CHAPTER 1

WHAT IS MATERIALS CHEMISTRY?

Life in the 21st century is ever dependent on an unlimited variety of advanced materials. In our consumptive world, it is easy to take for granted the macro-, micro-, and nanoscopic building blocks that comprise any item ever produced. We are spoiled by the technology that adds convenience to our lives, such as microwave ovens, laptop computers, digital cell phones, and improved modes of transportation. However, we rarely take time to think about and appreciate the materials that constitute these modern engineering feats.

The term material may be broadly defined as any solid-state component or device that may be used to address a current or future societal need. For instance, simple building materials such as nails, wood, coatings, etc. address our need of shelter. Other more intangible materials such as nanodevices may not yet be widely proven for particular applications, but will be essential for the future needs of our civilization. Although the above definition includes solid nanostructural building blocksthat assemble to form larger materials, it excludes complex liquid compounds such as crude oil, which may be more properly considered a precursor for materials.

A general description of the various types of materials is illustrated in Figure 1.1. Although this indicates sharp distinctions between various classes, there is often ambiguity regarding the proper taxonomy for a specific material. For example, a thin film is defined as having a film thickness of less than 1 μm; however, if the thickness drops to below 100 nm, the dimensions may be more accurately classified within the nanoscale regime.[11] Likewise, liquid crystals are best described as having properties intermediate between amorphous and crystalline phases, and hybrid composite materials involve both inorganic and organic components.

The broadly defined discipline of materials chemistry is focused on understanding the relationships between the arrangement of atoms, ions, or molecules comprising a material, and its overall bulk structural/physical properties. By this designation, common disciplines such as polymer, solid-state, and surface chemistry would all be placed within the scope of materials chemistry. This broad field consists of studying the structures/properties of existing materials, synthesizing and characterizing new materials, and using advanced computational techniques to predict structures and properties of materials that have not yet been realized.
1.1. Historical Perspectives

Although the study of materials chemistry is a relatively new entry in both undergraduate and graduate curricula, it has always been an important part of chemistry. An interesting timeline of materials developments from Prehistoric times to the present may be found in Appendix A. By most accounts, Neolithic man (10,000–300 B.C.) was the first to realize that certain materials such as limestone, wood, shells, and clay were most easily shaped into materials used as utensils, tools, and weaponry. Applications for metallic materials date back to the Chalcolithic Age (4,000–1,500 B.C.), where copper was used for a variety of ornamental, functional, and protective applications. This civilization was the first to realize fundamental properties of metals, such as malleability and thermal conductivity. More importantly, Chalcolithic man was the first to practice top-down materials synthesis (see later), as they developed techniques to extract copper from oxide ores such as malachite, for subsequent use in various applications.

Metal alloys were first used in the Bronze Age (1,400 B.C.–0 B.C.), where serendipity led to the discovery that doping copper with other compounds drastically altered the physical properties of the material. Artifacts from the Middle East dating back to 3,000 B.C. are found to consist of arsenic-doped copper, due to the wide availability of lautite and domeykite ores, which are rich in both arsenic and copper. However, due to arsenic-related casualties, these alloys were quickly replaced with tin–copper alloys (bronze) that were widely used due to a lower melting point, higher hardness, and lower brittleness relative to their arsenic forerunner.

The Iron Age (1,000 B.C.–1,950 A.D.) first brought about applications for iron-based materials. Since the earth’s crust contains significantly more iron than copper (Table 1.1), it is not surprising that bronze was eventually abandoned for materials applications. An iron silicate material, known today as wrought iron, was