective eigenenergies. Note that the Schrödinger equation for 1D system reads

$$i\eta\frac{\partial \Psi}{\partial t} = -\frac{\eta^2}{2m}\frac{\partial^2 \Psi}{\partial x^2}$$

and the plan wave solution has a form $\Psi = \Psi_0\, exp(ikx)exp(iEt/\eta)$

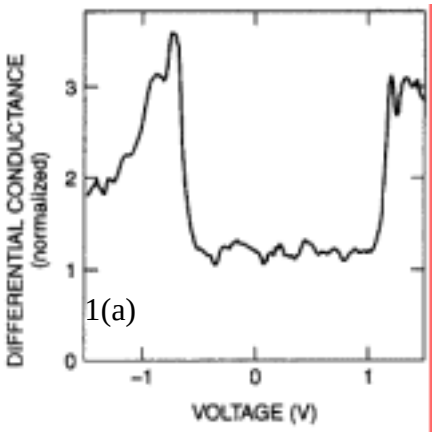
8. (10% + 2% bonus) The direct lattice and reciprocal lattice for graphene are shown below:

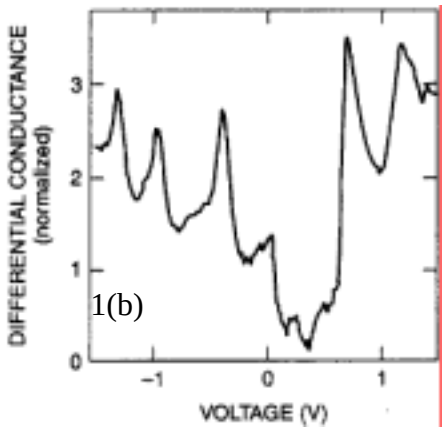


When rolled up into a nanotube, the constrain set by the boundary condition becomes

$\vec{k} \cdot \vec{c} \equiv k_C |c| = k_x a(m+n) + k_y b(m-n) = 2\pi\nu$, where $\vec{c} = m\vec{a}_1 + n\vec{a}_2$ and ν is an integer. From this, please (a) explain why armchair tubes are always metallic, (b) find the conditions for zigzag tubes to be metallic and (c) write down the condition for chiral tubes.

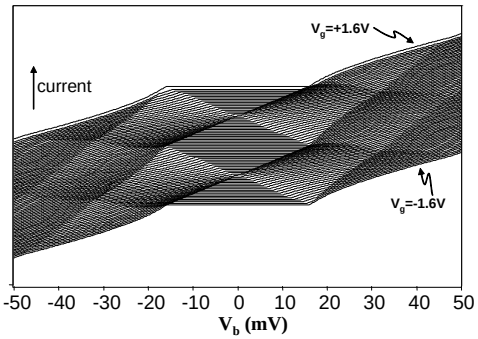
9. **(a)** (5%) The measured (d*I*/d*V*)/(*I*/*V*) curves for two single-walled carbon nanotubes with chiralities (11,7) and (9,9) are displayed below. What are the tube chiralities for these curves? Why you choose so. [Reference: Cees Dekker (Physics Today, May, 1999, pp.22-28)]

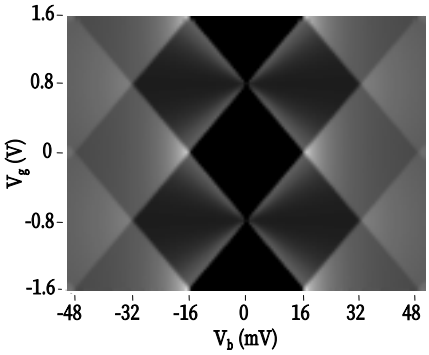




(b) (5%) The following 4 curves are d*I*/d*V* curves measured for four semiconductor single-walled carbon nanotubes with different diameters: one 1.2nm, two 1.4nm and one 2.0nm. What are the corresponding tube diameters for these curves? Why you choose so? [Reference: Wildoer et al. Nature, 391, 59 (98)]

10. (a) (5%) The figures below show (left) the calculated current-bias voltage (IV_b) characteristics of a single electron transistor for gate voltages V_g ranging between -1.6V and 1.6V and (right) the differential conductance (dI/dV_b) intensity plot of the same set of data (brighter=higher conductance). From these plots, please find out the gate capacitance C_g and the sum capacitance $C_\Sigma \equiv C_s+C_d+C_g$ of the transistor. What is the charging energy of this device in terms of temperature? (note: 1meV=11.6K)





(b) (3%) For observation of Coulomb blockade behaviors, both thermal and quantum fluctuations have to be surmounted. Please state the two criteria for the charging effect to become observable.

(c) (2%) The charging energy E_C of a SET with a metallic island covered by 10% of tunnel barrier and energy level spacing E_K of a quantum dot as a function of island (dot) diameter are shown in the plot below (after K. Likharev). From this plot, please estimate the required island (dot) diameter for E_C (E_K) = 300K.