Chapter 0

Introduction

As we start this study of Particles and Symmetries it seems appropriate to try to provide an overview, *i.e.*, some version of the big picture goals for this course. As the title of the course implies, our goal is to provide an introduction to an area of physics that has seen dramatic progress in the last 50 years - particle physics. A central tool during this progress has been the exploitation of the underlying symmetries, the other subject in the title, of the interactions of these particles. The short version summary of this progress is encoded in the so-called Standard Model of Particle Physics (typically denoted the SM), which identifies the particles (degrees of freedom) and interactions between the particles relevant to the understanding of nearly all of the physical universe. When we include collective behavior (quarks bounds in nuclei, electrons bound in atoms, atoms bound in solid matter) plus classical gravity, we have a nearly complete explanation for the physics of the very large, *e.g.*, the evolution of the universe from very early times, down to the physics at the shortest distances now observable at particle accelerators. To have full quantitative command of this fundamental understanding requires a tool not at our disposal - quantum field theory. However, we will be able to outline a "semi-classical" (building block) picture of particle physics using only special relativity, quantum mechanics and symmetries, which is remarkably complete and relatively quantitative. The most recent addition to the SM is the so-called Higgs boson (named after the physicist Peter Higgs), whose apparent discovery at the Large Hadron Collider (the LHC) at CERN (in Geneva, Switzerland) was announced on the 4th of July, 2012 (and essentially confirmed to have the expected properties during meetings held in March of this year). The existence and interactions of this particle were predicted based on theoretical (*i.e.*, mathematical) considerations, and the confirmation of the expected properties constitutes a major step forward in particle physics research. As noted, this confirmation has essentially been announced just weeks ago, with only a few details still to be verified.

From a pedagogical perspective, this study of particle physics will provide us with the opportunity to discuss special relativity in detail and practice using it to describe the kinematics of particle collisions at high energy, especially the role of 4-dimensional momentum conservation (which is itself associated with the symmetry associated with the invariance of physics under translations in space and time) and the speed of light as the *universal* speed limit. We will want to develop facility with 4-vector notation and the transformations (boosts) that take us between different inertial reference frames. From quantum mechanics we will make use of (and practice using) the uncertainty principle and the important role of the eigenstates of (commuting) operators. In particular, we will want to become efficient at using operator notation to relate different states within the degenerate multiplets that arise due to symmetries. You should have seen this structure in the context states of *definite* total angular momentum, but *varying* angular momentum component along 1 spatial axis. Transformations between these states are accomplished using the (hopefully familiar) raising/lowering (ladder) operators. Finally we will use symmetries (and the underlying mathematics of group theory) to tie this all together and keep the mathematics simple. This approach will include the use of "approximate" symmetries - where there is no true (exact) invariance under certain transformations, but rather the transformations induce only numerically "small' changes. This will allow us to simplify complex computations in terms of *perturbative* expansions organized in terms of powers of these small changes (such expansions are an essential tool for your physics toolbox). All during the quarter we should be honing our skills for making order-of-magnitude estimates, *i.e.*, being able to estimate a value for a given quantity even when we do not know (or do not understand) all of the details.

Do not be concerned if all of these concepts are not clear at the outset. Also you should expect that initially portions of our discussions may seem more "abstract" than you are accustomed to. However, you should become concerned if clarity does not develop quickly over the next 10 weeks. Finally do not be surprised if our approach seems somewhat circular. We will try to introduce the relevant vocabulary and concepts in the early lectures, and then return to the same concepts in the context of a more complete formalism in the latter lectures.