logarithms and are written as $\ln x$. For practical calculations, one often uses logs to the base 10, called **common logarithms** and written as $\log x$, $\log_{10} x$, or $\lg x$. We have

$$\ln x \equiv \log_e x, \qquad \log x \equiv \log_{10} x \tag{1.66}$$*

$$\text{If } 10^t = x, \quad \text{then } \log x = t. \qquad \text{If } e^s = x, \quad \text{then } \ln x = s. \tag{1.67}$$

From (1.67), we have

$$e^{\ln x} = x \qquad \text{and} \qquad 10^{\log x} = x \tag{1.68}$$

From (1.67), it follows that $\ln e^s = s$. Since $e^{\ln x} = x = \ln e^x$, the exponential and natural logarithmic functions are inverses of each other. The function e^x is often written as $\exp x$. Thus, $\exp x \equiv e^x$. Since $e^1 = e$, $e^0 = 1$, and $e^{-\infty} = 0$, we have $\ln e = 1$, $\ln 1 = 0$, and $\ln 0 = -\infty$. One can take the logarithm or the exponential of a dimensionless quantity only.

Some identities that follow from the definition (1.67) are

$$\ln xy = \ln x + \ln y, \qquad \ln (x/y) = \ln x - \ln y \tag{1.69}$$*

$$\ln x^k = k \ln x \tag{1.70}$$*

$$\ln x = (\log_{10} x)/(\log_{10} e) = \log_{10} x \ln 10 = 2.3026 \log_{10} x \tag{1.71}$$

To find the log of a number greater than 10^{100} or less than 10^{-100}, which cannot be entered on most calculators, we use $\log(ab) = \log a + \log b$ and $\log 10^b = b$. For example,

$$\log_{10} (2.75 \times 10^{-150}) = \log_{10} 2.75 + \log_{10} 10^{-150} = 0.439 - 150 = -149.561$$

To find the antilog of a number greater than 100 or less than -100, we proceed as follows. If we know that $\log_{10} x = -184.585$, then

$$x = 10^{-184.585} = 10^{-0.585} 10^{-184} = 0.260 \times 10^{-184} = 2.60 \times 10^{-185}$$

1.9 STUDY SUGGESTIONS

A common reaction to a physical chemistry course is for a student to think, "This looks like a tough course, so I'd better memorize all the equations, or I won't do well." Such a reaction is understandable, especially since many of us have had teachers who emphasized rote memory, rather than understanding, as the method of instruction.

Actually, comparatively few equations need to be remembered (they have been marked with an asterisk), and most of these are simple enough to require little effort at conscious memorization. Being able to reproduce an equation is no guarantee of being able to apply that equation to solving problems. To use an equation properly, one must understand it. Understanding involves not only knowing what the symbols stand for but also knowing when the equation applies and when it does not apply. Everyone knows the ideal-gas equation $PV = nRT$, but it's amazing how often students will use this equation in problems involving liquids or solids. Another part of understanding an equation is knowing where the equation comes from. Is it simply a definition? Or is it a law that represents a generalization of experimental observations? Or is it a rough empirical rule with only approximate validity? Or is it a deduction from the laws of thermodynamics made without approximations? Or is it a deduction from the laws of thermodynamics made using approximations and therefore of limited validity?

As well as understanding the important equations, you should also know the meanings of the various defined terms (closed system, ideal gas, etc.). Boldface type (for example, **isotherm**) is used to mark very important terms when they are first defined. Terms of lesser importance are printed in italic type (for example, *isobar*). If you come across a term whose meaning you have forgotten, consult the index; the page number where a term is defined is printed in boldface type.

Suggestions for solving problems are given in Sec. 2.12. It's a good idea to test your understanding of a section by working on some relevant problems as soon as you finish each section. Do not wait until you feel you have mastered a section before working some problems. The problems in this book are classified by section.

Cramming does not work in physical chemistry because of the many concepts to learn and the large amount of practice in working problems that is needed to master these concepts. Most students find that physical chemistry requires a lot more study and problem-solving time than the typical college course, so be sure you allot enough time to this course.

Read with a pencil at hand and use it to verify equations, to underline key ideas, to make notes in the margin, and to write down questions you want to ask your instructor. Sort out the basic principles from what is simply illustrative detail and digression. In this book, small print is used for historical material, for more advanced material, and for minor points.

This is a far more effective way of learning than to keep rereading the material. You might think it a waste of time to make summaries, since chapter summaries are provided. However, preparing your own summary will make the material much more meaningful to you than if you simply read the one at the end of the chapter.

A psychologist carried out a project on improving student study habits that raised student grades dramatically. A key technique used was to have students close the textbook at the end of each section and spend a few minutes outlining the material; the outline was then checked against the section in the book. [L. Fox in R. Ulrich et al. (eds.), Scott, Foresman, 1966, pp. 85–90.]

Before reading a chapter in detail, browse through it first, reading only the section headings, the first paragraph of each section, the summary, and some of the problems at the end of the chapter. This gives an idea of the structure of the chapter and makes the reading of each section more meaningful. Reading the problems first lets you know what you are expected to learn from the chapter.

You might try studying occasionally with another person. Discussing problems with someone else can help clarify the material in your mind.

Physical chemistry is a demanding subject and requires a substantial investment of time to learn. A study of violin students found that those judged the best had accumulated at age 18 an average of 7400 hours of lifetime practice, as compared with 5300 hours for those violinists judged only as good, and 3400 hours of practice for violinists at a still-lower playing ability [K. A. Ericsson et al., **100,** 363 (1993)]. Studies of experts in chess, sports, and medicine have found similar strong correlations between the level of expertise and the amount of practice. Ericsson stated that "The extensive evidence for modifiability by extended practice led my colleagues and me to question whether there is any firm evidence that innate talent is a necessary prerequisite for developing expert performance [see G. Schraw, **17,** 389 (2005)].

Additional support for the primary importance of effort are the following statements (C. S. Dweck, Dec. 2007, p. 36): "research is converging on the conclusion that great accomplishment, and even what we call genius, is typically the result of years of passion and dedication and not something that flows naturally from a gift"; "hard work and discipline contribute much more to school achievement than IQ does"; "studies show that teaching people . . . to focus on effort rather than intelligence or talent, helps make them into high achievers in school and in life."

Ericsson emphasizes the importance of practice: "deliberate practice is a highly structured activity, the explicit goal of which is to improve performance. Specific tasks are invented to overcome weaknesses, and performance is carefully monitored to provide cues for ways to improve it further." [K. A. Ericsson et al., *Psychologic. Rev.,* **100,** 363 (1993)]. It's a good idea to analyze the kinds of mistakes you are making in physical chemistry and deliberately aim to improve in areas you are deficient in. If you are getting problems wrong because you are making mistakes in calculus or algebra, practice doing derivatives and integrals. If you get problems wrong because you are being inconsistent with units, get in the habit of always including the units of each quantity when you do problems, and take the time to make sure that units cancel so as to give the proper units for the answer; make sure you know what the SI units are for each physical quantity encountered. If you are getting problems wrong or are unable to do problems because you overlook or misinterpret or misapply the conditions given in the problems, make sure you are familiar with the precise definitions of such terms as isothermal and adiabatic, pay careful attention when you read a problem to what the conditions are, and when you learn starred equations, make sure you also learn the conditions of applicability for each equation.

As to studying, research has shown that students who study in a quiet place do better than those who study in a place with many distractions.

Get adequate sleep. The study of violinists mentioned previously found that the violinists considered adequate sleep to be an important factor in improving performance, and the two best groups of violinists averaged 5 hours more of sleep per week than the lowest level of violinists. College students are notoriously sleep deprived. Numerous studies have shown the negative effects of sleep deprivation on mental and physical performance. (For the amusing and insightful account of one college student, see A. R. Cohen, *Harvard Magazine,* Nov.–Dec. 2001, p. 83—www.harvardmagazine.com/on-line/110190.html.)

Some suggestions to help you prepare for exams are

1. Learn the meanings of all terms in boldface type.
2. Memorize all starred equations *and* their conditions of applicability. (Do not memorize unstarred equations.)
3. Make sure you *understand* all starred equations.
4. Review your class notes.
5. Rework homework problems you had difficulty with.
6. Work some unassigned problems for additional practice.
7. Make summaries if you have not already done so.
8. Check that you understand all the concepts mentioned in the end-of-chapter summaries.
9. Make sure you can do each type of calculation listed in the summaries.
10. Prepare a practice exam by choosing some relevant homework problems and work them in the time allotted for the exam.

My students often ask me whether the fact that they have to learn only the starred equations means that problems that require the use of unstarred equations will not appear on exams. My answer is that if an unstarred equation is needed, it will be included as given information on the exam.

Since, as with all of us, your capabilities for learning and understanding are finite and the time available to you is limited, it is best to accept the fact that there will probably be some material you may never fully understand. No one understands everything fully.

1.10 SUMMARY

The four branches of physical chemistry are thermodynamics, quantum chemistry, statistical mechanics, and kinetics.

Thermodynamics deals with the relationships between the macroscopic equilibrium properties of a system. Some important concepts in thermodynamics are *system* (*open* versus *closed; isolated* versus *nonisolated; homogeneous* versus *heterogeneous*);