

# Preface

Supersymmetry (SUSY) is a lovely theoretical construct, and has captured the imagination of many theoretical physicists. It allows for a new synthesis of particle interactions, and offers a new direction for the incorporation of gravity into particle physics. The supersymmetric extension of the Standard Model also ameliorates a host of phenomenological problems in the physics of elementary particles, if superpartners exist at the TeV scale. These new states may well be discovered in experiments at high energy colliders or in non-accelerator experiments within the next few years!

There are several excellent books that explore the theoretical structure of supersymmetry. These advanced texts are rather formal, and focus more on the theoretical structure rather than on the implications of supersymmetry. This makes them somewhat inaccessible to a large number of our experimental as well as phenomenological particle physics colleagues, working on the search for the new particles predicted by supersymmetry. Our goal in this book is to provide a comprehensive (and comprehensible) introduction to the theoretical structure of supersymmetry, and to work our way towards an exploration of its experimental implications, especially for collider searches. Although we have attempted to orient this book towards experimentalists and phenomenologists interested in supersymmetry searches, we hope that others will also find it interesting. In particular, we hope that it will provide theorists with an understanding and appreciation of some of the experimental issues that one is confronted with in the search for new physics.

We use the language of four-component relativistic spinors throughout this text, rather than the sometimes more convenient approach using two-component spinors. Although this makes some of the manipulations, especially in Chapters 5–6, appear to be somewhat more cumbersome, we felt that the use of four-spinors, which is familiar to most “practical particle physicists,” would make up for this. For this reason, and also because we did not want to adopt a schizophrenic approach using two-component spinors for some things, and four-component spinors for others, we have eschewed the use of two-component spinors throughout.

After a review of the Standard Model (mainly to set up notation) and an examination of the motivations for weak scale supersymmetry, the text naturally divides into three parts. The first part (Chapters 3–7) of the book introduces supersymmetry, and details how to construct globally supersymmetric relativistic quantum field theories. We provide a “master formula” for the Lagrangian of a general, globally supersymmetric non-Abelian gauge theory that can serve as the starting point for the construction of supersymmetric models of particle physics. The inclusion of supersymmetry breaking is discussed in Chapter 7.

The second part of the book applies these lessons and develops the so-called Minimal Supersymmetric Standard Model, the MSSM, which is (almost) the direct supersymmetrization of the Standard Model. The physical particles of the MSSM are identified, and their various couplings, which are necessary for exploration of the broad phenomenological implications of the theory, are calculated. An assortment of implications of the MSSM are examined in Chapter 9, including the SUSY flavor and  $CP$  problems, renormalization group running, cosmological dark matter, and more. We discuss local supersymmetry (which, we show, includes general relativity) in Chapter 10, and in the following chapter present an overview of some of the specific mechanisms by which Standard Model superpartners may acquire supersymmetry breaking masses and couplings.

The final third of the book is oriented towards collider physics. We detail the calculations of scattering cross sections and decay rates starting from the couplings of supersymmetric particles that were found in Chapter 8. We focus on technical aspects of these calculations, including methods for dealing with Majorana particles, which the reader may not be familiar with. We also outline methods for simulation of collider scattering events in which supersymmetric matter has been produced. We then discuss what has been learned, and what may be learned, about weak scale supersymmetry from past, present, and future experiments at both hadron and  $e^+e^-$  colliders. In a final chapter, we go beyond the MSSM, but only insofar as to introduce  $R$ -parity violation, which changes the phenomenology considerably. In three appendices, we present formulae for evaluating tree-level scattering cross sections at electron–positron as well as hadron colliders, decay rates of supersymmetric particles, and decay rates of the several Higgs bosons present in all SUSY models. Various exercises are interspersed throughout the text. Some of these are pedagogical in nature, asking the reader to fill in or complete a calculation, while others develop the subject beyond the discussion in the text.

We have not attempted to make a comprehensive list of references to the vast literature on supersymmetry. Where we develop a topic from scratch, we reference only some of the classic papers on the subject. Sometimes, this means that we may not reference earlier pioneering work in favor of more complete studies that may prove more useful to a reader attempting to learn the subject. However, where we

content ourselves with stating a particular result rather than deriving it completely – this is more frequently the case in the latter part of the text where we discuss supersymmetry phenomenology – we provide a reference where the reader may find further details. Thus, except for referencing some classic papers, we generally provide references only to papers where necessary details not presented in the text may be found. We apologize to the reader for this shortcoming, and also to the many researchers whose work has not been explicitly referenced.

Although we hope that the interested reader will work through the entire book, those who are interested only in phenomenology and are willing to accept supersymmetric couplings from the MSSM at face value, can skip Chapters 3–7 altogether. Chapter 10 can also be omitted without essential loss of continuity. Alternatively, the reader who is interested in model-building but does not want to work through the machinery of SUSY may use the “master formula” in Chapter 6 as a starting point, focussing on its use for writing down supersymmetric models. We urge all readers to visit Chapter 3, where many of the extraordinary properties of supersymmetric theories are explicitly illustrated.

We assume that the reader is familiar with tree-level calculations in quantum field theory through QED, as presented, for instance, by the first seven chapters of *Introduction to Quantum Field Theory*, by M. Peskin and D. V. Schroeder. We also assume some familiarity with the Standard Model of particle physics, but just in the unitarity gauge, as presented for instance in *Collider Physics*, by V. Barger and R. J. N. Phillips. No prior knowledge of supersymmetry is assumed. Indeed we have done our utmost to develop this subject from scratch, paying attention both to concepts as well as to technical details that will enable the reader to carry out research in the field. However, while we have emphasized pedagogy in our development of topics to do with supersymmetry, it is not possible to be as detailed on every topic that is necessary for describing the implications of supersymmetry for particle physics. Aside from tree-level quantum field theory and the basics of the Standard Model that we have already mentioned, these might include the ideas of the parton model, collider kinematics, Grand Unification, renormalization group methods, Big Bang cosmology etc. that have become part of the repertoire of many working particle physicists. Although we develop these ideas enough for the reader to be able to follow along, the reader who is interested in their detailed development is urged to consult the references in the text, and also the excellent treatment in the many text books listed in the Bibliography.

In writing this book, we are indebted to an enormous number of people, including teachers, students and colleagues from whom we have learned much. One of us (XT) benefited vastly from S. Weinberg’s lectures on supersymmetry at the University of Texas at Austin in Spring 1982. Much of what we know is the result of collaborations and discussions over the years with many people,

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