The Science of Cooking

Understanding the Biology and Chemistry Behind Food and Cooking

Joseph J. Provost, Keri L. Colabroy
Brenda S. Kelly, Mark A. Wallert

WILEY

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PREFACE

Interest in cooking, baking, and food has risen tremendously over the past few years. In fact, the popularity of food and cooking within the 18–34-year-old demographic group draws more than 50 million viewers to food- and cooking-based cable shows and websites each month. Many faculty members have tapped into this interest, creating unique and interesting courses about science, food, and/or cooking. This aim of *The Science of Cooking: Understanding the Biology and Chemistry Behind Food and Cooking* is to teach fundamental concepts from biology and chemistry within the context of food and cooking. Thus, the primary audience for the text is nonscience majors, who are fulfilling a science curricular graduation requirement. However, we anticipate that there may be instructors and students with a more significant interest in science who may utilize the book as a catalyst to fuel further study in the area. We hope that this book helps reduce the barriers to teach courses related to science, food, and cooking and opens up new opportunities for those already teaching about food and cooking.

We also recognize that there are important pedagogical approaches to learning that are well beyond the scope of a textbook. The companion website has over 35 guided inquiry activities covering science basics such as chemical bonding, protein structure, and cell theory and such food-focused topics as meat, vegetables, spices, chocolate, and dairy. These are carefully crafted and classroom-tested activities designed for student teams to work on under the guidance of an instructor. The activities introduce the scientific concepts in a way that complements the text while giving students practice in critical thinking about the relevant foundational principles of chemistry and biology. We have also created a series of food- and cooking-based laboratories. These experiential learning opportunities involve hypothesis design and help teach the scientific process and critical concepts while engaging students in fermentation, cheesemaking, analyzing food components, and other hands-on exercises. The laboratories have been designed to minimize cost and hazardous materials; some are even appropriate to assign as homework to be done in a student's home kitchen.

The Science of Cooking: Understanding the Biology and Chemistry Behind Food and Cooking is food centered while including several chapters that introduce fundamental concepts in biology and chemistry that are essential in the kitchen. In the first few chapters of the book, students will learn about molecular structure, chemical bonding, cell theory, signaling, and biological molecule structure. These concepts are drawn upon in later chapters; for example, students will learn the science behind cheesemaking, meat browning, and fermentation processes. The chapters are also full of interesting facts about the history of the food, ailments, or cures associated with the food, all guided by in-depth discussions of the science behind the food.

Of course, there is a rich history of literature on and the science of food and cooking. We have taken some space to acknowledge those who helped build and grow modernist cooking. Special thanks go to Harold McGee and Shirley O. Corriher for their pioneering work, inspiration, and kind words as we developed this work. We hope to add to the scientific culture that they and others have created in the kitchen.

Inquire, Learn, Investigate, and Eat Well!

ABOUT THE AUTHORS

Dr. Joseph J. Provost is a professor of chemistry and biochemistry at the University of San Diego. He has helped create and teach a science of cooking class and taught to small and large classes. Provost has served on educational and professional development committees for the American Society for Biochemistry and Molecular Biology, Council on Undergraduate Research, and the American Chemical Society while teaching biochemistry, biotechnology, and introductory chemistry laboratories. For the past 18 years, he has partnered with Dr. Mark Wallert as they research non-small cell lung cancer focusing on processes involved with tumor cell migration and invasion. When not in the lab or class, Provost can be found making wine and cheese, grilling, and then playing or coaching hockey.

Dr. Keri L. Colabroy is an associate professor of chemistry at Muhlenberg College in Allentown, Pennsylvania, where she created and teaches a course on kitchen chemistry for nonscience majors. When she isn't evangelizing nonscience majors with her love of chemistry, Colabroy is teaching organic chemistry, biochemistry courses, and a first-year writing course on coffee while also serving as codirector of the biochemistry program. Her scholarly research is in the area of bacterial antibiotic biosynthesis with a focus on metalloenzymes and actively involves undergraduates. Colabroy serves as coordinator for undergraduate research at the college and participates on the Council on Undergraduate Research in the Division of Chemistry. When not in the lab or class, Colabroy can be found chasing her two small children or singing in the choir.

Dr. Brenda S. Kelly is an associate professor of biology and chemistry at Gustavus Adolphus College in St. Peter, Minnesota. Kelly's immersion into teaching about science and cooking began in 1997 when she cotaught a January term course, The Chemistry of Cooking, that enrolled science majors who knew little about cooking and nonscience majors who were excellent cooks. The immense number of resources that she used to gather information for the course, as well as the diverse student population who would have benefited from a single resource, suggested a need for an undergraduate textbook for such a course. In addition to talking with her students about cooking as one big science experiment, Kelly teaches courses in biochemistry and organic chemistry and has an active undergraduate research lab where she engages her students in research questions related to protein structure and function. When she is not busy in her current interim role as associate provost and dean of the Sciences and Education at Gustavus, Kelly enjoys cooking, baking, and running (not at the same time) and spending time with her family.

Dr. Mark A. Wallert is an associate professor of biology at Bemidji State University in Bemidji, Minnesota. Mark was an inaugural member of Project Kaleidoscope Faculty for the twenty-first century in 1994 and has worked to integrate inquiry-driven, research-based laboratories into all of his courses. For the past 18 years, he has maintained a research partnership with Dr. Joseph Provost where they investigate the role of the sodium–hydrogen exchanger in cancer development and progression. Mark is the Northwest Regional Director for the American Society of Biochemistry and Molecular Biology Student Chapters Steering Committee where he has helped organize the Undergraduate Research in the Molecular Sciences annual meeting held in Moorhead, Minnesota, for the past 10 years. In 2005, Mark was recognized as the Council for Advancement and Support of Education/Carnegie Foundation for the Advancement of Teaching Minnesota College Professor of the Year. When not engaged in campus and research activities, Wallert can be found spending time with his family and enjoying the abundance of nature in northern Minnesota.

ABOUT THE COMPANION WEBSITE

This book is accompanied by a companion website:

www.wiley.com/go/provost/science_of_cooking

The website includes:

- Guided Inquiry Activities
- Inquiry and Scientific Method based Laboratory Experiments
- Color Infographics with Recipe and Science Behind the Food
- Powerpoint files with all chapter images
- Powerpoint files for teaching
- Learning Objectives for a course and each chapter
- Practice Questions

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THE SCIENCE OF FOOD AND COOKING: MACROMOLECULES

Guided Inquiry Activities (Web): *1, Elements, Compounds, and Molecules; 2, Bonding; 3, Mixtures and States of Matter; 4, Water; 5, Amino Acids and Proteins; 6, Protein Structure; 7, Carbohydrates; 8, pH; 9, Fat Structure and Properties; 10, Fat Intermolecular Forces; 11, Smoking Point and Rancidity of Fats*

1.1 INTRODUCTION

The process of cooking, baking, and preparing food is essentially an applied science. Anthropologists and historians venture that cooking originated when a pen holding pigs or other livestock caught fire or a piece of the day's catch of mammoth fell into the fire pit. The smell of roasted meat must have enticed early people to "try it"; the curious consumers found culinary and nutritional benefits to this new discovery. The molecular changes that occurred during cooking made the meat more digestible and the protein and carbohydrates more readily available as nutrients. Contaminating microbes were eliminated during cooking, which made the consumers more healthy and able to survive. Moreover, the food was tastier due to the heat-induced chemical reactions between the oxygen in the air and the fat, proteins, and sugar in the meat. Harnessing the knowledge of what is happening to our food at the molecular level is something that good scientists and chefs use to create new appetizing food and cooking techniques.

We are all born curious. Science and cooking are natural partners where curiosity and experimentation can lead to exhilarating and tasty new inventions. Scientific

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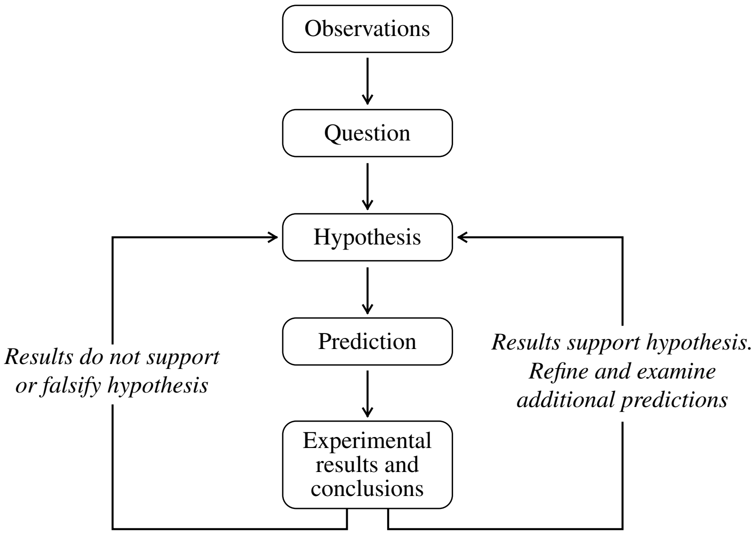

FIGURE 1.1 The scientific method. Scientists use a testable method originating from observations to generate a testable hypothesis to conduct their work. A cook or baker can also use this method to create a more interesting food.

discovery is driven by hypothesis (see Fig. 1.1 for a model of the scientific method). An observation of an event creates a question and/or a statement that explains the observation or phenomenon: the hypothesis. The hypothesis can then be tested by a series of experiments and controls that supports or falsifies the hypothesis, starting the cycle over again. For example, a scientist might observe that the growth rate of cancer cells in a petri dish slows when the cells are exposed to a sea sponge. The scientist may then hypothesize that a molecule found in the sponge binds to a protein in cancer cells. After adding the compound to a tumor, its growth slowed and the cells die. Looking at how all of the individual molecules found in the sea sponge affect the growth of cancer cells can test this hypothesis. These experiments can lead to a more advanced hypothesis, testing and eventually finding a new compound that can be used to fight cancer.

Cooking can also be a hypothesis-driven process that utilizes biology, chemistry, and physics. As you cook, you use biology, chemistry, and physics to create hypotheses in the kitchen, even if you weren't aware of being a scientist. Each time you try a recipe, you make observations. You may ask yourself questions about what you added to the concoction or how the food was baked or cooked. This creates a hypothesis or a statement/prediction that you can test through experimentation (your next attempt at the dish). A nonscientific idea is often approached as something to prove. That is different from hypothesis testing. A hypothesis is falsified rather than proven by testing. Cooking does just this; it will falsify your test rather than prove it. Tasting, smelling, and visualizing your results tell you if your hypothesis was supported or falsified. If wrong, you may create a new hypothesis that might be generated by the time you have washed the dishes from your first experiment! Learning more of the basic science behind food and cooking will help you appreciate the world around you and become a better scientist and a better cook, baker, and consumer.

1.2 FUNDAMENTALS OF FOOD AND COOKING

Bread baking provides a great example of the importance of having a scientific understanding of cooking and baking. Take a close look at bread. Notice that it is made of large and small caves surrounded by a solid wall (Fig. 1.2).

The key to bread is making a way to trap expanding gases in the dough. Adding water to flour and sugar allows for the hydration and mixing of proteins and carbohydrates. Kneading the dough stretches a protein called gluten, which allows for an interconnected network of protein ready to trap gas that is generated by the yeast. During the proofing step of making bread, the yeast converts sugar into energy-filled molecules, ethanol, carbon dioxide gas, and other flavorful by-products. The heat applied during baking allows the water to escape as steam, which expands the bread, links the gluten protein molecules further, and traps carbon dioxide gas. While this is happening, the heat catalyzes chemical reactions between proteins and sugars, creating a beautiful brown color, a dense texture, and over 500 new aromatic compounds that waft to your nose. Clearly there is a lot of science that goes into making a loaf of bread.

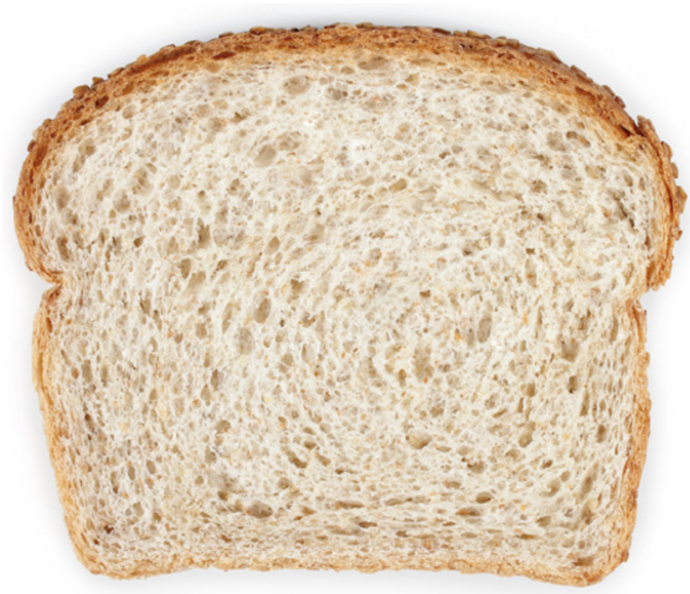

FIGURE 1.2 Structure of bread. A close look at bread demonstrates the requirement of proteins and carbohydrates needed to trap expanding gases.

Preparing food and drink is mostly a process of changing the chemical and physical nature of the food. Molecules react to form new compounds; heat changes the nature of how food molecules function and interact with each other, and physical change brings about new textures and flavors to what we eat. To gain a better appreciation for these chemical and physical processes, a fundamental understanding of the building blocks of food and cooking must first be understood. In the following two chapters we will study the basic biological principles of cooking, tasting, and smelling.

One of the most important building blocks of food is water; our bodies, food, and environment are dependent on the unique chemistry and biology of this molecule. Large biological molecules such as proteins, carbohydrates, and fats comprise the basic building blocks of food. Smaller molecules, including vitamins, salts, and organic molecules, add important components to cooking and the taste of food. Finally, the basics of plant and animal cells and cellular organization are key to understanding the nature of food and cooking processes. However, before we get into some of the science fundamentals, it is important to recognize and acknowledge the origins of and the chefs who first embraced the science behind their profession.

1.2.1 Science, Food, and Cooking

Many chefs and bakers embrace the collaboration of science and food. Historically, one means whereby science has been utilized in the kitchen is in the area of food technology—the discipline in which biology, physical sciences, and engineering are used to study the nature of foods, the causes of their deterioration, and the principles underlying food processing. This area of food science is very important in ensuring the safety and quality of food preparation, processing of raw food into packaged materials, and formulation of stable and edible food. College undergraduates can major in "food science" or attend graduate studies in this area, working for a food production company where they might look at the formulation and packaging of cereals, rice, or canned vegetables. Recently a new marriage of science and food, coined molecular gastronomy, has grown to influence popular culture that extends far beyond the historical definition of food science. A physicist at Oxford, Dr. Nicholas Kurti's interest in food led him to meld his passion for understanding the nature of matter and cooking. In 1984 Harold McGee, an astronomist with a doctorate in literature from Yale University, wrote the first edition of the influential and comprehensive book *On Food and Cooking: The Science and Lore of the Kitchen* [1]. This fascinating book is the basis for much of the molecular gastronomy movement and describes the scientific and historic details behind most common (and even uncommon) culinary techniques. Together with cooking instructor Elizabeth Cawdry Thomas, McGee and Kurti held a scientific workshop/meeting to bring together the physical sciences with cooking in 1992 in Erice, Italy. While there were more scientists than chefs attending, with a five to one ratio, the impact of the meeting was significant. It was at Erice that the beginnings of what was then called molecular and physical gastronomy became the catalyst for an unseen growth in science and cooking. Hervé This, a chemist who studies the atomic and subatomic nature of chemistry, attended the workshop and has been a key player in the growth of molecular gastronomy. Dr. This blames a failed cheese soufflé for sparking his interest in culinary precisions and has since transformed into a career in molecular gastronomy. Other participants of the meetings include chef Heston Blumenthal and physicist Peter Barham, who have collaborated and influenced many molecular-based recipes and projects. Finally another scientist, biochemist Shirley O. Corriher, was present at these early meetings (Box 1.1). Shirley found her love of cooking as she helped her husband run a school in Nashville in nearby Vanderbilt Medical School where she worked as a biochemist. Her influence on science and cooking includes a friendship and advisory role with Julia Child and the many informative, science approach-based cookbooks (Ms. Corriher, personal communications, June 2012). The impact on popular culture and influence on modernist cooking are immense. For 13 years, Alton Brown brought the scientific approach to culinary arts in the series *Good Eats*. Through the work of all of these scientist chefs, use of liquid nitrogen, a specialized pressure cooking called sous vide, and unique presentation and mixtures of flavors are now more commonplace and creating new options for the daring foodie.

BOX 1.1 SHIRLEY CORRIHER

Shirley Corriher has long been one of the original scientists/cooks to influence the new approach to cooking and baking. Using everyday language as a way to explain food science, Shirley has authored unique books on becoming a successful cook and baker with her books *CookWise* [2] and *BakeWise* [3]. Her influence on popular acceptance of science on cooking and baking includes a friendship with Julia Child, appearances on several of Alton Brown's *Good Eats* episodes, and her involvement in the growth of the science and cooking. Shirley earned a degree in biochemistry from Vanderbilt University where she worked in the medical school in a biomedical research laboratory while her husband ran a school for boys. She recalls her early attempt to cook for the large number of boys. Little did she know this experience would be the beginning of a new career. Shirley describes how she struggled with the eggs sticking to the pan and worrying that there would be no food for the students. Eventually she learned to heat the pan before adding the eggs. The reason was that the small micropores and crevices of the pan would fill and solidify in the pan. This sparked the connection between science and cooking for her. After a divorce Ms. Corriher and her sons were forced into a financial struggle, where they had to use a paper route as a source of income, a friend, Elizabeth Cawdry Thomas, who ran a cooking school in Berkeley, California, asked her to work for her cooking school where she learned formal French cooking while on the job. Later Shirley found herself mixing with a group of scientists and chefs who appreciated the yet to be studied mix of science and cooking. In 1992, the group including Thomas, Kurti, and Harold McGee obtained funds to bring scientists and chefs together to support workshops on nonnuclear proliferation in Erice, Sicily. Shirley was a presenter at that first meeting leading discussions on emulsifiers and sauces and continued as a participant in each of these early workshops (Ms. Corriher, personal communications, June 2012). Corriher recalls that the term molecular gastronomy was voted on by the core group to reflect both the science and culinary aspects of the meeting. Shirley talks of a respect and friendship between herself and leading food scientist Harold McGee. Shirley recalls reading his book and called him to ask him where had he been all this time? She said, “You don’t know me, but I and many other ladies in Atlanta are going to bed with you every night!” Her books using science to explain how to become a better cook and baker are extremely popular. Her approach to trust in yourself and understanding the science of kitchen work is certainly an inspiration given by a person with a unique route to her spot in American culinary society.

1.3 THE REAL SHAPE OF FOOD: MOLECULAR BASICS

What are the fundamental units of all food and cooking processes? Atoms and molecules! All living systems (animals, microbes, and smaller life forms) are made of atoms and molecules. How these atoms and molecules are organized, interact, and react provides the building blocks and chemistry of life. It makes sense that to best understand cooking and baking at the molecular level, you must first appreciate how atoms and compounds are put together and function. Let’s start with the basics and ask, what is the difference between an atom and molecule? The answer is simple: an atom is the smallest basic building block of all matter, while molecules are made when two or more atoms are connected to one another.

An atom consists of three main components also known as subatomic particles. These subatomic particles are called protons, neutrons, and electrons. A simple description of what and where these particles are located is that protons and neutrons are found in the center or nucleus of the atom, while electrons orbit the core of the atom (Fig. 1.3). Protons are positively charged particles with an atomic mass of one atomic mass unit. Neutrons essentially also have an atomic mass of one, but do not have an electrical charge. Electrons have almost no mass and have an electrical charge of −1.

The elements of the periodic table are arranged and defined by the number of protons present within an atom of a given element. The number of protons defines an atom, not the electrons or neutrons. A quick examination of a periodic table shows that their proton number organizes atoms: from the smallest atom, hydrogen, to the largest atom, ununoctium. As stated, the number of protons in an atom defines that atom. Any atom with six protons is a carbon; any atom with seven protons is nitrogen. Thus, if a carbon atom gains a proton, it becomes a nitrogen atom. However, if a carbon atom gains or loses an electron, it still is a carbon, but now has a charge associated with it. The total number of protons and electrons defines the charge of an atom. An atom of any element with an equal number of protons and electrons will have a net neutral charge; atoms that have gained an electron will have a negative charge, and those that have lost an electron will have a positive charge. Most of the atoms of the elements on the periodic table can gain or lose one or more electrons. The numbers of neutrons within a given type of atom can also vary. Isotopes are

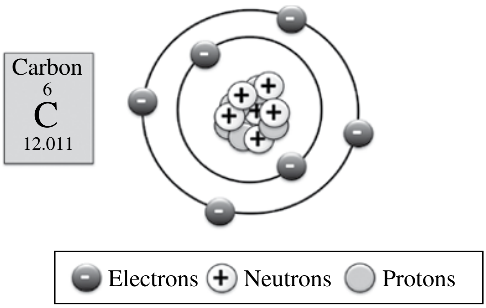

FIGURE 1.3 Atomic structure. Atoms are made of electrons in orbitals around the nucleus where protons and neutrons are found. The identity of an atom is the number of protons.

atoms that have the same number of protons but differ in the number of neutrons. Carbon 12 and carbon 13 both have six protons (thus they are carbon), but carbon 12 has six neutrons for a total atomic mass of 12, while carbon 13 has seven neutrons and when including the mass of the protons has an atomic mass of 13 (6 protons + 7 neutrons = 13 atomic mass) (Fig. 1.4).

What about a compound or a molecule? How does a molecule differ from an atom or compound? A molecule is a substance of two or more atoms connected by sharing electrons (covalent bonds). A compound is a chemical substance made of different atoms. Compounds can be made of atoms held together by ionic or covalent bonds where molecules are made only of covalently bonded atoms. Thus all molecules are compounds, but not all compounds are molecules. Molecules are often categorized further into organic (those molecules containing mostly carbon atoms) and inorganic molecules (everything else).

Most of the compounds found in living things contain carbon, hydrogen, nitrogen, or hydrogen atoms. A group of other elements, including sulfur, magnesium, and iron, make up less than 1% of the atoms in most living systems. Trace elements, such as copper, zinc, chromium, and even arsenic, although necessary for biological function, only make up a minute portion of an organism, less than 0.01% of all atoms. Due to their complexity and impact on their behavior in cooking, let's talk a little bit more about the bonds that connect atoms together.

1.3.1 Ionic and Covalent Compounds

There are two types of bonds that connect two atoms to yield a molecule or compound: ionic and covalent. Ionic bonds form between atoms that have opposite charge due to the loss or gain of electrons (Fig. 1.5). Atoms that have become charged have their own name—ions. Ionic bonds form when an ion with a positive charge (a cation) is bonded to an ion with a negative charge (an anion). The resulting molecule is called an ionic compound or a salt. This terminology is apropos because the salt that you sprinkle on your popcorn, NaCl, is an ionic compound consisting of a positively charge sodium atom or ion (Na^+) and a negatively charged chlorine atom or ion (Cl^-).

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57–70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.21	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **TI** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89–102 * *	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
**Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

FIGURE 1.4 Periodic table. Each atom is arraigned based on the number of proton (elemental number) increasing from left to right and top to bottom. Scientists use the periodic table to understand the physical characteristics. LeVanHan, https://commons.wikimedia.org/wiki/File:Periodic-table.jpg. Used under CC-BY-SA 3.0 Unported https://creativecommons.org/licenses/by-sa/3.0/deed.en, 2.5 Generic https://creativecommons.org/licenses/by-sa/2.5/deed.en, 2.0 Generic https://creativecommons.org/licenses/by-sa/2.0/deed.en and 1.0 Generic license https://creativecommons.org/licenses/by-sa/1.0/deed.en.

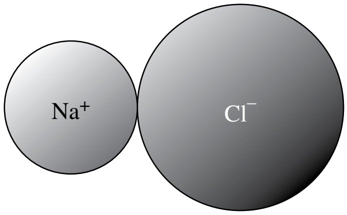

FIGURE 1.5 Ionic compound (sodium chloride). A positively charged cation (Na^+) forms an ion bond to a negatively charged anion (Cl^-) to form an ionic compound.

Thus compounds are divided into molecules that have a charge or those without a charge. Ionic compounds are molecules that have somehow lost or gained an electron resulting in a compound with two parts; one atom or group will be positive charged and bonded to another atom or group of atoms with a negative charge. One of the atoms in an ionic compound will have at least one metal element (Na, K, Ca, Al, etc.). Metal atoms more readily give or accept electrons transforming the atoms into charged ionic elements. The simplest ionic compounds are formed from monoatomic ions, where two ions of opposite charge act as the functional unit. A good example is table salt, or sodium chloride (NaCl). In addition to single atom ions, a group of covalently bound atoms can also possess an overall charge called polyatomic ions. Polyatomic ions are made of several atoms bonded as a group, which is charged. Potassium nitrate, commonly called saltpeter and used in curing meat, is a complex polyatomic ion with the chemical formula KNO_3, where the potassium ion (K^+) provides the positive charge and the nitrate ion provides the negative charge (NO_3^-). Nitrate compounds have been historically used to preserve meats and fish. The nitrate dries the meat by drawing the water out of the muscle tissue leaving an inhospitable environment for bacteria to grow.

As a solid, ionic atoms are tightly held together by opposite charges in large networks called a lattice. In water, however, the attractive force between cation and anion components of the ionic compound is shielded by water and separate from one another. You can see this phenomenon with your very own eyes as you watch a teaspoon of salt dissolve in a glass of water. What is happening at the molecular level? Water is a polar covalent molecule with a positive and negative partial charge. The hydrogens have a partial positive charge, while the oxygen has a partial negative charge. Water molecules align with the charge of the ion forming a solvating shell of water (Fig. 1.6). This coating of water acts to shield the attraction between the ions, which can then separate from one another, dissolving in the water.

Salts are a very important aspect of foods, cooking, and taste and are often key to the demise of success of a given dish. Thus, when we refer to salts throughout the rest of this text, we will specify whether we are using the scientific definition of salt (an ionic compound made up of a cation and anion) or the common definition of salt (meaning table salt, or NaCl).

Can you have molecules that are made up of uncharged atoms? Yes, these molecules are called covalent or molecular compounds (as opposed to the ionic compounds or salts referred to earlier). In covalent compounds, sharing electrons holds atoms

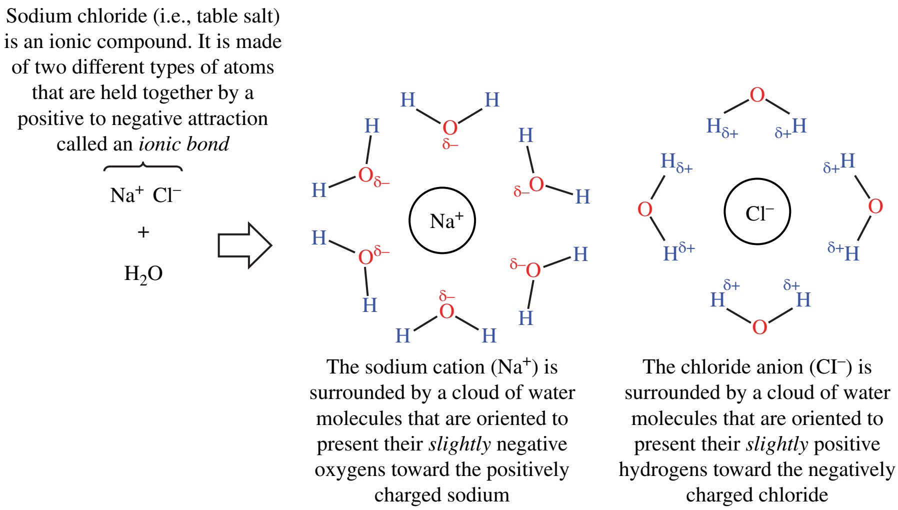

FIGURE 1.6 Salt dissolves in water. In water, the polar nature of water surrounds and reduces the attractive force between ionic compounds dissolving each ion into the water solution.

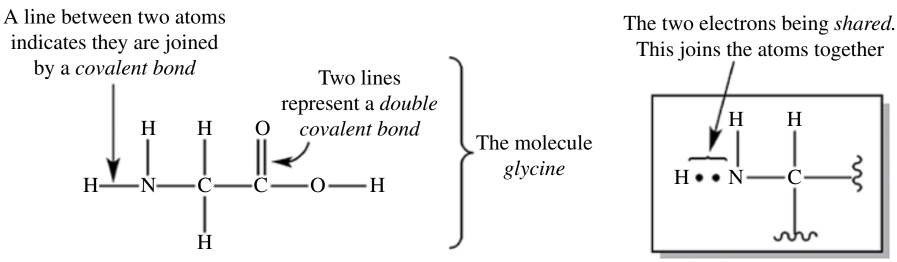

FIGURE 1.7 Covalent bonds have shared electrons. The sharing of two electrons forms a covalent bond. The straight line between atoms represents these electrons. Electrons are very tiny particles with negative charge. Every atom of each unique element has a specific number of electrons. For example, every hydrogen atom has one electron.

together; the force that ties the atoms together is called a covalent bond. The amino acid glycine is a great example of a covalent compound (Fig. 1.7). In a molecule of glycine, each nitrogen, carbon, oxygen, and hydrogen atom shares electrons with neighboring atoms forming a bond. The sharing of electrons that creates these covalent bonds has a particular order. Sharing of one set of electrons between atoms creates a single bond often shown by a single line drawn between the atoms. A double or triple bond is created when two or three pairs of electrons are shared between atoms (Fig. 1.8). Covalent compounds are made up of nonmetal atoms and are typically much more diverse (i.e., different arrangements of atoms) and larger (i.e., more atoms) than ionic compounds. The main difference between ionic and covalent compounds is that covalent compounds are not held together by charges, but atoms are bonded