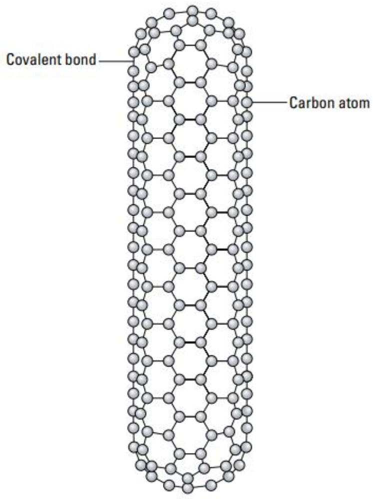
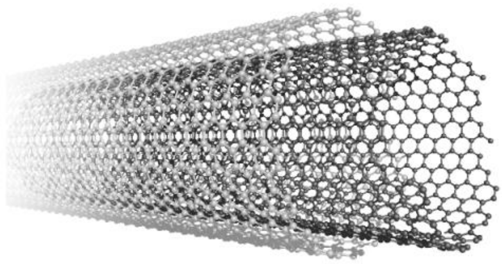
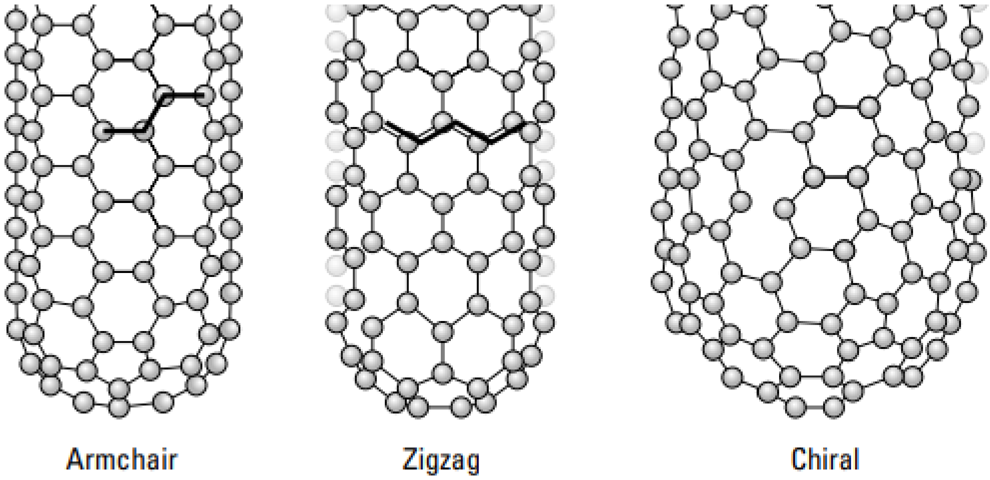
Lecture-9. Nanotubes

As far back as 1959, Roger Bacon had produced images of carbon nanotubes. In the 1980s, Howard Tennant applied for a patent for a method to produce them. In 1990, Richard Smalley postulated the concept that if buckyballs get big enough, they become carbon cylinders. But it wasn't until 1991 that Sumio Iijima, a researcher at NEC's Fundamental Research Lab, not only took photos of nanotubes, but also put two and two together to explain what nanotubes actually are — and put a name to them. He placed a sample of carbon soot containing buckyballs in an electron microscope to produce some photographs of buckyballs — which he in fact did — but some odd, needleshaped structures caught his attention. It turned out that these needle shapes were actually cylinders of carbon atoms that were formed at the same time that the buckyballs were formed. Like buckyballs, these cylinders (called carbon nanotubes) are each a lattice of carbon atoms — with each atom covalently bonded to three other carbon atoms. Carbon nanotubes are basically buckyballs, but the end never closes into a sphere when they are formed. Instead of forming the shape of a sphere, the lattice forms the shape of a cylinder, as illustrated in Figure 4-4. Nanotubes come in a couple of varieties. They can either be single-walled carbon nanotubes (SWNT) or multiwalled carbon nanotubes (MWNT). As you might expect, an SWNT is just a single cylinder, whereas an MWNT consists of multiple concentric nanotube cylinders, as illustrated in Figure 4-5. We'll tell you about SWNTs rather than MWNTs, because most research is focused on developing uses for single-walled nanotubes. The length and diameter of SWNTs varies, but a typical SWNT would be about 1 nanometer in diameter and a few hundred nanometers in length. The smallest diameter anybody has ever seen in SWNTs is about the same as the C60 buckyball, just under 1 nanometer.





Researchers found that by adding just a few percentage points of vaporized nickel nanoparticles to the vaporized carbon (using either the arc-discharge or laser-vaporization method to produce the vapor), they could make as many nanotubes as buckyballs — or even more. Here's why: Carbon atoms dissolve in the metal nanoparticle. When the metal nanoparticle is filled to the brim with carbon atoms, carbon atoms start sweating onto the surface of the particle and bond together, growing a nanotube. When you anchor one end of the growing nanotube to the metal nanoparticle, it can't close into the sphere shape of a buckyball. This also allows the nanotubes to incorporate many more carbon atoms than a buckyball. This method produces both single and multiple walled nanotubes intermingled with carbon soot. (If you want to know how to get nanotubes out of the marshmallows you roast over your campfire, flip over to Chapter 5, where we discuss methods of removing nanotubes from the carbon soot and untangling them.).



A carbon nanotube is a cylinder of carbon atoms covalently bonded together, sort of like a sheet of graphite rolled into a cylinder. Some of these cylinders are closed at the ends and some are open. Each carbon atom is bonded to three other carbon atoms and forms a lattice in the shape of hexagons (sixsided rings of carbon atoms), except near the end. For nanotubes with closed ends, where the ends start to curve to form a cap, the lattice forms pentagons (five-sided rings of carbon atoms). The lattice can be orientated differently, which makes for three different kinds of nanotubes. As shown in Figure 4-6, in armchair nanotubes, there is a line of hexagons parallel to the axis of the nanotube. In zigzag nanotubes, there's a line of carbon bonds down the center. Chiral nanotubes exhibit a twist or spiral (called chirality) around the nanotube. We discuss how the orientation of the lattice helps determine the electrical properties of the nantube later in this chapter.