Mansoura University
Communications & Electronics Engineering Department
M.Sc. 1st year: Quantum Electronics Course (Open Resources)
Final Exam: Sept. 15th, 2013
(Total marks = 100) (2 pages) (Time allowed: 3 Hours)

Q1) Define Nanotechnology and list some of its current and most promising applications (max. of two pages). (total of 10 marks)

Q2) Define Coulomb Blockade and discuss the two conditions for observing this phenomenon (max. of two pages). (total of 10 marks)

Q3) (total of 30 marks: a) 15 marks and b) 15 marks))
The current-voltage (I-V) characteristics of a nanoscale device can be calculated from:

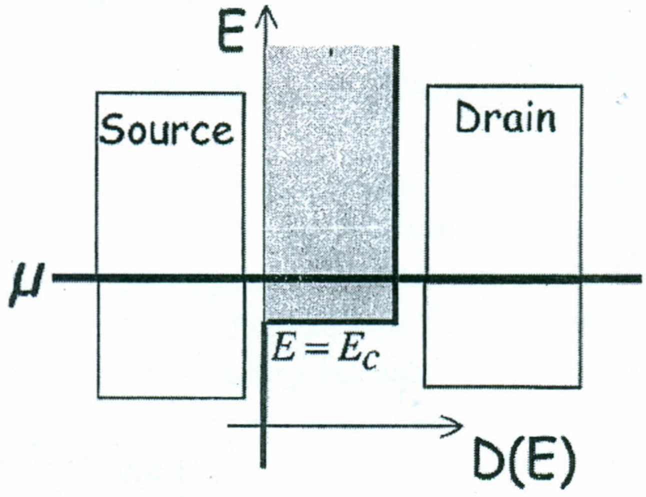
$$I = \frac{2q}{\hbar}\int dE\, D(E-U)\frac{\gamma_1\gamma_2}{\gamma_1+\gamma_2}[f_1(E)-f_2(E)]$$

where $f_1(E) = \dfrac{1}{e^{(E-\mu_1)/kT}+1}$ and $f_2(E) = \dfrac{1}{e^{(E-\mu_2)/kT}+1}$

Also $U = U_L + U_0(N-N_0)$. Assume $U_0 = 0$ and the Laplace potential U_L to be a fraction α of the drain potential V_D (the source potential is assumed zero):

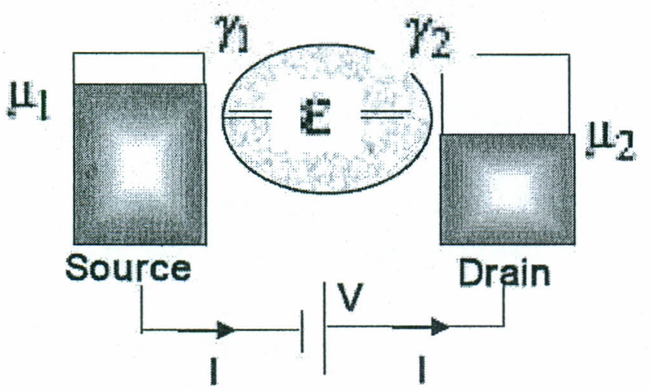
$$U_L = -q\,\alpha V_D,$$ α being a constant between 0 and 1.

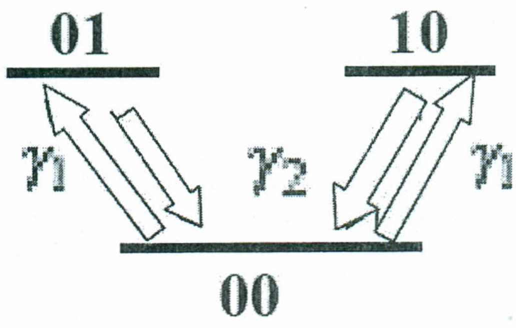
A channel has a density of states as shown, namely a constant non-zero value for $E \ge E_C$ and zero for $E < E_C$. Assume that the equilibrium electrochemical potential μ is located above E_C as shown. Sketch the current versus drain voltage assuming that the electrostatic potential of the channel (a) remains fixed with respect to the source ($\alpha = 0$) and (b) assumes a value halfway between the source and drain potentials ($\alpha = 0.5$),
Explain your reasoning clearly.



 (Dr. Sameh Rehan)

Q4) A box has two degenerate energy levels both having energy, ε. The electron-electron interaction energy is so high that no more than one electron can be inside the box at the same time. (total of 30 marks)





a) Use the multi-electron picture to derive the correct expression for the maximum current, $I_{max1} = f(\gamma 1, \gamma 2, q, \hbar)$, that flows when a voltage V is applied with the polarity as shown ($\mu_1 > \mu_2$). (15 marks)

b) Assuming $\gamma 1 = 10\,\gamma 2$, state $I_{max1} = f(\gamma 2, q, \hbar)$. (4 marks)

c) If the polarity of the applied voltage is reversed ($\mu_2 > \mu_1$), state the new expression for $I_{max2} = f(\gamma 1, \gamma 2, q, \hbar)$. (5 marks)

d) Assuming $\gamma 1 = 10\,\gamma 2$, state $I_{max2} = f(\gamma 2, q, \hbar)$. (4 marks)

e) Which maximum current I_{max1} or I_{max2} is bigger? (2 marks)

Q5) The Single-Electron Box (SEB) is one of the basic Single-Electron Nano Devices (SENDs): (total of 30 marks)

a) Describe what is the SEB and state its two main drawbacks. (5 marks)

b) Drive the equation for the free energy of the system, Ef(n). (10 marks)

c) What is the supply voltage range, within which Coulomb blockade effects are in effect (? < Vg < ?)? (5 marks)

d) What is the supply voltage range, within which the tunnel junction voltage oscillates between (? < Vt < ?)? (5 marks)

e) Draw the relationship between Vt and Vg for the SEB. (5 marks)

 (Dr. Sameh Rehan)