CHAPTER 1

INTRODUCTION: SCIENCE, SOCIETY, AND HISTORY

TELL SOMEONE THAT YOU ARE READING about the history of science and their first reaction will probably be to ask: "What's that?" We instinctively associate science with the modern world, not with the past. Yet a moment's thought resolves the paradox—like any human activity, science has a history, and most people can recall at least a few "great names" associated with key discoveries that have shaped our modern way of thought. Scientists themselves think about the past along similar lines, though they may have a more esoteric list of names at their disposal linked to the major discoveries in their own area. For the scientist, pinpointing a sequence of great advances in our knowledge of the world creates an image of modern science as the continuation of a progressive struggle to drive back the boundaries of ignorance and superstition. But some of the great names familiar to the public evoke images that suggest that the advance of science has not been a smooth process of fact gathering. Almost everyone has heard the story of Galileo's trial by the Inquisition for teaching that the earth goes round the sun, and the controversy sparked by Darwin's theory of evolution remains active still today. As science has come to play an ever-increasing role in our lives the potential for controversy expands so that it now includes our ability to interfere with the most fundamental aspects of our biological and psychological character and even the biosphere of the earth itself. It would be surprising indeed if the history of these areas of science turned out not to be controversial.

The scientists themselves are relatively comfortable with the fact that some of the great discoveries had consequences that forced everyone to rethink their religious, moral, or philosophical values. Science textbooks often tell stories about the great discoveries that present them as steps in a cumulative process by which our understanding of the natural world has expanded. If the new knowledge challenged existing beliefs, then people simply had to learn to live with it. The history of science certainly gains some of its popular audience by exploring the impact of science on the wider world. But it also likes to evaluate the traditional stories that the scientists tell about the past, and in some cases the results are welcomed less eagerly by the scientists. All too often, it turns out that the conventional stories are vastly oversimplified—they are myths that "tidy up" the messy process of controversy surrounding any new innovation (Waller 2002). These myths present a clear-cut image of heroes (who discover or promote the new theory) and villains (who oppose it, usually because their objectivity is subverted by their existing beliefs). Historians often refer to the stories of the great discoveries as a form of "Whig history," a term borrowed from those British historians of the Whig or liberal party who retold the nation's history in terms of the inevitable triumph of their own political values. Nowadays, any history that treats the past as a series of steppingstones toward the present—and assumes that the present is superior to the past—is called Whig history. The conventional stories of the past that appear in the introductory chapters of science textbooks are certainly a form of Whiggism. Historians take great delight in exposing the artificially constructed nature of these stories, and some scientists find the results uncomfortable.

In principle, though, there is no reason why scientists (of all people) should shrink from exposing their ideas to scrutiny, even if the evidence used is based on old books and papers, rather than laboratory tests. If the results paint a more complex and realistic picture of how science works, anyone engaged in modern scientific research ought to recognize the value of portraying past developments in same terms as the present. Instead of cardboard cut-out figures, they can have real heroes, warts and all.

The scientists are understandably less happy when detailed studies of past or present controversies lead people to challenge the actual process by which science claims to advance our knowledge of the world. The modern "science wars"—in which scientists have responded bitterly when the objectivity of science itself has been challenged by sociological critics—illustrate that there is more at stake here than a simple conflict between scientific fact and subjective values. Those who do not like the consequences of science are increasingly inclined to argue that a process that generates potentially dangerous techniques cannot be seen as the mere acquisition of factual knowledge. The history of science has inevitably been sucked into the science wars since some of the ammunition used by those who attack science comes from the reevaluation of key areas where science has generated controversy in the past. The critics argue that the very foundations of scientific "knowledge" are contaminated by values. Science constructs a view of the world that sees it through tinted glasses—so we should hardly be surprised when it turns out that what is offered to us as knowledge tends to reinforce the value system of the military-industrial complex that funds it. Scientists respond with fury when confronted with this line of argument. If science is just another value system no more privileged than anyone else's, why does it work so well when we apply it to manipulate the world via technology and medicine? Those who pay are at least paying for results, not fairy stories. There is a genuine tension here, and the history of science is sucked into the debate as one of the prime sources of information about how science actually works.

Anyone turning to this survey of the history of modern science expecting an uncontroversial list of great discoveries is thus in for a shock. Virtually all the topics and themes we discuss are the subject of intense debate, often sustained by differing perspectives derived from historians' attitudes toward modern science as a whole or toward particular theories and their applications. Teaching as we do in Northern Ireland, we are used to the idea that history can become a battleground on which people with rival opinions seek to validate their beliefs. Irish history can be told from two very different perspectives, depending on whether you approach it from a Nationalist or a Unionist perspective. Was Oliver Cromwell a hero who made British civilization safe in Ireland, or the villain who massacred the inhabitants of Drogheda? It depends on your point of view—each side has constructed its myths of the past, and each may be discomfited when the academic historian uses hard evidence to probe those myths. The history of science certainly challenges many of the myths created by those who present science as a disembodied search for the truth—but does it necessarily support those who claim that science is no more than the expression of a particular value system? Perhaps a middle way is possible, presenting a vision of science as a human activity, albeit one that has more concrete achievements to its credit than most others. In a sense, the very dangers the critics warn about arise from the fact that science performs work, in the sense that it can be applied to change the world we live in.

What we hope you will learn from this book is a willingness to see history as something more than a list of names and dates—it is something that people argue about because the evidence can be interpreted in different ways and they care passionately about the interpretation they support. You will see how historians use evidence to challenge myths, but you should also be cautious and critical in your evaluation of any alternative stories they offer (including our own). It may be hard work, but it will force you to confront important issues—and it will be a lot more fun than learning names and dates.

The rest of this introduction will put flesh on the bare bones of the conflicts outlined above, beginning with a brief survey of how the history of science became the professional field of study it is today. This is important, because many of the older books listed in the readings below—still used because they are classics in their field—were written when the discipline worked very differently from the way it does now. We then outline the more recent developments that have created the modern approach to the subject, including the more sociological techniques that generate the controversies mentioned above. Knowing something about the history of the history of science will help you to understand why the issues discussed in the rest of this book are often so controversial.

The Origins of the History of Science

Something like a history of science in the modern tradition began to emerge in the eighteenth century. This was the Age of Enlightenment, when radical thinkers proclaimed the power of human reason to throw off ancient superstition and provide a better foundation for society. Many of these Enlightenment thinkers were hostile to the Church, which they saw as an agent for the old social hierarchy derived from feudal times. The medieval period was portrayed as one of stagnation, imposed by the Church's rigid endorsement of the traditional worldview. The radicals saw the New Science of the previous century as the first manifestation of a renewed flowering of rational thought and hailed the chief contributors to the modern worldview, including Galileo and Newton, as its heroes. The fact that Galileo had gotten into trouble with the Church for proclaiming Copernican astronomy merely fueled their suspicion of that institution. They carefully suppressed any hint that Newton had dabbled in magic and alchemy. From the Enlightenment's view of its own immediate past we have inherited the assumption that the Scientific Revolution of the seventeenth century was a turning point in the progress of Western thought, and a pantheon of heroes identified with the key steps in the foundation of modern cosmology and physical science.

In 1837 the British scientist and philosopher William Whewell published a massive *History of the Inductive Sciences*. It was Whewell who actually coined the term "scientist," and he had a very specific agenda that in some respects modified the Enlightenment program. He certainly agreed that science was a progressive force, but he had a new vision of how it should set about building an understanding of nature, derived from the German philosopher Immanuel Kant. For Kant and Whewell, knowledge was not simply derived passively from the observation of nature—it was imposed by the human mind via the theories we use to describe the world. The scientific approach rested on the rigorous testing of new hypotheses by observation and experimentation. Whewell subsequently published a *Philosophy of the Inductive Sciences* in which it became clear that his purpose was to use history as a means of illustrating how his vision of the methodology of science was applied in practice. In this respect he contributed to what would become a principal motivation for the creation of the modern discipline of the history of science.

Whewell was more conservative than the Enlightenment thinkers in that he defended the possibility that the scientist might find phenomena that could only be explained as the result of divine intervention. Later on he would refuse to allow a copy of Darwin's *Origin of Species* into the library at Trinity College, Cambridge, because it replaced divine miracle with natural evolution. But to a new generation of radical thinkers in the late nineteenth century, Darwinism confirmed that science was continuing its assault on ancient superstitions, renewing the campaign begun by Galileo. A new generation of histories emerged stressing the inevitability of a "war" between science and religion, a war that science would inevitably win. J. W. Draper's *History of the Conflict between Science and Religion* of 1875 was a pioneering effort in this revival of the Enlightenment program. The metaphor of conflict continues to dominate popular discussion of the relationship, although it has been extensively challenged by later historians.

To those who (like Whewell) retained the hope that science and religion could work in harmony, the materialist program of the Enlightenment was a positive danger to science. It encouraged scientists to abandon their objectivity in favor of the arrogant claim that the laws of nature could explain everything. Alfred North Whitehead's *Science and the Modern World* (1926) urged the scientific community to turn its back on this materialist program and return to an earlier vision in which nature was studied on the assumption that it would reveal evidence of divine purpose. This model of science's history dismisses episodes such as the trial of Galileo as aberrations and portrays the Scientific Revolution as founded on the hope that nature could be seen as the handiwork of a rational and benevolent Creator. For Whitehead and others of his generation, evolution itself could be seen as the unfolding of a divine purpose. This debate between two rival views of science—and hence of its history—is still active today.

In the early twentieth century, the legacy of the rationalist program was transformed in the work of Marxists such J. D. Bernal. Bernal, an eminent crystallographer, berated the scientific community for selling out to the industrialists. In his *Social Function of Science* (1939) he called for a renewed commitment to use science for the good of all. His 1954 *Science in History* was a monumental attempt to depict science as a potential force for good (as in the Enlightenment program) that had been perverted by its absorption into the military-industrial complex. In one important respect, then, the Marxists challenged the assumption that the rise of science represented the progress of human rationality. For them, science had emerged as a by-product of the search for technical mastery over nature, not a disinterested search for knowledge, and the information it accumulated tended to reflect the interests of the society within which the scientist functioned. The aim of the Marxists was not to create a purely objective science but to reshape society so that the science that was done would benefit everyone, not just the capitalists. They dismissed the program advocated by Whitehead as a smokescreen for covering up science's involvement in the rise of capitalism. Similarly, many intellectual historians reacted furiously to what they regarded as the denigration of science implicit in works such as the Soviet historian Boris Hessen's "The Social and Economic Roots of Newton's 'Principia'" from 1931. The outbreak of World War II highlighted two conflicting visions of science's history, both of which linked it to the dangers revealed in Nazi Germany. The optimistic vision of the Enlightenment had vanished along with the idea of inevitable progress in the calamities that the Western world had now experienced. Science must either turn its back on materialism and renew its links with religion or turn its back on capitalism and begin fighting for the common good.

It was at this time that the history of science began to achieve recognition as a distinct academic specialization. There had been earlier efforts, but these had enjoyed limited success. The Belgian scholar George Sarton founded the journal *Isis* in 1912—it continues today as the organ of the History of Science Society—but on moving to America he found it impossible to persuade Harvard University to create a history of science department at that time. The first specialist departments only began to flourish after World War II, reflecting a concern that the technological consequences of science were now so powerful that broader analysis of its history was essential to understand how it had come to play this dominant role in society. But with the outbreak of the Cold War against Soviet Russia, it was inevitable that Bernal's Marxist outlook would be marginalized. Despite the obvious links with technology, the image of science as a by-product of social and economic forces was unacceptable. The alternative was a return to the idea that science represented an important intellectual force in Western culture, paving the way for progress not by its subservience to industry but by its independence and innovation, which had given us a better understanding of nature at a theoretical level. It was the practical applications of this new knowledge that were the by-product—the Marxists had got it the wrong way round. Those applications could be studied quite separately from the development of pure science, which now became, in effect a part of Western culture to be studied by the techniques of intellectual history or the history of ideas. What counted was theoretical innovation at the conceptual level and the process by which theories were tested against the evidence.

This approach to historiography followed the Enlightenment program to the extent that it saw the emergence of the scientific method, and the main steps in the creation of the modern worldview, as major contributions to human progress. Much attention thus focused on the Scientific Revolution of the seventeenth century and the associated developments in astronomy and physics. Later steps were also highlighted and used to define the main line of advance in scientific thought. The advent of Darwinism was seen as a key step forward, and developments in associated sciences such as geology were defined as good or bad depending on whether they seemed to promote the search for natural processes of change. To some extent, the field thus continued and extended the Whiggish approach favored by the scientists themselves, because progress was defined in terms of steps toward what were perceived to be the main components of our modern worldview. In another respect, however, the new historiography of science did go beyond Whiggism: it was willing to admit that scientists were deeply involved with philosophical and religious concerns and often shaped their theories in accordance with their views on these wider questions. A leading influence here was the Russian émigré Alexandre Koyré, working in France and America, who used close textual analysis of classic works in science to demonstrate this wider dimension. Koyré (1978) argued that Galileo was deeply influenced by the Greek philosopher Plato, who had taught that the world of appearances hides an underlying reality structured along mathematical lines. Newton, too, turned out to be a far more complex figure than the old Enlightenment hero, deeply concerned with religious and philosophical issues (Koyré 1965).

The one area of influence that was not considered relevant was the social and economic. Marx's suggestion that Darwin's theory of natural selection reflected the competitive values of the capitalist system was not on the agenda, nor was the association of science with technology and industry. No one doubted that science did have important consequences for society at large, either by influencing religious or political debates or by providing practical information that could be applied through technology or medicine. But these practical applications always came after the science was finished—they had no influence on how the actual research was done. There was supposed to be a clear distinction between the "internal" history of science, which studied the intellectual factors involved in the development of theories, and "external" history, which looked at the wider implications of what was discovered. The postwar generation of historians had a clear preference for internal history—they wanted a history of science firmly situated within the history of ideas, with the external applications left for the separate disciplines of the history of technology and the history of medicine. A good example of this generation's work is Charles C. Gillispie's *Edge of Objectivity* (1960); its most enduring legacy is the monumental *Dictionary of Scientific Biography* (Gillispie 1970–80).

Because of its focus on how new theories were developed, this approach to the history of science revived the program sketched out by Whewell. History was to be used as a source of examples to illustrate the correct application of the scientific method. The history of science and the analysis of the scientific method were supposed to go hand in hand, and several universities now founded departments of the history and philosophy of science. This was, in any case, a period when work in the philosophy of science was extremely active. The old idea of science as a process of fact gathering had been replaced by the "hypothetico-deductive method" in which the scientist proposed hypotheses, deduced testable consequences, and then allowed experimental tests to determine whether the hypothesis should be rejected (Hempel 1966). This emphasis on the scientists' willingness to test and, if necessary, refute hypotheses was carried even further by Karl Popper in his *Logic of Scientific Discovery* (1959). Popper's starting point was the need to establish a line of demarcation separating science from all other intellectual activities such as theology and philosophy. The defining character of science was its reliance on "falsifiability": a scientific hypothesis is always framed in such a way as to maximize its exposure to experimental testing and potential refutation. According to Popper, religious believers, philosophers, and social analysts all evade this requirement by making their propositions so vague that they can explain almost anything and thus can never be refuted. Science thus provides a unique form of knowledge about the world because its theories have all survived rigorous testing.

There was, however, an uncomfortable consequence of the hypothetico-deductive method as far as scientists were concerned. As Popper stressed, no hypothesis can ever be proved to be true because no matter how many positive tests it survives, there is still the possibility that the next one may refute it. The history of science is full of examples showing that a theory can be successful for decades or even centuries and then be exposed as false—think of Einstein's undermining of the conceptual foundations of Newtonian physics. This means that our current theories, too, will eventually be refuted; they can be accepted only provisionally, as the best guides we have available at the moment. Scientists reluctantly accepted this implication of the new philosophy of science, giving up their claim to be providing absolutely true knowledge of the real world. They were willing to do this because Popper offered them a different defense of their objectivity through his criterion for distinguishing science from all other forms of knowledge. Science was objective in the sense that it exposed the weaknesses of its claims as quickly as possible and went on to devise something better.

There was, however, another problem lying at the heart of Popper's methodology that made historians of science instinctively suspicious. For Popper, the good scientist actively seeks to refute the current hypothesis—it is tested in the hope of exposing its weaknesses as quickly as possible. This delineation of what constitutes good science does not fit very well with the observed behavior of scientists, past or present. On the contrary, they get very attached to a successful theory, especially if they have built their careers on it, and are often reluctant to consider, if not actively hostile to, any suggestion that it should be replaced. Here was the point at which the history and philosophy of science began to part company. It seemed to many historians that the more they studied the actual behavior of scientists, the less it fit the idealized picture of the scientific method that the philosophers were devising. The philosophy of science was becoming an armchair discipline, creating ever more elaborate ideas about what scientists ought to do that were increasingly out of touch with how science really worked. The way was opening up for a challenge that would take the history of science in a new direction, creating a sociological model that would study the actual functioning of the scientific community.

Science and Society

The challenge came in the form of Thomas S. Kuhn's *The Structure of Scientific Revolutions* (1962), which sparked immense debate and has since become a classic. Kuhn argued that the replacement of theories is a much more complex affair than the orthodox or Popperian philosophies of science imply (on the resulting debate, see Lakatos and Musgrave [1970]). Kuhn used history to show that successful theories establish themselves as the "paradigm" for scientific activity in the field: they define not only acceptable techniques for tackling problems but also which problems are to be considered relevant for investigation. Not surprisingly, the cards are stacked in the theory's favor because the chance of falsification is minimized by working in "safe" areas. Science done under the influence of a dominant paradigm is what Kuhn calls "normal science": it is real research, but it is more concerned with filling in minor details than probing the foundations. Scientific education involves brainwashing the students so they accept the paradigm uncritically. Even when anomalies (experiments or observations that give unexpected results) begin to appear, the scientific community has become so loyal to the paradigm that older scientists refuse to admit that it has been falsified and continue as though it were still functioning smoothly. Only when the number of anomalies becomes unbearable will a "crisis state" emerge, when younger and more radical scientists begin to look around for a new theory. When a new theory is found that deals with the outstanding problems, it soon establishes itself as the new paradigm and another period of unadventurous normal science begins.

Kuhn's approach stresses that each paradigm represents a new conceptual scheme, incompatible with any other. But it also treats science as a social activity: scientists develop professional loyalties to the paradigm they were educated into that also restrict their ability to challenge the status quo. If this interpretation is valid, there are episodes in which science is anything but objective. On the contrary, scientists will use any trick in the book to defend the theory on which so many careers were founded. Objectivity may seem to be restored at the time of a revolution, but this is soon lost. And although the new paradigm seems to expand our range of knowledge by dealing with facts that could not be incorporated into the old theory, Kuhn notes that there are cases where successful lines of investigation under the old paradigm were abandoned under the new. Not surprisingly, scientists were deeply unhappy about Kuhn's analysis, but historians—while critical of his actual model of revolutions—found his approach a refreshing alternative, one that seemed to offer a more realistic model of how science is actually done.

Sociologists of science such as Robert K. Merton and his followers had also started casting an eye on the sociological conditions that made science possible. While Merton assumed that scientific knowledge was the straightforward result of applying scientific methodology, he argued that particular social conditions, or "norms," needed to be established in order for the scientific community to be able to flourish and apply the scientific method properly (Merton 1973).Without these norms—or generally understood rules of behavior—science would be distorted in various ways by ideological contamination. Merton identified four norms: universalism (scientific claims would be assessed impartially, with no reference to the individual scientists making them), communism (scientific knowledge belonged to the scientific community rather than to individual scientists), disinterestedness (scientists would not develop an emotional or other attachment to their work), and organized skepticism (scientists would systematically subject scientific claims to rigorous checking). Merton's norms were meant to provide a way of distinguishing science from other kinds of activities as well as defining the social circumstances under which science could flourish. Unlike Kuhn, so long as the norms were in operation, Merton did not believe that social circumstances could affect the development of scientific knowledge. Only in societies where the norms could not operate—such as Nazi Germany—did science become contaminated by ideological factors.

Subsequent work has expanded on insights contained explicitly or implicitly in Kuhn's work, sometimes in directions he would not have approved. His book is now seen by some as a pioneering contribution to the mode of analysis called postmodernism, although the main source of this movement derives from French philosophers such as Michel Foucault (1970; see Gutting 1989) or Jacques Derrida. For some, at least, within the postmodernist academic community, science has no privileged position as a source of knowledge because scientific literature forms just one among many rival bodies of texts seeking to gain control of our thoughts and activities. Science's success rests not on any truth value in its propositions but on the power of its proponents to enforce their own interpretations and "readings" of those texts on others. On the model of the history of thought provided by Foucault, Kuhn was quite right to claim that successive paradigms represent different patterns of analysis that cannot be compared objectively with one another. It is like a gestalt switch in psychology: what seems obvious from one perspective simply cannot be seen or understood from the other. The whole idea of science offering cumulative factual knowledge of the world thus goes out the window—leading to howls of outrage from scientists who perceive the "academic left" that endorses this relativist view of knowledge as a major threat to their position (Gross and Levitt 1994; Brown 2001). The resulting controversies, which became known as the "science wars," saw scientists defending their role as experts offering factual information about the world against sociologists who insisted that no one version of knowledge should be accorded such privileged status. Few historians would go so far as some postmodernists in their portrayal of science as a collection of free-floating texts with no reference to the material world. But the ideas of Kuhn and Foucault have forced us to think far more carefully about the literature of earlier periods, driving home the need to avoid reading modern ideas into older texts and alerting us to the possibilities that concepts and distinctions that we take for granted today may have been literally unthinkable for earlier generations of scientists.

The protests against the academic left have also been launched against another major development that has influenced the history of science: the intensification of interest in the way the scientific community functions. Kuhn drew attention to the power that prominent scientists have to shape the way their students and colleagues respond to new hypotheses. Only the most original would be willing to "rock the boat" by suggesting a totally new approach, and this tactic would only succeed when almost everyone had reluctantly begun to admit that the current paradigm was facing difficulties. Historians and sociologists of science then saw that it was often not enough to have good ideas or good evidence to back them up—the successful scientist has to persuade his or her colleagues to take new ideas seriously, often in competition with a host of rival proposals. While it might be nice to imagine that the winner will always be the one with the best evidence, things are rarely so straightforward. It is rare indeed for new evidence to be so unambiguous that it commands immediate assent. Success or failure often hinges on "nonscientific" factors as well, such as access to good research funding, new jobs, or the editorial committees of important journals. The emergence of the modern form of scientific community, with its societies, meetings, and journals, thus becomes a crucial factor in the creation of science as we understand it today. And studying a "revolution" involves showing how the new theory made its way within the political maneuvers that determined who had influence in the community as much as it involves studying conceptual changes and innovations in practice (Golinski 1998).

Investigation of such factors has now gone far beyond the Kuhnian model, however, because it is clear that as the scientific community has grown in size, it has become ever more specialized and fragmented. Theories can often become dominant only within a single narrow community of specialists, and the most innovative work will require the founding of a "splinter group" that establishes itself as a separate research tradition. The processes of professionalization and disciplinary specialization are now seen as crucial to the way science advances, to the extent that some historians no longer concentrate on broad theoretical perspective such as evolutionism in biology. Unless a theory is used to establish a distinct research tradition, it becomes marginalized in this new historiography—leaving some historians to wonder if such a sociological approach may have thrown the baby out with the bathwater. In some cases, theories have gained recognition precisely because they have served as bridges between specializations.

One consequence of this new approach is a recognition that science is a practical activity in which the devising of new techniques is as crucial as conceptual innovation. New specialisms often involve not only new theories but also new forms of apparatus requiring skilled operation to get meaningful results out of them. A now classic study by Steven Shapin and Simon Schaffer (1985) showed how seventeenth-century debates about the nature of the air depended crucially on who had access to the very few air pumps then available, along with the practical skill needed to make these primitive machines work properly. But this focus on the need to see science as a body of practice as well as theory goes far beyond laboratory apparatus. Developments in natural history depended on the founding of museums in which specimens could be used for comparison. Geologists had to develop techniques for mapping strata and representing their order of succession, and as Martin Rudwick (1985) has shown, there was an intense period of negotiation among specialists to agree on which techniques to use. The creation of modern genetics was to a large extent dependent on identifying and learning to control a suitable research organism, most notably the fruit fly *Drosophila melanogaster* (Kohler 1994). More seriously threatening to the old internal-external division is the growing evidence that scientists' choice of research areas and the techniques needed to investigate them often depended on their links with industrialists hoping to exploit the new knowledge. Nineteenth-century physicists such as William Thomson (Lord Kelvin) may have been brilliant theoreticians—but they worked hand in glove with the manufacturers of steam engines and the companies laying telegraph cables, and their work shows clear evidence of their involvement in the resulting practical problems.

Modern scientists have become used to the need for vast amounts of financial support, and few would deny that practical concerns often shape the priorities of researchers, determining which problems get investigated and which do not. But the suggestion that science can be driven by practical concerns points us toward the more controversial claim that what is presented as scientific "knowledge" may itself reflect the interests of those who do the research. Here we enter the domain of the "sociology of knowledge," which insists that science should be studied like any other form of knowledge—by looking at how it expresses and maintains the interests and values of those who construct it. The supposed "objective truth" of scientific theories can play no part in explaining their origins or why their supporters defend them. The parallels between this and the postmodernist view described above are obvious: if each scientific theory must be treated as a conceptual system that cannot be judged by the standards of any other, then no theory can claim to be closer to the truth. The sociology of science movement links the existence of alternative visions of reality to the interests of the groups that promote them. The original exponents of this sociological perspective are often called the Edinburgh school—since many of them originally taught at the Science Studies Unit of the University of Edinburgh (Barnes and Shapin 1979; Barnes, Bloor, and Henry 1996). They argue that science is a social activity like anything else and must be analyzed by sociological methods. The knowledge claims made by scientists should be treated in just the same way as those made by religious thinkers or political leaders. Just as religions and political systems are expressions of the interests of particular groups in society (usually the rulers), so scientific knowledge expresses the values of those who create it. Scientific theories are not collections of facts; they are models of the world that are to some extent capable of being tested by the facts. But those facts do not determine the structure of the theories absolutely, and the theories may thus be shaped by images of the world dictated by social values. As the study by Shapin and Schaffer (1985) showed, those interests may be philosophical or political, as well as economic, or they may reflect professional rivalries. The point is that to understand what is really going on in any piece of scientific research, we cannot simply assume that the whole thing is being determined by the structure of a "real world" that will be accurately represented by any successful model.

Critics of the Edinburgh school argue that their image of science is unrealistic. Science must offer knowledge of the real world or it will not help us to control that world via technology. If social values alone determine what counts as scientific knowledge, scientists would be free to make up any theory they chose and simply manipulate the testing to make it look like the theory was working. The theory would be accepted uncritically by everyone who shared the same social values. It would be rejected by those who had different values, and science could never come to a consensus of which theory was the best. That the community often does come pretty close to a consensus however, clearly cannot rule out the possibility that social factors shaped the origins of the successful theory (Darwin's theory of natural selection is a case in point). Sociologists insist in response that they do not claim that scientists "make it up as they go along." On the contrary, they are particularly interested in the ways in which scientists use the results of their experiments, their instruments, and their measurements to convince others of the superiority of their research programs (Collins 1985; Latour 1987). They point out, however, that in any situation there will be more than one way of pushing research ahead, and more than one way of devising a workable model. Which area of research, and which model, is actually chosen will depend on the interests of the particular group of scientists concerned. The supporters of one model may eventually able to convince the whole community that it offers the best solution, but the fact that even physics has experienced conceptual revolutions suggests that successful theories do not offer "correct" representations of the real world in any absolute sense.

In a complex and value-laden area such as the biology of human nature, it is possible to construct rival models that will each appear to work as the basis for scientific research, and the possibility of convincing everyone that a particular theory is correct are more limited. In part this is because more than one area of science can claim the right to offer theories relevant to the main questions. Biologists will naturally prefer models of human nature that stress the determining role of biological factors, since this allows them to insist that their expertise must be taken into account. Social scientists want to rule out biology so that *they* appear as the only relevant experts. Even more seriously, political values will determine what counts as acceptable theorizing—yet everyone assumes that ideas consistent with their own values are more likely to generate good, uncontaminated science (see chap. 18, "Biology and Ideology"). Political conservatives may try to argue that certain kinds of human behavior, or certain limitations of human ability, are built in by our biology—they are "natural" and hence inevitable, imposing constraints on social structures that we ignore at our peril. Liberals may want to deny the role of such factors so they can claim that improved conditions will indeed be able to promote a better society.

Each side will try to exploit the alleged objectivity of science to its advantage. It will try to discredit its opponents' position as "bad" or distorted science. The good guys always do hard, objective science, the bad guys let themselves be led astray by their political, religious, or philosophical preferences. The fact that some debates seem hard to resolve, however, suggests that neither side's claim for complete objectivity is valid. Each allows its criteria for what makes "good" science to be determined by its preconceptions. The sociologists of science argue that both sides are equally wrong—it is politics that forces people into polarized positions in which one side or the other is dismissed as trivial or irrelevant for practical purposes. Since the rival positions reflect deeply entrenched social and political values, it is hardly surprising that neither side seems able to score a permanent victory in the debate, even though each claims to be doing good science.

The controversies that have raged (and still rage) in some areas of biology suggest that we cannot ignore the sociologists' challenge to the objectivity of science. Physical scientists may claim that their knowledge is "harder" because it is backed up more easily by experimental tests, but the sociologists will have none of the distinction between hard and soft sciences. And history certainly offers examples where the search for knowledge in physics has reflected the scientists' wider beliefs and values. In the end, though, we do not want to present the history of science in a way that forces us to take a position on either side of the science wars. Both the history and the sociology of science provide ample evidence that science is a human activity, not an automated process that could be done equally well by a giant computer. Philosophical commitments, religious beliefs, political values, and professional interests have all helped to shape the way scientists have constructed and promoted their models of the world. At best only a few radical postmodernists have claimed that science is just make-believe. Sociologists of scientific knowledge like the Edinburgh school and the historians of science who have adopted their insights know that to make a research program stick, its proponents have to produce measurable results, and in this case "knowledge"—in the sense of our ability to describe and control nature—expands. In this respect, some of the spokespersons for science in the science wars seem to be aiming at the wrong target. Whether this link to practice satisfies the philosophers' criterion of objectivity isn't really the point: if the scientists were happy with Popper's warning that they could provide only provisionally valid information, they ought to be able to accept the more realistic model of science provided by sociologically inclined historians. In the end, scientists, too, have something to gain from a model of scientific development that accepts that it does indeed provide far more sophisticated knowledge of how the world works but refuses to see it as constructing a totally disinterested and immutably true model of nature. We live in an age where the general public often sees scientists having to take sides on controversial issues related to public health or the environment. They need to know that scientific research is a complex process in which it is not impossible for two perfectly legitimate projects to suggest opposing positions on some controversial question. Anything that helps people to understand why new research cannot offer instant answers to every complex problem will be a bonus rather than a danger to those trying to defend science's integrity and authority.

Why Modern Science?

This book offers a history of modern science, and we conclude with a few words explaining why we focus so strongly on the past few centuries. A previous generation of scholars would have taken it for granted that a survey of the history of science must begin with the natural philosophy of the ancient Greeks, acknowledge the important contributions of Islam, and then deal with the revival of learning in the medieval West, before moving on to tackle the Scientific Revolution of the sixteenth and seventeenth centuries. In taking that revolution as our starting point, we do not intend to suggest that the earlier developments were insignificant and we urge those who wish to know more about the foundations on which modern science has been built to consult David Lindberg's survey *The Beginnings of Western Science* (1992). It is particularly important that we recognize the debt that modern science owes not just to classical antiquity but also to the civilization of Islam, which nurtured and extended the traditions of ancient natural philosophy and provided a vital foundation for later developments in Europe. We should also note that Chinese culture produced many important inventions, including gunpowder and the magnetic compass, along with a philosophy of nature very different to that which eventually emerged in the West. Joseph Needham's monumental survey *Science and Civilisation in China* celebrates this alternative tradition. Needham also tried to answer the vexed question of why China did not build on this foundation to generate a scientific revolution equivalent to that which occurred in Europe (Needham 1969).

By recognizing the contributions made by other cultures we avoid the implication that the Scientific Revolution with which we begin was a genuine revolution in which an entirely new approach to nature appeared from nowhere to put Europe on course for world dominance in the study of nature. One product of the new sociological approach to history is Steven Shapin's account of the "revolution" (1996) that declares openly that there was no such thing because modern science emerged from a complex of changing attitudes and activities that influenced all areas of life and belief at the time. But in the end, a new kind of activity that we call science did emerge, resulting in an explosion of new methods, theories, organizations, and practical applications. The new developments in the history of science described above have tended to focus on the modern period precisely because it is during the past few centuries that the kind of activity that we recognize as science emerged—and the changes become even more striking when we move into the modern era of "big science" driven by industrial and military concerns. Compare the annual *Critical Bibliography* issued by the journal *Isis* for, say, 1975 with one for a recent year, and the change of emphasis is striking. The number of publications on ancient science, Islamic science, medieval science, and Renaissance science has remained more or less static (and has decreased as a proportion of the whole). Publications on the period from the seventeenth to the nineteenth centuries have increased slightly. But studies of twentieth-century science have increased dramatically, making it now by far the biggest category of publications. And a large proportion of those twentieth-century studies focus on American science—because that is where the most history, as well as the most science, is being done.

This change of emphasis is almost certainly a reflection of the modern tendency to see the history of science less in terms of conceptual (theoretical) innovations and more in terms of research schools, practical developments, and the ever-increasing influence of government and industry. When the focus was on the history of scientific ideas (including the idea of the scientific method itself) it seemed obvious that the natural philosophy of the Greeks should form the starting point—to begin with the Scientific Revolution would leave the whole project without a foundation. But when science is defined more in terms of how the modern scientific community operates, then forms of natural knowledge gained under different social environments seem less obviously foundational (although the study of how science functions in those other societies ought to be of interest for comparative purposes). Historians have become more interested in the creation of professional networks defined by scientific societies, journals, and university and government departments and in the interaction of scientists with industry, government, and the general public. These are all institutions and connections that were established in the period from the seventeenth to the twentieth centuries. There has also been massive increase in the actual amount of science being done in the modern period, with more being added all the time (what was new science in 1975 is history now). At the same time, the history of science has gained a new role within science studies departments, and here the focus is almost necessarily on developments that lead straight into the dilemmas of the modern world.

In recognition of this change of emphasis we have chosen to focus on science since the seventeenth century and to include as wide a range of topics within that area as is practical for a single book. Our first part deals more conventionally with developments within science itself, beginning with the Scientific Revolution and then focusing on major themes within individual sciences. Here we have tried to combine the traditional interest in the emergence of new theories with the modern approach based on the emergence of disciplines and research programs, with illustrations of the reassessments made possible by the new methods of study. Part 2 offers a more thematic set of cross-sections through the history of science, including traditional interests such as the links with technology, medicine, and religion, along with newer areas of study such as popular science. Whichever section you begin with, remember that you can always gain a wider perspective by looking for the cross-references that show how all these topics and themes intertwine. We don't pretend that it will be easy to build up an overview, but we hope that in the process you will gain a new respect for science and a better understanding of its importance for our lives.

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