Chapter Thirty-Two

Instrumentation

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The study of scientific instrumentation in the United States is a relatively new field of historical research, even though mathematical instruments were carried onboard the European ships that brought explorers to the coasts of North and South America 500 years ago. This chapter will trace the historiographical development of the field, describe current topics of research, list resources available (particularly in the form of material culture), and make suggestions for future projects.

Defining Scientific Instrumentation

It is necessary to begin with three questions: What is an instrument? What makes it scientific? And where does one begin and end? As scholars have pointed out, there is ambiguity in the term, "scientific instrument" (Baird 2004; Taub 2009, 2011; Van Helden and Hankins 1994; Warner 1990). The *Oxford English Dictionary* (*OED*) defines "instrument" as "a material thing designed or used for the accomplishment of some mechanical or other physical effect." By this definition, a scientific instrument could be a microscope that magnifies the image of tiny things, a Bunsen burner to heat a flask of water, or a surgical knife used to open a body. The *OED* goes on to say that the word may "also [be] applied to devices whose primary function is to respond to a physical quantity or phenomenon, esp. by registering or measuring it." This adds thermometers and magnetic compasses, spectrometers and acoustical resonators, pulse height recorders and timers. But the *OED* suggests boundaries to these definitions, saying that the former are mechanical contrivances that are usually "portable, of simple construction, and wielded or operated by the hand" and the latter "may function with little direct human intervention and be of complicated design and construction." These qualifiers seem too restrictive for modern scientific instruments, for an environmental test chamber or a particle accelerator are rarely portable or simple, and a wind vane,

A Companion to the History of American Science, First Edition.
Edited by Georgina M. Montgomery and Mark A. Largent.

meter stick, or electrometer need not be complicated. But the *OED* concedes that an instrument is "distinguished from a *machine*, as being simpler, having less mechanism, and doing less work of itself; but the terms overlap." It also acknowledges that the user's social and professional status influences the choice of terminology: An "instrument" is "now usually distinguished from a tool, as being used for more delicate work or for artistic or scientific purposes: a workman or artisan has his *tools*, a draughtsman, surgeon, dentist, astronomical observer, his *instruments*."

A broader definition of an "instrument" is given by a recent encyclopedia devoted to "Instruments of Science" (Bud and Warner 1998). It includes test equipment for industry and health; drawing instruments; model organisms such as mice and *Drosophila*; cameras and projection lanterns; models such as globes, planetaria, and orreries; calculating tools such as sectors, slide rules, and computers; pocket sundials; and sextants – in short, the principal apparatus of astronomy, biology, chemistry, geology, mathematics, medicine, physics, psychology, navigation, surveying, and horology. As collections are assembled, they can be even more expansive in their interpretation. The Harvard Collection of Historical Scientific Instruments, for example, holds telegraph, telephone, radio, and radar equipment, phonographs and early pressings, balloons and kites, test tubes and chemical glassware, mineral specimens, metabolism cages, zoetropes and kaleidoscopes, anatomical models, tuning forks, an organ, vacuum tubes, a rocket nose cone, and a whiffle ball. Thus the term "scientific instrument" applies to objects employed by scientists not only for experiment and measurement but also for teaching, calculating, modeling, and communication. It applies to the apparatus of land-based, practical disciplines related to astronomy – i.e., time finding, navigation, and surveying. It also applies to the material culture of science that finds its way into the hands of nonscientists for their daily use – e.g., pocket sundials and pocket calculators, almanacs, magnifying glasses, dunking birds, and pregnancy test kits. The categorization owes much to the commercial interests of manufacturers and retailers, patent offices, and mechanics' fairs in the nineteenth century, as well as to the classifications employed by museum curators and collectors (Taub 2009; Warner 1990).

As Ulrich et al. (2015) have shown, the classification of all forms of material culture is unstable. A Pyrex pie dish bought at a local supermarket becomes a scientific instrument when placed underneath a metabolism cage to catch the lab rat's waste to be analyzed. A tuna fish can swapped for a Fisher Scientific feeding bowl inside the cage is also part of the instrument. Human teeth pulled from the mouths of Bostonians at Harvard Dental School circa 1900 were anatomical specimens first, carefully suspended from wires inside glass vials. Sixty years later they became another type of scientific instrument when they were ground up and analyzed at the Harvard School of Public Health in order to establish a baseline for environmental levels of polonium to be compared to the polonium absorbed from tobacco smoke by Bostonians. In practice, a scientific instrument can be anything used for a scientific purpose.

To complicate matters further, Warner (1990) has pointed out that the term "scientific instrument" was not adopted until the mid-nineteenth century. Before that time, the instruments were labeled "mathematical," "optical," and "philosophical." Mathematical instruments included all the tools used by mathematical practitioners, who worked in the sixteenth through nineteenth centuries in a variety of applied disciplines in which arithmetic and geometry were employed to solve real-world problems. These disciplines included astronomy, surveying, navigation, fortification, gunnery, dialing, cartography, and computing. The instruments were distinguished by having engraved divisions against which measurements were taken. Examples included sundials, theodolites, sectors, quadrants, and astrolabes. Drawing instruments were usually classified under mathematical instruments, because etuis included protractors, measuring rules, sectors, and dividers, which were employed together for calculations, plus pens, pencils, and compasses used to make maps and charts. Late in the nineteenth century, such instruments came to be called engineering instruments. Optical instruments included lenses, prisms, and mirrors, plus telescopes, microscopes, refractometers, and such which incorporated these components, as well as spectacles and reading glasses. Philosophical instruments took their name from the study of nature known in the early modern period as "natural or experimental philosophy." Philosophical instruments included air pumps, electrical machines, chemical apparatus, and pedagogical devices. In historical discussions, scholars frequently resort to the terminology of the day, but they also pragmatically employ the label "scientific instrument," knowing full well that it is anachronistic but too useful to do without.

Historiography

Most writing about scientific instrumentation has been done by Europeans about European objects but the historiographic arc is instructive and applicable in many ways to the American scene. For most of the twentieth century, scholars were divided into two camps. On one hand, there were historians of science who were biased towards text-based sources. On the other, there were individuals who worked closely with surviving apparatus – e.g., curators of museum collections, collectors, and dealers.

The founder of the discipline of the history of science, George Sarton, emigrated in 1915 to the United States and spent most of his career at Harvard. Sarton was interested in the broad sweep of scientific ideas across civilizations and centuries, and paid little attention to scientific instruments and the details of experiments. Another influential visitor to the United States was Alexandre Koyré. He saw the history of science as part of intellectual history. In "Galileo and Plato" (1943), Koyré argued that observation and experience got in the way of good science. Galileo, he said, dispensed with real-world experiments in favor of philosophical thought experiments unclouded by the messiness of real-world equipment. For Koyré, the heroes of the Scientific Revolution were not craftsmen-scholars, but philosophers who rarely built more than a theory. Sarton, Koyré, and their students, consequently focused attention on the logic of scientific ideas, the influence of philosophical beliefs, and other matters "internal" to the ship of science. By contrast, so-called "externalists" followed the course set in the 1930s by Boris Hessen in *The Social and Economic Roots of Newton's "Principia"* (1931) and Robert K. Merton in *Science, Technology and Society in Seventeenth Century England* (1938), exploring how that ship was tossed about by waves of religion, politics, and economics. By the late third and fourth quarters of the twentieth century, scholars were merging these two streams, with case studies of how religious and political beliefs strongly colored scientific ideas and practice (Shapin and Schaffer 1989).

During this same period there were very few specialized museums of science. Old instruments were kept with decorative arts in art museums, and with technology and industrial arts in national museums. They were also scattered among rooms in historic houses, left in closets of retired apparatus in institutions of higher learning, or beloved in private collections. For example, from 1923 to 1938, the Museum of Fine Arts, Boston, exhibited a private collection of portable sundials dating from 1600 to 1900, which had belonged to Harold C. Ernst, MD, professor of bacteriology at Harvard Medical School. At nearly the same time (1927–1936), the Metropolitan Museum of Art in New York put on display the sundial collection of the late John C. Tomlinson, Sr., a prominent New York attorney. These loaned objects complemented the museum's own holdings of sundials, clocks, and other scientific instruments, which were kept in its decorative arts department and were overseen by curators of Western European art. After the closure of the Philadelphia Centennial Exposition, 1876, the Smithsonian Institution relocated 60 boxcars worth of exhibits on American history, art, zoology, geology, anthropology, medicine, and the technologies of metallurgy, printing, transportation, textiles, fisheries, and agriculture to a new US National Museum. When the building opened in 1881, exhibits on scientific instruments created by firms like Keuffel & Esser (mathematical, drawing), Codman & Shurtleff (surgical, dental), Joseph Zentmayer (microscopes), and W. & L.E. Gurley (surveying), were part of the mix. The Adams National Historical Park in Quincy, Massachusetts, has always shown off globes and telescopes belonging to President John Quincy Adams in their original home setting, and Thomas A. Edison's apparatus remains on view in his laboratory in West Orange, New Jersey, now part of the Edison National Historical Park. Colleges and universities frequently preserve many laboratory instruments in formal or informal collections. Research equipment of one generation often becomes the teaching instruments of the next. Examples of such collections are found at Harvard, Dartmouth, Transylvania University, and the University of Mississippi, to name just a few. Medical schools and hospitals also preserve anatomical specimens, microscopes, and surgical instruments in special collections – for instance, in Harvard's Warren Anatomical Museum in the Countway Library of Medicine or in the Medical Museum of the Armed Forces Institute of Pathology (now part of the National Museum of Health and Medicine). The East India Marine Society of Salem, established in 1799 by sea captains, still exhibits maritime instruments amidst natural and artificial curiosities brought back from voyages around either the Cape of Good Hope or Cape Horn.

In the first half of the twentieth century, those who took care of this material culture of science were usually not formally trained in the history of science, being art historians or senior scientists, and they tended to take an antiquarian approach. They appreciated the instruments for their artistry and craftsmanship, or they sentimentally valued them because of a famous former owner. If the instruments were displayed at all, they were displayed in isolation as artistic productions or library furnishings, which often made the circumstances of their prior scientific use or social context hard to understand. Publications by collectors and scientists concentrated on the development of a particular class of instrument, often including a chronology of related devices and their makers. These early works read like catalogs, but their value should not be dismissed. They laid down important scaffolding for locating the objects and makers in time and place. Examples include Clay and Court (1932) on microscopes, King (1955) on telescopes, and Mayall and Mayall (1938) on sundials.

In 1947, an International Union of the History of Science (IUHS) was established under the banner of the International Council of Scientific Unions and the endorsement of UNESCO with the sponsorship of the Académie Internationale d'Histoire des Sciences. One of its first commissions, established in 1952, was a Commission des Instruments Scientifiques (today known as the Scientific Instrument Commission of the International Union of the History and Philosophy of Science, Division of History and Technology). Its first major project was the establishment in 1956 of a committee to produce a worldwide inventory of historical scientific instruments. The creation of a society of curators, historians, and scientists interested in the preservation and study of early scientific instruments was an important step in the development of the field. Key players in those early years were Henri Michel, Francis Maddison, Maurice Daumas, and in the United States, I. Bernard Cohen, Derek de Solla Price, and Silvio A. Bedini. The Scientific Instrument Commission is still active today, but the field has been augmented by specialized societies for astrolabes, sundials, telescopes, slide rules, balances, and maps, each holding its own meetings and publishing its own journals. Organizations based in the United States, but with international membership, include the North American Sundial Society, the Antique Telescope Society, the Oughtred Society, and the International Society of Antique Scale Collectors.

At a time when few scholars looked at scientific apparatus as more than window dressing, two individuals played an important role in bringing their cultural value to light in the United States: David P. Wheatland and I. Bernard Cohen (Schechner 2012). A 1922 graduate of Harvard College with a bachelor of science degree, Wheatland went to work in 1928 for the Harvard Physics Department, first as a technical assistant to a faculty member, then as department secretary, and in 1940, as the assistant director of the Cruft Research Laboratory of Physics. He oversaw the building of the Mark I computer and was its first civilian operator. Wheatland's duties led to numerous encounters with obsolete instrumentation often discarded in stairwells and attics of the science buildings on campus. He was already a collector of rare books on electricity and magnetism, and he was astonished to see the apparatus depicted in engravings in those books reified in the castoff instruments. He understood that these objects represented an important part of local scientific heritage, but he feared that they were in physical danger due to neglect as well as the propensity of faculty and students to cannibalize them for spare parts. Since the Physics Department did not then see any value in the instruments, Wheatland took them into his office for safe-keeping. He often reunited parts that had long been separated, and he cleaned and repaired the apparatus. When his small office became filled to overflowing with "foundlings," Wheatland sought a new space for the assemblage.

One person taken with Wheatland's cause was I. Bernard Cohen, since 1942 an assistant professor of the history of science, Sarton's student, and the first person to get a PhD in history of science in the United States. Cohen was investigating similarities in the work of Benjamin Franklin and Isaac Newton, and learned that Franklin in the 1760s had personally selected in London many of the rediscovered instruments now in Wheatland's Harvard office (Cohen 1941, 1956). Cohen helped Wheatland to recover other primary documents in the university archives related to the acquisition and use of the apparatus for research and teaching. Together they set up the first exhibition of the instruments in February 1949 (Wheatland and Cohen 1949). This project led to the formal establishment of the Collection of Historical Scientific Instruments with

Wheatland as curator. Cohen's findings about experimental philosophy at Harvard were published in *Some Early Tools of American Science* (1950).

Wheatland continued to collect with context in mind as he rescued instruments from dusty corners and dumpsters at Harvard. He had a real knack for knowing what would be of fundamental historical importance long before anyone else thought to save it. His charming book (Wheatland 1968) stood out because it was neither a technical description of the featured instruments nor a family tree on which he located them like some sort of evolving species. Rather it contained stories about each instrument: what it cost to buy and repair, how professors and students interacted with it, expeditions it went on, and so forth.

If this group of early instrument devotees shared anything in common with the historians of science of their day, it was an "externalist" method. They believed that to understand science – much less its apparatus–one could not simply look at scientific theories. Those who worked with scientific instruments argued for the importance of technical developments, artisanship, commercial practices, cultural aesthetics, social hierarchies, and consumption of instrumentation in understanding the scientific enterprise. During the second half of the twentieth century, more and more members of the Scientific Instrument Commission were trained in the history and philosophy of science, and their publications situated the instrumentation into larger themes in the history and philosophy of science. Topics included mathematical practitioners and the London instrument trade, the material culture of astronomy in people's daily lives, iconography of scientific instruments, how scientific theory and social values influence instrument design, popular science and the spectacle of experiments, courtly patronage and competition, outfitting research expeditions, technology transfer, and relationships between master and apprentice, scientist and craftsman (Anderson, Bennett, and Ryan 1993; Grob and Hooijmaijers 2006; Morrison-Low 2007; Schechner 2001).

Back in the other camp, some historians of science not associated with instrument collections became interested in the 1980s in the connections between theory, experiments, and laboratory culture (e.g., Gooding, Pinch, and Schaffer 1989). Instruments were part of these histories, but they were viewed as unproblematic in and of themselves. In 1994, the History of Science Society published an issue of *Osiris* devoted to the topic of *Instruments* (van Helden and Hankins 1994). While regarded as a "coming of age" for instrument studies, contributors to this volume relied almost exclusively on textual sources in their papers, and only one author had any hands-on experience with actual museum objects.

Some who had hands-on experience found this irksome, particularly when artist David Hockney made the news and garnered a lot of support from the public and scientists for his book, *Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters* (Dupré 2005). Hockney claimed that Renaissance artists could not have painted with such exquisite realism without the help of optical instruments on the sly. One problem with broad claims (such as those made by Hockney and his defenders) about the use and performance of particular instruments was that these claims were based solely on what natural philosophers (scientists) or mathematical practitioners (engineers and technicians) had written about their own inventions or procedures. Such reports are notoriously unreliable and idealized. For instance, during the time of the Old Masters, many published descriptions of instruments were no better than science fiction, describing an imaginary device that was never made or never could work given the quality of materials available and the craft skills of the period (Schechner 2007). Although the hands-on scholars were glad to see what Jim Bennett, the keeper of the Museum of the History of Science in Oxford, called the "current vogue for instrument studies" (Bennett 2003), they still felt marginalized by mainstream history of science where few scholars thought it advantageous, much less necessary, to examine surviving examples or use reconstructions. To address these concerns, Bennett helped to organize a conference, "Do Collections Matter to Instrument Studies?" which was sponsored jointly by the Scientific Instrument Commission of the International Union of the History and Philosophy of Science and the British Society for the History of Science, and held in Oxford in June 2002. In the United States, Sara Schechner, the curator of Harvard's Collection of Historical Scientific Instruments, organized "The Material World of Science, Art, Books, and Body Parts," which was the opening plenary session for the annual meeting of the History of Science Society in Milwaukee in November 2002. The papers delivered at these meetings argued strenuously that the material culture of science offered historians rich evidence that could not be gleaned from textual sources alone. This point continues to be made by museum-based scholars (Morris and Staubermann 2010), but only recently has it been given space in journals such as *Studies in the History and Philosophy of Science* (Taub 2009) and *Isis* (Taub 2011) in the form of small assemblages of papers that take tangible scientific instruments as their starting points.

Bibliographic Essay

The first instruments to make it to the shores of the New World were navigational, surveying, time-finding, and time-keeping instruments, which were needed to explore the coastlines and establish working colonies. The inventories of expeditions such as those of Martin Frobisher in 1576–1578, reports by Thomas Harriot and others, and archaeological digs at sites like Jamestown give a fair picture of these early instruments: They included mariners' compasses, azimuth compasses, nautical charts, dividers, lodestones, sand glasses, logs and lines, sounding leads, cross staffs, backstaffs, mariners' astrolabes, quadrants, sundials, nocturnals, surveyors' theodolites, plane tables and plane table compasses, variation compasses and dip needles, globes, armillary spheres, and mechanical clocks. A pocket sundial played a central role in the famous story of Captain John Smith being rescued by Pocahontas (Schechner 2007). And chemical apparatus for assaying ores was employed in Jamestown. An excellent introduction to the instruments of colonization from an American perspective can be found in a special issue of *Rittenhouse* (Hicks 2007). For the instrumentation set within global contexts, see *The World of 1607*, the catalog of an exhibition celebrating the 400th anniversary of the Jamestown settlement (Jamestown-Yorktown Foundation 2007).

Mathematical instruments also had the distinction of being the first scientific instruments to be sold, made, and repaired in the American territories. Crude slate sundials were made locally at colonies like Avalon, established in 1621 in Newfoundland (Schechner 2004). Otherwise, the earliest known, native-built instruments were eighteenth-century wooden instruments for navigation and quirky wooden copies of brass surveying instruments. A London-made surveyor's compass was fashioned of brass with a silvered magnetic compass whose wind rose was exquisitely engraved and surrounded by a raised ring divided into degrees. Its American-made counterpart was rough-hewn wood with a printed paper wind rose and a divided circle of pewter. American manufacturers turned to wood because the local supply of metals was small, and there were few skilled artisans who knew how to work with it before the second quarter of the nineteenth century. Instrument makers could melt down broken brass implements to fashion new parts, but impurities in the metal made such brass unsuitable for instruments with magnetic compasses. Given the expense and trouble of importing quality brass in ingots and sheets, makers turned to wood, or simply skipped manufacturing all together and sold ready-made imported mathematical instruments (Bedini 1975: 191–6).

To learn more about the makers of surveying instruments in the eighteenth and nineteenth centuries, Smart (1962–1967) offers a starting point in the form of a catalog of makers, but some of the information is dated. Bedini's *Early American Scientific Instruments and Their Makers* (1964) is also devoted to surveying instruments. He divides makers into those who worked primarily in wood, and those who worked in brass, and an appendix divides practitioners into geographical regions and the types of instruments they sold. A problem with this book, however, is a concern that Bedini often took at face value advertisements by persons claiming to be instrument *makers*, when now it is more clear that many were *sellers* and *repairers* of goods imported from England (Schechner 2009). A rare, London-trained mathematical instrument maker in the American colonies was Anthony Lamb; his story is told by Bedini (1984). Bedini's *With Compass and Chain* (2001) is a more nuanced examination of the work of cartographers, surveyors, and instrument makers in the American colonies and new republic, and his *Thinkers and Tinkers* (Bedini 1975) includes the work of navigators and their instrument makers.

Telescopes arrived in the New World not long after their invention in 1608 in Holland. A spyglass was employed for military purposes on a Portuguese ship off Brazil in 1614, a Dutch ship off Peru in 1615, and by the English governor of Bermuda in 1620, but the first telescope for astronomical use was owned by John Winthrop, Jr., the governor of the colony of Connecticut, circa 1657 (Schechner 2014). In the eighteenth century early newspapers and diaries show public interest in stargazing. Colonial astronomers needed high-quality instruments for eclipse expeditions, observations of the Transits of Venus in 1761 and 1769, and geodetical surveying. Ships' captains found spyglasses useful at sea, and telescopes were in demand by officers during the American Revolution. But except for the very rare, occasional homemade instrument, all telescopes were imported from Europe. As with the navigational and surveying instruments, the reason was the want of brass for the tubes of reflecting telescopes. The other problem was the glass. There were no local manufactories for optical glass. Indeed, a close examination of the advertisements of opticians and spectacle makers until the end of the nineteenth century shows that the component lenses, mirrors, and prisms were imported. Even Bausch and Lomb imported its lenses until 1870, making a name for itself on the frames that held the lenses. It was more cost-effective to buy ready-made from Europe than grind one's own (Schechner 2009). When America's first major telescope makers came on the scene in the antebellum period – Amasa Holcomb, Henry Fitz, and Alvan Clark – and supplied the observatories that were popping up like mushrooms around the United States, they also imported the optical glass that they ground for their instruments (Multhauf et al. 1962; Warner and Ariail 1995). Only after World

War I disrupted the imports from Europe, especially from Germany, did the US government make native glass production a high priority (United States Army, Ordnance Department 1921).

Much has been published about the 400-year history of the telescope, including American innovations in wide-field photographic telescopes (astrographs) for land-based meteor studies, space telescopes for deep sky work, radio telescopes, and spectroscopic instruments applied to telescopes (Brandl, Stuik, and Katgert-Merkelijn 2010; Morrison-Low et al. 2012). Nevertheless, little has been written about the development of the optical instrument industry in the United States. *Artists and Optics* (Warner and Ariail 1995), a book devoted to the firm of Alvan Clark and Sons, the telescope makers, is primarily an expanded catalog of all the known instruments sold by the firm, but extremely useful. So are the many articles about lesser-known telescope makers and American observatories published in the *Journal of the Antique Telescope Society.* Nonetheless, much more work is needed to understand how Clark went from being a portrait artist to the maker of the world's largest refractors. The careers and workshop practices of his rivals (such as Henry Fitz and John Brashear) are also worthy of future study.

A similar story of imports making up for a dearth of American innovation and skill is told for microscopes until the mid- to late nineteenth century. Warner (1985) has suggested that a lack of collaboration between engineers, artisans, businessmen, scientists, and government was to blame for the absence of a precision optical industry in Philadelphia. This situation deserves further examination and comparison with the conditions that aided the development of optical firms like the Spencer Lens Company in upstate New York and the work of Robert B. Tolles of Boston Optical Works in Massachusetts.

The lack of scientific glass and brass before the second quarter of the nineteenth century also delayed the manufacture of philosophical apparatus in America, because these materials were central to instruments such as air pumps, electrical machines, hydrostatic and mechanical apparatus, thermometers, and barometers (Schechner 2006). Consequently the study of philosophical instrumentation in the American hemisphere is a study of imports from the parent colonies (England, France, Spain, and Portugal) until the mid-nineteenth century. Many books catalog the cabinets of apparatus at colleges during this period (e.g., Cohen 1950; Granato and Lourenço 2014; Pantalony, Kremer, and Manasek 2005), and Schechner (1982) describes how many items passed through the hands of the Reverend John Prince of Salem, Massachusetts. Prince not only served as an intermediary between the academies and the London instrument makers but also did repair work (Schechner 1996, 2006). Laboratory exercises in the period 1880–1920 are addressed in Heering and Wittje (2011).

The apparatus for teaching mathematics in the United States from 1800 to the present – blackboards and projectors, slide rules and blocks, protractors and graph paper, geometric models and calculators – is well explored in Kidwell, Ackerberg-Hastings, and Roberts (2008). Another good resource is *Rittenhouse: Journal of the American Scientific Enterprise* (1986–2012), a print journal devoted to the production and use of scientific instruments in North America. This is a good place to learn about the instrument makers and retailers from the nineteenth century onwards who supplied everything from school apparatus to telegraph equipment, research quality laboratory microscopes to home medical devices, ship chronometers and experimental psychological apparatus. The journal has now evolved into an online platform, *eRittenhouse* (2013–) and broadened its coverage to all of the Americas. In addition to the manufacture, sale, and use of instruments in the Americas, it also looks at their social impact.

Clocks and watches are generally considered a specialty of antiquarian horologists, but time finding employs observations of the sun and stars with sundials and other astronomical instruments, and these in turn are used to set clocks, watches, sand glasses, and various timing devices. Moreover, clocks not only regulate our lives but also our scientific instruments. America's relationship to clocks is the subject of Stephens (2002).

To extend human life and improve its quality, people turn to healers, physicians, and surgeons. The material culture of health and medicine is the object of study by curators in the Medical Museums Association and related organizations devoted to the history of pharmacology. A history of the American surgical instrument trade is Edmonson (1997).

For research questions on any topic related to scientific instruments the website of the Scientific Instrument Commission (http://iuhps.org/) maintains a database of publications and a cumulative bibliography, as well as links to online scientific instrument trade catalogs, videos, and other resources.

Lastly, major resources for studies of scientific instruments are the instruments themselves, and these can be found in museums, colleges and universities, astronomical observatories, research laboratories, libraries, industrial factories, hospitals, and even the local city hall. Notable North American collections and their specialties include:

- *Adler Planetarium* (Chicago, IL): astronomy, navigation, surveying, time finding, time keeping, mathematics, and cartography, featuring many instruments from the Middle Ages and Renaissance.
- *Bakken Library and Museum* (Minneapolis, MN): electrical phenomena in the life sciences and medicine.
- *Canada Science and Technology Museums Corporation* (Ottawa, ON) supports three museums – the *Canada Science and Technology Museum*, the *Canada Aviation and Space Museum,* and the *Canada Agriculture and Food Museum*: Material culture illustrating how science and technology have shaped Canadian culture; instruments of astronomy, surveying, meteorology, physics, and industries used by departments of the Government of Canada, such as Natural Resources and the National Research Council.
- *Case Western Reserve University* (Cleveland, OH), *Dittrick Medical History Center:* diagnostic, therapeutic, and surgical instruments.
- *Chemical Heritage Foundation* (Philadelphia, PA): alchemical and chemical instruments and artifacts related to the chemical industry.
- *Dartmouth College* (Hanover, NH), *Hood Museum of Art*, *Dartmouth Collection of Scientific Instruments:* items dating back to the founding of the college in 1769 as well as more recent research.
- *Harvard University* (Cambridge, MA), *Collection of Historical Scientific Instruments:* teaching and research instruments from a broad range of scientific disciplines, many with a Harvard history.

- *Harvard University* (Boston, MA), *Warren Anatomical Museum in the Francis A. Countway Library of Medicine*: medical and surgical instruments, anatomical models and specimens.
- *Huntington Library* (Pasadena, CA), *Burndy Library Collection*: electrical instruments, rare early light bulbs, and miscellanea.
- *Manitoba Museum* (Winnipeg, MB): navigational instruments associated with the Hudson's Bay Company.
- *Mariner's Museum* (Newport News, VA): navigational, oceanographic, and maritime instruments from the sixteenth to twentieth centuries, as well as communication equipment such as lights, buoys, and radios.
- *Maritime Museum of the Atlantic* (Halifax, NS): nautical instruments, nineteenth century onward.
- *Massachusetts Institute of Technology* (Cambridge, MA), *MIT Museum*: artifacts documenting MIT's scientific and engineering work.
- *McGill University* (Montreal, QC) is home to three significant collections of instruments: The *Rutherford Museum* has apparatus used by Ernest Rutherford at McGill, 1898–1907. The *McPherson Collection* holds physics instruments from the mid-nineteenth century to about 1920. The *McCord Museum*, formerly administered by McGill, but now a private institution, has material culture related to Montreal and Canada.
- *Musée Stewart au Fort de l'île Sainte-Hélène* (Montreal, QC): globes, sundials, mathematical, surveying, and medical instruments, and the philosophical instruments used by Abbé Nollet and his student Sigaud de Lafond.
- *Musées de la Civilization* (Quebec City, QC) is a consortium of four museums whose focus is the history of French-speaking culture in North America but also includes ethnographic collections related to First Nations. The *Musée de la Civilization* has one of the largest collections of French scientific instruments outside of Paris, including late eighteenth- and nineteenth-century laboratory apparatus, which are part of the important *Séminaire de Québec Collection*.
- *Mütter Museum of the College of Physicians of Philadelphia* (Philadelphia, PA): from suture needles to iron lungs, medical and surgical instruments of all kinds, as well as anatomical models and specimens.
- *Mystic Seaport* (Mystic, CT): navigational and maritime instruments, maps and charts, and watercraft reflecting America's relationship with the sea and inland waterways since 1530.
- *National Air and Space Museum, Smithsonian Institution* (Washington, DC): astronomy, space astronomy, and aeronautics from the modern period, with a focus on US history.
- *National Museum of American History, Smithsonian Institution* (Washington, DC): instruments of astronomy, physics, chemistry, horology, surveying, and navigation, many of which are of European origin, although American artifacts are featured.
- *National Museum of Health and Medicine, Smithsonian Institution* (Washington, DC): material culture related to the history and practice of American medicine and military medicine, including anatomical models and specimens, surgical, dental, diagnostic, and therapeutic instruments, and the *Billings Microscope Collection*.
- *South Carolina State Museum* (Columbia, SC), *Robert B. Ariail Collection of Historical Astronomy:* telescopes and astronomical apparatus, many American-made.

- *Transylvania University* (Lexington, KY), *Monroe Moosnick Medical and Science Museum*: natural philosophy teaching apparatus, 1820–1850.
- *University of Mississippi Museum* (Oxford, MS), *Millington-Barnard Collection of Scientific Instruments*: nineteenth-century apparatus for teaching astronomy, physics, and natural philosophy.
- *University of Toronto Scientific Instruments Collection* (Toronto, ON): astronomy, chemistry, computing, psychology, and physics, primarily nineteenth and twentieth century.
- *Vancouver Maritime Museum* (Vancouver, BC): navigation, fishing, boating, naval affairs, with focus on the Pacific Northwest.
- *Yale University* (New Haven, CT), *Yale Peabody Museum of Natural History*, *Division of Historical Scientific Instruments*: containing apparatus primarily related to physics, medicine, and anthropology.

Today research in scientific instrumentation is more expansive than it has ever been and more integrated into historical and philosophical approaches. And yet, publications about the development and use of instruments in an American context are scarce. So many topics beg to be studied – e.g., the transition from imports to native fabrications (Max Kohl of Chemnitz to CENCO of Chicago); the impact of economics and trade tariffs, war and politics; why the American System of Production was put to work in the Waltham Watch factory but not the workshops of major suppliers of telescopes and microscopes; how instruments were chosen for expeditions (such the survey of Mason and Dixon or the westward exploration of Lewis and Clark); the place of instruments in industrial settings, such as breweries and pharmaceutical firms; how "new" materials (such as hard rubber, plastics, aluminum, anodized metals) become part of instruments; the relationships between instruments and art; and whether "big science" buildings such as observatories or accelerators are instruments in and of themselves.

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ILLUSTRATIONS

The published text omitted these images but I attach them here as a bonus.

[Fig. 1] Samuel Emery, a mathematical instrument maker, in Salem, Massachusetts pasted this trade card of his wares into the case of an English octant he repaired for a customer, circa 1802. Collection of Historical Scientific Instruments, Harvard University, DW0534.

[Fig. 2] David P. Wheatland (*left*) and I. Bernard Cohen take a break in front of an electrical machine made by Benjamin Martin, London, 1766. Benjamin Franklin selected the instrument for Harvard. Collection of Historical Scientific Instruments, Harvard University, 0012.

A Companion to the History of American Science

Edited by

Georgina M. Montgomery and Mark A. Largent

WILEY Blackwell

This edition first published 2016

Registered Office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Offices
350 Main Street, Malden, MA 02148-5020, USA
9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

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Library of Congress Cataloging-in-Publication Data

A companion to the history of American science / edited by Georgina M. Montgomery and Mark A. Largent.
pages cm – (Wiley Blackwell companions to American history)
Includes bibliographical references and index.
ISBN 978-1-4051-5625-7 (cloth) 1. Science–United States–History. I. Montgomery, Georgina M., editor. II. Largent, Mark A., editor. III. Series: Wiley-Blackwell companions to American history.
Q127.U6C635 2015
509.73–dc23 2015019362

A catalogue record for this book is available from the British Library.

Cover image: http://siarchives.si.edu/collections/siris_sic_10277

Set in 10/12pt Galliard by Aptara Inc., New Delhi, India

1 2016

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