Problem Sheet 3 - Nanomaterials

Submission deadline: 1pm on 28th March 2025

Fundamental constants and formulae can be found in the Exam Summary Sheet (available on Moodle).

Problem 1

a) Explain the general principle of "electrical doping of graphene". [2]

b) Describe an experiment to measure the mobility of carriers in graphene. What values would you expect to be measured? [2]

c) Compare the temperature dependence of the intrinsic carrier density in graphene and in a 3D semiconductor such as silicon. Which dependence do you think is best for device applications? [2]

d) Give an analytical expression for the optical absorption of graphene near a K point and calculate (in %) the absolute value of such absorption for a wavelength of 800 nm. [2]

e) Explain what is meant by "Pauli Blocking" in graphene. [2]

f) Describe an experiment to measure the level of doping in graphene, also in relation to the phenomenon of Pauli blocking. [2]

g) Determine the number of layers in a graphene specimen displaying an optical absorption of 10 %. Discuss your results and the prospects for using graphene multilayers as semitransparent electrodes. [3]

Problem 2

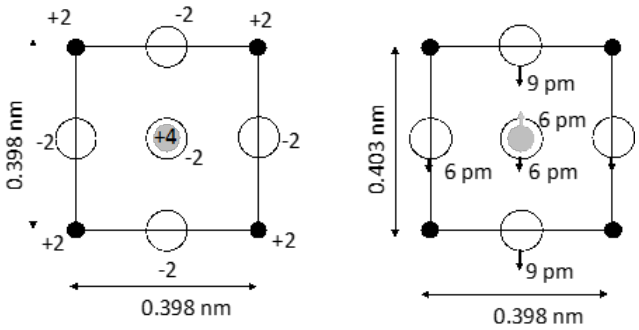
a) By using appropriate formulae and symbols, give a quantitative definition of the bulk (volume) polarisation of a material. [2]

b) Explain the difference between dielectric, paraelectric and ferroelectric (FE) materials, specifying in particular the relation of polarization vs. electric field for the different classes. [3]

c) Draw a diagram of the polarisation (vs. electric field, E) for a ferroelectric material and explain the naming of this class of materials. [2]

d) Explain why FE materials can be used to build electric memories. [1]

e) State what is the order parameter used in Landau's theory to derive the phase transitions properties. [1]



f) State if the melting of an ice cube is a first order or a second order phase transition. [1]

g) State what type are FE phase transitions. [2]

h) Explain the mechanism giving rise to hysteresis for a FE material, in terms of appropriate graphs of the free energy vs. the polarisation P in the significant points of the P vs. E characteristic. [3]

Problem 3

a) Draw the unit cell structure of the prototypical ferroelectric perovskite oxide barium titanate in its paraelectric and ferroelectric phases [2]

b) Draw a graph of the free energy as a function of polarisation at temperatures $T = T_C$, $T > T_C$ and $T < T_C$ for a uniaxial FE crystal. [3]

c) Calculate the polarisation volume density arising as a result of the displacements indicated for the crystal, schematically indicated (as a two-dimensional projection) in the image below and undergoing a transition from cubic to tetragonal structure (represented on the left- and right-hand sides in the figure below, respectively). *Hint: this can be considered a model for barium titanate - black filled circles represent Ba^{2+}, white circles O^{2-}, and the grey central circle Ti^{4+} ions. [5]