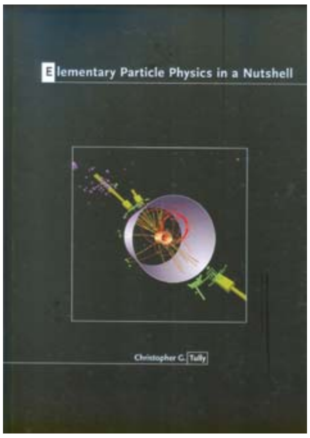

Elementary Particle Physics in a Nutshell. Christopher G. Tully. Princeton University Press, 41 William Street, Princeton, New Jersey 08540, USA. 2011. ix + 303 pp. Price: US$ 75.00/£52.00.

This book among the 'nutshell' series published by Princeton University Press, is designed to be a textbook for first-year graduate students preparing to take up research in theoretical and experimental elementary particle physics. The author is an experimental particle physicist who works in Princeton University, USA. It contains subject matter for a one-semester course, which would run in parallel to a course in quantum field theory, which is the basis of modern-day elementary particle physics. Quantum field theory (the book under review is a companion to the popular book *Quantum Field Theory in a Nutshell* by A. Zee, which has now gone into a second edition) is the union of quantum mechanics and the special theory of relativity, and is the frame-work in which one understands how matter can transmute from one form into another. The subject was born in the physics of nuclei and subsequently found applications in the sub-nuclear domain, that in which the weak and strong interactions reign supreme, along with the electromagnetic interactions. The weak interactions are, among other things, those that are responsible for the beta decay of nuclei, and also for the decay of free neutrons. The strong interactions are those that keep the quarks and gluons bound inside particles such as protons and neutrons, whereas the familiar electromagnetic interactions are responsible for atomic stability. Today the electromagnetic and weak interactions are 'unified' into the electroweak interactions: they have a common birth, but look very different. The weak interactions are short-ranged and particles that transmit them are very heavy, while the electromagnetic interactions are infinite-ranged and the particles that transmit them, the photons, are massless. The gluons which transmit the strong interactions are massless, but the force is short-ranged due to a phenomenon known as 'confinement'. The particles that participate in these interactions come in several 'flavours' and are known as leptons (e.g. the electron and its neutrino, and their more massive counterparts), and quarks (the up and down quarks that constitute protons and neutrons, and their heavier counterparts). The leptons participate in the electroweak interactions but not in the strong interactions, while the quarks participate in all of them.

The overarching theory that describes all these interactions has come to be known as the 'standard model'. We stand today at the crossroads where the standard model appears to describe all known interactions accurately. Large masses of data have been collected from generations of experiments at colliders, where electrons are collided with positrons, protons on anti-protons, electrons on protons, including those at the Large Electron Positron collider at CERN in Geneva, at the Tevatron in Fermilab, USA, at the B meson factories at SLAC in USA and at KEK in Japan. The collider experiments are based on the principle that the energy of the collision can lead to the production of very massive particles in accordance with the special theory of relativity, and their subsequent decay products observed in detectors. Many properties of the elusive neutrinos have been discovered only in the past decade in large observatories. It has been confirmed that they oscillate from one flavour to another, thereby explaining the shortfall of observed solar neutrinos, for instance.

And yet there are tantalizing hints that there are vast surprises. Of these the most significant one appears to be that the Higgs particle that is predicted by this theory (on the path to providing masses to the force carriers of the weak interactions and to the quarks and leptons) has failed to show up in the most ambitious project ever built by experimentalists, namely the Large Hadron Collider (which collides protons on protons and heavy ions) which has been operating at CERN for the last couple of years.

What then waits for us? How do we then go beyond a theory that is seemingly so successful? These are the questions that the students of elementary particle physics, for which the book under review has been written, will answer in the course of the coming years in their research activity. The book is organized in several beautiful chapters covering the basic formalism. It provides a comprehensive view of the standard model of the year 2011, is modern and gets down to business very quickly. As the author suggests, the story of elementary particle physics is as much about the present as it is about the past, as much about the micro- as it is about the macrocosm: it is the rules of elementary particle physics which also govern the nature of the cosmos in the standard big-bang picture.

The book is organized into nine excellent chapters. In chapter 1, the author provides an overview of the standard model, discussing important issues such as handedness of particles, the notion of hypercharge central to the electro-weak interactions (unified theory of electromagnetism and weak interactions), notions of mass and charge, and to the Higgs mechanism which is central to the standard model. The Higgs mechanism is one for which an analogy exists in superconductivity where the Cooper pair of electrons provides a condensate. It is such a Higgs condensate that provides the masses to the force carriers of the weak interactions and the quarks and leptons, and leaves behind at least one ghostly survivor, the raison d'etre for the Large Hadron Collider.

The study of elementary particles and their interactions requires a language of great precision and rigour, namely that of quantum field theory. One studies the motion of particles as they traverse along and experience the presence of others via the exchange of the force carriers. Indeed, these are the inter-particle interactions. What are the rules that govern the motion of free particles? Of particles that bounce off each other? How shall we describe the life of short-lived particles, those that come into being in collisions of other particles and decay soon after? How do they come into being? How does the Einstein theory which says that energy and mass are interchangeable dictate these phenomena?

Indeed, in chapter 2, the rules in the simplest of these theories, that of electrons and photons, namely quantum electrodynamics is taken up. With great ease and clarity the author sets up these and introduces the Lorentz transformation, the keystone for the rise of the theory of relativity and describes the solutions of the Dirac equation which are the relativistic equations that describe half-integral spin objects. The author goes on to describe photons, the quanta of spin-1 (vector) fields which couple of electrons to give rise to electrodynamics. The full quantum theory was later developed and studied by Richard Feynman, Julian Schwinger, Sin-Itiro Tomonaga and also Freeman Dyson. The upshot of all the theory is that it gives a framework for the computation of what physicists measure in experiments such as collision 'cross-sections' and decay lifetimes.

An important organizing principle which reproduced quantum electrodynamics is known as a gauge principle, which was first introduced by Hermann Weyl. The vector fields naturally arise when one demands an invariance under symmetry operations of a quantity known as the Lagrangian that is written in terms of the fields of which the particles are the quanta. The Lagrangian is associated with kinetic and potential energies of the system, and describes the content of the physical system. Electrodynamics arises when the symmetry is a simple commutative (Abelian) rotation in an internal space. The weak interactions can be introduced if a more complicated 'non-Abelian' rotation based on mathematical structures known as special unitary groups is postulated, and so can the strong interactions. For the weak interactions, this does not account for why its force carriers become massive. That can happen when a suitable condensate forms in the vacuum. The original Higgs mechanism that was set up for the simple rotation can be suitably generalized for the case of non-Abelian rotations. Chapter 3 concerns itself with all these phenomena and provides a highly accessible but sufficiently detailed introduction to all the ideas that are needed.

In chapter 4, the author turns his attention to matter that is made up of quarks (and anti-quarks) and gluons. He introduces in a very physical manner some of the deep properties of field theories, including that of 'renormalization' due to which even the strength of the interaction changes as the distance scale that is probed is changed. This is at the heart of the strong interactions, which the author introduces with great ease. In chapter 5, the author goes on to the principles of detectors and measurements, covering such diverse topics as experiments to detect the as yet unseen dark matter. Esoteric topics such as the observation of 'jets' of strongly interacting particles that are omnipresent in experiments such as in the Large Hadron Collider are discussed.

A particularly commendable chapter is chapter 6 on neutrino properties and measurements of the mixing in the quark sector (named after Cabibbo, Kobayashi and Maskawa) – although these are well known in seminar circuits, they have rarely made it to textbooks. The treatment of the masses and mixings of neutrinos, and of the mixing of the quarks is a highly accessible introduction and is useful also to the practitioner. Notions such as the 'unitarity triangle' which tests the consistency of models of mixing are elegantly described.

In chapters 7 and 8, the author turns to collider physics at electron–positron machines and hadron colliders, and discusses at length important technical topics associated with exotic particles such as the W bosons, τ leptons and top quarks, to name a few. Electron–positron colliders have been successful in the past, including the famous Large Electron Positron (LEP) collider at CERN, and the Stanford Linear Collider in USA, which have studied the properties of the neutral weak force carrier, the Z boson, and the charged ones, namely the W bosons. Properties of the exotic τ lepton have also been studied in this environment. There is now worldwide interest in a high-energy counterpart of these for the future, known as the International Linear Collider project, which is now at an advanced stage of consideration for sanction and construction. Hadron colliders, the topic of chapter 8 on the other hand, can reach much higher energies than the electron–positron counterparts, since the synchrotron losses are much smaller. On the other hand, since hadrons are composite objects, the actual energy available for a given collision is degraded since the momentum is distributed among the constituents. Furthermore, the initial state is not a 'clean' one, as the ubiquitous strong interactions cannot be switched-off. These introduce important complications which need to be understood. The author provides a thorough discussion of the necessary background needed in the chapter. In chapter 9, there is a round-up on Higgs physics up to the present and in future experiments. For instance, the important limits obtained from the LEP experiment are discussed in some detail, the mechanisms for the production at electron–positron and hadron colliders compared, and many details on the experimental aspects are provided.

In summary, the book is a valuable and important addition to libraries, personal and institutional. It would serve as an excellent textbook to students taking up research in elementary particle physics and also as a reference volume. It has useful exercises and references. It is my hope that in the coming years, as the Large Hadron Collider sheds light on the high-energy frontier, the author would update the book and bring out a future edition.

ACKNOWLEDGEMENTS. I thank I. Sentitemsu Imsong for comments and a careful reading.

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Annual Review of Physical Chemistry, 2011. S. R. Leone *et al.* (eds). Annual Reviews, 4139 El Camino Way, P.O. Box 10139, Palo Alto, California 94303-0139, USA. Vol. 62. xii + 681 pp. Price: US$ 86.

The *Annual Review of Physical Chemistry* has remained an important source for authoritative and critical reviews on various topics in physical chemistry for over six decades. I have personally been a beneficiary of excellent reviews on topics in and beyond my areas of research interest. I vividly remember the excellent reviews by H. S. Johnston on atmospheric chemistry in volumes 35 and 43, and reading these made me an 'expert' in atmospheric chemistry giving popular talks in many places. I have, of course, never worked on atmospheric chemistry myself. Every time my students ask for topics to give literature seminars which have to be outside their research areas, I tell them to go through the last few volumes of *Annual Review of Physical*