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978-1-107-00678-2 — A Life Scientist's Guide to Physical Chemistry
Marc R. Roussel
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A LIFE SCIENTIST'S GUIDE TO PHYSICAL CHEMISTRY

Motivating students to engage with physical chemistry through biological examples, this textbook demonstrates how the tools of physical chemistry can be used to illuminate biological questions. It clearly explains key principles and their relevance to life science students, using only the most straightforward and relevant mathematical tools.

More than 350 exercises are spread throughout the chapters, covering a wide range of biological applications and explaining issues that students often find challenging. These, along with problems at the end of each chapter and end-of-term review questions, encourage active and continuous study. Over 130 worked examples, many deriving directly from life sciences, help students connect principles and theories to their own laboratory studies. Connections between experimental measurements and key theoretical quantities are frequently highlighted and reinforced.

Answers to the exercises are included in the book. Fully worked solutions and answers to the review problems, password-protected for instructors, are available at www.cambridge.org/roussel.

MARC R. ROUSSEL is Professor of Chemistry and Biochemistry at the University of Lethbridge, Canada. His research on the dynamics of biological systems lies at the interface of chemistry, biology and mathematics. He has been teaching physical chemistry for more than 15 years.

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Dedicated to all the students
who have studied and will study
physical chemistry
in my classes at
the University of Lethbridge

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Preface

To the student

I wrote this book for you.

When I came to the University of Lethbridge in 1995, I started teaching physical chemistry to a mixed class of chemistry and biochemistry students. I have been teaching versions of this course ever since. My first year here, I picked a book that *I* liked. Boy, was that a mistake! First of all, the book contained almost no examples that appealed to the biochemists, who were the majority of the students in the class. Second, it was filled with mathematical derivations, which I found very satisfying, but which sometimes obscured the concepts of physical chemistry for the students.

Having made this mistake, I started looking around for other textbooks. The ones that I liked the best, Barrow's *Physical Chemistry for the Life Sciences* and Morris's *A Biologist's Physical Chemistry*, were out of print at the time. We used a few different textbooks over the years, and some of them were very good books, but my students were never completely happy, and so I wasn't happy. In some cases, the books contained too much math and not enough insight. In others, too many equations were presented without derivation or explanation, which undermined the students' understanding of the material. I therefore set about writing a book for my students, and therefore for the broader community of life science students who need a term of physical chemistry. Given my experience with other textbooks, I had a few criteria in mind:

- I wanted it to be a book that students could read and understand, and not just one they would open up when the professor told them to solve problems 1, 2 and 4 from Chapter 8. As a corollary to that, and adapting a phrase from Canadian history, I thought that we should use *calculus if necessary, but not necessarily calculus*. A lot of the theory of thermodynamics, in particular, is very elegantly phrased in terms of multi-variable calculus, but unless you have a couple of years of university-level calculus behind you, it's sometimes hard to appreciate what this beautiful theory is telling you. We do need some calculus in physical chemistry, but in a first course, we don't need nearly as much as you find in many physical chemistry books.

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- I wanted to derive as many of the equations as possible, because I do think there is value in knowing where an equation comes from, even if you can't necessarily reproduce every step of the derivation yourself.
- I wanted the book to be relevant to life science students since I had so many of them in my class. Now I'm one of those people who think that scientists should be broadly interested in science, so you will find lots of examples and problems in the book that have nothing to do with the life sciences. Some of them, particularly those that come from other areas of the chemical sciences, were chosen because they provide simple illustrations of key concepts. Ultimately, it's all about learning the concepts so that you can apply them to your studies of living systems, and when it's easier to learn a concept using an uncomplicated example from, say, organic chemistry, then that's what you're going to get. Others were chosen because I think they're cool, and judging from the classroom discussions we've had over the years, so do my students. But you will also find many, many examples and problems directly inspired by the life sciences.
- I sometimes tell my students that an education in science involves learning a progressively more sophisticated set of lies, until finally the lies are so good that you can't tell them apart from reality. In lower-level courses, we tell students a lot of lies. I usually try to tell my students when I'm lying to them, and I've tried to do the same in this book, on the basis that it's important to know how far you can trust a certain equation or theory.
- Physical chemistry is an experimental science, so I wanted that to be reflected in the book. I try whenever possible to talk about experimental methods. I use as much real data as possible in the examples and problems. I also spend a lot more time and space than is customary discussing the analysis of data, particularly in the kinetics chapters. The ability to critically look at data is, I hope, something you will be able to use beyond this course.
- I think that students should have lots of opportunities to test their knowledge. I also think that these opportunities have to be at least a little structured. I've done a couple of things to help you with this:
  (1) The exercises are not concentrated at the ends of the chapters. Rather, I have exercises spread throughout the book, in short exercise groups, as well as some end-of-chapter problems. I'll come back to that in a minute.
  (2) I give answers to *every single problem* at the back of the book. You shouldn't need to wonder if you solved the problem correctly or not.

Drafts of this book have been used here at the University of Lethbridge for some years, so it's been thoroughly field-tested on students just like you. Hopefully, you will find, as they have, that while physical chemistry is a difficult subject, it is one you *can* master with a little effort. You may even discover that you enjoy it.

Studying physical chemistry

Most of the students who get in trouble in physical chemistry just don't keep up with the material. It's not a subject where cramming is an effective study strategy, so you really need

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to set some time aside every week to read the book and to solve some problems. Reading a physical chemistry book is something you do with a pad of paper, a pencil and a calculator, because you usually need to work out some of the steps in the derivations or in the examples in order to make sure you understand them properly. Beyond that, I have placed exercise groups after most sections. The idea is that you can verify your learning *right away* with a handful of questions that require the material in the section you have just read. You should be doing those problems as you go, i.e. you should sit down to solve some problems at least once a week, and maybe more often if you can manage it. Is this a lot of work? You bet! But it will make it easier for you to study for the tests, and it should improve your grade. And, let's face it, it's a lot more fun to be successful in a course than not.

When test time comes around, have a look at the ends of the chapters. I've put a selection of problems there, too, so that you can test your understanding of a larger slice of the material.

Finally, at the end of term, when you're preparing for the final exam, I've created a long set of questions to help you review all the material in the book. You may not cover every page of the book in your course, so you may see some problems there that aren't relevant to you. Hopefully by this point you'll be able to recognize these, or your instructor may help you pick through this selection of problems.

You should, I hope, have all the resources at hand that you need to study physical chemistry. Good luck!

To the instructor

This book was designed for a single-term course in physical chemistry for life science students (although I use it in a mixed class of biochemists and chemists). I assume that students have acquired the standard background of first-year science courses: two terms of general chemistry, one term of calculus and one term of physics. Particularly when it comes to mathematics, I try to help the students along when we draw on this background, but you may need to fill in some of the blanks if your students come to this course without some of these prerequisites.

Because this is a book intended to be used in a single-term course, some choices had to be made in terms of the topics covered. Quite apart from the time constraints, I also wanted to keep the production costs down, which implies some restraint in terms of topic coverage. This book focuses particularly on thermodynamics and kinetics, because these are the areas of most direct relevance to life science students. I have included a little bit of quantum mechanics and spectroscopy to support the other two topics, although the book was written so that you can bypass this material. I would, however, suggest that you include Section 3.2 on the Boltzmann distribution if you can. This was a late addition to the book, but after I wrote it, I found that I could explain many topics in the rest of the book much more straightforwardly.

Despite my overall attempt to limit the size of the book, I have tried to maintain some flexibility in the sequences you can take through the book. Accordingly, there is a bit more

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material in this book than you could cover in one term. In my own class, we cover almost all of Parts Two and Three (thermodynamics and kinetics) in a standard three-credit-hour (3 hours per week times 13 weeks) course.

A little while ago, I decided to change all the notations in this book to those recommended in the IUPAC Green Book (*Quantities, Units and Symbols in Physical Chemistry*). I came to this decision after a long period of using a combination of notations commonly used in other textbooks and a few I had invented myself. There are certainly advantages to using one's own notations, but eventually I decided that the proliferation of non-standard notations by textbook authors was doing more harm than good. I think we've all had the experience of reading books or scientific papers where we had to keep flipping back and forth to figure out what x or y represented. While some of the IUPAC notations are, in my opinion, not particularly elegant, they have the advantage of being standard for the field.

Contacting me

If you have comments or suggestions about this book, feel free to contact me by email: roussel@uleth.ca. I would be happy to hear from both students and instructors. I would be particularly interested to hear from instructors what sections you included or excluded in your course, and whether there is any material that you really think I should add in a future edition, should I ever be asked to write one.

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I would like to thank all of the Chemistry 2710, 2720 and 2740 students who have helped me work through the various versions of this book. Your questions and comments have had a great influence both on this text and on my own thinking about some of the problems raised during the study of physical chemistry.

I also must thank my wife Catharine and son Liam for allowing me the time to complete this project. Your support and understanding mean everything to me, always.

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