Introduction

For several decades, I have felt uncomfortable with the idea of paradigm shifts in the life sciences. In both my reading of Thomas Kuhn's *The Structure of Scientific Revolutions* (1962) and in the one conversation I had with Kuhn around 1974, in Princeton, when Bentley Glass asked me to look into setting up a history of science program at Stony Brook University, I asked Kuhn why paradigm shifts were rare or nonexistent in the life sciences. He told me that the physical sciences depended more on theory than biology and that biology was largely descriptive. He was also shifting his interest at that time to the vocabulary of science and how the words chosen to represent scientific findings and theories were influential in how science was perceived.

Kuhn's book was immensely stimulating and influential. I liked his idea of the shift that took place in Copernicus' model of the solar system, replacing the Ptolemaic view of an Earth-centered universe. I did not like his perception of what he called "normal science." It set up in my mind a group of scientists in which all but one, or a very few, perhaps over several generations, labored at putting pieces of jigsaw components into a mental picture that guided them. This was not really intended as trivializing the workers in normal science, but it certainly did not lift them to the esteem of the paradigm shifters who might be rarer than Nobel laureates by an order or two of magnitude. Creating a new worldview is extremely rare. Creating scientific revolutions is not. I believed that most of the Nobelists and high achievers I knew or whose work I admired introduced new discoveries, constructed brilliant experiments, introduced new tools to use, or developed new procedures that resulted in new fields of study. None of those were worldview constructions and none of those were paradigm shifts.

There are many ways to interpret how new fields arise or how they have evolved into their present states. The term "scientific revolution" suggests both an overthrow and replacement of how we interpreted the universe and applied it in our daily lives. No one argues against it having provided a pervasive influence on human life as the Renaissance shifted a transition from medieval to modern society. It ranks with the use of the "industrial revolution" to describe the era of steam-driven manufacturing. It also ranks with the term "agricultural revolution," an event spread out over millennia in prehistoric times. We would trivialize the term "revolution" if we also applied it to how safety matches were made or how seedless oranges could be perpetuated by grafting.

The term "theory" is also difficult to define and use because it can refer to an untested idea, a well-tested concept, or a settled fact. Is the atomic theory still a theory with the working out of 92 natural elements and a dozen or so synthetic ones? When do we elevate an idea from its status as a hypothesis to its status as a theory? Is it a theory or a fact that a forest is primarily composed of trees? Is it a theory or a fact that a living human body is composed of cells?

In this book I discuss theories, revolutions, and fields and how they are interpreted in the life sciences. If they are named, they can be described as paradigm shifts in Kuhn's 1962 sense. They can be described also as having incrementally developed through experimentation, new tools for generating new data, and insights or theories emerging from the abundance of new data. I do not believe it fair to either the idea of paradigm shifts or the idea of incrementalism to limit the terms "field," "revolution," or "theory" to just one of these two different ways to interpret the history of how they came into existence and their status today. I am aware that Kuhn reflected on the limits of his theory of paradigm shifts, and he believed his ideas were being extended into fields that did not apply (especially some of the social sciences and politics) and that his views were misinterpreted as denying the existence of an external reality or that all interpretations were constructions by consensus of those in any given field of knowledge.

As I studied the history of the gene concept, H.J. Muller's career when I did his biography, the history of classical genetics, the history of the idea of mutation, and the history of the biology of sex determination, I looked for paradigm shifts (in Kuhn's 1962 sense) and found none. Was I looking in the wrong place? Was I misinterpreting Kuhn? Was Kuhn correct that biology is still largely descriptive and that what we call the cell theory, the chromosome theory of heredity, the theory of the gene, the theory of evolution by natural selection, the theory of epigenetic development, and the theory of a molecular basis of life are just descriptive? If they are elevated to the status of paradigm shifts, what worldviews of science did they replace? What components in the older views were shuffled and renamed to create the new biological paradigm shifts?

This book is about the changes or progress in the life sciences that affect much of the basic science in these disciplines. I have presented narratives of the development of these fields, which are superficial to a scholar in the history of science who has paid a lot of attention to a richer story that could be told. Although I am aware of the many lesser-known contributors who fleshed out each field or each theory, I stress the major players. The life sciences are also connected to one another and it is impossible to isolate each discipline without reference to cognate fields and shared tools that they may use. That, too, is important to know about how the life sciences have evolved. I call the process incrementalism. It is Kuhn's "normal science" raised to a more significant level. Scientists are not solving a jigsaw puzzle. Most of the time they have no idea where innovation will lead, and the paradigm, if it exists, is a constantly changing one, not a photograph on a box propped up on the table for us to look at.