INTERNATIONAL EDITION

Introduction To Materials Science And Engineering

A Guided Inquiry

Elliot P. Douglas

ALWAYS LEARNING

PEARSON

Physical Constants

Avogadro's number, N_A	6.023×10^{23} mol^{-1}
Atomic mass unit, amu	1.661×10^{-27} kg
Electric permittivity of a vacuum, ϵ_0	8.854×10^{-12} C/(V · m)
Electron mass	9.109×10^{-31} kg
Elementary charge, e	1.602×10^{-19} C
Gas constant, R	8.314 J/(mol · K)
	1.986 cal/(mol · K)
	5.189×10^{19} eV/(mol − K)
Boltzmann's constant, k	1.38×10^{-23} J/K
	8.62×10^{-5} eV/K
Planck's constant, h	6.626×10^{-34} J · s
Speed of light (in vacuum), c	2.998×10^{8} m/s
Bohr magneton, μ_B	9.274×10^{-24} A · m^2

SI Prefixes

giga, G	10^9
mega, M	10^6
kilo, k	10^3
milli, m	10^{-3}
micro, μ	10^{-6}
nano, n	10^{-9}
pico, p	10^{-12}

Conversion Factors

Length	1 meter	= 10^{10} Å = 10^9 nm
		= 3.281 ft
		= 39.37 in.
Mass	1 kilogram	= 2.205 lb$_m$
Force	1 newton	= 0.2248 lb$_f$
Pressure	1 pascal	= 1 N/m^2
		= 0.102 kg$_f$ /m^2
		= 9.869×10^{-6} atm
		= 145×10^{-6} psi
Viscosity	1 Pa · s	= 10 poise
Energy	1 joule	= 1 W · s
		= 1 N · m
		= 1 V · C
		= 0.239 cal
		= 6.242×10^{18} eV
		= 0.7376 ft lb$_f$
Temperature	˚C	= K − 273
		= (˚F − 32)/1.8
Current	1 ampere	= 1 C/s
		= 1 V/Ω

Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.71	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc 98.91	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.4	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
6	55 Cs 132.91	56 Ba 137.33	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.22	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.2	83 Bi 208.98	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra 226.03	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (266)												

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

Introduction to Materials Science *and* Engineering

A GUIDED INQUIRY

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Elliot P. Douglas
University of Florida

International Editions
contributions by
Abhishek Kumar Singh
Indian Institute of Science
Bangalore

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Contents

Preface to Instructors

This is not a typical textbook. Typical textbooks really serve as reference texts, a place where students can go to find information that they need. This text is designed with a very different goal in mind. It is a learning tool, a book that students use to help them learn. Thus, two very important philosophies underlie it:

1. *Students learn by being actively engaged.* The theory of constructivism states that learning occurs when learners "think about what the teacher tells them and interpret it in terms of their own experiences, beliefs, and knowledge."[1] One practical application of the constructivist approach is through the learning cycle model.[2–4] In this model there are three phases of learning. The first is *exploration*, in which the learner manipulates data or information. This leads to the second phase, *concept invention* or *term introduction*. In this phase the learner uses the data to develop general rules or concepts. Finally, in the *application* phase, the learner applies the concepts developed to new situations. This learning cycle models both the way scientific research is done and the way young children learn about their world. Traditional teaching skips the exploration phase and begins with concept invention. Studies have shown, however, that learning occurs better when the concept invention phase comes later in the sequence[3, 5, 6] and when the learners themselves invent the concepts (rather than being told about them). This approach to learning is the basis for constructivism. In a constructivist approach the roles of the instructor and students are quite different from those in a traditional class.[7] In the approach used in this text, students work together in teams to come to a common understanding of new concepts.
2. *Students do not need to be told every detail about every topic.* Rather, they need to learn the fundamental concepts. For example, this book does not have information about all 14 Bravais lattices. Rather, it focuses on the cubic crystal systems, with the idea that these systems serve as models from which students can learn the important concepts of crystals.

This book can be used in many ways, but was written based on the approach of Process-Oriented Guided Inquiry Learning (POGIL). POGIL was initially developed as a means of teaching general chemistry and has since spread to many other fields. POGIL is used in many different ways, but its basic approach shifts the primary responsibility for learning from the instructor to the student. There are many resources at the POGIL website (http://pogil.org/), including a detailed Instructor's Guide to POGIL (http://pogil.org/resources/implementation/instructors-guide). The preface you are reading now describes how I use it in my 100-student Introduction to Materials class. For more details and other tips on how to implement POGIL in your class, you should get the free Instructor's Guide from the POGIL website.

In my POGIL class I do not lecture. Rather, students work in teams, typically of four students, using the book as their guide. Each section of the text has three primary components: 1) data or information as background material; 2) guided inquiry questions, which are designed to lead the students to understanding the fundamental concepts represented by the data; and 3) application questions (end-of-chapter problems), which provide the students with practice in solving problems using the concepts they have derived. My role is to guide the students, walking around the room and probing them with questions to check their understanding. Farrell et al. have described the roles of students within the groups and the class procedures.[8, 9] Typical roles are Manager (responsible for ensuring that tasks are completed), Recorder (records the group's answers), Presenter (presents group answers to the class), and Technician (the only person allowed to use a calculator). The typical class period proceeds as follows:

1. I give a brief recap of the previous day or an introduction to that day. Sometimes basic content is provided in a mini-lecture.
2. Students begin working on the day's section of the text.
3. I observe the groups and may interact with them in several ways. I may respond to questions from a particular group or may ask questions of particular members of a group. This latter technique is particularly useful if it appears that one member of a group is lagging behind the others in understanding.
4. If a particular question is causing difficulty for several groups, I may choose to interrupt all groups and have the Presenters from each group discuss their group's answer. In this way, different approaches can be compared and a consensus answer obtained.
5. Concept Checks are provided throughout the class period using student response systems ("clickers"). These multiple-choice questions are an important way to give students feedback on their understanding of the concepts. Without this feedback students often feel "lost" and may think they have not learned anything. If most members of the class get the question correct, we move on to the next section of the text. If a substantial number of students get it wrong, we discuss the possible answers and then try the question again.
6. With about 5 to 10 minutes left in class I stop the activity. I may summarize the day's activities myself, or ask the Presenters to present some aspect of their group's work as a means of providing a summary. Reviewing the learning objectives for that day's section of the text provides a useful means of summarizing the class period and pointing out to the students what they have learned that day.
7. Students are then given a brief period of time to answer a series of questions, such as: *What was the most important thing you learned today? What questions do you still have about the material? What was a strength of your group's performance? What could be improved about your group's performance?* The answers to these questions serve as the basis for the review and introduction for the next day.

This approach has been used successfully in a wide variety of classrooms, from large introductory classes of 300 students to smaller classes of 20. It has many variations, and each instructor must decide what works best for their classroom. Ultimately, however, the focus should be on enabling students to actively engage in the content and discover those concepts for themselves.

Resources for Instructors

MasteringEngineering™. www.masteringengineering.com. The Mastering™ platform is the most effective and widely used online tutorial, homework, and assessment system for the sciences and engineering. Now including Materials Science and Engineering, this online tutorial homework program provides instructors customizable, easy-to-assign, and automatically graded assessments, plus a powerful gradebook for tracking student and class performance.

Pearson eText. The integration of Pearson eText within MasteringEngineering gives students with eTexts easy access to the electronic text when they are logged into MasteringEngineering. Pearson eText pages look exactly like the printed text, offering additional functionality for students and instructors including highlighting, bookmarking, and multiple view formats.

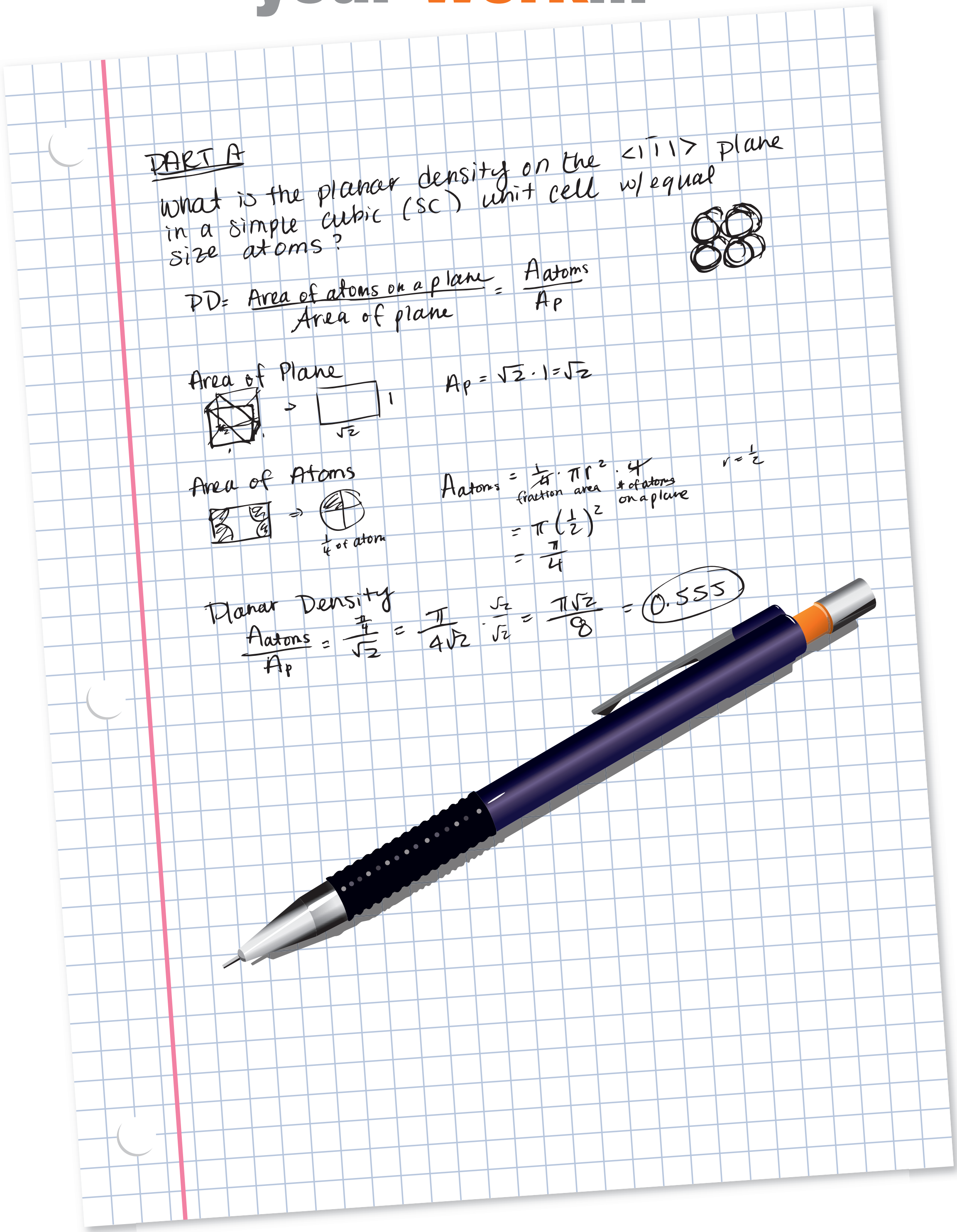
Instructor's Manual. The instructor's manual includes solutions to all of the problems from the book as well as to the Guided Inquiry Activities. The manual also includes suggested guidelines and best practices for implementing Guided Inquiry in class.

Presentation Resources. Photographs, figures, tables, and charts from the book are available as PowerPoint slides. A set of lecture slides written by the author will also be available.

All requests for instructor resources are verified against our customer database and/or through contacting the requestor's institution. Contact your local Pearson Education representative for additional information.

1. Jonassen, D. H. *Computers as Mindtools for Schools, Engaging Critical Thinking,* 2nd ed. Upper Saddle River, NJ: Prentice-Hall, 1996.
2. Lawson, A. E. *Science Teaching and the Development of Thinking*. Belmont, CA: Wadsworth Publishing Company, 1995.
3. Abraham, M. R., and Renner, J. W. "The sequence of learning cycle activities in high school chemistry." *J Res Sci Teach* (1986), 23(2): 121–43.
4. Renner, J.W. et al. "The importance of the form of student acquisition of data in physics learning cycles." *J Res Sci Teach* (1985), 22(4): 303–25.
5. Hall, D. A., and McCurdy, D. W. "A comparison of a biological sciences curriculum study (BSCS) laboratory and a traditional laboratory on student achievement at two private liberal arts colleges." *J Res Sci Teach* (1990), 27(7): 625–36.
6. Renner, J. W., and Paske, W. C. "Comparing two forms of instruction in college physics." *Amer J Phys* (1977), 45(9): 8519.
7. Spencer, J. N. "New directions in teaching chemistry: A philosophical and pedagogical basis." *J Chem Educ* (1999), 76(4): 566–9.
8. Farrell, J. J., Moog, R. S., and Spencer, J. N. "A guided inquiry general chemistry course." *J Chem Educ* (1999), 76(4): 570–4.
9. Hanson, D., and Wolfskill, T. "Process workshops–A new model for instruction." *J Chem Educ* (2000), 77(1): 120–30.

your work...

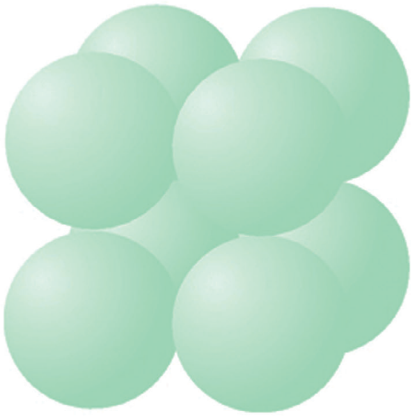

PART A
What is the planar density on the <1̄11> plane in a simple cubic (SC) unit cell w/ equal size atoms?
PD = Area of atoms on a plane / Area of plane = Aatoms / Ap
Area of Plane
1
√2
Ap = √2 · 1 = √2
Area of Atoms
1/4 of atom
Aatoms = 1/4 · πr² · 4
fraction area
# of atoms on a plane
r = 1/2
= π(1/2)²
= π/4
Planar Density
Aatoms / Ap = (π/4) / √2 = π / 4√2 · √2/√2 = π√2 / 8 = 0.555

your answer specific feedback

Part A

What is the planar density on the $\langle 1\bar{1}1 \rangle$ plane in a simple cubic (SC) unit cell with equal size atoms?

(Figure 1)



Express your answer numerically.

PD = .555

Submit   Hints   My Answers   Give Up   Review Part

Try Again; 5 attempts remaining

It appears that you calculated the planar density on the wrong plane. Recall that each index that defines the plane is the reciprocal of the intercept.

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Preface to Students

Teaching and learning are correlative or corresponding processes, as much so as selling and buying. One might as well say he has sold when no one has bought, as to say that he has taught when no one has learned.

John Dewey (1910). *How We Think.* Boston: D.C. Heath and Company, p. 29.

Botany is the study of plants, not the study of books.

Charles E. Bessey (1889). *The Essentials of Botany.* New York: Henry Holt, p. ix.

Take a moment and flip through this book. It looks a lot different from most other textbooks, doesn't it? That is because this is not a typical textbook. This book is based on the concept of *guided inquiry*—an approach to learning based on research on how people think and learn. Cognitive scientists (people who study how we think) have developed models to describe how we learn. A common feature of these models is that we don't learn by having information deposited in our brain. Instead, we learn when we try to figure out how something works, process information as we do that, and compare it to information we already have. A simple example would be how a toddler learns to eat with a spoon. We can't just tell the toddler what to do—the toddler has to play with the spoon and figure out how to make it work. Now think about how scientific discoveries occur—they occur when someone gathers a lot of data and then plays around with it trying to make sense out of it.

The same approach applies to learning in classrooms. It turns out that lectures are not a very good way to learn material. This may seem wrong to you. Because we've gotten used to lectures, many of us believe we learn best from lectures. If you believe this to be true about yourself, think back carefully to how you learned in a lecture class. Did you really understand the material at the moment the professor said it? Or did you need to play around with the material—rewriting your notes, solving the homework, discussing it with your friends—in order to understand it? Research clearly shows that learning improves in a classroom that is active, one in which the students are engaged by doing things. If you want to read a good summary of this research, find the article "Inductive teaching and learning methods: Definitions, comparisons, and research bases" by Michael Prince and Richard Felder (*J Eng Educ* (2006), 95(2): 123–138).

There are many different types of active learning. This text is based on one approach, called *guided inquiry*. Guided inquiry is in many ways like scientific research. You are asked to sort through information to come up with the general concepts. However, it is guided in the sense that you are not left completely on your own. To make sure that you get to the important concepts and don't go off in the wrong direction, you are asked to answer specific questions that have been written to help you sort through the information and get to the right place.

The Guided Inquiry Activities are comprised of two types of guided inquiry questions:

Exploration questions ask you to find information that is already presented in the text, or to give answers from common knowledge. You should not have to go searching other texts or websites to find the answers.

Concept invention questions ask you to use the answers from the exploration questions to figure out a general concept or approach to solving a problem. Again, you should not have to go searching other books or websites to find the answers. Use the answers to the exploration questions to figure these out. Concept invention question are the key questions of each chapter, because this is where the discovery occurs. In a typical lecture class you would be told the answers to these questions. However, if you work to figure them out yourself, you will understand the material better.

There is also a third type of guided inquiry question that is not part of the activities in the middle of the chapters. These are application questions, which give you practice using the concepts. The application questions are the end-of-chapter problems. There are two types of problems: *skill problems* and *conceptual problems*. Skill problems are very similar to the example problems in the chapter, and applying the concepts to them should be fairly straightforward. Conceptual problems ask you to think a bit beyond the example problems. They are still based on the same concepts, but they apply them in different ways from what you have seen in the chapters.

In addition to the guided inquiry questions, this book has several other features that will help you:

Concept Checks: These are questions that test your understanding of key points. Answers to the Concept Checks are in the back of the book, but before looking at the answers you should make sure to try to solve the questions yourself. It's much easier to see how an answer was obtained than to try to figure it out yourself.

Example Problems: Once you go through the questions and figure out the main concepts, you'll see example problems with solutions that can help you understand how to apply the concepts. Sometimes the example problems include hints that will help you when you have to solve similar problems. As with the Concept Checks, you should try to solve problems yourself before you look at the Example Problems for hints.

Application Spotlights: These are brief descriptions of how some of the concepts and ideas are actually used in engineering, with an emphasis on issues related to the environment.

Using this book may take some getting used to. You are probably being asked to think about new material in a way that you haven't been before. Give it a chance—if you embrace the approach and make an effort, you will find in the end that you will have a deeper understanding and that the extra work was worth it.

Acknowledgements

While this textbook was largely written over a three-year period, its origins go back much further. I took the first step on my path to this book when I was hired at the University of Florida in 1996. In my very first semester I gave some guest lectures in the Introduction to Polymers class and asked the students to give me end-of-semester evaluations. The response to my teaching was not positive, with comments such as, "Keep Douglas out of the classroom." I taught the Introduction to Materials course for the first time the following semester, spring of 1997, with results that were not much better. After struggling for a few semesters I was fortunate to be accepted to the Teaching Teachers to Teach Engineering (T4E) program at West Point in 1998, now known as the ExCEEd Teaching Workshop run by the American Society of Civil Engineers. At this program I learned how to be an effective lecturer, including my first introduction to some basic active learning techniques. I was fortunate to be invited back as a facilitator to help other faculty for the next eight years. Over that time many people gave me advice, too many to mention them all, but I would specifically like to thank Col. Stephen Ressler and Ltc. Jim O'Brien (ret) for their guidance and mentorship.

By the early 2000s I was growing dissatisfied with lectures and was looking for ways to more fully involve my students in their learning. At the American Chemical Society National Meeting in 2003 I happened onto a symposium on POGIL and was intrigued. I investigated it further and since I was teaching a freshman materials chemistry class the following spring, decided to use the existing POGIL materials for general chemistry in that class. I also requested that an experienced POGIL practitioner visit my classroom and host a workshop, mainly so I could learn more about POGIL. After that one-semester experiment that particular class was dropped from our curriculum (not because I had used POGIL!). The only choice remaining to me was to begin to write my own activities for my Introduction to Materials class. The first one I wrote was on mixtures, which eventually became Section 6.1 of this book.

A number of people associated with the POGIL Project supported and encouraged me from those first days. Again, there are too many to mention, but I would specifically like to thank Rick Moog of Franklin & Marshall College, Director of POGIL, and Frank Creegan, retired from Washington College. Also, critical support was provided by the National Science Foundation, who provided two grants for the initial development and testing of the materials that became this textbook.

This book would not have been possible without the vision of the staff at Pearson. Holly Stark, Executive Editor, had the vision to see the potential of moving beyond the traditional textbook to a new kind of learning. Without her support, both to me and within Pearson, this book would not have been possible. Clare Romeo, my production project manager, turned the manuscript into something that looks like a real textbook and that reflects the guided inquiry philosophy. Many others at Pearson whom I don't know had an integral hand in creating the book you are holding, and my appreciation goes out to those unsung and unknown contributors.

I used various versions of this manuscript over the course of seven years. The students in those classes suffered through mistakes in the manuscript, hand-drawn figures, and my fumbling attempts at using guided inquiry. To them I apologize and assure them that the input they provided, no matter how harsh it seemed to me at the time, only served to make this text better and to improve the experience of future students.

I also want to thank the reviewers who found mistakes and provided suggestions on how to improve the book: Richard Hennig, Cornell University; Patrick Ferro, Gonzaga University; David Bahr, Washington State University; Debbie Chachra, Olin College; Amy Moll, Boise State; Satya Shivkumar, Worcester Polytechnic Institute; Cindy Waters, NCA&T State University; Mark Weaver, University of Alabama; Lia Stanciu, Purdue University; Trevor Harding, California Polytechnic State University; Doug Irving, North Carolina State University; Stephen Krause, Arizona State; Jerry Floro, University of Virginia; Eunice Yang, University of Pittsburgh.

Finally, I want to thank my wife Heidi. While many authors thank their wives for support, Heidi played an active role in making this text what it is. She actively pushed me to write and publish this book, even before I started working with Pearson. During the writing production she made specific suggestions to improve it, and if you look carefully you will see she is credited with providing two of the photos (which are pictures of our two children, Spencer and Gracie). This text would not be what it is without her.

Elliot Douglas

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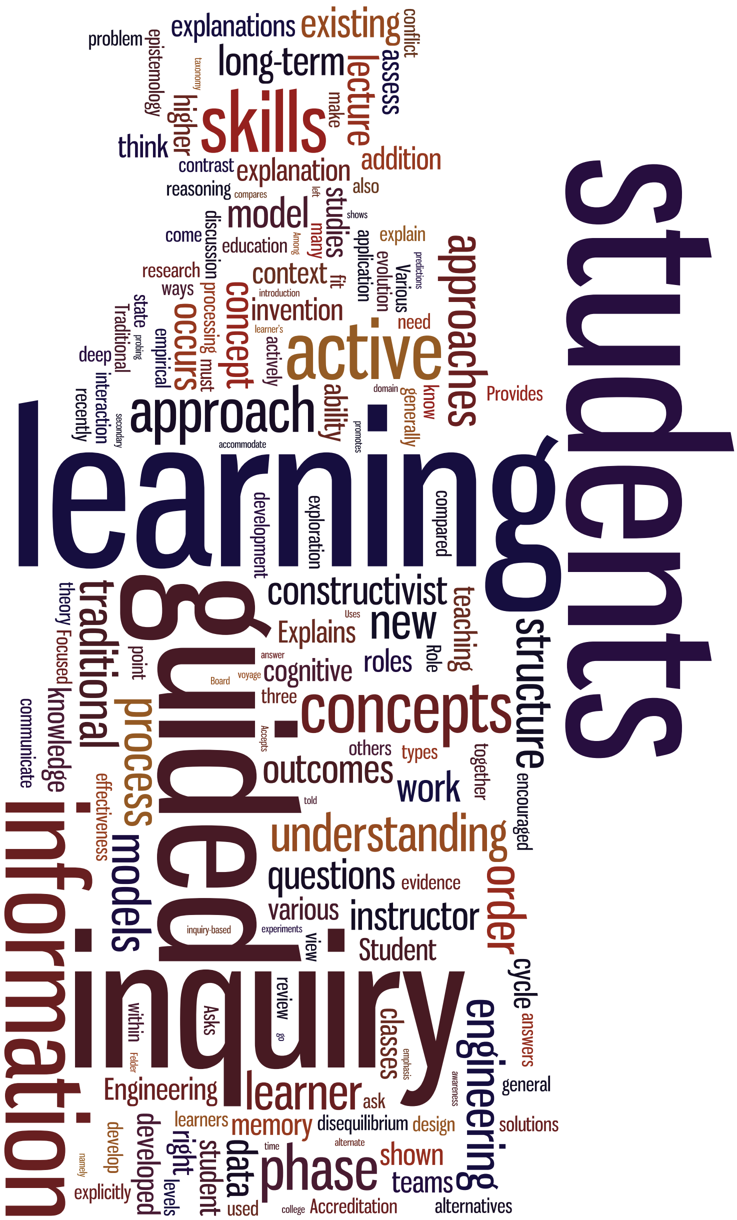
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Asks
ask

What Is Guided Inquiry?

Take a moment and flip through the pages in this book. You should notice that this text is very different from texts you have used in other classes. What you probably see is that there are a lot of questions for you to answer throughout the chapters, not just problems to solve at the end of each chapter. As you use this text you will notice some other important differences. One big difference is that not all the information you need to learn is given to you. The questions, which are called Guided Inquiry (GI) questions, are used to help you discover the concepts and ideas for yourself, instead of just reading about them. This approach, in which you figure out the information you need to know, is called active learning. Although active learning may not be something you have experienced before, a lot of research has shown that it works better than just being lectured to.

Since this text is based on active learning, you are not going to be told how it works or why it might be better than lectures. Instead, you will go through an active learning exercise to figure this out for yourself. We will begin with an activity on the First Law of Thermodynamics. This topic should already be somewhat familiar to you, so it provides a good way to compare how you will learn in this class compared to a typical lecture class. By the end of this chapter you will:

- Understand the First Law of Thermodynamics.
- Understand what is meant by guided inquiry.
- Understand the differences between a traditional lecture class and a guided inquiry class.

1.1 First Law of Thermodynamics

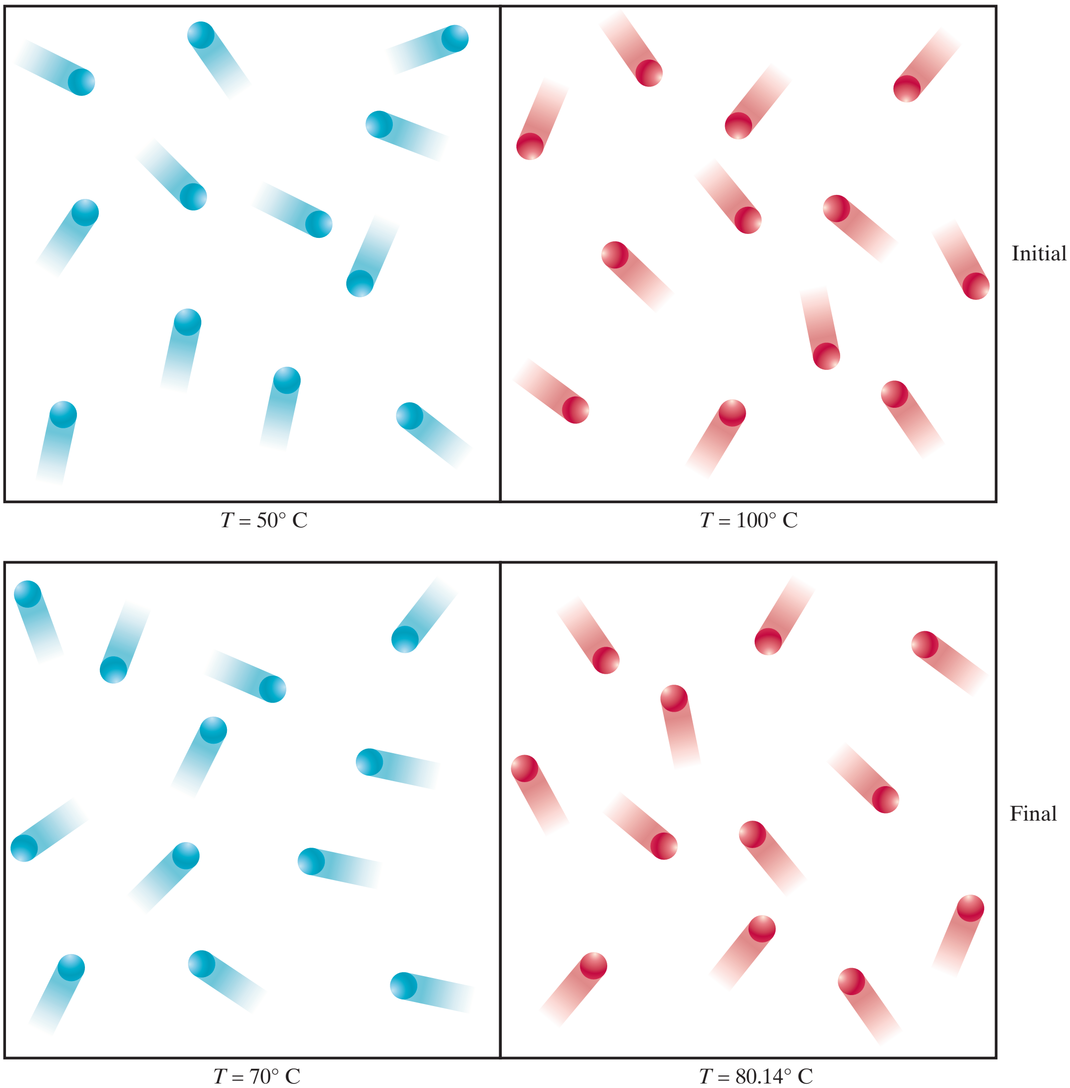
LEARN TO: Define heat and work.
Explain the First Law of Thermodynamics.

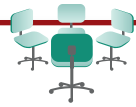
Thermodynamics is the study of changes in energy and flow of heat. Although thermodynamics is heavily mathematical, it also has a lot of practical applications. We can use it to understand the behavior of engines, power plants, and materials. In reality, much of science and engineering would not be possible without an understanding of thermodynamics.

Much of thermodynamics can be explained by three basic laws. We can't actually prove that any of these laws are true, but we have never found anything that contradicts them. We will begin our examination of the first law by looking at how temperature changes when two gases at different temperatures are put into contact with each other. **You should answer the first set of questions based on Figure 1.1.1.**

Figure **1.1.1**

Containers of two gases at different temperatures in contact with each other. The initial and final temperatures of the gases are shown.





Guided Inquiry: Heat

1.1.1 What is the initial temperature of the cold gas? What is the initial temperature of the hot gas?

Work as a group to answer questions 1.1.1–1.1.9 and make sure everyone agrees on each answer before moving on to the next question.

1.1.2 What is the final temperature of the cold gas? What is the final temperature of the hot gas?

1.1.3 In which direction does energy flow in this system?

1.1.4 What is the initial energy of the cold gas? What is the final energy of the cold gas?

The energy of a molecule of a gas can be calculated by $E = \frac{3}{2}kT$, *where* k *is Boltzmann's constant and* T *is the temperature in Kelvin.*

1.1.5 What is the initial energy of the hot gas? What is the final energy of the hot gas?

1.1.6 What is the energy change of the hot gas? What is the energy change of the cold gas?

1.1.7 How much energy was transferred between the hot gas and the cold gas?

1.1.8 What is the total energy change of the system?

1.1.9 Write an equation relating energy loss and gain for the gases.

This is a concept invention question, where you have discovered something about thermodynamics.

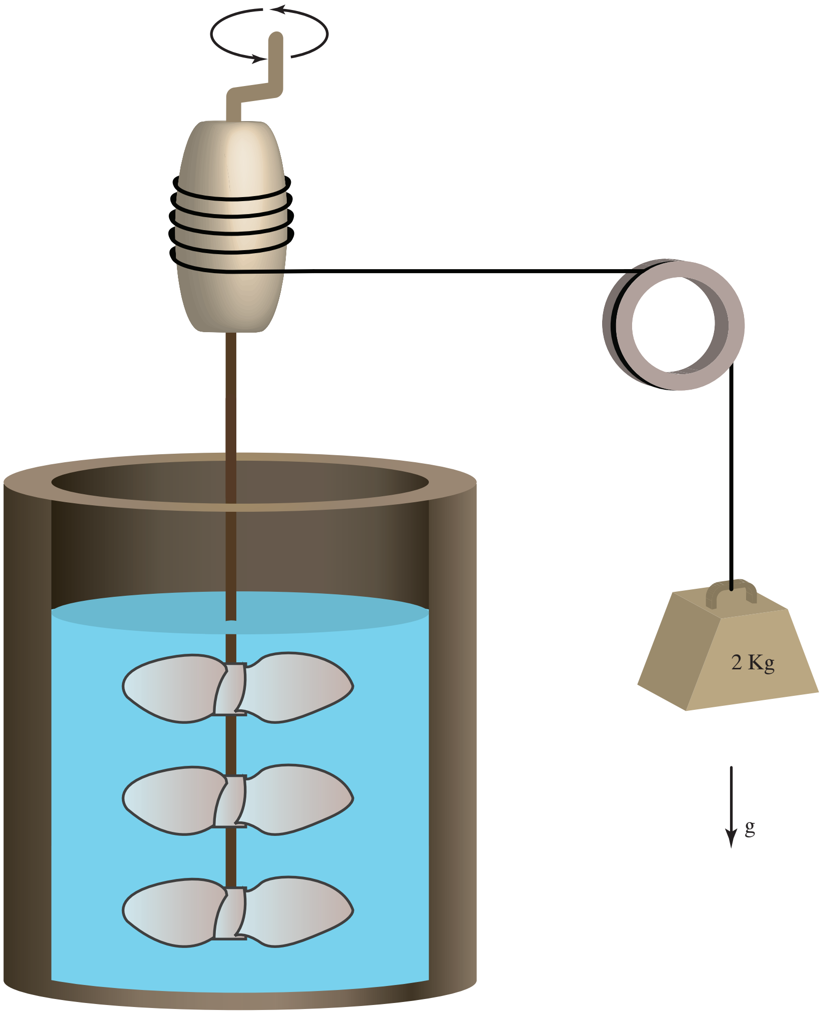
Concept Check **1.1.1**

- **A hot piece of copper is placed in contact with a cold brick. If the copper loses 5 calories of energy, how much energy does the brick gain?**

The first set of questions only considered thermal energy. When there is a temperature difference, the energy that is transferred is called "heat." However, other kinds of energy can be transferred. When energy is transferred without a difference in temperature, we call that energy transfer "work." **In the next set of questions you will examine the relationship between heat and work.**

Figure 1.1.2

Illustration of James Joule's experiment on heat and work.



Guided Inquiry: Work

1.1.10 What is the mass of the weight hanging off the pulley in Figure 1.1.2?

1.1.11 If the mass drops, what happens to the paddles in the water?

1.1.12 The mass drops 5 cm. How much does its potential energy change?
Remember, the potential energy of an object is mgh, *where* m *is the mass,* g *is* 9.8 m/s^2, *and* h *is the height. When* m *is in* kg *and* h *is in meters, the potential energy is in joules.*

1.1.13 When the mass drops 5 cm, how much work is done by the paddles?

1.1.14 When the mass drops, the temperature of the water increases. Where did the energy come from to increase the temperature of the water?

1.1.15 How much energy was transferred to the water to raise its temperature?

1.1.16 Write an equation relating the work done by the mass and the energy change of the water.

1.1.17 The apparatus in Figure 1.1.2 is modified so that the container of water is placed on top of a hot brick. As the mass falls 5 cm, 1.2 J of heat are transferred from the brick to the water. What is the total change in energy of the water?

1.1.18 Write an equation that relates the work done by the mass, the heat transferred from the brick, and the energy change of the water.
The equation you have created is the First Law of Thermodynamics.

1.1.19 Describe the First Law of Thermodynamics in words.

Concept Check **1.1.2**

- **According to the First Law of Thermodynamics, could heat be transferred from a hot object to a cold object, resulting in the hot object getting hotter and the cold object getting colder?**

1.2 Active Learning

LEARN TO: Describe the procedures of a guided inquiry class.
Compare the advantages and disadvantages of a traditional lecture class and a guided inquiry class.

Now that you have tried out an active learning exercise, let's think about how the active learning class works. Since you should have learned about the First Law of Thermodynamics in a previous chemistry or physics class, we're going to compare that class with the activity you just finished. Take a moment and remember what that class was like.

Figure 1.2.1 shows two ways of organizing a class. In Class 1, most or all of the time is spent by the instructor explaining concepts to the students and showing them practice problems. Students then practice using that information on homework problems. This type of class would be considered a lecture class. In Class 2, most or all of the time is spent by the students figuring out the concepts from information that is provided to them. There may be an occasional short mini-lecture or discussion. Class 2 is an active learning classroom, which means that the students are asked to be active during the class time. There are many different versions of active learning. And of course a class can be a mixture of a lecture class and an active learning class—you may have a lecture class in which the instructor occasionally has you work on something, or an instructor might mix some days of active learning and some days of lecture.

There is research that compares the effectiveness of lecture and active learning classrooms, but for most students what is more important is their own experience. **In the next set of questions you will reflect on your experience in the first part of this chapter and think about how this approach might affect your ability to learn.**

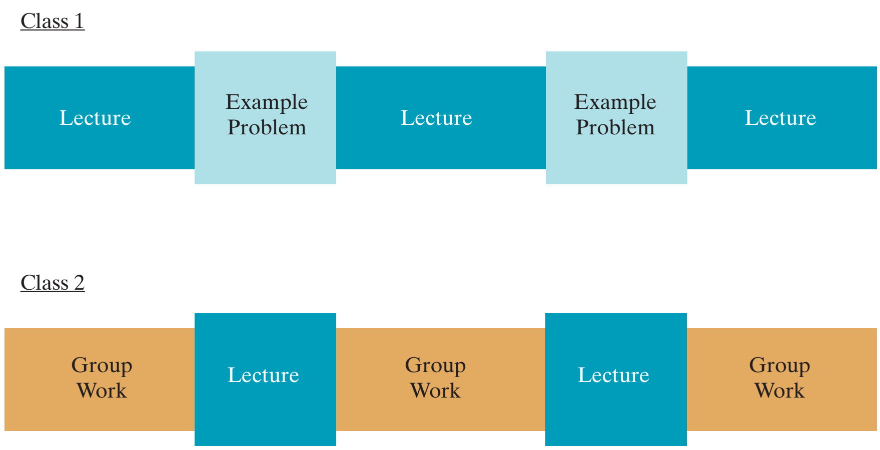


Figure **1.2.1**
Schematic showing two ways of organizing a class.

Guided Inquiry: Active Learning

1.2.1 In Class 1, who is most responsible for explaining concepts? Who is responsible in Class 2?

1.2.2 Which type of class is more like scientific research?

1.2.3 Thinking back on your general chemistry or physics class where you first learned about thermodynamics, was that more like Class 1 or Class 2? Explain why.

1.2.4 Were questions 1.1.1–1.1.19 of this chapter more like Class 1 or Class 2? Explain why.

1.2.5 List three advantages and three disadvantages of Class 1.

1.2.6 List three advantages and three disadvantages of Class 2.

1.2.7 Which type of class do you think would be most effective for learning? Explain why.

Summary

While hopefully you learned something about the First Law of Thermodynamics, the primary goal of this chapter was for you to experience a guided inquiry lesson and compare it to a traditional lecture class. Neither approach is perfect, and you likely identified advantages and disadvantages for each. But on balance, active learning classes lead to better student learning and improvements in thinking skills. Be forewarned, however, that you may not be told all the answers by your instructor. The book does provide many opportunities for you to make sure you are on the right track: Concept Checks, Example Problems, and Mastering Engineering (the online homework system). Also, sometimes the way a Guided Inquiry question is asked will make you realize that you got a previous Guided Inquiry question wrong.

To be successful using this book you will need to accept a different way of learning. For example, in this chapter, you were never told what the First Law of Thermodynamics is, but you were able to figure it out. This is the way real-world engineering works, so think of this book as not just a way to learn materials science and engineering, but also as a way to learn how to be an engineer.

Smartphones rely on the use of all types of materials, from the ceramic glass screen, to the metal casing, to plastics used as parts of the various electronic components. (3Dstock/Shutterstock)

2

What Is Materials Science and Engineering?

Materials science and engineering (MSE) deals with the stuff things are made out of. Since everything is made out of something, materials engineering touches every aspect of our lives. The importance of materials can be seen by how we name prehistoric times in human history; Stone Age, Bronze Age, Iron Age. Development of new materials throughout human history has allowed civilization to advance because these new materials have allowed humans to do things they couldn't do before. For example, the development of iron led to more durable tools for farming and more effective weapons.

The goal of this chapter is to provide you with an introduction to the basic idea of materials science and engineering: structure–property–processing relationships. Everything we do in materials science is related to how these elements interact with each other. By the end of this chapter you will:

Understand how we classify materials and how they differ from each other in their properties and uses.

Understand how the elements of structure, properties, and processing relate to each other.

2.1 Types of Materials

LEARN TO: Classify materials into different types.
Identify how different materials are used.

There are many different ways to classify materials and many different names people use; nanomaterials, biomaterials, functional materials, self-assembled materials, biomimetic materials, etc. But fundamentally we can say that, based on structure (that is, the type of bonding present), there are three types of materials: metals, polymers (which include plastics and rubbers), and ceramics. **The next set of questions will get you to think about what distinguishes each of those types of materials and how they are used.**

Guided Inquiry: Types of Materials

2.1.1 List three examples each of a metal, a polymer, and a ceramic.
Make sure to discuss these questions together in your group.

2.1.2 List three unique properties each for metals, polymers, and ceramics.

2.1.3 List three applications that are uniquely suited for each type of material.

Concept Check 2.1.1

- **What type of material would be best suited for the thermal insulation of a high-temperature furnace?**
- **What type of material would be best suited for lightweight air freight containers?**

Another way to classify materials is based on function—that is, some unique properties it has or how it is used. **In the next set of questions, you will think about the different properties needed for various applications.**

Guided Inquiry: Applications of Materials

2.1.4 List three properties that are important for a material that will be used for a bridge.

2.1.5 List three properties that are important for a material that will be used as an internal fixation plate for a broken bone (see Figure 2.1.1).

2.1.6 List three properties that are important for a material that will be used as a computer chip.

Concept Check 2.1.2

- **What properties are important for a material that will be used for a trash can?**

Figure 2.1.1

X-ray image of an internal fixation plate that was implanted in the author when he broke his arm in a cycling accident.

Materials whose primary function is to provide mechanical strength or stiffness in an engineered structure are called *structural materials*. Materials used in the body are called *biomaterials*. Materials used specifically for their electronic properties are called *electronic materials*. There are many other possible functional categories, and you can probably think of several. For example, there are magnetic materials which are used for their magnetic properties; high temperature materials which are important for applications such as jet engines; nuclear materials, which are used in nuclear reactors; and many others. Obviously one material can be in more than one of these functional categories. For example, stainless steel is used both as a structural material in applications such as pressure vessels and as a biomaterial for metal plates and screws for bone repair. The important point to keep in mind is that one material can have many different uses. We select materials for these uses based on the particular advantages and disadvantages they have in those particular applications. In the next set of questions, you will have a chance to decide for yourself how to classify different material, using the examples shown in Figure 2.1.2. **For these questions just consider the three categories of structural materials, biomaterials, and electronic materials.**

(a)

(c)

(b)

Figure 2.1.2

Examples of materials applications: (a) airplane wing; (b) soda bottle; (c) spark plug; the white piece is the insulating component.

(Photo courtesy of Lifeprints Photography)

Guided Inquiry: Classification of Materials

2.1.7 For each item in Figure 2.1.2, identify the type of material based on its structure.

2.1.8 For each item in Figure 2.1.2, identify the type of material based on its function.

2.1.9 For each item in Figure 2.1.2, identify what you think are the unique properties of the material that make it especially suitable for that application.

2.1.10 Many of the ages of human civilization are named after the primary materials that were used (Stone Age, Bronze Age, etc.). What materials age do you think we are we in right now?
There is no single correct answer to this question. Think about the different ways materials are used.

Concept Check **2.1.3**

- **What types of materials can be used as electronic materials?**
- **What types of functions can a metal be used for?**

Application Spotlight **Nanotechnology**

(Shuming Nie/National Institute of General Medical Sciences)

We often hear about nanotechnology, but what is it? Although many people think of miniature devices when they hear the term "nano," nanotechnology actually refers to the materials that are used. We can define nanotechnology as the use of materials that have some dimension on the order of nanometers and that have unique properties because of that small size. The figure shows one example of a size-dependent property. "Quantum dots" of semiconductors that are less than 100 nm in diameter will fluoresce at different wavelengths depending on the size of the nanoparticles. Larger particles emit light of longer wavelengths, resulting in red emission. As the particles get smaller, the wavelength of the emitted light gets shorter. These types of particles are being used in photovoltaics for solar energy applications. This is just one example of how materials are used in nanotechnology. Other applications for nanomaterials include new methods of delivering drugs, ultrasensitive pollution detectors, and novel types of electronic devices for computers.