Exam for Nanophysics & -technology **Autumn 2012, term Ib**

29. 01. 2013

Write your name and student number on each sheet and number the sheets.
Use for each question a different sheet.

Name: ______________________________

Student number: ______________________________

Question	1	2	3	4	5	6	7	8	9	10	11	Σ
Points												

1. Scaling laws (5 points)

a) A microcantilever beam 100 μm long and a diving board 5 m long are both deflected and then released simultaneously. Estimate how many oscillations the microcantilever beam completes in the time the diving board completes a single oscillation.

b) Based on the scaling laws, how many times greater is the strength-to-weight ratio of a nanotube (D = 10 nm) than the leg of a flea (D = 100 μm)? Than the leg of an elephant (D = 2 m)?

c) In designing an electrostatic actuator made from parallel plates, you can either double the plates' areas or halve the distance separating them. Which provides a greater improvement in the electrostatic force?

2. Orbitals (2 points)

Write out the electron configuration of Neon in the form $1s^2$ …, etc. Which is easier to ionize: Ne or Na? And why?

3. C_{60} (2 points)

Find the minimum speed of a C_{60} molecule in vacuum, if it is known to be located precisely at x, y, z = 0 plus or minus 0.01 nm in each direction.

4. Bonding (5 points)

Characterize the bonding type for the following bonds [a) to c)] and rank them from strongest to weakest (explain why):

a) the bond between hydrogen and oxygen in a water molecule;

b) the bond between sodium and chloride in the NaCl molecule;

c) the bond between atoms in a metal;

d) the van der Waals bond between adjacent hydrogen atoms.

5. Nanomechanics (5 points)

a) An atom in a lattice has a resonance frequency of 10 THz. According to quantum mechanics, what is the lowest amount of energy this oscillator can have?

b) A cantilever beam has length l = 100 μm, width w = 40 μm, thickness t = 5 μm, modulus of elasticity E_M = 100 GPa, density ρ = 2000 kg/m^3 and damping coefficient b = 10^{-7} N s/m.
What is the beam's damped natural frequency?
What is the quality factor?
Hint: m_{eff} = 0.24 m for a cantilever beam.

c) A harmonic oscillator with spring constant k and mass m loses 3 quanta of energy, leading to the emission of a photon.
What is the energy of this photon in terms of k and m?
If the oscillator is a bonded atom with k = 15 N/m and m = $4*10^{-26}$ kg, what is the frequency of the emitted photon?

6. Doped semiconductors (4 points)

a) A piece of n-doped Si is joined with a piece of p-doped Si. These two materials form an abrupt p-n-junction. Explain what happens at the interface between the p- and n-doped semiconductor.

b) Make a sketch of the band diagram of such a heterojunction.

c) When deriving the law of mass action, we did not make any assumption about the doping and the position of the chemical potential, and therefore the law of mass action is also valid for doped semiconductors. In the case of a n-doped semiconductor, the electron concentration is much higher than that in the intrinsic case and the law of mass action therefore implies that the hole concentration is much smaller. Use a simple physical argument to explain why one should expect this.

7. Structures of reduced dimensionality (4 points)
Suppose a semiconductor quantum well of width *a*, a quantum wire of square cross section (*a* x *a*) and a quantum dot of volume (*a* x *a* x *a*). In the case of GaAs, and for *a* = 6 nm, calculate the energy E_1 of the electron ground level for each structure. Qualitatively comment why the value of E_1 gets larger when the confinement of the structure increases.
Hint: The effective electron mass for GaAs is $m_e^* = 0.067\ m_e^0$.

8. 1D rectangular potential (2 points)
An electron is in a one-dimensional rectangular potential well with barriers of infinite height. The width of the well is equal to L = 5 nm. Find the wavelengths of photons emitted during electronic transitions from the excited states with quantum numbers n = 2, λ_{21}, and n = 3, λ_{31}, to the ground state with n = 1.

9. SET (2 points)
For a room temperature Coulomb blockade device (e. g. a single electron transistor) to be constructed using a spherical quantum dot, estimate how small the quantum dot should be.
Hint: For a sphere (QD):

$$C = \frac{Q}{V} = \frac{Q}{\frac{Q}{4\pi\varepsilon_0 R}} = 4\pi\varepsilon_0 R$$

10. GMR and TMR (4 points)
Compare giant magnetoresistance (GMR) and tunnelling magnetoresitance (TMR) to each other.

a) Describe shortly what is needed that either GMR or TMR is observed and describe the effect itself.
b) What is the difference between GMR and TMR?

11. Carbon nanotube (2 points)
Sketch a wrapping vector with m = 3 and n = 4 on a graphene sheet. What is the diameter of a carbon nanotube for this wrapping vector?
Hint: The distance between two C atoms is 1.41 Å.

Constants:
Planck's constant: $h = 6.626*10^{-34}$ Js
Reduced Planck's constant: $\hbar = h/2\pi = 1.055*10^{-34}$ Js
Dielectric permittivity: $\varepsilon_0 = 8.854*10^{-12}$ F/m
Atomic mass unit: $u = 1.66*10^{-27}$ kg
Electron mass: $m_e = 9.109*10^{-31}$ kg