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Carbon Nanotubes: From Basic Research to Nanotechnology

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PREFACE

It is about 15 years that the carbon nanotubes have been discovered by Sumio Iijima in a transmission electron microscope. Since that time, these long hollow cylindrical carbon molecules have revealed being remarkable nanostructures for several aspects. They are composed of just one element, Carbon, and are easily produced by several techniques. A nanotube can bend easily but still is very robust. The nanotubes can be manipulated and contacted to external electrodes. Their diameter is in the nanometer range, whereas their length may exceed several micrometers, if not several millimeters. In diameter, the nanotubes behave like molecules with quantized energy levels, while in length, they behave like a crystal with a continuous distribution of momenta. Depending on its exact atomic structure, a single-wall nanotube –that is to say a nanotube composed of just one rolled-up graphene sheet– may be either a metal or a semiconductor. The nanotubes can carry a large electric current, they are also good thermal conductors.

It is not surprising, then, that many applications have been proposed for the nanotubes. At the time of writing, one of their most promising applications is their ability to emit electrons when subjected to an external electric field. Carbon nanotubes can do so in normal vacuum conditions with a reasonable voltage threshold, which make them suitable for cold-cathode devices. Nanotubes are also good candidates for the design of composite materials. They can increase the conductivity, either electrical or thermal, of polymer matrices which they are embedded in at a few weight percents, while improving the mechanical resistance of the materials. Most spectacular, but still far from industrialization, is the nanotube-based field-effect transistor. Here, a single-wall semiconducting nanotube, contacted to two electrodes, may block or may transmit an electric current depending on the potential applied to a gate electrode placed at near proximity. Many other applications are foreseen, among which nanoscopic gas sensing in which one property of the nanotube, sensitive to adsorbed molecules, is measured. Gas selectivity may be realized by a suitable functionalization of the nanotubes. Optical and opto-electronic properties of single-wall nanotubes are also promising for infra-red applications.

While the list of potential applications increases every month, the basic properties of intrinsic nanotubes are well documented and relatively well understood. Only relatively, because there remain several important open issues. Many-body effects, although predicted to occur in one-dimensional systems since a long time, are not clearly evidenced. Luttinger-liquid behavior,
for instance, is not fully recognized by experiments on metallic nanotubes. Excitons in semiconducting tubes constitute another topic of recent, sometimes controversial debates. More important, perhaps, the synthesis and growth mechanisms of the carbon nanotubes are not clearly pinned out. It is remarkable that these beautiful molecules can be produced in such many different physical and chemical conditions (electric arc discharge, catalytic chemical vapor deposition, laser ablation ...). Partly due to that, it is still not possible at the time of writing to produce nanotubes with all the same structure in a controllable way. Large-scale, but detailed characterization of the nanotubes, like with any other nanostructures, remains a great experimental challenge that will need to be overcome.

Whether or not nanotubes will have important industrial applications is not the essential point for the time being. What can be given for sure is that the carbon nanotubes have triggered an intense research activity thanks to which nanotechnology is developing so fast. The nanotubes are indeed ideal objects to deal with in this context before other nanostructures, perhaps, will supplement them and will open the way to real technological applications. In this book, many aspects of the nanotubes are either touched or described in details. The book is a snapshot, incomplete perhaps, of the state of the art at the time where the ASI took place, on the shore of the Black Sea.

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