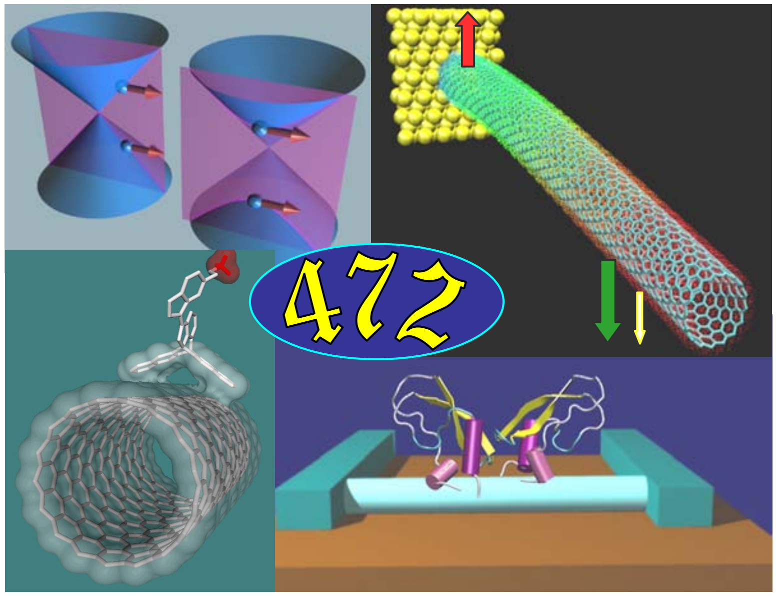
FALL 2005



PHY 472

Physics and Applications of Nanoscale 1D Systems

Director: Prof. Slava V. Rotkin
When/Where: M/F 11:10, Whitaker 451
Credits: 3 **CRN #**: 42482 **Section**: 010
Prerequisites: Phys 369, Phys 363 (ECE 451 or Mat 201, Mat 302) or equivalent, or instructor consent.

The graduate course will cover essential physics of nanoscale 1D-systems and their device applications. The course focuses on novel materials such as carbon nanotubes, semiconductor nanowires and biological systems. Their unique electronic properties will be considered at greatest extent though we will also overview mechanic/structural and optical properties.

The fundamental physics effects that manifest themselves in 1D will be introduced, such as quantum phenomena, poor screening of Coulomb interaction, strong correlations, many-body effects, etc.

As for the applications, a review of various devices ranging from ion channels and new electromechanical systems to electronic molecular transistors, that are not usually described in current textbooks, will be given. We will stress on the difference of the 1D device physics from the bulk solid state physics, and thus derive fundamental restrictions, novel functions and possibilities that appear at nanoscale.

A close relation of these subjects to both solid state physics and (bio-)organic chemistry and material science is emphasized. Similarity of carbon nano-materials to organic molecules, thus making a natural link to a biological nanoscale objects, like proteins, will be further discussed along with bio-applications.

Texts:
- Applied Physics of Carbon Nanotubes: Fundamentals of Theory, Optics and Transport Devices // Eds. SV. Rotkin, S. Subramoney // vol. in Nanoscience and Nanotechnology Series // Publ: Springer (c2005)
- Current journal articles to be handed out.

Recommended reading:
- Science and application of nanotubes // Eds. D. Tomanek and R. J. Enbody. // Publ: New York : Kluwer Academic/Plenum, (c2000).
- Handbook of Nanoscience, Engineering and Technology // Eds.: W. Goddard, D. Brenner, S. Lyshevski, G.J. Iafrate // CRC Press (2000).
- The science of fullerenes and carbon nanotubes // M.S. Dresselhaus, G. Dresselhaus and P. Eklund, Academic (1996).

Grading:
- term paper / final presentation (40%),
- homework / quiz results (30%)
- midterm evaluation (30%).

Accommodations for Students with Disabilities: If you have a disability for which you are or may be requesting accommodations, please contact both your instructor and the Office of Academic Support Services, University Center 212 (610-758-4152) as early as possible in the semester. You must have documentation from the Academic Support Services office before accommodations can be granted.

<u>**Course outline**</u>

Chapter A: Introduction to carbon based novel materials

1. Introduction to the field of carbon-based materials.

1.1. Types of carbon-based organic and inorganic materials.
1.2. Historical introduction: discovery of nanotubes. Methods of nanotube synthesis.

2. Symmetry and structure of nanotubes (NTs).

2.1. Single- and multiwall NTs, nanowires and whiskers. Graphite Polyhedral Crystals and Nano-cones.
2.2. Structure of graphite. Scrolling of graphene monolayer.
2.3. Symmetry of single-wall nanotubes (SWNT).
2.4. Chirality of SWNT: armchair and zigzag SWNT. Commensurability in multiwall nanotubes (MWNTs).
2.5. SWNT ropes. Tube-tube interactions.

3. Electronic structure of SWNTs.

3.1. Introduction to the band structure calculation.
3.2. Tight binding approach (TBA), Hueckel/LCAO.
3.3. From graphene to the NT: Band folding scheme.
3.4. Metallic, semiconductor and secondary-gap semimetallic nanotubes.
3.5. Experimental: SWNT Raman characterization, scanning tunneling spectroscopy, photoluminescence.
3.6. Beyond one-band TBA.

4. Mechanical properties of nanotubes.

4.1. Elastic theory for SWNT and MWNT.
4.2. Experimental study of nanotube elasticity.
4.3.* SWNT defects, plasticity of SWNTs.

Chapter B: Fundamentals of applied physics of one-dimensional (1D) devices

5. Classical phenomena in 1D devices.

5.1. Electrostatics of 1D systems.
5.2. Calculation of charge density distribution in SWNT channel at equilibrium.
5.3. Field enhancement in 1D systems.

6. Quantum effects in SWNT based devices.

6.1. Density of States (DoS) of 1D electronic system.
6.2. Quantum capacitance of 1D electronic system.
6.3. Depolarization and effective dielectric function.
6.4. Linear static and dynamic polarization of SWNT.
6.5. Many-body effects in SWNTs: Exciton and gap renormalization.

7. Band gap engineering in graphitic materials.

7.1. Symmetry and band gaps in SWNTs.
7.2. Metal-insulator transition in semiconductor NTs.
7.3. Effect of environment on the bandstructure: Spontaneous symmetry breaking at the polar surface.
7.4. Breaking of “super”-symmetry of armchair NTs.
7.5. Molecular doping and gating: Composite organic-inorganic materials, DNA-NT complexes.

8. Transport in nanotubes and nanowires.

8.1. Electronic transport: Ballistic versus diffusion models.
8.2. Experimental: Scanning probe microscopy, scanning tunneling spectroscopy, DC/AC conductivity.
8.3. Contact phenomena: Schottky barrier theory.
8.4. Nanotube Field Effect Transistors (FETs) and elements of molecular logic.
8.5.* Introduction to the general problem of ion channels. Ion and molecule transport in nanotubes: SWNT as an artificial ion channel.
8.6. Screening properties of finite-length SWNT as water channels. NT attofluidic devices.

9. Charge carrier scattering in nanotubes.

9.1. Intrinsic defects in NTs. Structural defects, interwall/intrarope interactions, chemical modification.
9.2. Influence of the surface: vdW cohesion, charge injection, impurity scattering.
9.3. Fundamentals of the phonon scattering theory.
9.4. Coulomb impurity scattering.
9.5. Charge trapping and hysteresis/memory effect in 1D-FETs.
9.6.* Local chemical gating: modulation of charge carrier transport. Nanotube sensors.

O.* van der Waals/Casimir (vdWC) cohesion.

O.1.* Standard approach: Lennard-Johns potential.
O.2.* NEMS: Experimental evidence for vdWC forces.
O.3.* Fundamentals of theory of the vdWC interaction. Casimir approach to the calculation of vdWC energy.
O.4.* Collective modes and vdWC cohesion in NTs.

* - optional

Chapter C: Non-conventional device applications

10. Electromechanical action of nanotubes.

10.1. Nanoelectromechanical systems (NEMS).
10.2. Experimental: Actuation, prototypes of NT-NEMS.
10.3. Theory of nanoscale electromecanical device.

11. Molecular electronics

11.1. Introduction into molecular devices.
11.2. Field-Effect devices and contact phenomena.
11.3. Metallic Field-Effect Transistor. Multiple gate and superlattice molecular devices.
11.4. Molecular NEMS.

12. Devices with semiconductor nanowires

12.1. Nanowires versus nanotubes.
12.2. Nanowire electromechanical systems and sensors.
12.3.* Nanowire transistors and nano-photodiodes.

OO.* Perspectives of non-conventional devices