

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. (But beware of the details of the big picture coming from someone who has not yet taught the 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, 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 bound 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.

From a pedagogical perspective, this 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 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 have probably 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 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 will include the use of “near” symmetries - where there is not true (exact) invariance under certain transformations, but rather the transformations induce only “small” changes. This will allow us to simplify complex computations in terms of perturbative expansions in these small changes (another 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) some of the details.

Do not be concerned if all of these concepts are not clear at the moment. But you should become concerned if clarity does not arise over the next 10 weeks.