THE ERA OF EXPERIMENTS AND THE AGE OF WONDER

THE ERA OF EXPERIMENTS AND THE AGE OF WONDER

Scientific Expansion from the Seventeenth to the Nineteenth Centuries

EDITED BY
LILLA VEKERDY

Proceedings of the Symposium in Honor of the Reopening of the Dibner Library of the History of Science and Technology and the Smithsonian Libraries' Resident Scholar Program

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About Smithsonian Libraries

The Smithsonian Libraries comprises a network of twenty-one specialized research libraries located in the Smithsonian's museums and research centers. Our collection of 2 million volumes includes 50,000 rare books and manuscripts, complemented by more than 120,000 electronic books, journals, and databases, and an expert staff who daily serve the information needs of the Institution's scientific, research, exhibition, and education colleagues, as well as Internet users worldwide. The Dibner Library of the History of Science and Technology is one of several rare book and manuscript collections under the care of the Smithsonian Libraries. The Joseph F. Cullman 3rd Library of Natural History in the National Museum of Natural History houses a magnificent collection on biodiversity and natural history; the DeWitt Clinton Ramsey Room in the National Air and Space Museum includes the Bella Landauer Collection of sheet music among its ballooning and aviation collections; in the Fred and Rae S. Friedman Rare Book Room at the Cooper Hewitt Smithsonian Design Library in New York City are located beautifully illustrated works of European and American design. Additional specialized collections of rare books from Asia, artists' books, manufacturers' trade catalogs, design archives, and many other topics are discoverable through the Smithsonian Libraries online catalog and in its digitized collections at *www.library.si.edu*.

Preface

Library digital scanning programs include rare books and manuscripts, which make their contents available to many more people than could ever visit rare book repositories. Such programs add much value by making documents easier to read, transcribing them at times, and bringing together related items housed in disparate repositories for ease in research. The original items, however, are equally important as physical and historical artifacts in the history of printing, publishing, provenance, and even the technologies and contexts of their contemporary times. No computer screen can convey accurately the size, color, patina, shape, feel, or emotion evoked by a volume or document that has also been touched by the hands of the past. It can be seen in the eyes of visitors to the Smithsonian Libraries, who are thrilled with letters signed by Galileo or Isaac Newton or with the first illustrations of North American animals and plants in the eighteenth-century volumes of Mark Catesby.

On March 4–5, 2010, the Smithsonian Libraries celebrated its rare book collections with a symposium to mark the reopening of the Dibner Library of the History of Science and Technology and its Resident Scholar Program following a two-year closure caused by renovations in the National Museum of American History (NMAH), where the library is located. Titled "The Era of Experiments and the Age of Wonder: Scientific Expansion from the Seventeenth to the Nineteenth Centuries," the symposium brought together a broad range of scholars, headlined by British author Richard Holmes, whose best-selling group biography of scientists and poets in the eighteenth and nineteenth centuries, *The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science* (2008), won the Royal Society Prize for Science Books and the National Book Critics Circle Award for General Nonfiction. Showing how discoveries of early scientists and explorers like Joseph Banks, William and Caroline Herschel, and Humphry Davy were carried into the poetry of Byron, Coleridge, Shelley, and Keats, Holmes' book clearly demonstrates that C. P. Snow's "two cultures" were not nearly as far apart as they seem to have become. Here, Holmes's essay on how he, a former literature professor, was stimulated to explore this fascinating subject was also the 2010 Dibner Library Lecture, an annual event sponsored by the Dibner family. Holmes's lecture, followed by a reception, was the evening centerpiece on Thursday, the symposium's first day.

Prior to the lecture, the audience gained a contextual overview of the Dibner Library reopening celebration, which started with the Smithsonian's Under Secretary for Science, Eva J. Pell, explaining the role of science at the Smithsonian and the importance of the Smithsonian Libraries in supporting the scientific research and investigations undertaken by the Institution's scientific staff. Ronald S. Brashear, former head of the Smithsonian Libraries' Special Collections Department and curator of physical sciences rare books, joined with current department head Lilla Vekerdy to provide a history of how the Dibner

Library and the Resident Scholar Program came into being. Vekerdy's essays cover well the content from both her and Brashear in her absorbing account of the life of book collector Bern Dibner—"electrical engineer, inventor, entrepreneur, and science historian"—whose desire to thank the country that stimulated his success resulted in his rare book and manuscript donation to the Smithsonian on the occasion of the 1976 American bicentennial. She recounts how Dibner's emphasis on sharing his collection—the "primary evidence of the record of discovery," as he put it—led to the establishment of the Dibner Library Resident Scholar Program; some of the program's beneficiaries spoke during the day.

At the conference, Peggy Aldrich Kidwell participated in a panel of Smithsonian curators and Dibner Resident Scholars, who discussed the influence of the Dibner Library's collection on their work. In her essay here, Kidwell, the NMAH curator of mathematics, provides an example of how the scholarship of both Smithsonian historians and resident scholars have benefitted from the Dibner Library's extensive collections. Kidwell shows how for twenty years she and the Dibner staff have hosted a group of young collegiate women participating in a summer program at George Washington University to encourage them to continue graduate studies in mathematics. To prepare for the class, Kidwell always selects for an exhibit items from the library's significant collection on the history of mathematics.

David DeVorkin, senior curator of the history of astronomy and the space sciences, provides another example of collection use. As curator of the National Air and Space Museum's *Explore the Universe* exhibition, he brought together some of "the most important astronomical instruments in human history," but found the display incomplete without including complementary publications from the relevant time periods. A dedicated kiosk curated by the Dibner's librarian was the answer, the first of several such exhibitions of Dibner volumes in other Smithsonian museums.

Context is often the word used by curators, as it is for Steven C. Turner, NMAH curator of physical sciences, who "uses period sources, such as those in the Dibner Library, to understand science and scientific instruments in their full historical context." All of these curators demonstrate how rare books and manuscripts, valuable artifacts in their own right, are also vital for the information they contain.

Independent scholar Pamela O. Long, one of the first resident scholars, focuses her essay on how important Bern Dibner's collection is to historians of science and technology. Calling him a "brilliant collector," Long described Dibner's passion for collecting in depth—not just first editions, but all subsequent editions of an essential historical book plus all the relevant materials to provide context. Although some of the sixteenth-century works of particular interest to her have been digitized, Long emphasized the significance of using the original; a digital version "can never substitute for examining and reading the actual books and comparing them side by side, both as material objects and in terms of their substantive textual and visual content." Long's rationale is the basis for why the Smithsonian Libraries values its rare books and manuscripts so highly and carefully conserves and cares for them, notwithstanding the importance of digitization in making such works available for examination by a global audience.

Marc Rothenberg's essay continues the history of American learned societies, patterned on the Royal Society of London, which figured prominently in the era discussed by Holmes and in the birth of American science. He used the career of American physicist Joseph Henry, also the first secretary of the Smithsonian Institution, as a theme to describe how important the societal support structure and communication processes of American learned societies were to the organization and progress of American science. Henry was involved in the founding of several major nineteenth-century societies. I include a complementary paper on how the period's scientific communication was facilitated by "agents of exchange," who helped the Smithsonian and other American organizations distribute their publications abroad and gather those of foreign societies for delivery to the United States. The symposium ended with a presentation (not included herein) from Harvard University's Conevery Bolton Valenčius on the continuing need for historical collections.

We are eternally grateful for the support of the members of the Dibner family, first Bern and his son, David, and his wife, Frances, and now their three sons, Brent, Daniel, and Mark, for providing the funds that bring the treasures of the Dibner Library of the History of Science and Technology to the attention of the American people and the world for scholarship and enjoyment.

Nancy E. Gwinn
Director, Smithsonian Libraries
Washington, D.C.
July 30, 2014

Scientific Expansion in the Seventeenth through Nineteenth Centuries

Romantic Science: On Writing *The Age of Wonder*

Richard Holmes

Ten years ago, after completing a two-volume life of the poet Samuel Coleridge, I began to wonder about scientific discovery during the period of Coleridge's lifetime, between 1772 and 1834. This was the high watermark of British Romanticism, one of the best-known and best-loved periods in the whole of English literature. So why was so little known about the science, and the scientists, of this same era? Was the divisive influence of C.P. Snow's 1959 lecture, "The Two Cultures," still at work? [1]

Most people could quote the names of at least a dozen poets and writers of this period. Yet the only scientific name popularly known between Isaac Newton and Charles Darwin was—probably—that notorious and fictional bioengineer Doctor Victor Frankenstein. Was science—were scientists—so entirely irrelevant to the huge imaginative achievement of Romanticism? After all, one of Coleridge's greatest friends was the chemist Sir Humphry Davy, who eventually became president of the Royal Society. Coleridge had once promised Davy, in a memorable moment of scientific enthusiasm, that he would "attack Chemistry like a shark." [2] Later he suggested that he and Davy—together with Wordsworth—should set up a chemical laboratory together in the Lake District. Finally Coleridge wrote to Davy one of his most brilliant, seminal, and provoking remarks: "Science, being necessarily performed with the passion of Hope, it is Poetical." [3]

Nevertheless, it was still traditionally assumed that all the poets—like William Blake—hated and distrusted science; while all the scientists—like Isaac Newton—despised and disdained to talk to the poets. The antagonism, so to speak, was mutual. As William Blake famously exclaimed, "Bacon and Newton, sheathed in Dismal Steel." [4]

This position was vividly illustrated by Blake's iconic picture of Newton drawn in 1795, a demonic figure bent grimly over his measuring compasses, reducing the entire world to geometry and mathematics. Here, it was argued, began the fatal division between "Two Cultures," between Imagination and Reason, between Arts and Sciences. Indeed, two hundred years later, a modern version of this figure by Eduardo Paulozzi, an enormous bronze statue—*Newton, after William Blake* (1995)—now with explicit suggestions of Frankenstein's monster, was solemnly placed in the courtyard of the new British Library in Euston Road, London, thus guarding Cerebus-like the entrance to one of the great centers of learning in the Western world.

So you could say that ten years ago I became interested in what we now call the "public understanding of science." I began to ask, what was the real impact of science on poets and writers of the British Romantic period? Who were the scientists that influenced them and what sort of science were they doing? I aimed to look at the period of roughly sixty years, or two generations (1770–1830).This was exactly the "lost period" of British science, between Isaac Newton and Charles Darwin, when only European figures (like Cuvier, Lavoisier, and Laplace) seemed to dominate the field. I found there were two historic British voyages of exploration that framed almost exactly this time span: Captain James Cook's first circumnavigation through the Pacific starting out in 1768, and young Charles Darwin's voyage to the Galapagos starting in 1831. These became my points of departure and arrival, and set the adventurous ranging tone of the whole book.

One of the first things I learned was that at this time there was no such word as "scientist." It was only coined in 1833 at a historic meeting of the newly founded British Association for the Advancement of Science, held that year in Cambridge.[5] Nevertheless I came up with a main cast list of more than sixty scientists and writers. Among the scientists were Joseph Banks, explorer, botanist, and anthropologist; William Herschel and Caroline Herschel, astronomers; Jean-Pierre Blanchard and Laetitia Sage, balloonists; Mungo Park, African explorer; Humphry Davy, chemist; William Lawrence, surgeon; Dr. Victor Frankenstein, the fictional bioengineer; and several young pre-Victorian scientists, Michael Faraday, Mary Somerville, and Charles Lyell, for example. Among the poets and writers were Erasmus Darwin, Coleridge, Wordsworth, Keats, Percy Shelley, Mary Shelley, Anna Barbauld, and Lord Byron.

The women had an important role in the story. I felt conventional science historians had rather ignored them. They help us look at the development of science in a different, and often surprising, way. For example, Anna Barbauld was Dr. Joseph Priestley's assistant during his great experiments on the nature of air in Birmingham in the 1770s. He was testing the effect of lack of oxygen on laboratory animals like birds and mice. One evening, when she was clearing up the laboratory for the next day's work, Anna left the following poem on a piece of paper stuck between the animals' cages, which she titled *The Mouse's Petition to Dr Priestley, Found in the Cage where he had been Confined all Night* (1773):[6]

> For here forlorn and sad I sit,
> Within the wiry Grate,
> And tremble at th' approaching Morn
> Which brings impending fate.
>
> The cheerful light, the vital air,
> Are blessings widely given;
> Let nature's commoners enjoy
> The common gifts of heaven.
>
> The well-taught philosophic mind
> To all compassion gives;
> Casts round the world an equal eye,
> And feels for all that lives.

Barbauld describes the laboratory animal as a "freeborn mouse." It is arguably the first ever animal rights poem. One could compare this with two lines near the opening of Blake's "Auguries of Innocence": "A robin redbreast in a cage / Puts all heaven in a rage. . . . "[7]

Taking my cue from Coleridge, the book began to explore the Hope and Wonder of science, but also its Fearfulness and Menace, a double-edged sword that we are all more than conscious of today. The constant ambiguity was finally expressed in my polarized subtitle: "How the Romantic Generation Discovered the Beauty and Terror of Science."

These two terms—Beauty and Terror—are also central to the underlying Romantic theory of "the Sublime," as developed in the famous 1757 essay by Edmund Burke, *A Philosophical Enquiry into the … Sublime and Beautiful*.[8] I was arguing that not only literature, but also science, could be "sublime" in this technical, philosophical sense and moreover lead to a new perception of "the Sublime" in nature.

* * * *

To write a book of this kind also raised problems of chronology and structure. I wanted it to be a group biography, but one spaced over some sixty years, covering several disciplines, many locations in Britain (as well as some in France and Germany), and linking several diverse sets of friends and colleagues. I wanted the driving effect of a single narrative—the creation of Romantic Science—but one built out of diverse biographies with strong local color and rich in digressions. Above all, I wanted to include the lives of the scientists themselves, their emotional and subjective experiences, their own hopes and beliefs, within the objective achievement of the science they were making. One immediate and important consequence of this was that the book became concerned with scientific error and failure, as much as with success. It became a book about science as a human endeavor.

It was important to show, for example, that William Herschel—who first discovered Uranus, the seventh planet in the solar system—also believed there was life on the moon and very probably on the sun; or that Jean-Pierre Blanchard, who first crossed the English Channel in a hydrogen balloon—also believed that balloons could be steered with silken wings or bamboo oars; or that Humphry Davy—who invented the life-saving miner's safety lamp—also missed the chance of saving untold suffering by making surgical anesthesia available during the terrible butchery of the Napoleonic Wars.

So I wanted to tell a complex, human story, with a strong sense of both comedy and tragedy within the progressive advance of cumulative scientific knowledge. Great discoveries were passed on from hand to hand (the central collaborative triumph of science), but often at great cost and suffering and despair. I came to think of this unity in diversity as taking the form of "a relay race" of scientific stories.

But the question of "telling stories" was itself problematic. (This has been explored in a brilliant but little-known collection of essays, *Telling Lives in Science*, edited by Michael Shortland and Richard Yeo.[9]) The notion of any scientific discovery taking the neat, closed form of a literary story, with a precise beginning, a progressive middle, and a definite triumphant end, seemed misleading. I associated this traditional type of "eureka" story with the improving genre of Victorian science writing, often for children (for example, Henry Mayhew's *The Wonders of Science, or Young Humphry Davy*, 1856).[10] The actual work of scientific discovery rarely followed this pattern. Hesitations, misconceptions, dead ends, rivalries and collaborations, long drawn-out trials over years, and sudden chance breakthroughs over days, were nearer the truth.

Nevertheless this contingent nature of discovery could well be caught in narrative form. By going back to original sources—diaries, laboratory notebooks, contemporary letters, and early or rejected drafts of scientific papers and lectures—a vivid picture of the actual processes of science could be obtained. And, equally important, the feelings and imaginative struggles of the scientists involved.

For example, I explored a technique that I came to think of as the "vertical footnote." This worked as follows. While my main narrative moved forward in a largely conventional chronological form, a "horizontal" progress as it were, the footnotes provide sudden "vertical" or vertiginous plunges *down* into past history, or *back up* into contemporary science. For example, when describing the Herschels' prolonged nights of stargazing in the 1780s, I wanted to bring home to the reader what this might really have felt like. I described contemporary conditions—the ink freezing on Caroline's pen and so on—and then tried to surprise the reader with the same experience as viewed by quite different people at quite different times.

I leaped forward to a late-nineteenth-century British novel and then forward again to one of the greatest twentieth-century American astronomers. I then broke my own rule about never using the personal pronoun and added a personal memory from my researches at Cambridge to emphasize the profound psychological impact of the night sky. After various tinkerings, this is what I came up with:

> Standing under a night sky observing the stars can be one of the most romantic and sublime of all experiences. It can also be oddly terrifying. A hundred years later, Thomas Hardy took up amateur astronomy for a new novel, and in his description of Swithin and Lady Constantine sharing a telescope in *Two on a Tower* (1882) he captured something of the metaphysical shock of the first experience of stellar observation. "At night . . . there is nothing to moderate the blow with which the infinitely great, the stellar universe, strikes down upon the infinitely little, the mind of the beholder; and this was the case now. Having got closer to immensity than their fellow-creatures, they saw at once its beauty and its frightfulness. They more and more felt the contrast between their own tiny magnitudes and those among which they had recklessly plunged, till they were oppressed with the presence of a vastness they could not cope with even as an idea, and which hung about them like a nightmare."[11] My own first experience with a big telescope, the "Old Northumberland" at Cambridge Observatory, an 11-inch refractor built in 1839, left me stunned. We observed a globular star cluster in Hercules, a blue-gold double star Beta Cygni, and a gas cloud nebula (whose name I forgot to record) since it appeared to me so beautiful and malignant, according to my shaky notes like "an enormous blue jellyfish rising out of a bottomless black ocean." I think I suffered from a kind of cosmological vertigo, the strange sensation that I might fall down the telescope tube into the night and be drowned. Eventually this passed. The great Edwin Hubble used to describe an almost trance-like, Buddhist state of mind, after a full night's stellar observation at Mount Wilson in California in the 1930s. (See Gale Christianson, *Edwin Hubble,* 1995.[12]) [13]

Finally, to unify the book I eventually chose four key figures in the three dominant sciences of the period: botany, astronomy, and chemistry (which then included the study of electricity). They were Banks, the two Herschels, and Davy. They were not only great scientists, but people who changed the perception of science itself for a general public and especially for the writers of the period.

* * * *

Shortly before publication in autumn 2008, I was asked to present *The Age of Wonder* to the Royal Society, London, in front of an audience of two hundred scientists. (As W. H. Auden once wrote on a similar occasion, I felt like a provincial clergyman shuffling into a room full of dukes.) I wondered how to catch their attention. So I began my commentary like this: "This book is 485 pages long, weighs 0.598 kilograms, is five centimeters thick, and has 72 footnotes. It has four main protagonists, one of whom is a woman. It has a cast list of 60 characters, 30 percent of whom are French, German, or American. It contains no mathematical formulae, but over 307 lines of quoted poetry."

These unflinching statistics appeared to excite a first flicker of interest, and even of amusement. I then gave them what I thought would be the most paradoxical and unlikely combination: the poet Byron waxing lyrical on the subject of universal scientific knowledge. The stanza comes from, of all places, Byron's epic poem of wanderlust and eroticism, *Don Juan* (1819). Byronic science could be looked on as oxymoron. But in fact, I assured my audience, this was actually a very good summary of the contents of my entire book:

> He thought about himself, and the whole Earth,
> Of Man the wonderful, and of the Stars,
> And how the deuce they ever could have birth;
> And then he thought of Earthquakes, and of Wars,
> How many miles the Moon might have in girth,
> Of Air-balloons, and of the many bars
> To perfect Knowledge of the boundless Skies;
> And then he thought of Donna Julia's eyes.[14]

To my surprise the scientists were particularly delighted with the last line. It suggests, of course, the paradox that human love, the impact of a single heartbeat, might be as great as the impact of the entire body of universal scientific knowledge. I have to say the scientists were very indulgent. I survived the occasion, and the book eventually went on to win the Royal Society Science Books Prize for 2009.

Joseph Banks

The young botanist Joseph Banks provided my unifying figure, in both a scientific and a literary sense. His story runs through the whole relay race of the book. Banks went on Cook's first voyage in 1768 at age twenty-four; he came home to be elected president of the Royal Society in 1778, remaining in office for the astonishing length of forty-two years until his death in 1820, when he was in his seventies.

Banks's adventures begin the book and take it through to its last decade. Each chapter starts with him inaugurating a new project. Each of my subjects walks in—either literally or metaphorically—to one of Banks's famous planning breakfasts at Soho Square, London. Banks also grows old with the book; his views change regarding the function of science and its connection with empire and religious belief. He became the presiding genius or the Virgilian guide.

Sir Joseph Banks was not the stout, growling eminence whose monumental portrait we now find glaring down from the marble staircase of the Royal Society in Carlton House

Gardens, London. In my book he begins as an athletic young man, a sprightly botanist and adventurer, jumping down onto the volcanic beach at Tahiti from the deck of Captain James Cook's famous ship, HMS *Endeavour.*

He was certainly a moneyed, privileged, young man of the Enlightenment, who had been educated at Eton and Oxford and inherited large estates and income in Lincolnshire. But he was transformed into something else. Banks changes from a Linnaean botanist and collector, typical of the Enlightenment, to a new kind of Romantic anthropologist, closely involved with the native peoples and customs of the South Seas. This transformation is aptly symbolized by two drawings he commissioned on Tahiti by one of the expedition's official artists, nineteen-year-old Sydney Parkinson. The first is a meticulous technical study of breadfruit; the second is a tender, affectionate portrait of a young Tahitian mother and her little boy. The mother holds the child by the hand, and the child lets a small bird perch on his finger.

Banks learns the Tahitian language, customs, and religion and takes part in many of their ceremonies, including cooking, feasting, and tattooing. He joins a naked dance along the beach—not an erotic ceremony, as it turns out, but a solemn, mourning one. He becomes the confidante of the Tahitian queen and the lover of one of her maidservants. (The queen takes her revenge by having all his clothes stolen during a night he spends in her boat.)

He is even the first European to record one of the most distinct and impressive of all South Seas customs: Rounding the tip of a bay one morning in May 1769, he looked out to sea and saw something wholly unexpected and "truly surprising." This was the astonishing and never-to-be-forgotten sight, far out on the unprotected edge of the lagoon, of a group of dark Tahitian heads bobbing amidst the enormous dark blue Pacific waves. At first Banks thought they had been flung out of their canoes and were drowning. Then he realized that the Tahitians were *surfing.*

No European had ever before witnessed—or at least recorded—this strange, extreme, and quintessentially South Seas sport. It left Banks amazed by the courage and dexterity of the Tahitian surfers and the beauty and nonchalant grace with which they mastered the huge and terrifying Pacific rollers.

> It was in a place where the shore was not guarded by a reef as is usually the case, consequently a high surf fell upon the shore, a more dreadfull one I have not often seen: no European boat could have landed in it and I think no Europaean who had by any means got into [it] could possibly have saved his life, as the shore was coverd with pebbles and large stones. In the midst of these breakers 10 or 12 Indians were swimming. . . . [15]

Here the power of wild Nature was not tamed, but harnessed by human beings; and they evidently reveled in it. The Tahitians had developed what were clearly surfboards. These were pieces of smooth wooden planking, constructed out of the curved ends of old canoes. They were scornful of all danger and exultant in their physical skills.

> [W]henever a surf broke near them [they] divd under it with infinite ease, rising up on the other side; but their cheif amusement was carried on by the stern of an old canoe, with this before them they swam out as far as the outermost breach, then one or

> two would get into it and opposing the blunt end to the breaking wave were hurried in with incredible swiftness. Sometimes they were carried almost ashore but generally the wave broke over them before they were half way, in which case the[y] divd and quickly rose on the other side with the canoe in their hands, which was towd out again and the same method repeated.[16]

Most extraordinary of all, this perilous surfing evidently had absolutely no practical purpose or possible use. It was nothing to do with fishing, transport, or navigation. The Tahitians did this for the sheer, inexhaustible delight of the thing. It was a complete paradise sport: "We stood admiring this very wonderfull scene for full half an hour, in which time no one of the actors attempted to come ashore but all seemd most highly entertaind with their strange diversion."[17]

These observations led on to further reflections about a new view of nature, in which her powers are not "conquered" in a Western manner, but "harmonized" and harnessed. This is just one glimpse of Banks's romantic recognition of a different civilization, which I went on to examine in greater detail in the book.

William Herschel and Caroline Herschel

From geographical exploration I turned to astronomical, and the remarkable story of William and Caroline Herschel. Born in 1738, William Herschel was a German émigré from Hannover. Trained as a musician, Herschel settled in Bath, England, in 1766, where he became fascinated by the study of stars and planets, initially as an amateur hobby. In 1772 he brought his younger sister Caroline (born in 1750) from Hannover to join him in Bath, thereby releasing her from domestic bondage. Together they began the construction of homemade reflector telescopes, and their observations quickly opened a new chapter in astronomy. William's discovery of Uranus, the seventh planet in the solar system, on 13 March 1781, doubled the size of the observable solar system and subsequently led to a whole new conception of the structure of the universe. Caroline was not present on the actual night of the first sighting of Uranus, but she helped with all of William's subsequent observations during the ensuing thirty years; and she became one of the most renowned comet hunters in Europe. She was also the first woman in British science to be granted an official salary (a £50 annuity, which was enough to live on independently at that time) from the Crown, a notable watershed.

From 1782 the two Herschels continued their work at a new observatory outside Slough, close to the King's country residence at Windsor Castle. Here they built a series of telescopes, ranging up from ten to twenty feet in length, and finally produced a 40-foot giant, with a metal speculum mirror weighing more than a ton. This last became a local landmark and tourist attraction, even being recorded on one of the new Ordnance Survey maps.

Their observations established the idea of "deep space," but also of "deep time," and first identified the discus shape of our Milky Way. Herschel also proposed, in a series of revolutionary papers to the Royal Society, the existence of galaxies *outside* the Milky Way—such as Andromeda—and at previously unimagined distances. He called such galaxies "the laboratories of the universe," in which new stars were constantly being formed. He described these galaxies not as static creations, in the Biblical sense, but as dynamic structures with identifiable patterns of stellar formation, growth, and decay, not unlike plants. These new "organic" theories of what was in effect an "evolving" universe, transformed contemporary notions of the cosmos.

Besides tracing the scientific relationship between William and Caroline, I also wanted to show the extraordinary imaginative impact of their work in several other fields. To do this I looked particularly at the reactions of the poets Shelley and Keats to the new discoveries, and also of the musician Joseph Haydn. One of the most remarkable things was the very different kinds of conclusions they drew from it.

Percy Shelley had been inspired to buy his own (extremely expensive) telescope while an undergraduate at Oxford University. He made astronomy, and an imaginary journey through the stars, a central theme of his first major poem, *Queen Mab*, published in 1813 (still within Herschel's lifetime). Attached to it were a series of deliberately provoking prose notes on a variety of scientific and political subjects, including free love, vegetarianism, and climate change. Inspired by Herschel's "deep space" theories, he wrote a particular fierce note "On the Plurality of Worlds," that is, the existence of extraterrestrial life on what we would now call "exoplanets." He drew from this an atheist conclusion which would have delighted Professor Richard Dawkins:

> The indefinite immensity of the universe is the most awful subject of contemplation. He who rightly feels its mystery and grandeur is in no danger of seduction from the falsehoods of religious systems, or of deifying the principle of the universe. It is impossible to believe that the Spirit that pervades this infinite machine begat a son upon the body of a Jewish woman. . . . All that miserable tale of the Devil and Eve and an Intercessor, is irreconcilable with the knowledge of the stars. The works of His fingers have born witness against him. . . . Millions and millions of suns are ranged around us, all attended by innumerable worlds, yet calm, regular, and harmonious, all keeping the paths of immutable Necessity.[18]

Three years later, the reaction of the equally young poet John Keats was utterly different. Keats wrote his sonnet, "On First Looking into Chapman's Homer," very early one autumn morning in October 1816. It celebrates a deeply Romantic idea of exploration and discovery. Without actually naming Herschel, it picks out the finding of Uranus, thirty-five years earlier, as one of the defining moments of the age. Although combining many sources of inspiration (Keats possibly may have attended Charles Babbage's 1815 "Lectures on Astronomy" at the Royal Institution), the poem itself was written in less than four hours.

Keats was twenty years old and attending a full-time medical course at Guy's Hospital in London. He had stayed out all night with his friend and mentor, Charles Cowden Clarke, at his house in Clerkenwell, drinking and discussing poetry. Clarke had acquired an old 1616 folio edition of Chapman's verse-translation of Homer's *Iliad*, and they had taken turns reciting passages aloud. At particular passages Keats "sometimes shouted" with delight. A favorite was the gloriously extended simile of shining light from Book 5. This compares the golden glow of the Greek warrior Diomedes's helmet to the glow of the planet Jupiter rising above the sea in autumn:

> Like rich Autumnus' golden lampe, whose brightness men admire,
> Past all the other host of Starres, when with his cheerful face,
> Fresh washt in lofty Ocean waves, he doth his Skies enchase.[19]

With such images in his head, Keats left Clerkenwell at 6:00 a.m., shortly before autumn sunrise. The stars were still out as he crossed London Bridge making for his student lodgings at 8 Dean Street, Southwark, near Guy's. He noticed the planet Jupiter, very bright, setting over the Thames. The moment he got to his lodgings, he sat down and began to write, starting with the inspired line, "Much have I travell'd in the Realms of Gold. . . . " [20] This perfectly introduced two linked ideas of thrilling exploration and gleaming brightness, which orchestrate the whole poem.

Keats wrote so quickly that he was able to send a clean copy of the poem straight round to Cowden Clarke that same morning. Clarke remembered opening it at his breakfast table in Clerkenwell by 10:00 a.m. (a credit also to the postal system). He noticed the historical error—it was Balboa not Cortez who reached the Pacific—but was thrilled by the beauty and originality of the sonnet. Among other things, Keats had combined science and poetry in a new and intensely exciting way. Keats likened his own discovery of Homer's poetry to the experience of the great astronomer and the great explorer finding new worlds:

> Then felt I like some watcher of the skies
> When a new planet swims into his ken;
> Or like stout Cortez, when with wond'ring eyes
> He star'd at the Pacific, and all his men
> Look'd at each other with a wild surmise—
> Silent upon a peak in Darien.[21]

Both comparisons turn on moments of physical vision—watching, staring, looking "with wond'ring eyes." (This was the original manuscript reading, although Keats later changed it to the more conventional "with eagle eyes.") Physical vision—one might say scientific vision—brings about a metaphysical shift in the observer's view of reality as a whole. The geography of the earth, or the structure of the solar system, is in an instant utterly changed, and forever. The explorer, the scientific observer, and the literary reader experience the Sublime: a moment of revelation into the idea of the unbounded, the infinite.

In the case of Herschel's sighting of Uranus, Keats's word "swims" is brilliantly evocative, because of its sense of new life and movement. The planet is like some unknown, luminous creature being born out of a mysterious ocean of stars. Keats may also have realized that convection currents in the atmosphere, or in the tube of the telescope itself, can give objects the appearance of being seen through a rippling water surface.

Keats's vivid idea of the eureka moment of instant, astonished recognition celebrates the Romantic notion of scientific discovery. It is appropriate that this is expressed in the oddly anachronistic phrase, "into his ken" (grasp, knowledge), even though it may also be there for the rhyme. The efforts of other European astronomers, like Charles Messier (1730–1817) and Anders Johan Lexell (1740–1784), certainly took weeks, if not months, to confirm the identification of Herschel's "comet" in 1781. Yet it is also true that Herschel, too, despite the evidence of his own observation journal, gradually convinced himself that precisely such a moment of instant, sublime discovery had occurred in the garden at New King Street. So the paradox emerges that the scientist Herschel in the end may have remembered that night exactly as the poet Keats imagined it.

A third and much older artist who responded creatively to the Herschels' work was the great composer Joseph Haydn. Once again his reaction was revealingly, even astonishingly, different; and I have now explored it further than initially described in my book. It has long been accepted that Haydn's famous and beautiful oratorio *The Creation* was the religious work that crowned his career. Completed in 1798 when Haydn was sixty-seven, it was based on a pious libretto obtained by the London-based musical impresario Johann Peter Salomon. *The Creation* libretto was originally intended for Handel, but he composed *Messiah* instead.

The libretto was inspired by the traditional scriptural words from the King James Bible, the opening of the book of Genesis: "In the beginning God created the Heaven and the Earth. And the Earth was without form, and void; and the Darkness was on the face of the Deep. And the spirit of God moved upon the face of the Waters. And God said, Let there be Light: and there was Light."[22] Some additional elements were also taken from Milton's *Paradise Lost.* So the oratorio is fundamentally a religious work, as Haydn himself later movingly testified. "Never was I so pious," he wrote, "as when composing '*The Creation*.' I felt myself so penetrated with religious feeling that before I sat down to the pianoforte I prayed to God with earnestness that He would enable me to praise Him worthily."[23]

It is often said that, in the lives of the great eighteenth-century composers, there is only one parallel to this frame of mind—the religious fervor in which Handel composed *Messiah*. And Haydn had set out to rival him in piety, as well as in musical brilliance.

Yet it is also possible that the highly unusual musical ideas for the first two parts of *The Creation*—the orchestral "Representation of Chaos" with which it opens, and the recitative for the Archangel Raphael that follows—were strongly influenced by the new cosmological theories and discoveries of William Herschel. It is a strangely paradoxical idea that *The Creation* was also inspired by a distinctly secular, and even atheistical, science.

Haydn's 18-month visit to England in 1791–1792, the first of two he made to the English capital, was the first time he had ever voyaged outside Austria in his life. Though already in his sixties, he engaged with this new world with immense intellectual excitement. Among many adventures and expeditions recorded in his London diary, one highpoint was his visit to the Herschels' famous astronomical observatory at Slough in June 1792.

By now, the brother and sister astronomical team were renowned throughout Europe. Their enormous 40-foot reflector telescope, the biggest in the world, was one of the wonders of the age. As I have explained, both Herschels were also musicians. William was an accomplished composer and one-time organist and *Kapellmeister* of the Octagon Chapel, Bath. Caroline had trained as an opera singer and had successfully performed in Handel oratorios. Moreover, as the Herschels originally came from Hannover, they and Haydn immediately had German as a common language.

William's diary shows that he himself was absent from the Slough observatory during much of this month. But Caroline's journal records Haydn's visit as one of the highlights of their summer. One of the things they had to discuss was the generosity of their English patrons in the financing of both telescopes and symphonies—finances and accounting being Caroline's special department. But above all, Caroline was able to describe their astronomical work in detail to Haydn, while explaining her brother's discoveries with the utmost enthusiasm and pride.[24]

Haydn was an immensely hard worker—he would produce no fewer than twelve symphonies while in England—and he was evidently impressed by the punishing (not to say Teutonic) routine of the Herschels who, as Caroline explained, worked all day on astronomical calculations, and then could spend "six hours at a time on freezing winter nights,"[25] carrying out their observations. But as this was high summer, Haydn had plenty of leisure to look through all the telescopes—the 10-, 20-, and 40-foot models—and discuss with Caroline her brother's theories of stars, planets, and musical composition.

As I have indicated, Herschel's theories explored new and radical ideas about the formation of our own solar system, and the galaxies beyond it. They had been published in a number of scientific papers in the journal of the Royal Society, the *Philosophical Transactions*. They had also been popularized in the work of the poet and physician Erasmus Darwin (1731–1802), a leading member of the Lunar Society. They spread widely and were finally taken up in France by the atheist astronomer Pierre-Simon, marquis de Laplace (1749–1827), who called them "the nebular hypothesis" and published them in his own study of 1796 (originally titled *Exposition du système du monde*, but later known more popularly as *La mécanique céleste*).

The fundamental idea of the nebular hypothesis was a materialist or secular view of the universe. It proposed that, on the evidence of observational astronomy, our own planet Earth and solar system were *not* special or unique creations by God, as described in Genesis. They were just a tiny part of a general galactic evolution observable throughout the universe—an evolution that was *still continuing*.

Throughout the universe Herschel had observed vast gaseous nebulae condensing into huge star clusters through the action of Newton's "universal gravity." He was the first astronomer to identify them as independent galactic systems beyond our own Milky Way. For more than a decade Herschel had carefully studied, drawn, and described dozens of these—including, for example, our nearest galaxy, the spiral nebula Andromeda. He argued that the galaxies were still at various stages of "growth or decay," and from this he drew a radical new idea of the universe as a continuous creation. In that famous phrase, he had described these galaxies as "the laboratories of the universe." This was a thoroughly secular concept.[26]

Similarly, Laplace argued, there were millions of other solar systems besides our own. Other suns had spun out clusters of individual planets which circled around them, again through the force of universal gravity. There must be innumerable such "solar systems" even in our own Milky Way. So the whole universe was a laboratory. Clearly, these ideas moved away from the traditional six-day Creation "myth" of Genesis, and came much closer to modern ideas of evolutionary cosmology. They were supported by the "deep time" ideas of the British geologist James Hutton (1726–1797).

It seems likely that the early sections of Haydn's oratorio reflect something of such revolutionary speculations. This was emphasized by his giving such unusual and inventive attention to the idea of "chaos" at the opening on the work. Nothing that he—or indeed Handel—had previously written is remotely like these extraordinary passages. Haydn's use of unresolved musical phrases, unsettling shifts from major to minor chords, sudden bursts of melody broken off by unexpected dissonance, all seem to suggest the vision of a highly active, explosive, cosmological chaos: the whirling, colliding, and condensing of truly vast nebulae. It does not seem anything like the passive "brooding" darkness of the book of Genesis. What it so vividly summons are the luminous, celestial "laboratories" of Herschel and Laplace.

Sir Humphry Davy

My fourth figure was the great chemist Sir Humphry Davy. Young Davy was, of course, the friend of the poet Coleridge, and in their twenties they famously experimented together at the Bristol Pneumatic Institute with nitrous oxide, or laughing gas. They exchanged letters (also with Robert Southey) on the relations between poetry and science and on such subjects as the nature of "pain" and the possibilities of "chemical healing." It was in viewing Davy's work that Coleridge made that crucial declaration, which I am happy to repeat: "Science, being necessarily performed with the passion of Hope, it is Poetical."[27] It was at this time that Davy came within an ace of discovering surgical anesthetics.

But there was also a great deal of anarchic fun at the Bristol Institute, the kind of inventive mischief that still occurs in modern scientific laboratories. The Institute's indulgent director, Dr. Thomas Beddoes, gave this glimpse of Davy and Coleridge in experimental mode:

> Mr Davy breathed a large dose of GAS [nitrous oxide] at the same time as Mr C[oleridge]; and it produced a prodigious excitement, during which he exerted a degree of muscular power, that utterly surprised a very robust by-stander. But he was so far from sinking, like some spent Pythian Priestess, that his spirits were unusually good all day; nor has any LANGUOR succeeded. . . .[28]

Davy's subsequent career was equally tumultuous. He is now most obviously remembered for his use of the voltaic battery to resolve new elements such as sodium and potassium, his innovations in agricultural chemistry and tanning, his invention of the arc light (using carbon electrodes), and above all his triumphant design of the miner's safety lamp. This was a brilliantly simple device, employing a sheath of metal gauze—instead of glass—to insulate the lamp flame. It spread across the coal mines of Europe, as far as Poland and Russia, unhindered by patent restrictions. In providing safe access to the primary energy source of the day, it saved literally thousands of lives. Davy was also the first Englishman knighted for service to science since Sir Isaac Newton, and the first professional chemist (as opposed to astronomer or mathematician) to be elected president of the Royal Society of London. Altogether Davy conferred hitherto unexampled popularity—and even glamor—on the discipline of chemistry.

His flamboyant impact as a lecturer at the Royal Institution and the Royal Society became celebrated. An eyewitness, Thomas Dibdin, conveyed the theatrical atmosphere, as Davy exuberantly revealed the new alkali metals during his Bakerian Lectures of 1806–1808:

> The whole had the character of a noonday opera house. There stood Davy, every Saturday morning, as the mighty magician of nature—as one, to whom the hidden properties of the earth were developed by some Egerian priestess in her secret recess. Begirt by his immense voltaic battery—which was as so many huge cubical links of wood and metal, forming a vast mysterious chain, and giving to the whole a sort of picturesque and marvellous character—the lecturer called forth its powers with an air of authority, and in a tone of confident success. The hardest metals melted like wax beneath its operation. . . . The tremendous force of such an agency struck the learned with delight, and the unlearned with mingled rapture and astonishment; and the theatre or lecture-room rung with applause as "the mighty master" made his retreating obeisance.[29]

In his wonderful paper, *On the Safety Lamp for Coal Miners, with Some Researches into Flame* (1818), Davy produced one of the great set pieces of Romantic science writing. He related the human predicament of the miners, threatened by terrible explosions of firedamp, to the scientific solution found in the laboratory. He argued that applied science could be a force for good previously unparalleled in human society and might gradually liberate mankind from untold misery and suffering. The safety lamp becomes the symbol of science's "benevolence" and "the relief of man's estate." Deliberately echoing Bacon—as Lavoisier had once done—Davy claimed that scientific knowledge was disinterested power for good:

> The results of these labours will, I trust, be useful to the cause of science, by proving that even the most apparently abstract philosophical truths may be connected with applications to the common wants and purposes of life. The gratification of the love of knowledge is delightful to every refined mind; but a much higher motive is offered in indulging it, when that knowledge is felt to be practical power, and when that power may be applied to lessen the miseries or increase the comforts of our fellow-creatures.[30]

The *Edinburgh Review* ran a clarion article in praise of his work, written by the leading geologist Professor John Playfair. "It may fairly be said that there is hardly in the whole compass of art or science a single invention of which one would rather wish to be the author."[31] Playfair described the discovery as the result of pure inductive science, "in no degree the effect of accident" and "as wonderful as it is important." Its historic significance was unmistakable:

> This is exactly such a case as we should choose to place before Bacon, were he to revisit the earth, in order to give him, in a small compass, an idea of the advancement which philosophy has made, since the time when he pointed out to her the route which she ought to pursue.[32]

Here the word "philosophy" was used exclusively to mean "science" in the modern sense: what Playfair defined as "the immediate and constant appeal to experiment."

But Davy also gave, for perhaps the first time since Bacon, a much wider social and philosophic context to the whole business and ambition of science. This appears in three visionary statements on the progressive state of chemistry in his life time, which he delivered successively over some thirty years.

The first was his *A Discourse Introductory to a Course of Lectures on Chemistry,* originally given at the Royal Institution in 1802. In this Davy outlined both a social history and a heroic future for science. His central concept, echoing Coleridge, was that of Hope. Once awakened by science, man had become capable of "connecting Hope with an infinite variety of ideas." Above all science had transformed mankind's prospects across the planet by enabling him to shape his future, imaginatively and actively:

> It has bestowed on him powers which may almost be called creative; which have enabled him to modify and change the beings surrounding him, and by his experiments to interrogate nature with power, not simply as a scholar, passive and seeking only to understand her operations, but rather as a master, active with his own instruments.[33]

Davy announced to his spellbound audience at the Royal Institution that they were witnessing the dawn of "a new science":

> The dim and uncertain twilight of discovery, which gave to objects false or indefinite appearances, has been succeeded by the steady light of truth, which has shown the external world in its distinct forms, and in its true relations to human powers. The composition of the atmosphere, and the properties of gases, have been ascertained; the phenomenon of electricity has been developed; the lightnings have been taken from the clouds; and lastly, a new influence has been discovered, which has enabled man to produce from combinations of dead matter effects which were formerly occasioned only by animal organs.[34]

The second significant statement appears in his encyclopedic introduction to his collected *Lectures on Chemistry* of 1812, titled "The Progress of Chemistry." Here he gave a remarkable historical overview of chemistry since the Greeks and Arabs and outlined contemporary developments right across Europe. He claimed that Britain then led the world in chemistry, which had become the chief experimental science of the day, including work with voltaic batteries. Davy "ardently" dedicated these lectures to his fiancée, Jane Apreece.

Finally, in his extraordinary last book, *Consolation in Travel: The Last Days of a Philosopher,* published in 1830, Davy gave a retrospective and even mystical view of the role of the chemist in society. Here he claimed that chemistry was the fundamental basis for a scientific education, and the key to all future sciences. The great French naturalist Georges Cuvier (1769–1832) later called this remarkable book, with its unexpected mixture of travelogue, philosophy, and even speculative science fiction, "in some measure the work of a dying Plato."[35]

In this fifth dialogue, titled *The Chemical Philosopher,* Davy set out his hopes for the future of chemistry. It embodied all his passionate belief in science as a progressive force for good, both in its practical results and its cultural impact on the human spirit:

> Whilst chemical pursuits exalt the understanding, they do not depress the imagination or weaken genuine feeling; whilst they give the mind habits of accuracy, by obliging it to attend to facts, they like wise extend its analogies; and, though conversant with the minute forms of things, they have for their ultimate end the great and magnificent objects of Nature. . . . And hence they are wonderfully suited to the progressive nature of the human intellect. . . . It may be said of modern chemistry, that its beginning is pleasure, its progress knowledge, and its objects truth and utility.[36]

Davy claimed chemistry as the crown of a "liberal education" and assumed that a serious chemist would begin with an elementary knowledge of mathematics, general physics, languages, natural history, and literature. It is interesting that he included Latin, Greek, and French in this pedagogic prescription. Yet a chemist should nevertheless write up his experiments in "the simplest style and manner." But above all, he concluded, his imagination "must be active and brilliant in seeking analogies. . . . "[37]

* * * *

One of the most extraordinary consequences of Davy's scientific lectures appears in the work of the novelist Mary Shelley. This I explored at some length in a chapter called

"Dr. Frankenstein and the Soul" and have continued to examine it especially in relation to modern film and stage versions of the Frankenstein story. The most recent of these was Danny Boyle's spectacular stage production at the National Theatre, London, in spring 2011, for which I wrote the program note.

Mary Shelley's original full-length novel, *Frankenstein, or the Modern Prometheus*, was published anonymously by Lackington and Company, Finsbury Square, London, in March 1818. At the time it seemed so utterly strange and original, that reviewers thought it must have been written by Mary's father, the notorious anarchist philosopher William Godwin, or possibly by the great romancer Sir Walter Scott, or even by that dangerous atheist Percy Shelley. No one thought it could have possibly been written by a young woman still in her teens.

It is astonishing that it ever got written at all. During those few hectic months of composition, Mary's stepsister, Claire, bore Byron's illegitimate baby secretly in Bath; her half-sister, Fanny Imlay, committed suicide with an opium overdose in a Welsh hotel; and Percy Shelley's legal but abandoned wife, Harriet Shelley, "being far advanced in pregnancy" (according to *The Times*), committed suicide by throwing herself into the Serpentine. On top of all this, Mary found that she herself was pregnant. The manuscript of *Frankenstein* was delivered to the publisher just five weeks before her baby was born.

That Mary persisted in her writing throughout these domestic dramas is truly remarkable. But then it is hardly surprising that painfully adult themes of physical birth and death, of the terrors and responsibilities of parenthood, and of the agonies of the outcast or the unloved suffused her youthful imagination like blood.

Many years later, in a preface written for the popular edition of 1831, Mary gave a more Romantic explanation of how the novel came to be written. She said it was the result of a single, terrible nightmare she had dreamt that summer, of some crazed young doctor, a "pale student of unhallowed arts," who had assembled a creature from human body parts and brought it to life, thinking it would be the first of a beautiful and perfect new race. In her nightmare she saw "the hideous phantasm of a man stretched out, and then, on the workings of some powerful machine, shows signs of life, and stir with an uneasy, half-vital motion." [38]

No doubt this dream is authentic. All novelists (like most scientists) treasure such eureka moments. But Mary's letters and journals during the period of actual writing, from summer 1816 to autumn 1817, present a rather different picture of the young author at work. For a start, she was intensely conscious of her literary inheritance from her parents. William Godwin was a best-selling thriller writer of pursuit novels, such as *Caleb Williams,* as well as a philosopher. Her mother, Mary Wollstonecraft, the great feminist author of *The Rights of Woman*, had always wanted to write a novel but had only left an incomplete manuscript titled *The Wrongs of Woman* at the time of her death, in 1797, while giving birth to Mary.

So Mary Shelley felt she owed her parents a novel, and her husband, Percy Shelley (they had married hastily after Harriet's death), was equally enthusiastic: "very anxious," as she put it, "that I should prove myself worthy of my parentage." [39] He evidently discussed its themes with her, as she researched and wrote it. The 170-page manuscript of the novel as Mary originally drafted it, and then as Percy Shelley minimally edited it, has been recovered and now republished by the Bodleian Library. The comparison of these manuscripts scotches any idea that Percy Shelley somehow wrote the whole thing for her. It was always Mary Shelley's amazing creation.

Her journals also indicate how much, and how seriously, Mary drew from her reading and research. Although she never attended university (which was still forbidden to women), she had been fiercely educated at home by her philosopher father; and at eighteen she had the quick, enquiring mind of a brilliant post-graduate. She studied Davy's *Course of Lectures on Chemistry,* passages of which—as I show in my book—were incorporated virtually word for word into the novel. She used the scientific poetry and speculative evolutionary ideas of Erasmus Darwin (Charles Darwin's grandfather), notably *The Temple of Nature, or the Origin of Society* (1803).

Mary also drew from conversations in Geneva with Byron's brilliant but unstable young doctor, William Polidori, and later from Percy Shelley's medical advisor in London, the radical surgeon Sir William Lawrence. Lawrence had written about the anatomy practice of John Hunter (whose specimens can still be seen in the Royal College of Surgeons) and also knew of the galvanic theories of Giovanni Aldini, who used massive electric shocks in an attempt to revive a dead criminal in a notorious public experiment held in London in 1803.

It is significant that Lawrence was engaged throughout the period of 1816 to 1819 in an acrimonious public debate with another leading surgeon, John Abernethy, about the fundamental nature of life itself: Was there some mysterious "life principle"? Was there a "vital spark"? Did it produce the "mind" and "consciousness"? Did this come from God or electricity? Indeed, was there such a thing as a "human soul"? (Lawrence thought definitely not.) This "Vitalism Debate," as it was known, was being widely discussed in such journals as the *Quarterly Review* and by such authors as Coleridge in his *Notes towards the formation of a more comprehensive theory of life*.[40]

All these scientific speculations shaped the radical way Mary invented both the Creature and his visionary scientific creator, Victor Frankenstein. As for the Creature himself, his mind is initially a complete blank. He has no retained memories from the previous life of his transplanted brain. He has no knowledge, no language, no conscience. He is, in a sense, perfectly innocent. Perhaps his first experience is simply that of pain. His ideas of friendship, of speech and reading, of books and history, of love and moral responsibility, are formed as a child would form them, cumulatively by trial and error, but at increasing and painful speed.

He is soon cursed by the discovery that he is hideous, not beautiful; that he is loathed, not loved; that he is rejected by everyone who meets him, even eventually by his creator. Moreover he is an outcast, with profound longings for affection and sexual love that are fatally frustrated. He is, suggests Mary Shelley, like a fallen angel from Milton's *Paradise Lost*—but a vengeful angel, too.

Mary is equally fascinated by the obsessive character of Victor Frankenstein, arguably the first fictional study of a professional scientist in literature. Here it is worth repeating the extraordinary fact that even the word "scientist" had not been coined before 1833. It has been suggested that young Frankenstein is partly modelled on Percy Shelley as a rebellious undergraduate at Oxford (he was expelled for atheism), but also on Humphry Davy and William Lawrence and even on a mad German physicist, one Johann Ritter of Munich, who died "insane" in 1810.

However this may be, he is still Mary's unique creation. Victor Frankenstein is a strange, brilliant man, supremely inventive and skillful, an idealist who wants to "benefit all mankind," but who is also arrogant, obsessive, and even autistic in his human relations, noticeably with his fiancée, Elizabeth. So without intending it, Frankenstein produces a catastrophe. He creates a powerful and vindictive Creature who—if he breeds—may wreak havoc over the whole globe. It is this stereotype of the "scientist," the crazed man in the white coat that the novel has set loose—for good or ill—in so much subsequent science fiction literature.

In fact, the first 1818 edition of the novel ran to a mere five hundred copies. It was, significantly enough, the early theatrical adaptations which first popularized the book. *Presumption; or, the Fate of Frankenstein* was first staged at the English Opera House in July 1823 and opened to scandalous publicity ("do not take your wives, do not take your daughters, do not take your families") and to huge audiences. Mary Shelley herself attended in the stalls: "Lo and behold! I found myself famous! *Frankenstein* has had prodigious success as a drama . . . in the early performances all the ladies fainted and hubbub ensued!"[41]

There were five separate stage versions in the 1820s which were taken to Paris and eventually to New York. It was these performances that really made the novel and the novelist famous. Subsequently there have been more than ninety theatrical and cinema adaptations and parodies including the famous 1930s Boris Karloff film.

But unlike the original novel, these rarely allow the Creature to speak more than a few grunts. Whereas for Mary Shelley, the Creature becomes paradoxically the most articulate of all her creations. Starting with a few halting words, the Creature ends by delivering great soaring arias of speech, appealing for affection, for justice, for rights. Paradoxically, indeed, for human rights.

* * * *

There are many other subjects that I attempted to explore in *The Age of Wonder*—for example, the early ballooning experiments of Blanchard and the American John Jeffries, or the heroic African expeditions of Mungo Park. All of them seemed to offer fascinating new ways of looking at the dynamic interface between the arts and the sciences in the Romantic period, and radically to call in question the old, tired idea of the "Two Cultures" division, which frankly I have come to despise.

So now I am looking for ways of taking this work forward into the early Victorian period, that is to say, into the surprisingly interlocking worlds of—for example—Charles Lyell, Mary Somerville, Ada Lovelace, Charles Babbage, Michael Faraday, Edgar Allan Poe, Maria Mitchell, Robert Chambers, and Alfred Tennyson. But meanwhile, looking back over the last decade, I can sum up some of the things I have tried to do. Essentially, I have aimed to take risks and break conventions, by combining science and literature with my passionate (and probably naive) belief in the power of biography to animate and enlighten, and to *make things memorable*. I have hoped to do this, first, by exploring the possibilities of "group biography," especially as it can explain and illuminate the particular nature of teamwork in science; and second by showing the importance of biographical *narrative*, of accurate and vivid storytelling, in demonstrating the step-by-step (and often *step-by-misstep*) of the actual process of scientific discovery.

Next, I have wanted to discover the human face of science, the hearts and minds behind the "white coats," so my real subject is always scientific *passion* in all its manifestations. It is not only the poets who have the passion. Beyond this, I wanted to prove that late eighteenth-and early nineteenth-century European history is still important for understanding the twenty-first century, and not only in the West. One of my proudest reflections is that *The Age of Wonder* has recently been translated into popular Arabic, Russian, and Chinese editions.

Finally—though I have learnt that there is never a "finally" for a biographer—I have hoped to raise some provoking questions. What is the relationship between teamwork and the apparent "solitary genius"—both in science and in the arts? What is the true role of women in science? What has science to say about the human "soul" and theological belief more generally? And was my old master Coleridge really right, when he assured us that Science always brings Hope?

Notes

1. Charles P. Snow, *The Two Cultures and the Scientific Revolution: the Rede Lecture* (Cambridge: Cambridge University Press, 1959).For a useful discussion of the extensive controversy surrounding Snow's ideas about the split between the liberal arts and the sciences, see, for example, Stephen Jay Gould, *The Hedgehog, the Fox, and the Magister's Pox: Mending the Gap Between Science and the Humanities*(New York: Harmony Books, 2003).
2. Richard Holmes, *The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science* (New York: Pantheon Books, 2008; Vintage Books, 2009), 274.
3. Samuel Coleridge to Humphry Davy, 1 January 1800, in *Coleridge Collected Letters,* ed. E. L. Griggs (London: Oxford University Press, 1956), 1:557.
4. William Blake, "Jerusalem," in *The Poems of William Blake*, ed. John Sampson (London: Oxford University Press, 1960), 388.
5. William Whewell, *Quarterly Review,* no. 51 (1834):54–68.
6. Anna Laertitia Barbauld, *Poems* (London, 1773), 37. See also http://www.npr.org /blogs/krulwich/2010/04/21/126051517/a-mouse-asks-for-mercy.
7. William Blake, "Auguries of Innocence." See http://www.bartleby.com/41/356.html.
8. Edmund Burke, *A Philosophical Enquiry into the Origin of Our Ideas of the Sublime and Beautiful*. See http://www.bartleby.com/24/2/.
9. Michael Shortland and Richard R. Yeo, eds., *Telling Lives in Science: Essays on Scientific Biography* (Cambridge: Cambridge University Press, 1996).
10. Henry Mayhew, *The Wonders of Science; or, Young Humphry Davy* (New York: Harper & Brothers, 1856).
11. Thomas Hardy, *Two on a Tower* (1882); see http://www.readbookonline.net/read /9736/23148/, VIII [7th para. from end of chap.].
12. Gale Christianson, *Edwin Hubble: Mariner of the Nebulae* (Chicago: University of Chicago Press, 1995).
13. Holmes, *Age of Wonder,* footnotes 118, 119.
14. Lord Byron, *Don Juan,* 1819, canto 1, stanza 92.
15. Joseph Banks, *The Endeavour Journal 1768–71,* 29 May 1769 (University of New South Wales, Australia, http://gutenberg.net.au/ebooks05/0501141h.html).
16. Banks, *The Endeavour Journal*.
17. Banks, *The Endeavour Journal*.
18. Percy Shelley, "On the Plurality of Worlds," second note to *Queen Mab* (London, 1813).
19. George Chapman, transl., *Homer's Iliad,* 1616, quoted in Holmes, *Age of Wonder,* 206.

20. John Keats, "On First Looking into Chapman's Homer," 1816. See http://www.bartleby.com/126/24.html.

21. Keats, "On First Looking into Chapman's Homer," quoted in Holmes, *Age of Wonder,* 207. This version is from Keats's original manuscript of the poem, which was altered slightly when actually published in the *Examiner* on 1 December 1816.

22. Genesis 1:1–3 (King James Version).

23. J. Cuthbert Hadden, "The Creation," in *Haydn,* Chapter 7 (Edinburgh, 1902). See also https://www.questia.com/read/91375367/haydn, 136.

24. See *Caroline Herschel's Autobiographies,* ed. Michael Hoskin (Cambridge: Science History Publications, 2003).

25. Holmes, *Age of Wonder,* 119.

26. For a full discussion of this concept see Holmes, *Age of Wonder,* 123 and Note 185.

27. Coleridge to Davy, 1 January 1800, in *Coleridge Collected Letters,* ed. E. L. Griggs (London: Oxford University Press, 1956), 1:557.

28. Thomas Beddoes MD, *Notice of Some Observations Made at The Medical Pneumatic Institution* (Bristol: Biggs and Cottle, 1799), 8–9.

29. Thomas Dibdin, *Reminiscences of a Literary Life* (London: J. Major, 1836), 226.

30. Humphry Davy, *The Collected Works,* ed. John Davy (London: Smith, Elder and Co. Cornhill: 1839–1840), 6:6.

31. John Playfair, "Sir Humphry Davy's Lamp," in *Edinburgh Review*, no.11 (1816):232–233.

32. Playfair, "Sir Humphry Davy's Lamp," 233.

33. Davy, *Collected Works,* 2:318–319.

34. Davy, *Collected Works,* 2:321.

35. John Davy, "Memoir of Sir Humphry Davy," in Davy, *Collected Works,* 1:xi.

36. Humphry Davy, "Consolations in travel," Dialogue V, in Davy, *Collected Works*, 9:361–365.

37. Davy, *Collected Works*, 9:366.

38. Mary Shelley, "Author's Introduction 1831," *Frankenstein, or the Modern Prometheus*, ed. Maurice Hindle (Penguin Classics, 1992), 9.

39. Mary Shelley, "Author's Introduction 1831," 6.

40. Coleridge, "Notes Towards the Formation of a More Comprehensive Theory of Life" (1816), *Coleridge's Shorter Works,* vol.1, ed. H. J. Jackson and J. R. de Jackson (Routledge, 1995).

41. Betty T. Bennett, ed., *The Letters of Mary Shelley* (Baltimore: John Hopkins University Press: 1988), 1:369, 378.

Learned Societies and the Birth of American Science

Marc Rothenberg

During the three centuries that are the focus of this seminar, communication among scientists was essential to scientific progress.[1] Communication might be face-to-face or at a distance. It might be in a formal and structured environment, such as a chartered society, or in an informal club. Scientists communicated formally, at a distance, using journals and monographs and informally through private correspondence and newspapers. The informal organization could lead to a more formal structure. For example, the "Invisible College," the group of experimenters in England led by Robert Boyle (1627–1691) and linked to the scientific communities in the rest of Europe through the correspondence network set up by Henry Oldenburg (ca. 1619–1677), evolved into the Royal Society of London, with Oldenburg as secretary; the correspondence network was replaced as the means of communication by the publication of refereed papers in the *Philosophical Transactions*.[2] Two centuries later, a regular gathering of scientists in Washington parlors for conversation and refreshments eventually evolved into the Philosophical Society of Washington.[3]

The Dibner Library, the reopening of which we celebrated with this symposium, is a grand depository of many of the forms of communication used by scientists, including society proceedings, periodicals, textbooks, and monographs.

My charge was to discuss the role of learned societies in the development of American science in the nineteenth century. I am taking the liberty of using a broad definition of "learned societies" to include a wide range of voluntary associations: local, state, and national societies, state academies of sciences, national disciplinary societies, as well as informal, but regularly meeting, social gatherings of researchers to discuss topics of scientific interest.[4] Our thread through this complex infrastructure is the career of physicist Joseph Henry (1797–1878), Princeton professor (1832–1846) and first secretary of the Smithsonian Institution (1846–1878). Henry's library is part of the Dibner Library, and the bulk of his papers resides in the Smithsonian Institution Archives.[5] What I provide here is an overview, with a pause here and there to provide more details to develop certain points.

What value are such voluntary associations? Henry answered this question three times—once in mid-career and twice towards the end of his life. In his 1850 presidential address to the American Association for the Advancement of Science, he told the members "that Associations of this kind have an important bearing on the advance of knowledge is proved by abundant experience. The history of discovery will show that those who have secured for themselves immortal honor by their labors in extending the boundaries of knowledge have always appeared in groups." He went on to draw an analogy from thermodynamics: "We know that the light and heat evolved from an isolated portion of fuel is far less intense than when it is burned in connection with other combustibles; each portion increases the power of the other until the whole becomes excited to an intense glow, shedding its genial influence all around. So in the reciprocal action of mind on mind there is an excitement produced highly favorable to the perception of new truths; each mind illumines the other."[6]

Two decades later, in his 1871 presidential address to the Philosophical Society of Washington, Henry returned to this theme, basing his judgment on what was a lifetime of participation in such groups: "It is mainly through the influence exerted and the assistance rendered by such associations, that science is advanced and its results given to the world. Man is a sympathetic being, and no incentive to mental exertion is more powerful than that which springs from a desire for the approbation of his fellow men; besides this, frequent interchange of ideas and appreciative encouragement are almost essential to the successful prosecution of labors requiring profound thought and continued mental exertions. Hence it is important that those engaged in similar pursuits should have opportunities for frequent meeting at stated periods."[7]

In a later address, just months before his death, Henry again reflected on the role of the learned society in science. He credited learned societies with both diffusing and increasing knowledge: "It [a learned society] tends to keep alive an active spirit of scientific advancement, not only to diffuse a knowledge of discovery among its members, but also to stimulate—by friendly criticism and cordial sympathy to new efforts in the way of explorations into the unknown."[8] The increase was dependent upon the encouragement of open, but constructive discussion. "Free critical discussion" of any communication presented to it was "an essential feature of a scientific society." But "critical discussion" had to have as its objective the advancement of science. Henry warned that a scientific gathering should avoid "merely verbal criticism, undue harshness on one hand and unmerited praise on the other, regard being had to truth rather than to victory or mutual admiration."[9]

The learned society presented a support structure for both the researcher and, in many cases, the interested layperson; it was an institution within which those interested in science and concerned for its well-being could come together for the critical exchange of ideas and mutual support. It was also a mechanism for the distribution of those ideas beyond the immediate location of the organization. Learned societies produced communications of some sort. One of the iron rules of formal, structured societies was that they sponsored publications. Admittedly, the extent of a specific publication program was, in the end, determined by practical issues like the financial stability of the organization and the quality and quantity of the discussions. As Henry noted: "If its [a learned society's] object were merely the intellectual and moral improvement of its members it might dispense with any publication whatever,—even with the announcement of its existence. If however it aspires to the more important office of advancing science or of enlarging the bounds of thought and assisting to diffuse a knowledge of new truths, it should then publish—if not quarto volumes of transactions—at least a bulletin of its proceedings."[10]

When the Constitution was ratified in 1789, the United States possessed two learned societies: the American Philosophical Society,[11] established in Philadelphia in 1743, and the American Academy of Arts and Sciences,[12] established in Boston in 1780. Although the titles of the societies claimed national sway, in reality these were at best regional organizations. They were joined during the course of the nineteenth century by more than three hundred other local societies, some lasting but a few years, others still in existence. The great value of these societies to the scientist was that they met relatively frequently, as compared to a national organization, which might meet only once or twice a year. These societies, whether in Washington, D.C., Albany, Charleston, Denver, or Davenport, Iowa, shared a number of characteristics, but showed variation within them.[13] Perhaps the most important shared characteristic was that none of these local organizations was limited only to scientists. The specific qualifications for membership might differ from society to society, but Henry's characterization of those for the Philosophical Society of Washington will serve as a general standard: "a high appreciation of science, some familiarity with its principles, and capability of doing something in the way of promoting the objects of the association."[14] These societies consisted of a range of individuals, generally men (especially in the antebellum era) and primarily middle-class and professional: doctors, lawyers, businessmen, educators, ministers, pharmacists, agriculturalists, and plantation owners, with a sprinkling of farmers and other occupations. Male members typically would have attended an academy and/or college and would have been exposed to some formal education in science. Women members, who were most prevalent in western or midwestern societies, came from similar social backgrounds. The number of active researchers in such societies varied. Only about 15 percent of the members of the Albany Institute during its most active period, roughly from 1825 to 1840, could be considered scientists.[15] In contrast, the Philosophical Society of Washington, founded in 1871 by government scientists and engineers, both civilian and military, had upwards of 90 percent of its members from these fields.[16]

What did a young researcher like Henry gain from participation in such local societies? He would gain access to a library, put together through purchase, donation, and/or exchange, far superior to any he could have gathered on his own. Henry remarks particularly that Albany provided him access to "most of the European periodical literature."[17] Later, the American Philosophical Society offered him an attentive and supportive audience for his ideas, an audience which supplied "the quick appreciation of the peculiarities of my experiments or the approving nod which would say go on! I understand you!"[18] These societies offered publication outlets, a point I mentioned earlier. Last but by no means least, these societies enabled researchers, local community leaders, and potential patrons of science (including those who were part of the hiring process in educational institutions) to come together and discuss science.

One of the perennial questions facing American scientists is how to justify public support for basic scientific research; how can one go beyond touting technological applications in demonstrating the value of science to a culture? Henry was at the forefront of the effort. He spent sixteen years at Princeton telling future businessmen, plantation owners, ministers, lawyers, and politicians why the study of science would be important for advancement in their respective careers and thirty more years interacting with the political leadership of the nation. A positive relationship between scientist and patron, whether that patron was a private individual or the United States Congress, was essential for the progress of science in this country. In his interactions with the social and political leadership of Albany at the Albany Institute, and in Philadelphia at the American Philosophical Society, Henry learned valuable lessons that stood him well in the future.

As I mentioned earlier, communication among scientists could occur in both formal and informal settings. How important were the informal settings? That is hard to document and no doubt will vary from researcher to researcher.[19] But I have found it very suggestive that Henry belonged to no less than three informal groups during his career. Indeed, there was hardly a time from the early 1830s, shortly after he joined the faculty at Princeton and became part of the scientific community in the Philadelphia metropolitan area, until the early 1870s, that he did not belong to a group that met for good food, good drink, and good scientific conversation.

The first of these was "the Club" in Philadelphia. According to Henry, the club "has no name and must be kept secret so as to excite no jealousy."[20] It first met in December 1834 and continued meeting three or four times a year until—well, we do not know when. It is hard to specify when secret societies dissolve, but we think it survived to 1844 or 1845. Membership was limited to the leading physical scientists—physicists, geophysicists, astronomers, meteorologists, geologists, and chemists—who lived conveniently near Philadelphia. This was an elite group, which provided a more focused audience for scientific discussion than was available at the American Philosophical Society.[21]

A few years later, Henry had become a member of the Lazzaroni. Any student of nineteenth-century American science should need little introduction to this informal group of research scientists and science administrators. Led by Alexander Dallas Bache, director of the U.S. Coast Survey, Lazzaroni members both dined together and attempted to improve the quality and quantity of American scientific research by encouraging professionalization and specialization. I will not go into the extensive historiography surrounding the Lazzaroni.[22] Briefly, the Lazzaroni's heyday was during the early and mid-1850s. By 1859, Henry had begun to place a wedge in the group by refusing to unconditionally support member Benjamin Apthorp Gould (1824–1896) during his term as director of the Dudley Observatory in Albany, New York.[23] With the incapacitation of Bache in 1864 and Henry's continuing refusal to place the wishes of the members of the Lazzaroni above the good of science—demonstrated by his support of Spencer F. Baird for membership in the National Academy of Sciences over the objections of Lazzaroni member Louis Agassiz—the group dissolved.[24]

By then, Henry had turned to a new informal group in Washington, called the Saturday Club in honor of its meeting day, for scientific comradeship. Established in 1854, the Saturday Club survived seventeen years, ending only with the organization of the Philosophical Society of Washington. "The objects of this Club," according to Henry, were "social meetings for the discussion of scientific subjects and for general scientific conversations."[25] Although on one occasion Henry complained that the meetings had shifted from discussions of scientific subjects to "a mere conversational gathering,"[26] he also called the club "the source of pleasure and profit to me. Questions are frequently proposed and observations made which give rise to interesting associations."[27]

Henry's 8 March 1862 diary entry gives the flavor of these meetings. He brought up a conversation he had had earlier in the week with a Cape Cod fisherman about various aspects of fish behavior and the sense of smell in fish. This led to a general discussion of the sense of smell, including a rather inexact recollection of experiments conducted in London two decades earlier on the propagation of smells. Conversation then turned to echoes. A point made during the discussion led Henry, the founder of applied acoustics in the United States, to conceive of a series of experiments to test whether wall composition affected its sound reflecting ability. The evening concluded with a consideration of physiological optics—in particular, the response of the eye to specific colors.[28] Informal associations were an important and relatively uninvestigated platform for communication among scientists in the United States during the nineteenth century.

Before moving on to the national societies, I want to briefly mention the state academies of science. These are probably the most overlooked form of scientific organization in the United States.[29] Yet the Connecticut Academy of Sciences is among the oldest learned societies in the United States, dating back to 1799, whereas the California Academy of Sciences was founded just a few years after statehood, in 1853. Both evolved from essentially local societies with statewide pretensions into true state organizations.

The number of state academies expanded greatly after the Civil War. In the South and Midwest in particular, they were an important factor in enhancing communication among scientists living where there was a lack of local societies. Southern scientists faced the additional challenges of poverty and inadequate transportation that restricted attendance at national meetings. Geological and biological sciences were emphasized in those academies, but it is important to remember that Josiah Willard Gibbs' fundamental and transformative publications in physical chemistry appeared in the *Transactions of the Connecticut Academy of Sciences*.[30]

A number of societies claimed national status in the late-eighteenth and nineteenth centuries. These included the aforementioned American Philosophical Society and the American Academy of Arts and Sciences, as well as the National Institute. In many ways the latter was a typical local learned society, except that politicians and government clerks rather than doctors and lawyers were the primary professions represented among the membership.[31] Henry served for a time as its vice president, but he found some members' insistence that the society have national status to be inappropriate and that this undercut its effectiveness as a local scientific society. After attempts to reform it from within failed, he disengaged himself over several years and by 1856 was no longer active in the organization.[32]

Rivalling the National Institute for national status at the same time was the American Association for the Advancement of Science, founded in 1848, and modeled after the British Association for the Advancement of Science. It was the first American society that attracted a truly national membership.[33] As the meetings of the peripatetic society moved around the United States, scientists whose horizons were distinctly local had the opportunity to intermingle with national figures. Although the formal sessions sometimes left something to be desired (Henry felt that speakers sometimes played to the public rather than to their fellow scientists, and he advocated meeting behind closed doors),[34] the informal interaction—at meals or during excursions to natural wonders, such as Niagara Falls, or to scientific wonders, like museums and observatories—was an important form of communication.[35]

Complementing the American Association for the Advancement of Science was the National Academy of Sciences, established by act of Congress in 1863. Envisioned by the Lazzaroni as both an elite society and a source of expert scientific advice for the American government, the National Academy was seen by many members of the scientific community as essentially a private club for friends of Alexander Dallas Bache. Key figures in American science were originally excluded from the organization, and the level of enthusiasm among those in the organization was low, leading to poor attendance and relatively little intellectual exchange. Only after reforms pushed by Henry as president of the National Academy in 1870, which lifted the initial restriction of fifty members, did the Academy become a truly national society of the scientific elite.[36]

During the last quarter of the nineteenth century, a third form of truly national society appeared. As part of the process of professionalization of scientific disciplines, American scientists felt a need to move past the general societies and meet with other members of their discipline. Chemists began the process with the American Chemical Society in 1876. Geologists, anthropologists, physicists, astronomers, and various forms of biologists soon followed. Some societies were both disciplinary and professional, such as the Geological Society of America, which restricted membership to those "engaged in geological work or in teaching geology."[37] Others, like the American Astronomical Society, were more sympathetic to avocational, but serious, researchers.[38]

The downside of all national organizations, whether honorific, like the National Academy, or disciplinary, was that they met infrequently, and the considerable travel expenses and inconvenience often resulted in relatively low attendance at meetings. As Henry noted about the members of the Academy, "from their widely separated residences and their generally limited means of support, it is impossible that frequent meetings of the Academy can be held." Even with restricting meetings to one or two a year, only about half the membership attended.[39]

But despite this limitation, by the end of the century the United States had a multifaceted infrastructure for direct communication among scientists. Local and state learned societies, as well as informal groups, provided frequent, albeit sometimes intellectually limited, opportunities for conversation. National organizations provided the occasion for enriched communication at less frequent intervals. All of these groups were generating publications, reports, and correspondence to distribute scientific information around the nation.

Through diverse forms of communication, science evolved upward in the United States and throughout the world in the nineteenth, and indeed, in all the centuries since the Age of Wonder. The Dibner Library ensures that the fruits of that communication will be available to scholars in the twenty-first and ensuing centuries.

Notes

1. Communication was, for example, a major element in the Scientific Revolution. See Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1998), 106–109.
2. For Oldenburg and the rise of the Royal Society, see Marie Boas Hall, *Henry Oldenburg: Shaping the Royal Society* (Oxford: Oxford University Press, 2002); I. Avramov, "An Apprenticeship in Scientific Communication: The Early Correspondence of Henry Oldenburg," in *Notes and Records of the Royal Society of London,* 53 (1999), 187–201; and Michael C. W. Hunter, *Establishing the New Science: The Experience of the Early Royal Society* (Woodbridge, UK: Boydell Press, 1989).
3. J. Kirkpatrick Flack, *Desideratum in Washington: The Intellectual Community in the Capital City, 1870–1900* (Cambridge, MA: Schenkman Publishing Company, 1975).
4. The classic study of scientific societies in the United States is Ralph S. Bates, *Scientific Societies in the United States.* 3rd ed. (Cambridge, MA: MIT Press, 1965); essential for the antebellum period is Alexandra Oleson and Sanborn C. Brown, eds., *The Pursuit of Knowledge in the Early American Republic: American Scientific and Learned Societies from Colonial Times to the Civil War* (Baltimore: Johns Hopkins University Press, 1976); valuable both for its analysis of local societies and for moving the reader beyond a possible coastal bias is Daniel Goldstein, "Outposts of Science: The Knowledge Trade and the Expansion of the Scientific Community in Post-Civil War America," *Isis* 99 (2008), 519–546.
5. For Henry, see Albert E. Moyer, *Joseph Henry: The Rise of an American Scientist* (Washington, DC: Smithsonian Institution Press, 1997); Thomas Coulson, *Joseph Henry: His Life and Work* (Princeton, NJ: Princeton University Press, 1950); Nathan Reingold, "Henry, Joseph," *Dictionary of Scientific Biography*, ed. Charles C. Gillispie (New York: Scribners, 1972), 6:277–281.

6. Arthur P. Molella et al., eds., *A Scientist in American Life: Essays and Lectures of Joseph Henry* (Washington, DC: Smithsonian Institution Press, 1980), 38–39.
7. Joseph Henry, "The Organization of a Scientific Society," S*cientific Writings of Joseph Henry* (Washington, DC: Smithsonian Institution, 1886), 2 vols., 2:469.
8. Henry, "The Methods of Scientific Investigation and Its Application to Some Abnormal Phenomena of Sound," *Scientific Writings,* 2:514.
9. Henry, "Organization of a Scientific Society," *Scientific Writings*, 2:471.
10. Henry, "Organization of a Scientific Society," 472.
11. Edward C. Carter II, *'One Grand Pursuit': A Brief History of the American Philosophical Society's First 250 Years, 1743–1993* (Philadelphia: American Philosophical Society, 1993); Whitfield J. Bell Jr. "The American Philosophical Society as a National Academy of Sciences, 1780–1846." *Proceedings of the Tenth International Congress of the History of Science* (Paris: Hermann, 1964), 1:165–177; Walter E. Gross, "The American Philosophical Society and the Growth of Science in the United States, 1835–1850." Ph.D. diss., University of Pennsylvania, 1970.
12. Compared to the American Philosophical Society, the literature on the American Academy is very thin. For a quick overview of its early history, see Brooke Hindle, *The Pursuit of Science in Revolutionary America, 1735–1789* (repr., New York: W. W. Norton, 1974), 263–268.
13. For generalizations about local societies, I have depended upon the work of Goldstein. In addition to the article cited above, see his essay, "Societies and Associations," *The History of Science in the United States,* ed. Marc Rothenberg (New York: Garland Publishing, 2001), 526.
14. Henry, "Methods of Scientific Investigation," *Scientific Writings,* 2:515.
15. Based on the study by James M. Hobbins, "Shaping a Provincial Learned Society: The Early History of the Albany Institute." In Oleson and Brown, 117–150.
16. My analysis of the membership.
17. Henry to John Maclean, 28 June 1832, in Nathan Reingold et al., eds., *The Papers of Joseph Henry,* vol. 1 (Washington, DC: Smithsonian Institution Press, 1972), 435.
18. Henry to Alexander Dallas Bache, 16 April 1844, in Marc Rothenberg et al., eds., *The Papers of Joseph Henry,* vol. 6 (Washington, DC: Smithsonian Institution Press, 1992), 76.
19. It is an issue of continuing importance in science. For a brief exchange on the importance of informal clubs for the advancement of physics, see the "Letters" section in *Physics Today* 63, no. 5 (May 2010), 59–60.
20. Henry to John Torrey, 20 December 1834, in Nathan Reingold et al., eds., *The Papers of Joseph Henry,* vol. 2 (Washington, DC: Smithsonian Institution Press, 1975), 305.
21. For more on this group, see Reingold, *Papers of Joseph Henry,* 2:290n–291n, 348.
22. A sampling: Mark Beach, "Was There a Lazzaroni?" In George H. Daniels, ed., *Nineteenth-Century American Science: A Reappraisal* (Evanston, IL: Northwestern University Press, 1972), 115–132; Robert V. Bruce, *The Launching of Modern American Science, 1846–1876* (New York: Knopf, 1987); Lillian Miller et al., *The Lazzaroni: Science and Scientists in Mid-nineteenth Century America* (Washington, DC: Smithsonian Institution Press, 1972); Hugh R. Slotten, *Patronage, Practice, and the Culture of American Science: Alexander Dallas Bache and the U.S. Coast Survey* (New York: Cambridge University Press, 1994).

23. Mary Ann James, *Elites in Conflict: The Antebellum Clash over the Dudley Observatory* (New Brunswick, NJ: Rutgers University Press, 1987).

24. The clash over Baird is discussed in Marc Rothenberg et al., eds., *The Papers of Joseph Henry,* vol. 10 (Sagamore Beach, MA: Science History Publications, 2004), 392–400.

25. Henry Locked Book entry, 23 December 1854, in Marc Rothenberg et al., eds., *The Papers of Joseph Henry,* vol. 9 (Canton, MA: Science History Publications, 2002), 170.

26. Henry Locked Book entry, 18 December 1864, in Rothenberg, *Papers of Joseph Henry,* 10:451.

27. Henry Locked Book entry, 8 March 1862, in Rothenberg, *Papers of Joseph Henry,* 10:237.

28. Henry Locked Book entry, 8 March 1862, 237–239.

29. An example of a study of state academies is Alan E. Leviton and Michele L. Aldrich, eds., *Theodore Henry Hittell's "The California Academy of Sciences. A Narrative History: 1853–1906." Memoirs of the California Academy of Sciences*, 22 (1997). Another, which focuses primarily on the twentieth century, is Nancy Smith Midgette, *To Foster the Spirit of Professionalism: Southern Scientists and State Academies of Science* (Tuscaloosa: University of Alabama Press, 1991).

30. Lynde Phelps Wheeler, *Josiah Willard Gibbs: The History of a Great Mind* (New Haven, CT: Yale University Press, 1952).

31. Sally Gregory Kohlstedt, "A Step Towards Scientific Self-Identity in the United States: The Failure of the National Institute, 1844," *Isis* 62 (1971), 339–362. The charter of the National Institute expired in 1862.

32. Rothenberg, *Papers of Joseph Henry,* 9:305–307.

33. For the history of this society, see Sally Gregory Kohlstedt, Michael M. Sokal, and Bruce V. Lewenstein, *The Establishment of Science in America: 150 Years of the American Association for the Advancement of Science* (New Brunswick, NJ: Rutgers University Press, 1999). The section dealing with the period we are concerned with is Kohlstedt, "Creating a Forum for Science: AAAS in the Nineteenth Century," 7–49.

34. Henry to Chester Dewey, 7 November 1859, in Rothenberg, *Papers of Joseph Henry,* 10:122.

35. Kohlstedt, "Creating a Forum," 17.

36. See A. Hunter Dupree, "The National Academy of Sciences and the American Definition of Science." In Alexandra Oleson and John Voss, eds., *The Organization of Science in Modern America, 1860–1920* (Baltimore: Johns Hopkins University Press, 1979), 342–363; Rexmond Canning Cochrane, *The National Academy of Sciences: The First Hundred Years, 1863–1963.* (Washington, DC: National Academy of Sciences, 1978).

37. *Bulletin of the Geological Society of America* 1 (1890), 571.

38. Marc Rothenberg and Thomas R. Williams, "Amateurs and the Society during the Formative Years." In David H. DeVorkin, ed., *The American Astronomical Society's First Century* (Washington, DC: American Astronomical Society, 1999), 40–57.

39. Henry to James Hadley, 7 May 1869, in Rothenberg, *Papers of Joseph Henry,* 11:244.

Agents of Exchange: Origins of Scholarly Communication in Nineteenth-Century America

Nancy E. Gwinn

Understanding the fundamental nature of ourselves and the world that surrounds us has driven scientific inquiry for centuries. While examples of the lone scientist in the laboratory abound, the conduct of science has largely become a group enterprise, incrementally constructed on work that has gone before. Scientific experiments must be replicated if the results are to be accepted. Communication among scholars is vital to the process, and in the Internet age it is practically instantaneous. The leading challenge today may be how to manage the immensity of available information rather than obtaining it in the first place. In nineteenth-century America it was not so easy, yet Americans knew how important it was to establish communication among scholars in order for the new nation to take its place among European nations respected for their intellectual achievements.

In the late eighteenth and early nineteenth centuries, Americans borrowed the European structure of the learned society to organize their intellectual pursuits about the same time as they created their new nation. Members of the nascent learned and scientific societies desired to engage, share, compete, and collaborate in the pursuit of knowledge; they sought to feed their own curiosity but also to fuel American scientific progress. The societies promoted and fed the networks of scholarly communication, creating the publications, transactions, and proceedings that documented the results of their scholarly activities. These products became the means to barter for publications produced by like-minded groups in other lands. The network was physical, not virtual; there were many obstacles in the transport of physical items to be overcome.

International publication exchange programs in America began in 1771 with the publication and distribution of the first volume of the *Transactions* of the American Philosophical Society. More than a century later, in 1886, the first international convention governing exchange of official documents was signed in Brussels. Support for international publication exchange came from those who needed the information published by learned societies and academies and their members abroad, but the programs also reflected the growth of American cultural and scientific nationalism during the nineteenth century. International publication exchange programs provided a mechanism that helped give America a visible identity within the worldwide scientific community.

Americans had practiced science from colonial times, although not in great numbers and with few achievements comparable to those of European scientists, other than perhaps those of Benjamin Franklin. Science is not easy to practice in isolation; it requires organization and resources. Books were scarce in the new nation. Until 1830, only one of three books sold in the United States was actually produced there.[1] Costs were high for the individual pocketbook, especially for imported books. Not until 1816 did a change in the tariff law allow books destined for the use of philosophical societies to enter the country duty-free.[2] American naturalists like Thomas Say keenly felt the lack of European works describing American species.[3] The field of systematics required its practitioners to observe the rules of precedence for naming species. Say begged his friend, the Rev. John Melsheimer in England, to tell him what books he should order:

> [I]t is certainly of the first importance to a naturalist to know what has been done by others in his particular science in order that his researches may be directed to proper objects & that he may not do over again what has been better done by his predicessors [*sic*]—I am determined to be as cautious as possible in this respect.[4]

Say had to know about previous descriptions of species so he could give credit and avoid the embarrassment of describing, as though they were new, insects already well known in Europe.

Compared with European institutions, American library resources were meager, especially in the sciences. By 1792 the Library Company of Philadelphia had absorbed several smaller subscription libraries and grown to approximately 12,000 volumes, about the same size as Harvard. William and Mary, second in size to Harvard, had only one-fourth this amount. In 1800 no college library had more than 13,000 volumes. Yale's library contained only 5,000 volumes by 1808. In 1800 an English visitor to Princeton described the library as "most wretched, consisting for the most part of old theological books, not even arranged with any regularity." Whereas by 1816 Harvard's holdings had swelled to 20,000, making it the largest in America, it could not compare with the University of Göttingen's 200,000 volumes.[5]

Some of the wealthier and better connected Americans had established large personal libraries. Benjamin Vaughan's was "said to have been the largest in New England with the exception of Harvard's."[6] Author and educator George Ticknor's library eventually grew to 13,000 volumes.[7] A library was one of the expected accoutrements of a gentleman, but this did not guarantee that books would be available to budding young scientists. In 1792, when the Library Company of Philadelphia acquired the Logonian Library, "the Library Company became the largest medical library in the colonies." The 4,000-volume Logonian Library was the private library of James Logan, William Penn's secretary and noted book collector, and included the 1,400 medical books belonging to James' brother, British physician William Logan. [8] But one had to be a paid subscriber to borrow books from it. College library rules severely restricted use of the books, and in any case their collections were not strong in science.[9] In the 1790s, only 8 to 12 percent of college library collections were devoted to scientific subjects. As Brooke Hindle points out, "it was upon the academy or learned society that those who sought to advance science in the United States placed their major hopes," just as they had earlier in Europe.[10] By the time American scientific and learned societies began to proliferate in the early nineteenth century, their officers knew that if they distributed a publication to another society that also produced a publication, they would likely receive a return donation.

By 1803 the American Philosophical Society was considered one of the best scientific libraries in the United States, but it had only about 1,000 items. By 1858, it was still one of the largest with 20,000 volumes, and the Academy of Natural Sciences, also in Philadelphia, had 25,000, both largely built on active publication exchange programs. But these were still modest compared with European societies.[11]

The new Smithsonian Institution, founded in 1846, felt the lack of library resources just as keenly, especially for science. Charles Coffin Jewett, the Smithsonian Institution's first librarian and a promoter of the Smithsonian as the national library, felt the disparity in relation to Europe, comparing "the use of books by scholars . . . to the use of a dictionary by any intelligent man." In an early form of citation analysis in 1848, Jewett reviewed the sources used by several scholars in their works. In one, a history of chemistry, he counted 251 cited works, of which about 50 were common works found in any library of at least 5,000 volumes; of the remaining 191, he could find only 75 "in all our public libraries."[12]

Small wonder, then, that one of the earliest acts of Joseph Henry, the Smithsonian's first secretary, was to establish in 1848 an official publication series, the *Smithsonian Contributions to Knowledge,* and to identify all of the learned and scientific societies in the United States and around the world that might be interested in it, so as to begin a publication exchange program.[13] He knew this was the fastest and least expensive way to begin to build a scientific library; in fact many publications would not be available unless they were received through an exchange program. Within two years of beginning the program, the institution had arranged for free shipping of exchange publications and employed exchange agents in Europe and elsewhere. With a shipment capacity for transmission much larger than that required by the Smithsonian, Henry and his loyal assistant, Spencer Fullerton Baird, offered to facilitate exchanges on behalf of individual scientists and any other learned society or educational institution in the United States. By the 1860s, the Smithsonian Library had grown to about 40,000 volumes, in part because of the exchange program, but also with the help of copyright deposits, since Congress had conferred that status on the institution at its founding. By the 1880s, the Smithsonian had also become the official conduit for exchanges of U.S. federal documents with those of foreign governments.

While international publication exchange programs are part of institutional histories, they also embody the achievement of many remarkable individuals, here called "exchange agents," persons whose extraordinary personal efforts, credibility, and dedication made the programs work. Exchange agents were crucial to the nurturing of correspondence networks from the earliest establishment of learned societies in the eighteenth century. These individuals became part of the exchange networks that facilitated the process and helped overcome obstacles posed by poor transportation, customs house regulations, high shipping costs, and the burdens of recordkeeping. Networks set up for publication exchanges were also used in this period for other purposes such as exchange of natural history specimens, and exchange agents provided a variety of other services to societies and their members. Behind the most successful society exchange programs one usually finds a person who stayed with the task for many years to provide continuity and stability, and who was blessed with a long memory. American patriarch Benjamin Franklin and Irish-American immigrant David Bailie Warden in England and vice consuls John and Felix Flügel in Leipzig (to cover Europe) stand as exemplars of those without whom scholarly communication in earlier eras would have been far more difficult.

Benjamin Franklin

Benjamin Franklin's role as the first American exchange agent is one of his important, if lesser known, accomplishments. When he founded the American Philosophical Society, he used the Royal Society of London as a model and intended for his new society to keep up a correspondence with it and other societies.[14] Franklin was well aware of the need to publish and disseminate publications of American scientific information abroad. His travels to Europe and his scientific reputation, which stimulated members of the Royal Society of London not only to embrace him but also to elect him to four terms on its council, gave him the perfect opportunity to do just that. Franklin used his entrée into the Royal Society to full advantage to promote the cause of American science and to bring together scholars from both sides of the Atlantic. Tours of France, Scotland, Ireland, and parts of what is now Germany introduced him to an even wider circle of savants, who warmed to his wisdom and wit. He transmitted scientific papers and recommended French, English, and American friends for society memberships in England and Philadelphia.[15] His friend John Adams acknowledged that Franklin's "reputation was more universal than that of Leibnitz or Newton, Frederick or Voltaire; and his character more beloved and esteemed than any or all of them."[16]

It is not surprising that in 1771, when the American Philosophical Society published the first volume of its *Transactions*, the society turned to its founder as a primary, though not the only, medium of distribution to foreign societies and scientists.[17] The first shipment to Franklin, who was in England, contained eleven copies to be forwarded to the Royal Society, the Royal College of Physicians, the Society of Arts, and the British Museum, as well as to several individuals who had been elected to membership in the American Philosophical Society. A second shipment to Franklin included eighteen copies for foreign universities and academies and nine for Franklin himself to distribute.[18]

Franklin waited to promote the affairs of "his" society, as it was known to his European colleagues, until he was certain the reception of the first volume of *Transactions* would be favorable.[19] Fortunately, the volume contained the results of the society's first cooperative scientific endeavor: observations of the transit of Venus across the sun's face, which astronomers hoped would provide more accurate data for estimating the distance between the earth and the sun. To Franklin's satisfaction, the volume provoked a uniform, even at times eulogistic, chorus of praise, which conferred on his society an international reputation beyond the reality of its provincial character. This was fortunate, for with the hard times of the Revolution ahead, it would be fifteen years before the second volume appeared to a more critical audience.[20]

After Franklin died in 1790, the society was blessed with the arrival of John Vaughan, who served as member, secretary, treasurer, and librarian for fifty-seven years. Through personal donations and purchases, Vaughan took on building the society's library as a mission and vigorously superintended the procurement of books and manuscripts through exchange, donation, and, when all else failed, raising funds for purchase. But the heart of the library was the transactions and proceedings of the learned societies of the world, received through an exchange process that Vaughan carefully nurtured. To keep exchanges flowing required careful monitoring and elaborate correspondence. Vaughan skillfully employed a cadre of unofficial and official exchange agents. But none of Vaughan's agents was more assiduous in the task than David Bailie Warden.

David Bailie Warden

Vaughan and Warden were similar in many ways; however, Vaughan was a better businessman and Warden a better writer.[21] They were fairly close contemporaries. Vaughan was sixteen when Warden was born in County Down, Ireland, in 1772. Well educated with a master-of-arts degree from the University of Glasgow, Warden was captured and imprisoned by the English for his political associations. When, in 1798, he was banished from British territory, he immigrated to the United States. Of British birth but living in France, Vaughan had immigrated to the United States in 1782, sixteen years earlier. Both men became passionate Americans, both were fluent in French, and both remained bachelors and poured their intellectual and emotional energies into the new nation's cultural service. Though both were long lived for the time, one thing they did not share was vigorous health. Warden was plagued all his life with ill health; he suffered greatly in his last years and died in 1845, aged seventy-two. Vaughan died in 1841 at the age of eighty-five.

Upon reaching America, Warden took a position as principal tutor at Kinderhook Academy in New York State and continued to pursue scientific studies and medicine. His fortunes improved when General John Armstrong engaged him as private tutor to his children. When Armstrong was appointed U.S. minister to France in 1804, he took with him the engaging, energetic young man, now an American citizen, to be secretary of the Paris legation. Warden plunged into even more strenuous medical and scientific studies under the tutelage of such renowned French savants as naturalist George Cuvier, zoologist Etienne Geoffrey Sainte-Hilaire, and chemist Joseph Louis Gay-Lussac. In 1808, Armstrong appointed Warden consul and agent for prize cases (legal cases involving the seizure of ships during wartime that were considered "prizes" by the country doing the seizure), but both political problems and a serious personal conflict with his former mentor resulted in Warden's dismissal in 1810.[22] Although reappointed for a term, he was removed again in 1813. Thereafter, he supported himself mainly from his writings. His taste of consular service, however, gave him a passion for serving American interests and especially the cause of science.

Warden was already well connected with the French scientific community, and his positions as legation secretary and consul had placed him well to serve as a facilitator for scientific news, letters, and packages for American scientists. One of those was Samuel L. Mitchill, founder of the Society for the Promotion of Agriculture, Manufactures, and the Useful Arts in New York and, in 1797, one of the cofounders of the first American medical quarterly, the *Medical Repository*. Described as "Mitchill's eyes and ears in Paris," Warden performed a variety of services that included sending him French medical journals and distributing Mitchill's *Repository* in France.[23] Thomas Jefferson met Warden in 1809 and appreciated his assistance with gathering books and sending them safely to the United States through diplomatic channels to avoid the hazards caused by the Napoleonic wars. As Francis Haber described the connection:

> In the secretary of the American legation Jefferson found not only a willing servant for transmitting mail and books, but also an intelligent and discriminating man of learning who was in daily converse with his friends Lafayette, Baron von Humboldt,

> Kosciusko, and Destutt de Tracy; who knew how to deal with booksellers; who was informed in the latest developments of French science; and who could report on political events more openly and freely than a minister or ambassador.[24]

In 1809 Warden was elected to the American Philosophical Society and, in 1840, to his last society, the National Institute for the Promotion of Science; in between he was honored with election to sixteen others, including the Royal Academy of Sciences of the Institut de France. He moved easily among them and used his influence to promote American nominees. He was always willing to take guests to meetings.

After his election to the American Philosophical Society, Warden began a correspondence with Vaughan and started to provide many services to the society and other societies and individuals. He distributed the society's *Transactions*, sent acknowledgement letters to French societies on the American society's behalf for receipt of their proceedings, requested missing issues, and placed orders for subscriptions and books with booksellers. He read letters and manuscripts of society members before the scientific societies in Paris.[25] Through Vaughan and Warden, Joseph Henry received copies of the French National Institute's transactions *Compte Rendu* and other works for the Smithsonian. Warden was generous, perhaps to a fault: he donated his own works to the society, often along with others that were given to him. The extraordinary longevity and stability of the Vaughan–Warden interaction go far to explain the success of the American Philosophical Society's international publication exchange program.

Early exchange agents took personal interest in the books and journals transmitted, often taking the initiative to gather items of interest and donate them to appropriate repositories. They looked out for the safe transmission of packages, which was not an easy matter before advances in technology resulted in improvements in transportation. Wars and political disputes often invaded the intellectual world of the Republic of Letters, interrupting or destroying established transportation routes and raising costs of shipping. Exchange agents not infrequently waited for travelers headed in the appropriate direction to serve as personal couriers for letters and parcels, and often sent duplicates by different routes to improve the chances of final delivery.

None of the avenues for communication have closed—they have merely changed with technological advances. One of the most attractive features of the Smithsonian's international exchange system was the network of foreign agents established by Joseph Henry and his assistant secretary, Spencer Fullerton Baird, to receive and forward publications and, ultimately, to provide other services. Their ambition to integrate American science into the worldwide scientific communication system brought into service a variety of individuals and organizations to facilitate the distribution and gathering process. By this time, the Smithsonian was serving as the intermediary between American educational institutions and societies and their exchange partners abroad. Senders prewrapped and preaddressed their packages before they entered the system, so agents might not know the exact contents. But they knew the organizations and, more important, they knew they were operating under the Smithsonian banner, which placed a valuable imprimatur on all who were on the Smithsonian's list.

The Smithsonian's initial principal agents were well-placed individuals in Europe, but they differed from the volunteers of the past. Equally dedicated, they were nevertheless paid for the job, either by salary or on commission. Society membership was nice, but not necessary, if the person had an understanding of shipping firms, customhouse regulations, and forwarding processes. One of the most stable and productive relationships was with the Flügels, John the father and Felix the son, who served successively as American vice-consuls in Leipzig, Germany, and were Smithsonian exchange representatives starting in 1849 for fifty-six years.[26]

John and Felix Flügel

Perhaps it was obvious for Joseph Henry to think of using the services of American consuls to facilitate exchanges. Employed in foreign legations by the Department of State, they were responsible for representing American commercial interests abroad and helping to pave the way for American businessmen. It was important to find a reliable agent for the European continent, where most of the scientific societies were located, and especially in Germany, which at the time included Austria-Hungary, Bavaria, Prussia, Saxony, and Würtemberg. Henry found a likely candidate in John Flügel, vice-consul with the American legation in Leipzig, whose scholarly interests made him sympathetic with the ambition of the Smithsonian. Unfortunately, John Flügel died in 1855, but Felix succeeded him in the position of vice-consul and also in the role of Smithsonian agent.

Father and son shared similar scholarly interests and were active supporters of the exchange system, recognizing the value to be gained by individuals and organizations on both sides of the Atlantic. Both men were fluent in English and fascinated with linguistics as a field of study. John Flügel was the first lecturer in English at the University of Leipzig, receiving his doctor's degree in 1824. In the same year he published a grammar of the English language. Felix Flügel authored an English and German dictionary, first published in 1861 and which went through fifteen editions during the next thirty years.[27]

The duties of the Leipzig agent were fairly routine. Secretary Henry would alert him when the Institution had made its annual or, later, semiannual shipments and would send him packing slips directed to each recipient to accompany the packages to their final destinations. Flügel would alert the custom authorities in the port at Bremen and answer any questions about the contents of the packages. The shipments would then travel by rail to Leipzig, where they would be unpacked and repacked for their final destinations. Likewise, societies and individuals abroad would send their unsealed, preaddressed packages to Flügel, who would place them in large cases addressed to the Smithsonian Institution. The cases would then be carefully marked with the Smithsonian stamp and follow the path in reverse, entering the United States through the Port of New York. For this, the Smithsonian paid Flügel in 1860 an annual salary of $400.[28] Eventually Secretary Henry also gave Flügel an expense account to cover occasional small delivery charges or other unexpected expenses, so that, as far as possible, packages would arrive free of all expense to the recipients.[29] Because of the large quantity of publications sent, the U.S. Patent Office also paid Flügel a stipend, which he successfully requested to have increased in 1863 by a sum equivalent to $100 in gold so that he would not suffer from an unfavorable exchange rate.[30] Flügel employed both a clerk, who worked five hours a day on Smithsonian business, and an errand boy.

Flügel had occasional misunderstandings with the fiscally conservative Smithsonian secretary. Although he carefully followed Henry's rule about channeling correspondence through him, Flügel did not hesitate to write privately to Assistant Secretary Baird when he needed clarification. Flügel took too personally, for example, Henry's letter written at the outset of the Civil War, in which he urged Flügel to be as economical as possible and told him of the uncertainty he felt about the Smithsonian's future. Flügel wrote for advice from Baird, worrying that he had not gained Henry's confidence and reassuring Baird that he had always saved money whenever he could, even to the extent of reducing the amount of tips that his father used to give to porters and others. His father, Felix noted, "would not infrequently call my proceedings stingy & illiberal if he still lived."[31] Baird assured Flügel that he had nothing to worry about, being "very certain that in a crippled condition of the Smithsonian resources, the foreign exchanges will be the last to suspend operations. I am very sure that Prof. Henry is perfectly satisfied with your mode of doing business," he soothed, "and had no idea as long as it can be avoided of relieving you from it."[32]

While the Smithsonian shipments consisted primarily of publications, Flügel also handled shipments of specimens. These occasionally required more attention to ensure their safe handling, especially by customs employees. In 1864, he wrote that "one of the antlers of the reindeer was unfortunately broken at the Customhouse here when taken out by the officers who are not renowned for delicacy of touch; . . ."[33] Occasionally other measures were necessary. When the natural history society in the Bavarian town of Passau attempted to ship some beetles to the Smithsonian, Flügel found it necessary to open the case, which was too large and flimsy to be forwarded. "It was fortunate I did so," he wrote, "because we found that in one of the boxes more than a dozen or twenty of the coleoptera had got loose & would have caused great injury, if not fixed anew."[34]

The superintendence of shipments was not the only service Flügel supplied. He placed orders for journal subscriptions and occasionally purchased items on behalf of the Smithsonian or other government agencies.[35] When Baird needed woodcuts for a publication, Flügel found a willing artist in Leipzig.[36] He was eager to assist fledgling European societies by getting them on the Smithsonian's mailing list. In certain cases, he felt historical societies deserved something more than the Smithsonian's annual report, and he pushed Baird to arrange for U.S. Department of Agriculture publications to be sent to numerous European agriculture societies, which, he avowed, had been conscientiously forwarding their publications to the United States for years.[37] As Flügel's relationship with Baird evolved they exchanged postage stamps (Flugel's son collected them), and Flügel asked Baird to supply missing scientific terms for his dictionary. The aging Joseph Henry approved of a pair of spectacles, "much admired for the beauty of the frames and the perfections of the glasses," which Flügel supplied in 1871.[38] Flügel was the source of much news concerning political events in Germany and on the continent, especially if they affected exchange operations.

As much as Flügel served the Smithsonian, he also benefitted himself from his association with the institution. Being the Smithsonian's agent conferred significant status on foreign agents, who became known for their ability to ensure that packages reached their destinations, but who also were expected to channel other information to and from the institution. Furthermore, being the Smithsonian's agent could bring the incumbent work from other institutions, which might have a potential payoff in either cash or prestige. Flügel was willing to distribute publications for any society, receiving from one the encomium of "the Grand distributor at Leipzig."[39]

In conclusion, scholarly communication in the sciences is no less important today than it was in the nineteenth century. Publication of scientific results is crucial, even if publication means preprints in a database, electronic publishing, or digitizing a hard copy document. As colleges and universities were formed and expanded, their libraries established various gathering programs, and subscription-based scientific journals assumed much of the publishing role. Interlibrary loan and other borrowing agreements allow libraries to share books and journals. Information now whizzes around the globe at the speed of fiber optics and satellites. Printed publications are still valued by many individuals and especially in parts of the world that still have less access to the Internet or less bandwidth to receive large files. These early exchange agents relied largely on personal contacts and society memberships to carry out their functions, rather than organizational contacts. If publication exchange programs still exist at all, exchange agents are likely now to be found on the library staff, still as dedicated and persevering as ever, and still developing friendly relationships with their exchange partners. Economics threatens the continuance of scholarly journals, and their owners increasingly charge for subscriptions in place of exchange. We are in the midst of another great transformation, and a view of history helps us appreciate just how far we have come.

Notes

1. Russel Blaine Nye, *The Cultural Life of the New Nation, 1776–1830* (New York: Harper & Row, Harper Torchbooks, 1960), 249.
2. *The New American State Papers, Public Finance*, vol. 31. *Public Finance: Revenue* (Wilmington, Del.: Scholarly Resources, Inc., 1973), 142; James Gilreath, "American Book Distribution," *Proceedings of the American Antiquarian Society* 95 (1985):533.
3. Thomas Say (1787–1834) was a naturalist, interested in insects, mollusks, and crustaceans. He is often considered to be the father of descriptive entomology.
4. Say to Rev. John Melsheimer, 24 May 1816, Academy of Natural Sciences of Philadelphia (ANSP) Letters 1813–1825, Coll. 13, ANSP Library.
5. Whitfield Bell Jr., "Science and Humanity in Philadelphia, 1775–1790." (Ph.D. diss., University of Pennsylvania, 1947), 126; Lawrence A. Cremin, *American Education, the National Experience, 1783–1876* (New York: Harper, 1980), 305; Kenneth Brough, *The Scholar's Workshop: Evolving Conceptions of Library Service* (Urbana: University of Illinois Press, 1953; repr., Boston: Gregg Press, 1972), 3; Howard Clayton, "The American College Library, 1800–1860," in *Reader in American Library History*, ed. Michael H. Harris (Washington, D.C.: NCR Microcard Editions, 1971), 89; Nye, 184.
6. "Benjamin Vaughan," *Dictionary of American Biography*, XIX:234.
7. Nye, *Cultural Life*, 183.
8. James N. Green, "Library Company of Philadelphia," *International Dictionary of Library Histories*, ed. David H. Stam, I:405.
9. Joe W. Kraus, "The Book Collections of Early American College Libraries," *Library Quarterly* 93 (April 1973):157.
10. Brooke Hindle, *The Pursuit of Science in Revolutionary America, 1735–1789* (Chapel Hill: University of North Carolina Press, 1956), 262; Edwin Wolf 2nd and Marie Elena Korey, eds., *Quarter of a Millennium: The Library Company of Philadelphia, 1731–1981* (Philadelphia: Library Company of Philadelphia, 1981), v; Brough, 2–5.
11. William J. Rhees, *Manual of Public Libraries, Institutions, and Societies in the United States and British Provinces of North America* (Philadelphia: J. P. Lippincott & Co., 1859; repr. Urbana: University of Illinois, Graduate School of Library Science, 1967), 603–604.

12. Smithsonian Institution, *Third Annual Report of the Board of Regents of the Smithsonian Institution . . . During the Year 1848,* 30th Cong., 2nd sess., H. misc. Doc. 48, 41.

13. Parenthetically, although the Smithsonian ceased to offer this service to other organizations some years ago, the institution continues to publish the Contributions to Knowledge, now divided into twelve series on separate topics, and the Smithsonian Libraries continues to use these volumes as the means of exchange with over 3,700 partners worldwide. In keeping with the current transitional era, the volumes are published in both hard copy and electronic format.

14. The establishment of the American Philosophical Society and Benjamin Franklin's role in it is well covered in Hindle, *Pursuit of Science,* 67–78, 127–138.

15. Carl Van Doren, *Benjamin Franklin* (New York: Viking Press, 1938; repr. New York: Book of the Month Club, 1980), 422.

16. Charles F. Adams, ed. *Works of John Adams* (Boston, 1850–1856), I:660, quoted in Hindle, *Pursuit of Science,* 223.

17. On 22 February 1771, the APS enumerated the "most considerable Philosophical Societies . . . to which copies of the Transactions are to be presented," augmenting an earlier list of domestic recipients. The list included "the Royal Societies at Stockholm, Upsal, Berlin & Göttingen; Imperial Society of Petersburg; R. College of Physicians in London; Society for Promoting Arts & Manufactures, London; Philos. Society, Edinburgh; Dublin Society; Acad. Nat. Curiosorum; Society of Berne; R. Acad. Sc. Paris; Acad. of Bononia; Acad. Sc. at Turin; Acad. at Florence; British Museum; Universitys [*sic*] of Oxford, Cambridge, Dublin, Edinburg, Glasgow, St. Andrews and Aberdeen," which itself shows the burgeoning of learned societies and organizations in the last half of the eighteenth century. "Early Proceedings of the American Philosophical Society . . . compiled . . . from the Manuscript Minutes of Its Meetings from 1744 to 1838," *Proceedings of the American Philosophical Society* 22, part 3 (1884), 63.

18. "Early Proceedings," 75, 86.

19. Franklin to Jean-Baptiste LeRoy, 30 March 1773, *The Papers of Benjamin Franklin*, ed. William B. Willcox (New Haven, Conn.: Yale University Press, 1974), 20:130.

20. Hindle, *Pursuit of Science,* 143–145, 267–270.

21. Biographical details of David Bailie Warden are taken from Francis C. Haber, *David Bailie Warden: A Bibliographical Sketch of America's Cultural Ambassador in France, 1804–1845* (Washington, D.C.: Institut Français de Washington, 1954); William D. Hoyt, Jr., "The Warden Papers," *The Maryland Historical Magazine*, 36 (1941):306–314; 38 (1943):69–85; and Ellen Marks Bayly, *Guide to the Microfilm Edition of the David Bailie Warden Papers* (Baltimore: Maryland Historical Society, n.d.).

22. Prize cases were those prosecuted by Americans whose property had been seized when British and other vessels were captured by the French or countries controlled at different times by France, during the Napoleonic wars.

23. David Bailie Warden, *On the Origin, Nature, Progress and Influence of Consular Establishments* (Paris: Printed and sold by Smith, 1813), 26–27, 29; quoted in Haber, *David Bailie Warden.*

24. Haber, 8. Alexander Humboldt, German naturalist and explorer, had settled in Paris to write his account of his famous voyage to Central and South America. Polish general Thaddeus Kosciusko fought for the American colonists during the American Revolution. Comte Destutt de Tracy was a French philosopher and psychologist.

25. See, for example, Warden to Peter Du Ponceau, 1 June 1834, APS Archives, where he asks for "any new important facts concerning the ancient populations of the valley of the Ohio. In the course of last year, I read before the Roy. Antiquarian Society an analysis of Mr. Hodgson's dissertation on the Berber language which was well received, and lately a second reading was made—I lately communicated to the Royal Agricultural Society the second of Mr. Bulls' experiments concerning the combustion of wood etc."

26. A necrology of the Flügels states that Henry employed Dr. John G. Flügel in 1847. (Smithsonian Institution Annual Report 1904, 35.) However, the first mention uncovered in Smithsonian documents is a letter dated 1849. The first mention of Flügel in the Smithsonian annual reports is 1851. It is possible that earlier correspondence was destroyed in a fire in 1865 in the Smithsonian building.

27. Smithsonian Institution Annual Report 1904, 35.

28. Flügel to Baird, 14 February 1861, Spencer Fullerton Baird Papers, Record Unit (RU) 7002, Box 20, SIA.

29. Henry to Essex Institute, 30 March 1861, Letters Received, May 1860–May 1861, Essex Institute Archives, Peabody Essex Museum; Henry to William Dwight Whitney, 16 December 1862, W. D. Whitney Collection, Manuscripts and Archives, Yale University Library, New Haven, CT.

30. Flügel to Baird, 7 May 1863, Baird Papers, RU 7002, Box 20, SIA. This kind of currency fluctuation was a constant problem. The Smithsonian and other agencies began in 1862 to adjust Flügel's salary annually to account for currency fluctuations. For more negotiation on this point, see also Flügel to Henry, 4 December 1866; 19 January 1867, Incoming Correspondence, Office of the Secretary 1863–1879, RU 26, Box 5, SIA.

31. Flügel to Baird, 14 February 1861, Baird Papers, RU 7002, Box 20, SIA.

32. Baird to Flügel, 9 March 1861, Baird Papers, RU 7002, Box 3, SIA. When Henry later issued a round of warnings to all foreign agents concerning the enclosure of dutiable items in exchange parcels, Flügel responded sharply that nothing like "fraud upon the revenue" had ever been attempted. Flügel to Henry, 19 March 1866, RU 26, Box 5, SIA.

33. Flügel to Baird, handwritten note at end of invoice relating to an ethnographical collection from Lapland, 16 January 1864, RU 26, Box 5, SIA.

34. Flügel to Henry, 9 May 1864, RU 26, Box 5, SIA.

35. Flügel to Baird, 4 March 1868, Baird Papers, RU 7002, Box 20, SIA; Flügel to Henry 4 July 1867, RU 26, Box 5, SIA; Benjamin Franklin Sands, Naval Observatory, to Henry, 3 August 1868, RG 78: Records of the Naval Observatory, Miscellaneous Letters Sent, NARA. Henry cautioned Flügel about keeping purchases strictly separate from articles sent on exchange. Henry to Flügel, 17 August 1868; 12 October 1868, Outgoing Correspondence, Office of the Secretary, 1865–1891, RU 33, Vol. 11 (cont'd), SIA.

36. Flügel to Baird, 21 February 1868; 5 March 1868, Baird Papers, RU 7002, Box 20, SIA.

37. Flügel to Baird, 4 March 1868, Baird Papers, RU 7002, Box 20, SIA.

38. Flügel to Baird, 31 May 1865, 11 September 1865, RU 26, Box 5, SIA; Flügel to Baird, 2 June 1867, 27 August 1865, 15 February 1867, Baird Papers, RU 7002, Box 20, SIA. Henry to Flügel, 14 August 1871, Henry Collection, RU 7001, Outgoing Letterpress, 1865–1878, Box 4, SIA.

39. Joseph Jeanes to John Warner, 22 February 1858, Warner Papers, APS.

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The Dibner Library of the History of Science and Technology

Lilla Vekerdy

The Dibner Library of the History of Science and Technology is the Smithsonian Institution's collection of rare books and manuscripts relating to the history of science and technology. Contained in this world-class collection of 35,000 rare books and close to 2,000 manuscript groups are many of the most significant works in the history of science and technology dating from the thirteenth through the nineteenth centuries. The Dibner Library shares this collection with the public through research services, resident scholar programs, exhibitions, loans to other institutions' exhibits, and public programs.

The collection of the Dibner Library is incredibly rich in its field. The subject strengths are history of the physical sciences, particularly mathematics, astronomy, classical Renaissance natural philosophy, theoretical and experimental physics (especially electricity and magnetism), chemistry, engineering technology, and transportation, as well as scientific apparatus and instrumentation. The holdings include numerous works of Aristotle, Euclid, Ptolemy, Sacrobosco, Regiomontanus, Apian, Galileo, Kepler, Descartes, Newton, Laplace, Euler, Gauss, Orstead, and many others. The core of the collection is the approximately 11,000 rare books and manuscripts that the Burndy Library, founded by Bern Dibner (1897–1988), generously donated to the Smithsonian on the occasion of the nation's bicentennial in 1976.

In a 1979 interview,[1] Bern Dibner (Figure 1)—electrical engineer, inventor, entrepreneur, and science historian—described how his interest in collecting these history of science books came about. In the 1920s, reading economist Stuart Chase's book *Men and Machines*, which contains a chapter on Leonardo da Vinci,[2] Dibner was fascinated by da Vinci's "dichotomy of interest in the arts and the sciences."[3] Embracing art as well as anatomy, mechanics, and engineering, that dichotomy mirrored Dibner's own "dual interests." In 1936

FIGURE 1. Portrait of Bern Dibner, 1957, by Lucerne Roberts.

Dibner took a sabbatical year in Europe away from the operations of his electrical components manufacturing business, the by then well-functioning Burndy Company, which he had founded in 1924. He matriculated at the University of Zurich, traveled in France, Germany, and Italy, and bought his first books for reference in the late 1930s. This was the gradual beginning of the development of the Burndy Library.

Dibner's interest in da Vinci led him to obtain a small library of works about da Vinci that grew over the years as Dibner's interests expanded into the history of electricity, the history of Renaissance technology, and, finally, the history of science and technology in general. Dibner especially valued these books because they documented how new technologies and inventions expanded new horizons in intellectual development. His collection continued to grow and, in 1941, he formally set up the Burndy Library as a separate institution "to advance scholarship in the history of science."

By 1964, Dibner's collection totaled more than 40,000 volumes. To house the library more appropriately, he opened a new state-of-the-art building in Norwalk, Connecticut, where the Burndy Company had previously moved its headquarters. The library became known for its research significance and for its publication of a monograph in science history every year.

During the 1930s and Second World War, Dibner created connections with rare book dealers in Great Britain and in Italy, which he continued to use to develop his collection. He acquired entire libraries of famous scientists such as Alessandro Volta and Louis Pasteur, continued to collect the most significant landmarks in the history of science, and published an annotated bibliography, *Heralds of Science,*[4] about the 200 most important books in his collection. These *Heralds* are now all in the Smithsonian's Dibner Library and compose one of the first main groups for the Smithsonian Libraries' digitization projects (Figure 2).

FIGURE 2. Highlights of the Dibner Library, several of which are included in Dibner's *Heralds of Science*.

Being an electrical engineer, Dibner collected, with great interest, early works about electricity. The debate between Luigi Galvani and Alessandro Volta about "animal electricity" in the late eighteenth century is represented in the collection, as is Benjamin Franklin's famous treatise, *Experiments and Observations* . . . , 1751.[5] Franklin's work, as with many others in the Dibner Library, is present in its first edition and several subsequent editions as well, allowing the researcher to follow the evolution of certain ideas published at different times. Presently, there are close to 1,100 titles in the Dibner collection that discuss topics related to electricity and almost 500 that specialize in electrical engineering. These mostly came from Dibner's original collection, the Burndy Library.

Other significant parts of the Burndy Library that were donated to the Dibner collection in 1976 are 320 incunabula (i.e., early printed books manufactured with movable type between ca. 1450 and 1501), 1,600 manuscript groups/volumes, and numerous titles with first descriptions of scientific observations and discoveries, often profusely illustrated.

When asked in the same 1979 interview about the three greatest books in the history of science, Dibner listed Newton's *Principia* (1687),[6] whose application of mathematics to the three laws of motion are "the key to how the universe operates;" Copernicus's book on the revolution of heavenly spheres (1543)[7] (Figure 3) announcing the heliocentric worldview; and, as the most beautiful book, Vesalius's illustrated anatomy, the *Fabrica* (1543).[8] As a repository for so many historical treasures, the Dibner Library is not only a prime research institution but also a spectacular place to visit. It also plays a significant role in the fund-raising efforts of the Smithsonian Libraries. Donors and prospective donors often visit the collection on tours, and the staff members are central organizers of the Smithsonian Libraries' Adopt-a-Book development program.

In addition to the main collection of the Dibner Library, there are other special and rare book collections in its stacks: the World's Fairs Special Collection, the Comegy Family

FIGURE 3. The famous first illustration of the heliocentric Universe in Copernicus's *De revolutionibus* . . . , 1543.

Rare Book Collection, and the Alexander Graham Bell–Joseph Henry Collection. These are first-rate resources for mostly nineteenth-century research on a scope broader than the history of science and technology. All Dibner Library holdings are accessible through the Smithsonian Institution Research Information System online catalog, SIRIS.

The excellent collection of the Dibner Library serves the historical research needs of Smithsonian curators, researchers, and fellows, as well as scholars and the interested public both nationally and internationally. As a nonlending library, we provide research possibilities onsite by appointment; we also reach an increasingly growing audience through reference and outreach work via telephone, email, and social media. Recent inquiries sought information about historical book bindings, early history of photographical processes, late eighteenth-century maps, Civil War photographs, an original letter by Galileo, early nineteenth-century American indentures, the manuscripts of Baldassarre Boncompagni (1821–1894), and much more. Dibner Library resources also provide information for exhibition development in many museums of the Smithsonian, and the library has loaned items to other institutions such as the National Library of Medicine and the Rubin Museum of Art in New York. Collaborative efforts are frequent in the Dibner, especially with the National Museum of American History (NMAH). Dibner fellows (from the library's Resident Scholar Program) regularly lecture at the NMAH's Tuesday Colloquium Series, and NMAH curators and the Dibner curator often consult about new acquisitions.

Since the Smithsonian Libraries established its three resident scholar programs for the use of its special collections, the Dibner Library has had a continuous flow of scholars who are awarded fellowships and conduct research in the Libraries' collections year-round. The Dibner Library Resident Scholar Program offers one- to six-month fellowships for the particular use of the Dibner collections. The research work our resident scholars produce manifests in finished doctoral dissertations, scholarly articles, and monographs in various fields of the sciences and humanities. This interdisciplinary feature is one of the main advantages of using the diverse special collections of the Smithsonian Libraries; yet even within the holdings of the Dibner Library itself, there is a great potential for interdisciplinary research. All resident scholar programs are administered from the Dibner Library; the selection process and the additional logistics are taken care of by Dibner staff.

The Dibner Library participates in educational programs by giving tours and hosting classes for graduate, undergraduate, and high school groups, conducting special research projects for elementary school students, and giving presentations for continuing education programs to professionals. These audiences all very much appreciate being able to see or peruse the original rare books or manuscripts. The several-hundred-year-old items have an effect even on those with no professional interest in them.

The annual Dibner Library Lecture is another regular program for public education and outreach. Recent lectures include Harvard University professor Joyce Chaplin's *Benjamin Franklin's Political Arithmetic: A Materialist View of Humanity* (2006), and this year, under the aegis of this symposium, British author Richard Holmes's *Romantic Science* (2015).

With the symposium *The Era of Experiments and the Age of Wonder* we celebrated our resident scholar programs and the reopening of the Dibner Library. Part of this celebration's purpose was to tell the history of the library, and naturally I have emphasized the significance of the collection throughout this essay.

But let me turn again to Bern Dibner's own words in 1979. His interviewer asked him: "Why is the Dibner Library special?"[9] Dibner replied: "the special [function] that this library performs is to gather and to make available to scholars the primary evidence of the record of discovery. . . ."[10]

In his description, the word "primary" is emphatically important. The "evidence" is the books in the Dibner Library. These primary sources are published works of scientific ideas conveyed directly by their authors, not by way of someone else's secondary analyses. They are the most original resources with which to understand new findings, discoveries, theories, and observations. Going back to these roots makes the history of science research authentic and authoritative.

In the general history of libraries, Bern Dibner noted, science libraries are relatively "new" because science (and here he meant modern science) itself is new compared to philosophy or theology. He emphasized how short a time had passed since Darwin's *Origin of Species* was first read and what a great change happened in scientific thinking during this brief time period.[11] Dibner was an enthusiastic witness to a scientific age that he characterized as "still in the learning phase of how to use scientific knowledge to its best advantage." He did not believe in "scientific explanation" but in "changing human understanding"[12] of how to look upon the material world. This is what he followed in his collecting, the monument of which is represented in the outstanding collection of the Dibner Library of the History of Science and Technology.

Notes

1. Bern Dibner, *Interview [manuscript] by M. Krauss*, 1979.
2. Stuart Chase, *Men and Machines* (New York: MacMillan, 1929), 61–62.
3. Dibner, *Interview,* 28.
4. Bern Dibner, *Heralds of Science* (Norwalk, Conn.: Burndy Library, Inc., 1955).
5. Benjamin Franklin, *Experiments and Observations on Electricity: Made at Philadelphia in America* (London: Printed and sold by E. Cave, 1751).
6. Isaac Newton, *Philosophiae naturalis principia mathematica* (Londini: Jussu Societatis Regiae ac Typis Josephi Streater, 1687).
7. Nicolaus Copernicus, *De reuolutionibus orbium coelestium, libri VI* (Norimbergae: Apud Ioh. Petreium, 1543).
8. Andreas Vesalius, *De humani corporis fabrica* (Basileae: Ioannis Oporini, 1543).
9. Dibner, *Interview*, 44.
10. Dibner, *Interview*, 44.
11. Dibner, *Interview*, 59.
12. Dibner, *Interview*, 61.

The History of the Resident Scholar Programs at the Smithsonian Libraries

Lilla Vekerdy

It was in the year 1759 that Candide, an iconic figure of optimism and idealism, concluded his adventurous travels after visiting numerous countries and faraway lands and meeting various and sundry people. He started out looking for the best of all possible worlds and sailed around the globe in hope. And it was only a decade later when young Joseph Banks—later forty-one times reelected president of the Royal Society of London—arrived at the beaches of Tahiti hoping to discover Paradise and also to observe the 1769 transit of Venus. Naive and curious Candide, a fictional character created by the dry-humored philosopher Voltaire, can be considered an exaggerated representative of the French Enlightenment. The enthusiasm of Banks and his contemporary men of science, however, is a very different naivete—as we read in Richard Holmes's book *The Age of Wonder*.[1] Their eagerness rings true and denotes a historical age of scientific discoveries and literary ferment in England partially concurrent with the Enlightenment in the early Romantic period.

Voltaire, too, loved England for its vivid and dynamic scientific development and took this fondness home after his almost three-year exile in London. In addition to his numerous literary and philosophical works, he invested great effort, much money, and personal influence in the creation of the *Encyclopédie*,[2] a compilation of "all" arts and sciences known in his age. Edited by Denis Diderot, the first edition of this magnificent work, a 35-volume folio set, is held in the Dibner Library of the History of Science and Technology of the Smithsonian Libraries. It offers a great "voyage" in eighteenth-century science and knowledge in general.

Voyages as a way of learning were main characteristics of the seventeenth and eighteenth centuries, but it was realized earlier that travel as well as books and schooling can provide excellent education. Paracelsus, the sixteenth-century physician-philosopher, emphasized:

> He, who would explore [nature], must tread her books also with his feet. Writing is explored through its letters; and nature from land to land. Every land is a leaf. Such is the Codex Naturae; thus must her leaves be turned.[3]

Through the Smithsonian Libraries' Special Collections, its resident scholar program has provided since 1992 this "page-by-page" journey in science, art, and history for scholars from all over the world, primarily in the Dibner Library (Figure 1).

FIGURE 1. Resident scholars in the Dibner Library reading room.

Presently, the Smithsonian Libraries offers three Resident Scholar Programs: the Dibner Library, the Spencer Baird Society, and the Margaret Henry Dabney Penick Resident Scholar Programs. All three programs are administered from the Dibner Library.

The earliest document about the Smithsonian Libraries Resident Scholar Program was recently discovered by Smithsonian Libraries' deputy director, Mary Augusta Thomas. The 1982 document is her handwritten plan of the program and then a typewritten plan, complete with an application form.

Following years of organizational work, the first Dibner Study Award was offered to scholars in the history and bibliography of science and technology in 1992. Interestingly, in later years the term *bibliography* is not emphasized in the award announcements. The reason may be that applications for the fellowships and scholarship in general have shown dampening interest about the bibliographical aspects of rare books and about books as physical objects. The recurrent fields of studies in the Dibner collection recently have been the history of mathematics, physics, astronomy, social history, art history, and, naturally, the history of science and technology in general.

A notable feature of the first program description is that the annually granted award did not exceed $1,000 monthly. The current stipend for Dibner scholars is $3,500 per month.

The management procedures for the award in the beginning years were essentially the same as how we administer the Dibner Library Resident Scholar Program today. Each year, a printed announcement is sent to appropriate institutions (history departments, historical associations, history of science programs, and other academic institutions) as well as interested individuals. We place advertisements in academic and professional periodicals, such as the *Chronicle of Higher Education* and other journals in appropriate disciplines (history of science and technology, selected fields of social history, general history, etc.). With the development of the Internet, online notifications on listservs, websites, and other digital settings have been increasingly used to publicize the scholar programs.

The applications arrive in the spring, usually in March, and are reviewed by a four-to-five member selection committee composed of Library employees, museum curators, and historians from Washington, D.C.-area academic and research institutions. The applications are evaluated on the ingenuity of the research project idea, the feasibility of the project plan, the bibliography, and—most importantly—whether or not the project makes best use of the holdings of the Libraries' special collections. As with the first plan of the scholar programs, and to this day, the scholars are expected to write a detailed report of their experiences during their tenure at the Libraries.

I did not find any documentation of the resident scholar program idea in the years immediately after the 1982 plan. However, later documents show that in 1992 the first official Dibner resident scholar started working at the Dibner Library. The printed announcement for that first year's fellowship mentioned other Smithsonian library collections as resources in addition to the Dibner Library; however, since then, it has been an unspoken "rule" for this fellowship that the scholars use the Dibner Library as the primary resource for their research.

The Dibner Library Resident Scholar Program is funded by the Dibner Fund. The spending plan for fiscal year 1992 shows the details of the Dibner family's generous support that first year: $9,000 for stipends ($1,500 per month) and $1,000 for advertising, for a total of $10,000. This document also shows that in the beginning years the Dibner Award was given to two scholars annually for one to three months. Recently, we have often hosted three to five scholars in the same year.

As I mentioned earlier, one of the main advertising methods for the resident scholar programs are printed brochures. Through the years, these handsomely illustrated brochures have become standard representatives of the programs and have developed into a special small art form themselves.

An important aspect of the history of the Libraries' resident scholar programs is the number of the applications submitted and the actual number of researchers selected and supported by the programs. According to 2001 statistics, seventy-seven scholars applied during the first ten years of the Dibner Library fellowship. In comparison, we received twenty-six applications in 2009 alone. From the first year, 1992, to the current one, fifty-one Dibner scholars conducted research in the Dibner Library. The second program, the Spencer Baird Society Resident Scholar Program, hosted twenty-six scholars from its founding in 2000 to 2010. The third program, the Margaret Henry Dabney Penick Fellowship, began this year and is hosting one scholar for nine months. All three scholarships are now featured on the resident scholar programs announcement.

Whereas the unique resources of the Smithsonian Libraries have always attracted resident scholar applicants nationwide and from around the world, the growth of the programs in this respect is recently very significant. During the first ten years, researchers applied from eighteen states of the United States and from fourteen foreign countries, including Brazil, China, Germany, Nigeria, and Poland. The number of states and countries of applicants is much higher now: several additional American states, as well as Canada, France, the United Kingdom, Hungary, and Turkey are also represented on the list. The scholarship programs have become truly national and international.

The Spencer Baird Society Resident Scholar Program started in 1999 when the first invitations for research proposals were issued to the scholarly community. The first group of selected scholars arrived at the Smithsonian in 2000. This fellowship has been developed to encourage researchers to scrutinize the non-Dibner parts of the Libraries' Special Collections, including the Joseph F. Cullman 3rd Library of Natural History, the World's Fairs collections, the trade literature collection, air and space history materials, and collections in the fine and decorative arts and in architecture and design.

This year the Libraries are introducing a third resident scholar program, the Margaret Henry Dabney Penick Fellowship. Awarded for nine consecutive months, this long-term fellowship supports research by senior scholars into the legacy of Patrick Henry and his political circle, the early political history of the commonwealth of Virginia, the history of the American Revolution, and founding-era ideas and policy making, as well as science, technology, and culture in colonial America and in the early national period.

This month we finished a major renovation and remodeling project in the Dibner Library, which will provide improved circumstances for our readers and visitors. The greatest enhancements are the new lighting system and the functional and aesthetically pleasing furniture, funded by the generosity of the Dibner family.

The Dibner Library has been and remains primarily a place for scholarly research and the home for the resident scholar programs. However, its new interior attests to other important functions that the library plans to emphasize in the future. We have created a small conversation area at the east glass wall of the reading room. From there a nice view opens to the rare book stacks. One of the most impressive sights through this window is the folio set of Diderot's *Encyclopédie,* mentioned at the beginning of this essay. This seating area will be used mostly at special events and receptions, since fundraising is becoming an ever-growing part of Special Collections' everyday work. The new furnishing also enables presentations and lectures to be held in the room, which will provide for more outreach programs. Larger surfaces for exhibitions and displays will strengthen the reading room's third additional function as an exhibit hall. Please visit the room for two current displays: *Mathematics in Print* and *Sir Humphry Davy, the Father of Modern British Chemistry,* both of which pertain to talks presented in the Era of Experiments and Age of Wonder symposium.

As time passes, the Dibner Library, the resident scholar programs, and the Special Collections of the Smithsonian Libraries will open up more and more to scholarly audiences and the general public. Collaboration will characterize the services of the collections: working together with other collections, institutions, and outside researchers. As this year's American Library Association Rare Book and Manuscript Section Preconference suggests in its title—*Join or Die: Collaboration in Special Collections*—we also intend to support functions in this vein with the Dibner Library's new interior and new goals.

Digitization is an excellent way of opening up library collections and especially Special Collections. Access to archives, rare books, fine book art, or print collections was very limited before the digital era, so the change in these kinds of repositories is very significant. These are the places where most items exist in only a few copies and, if those are hidden, very few people have the chance to see or study them. Since the 1990s, extensive digitization has created the opportunity to access many of these items in the Smithsonian Libraries' collections. Mounting digitized versions of exhibitions and publications on the Internet has built links to a worldwide scholarly audience and to the general public, including our own Dibner and Baird Resident Scholars. Digitization and the internet obviously increased the interest in rare books, and I think both venues will remain strong parts of Special Collections work in the future.

And yet, scholars still want to come and consult the actual physical volumes, since books are not just surrogates carrying information but quite special media that combine form and content perfectly. Books are practical and long-lasting, their "hardware" endures for a very long time, and they can be read several hundred years after they are produced. One of them, a codex in the Dibner Library dating from ca. 1280, is still clearly legible, even though it was written 730 years ago.

I am referring to Bartholomaeus Anglicus's *The Properties of Things*,[4] a cumulative encyclopedia of the knowledge of sciences and natural history of the Middle Ages. A typical medieval feature of the work is that it was more a compilation than an originally written treatise by the author, who used various ancient and medieval sources and summarized various topics in one volume. We could say that it is an interdisciplinary book. From an educational and cultural viewpoint it is very important that rare books are often interdisciplinary. Although it is difficult to catalog or classify them because they encompass several different fields of the arts and sciences, they testify about intriguing integrated knowledge, a frequently discussed modern topic.

In his 1959 essay titled "The Two Cultures,"[5] C. P. Snow writes about a college where the School of Arts is at one end of the campus and the School of Sciences on the other. He saw a similar division between the sciences and humanities in modern Western cultures. "There seems then to be no place where the two cultures meet" he complains.[6] Knowing about the variety of fields and research contained in the rare books under the aegis of the Libraries Resident Scholar Program, we can say there *are* places where these "two cultures" meet. And one very significant one is the Dibner Library. And there are also those rare and very special time periods when the two cultures meet, like the *Age of Wonder* so convincingly and entertainingly described by Richard Holmes.

Notes

1. Richard Holmes, *The Age of Wonder* (New York: Vintage Books, 2008).
2. *Encyclopédie, ou, Dictionnaire raisonné des sciences, des arts et des métiers, par une société de gens de lettres; mis en ordre & publié par M. Diderot . . . & quant à la partie mathématique, par M. d'Alembert* . . . (A Paris : Chez Briasson . . . David l'aîné . . . Le Breton . . . Durand, 1751–1765).
3. Karl Sudhoff, ed., *Paracelsus, Sämtliche Werke* (München: Oldenbourg, 1922–1933), 11, 145–146.
4. Bartholomaeus Anglicus (13th cent.), *De proprietatibus rerum.* (Smithsonian Libraries, The Dibner Library of the History of Science and Technology, MSS 000241 B).
5. Charles P. Snow, *The Two Cultures and the Scientific Revolution: the Rede Lecture* (Cambridge: Cambridge University Press, 1959).
6. Snow, *The Two Cultures,* 17.

Sharing Mathematical Treasures from the Dibner Library

Peggy Aldrich Kidwell

The Dibner Library is a valuable resource for scholars exploring diverse aspects of the history of science and technology. It is a rich source for exhibitions on the floor of the National Museum of American History and on the Smithsonian website. The Dibner is also a wonderful place to introduce young women and men to rare mathematical books and manuscripts, as I describe here.

In the mid-1990s, Professor Dan Ullman of the mathematics department at George Washington University (GW) came to me with a question. The university had recently started a summer program designed to encourage women who were juniors in college majoring in math to consider going on to graduate school in the subject. The students, who came from all over the nation, would spend the bulk of their time attending short courses and listening to a range of outside speakers (mainly eminent female mathematicians). Dan thought the participants should see a bit of Washington while they were here. Might they combine a visit to the Smithsonian's Folklife Festival on the Mall with a glimpse of some of Dibner's mathematics collections?

The program involved about twenty students and faculty, too large a crowd for our collections area. Instead, I suggested that we mount a small exhibit of books and manuscripts inside the Dibner Library. Ron Brashear, the Dibner Librarian, kindly agreed to the proposal. As Table 1 indicates, the Dibner has been hosting the GW group annually ever since, except for two years when the museum was closed to the public for renovation.

I selected books and prepared labels for the first few exhibits myself. However, Amy Ackerberg-Hastings, then a PhD candidate at Iowa State University, no sooner volunteered to work with the mathematics collections than she was drafted to prepare the book exhibit *What Every Math Major Needs to Know* (Figure 1). Things went sufficiently well that we even wrote a short article for math professors about doing such exhibits.[1] The article has been published, although it has yet to inspire a flood of exhibits elsewhere.

While Smithsonian volunteers and interns are of remarkably high quality, few arrive on the verge of completing PhDs in the history of mathematics as Amy did. Nonetheless, with the patient cooperation of Dibner Library staff, we have produced a steady stream of ephemeral exhibits enjoyed not only by the GW summer participants but also by the public. An intern or volunteer selects books, writes and revises label text, designs and prints out labels, and presents their exhibits to visiting students and peers. As many interns are considering careers in museums or in the history of science, this is valuable experience. Dibner staff share expertise and editorial comments, arrange installation, and determine how long the books should be on view. There is no formal budget for any of this.

TABLE 1. Sharing treasures from the Dibner Library.

Date[a]	Exhibition Title	Curator/Organizer
1997	*New Things in Mathematics, 1450–1850*	Peggy Kidwell
1998	*Mathematical Books 1550–1850*	Peggy Kidwell
1999	*Geometric Models Made and Used in the United States*	Peggy Kidwell
1999	*Selected Mathematical Books*	Peggy Kidwell
2000	*500 Years of Geometry Textbooks*	Amy Ackerberg-Hastings, Iowa State University
2001	*Early Modern Mathematical Instruments in Print*	Amy Ackerberg-Hastings
2002	*What Every Math Major Needs to Know*	Amy Ackerberg-Hastings
2003	*Great Scots! Six Mathematicians of Distinction*	Heather Huntington, University of Maryland
2004	*The Allure of Numbers*	Peggy Kidwell
2005	*Mathematics and Motion from Aristotle to Einstein*	Peggy Kidwell
2006	*Ideas and Symbols: π, e and i*	Peter Lipman, Johns Hopkins University
2007–2008	[Dibner Library closed during renovation of National Museum of American History]	—
2009	*New Astronomy 400 Years Later*	Peggy Kidwell
2010 (March)	*Mathematics in Print*	Mary Kavanagh, George Mason University

[a] Unless noted otherwise, exhibitions were mounted in July of the year indicated.

FIGURE 1. Classics of mathematics in an exhibit case in the Dibner Library reading room.

Topics have ranged from mathematical instruments in print (done for a group at the Folger Shakespeare Library as well as for the mathematics majors), to great theorems in mathematics, to number theory and mathematical constants. With the 2003 exhibit *Great Scots!* we were even able to tie our theme to a country featured in the Folklife Festival. The 2009 display honoring the 400th anniversary of Kepler's *New Astronomy* was on view for a month and was seen by some four hundred visitors.

This modest program allows both interns and visitors to look carefully at a few splendid books, and occasionally manuscript letters, portrait prints, and objects. Both those who prepare these exhibits and those who visit them see up close treasures of the history of mathematics and the sciences. The staff of the GW summer program tells me their students uniformly give the Dibner visit high marks. Of course, I also immensely enjoy the interchange. The Dibner Library and the Smithsonian Libraries are generous indeed to let this program continue.

Although most of the exhibits we have created over the years have been for the summer program, we have targeted other audiences as well (Table 1). In March 2010, the month of this talk, the American section of the Forum on the History and Pedagogy of Mathematics held its annual meeting in Washington. Organizers asked if they might visit the Dibner Library and, despite all the disruptions of the renovation taking place in the National Museum of American History, Lilla Vekerdy, head of special collections, and her colleague Kirsten Van der Veen, kindly agreed. With their help, intern Mary Kavanagh, a student at George Mason University, selected a few incunabula, read about them, and prepared a small exhibit, *Mathematics in Print*. A smaller version of this exhibit was also on display during the Era of Experiments and the Age of Wonder symposium.

Notes

1. Peggy A. Kidwell and Amy Ackerberg-Hastings, "Exhibiting mathematical objects: making sense of your department's material culture," in *Hands-on History: A Resource for Teaching Mathematics*, ed. Amy Shell-Gellasch, Mathematical Association of America, 2007.

Bern Dibner's Way of Collecting and Its Importance for Scholars

Pamela O. Long

My essay focuses on the importance of Bern Dibner's collecting for historians of science and technology. From the point of view of historians, he was a brilliant collector, and his collections are important for scholarship. I have been fortunate to have been able to use two of Bern Dibner's libraries extensively. The first was the collection of the Burndy Library at MIT, which I used daily while I was a fellow there in 2000 and 2001 and which is now at the Huntington Library in California. I have also used the Dibner collection here at the Smithsonian, both while I was a fellow here and since then. As a historian of premodern science and technology, my scholarly research concentrates primarily on materials from the sixteenth century—the part of these collections that I know best.

What becomes clear from using the collections is that Bern Dibner understood the issue of depth and how important that depth is for scholarship. When he became interested in a topic or focal point, he collected the whole range of relevant materials. Whereas many book collections focus on first editions, the two Dibner collections often contain not only numerous first editions but also all or nearly all of the subsequent editions of particular books. This depth is extremely important for scholarship. To explain why, first I describe an example from the Burndy Library now at the Huntington.

Dibner was interested in obelisks and the transport of obelisks. I understand that his interest stemmed from his admiration for the wonderful late-Renaissance engineering and architectural book by Domenico Fontana, *Della trasportatione dell'obelisco vaticano,*[1] in which Fontana describes the moving of the Vatican obelisk from the side of St. Peter's Basilica to the front in 1586. Dibner subsequently wrote a small book, *Moving the Obelisks,* that provides a detailed discussion of the move.[2] In 2000, I and three colleagues, Brian Curran, Anthony Grafton, and Benjamin Weiss, began a book project about obelisks, using the materials of the Burndy Library. Our book, *Obelisk: A History*,[3] published in 2009, addresses the changing meaning of obelisks in diverse historical cultures and the different ways in which obelisks were transported. While we worked, we all became ever more aware of the magnificent depth of the Burndy collection's works on obelisks. I believe that the collection contains nearly every printed early item relevant to obelisks—strikingly beautiful large books and prints, highly ephemeral pamphlets and small booklets, as well as manuscript items. We could not have written our book without the Burndy's immense obelisk collection, nor could we have collected the numerous illustrations that we used for the book, selecting from a field of hundreds. Although I have not made a scientific study of the issue, I believe that the Burndy obelisk collection is probably the most complete in the world.

Now turning to the Dibner Library at the Smithsonian, I will illustrate its great range and depth of sixteenth-century engineering books with a couple of examples. The first is the *Theater of Instruments and Machines* by Jacques Besson [4] (Figure 1). The Dibner Library has digitalized one of the 1578 editions of this book and put it online with a useful introduction by Ron Brashear, a former Dibner Librarian. Besson was a French Protestant mathematics teacher and inventor who was briefly a Protestant preacher. His *Theater of Instruments and Machines* was the first of the so-called theaters of machines genre of literature. (These are usually large format books with numerous engravings depicting machines and machine parts.) In these large books, Besson displayed his own original mechanical inventions. After his death in 1573 numerous editions appeared, most with added commentary and explanations. The Dibner Library has five of these editions:

- The Latin edition, *Theatrum insturmentorum et machinarum*, published in Lyons in 1578 [5]
- A French edition, also published in Lyons in 1578 [6]
- A Latin edition published in 1582 [7]
- A German edition published in Mümbelgart in 1595 [8]
- Another French edition, published in 1596 [9]

In the collection as well is a manuscript book of machine drawings that Dibner collected and that includes some of the machines of Besson.[10] Dibner also collected two of Besson's earlier works—a treatise on a measuring instrument that Besson invented called the cosmolabe and a small tract on the compass—both of which are also here.[11]

Dibner collected these editions before the flourishing field of the history of the book had been established. What that field has taught us is that each version is different from the others and is worthy of study in itself. By studying specific editions, scholars can discover the context in which particular books were produced, the ways in which they were disseminated, and their reception within specific locales. Although a digital book is highly useful, it can never be a substitute for examining and reading the actual books and comparing them side by side, both as material objects and in terms of their substantive textual and visual content. The Dibner Library is one of the very few libraries where this kind of comparative approach can be carried out effectively with books in the collection.

In addition to collecting successive editions of particular works, Dibner collected many or all of the works written by the particular authors who interested him, not just their better-known writings. For example, the collection includes virtually all of the writings of the sixteenth-century physician and student of mining and mineralogy, Georg Agricola, starting with some of his lesser-known works and continuing through his famous, illustrated *De re metallica*, published a year after his death, in 1556.[12] Further, Dibner collected the *De re metallica* itself in most of its early editions, allowing scholars to compare those editions side by side and page by page.

In conclusion, the Dibner Library is a unique resource to scholars that allows them to study and compare numerous editions of particular works in one place. It is also a great library for historians because of its tremendous depth in terms of the writings of particular authors and in terms of its manuscript materials relevant to the printed books. In this increasingly digital age, scholars do benefit from the convenience of online copies, but they will always need to study actual physical books. For this reason, the Dibner Library will remain as vital a resource in the future as it has been in the past.

FIGURE 1. A "new" hand-cranked machine for lifting cement and stones to builders working on an overhead platform (Plate 35 of Jacques Besson, *Theatrum instrumentorum et machinarum . . .*, 1578).

Notes

1. Domenico Fontana, *Della trasportatione dell'obelisco vaticano: et delle fabriche di Nostro Signore papa Sisto V* (Rome: Domenico Basa, 1590).
2. Bern Dibner, *Moving the Obelisks* (Norwalk, CT: Burndy Library, 1950).
3. Brian A. Curran, Anthony Grafton, Pamela O. Long, and Benjamin Weiss, *Obelisk: A History* (Cambridge, MA: MIT Press, 2009.
4. Jacques Besson, *Instrumentorum et machinarum/quas Iacobus Bessonus Delphinas mathematicus et a machinis praeter alla excogitavit, multisque vigillis & laboribus excoluit*. . . . [Orlean: [n.p.], 1569). This is the very rare first edition of which the Dibner collection holds a photocopy from the original at Harvard University Library.
5. J. Besson, *Theatrum instrumentorum et machinarum Iacobi Bessoni*. . . . (Lyon: Barth. Vincentium, 1578).
6. J. Besson, *Theatre des instrumens mathematiques & mechaniques* (Lyon: Barthelmy Vincent, 1578).
7. J. Besson, *Theatrum instrumentorum et machinarum Iacobi Bessoni Delphinatis mathematici ingeniosissimi*. . . . (Lyon: Barth. Vincent, 1582).
8. J. Besson, *Theatrum oder Schawbuch: allerley Werckzeug und Rüstungen des hochverstendigen sinnreichen Mathematici*. . . . (Mümbelgart: Jacob Folliet, 1595).
9. J. Besson, *Theatre des instrumens mathematiques et mechaniques de Iaques Besson*. . . . (Lyon: Iaques Chouët, 1596).
10. Smithsonian Libraries, Dibner Library of the History of Science and Technology, "*Machine et instrumenti de piu celebratissimi autori,*" (manuscript, q MSS 000864 B).
11. Jacques Besson, *Le cosmolabe, ou, instrument universal: concernant toutes observations qui se peuvent faire par les sciences*. . . . (Paris: Ph. G. De Rouille, 1567–1569); J. Besson, *Description et usaige du compass euclidien: contenant la plus part dew observations qui se sont en la geometrie perspective, astronomie, & corographie* (Paris: Galiot du Pré, 1571).
12. Georg Agricola, *De re metallica libri XII* (Basel: Hieron Frobenium and Nocolaum Episcopium, 1556).

Utilizing Dibner Resources at the National Air and Space Museum

David DeVorkin

The opening of the modern cosmology exhibition *Explore the Universe* at the National Air and Space Museum (NASM) in September 2001 brought together critical elements of three of the four most important astronomical instruments in human history:

1. The 20-foot reflector built by William Herschel in the 1780s and used by him and later by his son, John, through the 1830s to gauge the structure of the sidereal universe.
2. The Newtonian cage from George Ellery Hale's 100-inch Hooker reflector at Mount Wilson, in southern California. It was employed in the 1920s and 1930s by Edwin Hubble to establish the distance to, and hence the existence of, external galaxies and to show that they are not static in space but move away from each other.
3. The backup primary mirror for the Hubble Space Telescope along with elements of its various instruments that confirmed the existence of supermassive black holes and helped to detect the accelerating universe and, therefore, the existence of an accelerating force called dark energy.

Instruments collected together and displayed in the gallery were chosen to characterize a specific point in time when an observation caused astronomers to start asking questions that led to a revolution in our thinking about what the universe is, and where we are in it. Thus a replica of Tycho Brahe's equatorial armillary that provided evidence that planets did not travel in Aristotelian circles around the Earth, but in ellipses, introduces a replica of a Galilean telescope that demonstrated that there were centers of motion in the Universe other than the Sun: both confirmations of the Copernican world model.

Far from an illustrated chronology of the material heritage of the last five hundred years of cosmological studies, *Explore the Universe* links the fundamental technologies employed by astronomers to revolutions in our understanding of its structure and nature. Our guiding principle—"new tools, new universes"—demonstrates that as we changed our technology of observation from visual pointing devices to optical telescopes, to photographic telescopes, to spectroscopic telescopes, and, most recently, to the digital technologies of today, our universe went from being geocentric, to heliocentric, to galactocentric, then quickly to acentric, and, most recently, to an accelerating medium driven by dominant dark forces and dark masses only indirectly detected and as yet unexplained.

During the design and construction phases of this exhibition, we engaged the resources of the Dibner Library to illustrate Tycho's great equatorial armillary instruments and Galileo's first telescopes and the observations he made with them. Dibner holdings also helped us illustrate the aerial telescope that Huygens employed to map out Saturn's rings and numerous other classical devices. We raided (with permission, of course) the astronomy collections at the National Museum of American History (NMAH) to display astrolabes of the last millennium as well as Tycho's instruments and replicas of Galilean and Newtonian telescopes.

At the exhibit's opening we, our visitors, astronomers, historians, and critics celebrated the rich trove of hardware collected, the engaging interactives, both electronic and mechanical, and the humbling conclusion of the exploration, which ended with questions and with constantly updating answers. But soon after the opening, we sensed that the story was not complete. Something terribly important to astronomical history was missing: there was not one book displayed in the room, real, virtual, or physical facsimile. This was not right.

Accordingly, we began discussions in early 2002 with the Dibner librarian, Ron Brashear, to see what could be done to rectify the situation. I knew too well that rare books could not be permanently displayed, and, in any event, we did not have enough room left in the exhibition to display more than a book or two at a time under proper conditions. We also did not have the historical specialist with expertise to decide which books would be most appropriate, or what to say about them. We therefore invited Ron to curate a new kiosk in the exhibition, in full view of the classical objects from the eleventh to the eighteenth and early nineteenth centuries, which would complement them and offer a historical presence for the official records of their design and use as icons of astronomical history. Ron accepted, and thus began our first sustained cross-bureau display scheme.

We agreed that if the Dibner staff would curate the kiosk, we would build it to the proper specifications. Dibner staff would periodically insert one book and a small label describing the work and to what page it was opened. We at NASM would install the kiosk, alarm and light it, and assist the Dibner curators and the NMAH and NASM registrars and collections specialists in removing and replacing books once every three months or so. Ron quickly worked up a spectacular listing from Dibner's holdings, and I breathlessly approved it. His first listing included:

1. Ptolemy, *Magnae constructionis*, 1538. First edition of the *Almagest* in the original Greek, along with the commentaries by Theon of Alexandria.[1]
2. Nicolaus Copernicus, *De revolutionibus orbium coelestium*, 1543. First edition of the classic work placing the Earth and the other planets in orbit around the Sun.[2]
3. Johann Bayer, *Uranometria* . . . , 1655. First edition published in 1603; large format star atlas with individual black-and-white plates of the constellations.[3]
4. Johannes Hevelius, *Prodromus astronomiae* . . . , 1690. The famous Hevelius star atlas with many fine illustrations of constellations.[4]
5. Tycho Brahe, *Astronomiæ instauratæ mechanica*, 1602. Illustrated book showing all of Tycho's large-scale astronomical instruments in great detail.[5]
6. Isaac Newton, "An Account of a New Catadioptrical Telescope . . . ," 1672. Tab. I illustrates the Newton telescope on exhibit in *Explore the Universe* (*ETU*).[6]
7. William Herschel, "On the Construction of the Heavens," 1785. Illustrated article covering material explained elsewhere in *ETU*.[7]

8. William Herschel, "Description of a Forty-feet Reflecting Telescope," 1795. Large illustration of Herschel's biggest telescope.[8]
9. Johannes Hevelius, *Selenographia; sive, Lunae description* . . . , 1647. Lunar atlas, contains wonderful illustration of Hevelius looking through one of his telescopes.[9]
10. Johannes Kepler, *Astronomia,* 1609. Classic work where Kepler describes how he found that the planets travel in elliptical orbits and not circular ones.[10]
11. Oronce Fine, *De mundi sphæra, sive, Cosmographia,* 1542. Beautifully printed work with nice frontispiece showing an astronomer with an astrolabe.[11]
12. Valentino Pini, *Fabrica de gl' horologi solari*, 1598. Nice illustrations of sundials.[12]
13. James Ferguson, *Astronomy* . . . , 1756. Nice folded frontispiece showing an orrery.[13]
14. Pierre Gassendi, *Tychonis Brahei, equitis dani, astronomorum coryphæi, vita,* 1655. Nice portrait of Copernicus.[14]
15. Galileo Galilei, *Sidereus nuncius magna*, 1610. Revolutionary work describing the first telescopic discoveries by Galileo.[15]

These works cycled through the exhibition for the next four years. One major criterion for book selection was that they would illustrate objects we had on display in the exhibition. This made gallery tours by curators and docents especially effective, allowing them to juxtapose objects with their original depictions, as in the case of Tycho's equatorial armillary (Figure 1). Every three to four months, Dibner, NMAH, and NASM staff gathered to perform the transfer, inspect both the incoming and outgoing volumes, test the security system, and then change the offerings on our museum website (Figure 2).

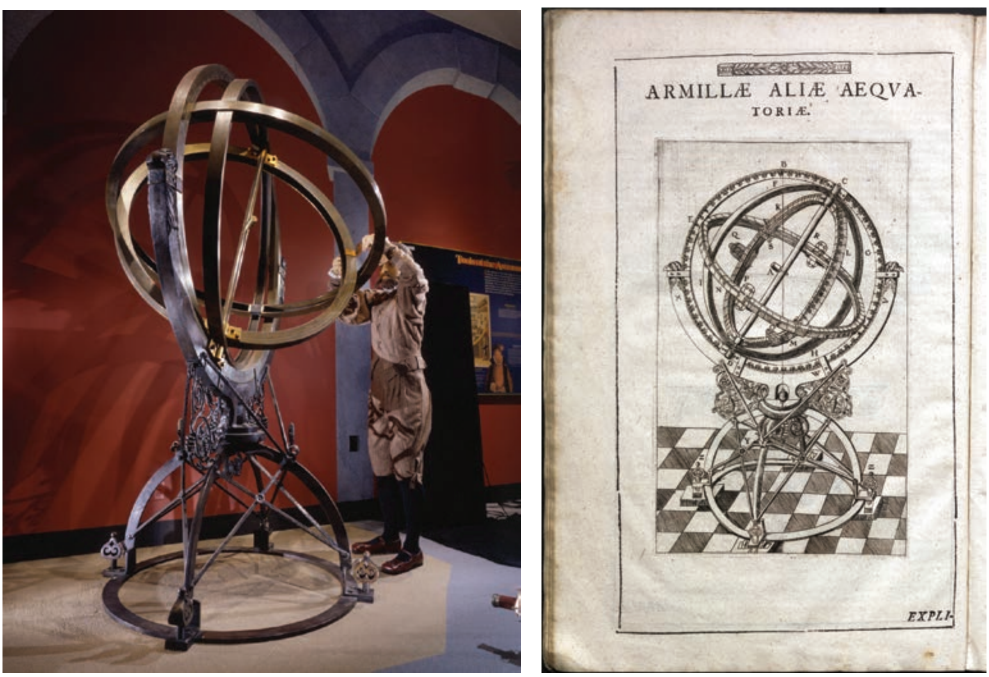

FIGURE 1. (*left*) Tycho Brahe's armillary sphere as displayed in *Explore the Universe*. Photo by Eric Long, National Air and Space Museum (NASM), Smithsonian Institution. (*right*) Depiction of the object from Tycho's *Astronomiæ instauratæ mechanica* (book no. 5 in the list proposed for display at NASM). Dibner Library of the History of Science and Technology.

FIGURE 2. Smithsonian Libraries conservator Vanessa Haight-Smith performing a book transfer for the display in NASM.

Knowing that 2009 would be designated the “International Year of Astronomy” by the International Astronomical Union to mark the 400th anniversary of Galileo’s application of the telescope to astronomical discovery, we opened a new round of discussions with Dibner staff near the end of the second cycle. We met first with Kirsten Van der Veen and then with the new Dibner librarian, Lilla Vekerdy, to see if we could invite Galileo’s *Sidereus nuncius* back to the museum for the last months of 2009 through the spring of 2010, at least to the anniversary date of the book’s publication, March 2010.

Everybody was excited about this new prospect and the obvious visibility it would accrue, but there were very real collections concerns: the Venice edition had already been exposed to the elements. The Frankfurt 1610 “street edition” was, however, available, and wonderfully symbolized the wide popularity of the work throughout Europe. But it too could not be exposed for such a lengthy time. In the end, we found a creative solution. The Dibner created facsimile editions of both works, and we displayed two books together: first the original Frankfurt and the facsimile Venice, and then the facsimile Frankfurt and the real Venice. We also upgraded the security of the vitrine, using 1/2-inch ultraviolet-blocking plastic, and moved the kiosk several feet to be in constant view of a security camera. We opened both volumes to a page illustrating Jupiter’s moons, mainly to illustrate how crude the street edition was compared to the truly original Venice edition.

The new installation opened just days before an important astronomical event at the National Air and Space Museum: the opening of a new public observatory (now named the Phoebe Waterman Haas Public Observatory) on our East Terrace. In the spirit of the International Year of Astronomy, we brought a professional telescope to the people in a big white dome, where it is now serving visitors four to five days a week. To mark the event, we hired "Galileo" (played by Mike Francis, an actor and impersonator from Boston) to attend and celebrate "first light." (Figure 3) He not only encountered his own *Sidereus nuncius* volumes in the exhibition (where he expressed some diffidence at the crude renditions in the Frankfurt edition) but engaged visitors with our (and his) telescopes (Figure 4). A local TV channel covered the full morning's events, and a great time was had by one and all—save for the fact that Galileo was almost arrested by the museum's security detail, unaware that he would emerge from the observatory during a press conference protesting the superiority of modern versions of his telescope.

In our first year of operation, the observatory educators have continued to use the Dibner collections by searching out renditions of the sun, moon, and brighter planets in published works from the past four hundred years. These have been reproduced with short essays and placed in binders on display to allow visitors to browse through and see how observers of yesteryear viewed the objects that the visitors were now viewing with our public telescope.

FIGURE 3. The author welcoming Galileo (actor Mike Francis) to the opening celebration of NASM's observatory in 2009—rededicated in 2013 as the Phoebe Waterman Haas Public Observatory.

FIGURE 4. The opening of NASM's new public observatory coincided with the museum's commemoration of the 400th anniversary of the use of a telescope in astronomy, for which the Dibner Library mounted a special display of two editions of Galileo's *Sidereus nuncius* in NASM's Explore the Universe gallery. The events attracted not only (left to right) the author and gallery curator (DeVorkin), the Smithsonian Secretary (G. Wayne Clough), and the director of the National Science Foundation (Arden L. Bement Jr.), but also "Galileo" himself.

Notes

1. Ptolemy, *Kl. Ptolemaiou Megales syntaxeos bibl. IG.... Claudii Ptolemaei Magnae constructionis, id est Perfectae coelestium motuum pertractionis, Lib. XIII. Theonis Alexandrini in eosdem Commentariorum lib. XI.* (Basileae: apud Ioannem VValderum, 1538).
2. Nicolaus Copernicus, *De revolutionibus orbium coelestium. libri VI.* (Norimbergæ: Apud Ioh. Petreium, 1543).
3. Johann Bayer, *Uranometria, omnium asterismorum continens schemata*. . . . (Ulmæ: sumptibus I. Görlini, 1655).
4. Johannes Hevelius, *Prodromus astronomiae*. . . . (Gedani: typis J.-Z. Stollii, 1690).
5. Tycho Brahe, *Astronomiæ instauratæ mechanica*. (Noribergae: apud L. Hvlsivm, 1602).
6. Isaac Newton, "An Account of a New Catadioptrical Telescope . . . ," in *Philosophical Transactions of the Royal Society of London*, 7 (1672): 4004.
7. William Herschel, "On the Construction of the Heavens," in *Philosophical Transactions of the Royal Society of London*, 75 (1785): 213.
8. William Herschel, "Description of a Forty-feet Reflecting Telescope," in *Philosophical Transactions of the Royal Society of London*, 85 (1795): 347.
9. Johannes Hevelius, *Selenographia; sive, Lunae description*. . . . (Gedani: Autoris sumtibus, typis Hünefeldianis, 1647).
10. Johannes Kepler, *Astronomia nova aitiologetos* [romanized]*: sev physica coelestis*. . . . ([Heidelberg: G. Voegelinus]: 1609).
11. Oronce Fine, *De mundi sphæra, sive, Cosmographia*. . . . (Parisiis: ex officina Simonis Colinæi, 1542).
12. Valentino Pini, *Fabrica de gl' horologi solari*. (Venetia: appresso M. Gvarisco, 1598).
13. James Ferguson, *Astronomy explained upon Sir Isaac Newton's Principles: and made easy to those who have not studied mathematics*. (London: printed for, and sold by author, 1756).
14. Pierre Gassendi, *Tychonis Brahei, equitis dani, astronomorum coryphæi, vita*. . . . *Accessit Nicolai Copernici, Georgii Peurbachii, & Joannis Regiomontani, astronomorum celebrium, vita*. (Hagæ-Comitvm: ex typographia A. Vlacq, 1655).
15. Galileo Galilei, *Sidereus nuncius magna*. (Venetiis: apud T. Baglionum, 1610).

The Case of the "Forgotten" Telescope

Steven C. Turner

My use of the Dibner Library stems from my interest in the history of science and, in particular, from my research on the history of scientific instruments. As much as possible, I try to work from period sources, using those works to understand science and scientific instruments in their full historical context. The Dibner is the ideal library for this kind of work, and it is hard to imagine doing this research without it. Online resources are wonderfully convenient, but there really is no substitute for having access to a proper library and working with the original works.

By way of illustration, I will describe one of my recent research projects—an investigation into eighteenth-century optics that I call *The Case of the "Forgotten" Telescope*.

It all began several years ago when I saw a curious little telescope in a private collection. It was similar to many of the small brass telescopes that I had seen over the years, except that this one had a strange scale engraved on the side of the tube (Figure 1).[1] Inside

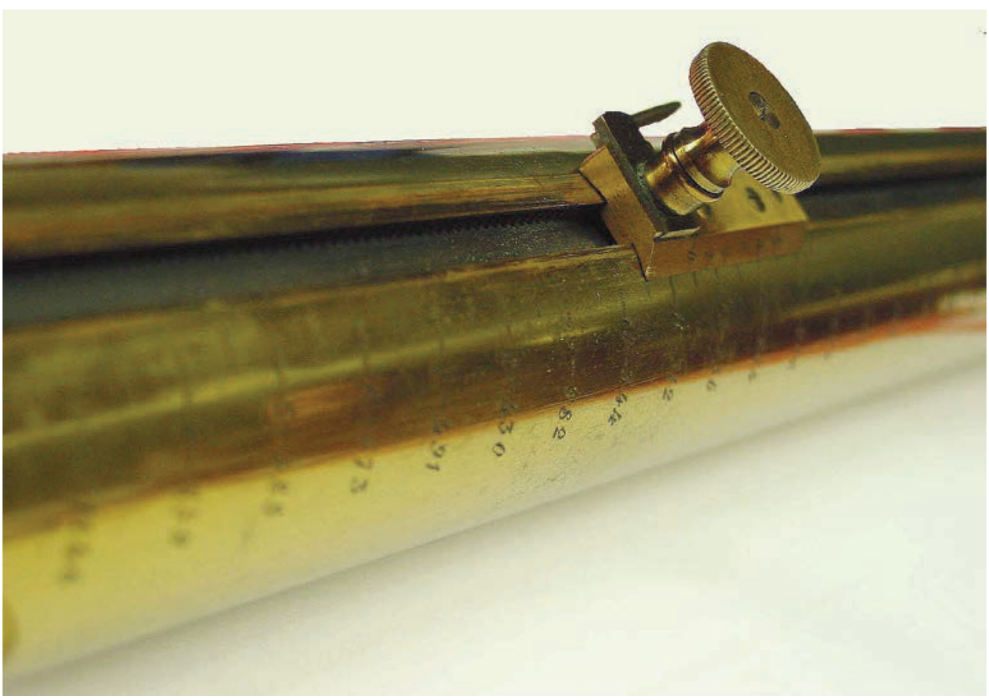

FIGURE 1. Engraved scale on the side of the telescope's tube.

FIGURE 2. Looking inside the telescope, with the eyepiece removed. Note the moveable prism inside the tube.

the tube, mounted on a special sliding assembly, was what I later discovered to be a particular kind of prism, a “Rochon prism” cut very carefully from a crystal of clear quartz (Figure 2).

When I returned to my office I set out to identify this new instrument. I felt confident in this because the history of astronomy—including astronomical instruments, like telescopes—is particularly well documented. So it got my attention when I was unable to identify it from any of the familiar histories. There were a few puzzling references to a “French telescope,” but really very little else. But when I began reading original articles from the late eighteenth century—and particularly from the Dibner Library’s extraordinary collection of French scientific works—I quickly discovered that my new telescope was a “Rochon’s micrometer.” It was used to measure angles *optically* and had been used for a variety of scientific and practical purposes throughout the nineteenth century (Figure 3). As I began to explore this story, I discovered that there was a clear point at which mention of this instrument, at least in English, simply ended. It truly was a “forgotten instrument,” and I resolved to hunt down the story. It has taken me some time to actually accomplish this, and I doubt that I could have done it without the Dibner Library and its *very* patient staff. But here, in a highly condensed form, is what I have found.

FIGURE 3. Rochon’s micrometer.

Rochon's micrometer was invented in 1777 by the French scientist Alexis Rochon (1741–1817). He was the caretaker of the important Cabinet de Physique du Roi (the King's scientific instrument collection) and a prominent member of the Académie des sciences.[2] He was also a prolific inventor. He actually proposed a large number of telescopes of widely varying designs, but it was only the micrometer that achieved more than token use (Figure 4).

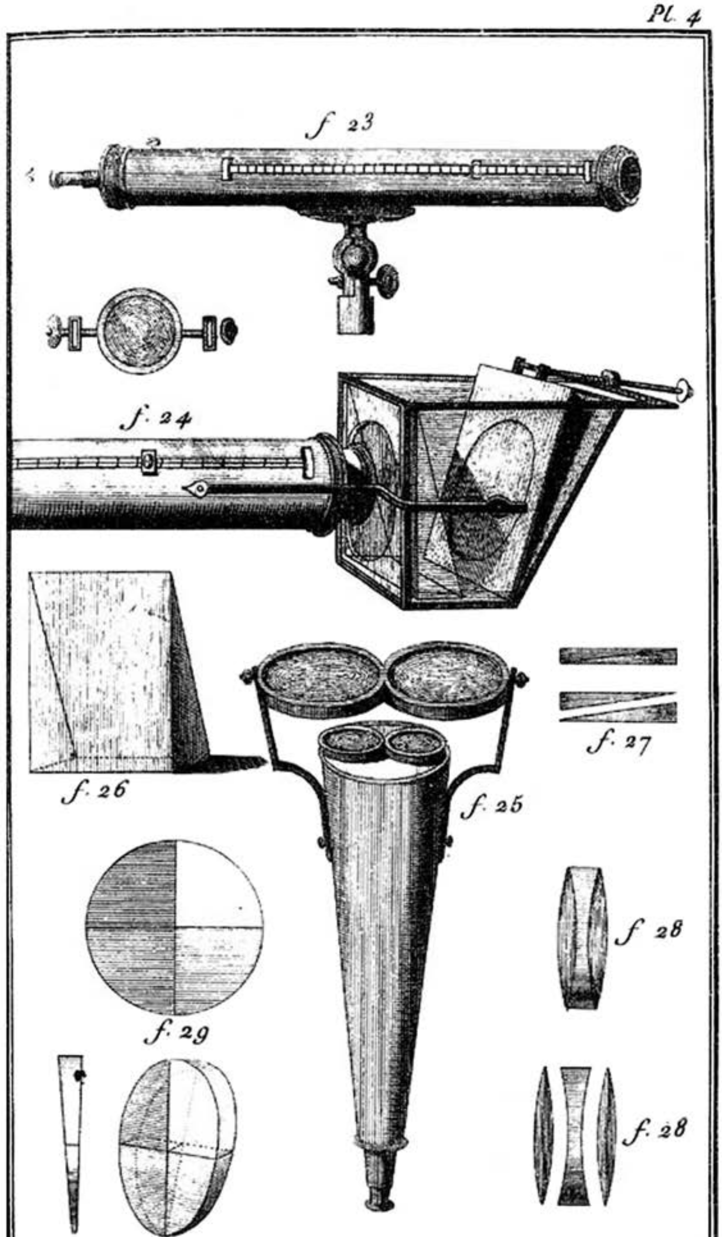

FIGURE 4. Woodcut of some of the telescopes Rochon designed. (From Rochon, *Recueil de memoires sur la mécanique et la physique*, Paris, 1783, plate 4.)

Rochon lived at a time when telescopes were becoming increasingly powerful. But whereas greater magnification is useful, the real challenge was to find a way to not only *see* objects with the telescope, but to also *measure* them. Making the telescope into a precision instrument was the frontier for scientific instrument design in the second half of the eighteenth century. And because England and France were the most prominently scientific countries, the development of measuring telescopes soon turned into a national competition between them. It was a gentlemanly competition, of course, but it was serious nonetheless. Most of the dispute was carried out in print, and optics texts from the mid-eighteenth to the mid-nineteenth centuries felt free to argue their nation's case and to diminish the achievements of the opposing nation.

Setting aside these intellectual property disputes, all of the most promising micrometer designs of this period used some variation of what was called the double-image principle—that is, manipulating the optical system to produce a double image and then measuring what it took to produce the effect. It sounds more complex than it really is, and there were a couple of interesting ways of doing it.

One was called the "divided-objective micrometer" and was first proposed in 1754 by the English instrument maker John Dollond (Figure 5).[3] In this system, the main lens of the telescope is literally sawn in half and then mounted on a mechanism that allows the lens halves to move independently. The instrument works like a regular telescope when the lens halves are next to each other in the starting position, but as the halves are offset they start to produce a surprising double image of the object being viewed. If the object is small, the lens halves only need to be displaced a little bit to produce two identical images, but larger objects require a larger movement of the lens halves to make two images. It is this displacement of the two lens halves that are measured; the larger the apparent width of the object being viewed, the further the lens halves must be separated.

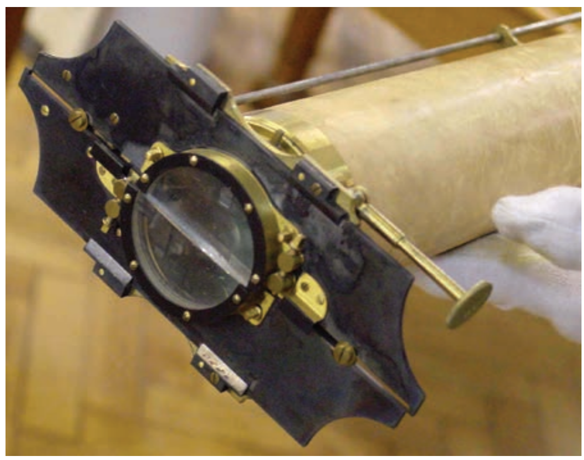

FIGURE 5. A divided-objective micrometer.

The other way to produce a double image was with Rochon's prism—which is what I saw on the inside of the Rochon micrometer that I discovered (Figure 6).[4] Without getting into too many details, this type of prism creates a double image when you look through it.

Because of its optical geometry, when the prism is placed in a telescope near the eyepiece, the instrument works just like a regular telescope and only one image is seen. But when the prism is moved inside the telescope, away from the eyepiece and toward the objective, it starts to produce a double image. The distance that the prism is moved is relative to the size of the object being viewed. The further from the eyepiece that the prism needs to be moved to make a double image, the greater the apparent width of the object being viewed.

It is easy to see the similarities between the two methods when they are used. Say, for example, that you had two observers, each having one of these micrometers, and they each wanted to measure the apparent size of the moon (Figure 7). If they were both looking at

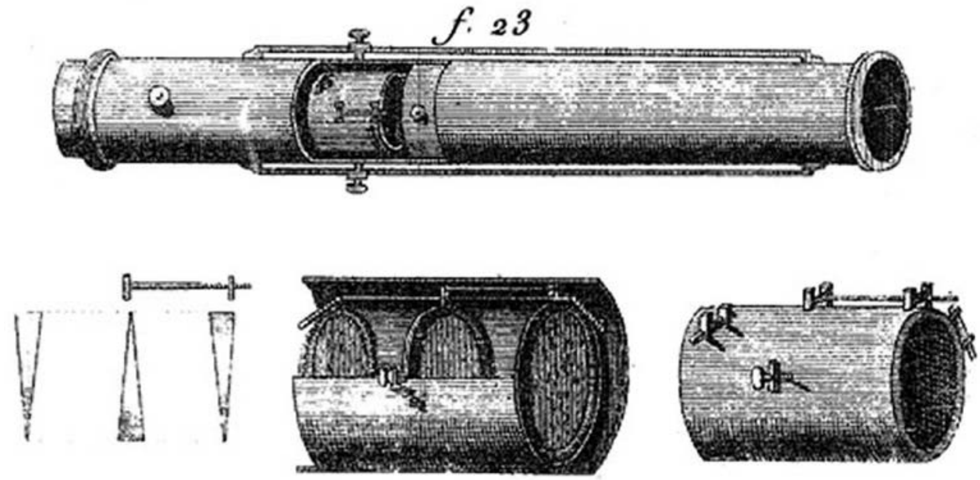

FIGURE 6. Woodcut of an early version of Rochon's micrometer. (From Rochon, *Recueil de memoires sur la mécanique et la physique*, Paris, 1783, plate 3 detail.)

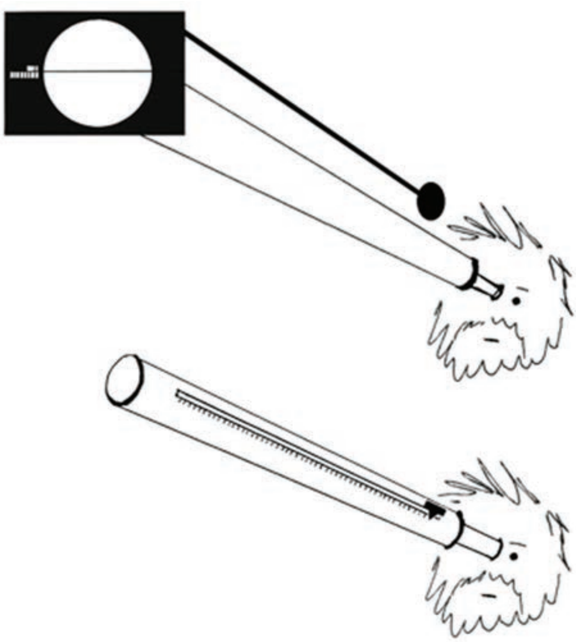

FIGURE 7. Diagram of two observers with different telescopes. The observer on top is using a divided-objective micrometer. The observer below has a Rochon prismatic micrometer.

the moon, with the divided-objective together and the Rochon prism near the eyepiece, they would both see a normal view of the moon (Figure 8). However, once the lens halves and prism begin to move, a second image of the moon suddenly appears and starts to move to one side of the original image (Figure 9). The goal is to keep moving either the lens halves or the prism until the two moon images are completely separate, but just touching each other (Figure 10). At this point, the measurement is complete, and reading the calibrated scales on each instrument gives the relative size of the moon. The same technique is used no matter what is being measured.

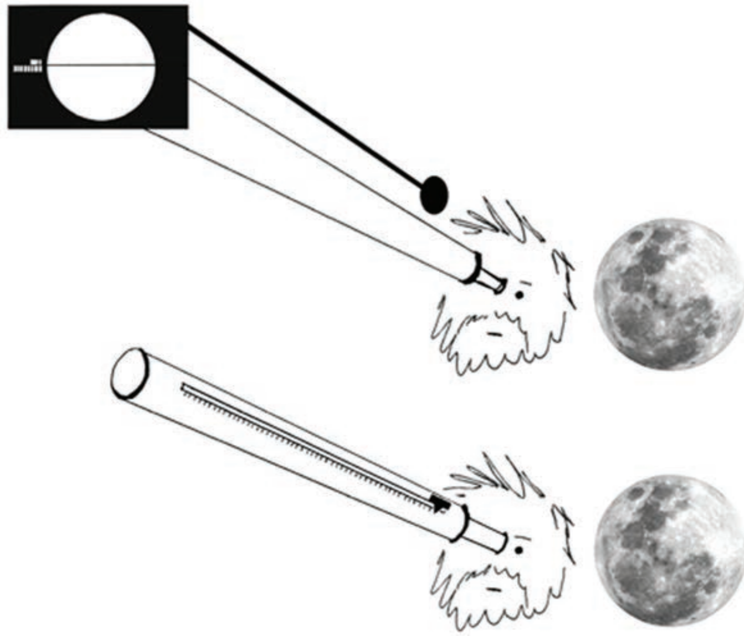

FIGURE 8. With lens halves together on the divided-objective micrometer (top) and with the prism near the eyepiece on the Rochon prismatic micrometer (bottom), both observers see the moon as a single image.

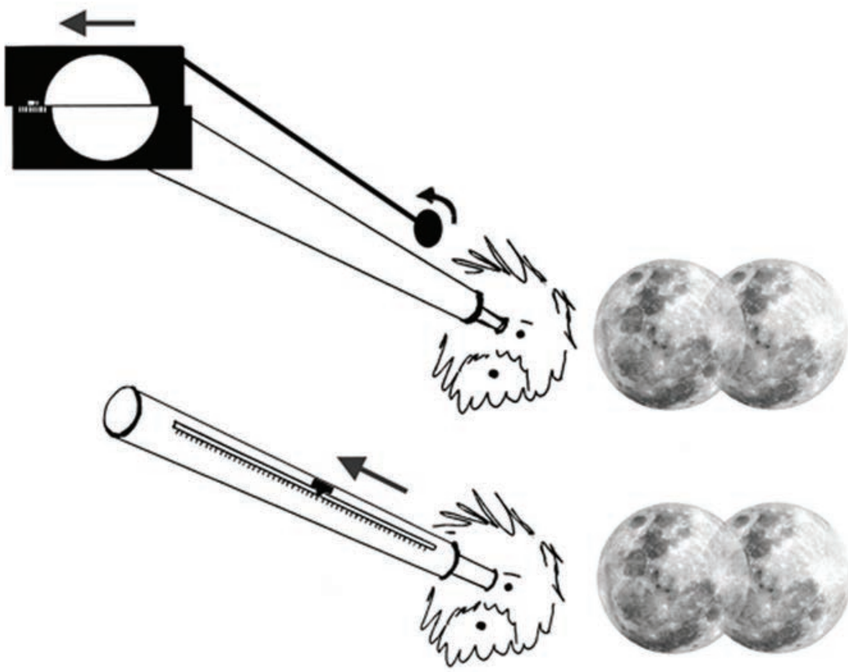

FIGURE 9. As the lens halves are separated on the divided-objective micrometer (top) and the prism moved away from the eyepiece on the Rochon prismatic micrometer (bottom), both observers begin to see a double image of the moon.

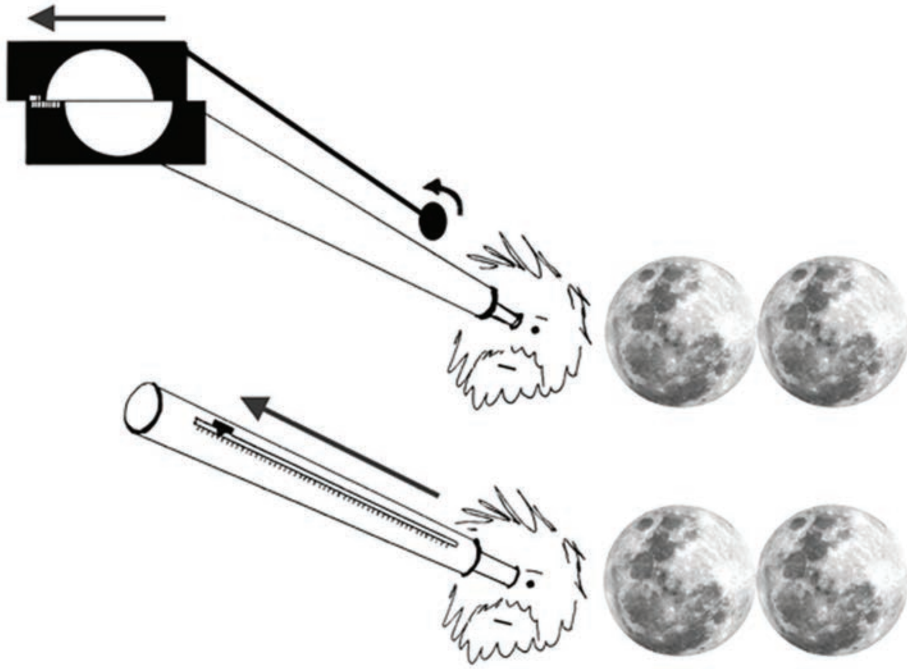

FIGURE 10. When the two moon images no longer overlap but appear to touch, as viewed through both the divided-objective micrometer (top) and the Rochon prismatic micrometer (bottom), the measurement is complete and the moon's angular width can be read from scales on each instrument.

Initially, both of these types of micrometers were developed openly, the English and French each having a pretty good idea of what the other was doing. Journals were, for the most part, freely circulated; scientists in both countries purchased instruments from each other; and personal contacts among both scientists and instrument makers were common. For example, when Rochon visited London in 1790 he was already well known and traveled freely. He brought and displayed examples of several of the instruments he had invented, including the Rochon micrometer and examples of the Rochon prism. He freely discussed his instruments with fellow scientists as well as English scientific instrument makers, several of whom he visited.

In 1791, however, like all French citizens traveling abroad during the early days of the French Revolution, Rochon was recalled to France. Suddenly, and for a period of nearly twenty-five years—until Napoleon was finally driven from power in 1815—contact between England and France, at least on the subject of micrometers, effectively ceased.

During that time, English refinements of the micrometer went toward improving the divided-lens technology. A compact version, with a divided lens in the eyepiece, was developed for naval use. Called an "up-coming glass," it was just accurate enough to tell if a distant ship was getting closer or farther away. This was still a useful thing to know, and there is some reason to think that Admiral Nelson may have had one of these at the battle of Trafalgar.

During the same period, French efforts—led mostly by Rochon—went toward refining the production of the prismatic micrometer, again with the intention of using it for military purposes—presumably for directing artillery fire. In 1802 we have a report of Rochon running an optical factory for the French navy, producing mirrors for nautical instruments as well as prisms and lenses for his micrometer telescopes. He recruited skilled opticians from Paris and undoubtedly trained others to make the precise quartz prisms that his telescopes required. In 1804 he received a special award from Napoleon for his contributions, and later that year Rochon presented his emperor with a specially-made micrometer telescope. Napoleon was impressed and asked him to prepare two more, which were likely presented as gifts to his generals.

During the nearly quarter of a century that France and England were out of touch, the Rochon micrometer became widely accepted in France. It was used for a variety of purposes and appears to have been made in significant quantities—with an increasing number of workmen able to produce it. In addition to its military use, it also had significant scientific applications. Alexander von Humboldt almost certainly took one with him to explore South America. The French scientist Jean-Baptiste Biot used it, as did the famous François Arago, who used the micrometer in several of his important experiments on polarized light. Arago also used it extensively at the Paris Observatory.

With the end of the Napoleonic wars and resumption of scientific contact between England and France, English astronomers realized that there had been developments across the channel that they did not know about—and one of them was Rochon's micrometer.

To give an idea of how isolated English scientists had become, in the summer of 1819, William Pearson, one of the England's leading astronomers, traveled to Paris specifically to learn about Rochon's micrometer, which he had read about but had never seen. The instrument was unknown in England, but on his first day in Paris he was able to walk into an instrument shop and buy one off the shelf.[5]

By the time of Pearson's visit, French instrument makers had been making Rochon prisms for nearly forty years. During that time they had accumulated a vast store of practical knowledge of how to find and work with natural crystals. Their knowledge and skill far exceeded that of English instrument makers, and although English makers tried to catch up, by 1829 it was clear that they had decided to leave crystals to the French. In that year Pearson published the second volume of his *An Introduction to Practical Astronomy*. This work summarized an extensive set of field tests that he had conducted with micrometers of all types, and it quickly became the standard work on the subject.

While Pearson's evaluation of Rochon's micrometer was generally quite favorable, his summary of it was not. Oddly, he criticized it first for not being based on scientific principles and then immediately accused Rochon of stealing the idea from the English. From this point on, Rochon's micrometer essentially disappeared from English history. Any reference to it after that inevitably leads back to Pearson and his negative evaluation.

This interesting, if somewhat obscure, story restores a forgotten instrument, but little else. Yet the fallout is surprisingly important. The expertise that the French instrument makers acquired in working with the quartz crystals used to make Rochon's prisms meant that French scientists had access to a class of advanced optical tools that were largely unavailable to English scientists, whose instrument makers could not produce them. And this resulted in distinct differences in many of the French and English scientific instruments throughout the nineteenth century. French instruments generally made much greater use of advanced optical design and natural optical materials. The English used a variety of alternative technologies in their scientific instruments, generally with good results. This split in scientific technologies, which began in Napoleon's time, still echoes in our own. It can be seen in astronomy, where French observatories distinctively still use double-image crystal micrometers to make angular measurements. Despite the fact that these prismatic micrometers produce good results they remain, for almost completely historical reasons, a distinctively French instrument.

These kinds of historic stories, especially stories from the history of science, are hard to find and even more difficult to explore. Scholars require specialized resources to do this kind of research, and in times of austerity it would be easy to say that this kind of work is unnecessary. But I argue that exploring the past enriches the present. This kind of history deepens our understanding and enriches our lives—much like the very special library whose reopening we are celebrating.

Notes

1. Photos and drawings in Figures 1–3, 5, and 7–10 are by the author.
2. D. Fauque, "Alexis-Marie Rochon (1741–1817), savant astronome et opticien," *Revue d'Histoire des Sciences,* 38 (1985), 3–36.
3. John Dollond, "A Letter from Mr. John Dollond to Mr. James Short, F. R. S. concerning an Improvement of Refracting Telescopes," *Philosophical Transactions (1683–1775),* Vol. 48, (1753–1754), 103–107.
4. Alexis Rochon, *Mémoire sur le micromètre de cristal de roche pour la mesure des distances et des grandeurs. Avec une instruction de M. Torelli-de-Narci sur la manière de se servir de la lunette contenant un micromètre fait avec des prismes de cristal de roche*, Paris: Beraud, 1807. This is Rochon's clearest and most detailed description of his micrometer.
5. William Pearson, *An Introduction to Practical Astronomy*, 2 vols., London, Printed for the author, and sold by Messrs. Longman, Hurst, Rees, Orme, Brown, and Green, 1824–1829.

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