# Foundations *of* Materials Science *and* Engineering

FOURTH EDITION

WILLIAM F. SMITH

JAVAD HASHEMI

# Foundations of Materials Science and Engineering

**Fourth Edition**

**William F. Smith**
*Professor Emeritus of Engineering*
*University of Central Florida*

**Javad Hashemi, Ph.D.**
*Professor of Mechanical Engineering*
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# Foundations of Materials Science and Engineering

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# ABOUT THE AUTHORS

**William F. Smith** is Professor Emeritus of engineering in the Mechanical and Aerospace Engineering Department of the University of Central Florida at Orlando, Florida. He was awarded an M.S. degree in metallurgical engineering from Purdue University and a Sc.D. degree in metallurgy from Massachusetts Institute of Technology. Dr. Smith, who is a registered professional engineer in the states of California and Florida, has been teaching undergraduate and graduate materials science and engineering courses and actively writing textbooks for many years. He is also the author of *Structure and Properties of Engineering Alloys,* Second Edition (McGraw-Hill, 1993).

**Javad Hashemi** is a Professor of Mechanical Engineering at Texas Tech University, where he has taught introduction to materials science since 1991. Javad received his Ph.D. in Mechanical Engineering from Drexel University in 1988. Dr. Hashemi has been teaching undergraduate and graduate materials and mechanics courses, as well as laboratories at Texas Tech University. He is also the principal developer of the virtual laboratory modules accompanying this textbook as part of a pilot project funded by National Science Foundation. Dr. Hashemi's current research focus is the areas of materials, biomechanics, and education for engineers.

# PREFACE

*Foundations of Materials Science and Engineering,* Fourth Edition is designed for a first course in materials science and engineering for engineering students. Understanding that this might be a student's first exposure to materials science, the book presents essential topics in a clear, concise manner, without extraneous details to overwhelm newcomers. Industrial examples and photographs used throughout the book give students a look at the many ways material science and engineering are applied in the real world.

## NEW FEATURES OF THE FOURTH EDITION

In addition to its already renowned student friendly writing style and applications to industry, the fourth edition offers new features including a thorough coverage of modern materials science topics that prepare students for life outside the classroom. The new sections are:

- New reference to smart materials/devices, MEMs, and nanomaterials (1.1)
- New reference to superalloys and their biomedical applications (1.3)
- Added discussion of engineering plastics and applications in automobiles (1.3.2)
- Added discussion of engineering ceramics and applications (1.3.3)
- Added discussion of composite materials (1.3.4)
- New coverage of smart materials and nanomaterials (1.5)
- New section featuring a simplified case study in selection of materials for the frame and forks of a bicycle (1.6)
- New coverage of amorphous materials was added in chapter 3
- Added references to long and short range order (SRO also known as amorphous materials) (3.1)
- Chapter 4 has been split into chapters 4 and 5 for the fourth edition so diffusion can be covered in a stand-alone chapter
- Coverage of microscopes added to the end of chapter 4
- Added coverage of planar defects and twin boundaries (4.4.3)
- New section on volume defects (4.4.4)
- New section on experimental techniques for identification of microstructure and defects (4.5)
- Added coverage of fine-grained metals and the Hall-Petch equation in chapter 6
- New case study in failure and coverage of recent advances in improving mechanical performance in chapter 7

- Added coverage of failure and fracture of metals (7.1)
- New section on ductile to brittle transition temperature (7.1.4)
- New section on recent advances and future directions in improving the mechanical performance of metals (7.7)
- New coverage of cooling curves in chapter 8
- Added coverage of intermediate compounds (8.11.1)
- Three new sections devoted to advanced alloys and their application in biomedical engineering have been added to chapter 9
- New section devoted to biomedical applications of polymeric materials added to chapter 10
- New section with coverage of bucky balls and carbon nano-tubes (11.2.12)
- New section on ceramic coatings and surface engineering (11.9)
- New section on ceramics in biomedical applications (11.10)
- New section on nanotechnology and ceramics (11.11)
- New section on bone: a natural composite material (12.11)
- New section on hydrogen damage (13.5.11)
- New section on nanoelectronics (14.9)
- New appendix featuring extensive materials properties reference

Other New Features:

- Learning objectives have been added to every chapter
- Icons have been added to highlight the supplemental media resources
- Many new chapter openers and interior photos are included

Retained Features:

- Over 1200 end-of-chapter problems and over 180 materials selection and design problems are offered
- Over 140 example problems
- Modern applications of materials
- A concise, readable style is used throughout; readers are given understandable explanations without excessive detail

## SUPPLEMENTS

### Student CD-ROM

There is a new student CD-ROM to accompany the fourth edition of *Foundations of Materials Science and Engineering* featuring a wealth of visualization and study materials.

- Three Virtual Labs, with video, interactive quizzing, and step-by-step real-life processes (with possible pitfalls), are included to better prepare students for the laboratory or serve as a simulation of an actual laboratory experience for students. Lab topics: Measurement of Hardness Using Rockwell Hardness test, Metallography, Tensile Testing.

- An extensive lab manual in PDF and Word formats coordinates with the Virtual Labs.
- MatVis is 2.0 crystal visualization software allows students to create different crystal structures and molecules, as well as view already created structures.
- ICENine Phase Diagram software allows students to search a list of phase diagrams and find the composition at any given temperature.
- EES (Engineering Equation Solver) computational software provides students with capability to solve materials science problems.
- Animations cover bonds, bond forces, rotating crystals, atomic packing arrangements, different crystal planes and coordination members, among other topics. Likewise, tutorials with sound are provided.
- Extensive, searchable materials properties database.
- Bonus chapters on "Materials for MEMS and Microsystems," a chapter from Tai-Ran Hsu's *MEMS and Microsystems: Design and Manufacture.*
- Numerous web links to professional sites and reference materials

## Instructor's Resource CD-ROM

- Lecture PowerPoint slides with added animations, videos, and images not included in the text
- Text images in Jpeg format
- Solutions manual in PDF and Word formats
- Teaching resources to help instructors incorporate the Virtual Labs and other media into their course
- Lab manual to accompany the Virtual Labs
- Sample syllabi
- Transition guides to help instructors transition from their current text to the fourth edition of Smith/Hashemi

**COSMOS CD-ROM for Instructors** The detailed solutions for all text problems are delivered in our new electronic Complete Online Solutions Manual Organization System. COSMOS is a database management tool geared towards assembling homework assignments, tests and quizzes. No longer do instructors need to wade through thick solutions manuals or huge Word files. COSMOS helps them to quickly find solutions, and also keeps a record of problems assigned to avoid duplication in subsequent semesters. Instructors can contact their McGraw-Hill sales representative at www.mhhe.com/catalogs/rep/ to obtain a copy of the COSMOS solutions manual.

**Online Learning Center** Web support is provided for the book at the website www.mhhe.com/smithmaterials. Visit this site for book and supplement information, errata, author information, and resources for further study or reference.

## ACKNOWLEDGMENTS

The co-author, Javad Hashemi, would like to acknowledge the everlasting love, support, encouragement, and guidance of his mother, Sedigheh, throughout the course of his life and career. He dedicates this textbook to her, to the love of his life Eva, to the most precious gifts of his life, Evan and Jonathon, to his siblings, and last but not least to the memory of his father.

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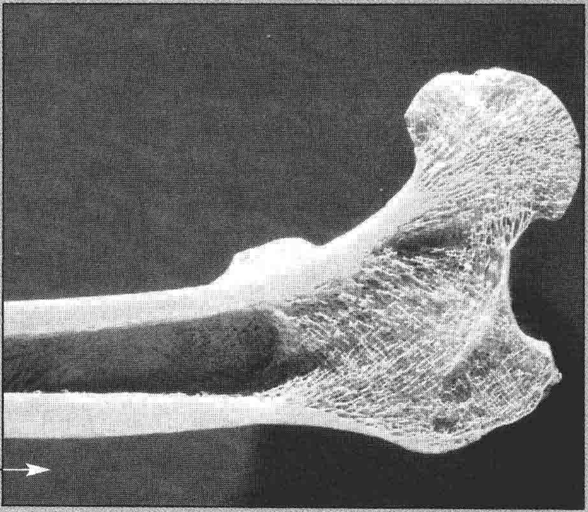
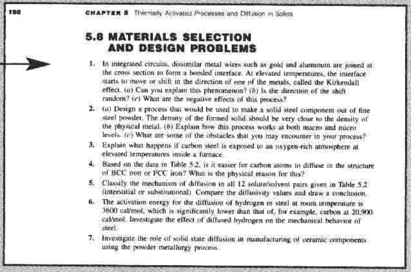
**Javad Hashemi**

# GUIDED TOUR

Modern materials science topics have been added throughout the text including:

- Smart materials/devices, MEMs and nanomaterials
- Biomedical applications
- Chapter 4 has been split into two chapters to allow diffusion to be covered alone
- Three new sections devoted to advanced alloys and their application in biomedical engineering
- Ceramics coverage has been expanded to include nanotechnology and ceramics



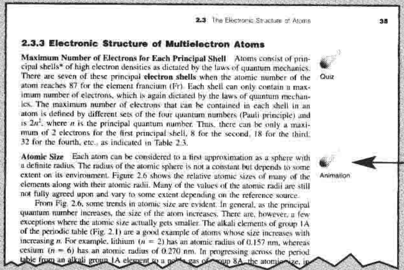


198 **CHAPTER 5** Thermally Activated Processes and Diffusion in Solids

**5.8 MATERIALS SELECTION AND DESIGN PROBLEMS**

1. In integrated circuits, dissimilar metal wires such as gold and aluminum are joined at the cross section to form a bonded interface. At elevated temperatures, the interface starts to move or shift in the direction of one of the metals, called the Kirkendall effect. (*a*) Can you explain this phenomenon? (*b*) Is the direction of the shift random? (*c*) What are the negative effects of this process?
2. (*a*) Design a process that would be used to make a solid steel component out of fine steel powder. The density of the formed solid should be very close to the density of the physical metal. (*b*) Explain how this process works at both macro and micro levels. (*c*) What are some of the obstacles that you may encounter in your process?
3. Explain what happens if carbon steel is exposed to an oxygen-rich atmosphere at elevated temperatures inside a furnace.
4. Based on the data in Table 5.2, is it easier for carbon atoms to diffuse in the structure of BCC iron or FCC iron? What is the physical reason for this?
5. Classify the mechanism of diffusion in all 12 solute/solvent pairs given in Table 5.2 (interstitial or substitutional). Compare the diffusivity values and draw a conclusion.
6. The activation energy for the diffusion of hydrogen in steel at room temperature is 3600 cal/mol, which is significantly lower than that of, for example, carbon at 20,900 cal/mol. Investigate the effect of diffused hydrogen on the mechanical behavior of steel.
7. Investigate the role of solid state diffusion in manufacturing of ceramic components using the powder metallurgy process.

Materials selection and design problems follow the end-of-chapter problems. These problems challenge students to create engineering solutions through materials selection and process design.



**2.3** The Electronic Structure of Atoms 35

**2.3.3 Electronic Structure of Multielectron Atoms**

**Maximum Number of Electrons for Each Principal Shell** Atoms consist of principal shells* of high electron densities as dictated by the laws of quantum mechanics. There are seven of these principal **electron shells** when the atomic number of the atom reaches 87 for the element francium (Fr). Each shell can only contain a maximum number of electrons, which is again dictated by the laws of quantum mechanics. The maximum number of electrons that can be contained in each shell in an atom is defined by different sets of the four quantum numbers (Pauli principle) and is $2n^2$, where $n$ is the principal quantum number. Thus, there can be only a maximum of 2 electrons for the first principal shell, 8 for the second, 18 for the third, 32 for the fourth, etc., as indicated in Table 2.3.

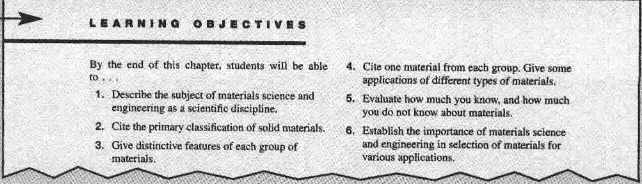
Quiz

**Atomic Size** Each atom can be considered to a first approximation as a sphere with a definite radius. The radius of the atomic sphere is not a constant but depends to some extent on its environment. Figure 2.6 shows the relative atomic sizes of many of the elements along with their atomic radii. Many of the values of the atomic radii are still not fully agreed upon and vary to some extent depending on the reference source.

Animation

From Fig. 2.6, some trends in atomic size are evident. In general, as the principal quantum number increases, the size of the atom increases. There are, however, a few exceptions where the atomic size actually gets smaller. The alkali elements of group 1A of the periodic table (Fig. 2.1) are a good example of atoms whose size increases with increasing $n$. For example, lithium ($n = 2$) has an atomic radius of 0.157 nm, whereas cesium ($n = 6$) has an atomic radius of 0.270 nm. In progressing across the period table from an alkali group 1A element to a noble gas of group 8A, the atomic size, in

Icons have been added to highlight the media supplement resources.



**LEARNING OBJECTIVES**

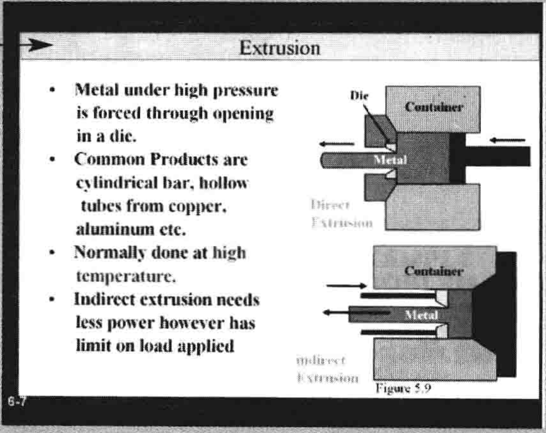
By the end of this chapter, students will be able to . . .

1. Describe the subject of materials science and engineering as a scientific discipline.
2. Cite the primary classification of solid materials.
3. Give distinctive features of each group of materials.
4. Cite one material from each group. Give some applications of different types of materials.
5. Evaluate how much you know, and how much you do not know about materials.
6. Establish the importance of materials science and engineering in selection of materials for various applications.

Learning Objectives have been added to each chapter to guide students' comprehension of the material.

# Teaching Supplements for the Instructor

## Instructor's Resource CD-ROM




Offering a wide range of class preparation and presentation resources, this CD helps instructors to easily transition to Smith/Hashemi's new edition.

- Lecture PowerPoint slides with added animations, videos, and images not included in the text
- Text images in Jpeg format
- Solutions manual in PDF and Word formats
- Teaching resources to help instructors incorporate the Virtual Labs and other media into their course
- Lab manual to accompany the Virtual Labs
- Sample syllabi
- Transition guides—to help instructors transition from their current text to the fourth edition of Smith/Hashemi

## COSMOS CD-ROM

This CD, also available to instructors only, provides electronic solutions delivered via our database management tool. McGraw-Hill's COSMOS is a powerful solutions manual tool to help instructors streamline the creation of assignments, quizzes, and tests by using problems and solutions from the textbook—as well as their own custom material.

## Engineering Equation Solver (EES)

EES is a powerful equation solver with built-in functions and property tables for thermodynamic and transport properties as well as automatic unit checking capability. It requires less time than a calculator for data entry and allows more time for thinking critically about modeling and solving engineering problems. While every new copy of our text is packaged with a CD-ROM containing the Limited Academic Version of EES, the full academic version of the EES engine is available free to departments of educational institutions who adopt this text.

## Course Management Systems—WebCT and Blackboard

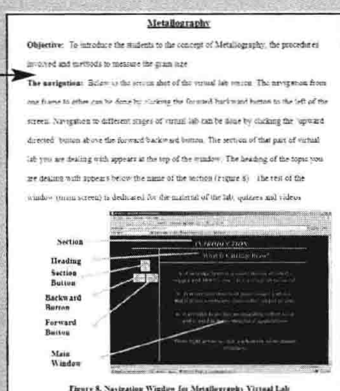
With help from our partners, WebCT and Blackboard, professors can take complete control over their course content. These course cartridges also provide online testing and powerful student tracking features.

# LEARNING SUPPLEMENTS FOR THE STUDENT

There is a new student CD-ROM to accompany the fourth edition of *Foundations of Materials Science and Engineering*. This CD-ROM features a wealth of visualization and study materials.

## VIRTUAL LABS

Three Virtual Labs, with video, interactive quizzing, and step-by-step real-life processes (with possible pitfalls), are included to better prepare students for the laboratory or serve as a simulation of an actual laboratory experience for students. Lab topics: Measurement of Hardness Using Rockwell Hardness test, Metallography, Tensile Testing. An extensive lab manual in PDF and Word formats coordinates with the Virtual Labs.

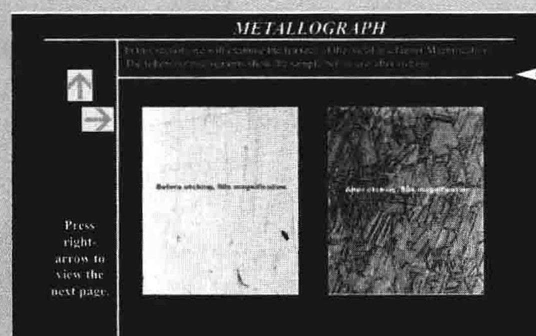

**Metallography**

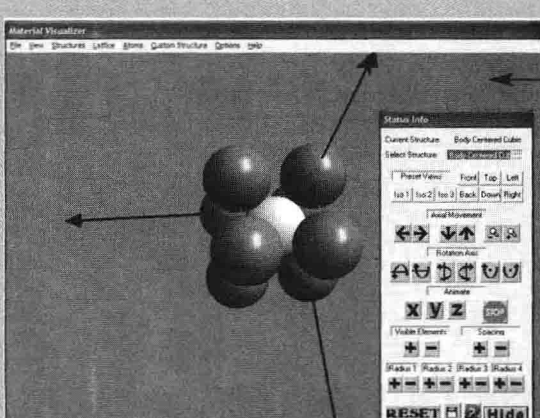
**Objective:** To introduce the students to the concept of Metallography, the procedures involved and methods to measure the grain size

**The navigation:** Below is the screen shot of the virtual lab screen. The navigation from one frame to other can be done by clicking the forward/backward button to the left of the screen. Navigation to different stages of virtual lab can be done by clicking the 'upward directed' button above the forward/backward button. The section of that part of virtual lab you are dealing with appears at the top of the window. The heading of the topic you are dealing with appears below the name of the section (Figure 8). The rest of the window (main screen) is dedicated for the material of the lab, quizzes and videos.



Figure 8. Navigation Window for Metallography Virtual Lab




## VISUALIZATION SOFTWARE

MatVis 2.0 crystal visualization software allows students to create different crystal structures and molecules, as well as view already created structures. ICENine Phase Diagram software allows students to search a list of phase diagrams and find the composition at any given temperature.

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