Materials Chemistry

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by

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Preface

Though most colleges and universities now have courses and degree programs related to materials chemistry, there is a need for a textbook that addresses inorganic-, organic-, and nano-based materials from a structure *vs.* property treatment. As I quickly discovered, trying to fill this void represented a daunting task of providing a suitable breadth and depth coverage of the rapidly evolving field of materials – all in a concise format. The material contained herein is most appropriate for junior/senior undergraduate students, as well as first-year graduate students in chemistry, physics, and engineering fields. In addition, this textbook will be extremely useful for researchers in industry as an initial source to learn about materials/techniques, with references provided for more detailed investigation.

After providing a historical perspective for the field of materials in the first chapter, the first concentration of the textbook focuses on solid-state chemistry. Though there are many popular textbooks that deal with this topic, my approach contains some unique perspectives. In addition to colored illustrations of archetypical crystalline unit cells, digital photos of models are also provided to add clarity to their structures. Further, a large section on amorphous solids including sol–gel techniques and cementitious materials is provided – largely left out of most solid-state textbooks. The next chapter on metals contains a thorough treatment of traditional and powder metallurgical techniques, with a focus on the complex phase behavior exhibited by the Fe–C system and steels. However, also left out of most metallurgy textbooks, I cover topics such as corrosion inhibition, magnetism, hydrogen storage, and the structure/properties of other metallic classes, such as the coinage metals and other alloys, such as those exhibiting shape-memory properties.

The next chapter deals with semiconducting materials, which consists of a discussion of band theory and semiconductor physics. Unique among other texts, I also describe in great detail the evolution of the transistor, with a discussion of current limitations and solutions currently being investigated by researchers in the field. Also described in this chapter is IC fabrication, including vapor deposition techniques, photolithography, and ion implantation. The current trends in applications such as LEDs/OLEDs, thermoelectric devices, and photovoltaics (including emerging technologies such as dye-sensitized solar cells) are also provided in this chapter.

Polymers and organic-based “soft” materials represent one of the largest materials classes; however, these materials are often left out of solid-state textbooks. Herein, I cover the chemistry of the five classes of polymers, from simple chains to complex branched dendritic architectures. Again, the approach is unique in that it covers traditional mechanisms and structure/property relationships for polymers, in addition to advanced topics such as homogeneous catalysis, polymer additives, and self-healing polymers. A detailed discussion of “molecular magnets” is also provided in this chapter, due to their relatively mild syntheses and “soft” properties relative to traditional inorganic-based magnets.

I devoted a significant effort in the next chapter to nanomaterials, due to their increasing popularity and relevance for current/future applications. In addition to structure/property descriptions and applications, essential topics such as nomenclature, synthetic techniques, and mechanistic theories are described in detail. The last chapter is also of paramount importance for the materials community – characterization. From electron microscopy to surface analysis techniques, and everything in between, this chapter provides a thorough description of modern techniques used to characterize materials. A flowchart is provided at the end of the chapter that will assist the materials scientist in choosing the most suitable technique(s) to characterize a particular material.

At the end of each chapter, a section entitled “Important Materials Applications” is provided, along with open-ended questions and detailed references/bibliography. Appendices are also provided that contain an interesting timeline of major materials developments, the complete Feynman speech “There’s Plenty of Room at the Bottom,” and a preliminary collection of materials-related laboratory modules. These additions were provided to promote student engagement through effective student–instructor interactions. Though I attempted to hit all of the “high notes” in the materials world, an obvious omission would be a detailed discussion of biomaterials – of increasing importance throughout the world. Applications such as biomimetics and drug delivery are presented in this edition; however, a detailed discussion of this topic was beyond the scope of providing a *concise* first edition – a separate chapter on this topic will appear in future editions.

The realization of a major milestone such as the completion of a textbook would not have been possible without the influence of many people in my life. First and foremost, I wish to thank my precious wife Diyonn for her patience and support during the many months of seclusion, as I crouched behind the laptop monitor. I am eternally grateful to my parents Frank and Pearl for their continuing support and godly wisdom, to whom I attribute all of my many blessings and successes. I must also acknowledge my Ph.D. advisor Andy Barron (Rice University) for his guidance and advice. I truly have never met anyone with as much drive and excitement for both materials research and teaching (as well as professional autoracing!). I thank him for being such an effective role model for the challenging and rewarding life of academia.

Of course, this textbook is the compilation of input from a number of my professional colleagues. I wish to thank Profs. Anja Mueller, Bob Howell (at CMU), Richard Finke (Colorado State University), and Jean-Claude Thomassian (at Georgia

Southern University) for their input and suggestions regarding various sections of this textbook. I am also very appreciative for the input provided by the first students to have access to evolving versions of the textbook – Nick Bedford, Jesse Thompson, Brandon Rohde, Brian Smith, Dan Denomme, Jason MacDonald, Laura Slusher, David Moyses, Michael Todd, Leontios Nezeritis, and Megan McCallum. The administration at CMU has also been a constant source of support. In particular, I wish to thank President Michael Rao, Dean Bob Kohrman, chemistry Chairman David Ash, and my faculty/staff colleagues from the chemistry department. I cannot express in words what their support has meant to me.

The close proximity to Midland, MI, a leading center of the chemical industry, has also provided much inspiration for this textbook and my research projects. In particular, Petar Dvornic (Michigan Molecular Institute) is a constant source of inspiration and also provided much feedback for this textbook. I also gratefully acknowledge Don Tomalia (Dendritic Nanotechnologies, Inc. at CMU) for his support since my arrival at CMU in 2002. Thanks for putting CMU on the map in the dendrimer field! I would also like to acknowledge the funding agencies of the Dreyfus Foundation, Research Corporation, and the Army Research Laboratory who provided support for my research interests during my first years at CMU.

Last, but certainly not least, I thank every reader of this book, and solicit your comments to my email fahlm1b@cmich.edu. Please let me know what you think of this edition; I will earnestly try to incorporate your suggestions to strengthen future editions.

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