INTRODUCTION

Kew Observatory, Victorian Science, and the "Observatory Sciences"

One more recent instance of the operations of this Society in this respect I may mention, in addition to those I have slightly enumerated. . . . I mean the important accession to the means of this Society of a fixed position, a place for deposit, regulation, and comparison of instruments, and for many more purposes than I could name, perhaps even more than are yet contemplated, in the Observatory at Kew.

ADDRESS BY LORD FRANCIS EGERTON TO BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, JUNE 1842

WHEN IN 1842 LORD EGERTON, PRESIDENT OF THE BRITISH ASSOCIATION for the Advancement of Science (BAAS), announced the association's acquisition of Kew Observatory (figure I.1), he heralded the inauguration of what would become one of the major institutions of nineteenth-century British—indeed international—science. Originally built as a private observatory for King George III and long in a moribund state, after 1842 the Kew building would, as Egerton predicted, become a multifunctional observatory, put to more purposes than were even imagined in 1842. It became distinguished in several sciences: geomagnetism, meteorology, solar astronomy, and standardization—the latter term being used in this book to refer to testing scientific instruments and developing prototypes of instruments to be used elsewhere, as well as establishing and refining constants and standards of measurement. Many of the major figures in the physical sciences of the nineteenth century were in some way involved with Kew Observatory. For the first twenty months of the twentieth century, Kew was the site of the National Physical Labora-

FIGURE I.1. Kew Observatory in 2012. Photograph by Lee Macdonald.

tory (NPL) before the new organization moved to its present location at Teddington.

For all that, little has been written about Kew Observatory—indeed, hitherto there has been no book-length work at all devoted to its history. Part of the problem with the historiography of Kew Observatory is that Kew has always meant different things to different people. To the astronomer, it is the place where Warren De La Rue began the first systematic effort to photograph the sun. To the geophysicist, it is associated with Edward Sabine and his projects to map Earth's magnetic field. To the meteorologist, it is an almost holy place, where new types of equipment were trialed and innovations in meteorological observation pioneered. The building remained in use as a meteorological observatory until 1980, enabling some meteorologists in modern times to look back on it with nostalgia because they themselves worked there while students or trainees.[1] Additionally, science historians sometimes cite it as a "public observatory" where a new type of experimental astronomy was pioneered or as a site where data was collected in the hopes of refuting Victorian materialist cosmologies.[2] The most extensive—and widely cited—general history of Kew Observatory is the 1885 paper by Robert Henry Scott, then director of the Meteorological Office. This is a very basic, uncritical chronology that offers no analysis, or even mention, of many of the politics behind the various changes in the running of Kew Observatory in the nineteenth century. Furthermore, it is a contemporary account by a practitioner of science and so lacks the historian's perspective. Other than Scott's account, there is only a small handful of articles dedicated to Kew Observatory, all of them from a similar uncritical, internal perspective.[3]

For this reason alone, given its importance as a nineteenth-century scientific institution, this book is intended to fill a major gap in the literature on Victorian science. The history of Kew Observatory also allows us to tackle some major issues that are of great current interest to historians of science in the nineteenth and early twentieth centuries. The life of the observatory from its acquisition by the BAAS in 1842 to its becoming a purely meteorological institution in the period 1910–1914 covers a period of history from the first years of Queen Victoria's reign to the eve of the First World War—practically the entire span of what we might call "Victorian science." In this book, I will address these issues by asking three major questions about Kew Observatory.

1. WHAT CAN THE HISTORY OF KEW OBSERVATORY TELL US ABOUT HOW THE PHYSICAL SCIENCES WERE ORGANIZED IN THE NINETEENTH AND EARLY TWENTIETH CENTURIES?

The issue of the organization of the physical sciences can be divided into three subquestions. First, how were the physical sciences funded? Secondly, how were they managed? Finally, what kind of people worked in these sciences? The patronage of science and to what extent this changed over the Victorian period has long featured prominently in the secondary literature. Kew offers a good case study that can further develop our knowledge as to how patronage worked in the physical sciences, particularly as Kew is not easy to categorize: it was not a publicly supported observatory, like Greenwich, nor was it a private observatory of the kind that belonged to one of the wealthy devotees of science who played a leading role in Victorian scientific discovery. Kew can also tell us much about which individuals and organizations managed science. In particular, it has the potential to throw new light on the nature of the ancient Royal Society (founded in 1660) and the much newer BAAS (founded in 1831), as well as their relationships with each other, since both organizations were heavily involved with Kew.

Finally, a study of Kew Observatory can offer much insight into who was involved in the physical sciences. The historian David Philip Miller has identified three groups of practitioners in the physical sciences that came to prominence in Britain in the decades after the Napoleonic Wars: the "mathematical practitioners," the "Cambridge network," and the "scientific servicemen." The mathematical practitioners worked in the military colleges, such as the Royal Military Academy at Woolwich, or else they came from commercial backgrounds, often in the city of London, and put the skills they had learned in professional life to use in mathematical sciences such as astronomy. The Cambridge network comprised those who had studied for the Cambridge mathematical tripos following the reforms in the mathematics syllabus in the 1810s and had remained close friends throughout their careers. John Herschel, George Airy, and Charles Babbage can all be considered members of the Cambridge network. The scientific servicemen were army and naval officers employed in scientific surveys and other projects, especially after the end of the Napoleonic Wars freed up some military resources.[4] Other historians have identified a fourth group: physicists based in the new research and teaching laboratories that emerged later in the nineteenth century.[5]

I have also adopted the term "gentlemen scientists" to describe the many wealthy devotees of science who had time and leisure to pursue their own research interests. For the early part of the 1840–1910 period, I use the term *devotees of science* instead of *gentlemen scientists*. The word *scientist*, although coined by William Whewell in the 1830s, did not come into common use until later in the nineteenth century.[6] *Gentlemen scientists*, however, makes a useful contrast with the *university physicists* who emerged later in the century. Some of these also belong to the other categories: for example, Miller classes the stockbroker-turned-astronomer Francis Baily as one of the mathematical practitioners, though he can also be considered a gentleman scientist in that he funded his astronomical work with his private fortune. All these groups had much involvement with Kew. Overall, the story of Kew Observatory between 1840 and 1910 may help shed light on the question as to what extent the social organization of the physical sciences changed over this period.

2. HOW DID THE "OBSERVATORY SCIENCES" AT KEW DEVELOP BETWEEN 1840 AND 1910?

In the popular imagination—and even in some scholarly histories of science—an observatory is typically seen as a place devoted solely to astronomical observation. Until recently, most of the literature on the history of observatories concentrated mainly on astronomy. Yet at most observatories in the nineteenth century—especially national observatories founded by the state—those who worked in them did other sciences as well, notably meteorology, geomagnetic observations, and standardization work, such as testing chronometers for their countries' navies and merchant shipping. Some historians, notably David Aubin, are now starting to address this overwhelming dominance of astronomy in the historiography of observatories—especially with the development of the concept of *observatory sciences*, defined as sciences involving observation such as meteorology as well as astronomy that are practiced within the common space of the observatory and share the same set of techniques.[7] Aubin has argued that the nineteenth century was a time of triumph yet also of crisis for the observatory, as these rapidly developing institutions had to adapt in order to accommodate new fields of work and communicate the results of that work through new media such as photography and the electric telegraph. Meteorology, for example, became a central part of the program of work at many observatories, including Kew; the results of meteorological observations were communicated and coordinated via the expanding telegraph network. Yet by the end of that century, the situation had changed again: observatories tended to specialize in just one observatory science, while each of the observatory sciences had come to be managed by separate, specialized institutions of state.[8]

Kew offers a better case study than most observatories with which to trace the evolution of the observatory sciences because a wider variety of these sciences was practiced at Kew than at most observatories of its time. In fact, after 1842, astronomy was not Kew's main purpose but just one of a diverse range of activities there. Kew became a national nerve center for several sciences that today are administered by five separate institutions: meteorology (now under the Meteorological Office), solar physics (run by the Science and Technology Facilities Council), standardization (National Physical Laboratory), and geomagnetism (British Geological Survey and Natural Environment Research Council). Yet Kew Observatory became less of a nerve center and more specialized as the century drew to a close: in meteorology it became an outstation, reporting to the Meteorological Office in London; solar astronomy moved to Greenwich; geomagnetism became predominantly routine work under the control of university physicists; while standardization emerged as the most important activity at Kew. Although it was still called "Kew Observatory" in the late 1890s, by then it was primarily a standardization laboratory: only a small portion of the work carried out there involved observation of external phenomena. The balance of activities at Kew had shifted from the work of an observatory toward that of a laboratory. Then, after the 1910 transfer of responsibility for Kew from the NPL to the Meteorological Office, the observatory came to specialize in just one science, meteorology. In Kew Observatory, we have a case study in the process of specialization in the observatory sciences during the late nineteenth and early twentieth centuries. It allows us to study the history of how these sciences evolved over the course of this period—with the added benefit that we do not have to take into account the many variables involved when considering the history of more than one institution in more than one country.

3. HOW DID STANDARDIZATION DEVELOP AT KEW IN THE CONTEXT OF THE CULTURE OF THE PHYSICAL SCIENCES BETWEEN 1840 AND 1910?

Various historians have described how the establishment of agreed physical constants and standards of measurement, including the precision instruments needed for making the measurements, became an important part of the culture of the physical sciences in the early nineteenth century. Standardization became an essential component of nation building, notably in revolutionary and postrevolutionary France, the German states during the same era, and in Britain after the end of the Napoleonic Wars. In the British case, there was a need for comparability of weights and measures across a large empire, for commercial and legal as well as scientific purposes. Government and business alike wanted reliable standards of length and weight to maintain Britain's preeminent position in global trade and also to reduce the widespread fraud that was allegedly encouraged by long-standing regional variations in British weights and measures. In 1824, an Imperial Weights and Measures Act had finally established a system of standards of length and weight, enshrined in law, after centuries of failed legislation.[9]

The British government's increasing interest in standardization began to affect Kew in the early 1850s when some army officers working in the Indian subcontinent became interested in meteorology, with a view to governing this part of the empire more efficiently using an improved knowledge of the weather. This led to the British East India Company wanting thermometers and other instruments that would be comparable with each other across the imperial possessions in India and beyond. Then, in 1853, United States Naval Observatory superintendent Matthew Fontaine Maury made moves to extend his system of ocean weather charts to all oceans around the globe. For this to become a reality, it was necessary to institute an internationally accepted system for recording weather observations aboard ships. Such a system was agreed to at an "International Meteorological Conference," held in August and early September 1853. Ten nations were signees, including Britain. To issue naval and merchant shipping with standardized meteorological instruments, as well as to administer the collation of the weather data obtained, the British government set up a new department, known initially as the Meteorological Department of the Board of Trade and headed by Robert FitzRoy, formerly captain of HMS *Beagle* during Charles Darwin's voyage around the globe.[10] Starting from the mid-1850s, the instruments issued by the Meteorological Department would all be tested at Kew Observatory, which rapidly became the preeminent place in Britain for testing meteorological and also magnetic instruments—not only for British ships and imperial observatories but for institutions in other countries as well. Yet existing accounts of nineteenth-century meteorology take this role of Kew Observatory for granted. There have been two brief descriptions of instrument testing at Kew,[11] but there has been no discussion as to how and why instrument standardization began there in the early 1850s.

In the second half of the nineteenth century, the growth of research and teaching laboratories in universities led to an expansion of the demand for precision measuring instruments. Precision measurement in the nineteenth-century laboratory has been well covered in modern scholarship with respect to universities—in particular, the rising generation of university physicists. In six case studies of university laboratories, Graeme Gooday has shown how these teaching laboratories trained undergraduates in the skills of laboratory measurement that were essential to the training of—and satisfying the growing demand for—school science teachers and entrants to the burgeoning electrical engineering profession. Similarly, Simon Schaffer has described the rise of measurement science at the Cavendish Laboratory in Cambridge and its relation to industry.[12] However, what of the institution that provided the precision instruments that were so essential not only to the university teaching laboratories but also to institutions such as the Meteorological Office, the Admiralty, and the merchant marine? Before the NPL opened in 1900, and in some cases even afterwards up to 1910, that institution was Kew Observatory. Again, practically nothing has been written on standardization at Kew in the histories of the NPL or in the wider literature on Victorian physics in relation to either the world of late Victorian science and industry or on its role in the origins of the NPL. One of the aims of this book is to address this gap in the literature.

LAISSEZ-FAIRE AND THE PHYSICAL SCIENCES, 1840–1910

Historians generally agree that the governance of science in Britain underwent profound changes in the decades between 1840 and 1910. Since the 1820s, attempts had been made to reform the Royal Society, Britain's most prestigious scientific body and the one with the most influence over government, from what some perceived as a club for wealthy gentlemen into a learned body representing the most serious and able practitioners of science. This change did not come easily: only in 1847 was the society's constitution amended so that admission to fellowship was granted on scientific merit alone.[13] Long after 1847, the issue of who should run the Royal Society was sometimes a contentious one.[14] In the meantime, the British Association for the Advancement of Science had emerged as a rival organization. The BAAS was founded in 1831 after a failed attempt by some leading men of science to reform the Royal Society. It had a much more democratic structure than the older body in that all decisions taken by its council had to be ratified at the association's annual meetings, which were held in a different provincial town each year, a deliberate break away from the Royal Society's image of an exclusive London club. Yet the distinction between the two bodies was not as clear-cut as might at first appear. In the absence of regular government grants, the BAAS still needed the support of wealthy aristocrats in order to gain influence and money.[15] In practice, many leading men of science, whatever their social position, belonged to both organizations—something that would have a strong influence on the development of Kew Observatory at various times in its history after 1842.

Systematic government grants to the Royal Society only commenced in 1850.[16] Before then, with the exception of scientific organizations connected with the army and navy, government financial support for science was on a strictly ad hoc basis, gained largely through lobbying and persuasion by grand figures, usually via the Royal Society. Failing this, funding had to come from private individuals or, after 1831, from the BAAS's limited funds, which originated largely from members' subscriptions and private donations. Significantly for the history of Kew Observatory, the BAAS's usual policy was to fund individual projects of limited duration or perhaps make grants to allow the purchase of equipment for specific purposes but not to support permanent scientific programs or institutions.[17] Therefore the attempts to gain financial support to transform Kew Observatory in the early 1840s—and to keep it running later that same decade when it was threatened with closure—can tell us much about the sources of patronage that devotees of science had to find in the second quarter of the nineteenth century, before government money became available on a regular basis.

There is broad agreement among scholars that in the first two-thirds of the nineteenth century, science-government relations followed the prevailing economic consensus of laissez-faire—the doctrine that government should not interfere in an economy that was presumed to be self-regulating.[18] The £1,000 government grant given to the Royal Society each year from 1850, if anything, encouraged this system: individuals could apply for money out of this grant to buy equipment for their own research, and so it rewarded individual enterprise. The grant was never intended to fund salaries or long-term projects. This situation began to be challenged in the late 1860s. At the BAAS's 1868 annual meeting, Lieutenant-Colonel Alexander Strange, a former inspector of scientific instruments for the Indian trigonometric survey, gave a paper whose very title expressed his views in one sentence: "On the Necessity for State Intervention to Secure the Progress of Physical Science."[19] Strange believed that the government had to invest more money in scientific education and research institutions if it was to keep up with increasing overseas competition in science and—particularly close to the heart of this former army officer—govern the British Empire effectively. Prominent among those agreeing with Strange was Lyon Playfair, who had helped to organize the 1851 Great Exhibition at South Kensington and who had afterwards campaigned for greater government input into science education. Both Playfair and Strange had served as jurors in the 1867 International Exposition in Paris, after which Playfair famously expressed alarm at how far foreign inventions had caught up with Britain since the 1851 exhibition.[20]

Strange's views caught on at the BAAS and his paper was enthusiastically taken up by some senior BAAS members and Fellows of the Royal Society. This led to a successful lobby for a Royal Commission to look into the state of science education and—most importantly for the history of Kew Observatory—that of institutions for scientific research. The commission, which ran from 1870 to 1875, was chaired by William Cavendish, seventh Duke of Devonshire (himself a Cambridge mathematics Wrangler) and hence became known as the Devonshire Commission. Its final report, published in 1875, recommended the establishment of more government-funded laboratories, including a new observatory dedicated to the physics of astronomy.[21]

Some well-known twentieth-century works on the organization and funding of science see the period of the Devonshire Commission as representing the start of organized science—meaning professional scientists working in government institutions or large companies, in contrast to the earlier regime in which science had largely been carried out by wealthy individuals working on their own time. For Donald Cardwell, in particular, there was no such thing as "the social organization of science" before the mid-nineteenth century. The history of British science before then was just a "preface" to it: "Important and not without historical interest, but still a preface."[22] Authors of Cardwell's generation all wrote during the third quarter of the twentieth century, at a time when science in Britain enjoyed generous state support and there was widespread agreement that it *should* enjoy such support. This led many historians to take a teleological view, seeing large-scale government investment in research institutions as inevitable—something since admitted by Roy MacLeod.[23] These authors generally concede that the initial impact of the Devonshire Commission on governments was small and that only slowly were its recommendations taken up. Yet they treat the end of the nineteenth century as a time in which twentieth-century state-supported science finally began to triumph over nineteenth-century laissez-faire—as symbolized by the establishment in 1900 of the National Physical Laboratory, an institution founded as a British answer to Germany's generously state-funded Physikalisch-Technische Reichsanstalt.[24]

Kew Observatory, however, does not fit into this tidy picture. In addressing the issue of the organization of science, one of the aims of this book is to use the history of Kew Observatory to challenge the idea that laissez-faire—and the physical sciences' consequent reliance on private sources of patronage—went out of fashion before the end of the nineteenth century. For in the chapters that follow I show how right up until it became part of the NPL in 1900, Kew remained an exemplar of the laissez-faire system in action. Before 1900, it received relatively little money from government grants. Most of its work was funded from private sources and—increasingly important later in the century—from the fees it charged for testing instruments on behalf of manufacturers and government bodies. In particular, I contend that the birth of the NPL was facilitated not by a change in the government's attitude but rather by the sheer lack of government support for observatories and laboratories. As the nineteenth century drew to a close, the ever-pressing need to make money forced Kew to turn itself effectively into a national standardization laboratory and so form the basis of a ready-made NPL. Historians of the NPL have shown that even after 1900 it retained many of the characteristics of Kew Observatory in the nineteenth century: its leaders continued to grumble about lack of funding, and the Treasury expected it to be self-supporting through the fees it charged for instrument tests.[25] In chapter 6 of this book, I argue that laissez-faire economics had an important bearing on the development of Kew Observatory, now the "Observatory Department" of the NPL, between 1900 and the eve of the First World War. This book thus challenges and revises the view of Cardwell and others as to the demise of laissez-faire with regard to scientific funding in the late nineteenth century. Rather, it aims to present a sense of continuity between Kew Observatory and the NPL and hence to show that in government support for the physical sciences, laissez-faire remained predominant into the first years of the twentieth century.

OBSERVATORIES IN NINETEENTH-CENTURY BRITAIN

Susan Faye Cannon and David Philip Miller have both pointed to the three decades following the end of the Napoleonic Wars as a period of expansion and increased cooperation in the physical and mathematical sciences.[26] A notable feature of this movement was the construction of many new observatories and the adaptation of older ones to new purposes, among them nonastronomical sciences. Dieter Herrmann has shown how the establishment of new observatories worldwide increased exponentially during the nineteenth century, from 31 in 1810 to 199 in 1900. It was also during the nineteenth century that the word *observatory* became common in English literature—and therefore culturally significant—as David Aubin has demonstrated using Google Books.[27]

Observatories in the nineteenth century can be grouped into three broad categories: national, university, and private observatories. This book uses the phrase *national observatory* as defined by Steven Dick: an observatory established, funded, and staffed by a national government for a purpose that the government deemed to be of national importance at the time. Dick has suggested that the nineteenth century saw the second wave of an overall "movement" to build national observatories; this movement began in the sixteenth century and was still continuing in the late twentieth century.[28] National observatories were founded by governments for very specific purposes, of which the main one was usually the measurement of celestial positions to supply data for navigation. The most prestigious national observatory in Britain was the Royal Observatory at Greenwich. Founded in 1675 to solve the problem of finding longitude at sea, by the 1830s Greenwich was a world standard in navigational astronomy. The observatory provided data for the production of tables providing stellar, planetary, and lunar coordinates that enabled sailors to find their position at sea quickly and accurately.

By the early 1830s, however, Greenwich was in some disarray. The reductions of observations into a form usable for longitude tables had fallen into arrears, and relations between Astronomer Royal John Pond and his staff were poor. In 1835 the Admiralty, the government department responsible for the Royal Observatory, replaced Pond with the thirty-four-year-old Cambridge mathematician George Biddell Airy. As Robert Smith and others have shown, Airy quickly turned the Royal Observatory into a factory-like regime that efficiently produced quality data for navigation and, later on, a national time service. Airy had such a powerful influence over the Royal Observatory that his name is practically synonymous with Greenwich between the mid-1830s and the early 1880s, despite his occasional disagreements with James Glaisher, the head of the magnetic and meteorological department at Greenwich from 1840. Airy saw himself primarily as a public servant. He believed that research with no immediate utilitarian purpose, such as sweeping the heavens for new nebulae or planets, lay outside the remit of Greenwich and should be left to private or university observatories that did not spend the state's money.[29] Yet he did not take kindly to criticism, nor to incursions by other public institutions onto territory that he felt was his. This would have an important bearing on the history of Kew Observatory from the 1840s onward.

Roger Hutchins has described how six observatories were established at universities in Britain and Ireland between the late eighteenth and early twentieth centuries. Their principal purpose was to facilitate undergraduate teaching in astronomy. In theory, they also worked in nonutilitarian branches of astronomy, such as stellar cataloging, measurements of double stars, and observations of comets, but in practice the demands of teaching often left little time for such work.[30] Forming a third category of observatories were the private observatories owned by wealthy devotees of science who spent their own money on astronomy. These gentlemen scientists were free to pursue their own agendas, as they were not required to teach or to do utilitarian work for the state.[31] Private observatories were not new in the nineteenth century, but many more of them were built after 1800. In the most comprehensive general survey of nineteenth-century amateur astronomy, Allan Chapman notes that in 1884, Armagh Observatory director John Louis Emil Dreyer published a list of some twenty-six private observatories that had done important work in the United Kingdom over the previous one hundred years.[32] A fourth category, "public observatory," has also been suggested, meaning an observatory owned and operated by a public body, such as a learned society or local government. Kew Observatory in the nineteenth century, run by the BAAS and then the Royal Society, has been described as a "public observatory."[33] However, the narrative of Kew as related in this book shows that "public" is not an easy category to apply to observatories.

Until the early nineteenth century, all three types of observatories concentrated more or less entirely on astronomy—and mostly one type at that: the "classical" astronomy of positional measurement.[34] This was dictated by the need of national observatories to serve the state, but the other types of observatories tended to concentrate on classical astronomy too, partly because before the advent of photography and spectroscopy, it was difficult to find out anything new about the physical nature of astronomical objects. The research on nebulae by the Herschels and Lord Rosse was an exception to this general rule. Then, in the 1830s, some observatories, including Greenwich, began serious work in two sciences that hitherto had not necessarily formed part of their routine—or, at most, had been incidental to that routine: geomagnetism and meteorology. At the beginning of the nineteenth century, geomagnetism and meteorology hardly existed as sciences organized on a national scale. In Britain, this situation persisted into the early 1830s, with geomagnetic work being done by isolated individuals such as the Royal Artillery officer Edward Sabine at Woolwich.[35] Elementary meteorological observations were being carried out at a small handful of locations, such as Kew Observatory (then still known as the "King's Observatory"), the Royal Society's headquarters at Somerset House, and the Radcliffe Observatory at Oxford, as well as by a few private individuals, but the science was not organized on a national scale until the 1850s.[36] But when these two observatory sciences did take off, they did so together. They were seen as being closely connected, for several reasons. Many thought that changes in the weather and Earth's magnetic field were subtly related to each other, or that both had astronomical origins, and in any case temperature and pressure were found to affect magnetic compass readings. Both sciences had clear importance to navigation in an age when Britain was the world's chief maritime power. In particular, the reasons for the behavior of the compass aboard ships were poorly understood, as were the weather and currents in many parts of the oceans. It was in this context that in the 1830s, some observatories began making systematic meteorological observations and also began monitoring Earth's magnetic field as part of a global campaign known as the "Magnetic Crusade," described in chapter 1.

THE ORIGINS AND EARLY HISTORY OF THE "KING'S OBSERVATORY"

The origins of Kew Observatory are well known and well documented. Nineteenth-century sources agree that it was originally known as the "King's Observatory"; it came to be called the "Kew Observatory" some years prior to 1840.[37] In an 1839 letter to John Herschel, Admiralty hydrographer Francis Beaufort remarked, "Perhaps I should have called it the Kew Observatory"—suggesting that the building had only recently come to be known by this name.[38] It was built in 1768–1769 for King George III to enable him to observe the transit of Venus on 3 June 1769. The building was designed by the eminent architect Sir William Chambers (who went on to design Somerset House) and was completed in time for the transit, which was successfully observed by the King and others in a clear sky.[39]

However, this spectacular beginning to the observatory's career was not matched by the work done in the years that followed, for it was not used, nor even intended for, astronomical research or navigational astronomy of the kind being done at Greenwich. To run the observatory the King appointed his former tutor, Stephen Charles Triboudet Demainbray, a much-traveled university lecturer of French Huguenot descent, as his "King's Observer." After the transit (which Demainbray observed with the King), Demainbray's duties seem to have been light. His principal duty was to take daily transit timings of the sun as it crossed the meridian; these observations were used to regulate high-quality clocks that kept standard time in the observatory and at several prestigious public places in London, among them the houses of Parliament. Basic meteorological observations, including recordings of temperature and rainfall, were commenced in 1773 and continued until 1840, with the thermometers placed in a north-facing window and the rain gauge mounted on the roof. The observatory was also used as an instrument repository and a place where members of the royal family received tuition from Demainbray. Kew was included in a 1777 survey of observatories by Copenhagen Observatory director Thomas Bugge, who noted that the building contained numerous instruments, including a transit telescope and a large mural quadrant. Bugge also noted that the basement contained "mathematical workshops."[40] When Demainbray died in 1782, the King appointed Demainbray's son, the Reverend Stephen Demainbray, as his observer at Kew. Both Demainbrays were assisted in the observations by their fellow Huguenot and family relative Stephen Peter Rigaud. Upon Rigaud's death in 1814, the job of assistant went to his son, also called Stephen Rigaud. Rigaud Jr. had been Savilian Professor of Geometry at Oxford since 1810 before he became Savilian Professor of Astronomy at the same university in 1827. He took over the running of Kew Observatory during the university's summer vacations, thus allowing the Reverend Demainbray to live in his Wiltshire parish during the summer months. Demainbray, Rigaud, an assistant, and a servant all appear to have drawn salaries for their work at Kew.[41] In 1827 Rigaud's wife died, leaving him to bring up his children on his own as well as perform his academic duties at Oxford. Although still officially an observer at Kew, he was seldom able to go there from then on. By this time, too, George III was dead and his successors to the throne took less interest in the observatory. This, plus the observatory's substantial salary costs, might well have been a motive for the government to drop its support for Kew.

It is easy to think of these shared jobs of the Demainbrays and Rigauds as sinecures and that the King used the building as little more than a showcase for his instrument collection. Yet Bugge's survey notes that the observatory contained some of the best equipment that money could buy at the end of the eighteenth century, including a mural quadrant and a precision measuring telescope, both made by leading astronomical instrument maker Jonathan Sisson.[42] A list of the observatory's astronomical instruments presented to Armagh Observatory in 1841, when the government withdrew its support from Kew, also includes some high-quality examples.[43] It was in the King's observatory that John Harrison's "H.5" marine chronometer was given its final successful test that enabled Harrison to claim the remainder of his share of the £20,000

"Longitude Prize." The chronometer was tested in the observatory over a ten-week period between May and July 1772. It was regularly compared with the observatory's clock, which was itself checked with meridian transits of the sun.[44] The transit timings were taken with a transit telescope suspended between two massive masonry piers on the ground floor of the observatory. This provided as good a time service as any at the end of the eighteenth century: before the advent of telegraphic communications, Greenwich was remote from Kew and central London, so time had to be determined and distributed locally.[45] Bugge noted that the foundations of the building "were laid 20 to 30 feet below the ground" in order to ensure a stable platform for the astronomical instruments.[46] In 1843, soon after becoming honorary superintendent at Kew under the BAAS, Francis Ronalds would make a remark that corresponded exactly with Bugge's notation: that the building's foundation was "of an extremely solid and costly kind."[47] In the mid-1840s, Ronalds would adapt the transit pillars to another type of precision measurement: the monitoring of tiny variations in Earth's magnetic field using a magnetometer suspended between these pillars.

Thus in Kew Observatory, the BAAS and the Royal Society had a ready-made space for precision measurement; it is clear from the evidence just noted that Ronalds was well aware of this. The building's suitability for precision measurement would have an important bearing on its history after 1842. Some modern scholarship has discussed how buildings such as the Physikalisch-Technische Reichsanstalt in Berlin were deliberately designed and built with metrology in mind.[48] Kew provides an opportunity to see how an existing building, constructed for astronomical and meteorological observations in an earlier age, was adapted for the measurement sciences of a later era.

PRIMARY SOURCES AND THE SCOPE OF THE BOOK

The volume of primary-source material on Kew Observatory increases as we progress through the nineteenth century. It is possible to learn much even from published primary sources, as few of them have ever been cited by historians. Reports of the Kew Committee appear regularly in the *BAAS Annual Report* from 1850 until 1871 inclusive; thereafter they can be found each year in the *Proceedings of the Royal Society*. These reports run to several (latterly over twenty) pages each and describe the previous year's activities at Kew in some detail. From the late 1850s they contain detailed financial accounts, including lists of the observatory's employees and their salaries. The volumes of the *BAAS Report* also contain many papers on specific projects at Kew, as do the Royal Society's *Proceedings* and *Philosophical Transactions*. But the value to the historian of these published sources is limited by their containing only what the members of the Kew Committee wanted their readers to hear. Like Scott's 1885 history (which is largely based on the annual reports), they frequently gloss over key developments, such as how and why John Peter Gassiot set up the trust that enabled the Royal Society to take over the running of Kew in 1871. Furthermore, very little primary-source material has been published at all on Kew before 1850. Therefore, to build a fuller picture of what happened at Kew in the period under discussion, it is necessary to turn to unpublished sources.

A large amount of archival material has survived, in the form of voluminous correspondence and minutes of meetings. The most important sets of minutes for the historian of Kew Observatory are those of the BAAS Council and the Kew Committee. The BAAS Council minutes are essential for establishing the basic narrative of events relating to Kew Observatory before the regular publication of Kew Committee reports began in 1850, especially as the correspondence for these early years is sometimes scattered and hard to find. These minutes were printed but not published, and so were not intended for general circulation. Those at the Bodleian Library in Oxford are mostly complete to 1868; copies relating to the years from 1868 to 1871, the period leading up to the handover of Kew from the BAAS to the Royal Society, are preserved in the files of the ever-meticulous George Airy.

The Kew Committee began taking formal minutes of its meetings in October 1849, and so from this date we can assemble a more detailed narrative. The minutes of the Kew Committee were handwritten in minute books and never printed, so they contain many details of the observatory's history that were confidential at the time. Furthermore, these minutes have never been used by *any* modern scholar, enabling us to discover vast amounts of new information and gain important new perspectives. The minutes for the post-1871 period are especially useful because they frequently refer to numbered correspondence. These letters are preserved in the National Archives at Kew and many of them still bear their original index numbers, making it easy to find many letters referred to in the minutes of the Kew Committee. Minutes for the 1840–1910 period tend to record merely a summary of what was agreed upon at a meeting, rather than what was actually discussed. Like the published sources, they sometimes present only an official version of events, leaving out the arguments and disagreements.[49] Nevertheless, due to their confidential nature, they contain many telling details that have been left out of the published record of events.

The richest—and most revealing—set of unpublished sources is the correspondence of the numerous individuals who were involved with Kew Observatory. The letters of Francis Ronalds, Kew's first superintendent, provide important insights into Kew's very first years under the BAAS, especially when read in conjunction with the BAAS Council minutes. The most useful correspondence for these early years is that of John Herschel, not only because of his views on observatories and his involvement in so many of the behind-the-scenes moves regarding Kew Observatory in the 1840s, but also because of his centrality to—and perceived authority in—so many of the physical sciences in these years. His approximately 15,000 incoming and outgoing letters are made all the more accessible by the invaluable *Calendar* of his correspondence, which outlines the location, reference, date, and brief details of each letter.[50] This allows letters to and from Herschel referring specifically to Kew Observatory and kindred subjects to be accessed very efficiently in the Royal Society archives and elsewhere.[51] The correspondence of George Airy, held at the Royal Greenwich Observatory archives in Cambridge, is indexed online, with brief details of each file, allowing relevant letters to be accessed quickly by ordering specific files. Airy's correspondence is especially useful in that Airy kept carbon copies of his outgoing letters, enabling the historian to read Airy's replies without having to visit the papers of the people he was writing to. This is especially important in the case of the many private individuals involved with Kew whose papers are now difficult to find.

The official papers of Kew Observatory at the National Archives are voluminous and the files are indexed online, albeit with no details. Some of the files, especially from the 1870s, mostly describe trivial day-to-day matters that add little to our overall understanding. Yet we can learn much from the correspondence of John Welsh, Balfour Stewart, and the Kew Committee, most of it unread by modern scholars. The Kew Observatory papers are part of a larger collection of papers of the Meteorological Office, which includes some important correspondence of Edward Sabine. Both these Sabine papers and the Kew Observatory files at the National Archives include some letters from John Herschel that are not indexed in the Herschel *Calendar*. Easily the largest repository of Sabine's correspondence is held in the Royal Society archives. These letters are not indexed, but they are filed alphabetically by correspondent, allowing us to easily find letters to Sabine from Herschel, Gassiot, and many of the other principal actors in the history of Kew Observatory between 1840 and the early 1870s.

The total volume of correspondence, even that relating directly to Kew Observatory, runs to many thousands of letters. Only those letters most helpful to my arguments and research questions have been cited in this book. The value of such a large volume of correspondence to the historian is twofold. First, it can be used to establish an almost day-by-day chronological narrative that can give a sharper picture of the development of Kew Observatory than can ever be put together from the published sources or than has ever been attempted by historians. Secondly, it can help reveal those *unofficial* views that the actors in the story of Kew Observatory might never have wanted to reveal to many of their colleagues or the wider public—more than is often possible in minutes.

This correspondence, as well as unpublished minutes, makes it possible to challenge and revise the received views about Kew Observatory, especially in the light of modern scholarship on nineteenth-century observatories, laboratories, and physical sciences generally. This helps to tackle the three great questions about Kew outlined earlier in this chapter. To achieve these aims, the book is divided into six chapters, each covering a distinct period, in part because for each period some specific questions can be asked. The chapters are arranged chronologically, in order to show how Kew evolved over time.

Chapter 1 covers only five years (1840–1845), but this short period deserves a chapter of its own because it was in these years that the Kew Observatory of the Victorian era was founded. This chapter asks the question, How and why was the Kew building transformed from an unused royal observatory and instrument repository into what some in the BAAS called a "physical observatory"? It then asks, What work did Kew Observatory carry out during its first years? It addresses the question of the organization of science by demonstrating the importance of Edward Sabine as the prime mover behind the project to turn Kew into a magnetic and meteorological observatory and showing how he used the interchangeability between the Royal Society and the BAAS to his advantage. I show that lack of government funding did not prevent Sabine from setting up his own observatory at Kew, independent of Greenwich. I also critically assess claims that Kew was a "physical observatory" of the kind described by historians writing about the observatory sciences or of the kind advocated by Herschel.

Chapter 2 covers the period 1845–1859, from the first attempts by the BAAS to close down Kew Observatory up to the death of John Welsh, its first paid superintendent, in 1859. Here I ask how Kew withstood the moves to close it and relate this to the introduction of the Royal Society government grant in 1850. Then I chart how the observatory sciences at Kew expanded to include a full geomagnetic program as well as the meteorological work. This chapter also begins to address the third of this book's fundamental questions: How and why did standardization originate and develop at Kew? I argue that the reasons for the introduction and expansion of instrument testing at Kew were due to factors of both demand and supply. On the one hand, the government needed large numbers of thermometers, barometers, and hydrometers, all tested to an agreed standard—especially when the Meteorological Department of the Board of Trade was established in 1854. Even before 1854, however, Kew began testing instruments in return for fees because it brought in much-needed extra income.

Chapter 3 describes the period of Kew Observatory's history that has already been most discussed by historians: the pioneering program carried out in the 1860s to photograph the sun and to relate sunspot periodicities to terrestrial magnetism and weather. The narrative begins in the early 1850s, overlapping with the time span of chapter 2, in order to address the question of how and why solar photography began at Kew. I also ask how the photoheliograph was used in practice. I show how the solar photography program was largely a private enterprise, directed by gentlemen scientists and implemented by little-known figures. Finally, I explore how this new observatory science of solar physics interacted with Sabine's magnetic and meteorological agenda. I build on the existing historiography in this field to show that Stewart's conflicts with Sabine owed as much to Stewart's vastly increased workload following the Meteorological Department's reorganization as to Sabine's disagreement with Stewart's theory-driven approach.

Chapter 4, covering the years from 1871 to the publication of Robert Scott's history in 1885, asks how and why BAAS decided to stop supporting Kew and what were the circumstances surrounding Gassiot's donation that were supposed to allow the Royal Society to run it. This chapter, too, sees Airy winning a partial battle in his long rivalry with Kew: I ask why the Kew photoheliograph was transferred to Greenwich and why Airy nevertheless failed to wrest control of the Kew meteorological observations. This provides significant new insights into the changing organization and specialization of the sciences from the 1870s onward, as does this chapter's finding that by the 1880s Kew was no longer taking the lead in magnetism and meteorology; rather, its work in these observatory sciences was increasingly in the service of other organizations. I also show that by 1885, standardization had become the most important branch of the work at Kew and argue that the standardization question is intertwined with the organization of science question. Contrary to assertions that Gassiot "came to the rescue"[52] in setting up his trust to run Kew, the Gassiot fund was never sufficient to support the observatory, and the Kew Committee needed to take on more standardization work due to the money it brought in.

A central question in chapter 5 is, How and why did Kew Observatory become part of—and the first site for—the National Physical Laboratory? I show that the existence of Kew Observatory was essential to the establishment of the NPL. I also argue that contrary to assertions by historians that the NPL was a triumph of government-supported science over prevailing laissez-faire attitudes, the NPL came into existence in the form it did precisely because of laissez-faire. The continuing dominance of laissez-faire is further emphasized in chapter 6, which describes the evolution of Kew Observatory over its ten years as the "observatory department" of the NPL before it became part of the Meteorological Office in 1910. Laissez-faire remained central to government policy toward the NPL and the Meteorological Office as well as Kew Observatory. This chapter further illustrates the increasing specialization of the observatory sciences, particularly with the establishment of the new magnetic and meteorological observatory at Eskdalemuir in 1908, after which Kew effectively ceased to be the multifunction institution that it had been throughout practically the entire Victorian era and beyond.

The concluding chapter returns to the book's three overall research questions. It attempts to answer each of them using the findings presented in chapters 1–6 and thereby assesses the importance of Kew Observatory in the history of the physical sciences in the nineteenth and early twentieth centuries. The conclusions critically examine and revise some currently accepted views, especially as to the origins of the NPL and, more broadly, the evolution of the observatory sciences and their relations with government in Britain during the Victorian era.