Nanophysics Exam 28-01-13

1. Scaling laws

a) we know that $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \propto D^{-3/2}$

and $\frac{5\,m}{100 \cdot 10^{-6} m} = 50.000$

thus $((50.000)^{-3/2})^{-1} = \sim 11$ milion

So the microcontilever oscillates more than 11 milion times in the time that the diving board oscillates one time

b) Strength $\propto D^2$
Weight $\propto D^3$ $\Big\} \frac{S}{W} = \frac{1}{D}$

10 nm $\Rightarrow \frac{1}{10 \cdot 10^{-9} m} = 10^{8}$

100 µm $\Rightarrow \frac{1}{100 \cdot 10^{-6} m} = 10^{4}$ } × 1000

2 m $\Rightarrow \frac{1}{2} = 0.5$ } ± 2000

c) $C = \frac{\varepsilon_0 \varepsilon_r A}{d} \propto \frac{D^2}{D} \propto D$

$F_e = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_r A}{d^2} V^2 \propto \frac{(D^2)(D^2)}{D^2} \propto D^2$

twice Area $F_e \propto \frac{(D^2)\, 2\, (D)^2}{D^2} \propto 2D^2$

Halve ~~twice~~ distance $\propto \frac{(D^2)(D^2)}{(\frac{1}{2}d)^2} \propto \frac{4D^2 D^2}{D^2} \propto 4D^2$

$\Rightarrow$ so best is to half distance.

2. Orbitals

Neon is 10th element : $1S^2\, 2S^2\, 2P^6$

$\Rightarrow$ Natrium is easier to Ionize because the electron configuration looks like:

[Ne] $3S^1$, and has an weak outer shell, at least weaker than the whole filled Neon outer shell

3) C-60
Heisenberg uncertainy principle:

$\Delta x \, \Delta P_x \geq \frac{h}{4\pi}$ $\Delta x = 0.02$ nm

$\Delta P_x = \frac{h}{4\pi \cdot 0.02 \cdot 10^{-9}} = 2.64$ N

$P = m \cdot V \Rightarrow \Delta P_x = m \cdot \Delta V$ $m = 60 \cdot 12 \cdot 1,66 \cdot 10^{-27} =$

$\Delta P_x = m \cdot \Delta V_x \Rightarrow \Delta V_x = \frac{\Delta P_x}{m} = 2.21$ m/s $\Rightarrow$ 1,10 m/s in each direction

4) Bonding

a → Hydrogen bond (weak)

b → Ionic Bond (strong)

c → metallic Bond (strong)

d → v/d Waals Bond (weak)

metallic and Ionic bonds are the two strongest. ⇒ which one of these is the strongest depends on the material. this is seen if you compare the melting temperatures of metals with salts. they are pretty much the same, however ~~here~~ since if you tare the molecules apart, Ionic Bonds will get together again, while metals are (in general) stable.

⇒ Ionic Bonds are stronger than metallic.

Same is for the weak bonds, they also strongly depend on the molecull. But in general, the v/d Waals force is considdered the weakest interaction with molecules.

1) Ionic
2) metallic
3) Hydrogen
4) v/d Waals.

5 nanomechanics

a) $E = \hbar \omega_0 \cdot n + E_0$ assume $E_0 = 0$

$\omega_0 = 2\pi f_0 = 2\pi \cdot 10 \cdot 10^{12}\ Hz$

$E = 2\pi \cdot 10 \cdot 10^{12} \cdot 1{,}055 \cdot 10^{-34} = 6{,}598 \cdot 10^{-22}\ J$

$= \underline{4{,}12\ meV}$

b) $k = \frac{E_m w t^3}{4L} = \frac{100 \cdot 10^6 \cdot 40 \cdot 10^{-6} \cdot (5 \cdot 10^{-6})^3}{4 \cdot 100 \cdot 10^{-6}} = 1{,}25 \cdot 10^{-9}$

$m = 100 \cdot 10^{-6} \cdot 40 \cdot 10^{-6} \cdot 5 \cdot 10^{-6} \cdot 2000 = 4{,}0 \cdot 10^{-11}\ kg$

$= L \times w \times t \times \rho$

$m_{eff} = 0{,}24 \cdot 4{,}0 \cdot 10^{-11} = 9{,}6 \cdot 10^{-12}\ kg$

$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m^*}} = \frac{1}{2\pi}(1{,}25 \cdot 10^{-9} / 9{,}6 \cdot 10^{-12})^{1/2}$

$f_n = 1{,}82\ Hz$

Quality factor

$Q = \sqrt{\frac{km'}{b}} = 3{,}46 \cdot 10^{-7}$

⇒ will be damped quickly

c) $E = N\hbar\omega_0$ and $\omega_0 = \sqrt{\frac{k}{m}}$

so 3 quanta of energy $\Rightarrow N = 3$

$E_{photon} = 3\hbar\omega_0 = 3\hbar\sqrt{\frac{k}{m}}$

to calculate frequency, we use $E = h \cdot \nu$

$h\nu = 3\hbar\omega_0$

$h\nu = 3\frac{h}{2\pi}\omega_0$

$\nu = \frac{3}{2\pi}\omega_0 = \frac{3}{2\pi}\sqrt{\frac{k}{m}} = \frac{3}{2\pi}\sqrt{\frac{15}{4\cdot 10^{-26}}} = 9.25\ THz$

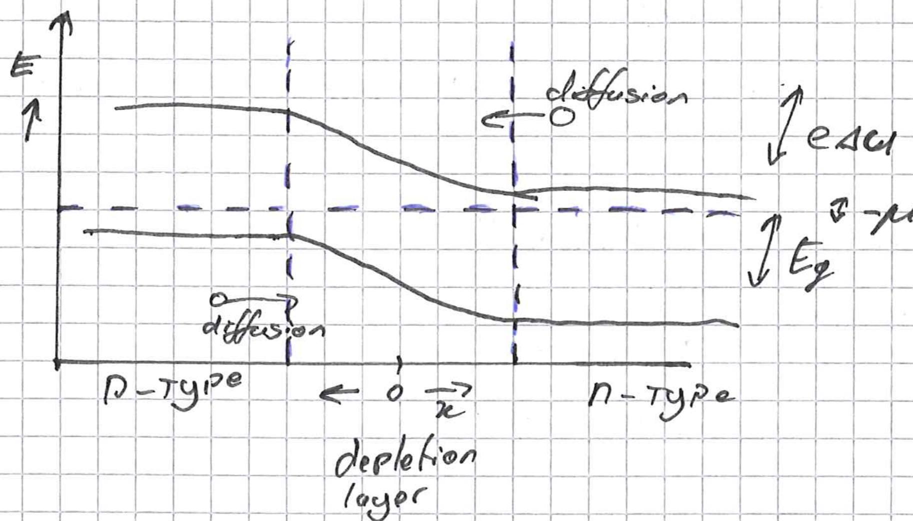
6) Doped semiconductors

a) P = Positively doped, so has more Holes
n = negatively doped, so has more electrons.

when joined, electrons from the n-region near the p-n interface tend to diffuse in the p region. when they do so, they leave positively charged donors in the n-region. likewise for the p-region, but they leave negatively charged acceptors.

$\Rightarrow$ The region near the interface loses neutrality and becomes charged, forming the depletion layer.

b)



c)

7. structures of reduced dimensionallity

from the schrödinger equation we get:

$$E = \frac{h^2}{8m}\left(\left(\frac{n_1}{l_x}\right)^2 + \left(\frac{n_2}{l_y}\right)^2 + \left(\frac{n_3}{l_z}\right)^2\right)$$

for quatum well, only one direction

$$E = \frac{h^2}{8m_{eff}}\left(\frac{1}{a^2}\right) = ~~3{,}76~~\ 2.4978 \cdot 10^{-20} J$$
$$= 0{,}156\, eV$$

Q-wire:

$$E = \frac{h^2}{8m_{eff}}\left(\frac{1}{a^2} + \frac{1}{a^2}\right) = 4{,}9957 \cdot 10^{-20} J$$
$$= 0{,}312\, eV$$

Q-dot

$$E = \frac{h}{8m_{eff}}\left(\frac{1}{a^2} + \frac{1}{a^2} + \frac{1}{a^2}\right) = 7{,}4935 \cdot 10^{-20} J$$
$$= 0{,}468\, eV.$$

=> the value of E gets larger as the confinement of the structure increases because we decrease the dimensions the particle can move, obvious is that if the particle has less space to spread, the energy gets confined in a smaller space, thus increasing here

8. 1D rectangular Potential

from schrödinger and previous Exercise we know

$$E = \frac{h^2}{2m}\left(\frac{n}{L^2}\right)^2$$

$$E_1 = \frac{h}{2m}\frac{1}{(5nm)^2} = 2.4099 \cdot 10^{-21} J$$

$$E_2 = \frac{h}{2m}\left(\frac{2}{5nm}\right)^2 = 9.639 \cdot 10^{-21} J$$

$$E_3 = \frac{h}{2m}\left(\frac{3}{5nm}\right)^2 = 2.169 \cdot 10^{-20} J$$

$$E = h\nu \Rightarrow \nu = \frac{\Delta E}{h} = 10.9 \cdot 10^{12} Hz = 10.9\, THz$$

$$\nu_{2,1} = \frac{E_2 - E_1}{h} = 10.9\, THz$$

$$\nu_{3,1} = \frac{E_3 - E_1}{h} = 29.1 \cdot 10^{12} Hz = 29.1\, THz$$

9 SET

for a Coulomb blockade to work properly
The thermal energy must be below the charging Energy

$k_B T < U \qquad U = \frac{e^2}{2C}$

$$k_B T \ll \frac{e^2}{2C} = \frac{e^2}{8\pi\varepsilon_0 R}$$

$$R < \frac{e^2}{8\pi\varepsilon_0 k_B T}$$

$$R < 27{,}84 \cdot 10^{-9} = 27.84 \text{ nm}$$

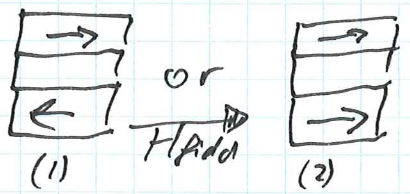
so a quantum dot smaller than 27 nm would be fine

10. GMR and TMR

a) GMR = Giant Magnetoresistance
TMR = Tunneling Magnetoresistance

Both work as a resistance that is build up from two layers of Ferromagnetic material, separated by another material.

by the spin difference in the FM materials there is a different resistance observed
this resistance can be changed by applying a magnetic field

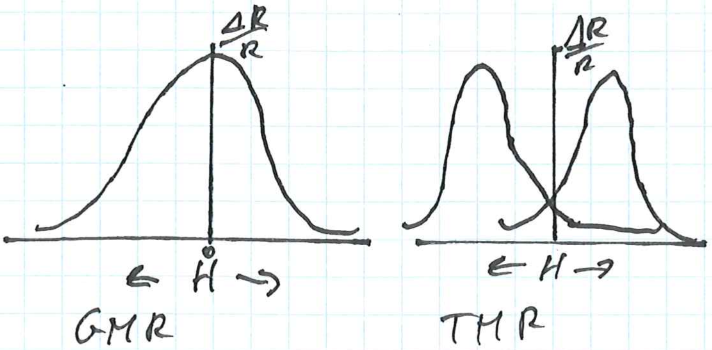


as seen in the drawing it is easy to see that the resistance in (2) is lower than in (1)

effect that is exploited here is the effect of spin on the resistance of the material.

b) difference is the working principle
for GMR the sandwiched material is nonmagnetic-conducting
for TMR " is an insulator

the difference is the resistance versus the field



for GMR the Resistance is High without a field

for TMR the Resistance is High with a field.

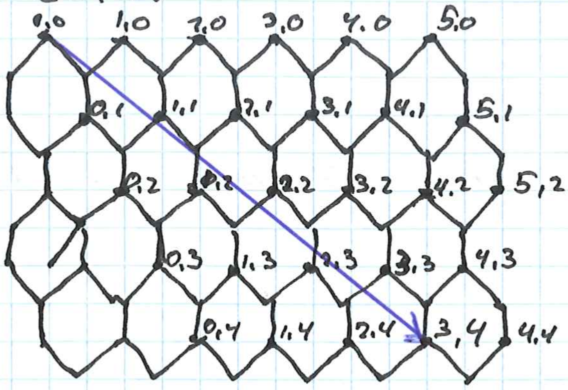
11. carbon nano Tube

$n > m \Rightarrow c = 3\,a_1 + 4\,a_2$

$$\text{diameter} = \frac{c}{\pi} = \frac{\sqrt{3}\, r_{cc}\,(m^2+mn+n^2)^{\frac{1}{2}}}{\pi}$$

$$d = \sqrt{3}\cdot 1{,}41 \;\frac{(3^2+3\cdot 4+4^2)^{\frac{1}{2}}}{\pi} = \underline{\underline{3{,}98\ \text{Å}}}$$

(3, 4)



wrapping vector for (3,4) in Blue