Preface

There are many ways to study food and to be considered an expert: a chef at a fine restaurant, a family cooking together at home, a hunter dressing a deer, an engineer designing a grain mill, a winemaker pressing grapes are all food experts. What distinguishes a food scientist is that they aspire to some level of understanding of *why* the food behaves as it does. Roald Hoffman (1998) talks about understanding as being either "vertical" or "horizontal"; vertical understanding offers a mechanism for a phenomenon in terms of more fundamental ideas, horizontal understanding is analysis within the terms of the existing discipline. A horizontal understanding of making an omelet would be a recipe; a vertical understanding would be in terms of protein chemistry and network formation. I agree with Hoffmann that the most useful understanding draws on both. For a food scientist to "understand" an omelet, the changes in the egg as it cooks must at be related to both changes in protein conformation and, at the same time, to the conditions in the pan controlled by the cook.

What then are the more fundamental ideas the food chemist should look for vertical understanding? Clearly the properties of food emerge from the molecules that make it up and introductory science courses are quite good at preparing students to think in terms of a molecular world. General chemistry courses teach the basics. Organic chemistry gives some functional groups and molecular transformations, and biochemistry provides the molecules of life and enzymatic catalysis. This course progression provides a reasonable background for vertical understanding for many aspects of food chemistry (e.g., browning reactions, lipid oxidation). However, many other food properties depend on the physical, non-covalent interactions of molecules in foods; topics touched on briefly in the most introductory general chemistry classes and then ignored. The student's understanding of the physical properties of foods is therefore fundamentally unscientific—they learn that a low water activity means the water is "bound" by the food components or that emulsion droplets "tend to" coalesce. This is, at best, science as proverbs with no possibility for real vertical understanding.

Another progression of courses would prepare a student to understand the properties of food in terms of physical chemistry. However that pathway is a difficult one, firstly because "real" physical chemistry courses often draw on a stronger background in chemistry and mathematics than is typical for a food science undergraduate. Secondly, many of the fundamentals of physical chemistry, especially quantum mechanics, are very demanding yet have only very limited use in understanding the physical properties of foods. Other material, for example activity coefficients, colloid science, and phase diagrams are immensely important in foods yet often mentioned only in passing in general physical chemistry classes. Lastly, general physical chemistry is in its nature general so few examples will be relevant to foods. (Biophysics, when it is available, is often a better option both in content and in examples).

The primary goal of my book is to help food science students reach a useful vertical understanding of the physical chemistry of foods within the context of their typical educational path. I have tried to introduce the important phenomena, the food science, but at the same time provide a mechanism for why they occur, the physical chemistry. An explanation is an argument, "because this, therefore that" and some ways of making these arguments are more helpful than others.

The arguments of physical chemistry are rigorously mathematical and, for the rare student that can master the mathematics, deeply satisfying. The rare student. More common is the student who learns the proof but loses the meaning, and more common still the student who loses both[1]. However, without mathematics the reasoning behind physical chemistry is reduced to imaginary models, "cartoons." Many physical chemists become instinctively uncomfortable at this point as they fear their subject will disappear in a flurry of hand waving. I argue though that the thoughtful use and refinement of physical models can provide a real pathway to understand the physical chemistry of foods.

We build our physical understanding of the world around us through a series of representations, of models, that we continue to either refine or reject based on their usefulness. We do this as a scientific culture, Newton built a theory of motion—Einstein refined it, but also importantly at individual and pedagogical levels. A child might wonder that the sky is blue and be satisfied to be told it reflects a blue sea, a useful model and an appropriate understanding at an early stage. Later, as an undergraduate, they could replace that model with a better one incorporating theories of Rayleigh scattering and structures of the lens and retina and yet later with sophisticated models of how photons interact with matter and how electrical stimulation leads to sensory perception. At each stage of their education, the individual understands the phenomenon at some level. None of the models is complete, but at each point the fact there is an argument, "the world is like this *because* of that, means the individual has something to argue against rather than just facts to accept. The process of rejecting models and building better ones is the process of both discovery and of learning.

I base the structure of the book around a very basic model of molecules attracting and repelling one another in the context of the randomizing effects of heat. This approach has the advantage of being deeply intuitive, the molecules making up the food can be understood as classical particles, and also of starting from the simplest pictures of solids, liquids, and gases from high school science. I use the first three chapters to set up this foundational physical model. The first chapter deals with the basic rules of thermodynamics and is

[1] One of my least favorite student questions is "Do we need to learn the equations?" No, but you do need to understand them.

likely to be a repetition for many readers (although in my experience, students can readily repeat a definition of entropy, enthalpy, and Gibbs free energy without really understanding what these terms mean). I have approached the topic from a molecular perspective where enthalpy is expressed as bonding and entropy as disorder. In Chap. 2 thermodynamic properties are expressed more explicitly in terms of the structure and interactions of molecules and intermolecular bonds are introduced in some depth. Chapter 3 uses the ideas of molecular interactions and the presence of a high-energy intermediate as a way to explain measurable rates of change.

The next two chapters use the basic model to address the very general problem of ingredient miscibility and its consequences. Phase behavior is central to the properties of most real food and rarely considered in any depth in general physical chemistry classes. Chapter 4 uses the thermodynamic rules from Chap. 1 to relate the molecular interactions from Chap. 2 to the properties of mixtures of molecules. This chapter contains the longest mathematical derivation in the text to calculate phase boundaries and to provide a more solid mental model of the roles of enthalpy and entropy to the central question of ingredient miscibility. Once phases have separated, the properties of the interface between them become important. Chapter 5 introduces a mechanical and energetic definition of surface tension and then discusses the properties that derive from it.

The remaining chapters apply the basic model and the resulting properties of multiphase materials to understand the structure and properties of specific types of matter important in foods (Crystals, Polymers, Dispersions, and Gels). However, having made the decision to focus on structures as the organizing principle of the book, some topics are necessarily split between chapters. In particular rheology is covered in Chap. 6, 7, and 8. Newtonian and non-Newtonian rheology is introduced in the context of viscous polymer solutions and refined in the context of dispersions. The rheological properties of solids are covered in the final chapter on gels.

The book is designed to be read as a narrative and as an introduction to a broader topic. Each proposition is developed from simpler concepts so the flow of chapters makes a logical sequence for a course of study. To make it easier to read I have tried to minimize in-text citations and used a bibliography at the end of each chapter to describe the material I found most useful writing the text and where the reader might look for a deeper understanding. Specific information from a particular source is cited as normal in the text.

I have used some of this material in my undergraduate food chemistry classes and found qualitative explanations to questions like why there is a delay before the onset of crystallization and why are polymer solutions viscous helpful. I use the text much more directly in my graduate course in "Food Physical Chemistry," but for this group how the theory is applied in the process of scientific discovery is much more important. I have included some examples of this as boxes in the text. I have found a useful format for graduate students is to ask them to read a section in advance and then give them some data from a paper and ask them to draw cartoons to explain how the changing organization of the molecules causes the changes seen, or, "The Reverse Problem" where they use a physical molecular model to predict the results of an experiment. I am deeply grateful to the students who have worked with me on iterations of the text and approaches to teach from it.

I am grateful to many of my colleagues, friends, and former students for helpful discussions and criticisms of drafts of parts of this work. Many of the good ideas in the book came from them; the remaining mistakes are mine alone. In particular Claire Berton-Carabin, Eric Dickinson, Ibrahim Gulseren, Rich Hartel, Denny Heldman, Julian McClements, Brent Murray, Perla Relkin, Don Thompson, Umut Yucel, Jochen Weiss made valuable contributions. I chose a single-author approach to achieve a greater unity of vision for most of the book but I am thankful to Rammile Ettelaie and Allen Foegeding for sharing their expertise and co-authoring the chapters on polymers and on gels.

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Lastly, I offer my inadequate thanks to my family for their patience and support as I worked through this long project. I could not have done it without them. Writing a book takes time, and your perspective changes as you write. What seemed important shifts, and it's hard to keep track of the essential narrative. About half way through this project I remember watching my baby daughter rolling around on a mat and thinking that would be a great analogy for a random walk. She could roll left and she could roll right but she would surely never leave the safe confines of the blanket. Now I have to rush to meet her from the school bus. Further corrections can surely wait for the second edition.

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