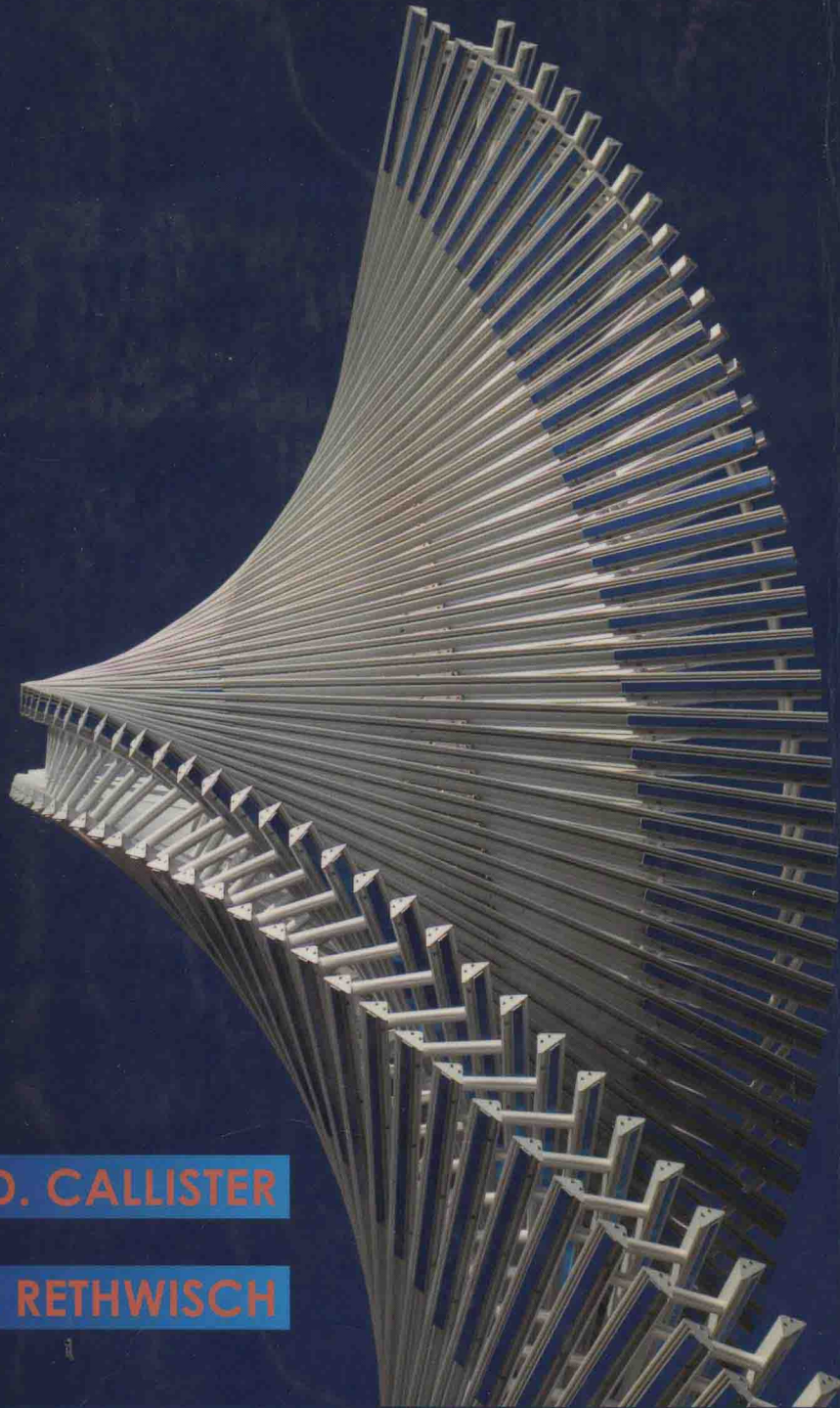


E · I · G · H · T · H E · D · I · T · I · O · N

Materials Science and Engineering



WILLIAM D. CALLISTER

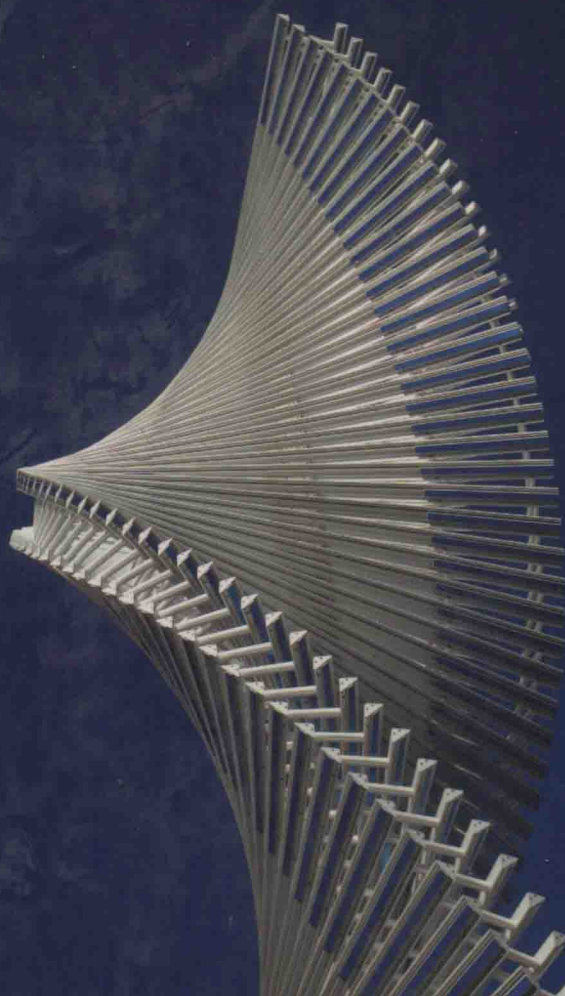
DAVID G. RETHWISCH

SI Version

Building on the extraordinary success of seven best-selling editions, Bill Callister's new Eighth Edition of **Materials Science and Engineering** continues to promote student understanding of the three primary types of materials (metals, ceramics, and polymers) and composites, as well as the relationships that exist between the structural elements of materials and their properties.

New to the Eighth Edition:

- Diffusion in semiconductors (Chapter 5);
- Flash memory (Chapter 18);
- "Biodegradable and Biorenewable Polymers/Plastics" Materials of Importance piece in Chapter 22.
- SI Version contains all International System of Units.



Authorized for sale in Canada, Australia, Europe, Asia, Africa and the Middle East Only

This book is authorized for sale in Canada, Australia, Europe, Asia, Africa and the Middle East only and may not be exported. Exportation from or importation of this book to another region without the Publisher's authorization is illegal and is a violation of the Publisher's rights. The Publisher may take legal action to enforce its rights. The Publisher may recover damages and costs, including but not limited to lost profits and attorney's fees, in the event legal action is required.



www.wiley.com/go/global/callister

ISBN 978-0-470-50586-1



90000



9 780470 505861

CALLISTER

RETHWISCH

Materials Science and Engineering

EIGHTH
EDITION



WILEY

EIGHTH EDITION

Materials Science and Engineering

William D. Callister, Jr.

*Department of Metallurgical Engineering
The University of Utah*

David G. Rethwisch

*Department of Chemical and Biochemical Engineering
The University of Iowa*

SI Version



WILEY

John Wiley & Sons, Inc.

Copyright © 2011 John Wiley & Sons (Asia) Pte Ltd

Cover image from © iStockphoto

All rights reserved. **This book is authorized for sale in Canada, Australia, Europe, Asia, Africa and the Middle East only and may not be exported outside of these territories.** Exportation from or importation of this book to another region without the Publisher's authorization is illegal and is a violation of the Publisher's rights. The Publisher may take legal action to enforce its rights. The Publisher may recover damages and costs, including but not limited to lost profits and attorney's fees, in the event legal action is required.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, website www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, website <http://www.wiley.com/go/permissions>.

ISBN: 978-0-470-50586-1

Printed in Asia

10 9 8 7 6 5 4 3 2 1

THE UNIVERSITY OF CHICAGO

Year	Month	Name	Address	City	State	Country
1951	Jan	John Doe	123 Main St	Chicago	Ill	USA
1952	Feb	Jane Smith	456 Elm St	Chicago	Ill	USA
1953	Mar	Robert Johnson	789 Oak St	Chicago	Ill	USA
1954	Apr	Mary White	101 Pine St	Chicago	Ill	USA
1955	May	James Brown	202 Cedar St	Chicago	Ill	USA
1956	Jun	Sarah Green	303 Birch St	Chicago	Ill	USA
1957	Jul	Michael Black	404 Spruce St	Chicago	Ill	USA
1958	Aug	Linda Gray	505 Willow St	Chicago	Ill	USA
1959	Sep	David King	606 Ash St	Chicago	Ill	USA
1960	Oct	Elizabeth Lee	707 Hickory St	Chicago	Ill	USA
1961	Nov	William Hall	808 Magnolia St	Chicago	Ill	USA
1962	Dec	Patricia Young	909 Sycamore St	Chicago	Ill	USA
1963	Jan	Richard Scott	1010 Dogwood St	Chicago	Ill	USA
1964	Feb	Barbara Adams	1111 Redwood St	Chicago	Ill	USA
1965	Mar	Christopher Baker	1212 Cypress St	Chicago	Ill	USA
1966	Apr	Nancy Wilson	1313 Juniper St	Chicago	Ill	USA
1967	May	Gregory Taylor	1414 Fir St	Chicago	Ill	USA
1968	Jun	Amanda Evans	1515 Hemlock St	Chicago	Ill	USA
1969	Jul	Benjamin Clark	1616 Larch St	Chicago	Ill	USA
1970	Aug	Stephanie Lewis	1717 Alder St	Chicago	Ill	USA
1971	Sep	Jonathan Hall	1818 Hawthorn St	Chicago	Ill	USA
1972	Oct	Christina King	1919 Beech St	Chicago	Ill	USA
1973	Nov	Matthew Lee	2020 Elm St	Chicago	Ill	USA
1974	Dec	Olivia Brown	2121 Maple St	Chicago	Ill	USA
1975	Jan	Isaac Green	2222 Oak St	Chicago	Ill	USA
1976	Feb	Sophia White	2323 Pine St	Chicago	Ill	USA
1977	Mar	Ethan Black	2424 Cedar St	Chicago	Ill	USA
1978	Apr	Ava Gray	2525 Birch St	Chicago	Ill	USA
1979	May	Noah King	2626 Spruce St	Chicago	Ill	USA
1980	Jun	Leah Lee	2727 Willow St	Chicago	Ill	USA
1981	Jul	Lucas Brown	2828 Ash St	Chicago	Ill	USA
1982	Aug	Grace White	2929 Hickory St	Chicago	Ill	USA
1983	Sep	Henry Black	3030 Magnolia St	Chicago	Ill	USA
1984	Oct	Isabella Gray	3131 Sycamore St	Chicago	Ill	USA
1985	Nov	Julian King	3232 Dogwood St	Chicago	Ill	USA
1986	Dec	Charlotte Lee	3333 Redwood St	Chicago	Ill	USA
1987	Jan	Samuel Brown	3434 Cypress St	Chicago	Ill	USA
1988	Feb	Amelia White	3535 Juniper St	Chicago	Ill	USA
1989	Mar	Benjamin Black	3636 Fir St	Chicago	Ill	USA
1990	Apr	Harriet Gray	3737 Hemlock St	Chicago	Ill	USA
1991	May	Isaac King	3838 Larch St	Chicago	Ill	USA
1992	Jun	Abigail Lee	3939 Alder St	Chicago	Ill	USA
1993	Jul	Jack Brown	4040 Hawthorn St	Chicago	Ill	USA
1994	Aug	Emily White	4141 Beech St	Chicago	Ill	USA
1995	Sep	Robert Black	4242 Elm St	Chicago	Ill	USA
1996	Oct	Victoria Gray	4343 Maple St	Chicago	Ill	USA
1997	Nov	William King	4444 Oak St	Chicago	Ill	USA
1998	Dec	Madeline Lee	4545 Pine St	Chicago	Ill	USA
1999	Jan	James Brown	4646 Cedar St	Chicago	Ill	USA
2000	Feb	Elizabeth White	4747 Birch St	Chicago	Ill	USA
2001	Mar	Michael Black	4848 Spruce St	Chicago	Ill	USA
2002	Apr	Sarah Gray	4949 Willow St	Chicago	Ill	USA
2003	May	David King	5050 Ash St	Chicago	Ill	USA
2004	Jun	Linda Lee	5151 Hickory St	Chicago	Ill	USA
2005	Jul	Christopher Brown	5252 Magnolia St	Chicago	Ill	USA
2006	Aug	Nancy White	5353 Sycamore St	Chicago	Ill	USA
2007	Sep	Gregory Black	5454 Dogwood St	Chicago	Ill	USA
2008	Oct	Amanda Gray	5555 Redwood St	Chicago	Ill	USA
2009	Nov	Benjamin King	5656 Cypress St	Chicago	Ill	USA
2010	Dec	Stephanie Lee	5757 Juniper St	Chicago	Ill	USA
2011	Jan	Jonathan Brown	5858 Fir St	Chicago	Ill	USA
2012	Feb	Christina White	5959 Hemlock St	Chicago	Ill	USA
2013	Mar	Matthew Black	6060 Larch St	Chicago	Ill	USA
2014	Apr	Olivia Gray	6161 Alder St	Chicago	Ill	USA
2015	May	Lucas King	6262 Hawthorn St	Chicago	Ill	USA
2016	Jun	Leah Lee	6363 Beech St	Chicago	Ill	USA
2017	Jul	Isaac Brown	6464 Elm St	Chicago	Ill	USA
2018	Aug	Grace White	6565 Maple St	Chicago	Ill	USA
2019	Sep	Henry Black	6666 Oak St	Chicago	Ill	USA
2020	Oct	Isabella Gray	6767 Pine St	Chicago	Ill	USA
2021	Nov	Julian King	6868 Cedar St	Chicago	Ill	USA
2022	Dec	Charlotte Lee	6969 Birch St	Chicago	Ill	USA
2023	Jan	Samuel Brown	7070 Spruce St	Chicago	Ill	USA
2024	Feb	Amelia White	7171 Willow St	Chicago	Ill	USA
2025	Mar	Benjamin Black	7272 Ash St	Chicago	Ill	USA
2026	Apr	Harriet Gray	7373 Hickory St	Chicago	Ill	USA
2027	May	Isaac King	7474 Magnolia St	Chicago	Ill	USA
2028	Jun	Abigail Lee	7575 Sycamore St	Chicago	Ill	USA
2029	Jul	Jack Brown	7676 Dogwood St	Chicago	Ill	USA
2030	Aug	Emily White	7777 Redwood St	Chicago	Ill	USA
2031	Sep	Robert Black	7878 Cypress St	Chicago	Ill	USA
2032	Oct	Victoria Gray	7979 Juniper St	Chicago	Ill	USA
2033	Nov	William King	8080 Fir St	Chicago	Ill	USA
2034	Dec	Madeline Lee	8181 Hemlock St	Chicago	Ill	USA
2035	Jan	James Brown	8282 Larch St	Chicago	Ill	USA
2036	Feb	Elizabeth White	8383 Alder St	Chicago	Ill	USA
2037	Mar	Michael Black	8484 Hawthorn St	Chicago	Ill	USA
2038	Apr	Sarah Gray	8585 Beech St	Chicago	Ill	USA
2039	May	David King	8686 Elm St	Chicago	Ill	USA
2040	Jun	Linda Lee	8787 Maple St	Chicago	Ill	USA
2041	Jul	Christopher Brown	8888 Oak St	Chicago	Ill	USA
2042	Aug	Nancy White	8989 Pine St	Chicago	Ill	USA
2043	Sep	Gregory Black	9090 Cedar St	Chicago	Ill	USA
2044	Oct	Amanda Gray	9191 Birch St	Chicago	Ill	USA
2045	Nov	Benjamin King	9292 Spruce St	Chicago	Ill	USA
2046	Dec	Stephanie Lee	9393 Willow St	Chicago	Ill	USA
2047	Jan	Jonathan Brown	9494 Ash St	Chicago	Ill	USA
2048	Feb	Christina White	9595 Hickory St	Chicago	Ill	USA
2049	Mar	Matthew Black	9696 Magnolia St	Chicago	Ill	USA
2050	Apr	Olivia Gray	9797 Sycamore St	Chicago	Ill	USA
2051	May	Lucas King	9898 Dogwood St	Chicago	Ill	USA
2052	Jun	Leah Lee	9999 Redwood St	Chicago	Ill	USA

Characteristics of Selected Elements

Element	Symbol	Atomic Number	Atomic Weight (amu)	Density of Solid, 20°C (g/cm ³)	Crystal Structure, 20°C	Atomic Radius (nm)	Ionic Radius (nm)	Most Common Valence	Melting Point (°C)
Aluminum	Al	13	26.98	2.71	FCC	0.143	0.053	3+	660.4
Argon	Ar	18	39.95	—	—	—	—	hert	-189.2
Barium	Ba	56	137.33	3.5	BCC	0.217	0.136	2+	725
Beryllium	Be	4	9.012	1.85	HCP	0.114	0.035	2+	1278
Boron	B	5	10.81	2.34	Rhomb.	—	0.023	3+	2300
Bromine	Br	35	79.90	—	—	—	0.196	—	-7.2
Cadmium	Cd	48	112.41	8.65	HCP	0.149	0.095	2+	321
Calcium	Ca	20	40.08	1.55	FCC	0.197	0.100	2+	839
Carbon	C	6	12.011	2.25	Hex.	0.071	~0.016	4+	(sublimes at 3367)
Cesium	Cs	55	132.91	1.87	BCC	0.265	0.170	1+	28.4
Chlorine	Cl	17	35.45	—	—	—	0.181	1-	-101
Chromium	Cr	24	52.00	7.19	BCC	0.125	0.063	3+	1875
Cobalt	Co	27	58.93	8.9	HCP	0.125	0.072	2+	1495
Copper	Cu	29	63.55	8.94	FCC	0.128	0.096	1+	1085
Fluorine	F	9	19.00	—	—	—	0.133	1-	-220
Gallium	Ga	31	69.72	5.90	Ortho.	0.122	0.062	3+	29.8
Germanium	Ge	32	72.64	5.32	Dia. cubic	0.122	0.053	4+	937
Gold	Au	79	196.97	19.32	FCC	0.144	0.137	1+	1064
Helium	He	2	4.003	—	—	—	—	Inert	-272 (at 26 atm)
Hydrogen	H	1	1.008	—	—	—	0.154	1-	-259
Iodine	I	53	126.91	4.93	Ortho.	0.136	0.220	1-	114
Iron	Fe	26	55.85	7.87	BCC	0.124	0.077	2+	1538
Lead	Pb	82	207.2	11.35	FCC	0.175	0.120	2+	327
Lithium	Li	3	6.94	0.534	BCC	0.152	0.068	1+	181
Magnesium	Mg	12	24.31	1.74	HCP	0.160	0.072	2+	649
Manganese	Mn	25	54.94	7.44	Cubic	0.112	0.067	2+	1244
Mercury	Hg	80	200.59	—	—	—	0.110	2+	-38.8
Molybdenum	Mo	42	95.94	10.22	BCC	0.136	0.070	4+	2617
Neon	Ne	10	20.18	—	—	—	—	Inert	-248.7
Nickel	Ni	28	58.69	8.90	FCC	0.125	0.069	2+	1455
Niobium	Nb	41	92.91	8.57	BCC	0.143	0.069	5+	2468
Nitrogen	N	7	14.007	—	—	—	0.01-0.02	5+	-209.9
Oxygen	O	8	16.00	—	—	—	0.140	2-	-218.4
Phosphorus	P	15	30.97	1.82	Ortho.	0.109	0.035	5+	44.1
Platinum	Pt	78	195.08	21.45	FCC	0.139	0.080	2+	1772
Potassium	K	19	39.10	0.862	BCC	0.231	0.138	1+	63
Silicon	Si	14	28.09	2.33	Dia. cubic	0.118	0.040	4+	1410
Silver	Ag	47	107.87	10.49	FCC	0.144	0.126	1+	962
Sodium	Na	11	22.99	0.971	BCC	0.186	0.102	1+	98
Sulfur	S	16	32.06	2.07	Ortho.	0.106	0.184	2-	113
Tin	Sn	50	118.71	7.27	Tetra.	0.151	0.071	4+	232
Titanium	Ti	22	47.87	4.51	HCP	0.145	0.068	4+	1668
Tungsten	W	74	183.84	19.3	BCC	0.137	0.070	4+	3410
Vanadium	V	23	50.94	6.1	BCC	0.132	0.059	5+	1890
Zinc	Zn	30	65.41	7.13	HCP	0.133	0.074	2+	420
Zirconium	Zr	40	91.22	6.51	HCP	0.159	0.079	4+	1852

Values of Selected Physical Constants

Quantity	Symbol	SI Units	cgs Units
Avogadro's number	N_A	6.022×10^{23} molecules/mol	6.022×10^{23} molecules/mol
Boltzmann's constant	k	1.38×10^{-23} J/atom · K	1.38×10^{-16} erg/atom · K 8.62×10^{-5} eV/atom · K
Bohr magneton	μ_B	9.27×10^{-24} A · m ²	9.27×10^{-21} erg/gauss ^a
Electron charge	e	1.602×10^{-19} C	4.8×10^{-10} statcoul ^b
Electron mass	—	9.11×10^{-31} kg	9.11×10^{-28} g
Gas constant	R	8.31 J/mol · K	1.987 cal/mol · K
Permeability of a vacuum	μ_0	1.257×10^{-6} henry/m	unity ^a
Permittivity of a vacuum	ϵ_0	8.85×10^{-12} farad/m	unity ^b
Planck's constant	h	6.63×10^{-34} J · s	6.63×10^{-27} erg · s 4.13×10^{-15} eV · s
Velocity of light in a vacuum	c	3×10^8 m/s (3×10^{10} cm/s)	9.8×10^8 ft/s

^a In cgs-emu units.

^b In cgs-esu units.

Unit Abbreviations

A = ampere	in. = inch	N = newton
Å = angstrom	J = joule	nm = nanometer
Btu = British thermal unit	K = degrees Kelvin	P = poise
C = Coulomb	kg = kilogram	Pa = Pascal
°C = degrees Celsius	lb _f = pound force	s = second
cal = calorie (gram)	lb _m = pound mass	T = temperature
cm = centimeter	m = meter	μm = micrometer (micron)
eV = electron volt	Mg = megagram	W = watt
°F = degrees Fahrenheit	mm = millimeter	psi = pounds per square inch
ft = foot	mol = mole	
g = gram	MPa = megapascal	

SI Multiple and Submultiple Prefixes

Factor by Which Multiplied	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi ^a	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

^a Avoided when possible.

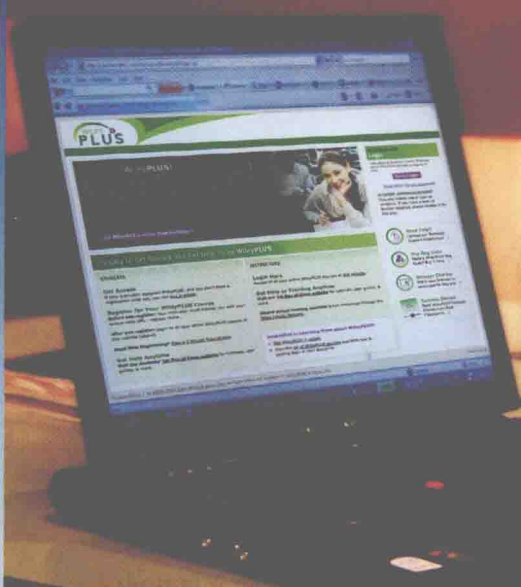




This online teaching and learning environment integrates the **entire digital textbook** with the most effective instructor and student resources to fit every learning style.

With WileyPLUS:

- Students achieve concept mastery in a rich, structured environment that's available 24/7
- Instructors personalize and manage their course more effectively with assessment, assignments, grade tracking, and more



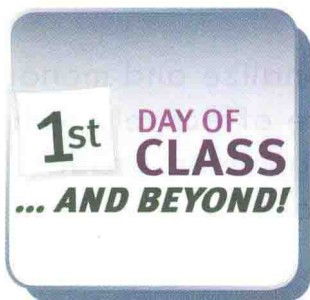
- manage time better
- study smarter
- save money

From multiple study paths, to self-assessment, to a wealth of interactive visual and audio resources, *WileyPLUS* gives you everything you need to personalize the teaching and learning experience.

»Find out how to **MAKE IT YOURS**»

www.wileyplus.com

ALL THE HELP, RESOURCES, AND PERSONAL SUPPORT YOU AND YOUR STUDENTS NEED!



2-Minute Tutorials and all of the resources you & your students need to get started
www.wileyplus.com/firstday



Student support from an experienced student user
 Ask your local representative for details!



Collaborate with your colleagues, find a mentor, attend virtual and live events, and view resources
www.WhereFacultyConnect.com



Pre-loaded, ready-to-use assignments and presentations
www.wiley.com/college/quickstart



Technical Support 24/7
 FAQs, online chat, and phone support
www.wileyplus.com/support



Your WileyPLUS Account Manager
 Training and implementation support
www.wileyplus.com/accountmanager

Dedicated to

*our wives, Nancy and Ellen, whose love, patience, and understanding
have helped make this volume possible*

In this Eighth Edition we have retained the objectives and approaches for teaching materials science and engineering that were presented in previous editions. **The first, and primary, objective** is to present the basic fundamentals on a level appropriate for university/college students who have completed their freshmen calculus, chemistry, and physics courses. In order to achieve this goal, we have endeavored to use terminology that is familiar to the student who is encountering the discipline of materials science and engineering for the first time, and also to define and explain all unfamiliar terms.

The second objective is to present the subject matter in a logical order, from the simple to the more complex. Each chapter builds on the content of previous ones.

The third objective, or philosophy, that we strive to maintain throughout the text is that if a topic or concept is worth treating, then it is worth treating in sufficient detail and to the extent that students have the opportunity to fully understand it without having to consult other sources; also, in most cases, some practical relevance is provided. Discussions are intended to be clear and concise and to begin at appropriate levels of understanding.

The fourth objective is to include features in the book that will expedite the learning process. These learning aids include:

- Numerous illustrations, now presented in full color, and photographs to help visualize what is being presented;
- Learning objectives, to focus student attention on what they should be getting from each chapter;
- “Why Study . . .” and “Materials of Importance” items that provide relevance to topic discussions;
- “Concept Check” questions that test whether or not a student understands the subject matter on a conceptual level;
- Key terms and descriptions of key equations highlighted in the margins for quick reference;
- End-of-chapter questions and problems designed to progressively develop students’ understanding of concepts and facility with skills;
- Answers to selected problems, so that students can check their work;
- A glossary, list of symbols, and references to facilitate understanding the subject matter.

The fifth objective is to enhance the teaching and learning process by using the newer technologies that are available to most instructors and students of engineering today.

FEATURES THAT ARE NEW TO THIS EDITION

New/Revised Content

Several important changes have been made with this Eighth Edition. One of the most significant is the incorporation of a number of new sections, as well as revisions/amplifications of other sections. New sections/discussions are as follows:

- Diffusion in semiconductors (Section 5.6).
- Flash memory (in Section 18.15).
- “Biodegradable and Biorenewable Polymers/Plastics” Materials of Importance piece in Chapter 22.

Other revisions and additions include the following:

- Expanded discussion on nanomaterials (Section 1.5).
- A more comprehensive discussion on the construction of crystallographic directions in hexagonal unit cells—also of conversion from the three-index scheme to four-index (Section 3.9).
- Expanded discussion on titanium alloys (Section 11.3).
- Revised and enlarged treatment of hardness and hardness testing of ceramics (Section 12.11).
- Updated discussion on the process for making sheet glass (in Section 13.9).
- Updates on magnetic storage (hard disk drives and magnetic tapes—Section 20.11).
- Minor updates and revisions in Chapter 22 (“Economic, Environmental, and Societal Issues in Materials Science and Engineering”), especially on recycling.
- **Appendix C (“Costs and Relative Costs for Selected Engineering Materials”)** has been updated.
- **End-of chapter summaries** have been revised to reflect answers/responses to the extended lists of learning objectives, to better serve students as a study guide.
- **Summary table of important equations** at the end of each chapter.
- **Summary list of symbols** at the end of each chapter.
- **New chapter-opener photos and layouts**, focusing on applications of materials science to help engage students and motivate a desire to learn more about materials science.
- Virtually all **Homework problems** requiring computations have been refreshed.

Processing/Structure/Properties/Performance Correlations

One new feature that has been incorporated throughout this new edition is a tracking of relationships among the processing, structure, properties, and performance components for four different materials: steel alloys, glass-ceramics, polymer fibers, and silicon semiconductors. This concept is outlined in Chapter 1 (Section 1.7), which includes the presentation of a “topic timeline.” This timeline notes those locations (by section) where discussions involving the processing, structure, properties, and performance of each of these four material types are found.

These discussions are introduced in the “Why Study?” sections of appropriate chapters, and, in addition, end-of-chapter summaries with relational diagrams are also included. Finally, for each of the four materials a processing/structure/properties/

performance summary appears at the end of that chapter in which the last item on the topic timeline appears.

Discipline-Specific Modules

A set of discipline-specific modules appear on the book's web site (Student Companion Site). These modules treat materials science/engineering topics not covered in the print text that are relevant to specific engineering disciplines—mechanical and biomaterials.

All Chapters Now In Print

Five chapters of the previous edition were in electronic format only (i.e., not in print). In this edition, *all chapters are in print*.

Case Studies

In prior editions, “Materials Selection and Design Considerations” consisted of a series of case studies that were included as Chapter 22. These case studies will now appear as a library of case studies on the book's web site (Student Companion Site) at www.wiley.com/go/global/callister. This library includes the following:

- Materials Selection for a Torsionally Stressed Cylindrical Shaft
- Automobile Valve Spring
- Failure of an Automobile Rear Axle
- Artificial Total Hip Replacement
- Chemical Protective Clothing
- Materials for Integrated Circuit Packages

STUDENT LEARNING RESOURCES

(WWW.WILEY.COM/GO/GLOBAL/CALLISTER)

Also found on the book's web site (Student Companion Site) are several important instructional elements for the student that complement the text; these include the following:

1. *VMSE: Virtual Materials Science and Engineering*. This is an expanded version of the software program that accompanied the previous edition. It consists of interactive simulations and animations that enhance the learning of key concepts in materials science and engineering, and, in addition, a materials properties/cost database. Students can access *VMSE* via the registration code included on the inside front cover of the textbook.

Throughout the book, whenever there is some text or a problem that is supplemented by *VMSE*, a small “icon” that denotes the associated module is included in one of the margins. These modules and their corresponding icons are as follows:

Metallic Crystal Structures
and Crystallography



Phase Diagrams



Ceramic Crystal Structures



Diffusion



Repeat Unit and Polymer
Structures



Tensile Tests



Dislocations



Solid-Solution Strengthening



2. *Answers to Concept Check questions.* Students can visit the web site to find the correct answers to the Concept Check questions.

3. *Extended Learning Objectives*—a more extensive list of learning objectives than is provided at the beginning of each chapter. These direct the student to study the subject material to a greater degree of depth.

4. *Direct access to online self-assessment exercises.* This is a Web-based assessment program that contains questions and problems similar to those found in the text; these problems/questions are organized and labeled according to textbook sections. An answer/solution that is entered by the user in response to a question/problem is graded immediately, and comments are offered for incorrect responses. The student may use this electronic resource to review course material, and to assess his/her mastery and understanding of topics covered in the text.

5. *Index of Learning Styles.* Upon answering a 44-item questionnaire, a user's learning style preference (i.e., the manner in which information is assimilated and processed) is assessed.

INSTRUCTORS' RESOURCES

The Instructor Companion Site (www.wiley.com/go/global/callister) is available for instructors who have adopted this text. Please visit the web site to register for access. Resources that are available include the following:

1. *Instructor Solutions Manual.* Detailed solutions of all end-of-chapter questions and problems (in both Word® and Adobe Acrobat® PDF formats).

2. *Photographs, illustrations, and tables that appear in the book.* These are in both PDF and JPEG formats so that an instructor can print them for handouts or prepare transparencies in his/her desired format.

3. *A set of PowerPoint® lecture slides.* These slides, developed by Peter M. Anderson (The Ohio State University), and adapted by the text authors, follow the flow of topics in the text, and include materials from the text and from other sources. Instructors may use the slides as is or edit them to fit their teaching needs.

4. *A list of classroom demonstrations and laboratory experiments.* These portray phenomena and/or illustrate principles that are discussed in the book; references are also provided that give more detailed accounts of these demonstrations.

5. In addition, all of the student learning resources described above are available on the Instructor Companion Site.

WILEYPLUS

This online teaching and learning environment integrates the entire digital textbook with the most effective instructor and student resources to fit every learning style.

With *WileyPLUS*:

- Students achieve concept mastery in a rich, structured environment that's available 24/7.
- Instructors personalize and manage their course more effectively with assessment, assignments, grade tracking, and more.