# What is Materials Chemistry

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## Examining the Question

In the past 10 years, materials chemistry has attracted worldwide interest as a new and important interdiscipline resulting from the confluence of two streams: chemistry, and materials science and engineering. Materials chemistry is clearly an emerging subdiscipline, related to both chemistry and materials science; however, the exact definition of materials chemistry remains a question. L.V. Interrante in 1992 referred to materials chemistry as "chemistry directed at the preparation, processing, and analysis of materials.[1] This was a common viewpoint at that time which should be developed further as research in this area flourishes.

I am fortunate to be involved in research and teaching of materials chemistry, but at the same time I am somewhat perplexed. In 1994 I was asked to start a course called "Materials Chemistry" for senior students in the Department of Materials Science and Engineering at Tsinghua University. When I entered the classroom the first question I was asked was "What is the definition of materials chemistry?" Since no textbook was available, I faced difficulty preparing lectures and my students had difficulty learning the subject. The only choice I had was to reorganize part of the contents of *New Directions in Solid State Chemistry*[2] and supply some review articles.With little satisfaction after one semester, I realized the urgent need for a real textbook on materials chemistry and for a satisfactory definition of that term.

To understand the concept of materials chemistry, we can review the definitions of chemistry and of materials. Chemistry is defined as "the science that deals with the composition of properties of substances,"[3] and focuses traditionally on atomic and molecular interactions, that is, study at the microscopic level. On the other hand, materials are "the substance or substances out of which a thing is constructed,"[3] that is, study at the macroscopic level. Traditionally, several well-established subareas of chemistry are involved in materials study, for example solid state chemistry, surface chemistry, and polymer chemistry. Each has its own direction and specific emphasis. Among these subareas, the definition of solid state chemistry seems to be closest to that for materials chemistry. In 1986 C.N.R. Rao and J. Gopalakrishnan defined the latter as follows: "Solid state chemistry deals with a variety of solids, inorganic as well as organic; the solids can be crystalline or non-crystalline....It is mainly concerned with the development of new methods of synthesis, new ways of identifying and characterizing materials and of describing their structure, and above all, with new strategies for tailor-making materials with desired and controllable properties...."[2] Here, synthesis, characterization, and processing for controllable properties of materials are emphasized. This definition is similar to that of Interrante's.

## The Traditional Role of Chemistry in Materials Science

As a new subdiscipline, materials chemistry must have its own characteristics, and must differ from those of other subareas of chemistry, especially from solid state chemistry. Actually, the origin of materials chemistry results from the evolution of chemistry in materials science as catalyzed by the development of modern high technologies.

The earliest studies in materials science were concerned with earth materials,[4] that is, minerals and stones. In fact, civilization started with the utilization of stone as tools. With the development of science and technology, the stone age progressed to the bronze age, the iron age, the porcelain age, the polymer age, and so on. During this evolution, chemistry played an important role.[5] Generally, the role of chemistry in materials science can be briefly described as follows: New materials are synthesized and characterized, their properties are identified by the discipline of physics, and new products are made through engineering design and processing (Figure 1).

The importance of chemistry (including synthesis and characterization) in materials science can be seen in this figure. J.L. Warren and T.H. Geballe pointed out in 1980 that the level of sophistication of materials science in a country is reflected in its level of synthesis and characterization, which in turn can be measured by the number of articles published in the *Journal of Solid State Chemistry*.[6]

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## Materials Chemistry: An Interdiscipline

Chemistry became more and more important in materials research and development as the world entered into the high-technology era, which is based on advanced materials. Competition in high technology relies greatly on developments in materials science and engineering. Therefore progress in the twenty-first century cannot be separated from development and utilization of new materials in such areas as bioengineering, information, energy, space, and oceanography.

The important position of materials science in this high-tech era requires the merging of chemistry with materials science. As a result new chemistry subareas and methods have been developed for materials study, for example, sol-gel, chemical vapor deposition, sonochemistry, shock-wave chemistry, microwave chemistry, magnetic-field chemistry, microgravity chemistry, and soft chemistry such as intercalation, redox insertion, dry extraction, grafting and pillaring, exfoliation reactions, and ion exchange. Several important events in the last 10 years have encouraged chemists to become involved in materials research.

- In 1986, at the Spring Meeting of the Materials Research Society, the contributions of chemistry to materials research were clearly evident. In fact, someone said, "Physics has had its crack at ceramics, now let chemistry have its turn." As a result, MRS published a proceedings entitled *Better Ceramics Through Chemistry*. A series of proceedings with the same title has been published in the following years.
- At almost the same time, J.G. Bednorz and K.A. Müller at IBM Laboratory reported the discovery of perovskite Ba-La-Bu-O superconductor.[7] In 1987, the American Chemical Society (ACS) held its 194th meeting where chemists focused on such topics as "Chemistry of High-Temperature Superconductors."[8] Chemists made substantial and even unique contributions to all aspects of oxide superconductors, including surfaces and interfaces, processing and fabrication, and applications.



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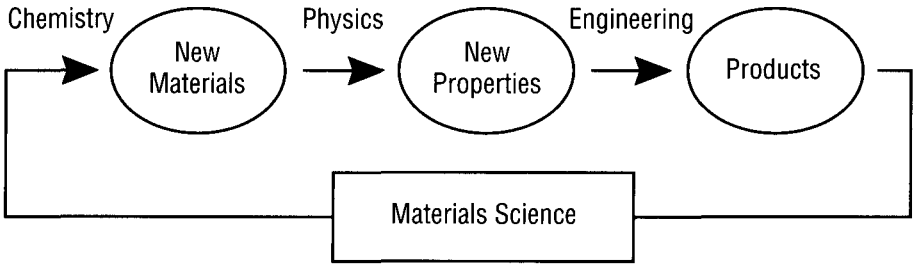


*Figure 1. A view of materials science as built on chemistry, physics, and engineering.*

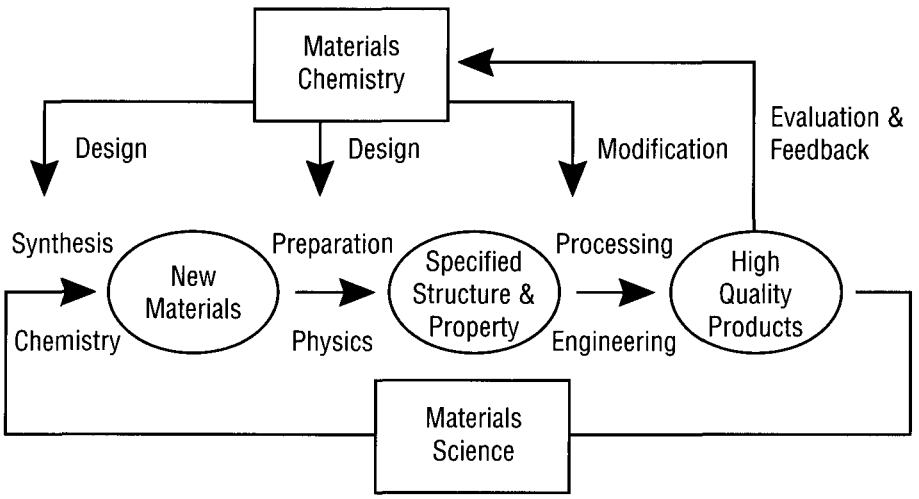


*Figure 2. The functions of materials chemistry in materials science.*

■ The collaboration of chemists H.W. Kroto (University of Sussex) and R.E. Smalley (Rice University) led to the discovery of carbon-60 Buckminsterfullerene in 1985.[9] [Editor's note: Kroto, Smalley, and R.F. Curl Jr. (Rice University) just received the Nobel Prize for their work on fullerenes.] In 1990 solid carbon-60 crystallites were obtained in the laboratory by W. Krätschmer et al.;[10] this discovery resulted in a global research wave. Subsequently, new materials such as graphite and $WS_2$ buckminster microtubes, and met-car $Ti_8C_{12}$ have also been reported.[11–13]

In response to the emerging subdiscipline of materials chemistry, ACS began publishing the journal *Chemistry of Materials* in 1989, and the Royal Society of Chemistry introduced the *Journal of Materials Chemistry* in 1991. ACS has also established a *Materials Chemistry Secretariat* to coordinate academic activities in materials chemistry. In 1992 a symposium on materials chemistry was initiated by ACS in which various topics related to materials chemistry are discussed. In 1993 a special meeting named "International Meeting on Chimie Douce: Soft Chemistry Routes to New Solids" was held in Nantes, France. Meanwhile, the International Union of Pure and Applied Chemistry (IUPAC) published a book entitled *Chemistry of Advanced Materials* as part of the IUPAC monograph series on Chemistry for the 21st Century. After its Meeting on Advanced Materials for Innovations in Energy, Transportation, and Communications held in Tokyo in 1987, IUPAC is going to focus its CHEMRAWN IX Meeting in Seoul in 1996 on The Role of Advanced Materials in Sustainable Development.

The inevitable outcome of the impact of chemistry on materials science is the emergence of "materials chemistry" as an interdiscipline that differs from the traditional role of chemistry in materials science (Figure 1). Materials chemistry has become involved in every corner of materials science with important and even unique contributions (Figure 2), and has become one of the most active and exciting areas in materials science.

A merging of chemistry and materials science clearly leads to the generation of materials chemistry, which bridges the gap between microscopic and macroscopic studies of substances. When we cite "materials chemistry," we refer to the study of materials (the goal) at macroscopic levels through chemistry routes (the way) at microscopic levels, thus including all chemical aspects of materials study. Thus the definition of materials chemistry can be given as follows: *Materials chemistry extends from atoms and molecules to useful substances that are achieved with design, synthesis, processing, modification, characterization, property prediction, and control of materials through chemistry routes.*

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