Introduction

If you've made it this far in your physics education, you may have been struck by the realization that as elegant as you may find Lagrangian mechanics or Maxwell's equations or the Schrödinger wave equation, there *must* be something deeper underneath.

Along the way, you may well have heard of something called the *Standard Model* of particle physics. It is normally spoken of, quite rightly in my opinion, in a tone of hushed reverence. If you've encountered the Standard Model only in passing, you may be underwhelmed. It's usually represented as a ranked list of fundamental interactions: *strong*, *electromagnetic*, *weak*, and (if it must be mentioned at all in this context) *gravity*.[1] The Standard Model is also a collection of particles and how they respond (or don't) to those fundamental forces (Figure 1).

For a theory that is meant to be elegant and to do away with so much of the rote memorization that characterizes early courses in physics, the Standard Model can seem to the uninitiated to be just a laundry list of things that happen.

It is anything but.

At its heart, the Standard Model is the theory of the symmetry of empty space, and the rules by which **classical fields** can occupy and interact within that space. You've likely already been exposed to at least one classical field: electromagnetism, the properties of which can described by Maxwell's equations and the Lorentz force law.

We will explore the symmetries of classical fields. Indeed, they will be the central focus of our attention. But we will ultimately need to deal with the quantum nature of the universe—which will in turn give rise to particles.

There are important differences between quantum mechanics and classical fields. Classical systems are deterministic, while quantum systems by necessity contain

[1] Gravity is not, in fact, part of the Standard Model at all—an omission that we as a physics community will need to deal with at some point.

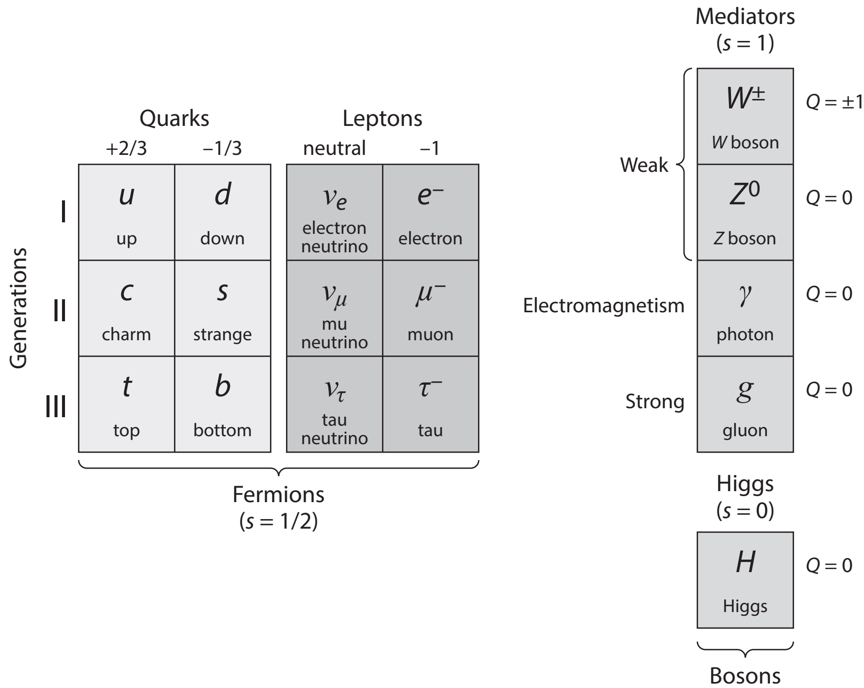

Figure 1. The Standard Model particle zoo. For the moment, "Quarks," "Leptons," "Mediators," and so on, are simply labels. Throughout this course, we'll delve into where this structure comes from.

uncertainty and randomness. But quantum mechanics and classical fields can be unified. For electromagnetism (and the other forces of the Standard Model) we have a *quantum field* version of the theory (QFT), wherein the field is broken down into indivisible chunks: the photons. While our main focus in this book is on the classical side of things, to produce any useful results, we'll need to do a few direct QFT calculations.

Don't fret.

We'll develop just-in-time plausibility relationships to indicate how these calculations should work. Should you wish to do the calculations in greater detail, you can find the *Feynman rules* for doing QFT calculations in Appendix C. Better yet, if you are planning on becoming a particle physicist, you can and should do this course in sequence with a formal QFT course.

We will focus our attention on the Standard Model fields: electromagnetism, the weak interaction, and strong force, as well as unifications among these. We'll see how they are derived from simple statements of symmetry, and along the way, we'll develop an understanding of group theory, Lagrangian mechanics, and symmetry breaking. By the end, we'll be prepared to talk meaningfully about electroweak unification and the Higgs boson, color confinement in the strong force, and what questions remain to be answered.