Introduction: The Aim and Structure of These Volumes

Philosophy of physics concerns the whole of physical reality, considered in a usefully generic way. For example, the physical world appears to have spatial and temporal aspects, so the existence and nature of space and time (or space-time) is a central topic. Matter, the sort of stuff of which tables and chairs and planets are composed, is a similarly central topic. By "a usefully generic way," I mean this: the most general question we can ask about matter is what sort of thing it is. For example, we might hold that matter is made of point-like particles, or of fields, or of one-dimensional strings, or of some combination of these, or of something else altogether. Given any one of these general accounts, there are further, more specific questions: how many sorts of fields there are, what the masses of the particles are, and so on. We will be concerned with the most general questions, rather than the more specific ones.

Philosophy of physics, as a discipline, is continuous with physics proper. The sorts of questions we will ask are among the questions physicists ask, and among the questions physical theories historically have tried to answer. But an astonishing amount of physics can proceed without answers to these questions. For example, the science of thermodynamics, as its name suggests, initially aimed at providing a precise mathematical account of how heat spreads through an object and from one object to another. But we can discover quite detailed equations governing heat flow and still not have an account of what heat *is*. Is it a sort of fluid (as caloric theory holds) that literally flows out of object and into another, or a sort of motion (as kinetic theory holds) that is communicated by interaction from one body to the other? If all you care about is how long it will take a 20-pound iron rod at 200° F to cool to 100° F when it is immersed in a large vat of water at 50° F, the equations of heat flow can provide the answer. But you will be none the wiser, having calculated the answer, about the fundamental nature of heat. An ironworker may not give a fig about the nature of heat, and the philosopher of physics may care equally little about the exact time it takes for the iron to cool down. A practicing physicist will typically care about both but may focus more on one or the other at different times. It is characteristic of a contemporary physics education that much more time is spent learning how to solve the equation and get a practical answer for the ironworker than in discussing the more "philosophical" questions about the nature of heat, or the nature of space and time, or the nature of matter. Physics students who are fascinated by these more foundational questions can find themselves frustrated by physics classes that refuse to address them. This volume is dedicated to them as much as it is to philosophers with an interest in physical reality.

The philosophy of physics has here been divided into three parts, spread over two volumes. Each of these volumes can be read independently of the other. But particular themes—most importantly, the need for a completely physical account of "measurement" procedures—are addressed in both volumes, so reading them in order will repay the effort. The first volume addresses the nature of space and time. It contains a brief history of debates about space and time from classical physics (Newton) through General Relativity. In physics, space and time (or later, space-time) serve as the stage on which the history of the physical universe plays out. But space and time themselves are elusive entities. The physical world presents itself to us as a collection of things and events in space that coexist or succeed each other in time. But space and time themselves do not appear to our senses: they have no color or flavor or sound or smell or tangible shape. What space and time seem rather to have is a geometrical structure. We will examine various theories about exactly what that structure *is*, and about what *has* that structure. The Theory of Relativity is presented, first and foremost, as a theory of the geometry of space-time. Special Relativity is explained in enough detail to solve specific problems about the behavior of clocks and rigid objects in a relativistic world. General Relativity is presented less rigorously. My aim has been to make the conceptual foundations of these theories absolutely clear, with particular attention to how the use of coordinates in physics relates to the underlying geometrical structure.

Volume 2 takes up the theory of matter. The first part of this volume presents the contemporary theory of matter: quantum theory. Unlike Relativity, there is no agreement among physicists about how to understand quantum theory. Indeed, the very phrase "quantum theory" is a misnomer: there is no such theory. Rather there is a mathematical formalism and some (quite effective) rules of thumb about how to use the formalism to make certain sorts of predictions. Here the difference between the ironworker and the philosopher of physics becomes acute. The ironworker (or the physicist in ironworker mode) doesn't particularly care about the nature of the physical reality: it is enough to calculate how various experiments should come out. The philosopher of physics cares about the underlying reality and attends to the predictions only insofar as they can serve as evidence for which account of the underlying reality is correct. In this part, we will consider some competing accounts of the nature of matter. These theories share much of the mathematics of quantum theory in common but nonetheless differ radically in their accounts of what exists.

If volume 1 covers space-time and the first part of volume 2 covers the material contents of space-time, it might seem that there is nothing more to discuss. Haven't we licked the platter clean? In a sense we have: all there is to the physical world, at a fundamental level, is accounted for by the theory of space-time and the theory of matter. Nonetheless, there are physical phenomena that are more perspicuously understood and explained by using a different set of concepts than those peculiar to space-time theory and quantum theory. A signal example of this is thermodynamics. Even though the phenomena addressed by thermodynamics are, at base, nothing more than the motions of matter in space-time, still a certain sort of insight, understanding, or explanation requires analyzing them with the conceptual tools of statistical mechanics. These same tools shed light on the appearance of probabilities in physics, on the explanation of statistical patterns of behavior, and on the apparent irreversibility or time-asymmetry of many phenomena. Our investigation of the relationship between thermodynamics, entropy, statistical mechanics, and irreversibility provides an example of how new insights into physical phenomena can be found even when the fundamental ontology and its laws are already known.

These books present an opinionated survey. There is far too much material and too little space to do justice to all the physical theories and philosophical positions that have been offered on these topics, and I make no pretense to try. Rather, I have considered a circumscribed set of alternative approaches that strike me as both clear and instructive. And I unabashedly advocate those that I think are the most promising and well founded. This is not a dispassionate overview of the field. But I hope that my selection of proposals illustrates what it is for a physical theory to be clear and comprehensible. Unfortunately, physics has become infected with very low standards of clarity and precision on foundational questions, and physicists have become accustomed (and even encouraged) to just "shut up and calculate," to consciously refrain from asking for a clear understanding of the ontological import of their theories. This attitude has prevailed for so long that we can easily lose sight of what a clear and precise account of physical reality even looks like. So whether or not you are attracted by the physical theories I will discuss (and many physicists will find them distasteful), I hope you come away appreciating at least their *intelligibility*. Whether these theories are correct or incorrect, insightful or wrongheaded, we know what they are claiming about the physical world. Physicists and philosophers must demand such clarity if we are to ever understand the universe we inhabit.