Preface
Science, Technology, and Quantum Physics: Mind the Gap

Quantum physics thus reveals a basic oneness of the universe.
Erwin Schrödinger

Figure P.1 Celestial map from the seventeenth century, by the Dutch cartographer Frederik de Wit (1630–1698).

In This Preface
P.1 Three Secrets of Nature xxxviii
P.2 From Natural Philosophy to Physics xxx
P.3 Physics the Most Fundamental Science xxxi
P.4 Quantum Physics: The Science of the Molecular Age xxxii
P.5 Why This Book xxxiv
P.6 In This Book xxxvii
P.7 Back to the Future xl

xxvii
To an artist, in Shakespeare’s words, All the world’s a stage. Taking this metaphor to another level, to a scientist, the whole universe is a colossal party with a cosmic dance on dance floors at all levels, ranging from an expanding universe with swirling galaxies, to planets revolving around their suns, to organisms of all shapes and sizes dancing through their life cycles, to molecules in action inside living and nonliving systems, to atoms making and breaking bonds to make molecules and crystals, to electrons dancing around the nucleus of atoms, and so on. The universe and everything in it, living and nonliving, originally started (and still starts) at the microscopic level, a level too small for human senses to resolve. In this book, we focus on the concept of micro in contrast to that of macro; micro means anything small enough not to be seen by the naked eye, including the size scales of micrometers, nanometers, and smaller items. Because the universe and everything in it is comprised of microentities, to fully understand the macro we need to understand the micro.

Humans, the macrobeings, have evolved to a relatively advanced level. For better or for worse we are late comers to this party of life on Earth. On the scale of a 12-h clock, if the party started at the hour zero (i.e., midnight) with the solidification of the earth’s crust, and if it is noon now, we have just arrived at 11:59:59. However, now that we have arrived, we are the most curious and ambitious creatures at the party. We want to know everything about everyone and everything in the party: Who (or what) are you? What are you made of? How did you get here? Where are you from, no I mean where are you originally from? Where are you headed, that is, what is your future?

All the answers accumulated from our age old queries have uncovered the three most important higher-level secrets of nature, important and general enough that they should become part of the thinking of scientists and students of all sciences.

P.1 THREE SECRETS OF NATURE

At first glance, the diversity around us is obvious and ubiquitous. However, during the entire history of the development of science, the history of discoveries and inventions, nature has taught us a very powerful lesson over and over again: Look for the underlying unity behind apparent diversity of things and phenomena, and therefore behind the laws governing those things and phenomena. In my opinion, the three most salient of all the secrets of nature that science has discovered so far are the following:

There Is an Underlying Unity Behind Apparent Diversity. This concept is a key point to understanding not only the things and phenomena around us, but also their diversity. For example, all life is made up of the same basic building block of life: the cell. Most great discoveries and breakthroughs in the history of science have revealed this secret over and over again: unity behind diversity.
All Macroscopic Things Are Composed of Smaller Building Blocks. This truth exists at various levels. For example, all materials around us are made up of molecules or crystals, all molecules and crystals are made of atoms, which in turn are made of subatomic particles (proton, neutron, and electron), protons and neutrons are made of quarks, and so on. This is also true about living organisms. For example, we are made of organs, organs are made of tissues, tissues are made of cells, cells are made of and run by the molecules of life and atoms or ions, and the molecules of life are made of atoms, and so on. This structural hierarchy is also apparent in our own inventions, for example, there are rooms contained in buildings, the buildings are contained in neighborhoods, and the neighborhoods make up a City, and so on.

Nature Does Its Most Important and Fundamental Work on a Smaller Scale. This statement means that if you really want to understand a macroscopic structure, you will need to understand its smaller building blocks. The bottom line is we cannot have the macroworld without the existence of a microworld.

The underlying unity behind diversity has been the key to major breakthroughs in the sciences. The history of physics can be told in terms of discovering the unification of multiple forces. For example, the terrestrial force that keeps us bound to the Earth and the celestial force that keeps the planets bound to the Sun are the same force: gravity. This realization helped Newton formulate the law of universal gravitation that applies to earth-bound problems, as well as explains the empirical laws of planetary motion discovered by Kepler. Unifying theories of electric and magnetic forces into a single theory of a force, called the electromagnetic (EM) force, was another great feat in physics, and the classical theory of EM is based on this unification. We now know from physics that our universe is shaped and governed by four fundamental forces: gravitational, EM, weak nuclear, and strong nuclear forces. For many, this may be unity enough, but the attempts to discover further unification continued, and there is great scientific evidence that even these four forces are different low-energy manifestations of a single force that was in action at the very beginning of the creation of the universe.

This history of unification of forces is intertwined with the history of discovering and understanding the smaller and smaller building blocks of matter. For example, physicists (and chemists) discovered that all materials around us are made of smaller components called molecules; the molecules are made of even smaller components called atoms; and atoms in turn are made of yet smaller constituents called neutrons, protons, and electrons. Physicists have probed neutrons and protons, and have discovered that they are made of even smaller and more fundamental particles called quarks. Therefore, the path of development that physics, and as a result other disciplines of science, have taken is the path from the macro (large) to the micro (small). As mentioned earlier, the reason for this is that we, the humans, are macrobeings and we
started observing things with the most primitive tools, our five senses (e.g., our eyes), which were the only tools easily available to us. These tools are limited to the macroworld. However, to our advantage, we humans had a capability that other organisms did not have, and that is, to develop tools and techniques: say technology. The gradual development of technology, and hence better tools (e.g., microscopes), enabled us to continue our journey of understanding and exploration from the macroworld of planets and visible objects around us to the microworld of molecules, atoms, and subatomic particles. In fact, by extending this idea we find there is a feedback loop between technology and basic fundamental science. As science evolves, new technologies emerge and in turn these new technologies allow for the creation of better and more powerful scientific tools. These tools in turn allow for new observations that lead to an even better understanding of the microscopic world, and so the cycle goes. For example, the colossal colliders at the particle physics lab at CERN (near Geneva, Switzerland) would not be possible without the capability of tracking particles to the precision of micrometers and microseconds provided by this technology, which itself is based on physics.

Combining the three secrets of nature, the truths of unification and the unity behind diversity are essential to our journey from the macro to the micro. This relationship among these three secrets of nature is the reason it has taken us this long to find them: the whole history of the development of science on this planet.

Rather ironically, when we had less information and knowledge than we have today, it appeared as if one person could know everything, and there was only one discipline called natural philosophy, the study of nature and the physical universe. Today’s physics is actually the modern version of natural philosophy.

P.2 FROM NATURAL PHILOSOPHY TO PHYSICS

In olden times, natural philosophy referred to the study of nature and the physical universe. It served as a precursor to developing fields of natural sciences led by physics. Rest aside physics, modern notions of science and scientists date only to the nineteenth century. Before then, the word “science” simply meant knowledge and the title scientist did not exist. For centuries, scientists were called natural philosophers, and these practitioners often pursued a wide variety of interests. A remnant of that heritage is a doctorate in physics, or other sciences, which is still called a Ph.D., and is an abbreviation for doctor of philosophy. The title of Isaac Newton’s scientific treatise published in 1687, commonly known as the Principia, is called The Mathematical Principles of Natural Philosophy. So, it is not a coincidence that long-established Chairs of Natural Philosophy at older universities are currently occupied largely by physics professors. The connection between physics and other disciplines of science can also be understood from the fact that all other fields of
science are historically developed from natural philosophy or its descendants. During the fourteenth and fifteenth centuries, the term *natural philosophy* was referred to what is now called physical science. By the mid-nineteenth century, with the increase of information and knowledge, it became increasingly clear that it was not generally practical for scientists to contribute to numerous areas. Thus specialization occurred and now there were physicists, chemists, biologists, geologists, and so on.

**P.3 PHYSICS THE MOST FUNDAMENTAL SCIENCE**

Being the most fundamental of all the sciences, physics has profoundly affected all science fields. Given its fundamental nature, students in many fields are required to take some physics courses in order to understand the fundamental principles underlying many phenomena across many science disciplines. In this sense, physics is intimately related to other sciences, and also to applied fields, such as engineering, medicine, and now nanotechnology. This is because principles discovered in physics apply to all natural sciences. For example, the principle of conservation of energy is common to all physical and chemical systems.

Chemistry is the scientific study of matter and materials and the changes that they undergo; matter is anything that exists, has mass, and occupies space; whereas a material is any kind of matter that can be used for something, such as glass. Starting with the macroworld as physics did, early chemistry largely dealt with substances, such as extracting metals from their ores, making pigments for cosmetics and painting, and fermenting beer and wine. Chemistry is the science that not only is most affected by physics, but also overlaps or collaborates with physics in many areas of study, such as atoms, molecules, and collections of atoms and molecules. A great example of the interaction between physics and chemistry is the quantum mechanical explanation of the relationships among chemical elements and the rules of their interaction (reactions) with one another captured in the periodic table.

Biology is the scientific study of life; that is, the study of living things and the phenomena related to them. Like physics and chemistry, biology also began its journey in the macroworld: finding and studying things that you can see with your naked eye, doing the counting, classifying them, and so on. By now, however, biology has progressed into the microworld in different disciplines, such as microbiology, biochemistry, and molecular biology. There are an enormous number of physical phenomena involved in developing a single cell into an organism and then maintaining the organism. In order to fully understand life, all these phenomena will be understood in terms of the principles of physics. Many key advances in the biological sciences already have been made possible by physics-based techniques. Some examples being used to study the molecules of life are the optical microscope to study cells, X-ray diffraction used to discover the structure of the deoxyribonucleic acid (DNA)
molecule, and the electron microscope. Nuclear magnetic resonance (NMR), a quantum mechanical phenomenon, is revolutionizing the field of medicine in the form of magnetic resonance imaging (MRI). With developments in genetics and molecular biology, an overwhelming amount of data is being generated in biology. The only way biologists will be able to fully make sense of these data is by developing a theoretical framework based on physics principles. Quite possibly in this process, we will discover new physics laws, partly because biological systems are generally different in some important ways from the physical systems that led to the current physics laws. After all, during its early days, biology helped physics in the discovery of the principle of conservation of energy. This principle was first realized and proposed by Dr. Julius Robert Mayer, a practicing physician, in terms of the amount of heat taken in and given out by a living body.

Needless to say, physics is also at the foundation of engineering and technology. Understanding the application of physics laws is necessary from designing a bike to an interplanetary spacecraft, from typewriters to computers, from a horse and wagon to a sports car, and from a radio to a flat screen TV. It is the understanding of matter at the atomic level, developed by discovering physics laws, that led to the semiconductor and microchip industry, and subsequently to computing, which led to the Internet revolution and the information age. Information technology has already become the fiber of all aspects of life in the modern world.

Although understanding the microworld at the atomic level, which was developed by physics, has been used in many fields, such as engineering and technology, we could not directly control microobjects, such as molecules and atoms. A big part of the reason is although physics studies in the twentieth century reached the levels of subatomic particles, such as quarks, other fields have been taking their time to catch up with molecules and atoms. Toward the end of the twentieth century, however, studies in most science fields had reached the level of molecules and gave rise to nanoscience and nanotechnology. This was first envisioned by a great physicist Richard Feynman, and expressed on December 29, 1959 during his talk at the meeting of the American Physical Society at California Institute of Technology titled: There Is Plenty of Room at the Bottom. This event is now considered to be the beginning of nanotechnology. Using nanotechnology, which is the application of nanoscience, enables us to control matter at the level of molecules and atoms: Mind the difference between understanding and controlling.

So, welcome to the twenty-first century, the age of molecules.

P.4  QUANTUM PHYSICS: THE SCIENCE OF THE MOLECULAR AGE

As mentioned earlier, all things macro are composed of things micro. It is the same truth that is being told through different stories in different disciplines.
A chemist will tell us that everything is made of atoms. A physicist will even go farther and tell us that the universe started off from a few fundamental particles, such as quarks and electrons: Quarks combined to make neutrons and protons, which combine to make nuclei. A nucleus combined with electrons to make atoms, which in turn bonded together to make molecules, and so on. A biologist will tell us that life evolved from certain molecules, which combined into the basic unit of life called a cell. Cells evolved into a whole variety of unicellular and multicellular organisms due to mutations in the genes, the source of evolution. These stories are telling us that nature has designed everything in the universe, living and nonliving, at a microscopic level from the bottom up.

Being human, our greatest blessing and our greatest curse has been that we are macrobeings, whereas the universe was built from the bottom up, we started investigating it from the top down. Obviously, the first things we saw and tried to understand around us were the macro items: our eyes laid upon stars, not atoms. This is why the history of physics started from planets, or other celestial and terrestrial bodies, and eventually made its way to atoms and subatomic particles. Similarly, the discipline of biology started from the study of living organisms, such as plants and animals, and made its way up to cells and the molecules in the cell. So, we had it backwards, and in this sense we have been very good reverse engineers.

We can boast as much as we like about our superiority to other organisms, but the fact remains that we as humans have our own limitations in understanding this universe. First, we can only investigate and understand so many things in our life time. Second, we can only investigate, gather information, obtain knowledge, and develop our understanding piecemeal. Some pieces may look different from each other at the surface. However, they may just be different facets of the same thing at some other level. Having only a partial knowledge, which are in different pieces, helps to obscure the big picture. Nature works the way it does without caring about our limitations. For example, nature did not create and does not need the borders and interfaces between different disciplines of science such as physics, chemistry, biology, and so on. These borders are the creations of our own limitations.

Here is another problem. Our common sense is built upon our experience with the macroscopic world. Therefore, the physics built from interacting with the macroscopic world, called Newtonian or classical physics (also called Newtonian and classical mechanics) makes sense to us. However, when our scientific studies entered the microscopic world, the laws of classical physics collapsed right before our eyes. Quantum physics came to our rescue and to this date has successfully explained microscopic structures and phenomena. Due to our macroscopic common sense and intuition, even the pioneers of quantum physics had, and we continue to have, trouble with digesting quantum physics. Common sense tells us, it only makes sense that it does not make sense to our common sense, because common sense is built from our experience with the macroscopic world. As you will see in this book, quantum phenomena
brutally violate our common sense. You will also see that classical physics actually is a special case, an approximation, of quantum physics. This means quantum physics is more fundamental, which is consistent with the fact that the universe is designed at the microscopic level, and is built from the bottom up. Therefore the reality of the macroworld that we experience on a daily basis has its roots in the microworld of atoms and molecules. This is also reflected by how a human is developed even today: Two half-cells (sperm and egg) join to make a zygote, which divides and develops into an embryo. Embryonic cells differentiate to make different parts of the body, and subsequently we have a full human being within months.

Even though quantum physics is more fundamental and general and classical physics is only an approximation of quantum physics, classical physics, which is an approximate science, works well in the macroworld. The reason is because those approximations are at the microscale; that is, they are so small they easily go unnoticed. So, while dealing with the macroworld, we can study and use classical physics and leave quantum physics for the microworld.

However, there is a problem with this approach, and hence an opportunity to be captured. As already mentioned, physics and its direct applications, as well as biology, chemistry, materials science, and other fields, have already entered the microworld. This situation has two aspects: individual and collective. Individual fields are developing their own subfields corresponding to the microscale, such as microbiology and molecular biology. All these fields are collectively organizing their efforts into what is termed as nanoscience and nanotechnology. For example, the entire field of molecular biology is biology at the microscale, or nanoscale level to be precise: The diameter of a DNA molecule is ≈2 nm, for example.

As nanoscience and, consequently, nanotechnology are progressing, we are learning how to handle and control molecules and atoms at individual levels. This opens the door to an endless array of opportunities, so much so that many of us are already calling the twenty-first century the nanoage or the molecular age. Quantum physics is the law of the land in the molecular age of the twenty-first century.

P.5 WHY THIS BOOK

Because everything is made of atoms, the macroscopic reality of our everyday experience in the macroworld has its roots in the microscopic world. So, here is the key to generating new ideas in making progress in all sciences in modern times: There are many things that atoms and molecules do, which cannot be understood in terms of what objects in the macroworld can do; whereas there is nothing that macroobjects do that cannot be understood in terms of what atoms and molecules can do. Quantum physics is the science that helps us to understand what atoms and molecules can do.
With this realization and with the fact that much of modern science, engineering, and technology are already dealing with molecules and atoms, comes the increased need to learn quantum mechanics even for nonphysics majors, such as chemistry, biology, engineering, materials science, computer science, nanotechnology, and related fields. This book, designed as a complete course in quantum mechanics for these nonphysics majors, can be used as a textbook for a stand-alone course in quantum mechanics. It can be part of another course or a series of courses, such as modern physics and physical chemistry, or as a part of a short program, such as nanotechnology. This book presents a rich, self-contained, cohesive, concise, yet comprehensive picture of quantum mechanics for senior undergraduate and first-year graduate student, nonphysics majors, and for those professionals at the forefront of biology, chemistry, engineering, computer science, materials science, nanotechnology, and related fields.

Most, if not all, books on quantum physics written for science students use abstract mathematical formulation of quantum mechanics and leave its implications and connections to the real world often nonintuitive. This kind of framework may be necessary for physics students, but often is a learning hurdle for nonphysics majors. However, the centerpiece of this mathematical system and of quantum mechanics is the wave function. This book begins with the wave function, which the students have already learned about during their introductory course in classical (Newtonian) physics while learning about waves, and uses simple calculus, which most science major students learn in their junior undergraduate years, to develop and explain the concepts and principles of quantum mechanics. Comprehensive coverage of quantum theory, supported by experimental results and explained through applications and examples, is presented without the use of abstract and complex mathematical tools and formalisms, such as bra–ket vectors, Hilbert space, matrix algebra, or group theory. Other features of this book that help take the mystery out and bring quantum mechanics home for nonphysics students, researchers, scientists, and technologists include the following:

1. It is shown throughout the book how quantum principles generate the same results as classical physics when we move from the micro- to the macroworld. Due to its universal importance across different fields, another principle emphasized throughout the book is the natural tendency of systems to be in a state of equilibrium, that is, in a state of minimum energy.

2. Throughout the book, concepts and principles of quantum physics are explained in the language of nonphysics majors by presenting examples and applications from nonphysics fields including chemistry, biology, nanotechnology, and related fields.

3. Living in the Quantum World, a section at the end of each chapter, features real-world applications of one or more quantum mechanics principles discussed in the chapter.
4. Enough study checkpoints and problems with solutions are presented throughout the book to make difficult concepts easy to understand.

5. The interfaces and connections between quantum physics and nonphysics fields, such as biology, chemistry, computing, and nanotechnology, are identified or introduced in an easy to understand fashion.

6. All concepts and principles of quantum physics are explained from scratch the first time they appear and no prior knowledge of quantum physics is assumed.

7. The material is presented in a logical learning sequence: a section builds upon previous sections and a chapter builds upon previous chapters. There is no hopping from topic to topic and no jargon without explanation.

8. Pictures, illustrations, tables, notes, and cautions are used to help us to understand the difficult and tricky concepts.

9. To ease the reader smoothly into the chapter, each chapter begins with an interesting picture with a light amusing note that is in a direct or subtle way related to the main issue in the chapter.

10. To inspire the students, the quantum mechanics related individual achievements within the communal environment are emphasized by presenting brief biographies throughout the book. It also contributes to keeping the presentation interesting.

Furthermore, this book takes advantage of the amazing story of how quantum mechanics was developed. The concepts and principles that make the foundation of quantum theory are developed in the context of the history of the gradual development of quantum mechanics, which some of us find as amazing as quantum mechanics itself. This facilitates the introduction of the key concepts and principles of quantum physics as explanations for the results of those historic experiments that could not be explained with classical physics. In doing so, the book illustrates in an interesting way the process of scientific discoveries and advances.

After introducing the foundational concepts and principles of quantum mechanics, such as quantization, the uncertainty principle, quantum mechanical tunneling, and wave–particle duality in the context of explaining the results of historical experiments in the first few chapters, they are woven together in the formalism of quantum mechanics. Subsequently, quantum theory is presented in a single wave equation called the Schrödinger wave equation. The forthcoming chapters demonstrate how the principles of quantum mechanics naturally arise when we apply this wave equation to solve physical problems. The relevance of these types of problems to nonphysics fields is demonstrated throughout the book.

The application of quantum physics to simple systems, such as the hydrogen atom and the periodic table of the elements, is extended in a logical way to complex systems, such as molecules and the assemblies of molecules. This
covers the topics of molecular vibrations, molecular rotations, and quantum 
statistics of assemblies of molecules. Also covered are the quantum mechanical 
foundations of modern techniques used across several fields, such as atomic 
and molecular spectroscopy, lasers, NMR imaging, and electron microscopy.

P.6 IN THIS BOOK

The laws of classical mechanics, or classical physics, were developed over the 
centuries by many scientists. Astronomers made contributions due to their 
interest in the heavenly (extraterrestrial or celestial) bodies. For example, the 
experiments, observations, and their explanation by Galileo Galilei (1564– 
1642) laid the foundations for the important discoveries that were made in the 
following two centuries. Issac Newton (1642–1727), another giant figure of 
those times, clearly understood the relationship among different variables 
involved in the motion of objects and put the work of centuries into three 
elegantly simple laws known as Newton’s laws of motion. Newton’s greatest 
gift was the unification of terrestrial and extraterrestrial (celestial) 
forces when he pointed out that the motion of planets around the sun can be 
understood by the same laws that govern the motion on Earth. Newton’s laws 
make the foundation of classical physics, which includes Maxwell’s equation 
of EM forces, unifying the concept of electric and magnetic forces into one 
force: the EM force. All these concepts that make up the core of classical 
physics are reviewed in Chapter 1 in a concise, but cohesive fashion. The core 
assumption of classical physics is that physical entities exist in two different 
types: particles and waves. This assumption is clearly reflected in the fact that 
classical mechanics (mechanics of particles) and optics (as waves) are two 
independent disciplines in physics with their own set of principles and laws 
and with their own series of experiments and course works. So, Chapter 1 is 
oriented toward making a clear distinction between waves and particles: either 
you are a particle or you are a wave. This treatment by classical physics of 
particles and waves as two different types of entities mirrors the physical 
reality that we experience as macrobeings. It makes sense to us to treat mate-
rial bodies or objects as particles and to treat some other phenomena as waves 
that do not fit into the particle picture, such as a ripple that spreads out from 
a single point of impact when you throw a little rock into a body of still water.

However, as mentioned earlier, because the objects of the macroscopic 
world are constituted of the objects of the microscopic world, the physical 
reality experienced by us in the macroworld has its roots in the microworld. 
Just before (or during the early days of) probing the microworld, the laws of 
classical physics were working so well that some scientists toward the end of 
the nineteenth century were becoming rather smug and making statements 
such as the one by William Thomson Kelvin in 1900: “There is nothing new to 
be discovered in physics now. All that remains is more and more precise 
measurement.”
But even Kelvin knew that there were challenges coming from the microworld, which he referred to in his speech in 1900 to the Royal Institution as “two clouds on the horizon”. The two clouds that Kelvin was referring to were the failure to find a medium through which EM waves would travel and the explanation of black-body radiation. The first cloud gave rise to Einstein’s theory of relativity, which is very briefly mentioned in Chapter 1. The second cloud eventually led to the development of quantum physics. So much for Kelvin’s prediction of the end of physics.

Chapter 2 describes how the experimental results from experiments, such as black-body radiation and the photoelectric effect, challenged the notion that EM waves (light) were just waves. Black-body radiation was one of the first experiments where classical physics broke down in explaining the results from the microworld. It is shown how quantum concepts were introduced to explain experimental results.

Chapter 3 discusses how another set of experiments challenged the classical notion that particles, such as electrons, are just particles and not waves. It explains how the core assumption of classical physics that particles and waves are two separate components of the physical reality, breaks down in front of experimental results from the microworld. These results can only be explained with the particle–wave duality of nature: A physical entity acts as a particle under certain conditions and as waves under a different set of conditions.

Wave–particle duality is at the heart of quantum physics. It gives rise to two very important concepts in quantum physics: probability (or uncertainty) and quantization. An example of probability (or uncertainty) is that you cannot predict with certainty the position and momentum of an entity at a given instant; you can only assign probabilities to different possible values of position and momentum. Quantization means that a confined entity, such as an electron in an atom, is only allowed to have certain discreet values of energy. Both of these concepts go against the grain of classical physics, where you can predict the position and momentum of a particle at a given moment and the particle can have any energy, not only certain discrete values of energy. However, as Chapter 4 explains, this quantum picture explains the experimental results well from the study of atoms in terms of Bohr’s model. His model explains in a somewhat ad hoc way how quantization keeps the electron in the atom from collapsing into the nucleolus as predicted by classical physics. Chapter 4 also describes how Bohr’s model explains the spectral lines emitted by heated gases, another puzzle that the physicists were facing toward the end of the nineteenth century. The Bohr model, although a semiclassical or semi-quantum mechanical model, demonstrates the power of quantization.

So, Chapters 2–4 introduce in a logical way some fundamentals of quantum mechanics in terms of the hypotheses and laws put forward by different scientists in the beginning of the twentieth century to explain some physical phenomena that classical physics failed to explain. Chapter 5 puts these fundamentals together into a few postulates and develops a minimal formalism of quantum mechanics for the rest of the book. This chapter also shows how
these postulates can be summed together into one equation: The Schrödinger equation, the fundamental equation of quantum physics.

Chapter 6 is devoted to taking the mystery out of the Schrödinger equation by examining its solutions through its application to simple, but abundantly practical problems, such as confinement and vibration (or oscillation). Most of the systems in the universe are confined or bonded to their environment, such as in electrons in an atom, atoms in a molecule, and so on. It is a natural tendency of a system to be in equilibrium, and when disturbed it will oscillate (or vibrate) about its equilibrium position, such as atoms in a molecule or a crystal. These countless examples in nature can be modeled in various ways, such as a particle in a box (confinement) and a harmonic oscillator (vibrations about an equilibrium position). While applying the Schrödinger equation to these two situations in Chapter 6, we demonstrate how solving the Schrödinger equation naturally gives rise to the principles and laws of quantum mechanics discussed in the previous chapters.

All matter (living and nonliving) is made up of atoms. Hydrogen, which makes up 9.5% of the human body mass, consists of the simplest atom: A confined system of one electron bound to one proton in the nucleus. Chapter 7 demonstrates how applying the Schrödinger equation to this simple system naturally gives rise to some quantum mechanical concepts and principles, such as quantization, principle quantum number, orbital quantum number, magnetic quantum number, and the rules associated with these quantum numbers.

The structure and properties of atoms show a pattern displayed in the periodic table of elements. One of the greatest triumphs of quantum mechanics is to present an explanation for this pattern. This topic is discussed in Chapter 8, which also introduces the quantum mechanical concept of spin and spin quantum number along with Pauli’s exclusion principle, regarding the occupation of quantum states. The exclusion principle also plays an important role in determining the electronic configuration of atoms.

Atoms bound together to make molecules including the molecules of life: carbohydrates, DNA, lipids, and proteins. The quantum states of molecules in terms of rotation and vibration of diatomic molecules are discussed in the framework of molecular spectroscopy in Chapter 9. There are many physical, chemical, and biological situations in which a large number of atoms or molecules are involved. The behavior of such collections or assemblies and the relationships of individual constituents to the collection are studied in statistical mechanics: statistics fused with mechanical laws. Some basic concepts and principles of statistical mechanics are developed in Chapter 10, where we clearly explore the interface between classical and quantum statistical mechanics. The vibrations and rotations of molecules are revisited in the collective statistical environment.

Now that almost all the sciences, including biology, chemistry, materials science, and computer science, that began with macroscopic studies are meeting physics in the microscopic, including the nano, world of molecules and atoms, the twenty-first century is shaping up to be the molecular age. Due to these
common issues and problems that scientists are dealing with on this size scale, this area in all sciences is collectively developing as nanoscience. The developing field of nanotechnology, the application of nanoscience, is increasingly allowing us to handle molecules and atoms at individual levels. Chapter 11 discusses quantum mechanics as a common thread through different fields of nanoscience and nanotechnology.

P.7 BACK TO THE FUTURE

History repeats itself in interesting ways at various levels. As already mentioned, all science disciplines that directly or indirectly emerged from one discipline, which was natural philosophy, are now converging in many ways into one field called nanoscience and its application, which is nanotechnology. Quantum physics, being the science of the small, is the common thread that runs through all these fields at the nano and smaller scales.

Finally, let us borrow a metaphor and its elaboration from Richard Feynman who, once referring to an unknown poet, said “The whole universe is in a glass of wine”. We do not know what the poet really meant by this, but a number of scientists from different disciplines sitting around a wine glass can together actually see the entire universe in it. A biologist, for example, sees the fermentation, the bacteria, and hence life. A chemist sees an interesting array of chemicals, ferments, enzymes, product, whereas a physicist sees the reflections and refraction in the glass, and the swirling evaporating liquid. Physicists and chemists both see the molecules of alcohol and atoms, such as carbon, hydrogen, and oxygen; the physicist sees protons and neutrons in the nucleus of the atoms and the quarks from which the atoms are composed. These are the same quarks from which the whole universe is made. Where did the glass come from? Rocks … fossils … secrets of life and the universe … evolution of stars … we can go on and on. I do not want to spoil the party, but remember, it is our small minds (our limitations), that divide this glass of wine, the universe, into physics, chemistry, biology, geology, and so on; nature sees no such divisions.

So, again about this glass of wine in the words of Feynman:

“Let’s put it all back together, not forgetting ultimately what it is for. Let it give us one more final pleasure: drink it and forget it all!” The party of life and the dance of the universe will continue. Take this book as a micro or quantum celebration of this party.

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