Chapter 1
An Introduction to Nanotechnology

Simona E. Hunyadi Murph

To understand the very large, we must understand the very small.

Democritus

Abstract Globalization of scientific knowledge and technological advances are sparking innovation and creativity across many fields at an unprecedented rate. Ground-breaking discoveries made in the mid-1980s, namely the development of scanning tunneling microscopy and the discovery of buckminsterfullerene, influenced scientists to envision the world at the atomic level and new paradigms emerged: nanoscience and nanotechnology. Through the manipulation of matter at the atomic level, today scientists can create novel materials with unique properties and functionalities. These new materials enable innovative technologies and applications across many fields from engineering to medicine.

Globalization of scientific knowledge and technological advances is sparking innovation and creativity across all fields at an unprecedented rate. Nearly every aspect of science and industry is driven to make advances in the (bio)medical fields, computing and electronics, environmental controls and remediation, transportation, energy production, chemical manufacturing, agriculture, and consumer products.

The technological revolution [1] that started decades ago with the introduction of electronic devices and silicon-based integrated circuitry [2] changed humanity forever. The information technology insurgency that emerged with the introduction of internet/broadband, personal computers, mobile phones, and email [3] created a global multi-dimensional world. These technologies re-defined the way we live, communicate, travel and experience the world. This burst of technological developments offered unprecedented opportunities for rapid social and economic progress in our society [4].

S.E. Hunyadi Murph (✉)
National Security Directorate, Savannah River National Laboratory, Aiken, SC, USA
e-mail: Simona.Murph@srnl.doe.gov

S.E. Hunyadi Murph
Department of Physics and Astronomy, University of Georgia, Athens, GA, USA

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Over the years, creation of smaller and smaller optical, mechanical, and electronic products and devices thrived, leading to energy efficient, lighter, and easier to operate devices. Today, the miniaturization revolution continues and scientists are manipulating the world at its smallest level: the atomic level. It was the physicist, Richard Feynman, who introduced this concept for the first time in 1959 in his famous talk “There’s Plenty of Room at the Bottom”. He speculated that one day, it may be possible to print all 24 volumes of Encyclopedia Brittanica on the head of a stick pin [5]. Feynman envisioned building circuits on the scale of nanometer that could be used as elements in more powerful computers and predicted the presence of nanostructures in biological systems. In 1965, he won the Nobel Prize jointly with Julian Schwinger and Sin-Itiro Tomonaga for their contributions to the development of quantum electrodynamics [6].

Two major breakthrough discoveries made in the mid-1980s opened the doors for the next generation of technological advancements in this area. It started with the development of scanning tunneling microscope (STM) in 1981, which makes it possible to image surfaces at the atomic level. This discovery, created by Gerd Binnig and Heinrich Rohrer, granted them the Nobel Prize in Physics in 1986 [7]. A few years after the development of the scanning electron microscope (SEM), in 1985, Richard Smalley and Bob Curl were able to create and isolate the first nanomaterial, named buckminsterfullerene (“bucky balls”). The buckyball molecule is a spherical fullerene molecule with the formula C_{60}. Kroto, Curl and Smalley were awarded the 1996 Nobel Prize in Chemistry for their roles in the discovery of buckminsterfullerene and the related class of molecules, the fullerenes [8].

These ground-breaking discoveries influenced scientists to envision the world at the atomic level and new paradigms emerged: nanoscience and nanotechnology. A nanometer, which is derived from the Greek prefix -nano, meaning “dwarf”, is one-billionth (10^{-9}) of a meter (Fig. 1.1). Scientists associate the word “nano” to materials, devices, objects that have at least one dimension on the 1–100 nm scale. By manipulating matter at the atomic levels, scientists create new materials with unique properties and functionalities that enable new technologies and applications across many fields from engineering to medicine. A wide variety of new nanoscale building blocks have emerged in the last decades, including fullerenes, metal and semiconductor nanoparticles, and various designer molecules.

As a matter of fact, in 2013, a team of Stanford engineers built a basic computer using carbon nanotubes [9], which has the potential to launch a new generation of electronic devices that run faster, while using less energy, than those made from silicon chips. In the medical field, scientists demonstrated that gold nanoparticles can be used for the destruction of cancer cells in vitro and in vivo in mice [10]. Pilot clinical studies on human patients with refractory and/or recurrent tumors of the head and neck are underway [11]. Currently, scientists can create nanomaterials that are stronger than Kevlar, which is used in bulletproof vests, and substances 100 times stronger than steel [12]. They are able to create fluorescent materials that are one thousand times brighter than conventional dyes or dyes used to image the inside of the human body [13]. The possibilities appear endless. The possibility of finding

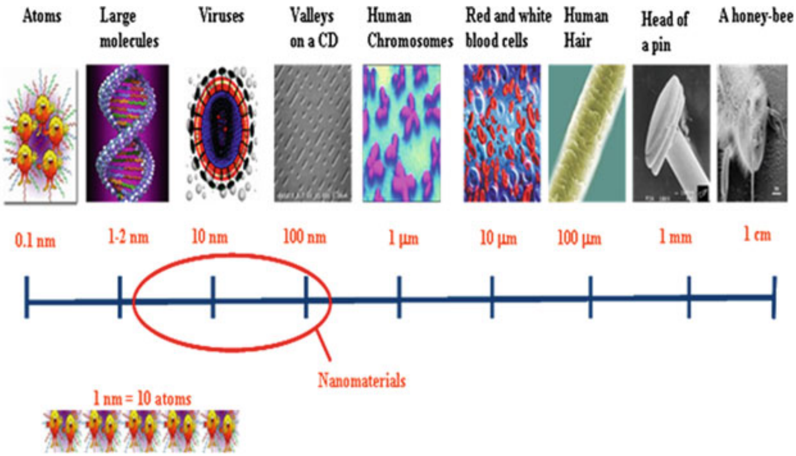

Fig. 1.1 Nano- and micro- meter scale of "things"

new and intriguing substances that can cure disease, help us explore and/or live in space, make us live longer and healthier lives, increase communications between people around the world, and discover new energy supplies is exhilarating.

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