Making Light:
Francis Hauksbee and the Isolation of Electric Fire

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Abstract:
Beginning in 1703 when he was appointed Demonstrator of Experiments for the Royal Society of London, Francis Hauksbee pursued a series of experiments on light, which would ultimately lead to his isolation of electric light. Several seventeenth- and eighteenth-century researchers took note of luminescent phenomena in the course of their experiments. Two in particular, Samuel Wall in England and Pierre Poliniere in France, even connected these phenomena with known electricks, such as amber. Francis Hauksbee set himself apart from other experimenters by designing and building unique scientific instruments, most notably an improved air pump. With this air pump, and the support of the Royal Society, Hauksbee was able to conduct a series of experiments into the nature of light. Initially these experiments focused on the effects of vacuum on light generation, but through his experiments Hauksbee established the presence of electricity in generating light, and created electrical instruments, such as the glass rod and globe generator, which would be used by subsequent generations of electrical researchers.

Keywords: history of electricity, Francis Hauksbee, air pump, electric effluvia, phosphorus, electric light, scientific instruments

This paper is currently being circulated for review amongst academics and independent researchers. Please contact dan[at]leverageresearch.org if you have questions or comments about this case study.

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Introduction

Electric light has been a part of the human experience for at least as long as recorded history. Phenomena like lightning strikes and the aurora borealis feature in some of our oldest narratives. Archaeological investigations in such distant locations as South Africa, Norway, and Australia have found prominent use of quartz in rock art, a fact widely attributed to that material's tendency to emit light when struck. Quartz has been used to make light-emitting ceremonial objects in the Americas for centuries.[1] Accounts of static discharges can be found in several ancient records. In the Roman world, for example, the emergence of "flames" from a figure's hair was seen as a good omen or blessing, as when Virgil describes Jupiter's blessing manifesting as "a light tongue of fire" on the head of Aeneas' son, or when the historians Livy and Valerius Maximus tell of flames heralding the rise of Servius Tullius, the sixth king of Rome.[2] The *Bowuzhi*, a record of events and natural wonders written around 290 CE during the Jin Dynasty, observes that "nowadays, it happens that when people are combing their hair, or when dressing and undressing, such lights follow the comb, or appear at the buttons when they are done up or undone, accompanied likewise by a crackling sound."[3]

From these third century accounts, we know that light and electricity have fascinated humanity since ancient times, but systematic explorations of electricity and light only became possible in the seventeenth century. Some earlier ideas in optics, meteorology, or the study of material substances were related to light. However, the categories used in each of these fields differ from those which we now understand as electric light. In ancient and medieval texts, one can often find lightning alongside the glow of heated metal, the flicker of putrefying fish, or the "burning of the sea" reported by sailors.[4] In reading these descriptions, one also gets a sense of just how strange many of these occurrences seemed to those who witnessed them. If "flames" emerging from the hair and body were as familiar as they are today, they could hardly warrant inclusion in a book of wonders, herald the rise of a king, or be taken as evidence of sorcery.[5]

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[1] Jamie Hampson, "The Materiality of Rock Art and Quartz: A Case Study from Mpumalanga Province, South Africa," *Cambridge Archaeological Journal* 23, no. 3 (2013): 363–7. Studies of such a site in the Mojave desert suggest that the practice of using quartz tools in the creation of rock art may go back some 12,600 years, see David S. Whitley et al., "Sally's Rockshelter and the Archaeology of the Vision Quest," *Cambridge Archaeological Journal* 9, no. 2 (1999): 221–47; Alfred Vincent Kidder, *The Artifacts of Pecos* (Garland Publishing, 1979), 93–94; Dale A. Olsen, "Shamanism, Music, and Healing in Two Contrasting South American Cultural Areas," in *The Oxford Handbook of Medical Ethnomusicology*, 2011, 135.

[2] Bk. II, lines 682–683 in Virgil, *The Æneid of Virgil*, trans. Harlan Hoge Ballard (Boston: Houghton, Mifflin, 1902), 85.

[3] Zhang Hua, *Bowuzhi*, ch. 9, p. 3a. Cited in Needham and Lu, *Science and Civilization in China*, vol. 4, 71–74.

[4] According to Seneca the Younger, for example, the aurora most commonly occurs when "fire is kindled by the friction of the atmosphere and is urged headlong by the wind" (*Questiones Naturales*, bk. I, ch. 14–15). A similar "conflict of principles" explanation for lightning can be found in ancient Chinese sources, as well (see Needham, *Science and Civilization in China*, vol. 3, 481–482).

[5] As in the case of Pope Gregory VII; Ionnis Wieri, *Opera Omnia*, 358.

These medieval classifications of light persisted into the seventeenth century. Scientific thinkers classified all light emitting phenomena together, and all electric phenomena together. Electricity was understood solely as an attractive force, similar to magnetism, until pioneering experimenters in the eighteenth century identified myriad other characteristics of electricity. One of these experimenters was Francis Hauksbee, an instrument maker who began working as an experimental demonstrator for the Royal Society of London in 1703. Hauksbee stands out from other electrical experimenters of his day because he was the first to experimentally isolate electric light.

Hauksbee's revolutionary advance provided the basis for new theories of light and electricity. Unknown to the present public, and hailed today by the Royal Society as the epitome of the "unsung hero," Hauksbee developed a set of new tools which allowed him to produce electric light at will. This case study will detail the rise of craft traditions that supplied the glass Hauksbee needed to make more advanced instruments and the competing research programs that attempted to make sense of electricity and light in the seventeenth century and provided a starting point for Hauksbee's own investigation. The study will show that Francis Hauksbee was the first person to experimentally isolate electric light. He invented and refined new instruments and apparatus to generate and study electric phenomena, particularly electric light. Finally, this study will trace the impact and reception of Hauksbee's instruments and experimental practices in the growing field of electrical studies.

Background

Barriers to Discovery

Natural light is unpredictable and irregular. Even in those instances where natural light phenomena can be recorded consistently or reliably, the nature of events like lightning strikes are nearly impossible to study under the kind of controlled conditions required for scientific study. The study of electric light was much more difficult than astronomy, anatomy, geography, or any other Early Modern field that dealt with light.[6]

In keeping with the idea that electricity was an attractive force, seventeenth-century studies employed threads, feathers, scraps of paper, and similar "light bodies" which could be easily moved to indicate the presence of electrical activity. However, these methods were not refined enough to indicate electricity from many instances of light production, such as that produced by

[6] Thomas Kuhn draws a distinction between the "observational sciences" (like anatomy, astronomy, and geography) in which the object of study is observable with the naked eye, and the "Baconian sciences" (chemistry, electricity, magnetism) in which the object of study is effectively invisible, and, during the Early Modern period, can only be studied indirectly by observing and recording their effects. These "Baconian" sciences require highly specialized conditions and instrumentation to reproduce stable effects.

striking quartz. Even though electrical phenomena were documented and theorized, many people still approached them with a sense of superstition. A 1689 report by the physician Camerarius, for instance, relates a case of static shocks in terms reminiscent of a haunting:

> In the month of November last year, a young man of very good temperament, having taken off his clothes to go to bed, perceived on the right side of his shirt three rays of light arranged in a triangle, looking around him to put cause such an effect, he brought his trembling hand to it, but the light immediately increased and spread over the whole shirt, and as he rubbed or agitated it, there came sparks and flames similar to those of several lighted candles. He left his room frightened [and] his shirt, brilliant with fire, inspired the same terror in those who saw him in darkness.[7]

Camerarius includes several useful pieces of information, including the color and brightness of the light, its sensitivity to different clothing materials, that it appeared only at night, and that it followed the young man even as he moved to a residence several miles away. A follow-up investigation two years later added that the man also produced light when combing his hair, particularly after cleaning it, and noting that he was particularly prone to sweating. According to contemporary understanding, motion was believed to be a necessary precondition for "exhalations" like producing light. Sweat would have been taken as evidence of internal motion, or "agitation," so the man being prone to sweating fit within a prevailing theory of light.[8]

Electricity was considered by some to be supernatural, and was comparatively rare. There are many reasons for this, but perhaps the most obvious concerns the material environment. Luminous static shocks are common in much of the world today; for many of us, a response like Camerarius' patient is difficult to imagine. Synthetic polymers are common in modern clothing, and are capable of accumulating large amounts of electric charge from contact with skin, hair, and other fibers. Before the twentieth century, clothing was made from natural materials like wool, linen, cotton, and hemp, which remain electrically neutral in most circumstances. Some materials available to early modern experimenters could produce electrical activity, such as amber or jet, but these are rare and working with them is difficult. Diamonds were a potential exception, since approximately one third of diamonds contain fluorescent elements that convert electrical energy into visible light inside the gem. However, this conversion requires heat and is not common to all electrical substances, which might then throw electrical researchers off the trail (as we will see it did for Boyle).[9]

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[7] Camerarius, "Sur des linges qui jettent de la lumiere pendant la nuit," 316–17.
[8] Camerarius, "Sur des linges qui rendoient de la lumiere dans l'obscurité," 320.
[9] Robert Boyle, "Observations Upon Diamonds," in *The Philosophical Works of the Honourable Robert Boyle Esq.*, 2nd ed., vol. 3, ed. Peter Shaw (London, 1738), 144–; Thomas M. Moses et al., "A Contribution to Understanding the Effect of Blue Fluorescence," *Gems & Gemology* 33, no. 4 (1997): 244–59.

Early modern experimenters relied primarily upon frictionally generated electricity for their work. Even today, however, with the benefit of sophisticated electrical theory and generations of material refinements, frictional electricity is a notoriously fickle domain—one in which experimental results and generalizations are, by contemporary standards, "neither stable nor reproducible."[10] How charged an object becomes and the extent to which it is capable of producing sparks depends not only on its composition but on the humidity, pressure, temperature, and acidity of surrounding materials. How the object is shaped can make a substantial difference, as can its texture, the amount of stress it is under, and the presence of any surface impurities.[11]

These limitations make it difficult to replicate electrical experiments based on frictional generation as well. In the 1660s, Otto von Guericke conducted a series of experiments using a globe made from sulfur to generate electricity through friction. His own letters describe repeated failures to reproduce his earlier results, and the closest thing to a replication published during the period reports only slight electrical attraction and a noise like the moving of a pendulum.[12] Scientists recorded a version of Guericke's experiment in 2010, and noted that the setup itself was difficult to work with and that even producing very basic phenomena such as attraction and repulsion demanded extreme patience.[13]

Problems emerged with less complicated experiments as well. Weather in particular influenced electric properties, leading some to misidentify electric materials as being non-electric, because conditions of humidity and temperature limited their electrical activity while they were being studied.[14] The scientific difficulty of reliably producing electric phenomena for experimental study in the early modern era was mitigated by advances in a seemingly unrelated technology – glass.

Glassmaking

Though the developments took some time to make their way into natural philosophy, Europe experienced a pronounced shift in wealth and materials during the late-Medieval and early

[10] Daniel J. Lacks and Troy Shinbrot, "Long-Standing and Unresolved Issues in Triboelectric Charging," *Nature Reviews Chemistry* 3, no. 8 (2019): 465–76; Yujun Xie and Zhen Li, "Triboluminescence: Recalling Interest and New Aspects," *Chem* 4, no. 5 (2018): 943–71.
[11] Shuaihang Pan and Zhinan Zhang, "Fundamental Theories and Basic Principles of Triboelectric Effect: A Review," *Friction* 7, no. 1 (February 1, 2019): 10–13.
[12] John L. Heilbron, *Electricity in the 17th and 18th Centuries: A Study of Early Modern Physics* (Mineola, N.Y. : Dover, 1999), 218–219. "Diverses Observations de Physique generale," Mémoires de l'Académie royale des sciences depuis 1666 jusqu'en 1699 (Paris, 1733), vol. 2, 233–234.
[13] Dietmar Höttecke, Andreas Henke, and Falk Riess, "Implementing History and Philosophy in Science Teaching: Strategies, Methods, Results and Experiences from the European HIPST Project," *Science & Education* 21, no. 9 (2012): 1233–61.
[14] Robert Boyle, "Experiments and Notes about the Mechanical Origin and Production of Electricity," in *Experiments, notes, &c. about the mechanical origine or production of divers particular qualities* (Oxford, 1675), Experiment VII. "The event of electrical experiments," the author notes, "is very uncertain, and varied by slight circumstances, some of which are altogether overlook'd."

modern periods. A combination of internal and external trade, and rapid imperial expansion (enabled by new military and sailing technology) put the region in an unprecedented position to access natural resources.[15]

With the aid of growing urbanization and related developments in commerce, these helped give rise to new markets for manufactured goods and to the various technologies needed to produce them. These, in turn, found their way into scientific circles, with novel materials and techniques feeding into instrument production and the crafts serving as a training ground and economic support for the most skilled experimenters.[16] The mechanical arts, for instance, found a significant outlet in sugar refining, while chemical knowledge and experimentation were heavily concentrated in textiles and associated dye work.[17] Glassmaking found a similar focus of application in electrical studies.

Initially produced for tableware, jewelry, and similar household items, glassware proved an essential component for scientific instrumentation throughout the Early Modern period. Its transparency, and the fact that it could be shaped and sealed, made it ideal for isolating scientific phenomena while still allowing for observation. The fact that it was non-reactive and relatively easy to clean made it useful for chemical experiments and studying phenomena sensitive to impurities or contaminants. When properly made, glass could also withstand extremes of pressure and temperature, allowing natural philosophers to study experimental phenomena under a wider array of conditions. Finally, it had several important electrical properties. It was an insulator, meaning that it resisted the flow of charge. It could take on a variety of forms, which meant that it was capable of being worked into the thin, large-surfaced shapes most adept at storing voltage. In contrast with many other materials at the time, it was also an exceptionally good frictional, or "triboelectric," generator because glass holds electrical charge very well, with the polarity depending on its composition and the material with which it is paired. [18] For example, when brought into contact with mercury, quartz glass and glass ceramic accumulate a relatively strong negative charge while common soda glass takes on a strong positive value.[19] In

[15] To give but one example, it is estimated that roughly 150,000 tons of silver was extracted from the Americas between 1500 and 1800 (Ward Barrett, "World Bullion Flows, 1450-1800," In *The Rise of Merchant Empires: Long-Distance Trade in the Early Modern World, 1350-1750* (Cambridge University Press, 1990), ed. James D. Tracy, 237. This influx of bullion is widely thought to have facilitated exchange within Europe for long afterwards, and to have catalyzed the rise of the German lowlands (Flanders and the Netherlands), which came, under Spanish control, to hold a considerable portion of the silver seized by Spanish colonists.

[16] Strikingly, of the dozen or so figures most significant in classical electricity (c. 1600-1870), no fewer than four—Francis Hauksbee, Stephen Gray, Benjamin Franklin, and Michael Faraday—came directly from the trades, while a fifth plausible contender, Pieter van Musschenbroek, hailed from one the era's preeminent instrument-making families.

[17] Simon Schaffer, "Experimenters' Techniques, Dyers' Hands, and the Electric Planetarium," *Isis* 88, no. 3 (1997): 456–83.

[18] Notably, the substances most associated with spontaneous discharge during this period, hair and fur, also occupy an extreme position in the triboelectric sequence, comparable to glass.

[19] Haiyang Zou et al., "Quantifying and Understanding the Triboelectric Series of Inorganic Non-Metallic Materials," *Nature Communications* 11, no. 1 (2020): 1–7.

the seventeenth century, glass provided the easiest way of obtaining the voltage needed for visible discharge.

Instrument-quality glass, however, is a relatively late invention. Glass making is a notoriously difficult art, depending not only on individual skill but on the availability of specific ingredients. The absence or inclusion of a given oxide, furnace design, and the source of silica (whether sand, flint, or quartz pebbles) can make all the difference for the workability, durability, and clarity of the glass produced. The presence of different compounds in the glass would also impact its electrical properties and suitability as a material for generators, making “pure” ingredients particularly important for electrical studies.[20] As ancient as the glass trade is, the first varieties suitable for application in electrical experiments emerged only around the mid-fifteenth century, when the artist Angelo Barovier brought together ground, calcinated flint pebbles from Ticino and purified Levantine plant ash to create an optically clear, low-impurity product known as *cristallo* or Venetian glass.

Arriving around the same time as the printing press and just before the onset of massive colonial expansion, the new glass was in a market of unprecedented interconnection and wealth, one able and eager to absorb new products. The crystalline façon de Venise glass became a marker of prestige across the continent, and while the means of producing it were closely guarded, the knowledge eventually spread. Within a few decades, knowledge had spread to nearby cities such as Florence and Genoa, and by the early sixteenth century, nearly identical products were being produced as far away as Antwerp.

The technology’s spread was facilitated by the expansion of Atlantic trade routes which brought increasing wealth to port cities beyond the Mediterranean, the climate-related demand of northern cities for window panes, and the Counter-Reformation, in which a considerable number of protestant artisans found themselves pushed to the North.[21] While northern Italy remained a key player in the glass industry, the market had become increasingly multipolar as time went on, with major centers emerging in the Dutch Republic and, eventually, London.[22]

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[20] 18th century electricians were quite aware of the variable quality of glass for their experiments, noting differences between regional producers and even recommending that experiments be carried out with specific varieties. This feature played an interesting role in early studies of the Leyden jar. See Pieter Present, “Petrus van Musschenbroek (1692–1761) and the Early Leiden Jar: A Discussion of the Neglected Manuscripts,” *History of Science* 60, no. 1 (2022): 119–23.

[21] Glass-workers in colder climates also had the natural advantage of increased demand for windowpanes, providing more outlets for their wares and opportunities for expansion; Macfarlane and Martin, *Glass*, 188.

[22] Though a relatively small producer at the beginning of the 17th century, the aforementioned influx of Southern glass-makers and a series of technical breakthroughs, including the adoption of nearby flint as a silica source and the use of lead oxide as a stabilizer, helped to propel the London industry forward.

The core of these industries was geared toward large markets such as housewares, windows, and spectacles.[23] However, novelties and advances from these areas eventually found their way into natural philosophy.[24] Clear glass containers were adopted in alchemical studies and used to fashion early thermoscopes and barometers. Improved mirrors and prisms initially sold for entertainment were adopted in optics. Spyglasses and microscopes first developed by spectacle-makers found powerful use in astronomy, medicine, and zoology.[25]

As the uses for glass became clear, an increasing number of instruments were built to purpose, either by skilled "mechanicks" employed by gentleman-philosophers or by an emerging class of independent instrument-makers.[26] People like Robert Hooke, who was responsible for the actual construction and operation of Robert Boyle's famed air-pump, fit the first category. The second category is defined by figures like Johan Musschenbroek, who founded the era's preeminent instrument-making workshop and whose son, Pieter, would share in the discovery of the famed Leyden Jar. Though small in comparison to other trades, a distinct instrument market had emerged by the mid-1600s, and by 1700 had developed to the point that trade catalogs advertised scientific apparatus, such as air-pumps, barometers, and medical instruments.[27] By 1700, the materials and skills needed to make instruments for electrical experimentation were well-established and widely available.

The Printing Press

The transition from a culture reliant on oral and scribal traditions to one that includes mechanical printing allowed important new dynamics to emerge in the communication of ideas.[28] The fact that mechanically printed texts are far cheaper to create than hand-copied ones means that more can be produced and disseminated and that classes of society that would otherwise be excluded from written culture are able to participate. This is particularly important for the integration of craft knowledge and natural philosophy. The fact that more written materials could

[23] Artisans specializing in experimental instruments emerged in the late 17th century, and catalogs of off-the-shelf products of the kind common in other markets would not appear until the 18th century.

[24] Despite having populations a fraction the size of France, Poland, or Spain during the same period, the production centers of northern Italy and the Dutch Republic account for what is arguably a majority of the leading experimentalists, including Swammerdam, Leeuwenhoek, Malpighi, Galileo, Fahrenheit, Torricelli, Boerhaave, Huygens, Snell, and Descartes (who worked in Holland despite his French origin). By the mid-to-late 17th century, southern England began to benefit as well, with Newton, Boyle, Halley, and Hooke's work relying quite directly on the region's clear, strong, and refractive lead glass.

[25] The telescope was independently created by the spectacle-makers Jacob Metius and Hans Lippershey, potentially with the help of fellow glass-worker Zacharias Janssen; the microscope is typically attributed to Lippershey and Janssen (S. Bradbury, *The Evolution of the Microscope* (New York: Pergamon Press, 1967), 21.). Newton is widely thought to have obtained his first prism from a local fair (Simon Schaffer, "Glass Works: Newton's Prisms and the Uses of Experiment," *The Uses of Experiment: Studies in the Natural Sciences*, 1989, 78).

[26] Stephen Pumfrey, "Who Did the Work? Experimental Philosophers and Public Demonstrators in Augustan England," *The British Journal for the History of Science* 28, no. 2 (1995): 131–56.

[27] Peter de Clercq, "Exporting Scientific Instruments around 1700," *Tractrix* 3 (1991): 79–120.

[28] Elizabeth L. Eisenstein, *The Printing Press as an Agent of Change* (Cambridge University Press, 1980), see especially ch. 2.

be produced with greater ease also allowed for the integration of larger bodies of information in a single work. A given book could draw on more sources, expanding the range of ideas it encompassed and rendering inconsistencies or disagreements between texts and traditions more noticeable. Incidental discoveries, tangents, and other details that might have been left out by the expensive hand-copying process could also be included, allowing readers to duplicate studies with greater ease and apprehend patterns not recognized by the original authors. Finally, while far from perfect, mechanical printing was more consistent than hand-copying on a per-manuscript basis. Hand-copying introduced opportunities for scribal error with each reproduction and rendered the transmission of detailed instructions more difficult as well as more expensive. The difference is clearest in the case of diagrams and figures, which demanded artistic skill and a content knowledge to render accurately. Printing additional copies of a technical work was much more likely to produce identical reproductions of the original.

Europe experienced dramatic shifts after the introduction of printing. The printing press spread north from fifteenth-century Mainz to the Low Countries of present-day Belgium and the Netherlands and south to the cities of northern Italy, establishing footholds by 1480.[29] By 1550, more works were being published in a single year than in any century before 1400.[30] These newly printed materials were more likely to cover the arts and technical knowledge than earlier hand-copied texts. Entire genres developed in the sixteenth century specifically to transmit technical knowledge related to alchemy, metallurgy, and other branches of knowledge. So-called “Books of Secrets” containing alchemical instruction and recipes remained popular through the sixteenth, seventeenth, and eighteenth centuries, and became a hallmark of print culture during that time.[31] With access to more advanced tools, materials, and skills, and the technology to disseminate new ideas, Europe experienced a relative boom in the publication of natural histories addressing a range of phenomena, including light.

Natural Histories of Light

In the case of light and electrical phenomena, the impact of the press was felt in a few ways. The first and most obvious was that it allowed the compilation of reports. Taking classical authors such as Pliny and Theophrastus as their models, early modern authors such as Conrad Gessner and Sebastian Munster set about documenting the range of their knowledge. Having more sources at their disposal, the records compiled by Gessner and Munster proved significantly

[29] Information on the geographic distribution of presses, see Jeremiah E. Dittmar, “Information Technology and Economic Change: The Impact of the Printing Press,” *The Quarterly Journal of Economics* 126, no. 3 (2011): 1154.
[30] Eltjo Buringh and Jan Luiten Van Zanden, “Charting the ‘Rise of the West’: Manuscripts and Printed Books in Europe, A Long-Term Perspective from the Sixth through Eighteenth Centuries,” 409–45. The estimated book output for the year 1550 is above 3,000,000 books; by contrast, the 14th century, which had the largest output of any going back to the 6th, saw only an estimated 2,750,000 made.
[31] William Eamon, “Arcana Disclosed: The Advent of Printing, the Books of Secrets Tradition and the Development of Experimental Science in the Sixteenth Century,” *History of Science* 22, no. 2 (1984): 111–50.

larger than older ones, swelling the ranks of familiar plants, animals, stones, medicines, and books (bibliographies became an increasingly useful tool).

Unsurprisingly, reports of luminous phenomena grew as well. Rehearsals of classical, biblical, and recent descriptions became commonplace in such collections, with authors attempting to discern some order in the myriad phenomena addressed by the literature. An illustrative case can be found in Johannes Jonstonus' 1631 *History of the Wonderful Things of Nature*.[32] The work contains separate chapters on fire (including fires under the earth, "fires in the waters," and miraculously enduring fires), comets, lightning, ignis fatuus (i.e., will-o-wisps), and ignis lambens, defined by Jonstonus as a flame that "riseth from a thin and fat exhalation, and cleaves to the hairs and clothes of living creatures."[33] The last of these entries informs readers of passages from Virgil, Livy, and Valerius as well as the comparatively recent events surrounding "a boy of Jena pulling off his shir[t] over the hinder part of his head" and "wip[ing] many sparks off with it," as well as a Countess whose hair "seemed to vomit forth fire" as it was combed, a Calabrian horse that "seemed to sparkle" when groomed at night, and the unfortunate story about a friend of philosopher Gerolamo Cardano who was accused of witchcraft after "flames" leaped from his cloak.[34]

These natural histories offered considerably more reports on these strange lights than the ancient and medieval manuscripts, and were far more accessible than earlier works had been. The genre continued to grow throughout the 1600s, with each decade witnessing the publication of new pamphlets and treatises. Phenomena such as the glowing of scraped sugar were recorded for what may have been the first time, and with imperial expansion, the philosophers of Europe found themselves in possession of many new materials and reports from distant lands. The Jesuit scholar Athanasius Kircher drew considerably on contacts in the Americas, receiving samples of lignum nephriticum (a wood containing fluorescent compounds) from modern-day Mexico and drawing on reports of ignis lambens from other clergymen in Chile and Peru.[35] Though classical sources and legendary accounts continued to appear in the literature, they were soon accompanied by a host of contemporary reports, which came to be seen as more trustworthy and left open the possibility of engagement with the author.[36]

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[32] Johannes Jonstonus, *An History of the Wonderful Things of Nature* (London, 1657), dedication. Notably, the sense of unfamiliarity is absent from his discussion of other "Naturall Wonders," such as lightning, rain, and snow, the last of which he recognizes as having "an infinite abundance" in winter. See Jonstonus, *An History of the Wonderful Things of Nature*, ch. 5, ch. 8, ch. 9.
[33] Jonstonus, *An History of the Wonderful Things of Nature*, 76.
[34] Jonstonus, *An History of the Wonderful Things of Nature*, ch. 4. The original account of the cloak incident may be found in Cardanus, *de veritate naturum*, book 10 chapter 49.
[35] Athanasius Kircher, *Ars Magna Lucis et Umbræ* (Amsterdam, 1671), ch. 5, col. 3, experimentum.
[36] As Eisenstein emphasizes, the shift from copied to printed materials fostered a significant shift in orientation toward the past, as the higher consistency of printed materials and the development of "revised" and "expanded" editions meant that newer manuscripts were less rather than more likely to include errors and omissions. Accordingly, forms of light with more consistent reports tended to stay in circulation while those that failed to garner continued observations became subject to increased skepticism.

Steep declines in the production costs for books allowed authors to include greater levels of detail in their accounts. Ancient and medieval records of glowing stones, sparks, and similar phenomena are often no more than a few sentences long. Sixteenth-century texts devote entire paragraphs or pages to a specific phenomenon, and by the seventeenth century one could find entire treatises dedicated to topics as narrow as luminescent insects, phosphorescent stones, or ignis lambens.[37]

Such works frequently included discussions of the form, color, and duration of a given light source; its material composition; where it could be found; how it might be produced; and the circumstances that proved favorable or unfavorable to producing it, including the season, time of day, ambient temperature, and the surrounding humidity.[38] In reading an account of luminous stones, for example, readers learned not simply that a certain specimen was to be found in a given land or in the possession of a notable figure but that it consisted of a "sulfurous gypsum much mixed with arsenic, antimony and copperas water," that its components could be assayed by certain methods (e.g., an acrid odor for sulfur), and that its capacity to emit light depended on its having been calcinated in a specially constructed furnace.[39]

Authors could also afford to report a greater number of their trials, so more reports of null results and extended exploratory trials became available. A 1627 study by Francis Bacon, for instance, lists more than a dozen trials on the glow of rotting wood, including placing the wood in a damp or dry room, leaving it outside in warm or frosty weather, steeping it in oil or water, and excising the shining portions of the wood to observe them in isolation. A generation later, one finds a similar approach in Boyle's studies of phosphorescent diamonds, which included trials in which the diamond was heated by flame, placed in boiling water, rubbed with cloth, rubbed against a piece of horn, pressed with a steel bodkin, rubbed and spit on, and rubbed then dropped in water.[40] This tradition of carefully recording investigations of scientifically interesting natural phenomena extended to studies of electricity and light.

Seventeenth-Century Studies of Electricity and Light

In his book *De Magnete*, published in 1600, William Gilbert provides the first systematic definition of electricity. Gilbert was primarily concerned with the nature of magnets, but needed to differentiate magnetic attraction from electrical attraction. Since ancient times natural philosophers failed to differentiate magnetic and electrical phenomena, going back at least as

[37] e.g., Ezechiel De Castro, *Ignis lambens, historia medica, prolusio physica, rarum pulchrescentis naturæ specimen, etc* (Verona: Franciscum Rubeum, 1642).
[38] See, e.g., Francis Bacon, "Topics of Inquiry Respecting Light and Luminous Matter," in *The Works of Francis Bacon: Translations of the Philosophical Works,* vol. 5 (Longman, 1861), 409-414.
[39] Kircher, *Ars Magna Lucis et Umbræ*, ch. 8.
[40] Robert Boyle, "Observations Upon Diamonds," in *The Philosophical Works of the Honourable Robert Boyle Esq.*, 2nd ed., vol. 3, ed. Peter Shaw (London, 1738), 144–172.

early as 77 C.E. with Pliny the Elder's work *Naturae Historiae*.[41] In exploring magnetism, Gilbert noted that it differed from electricity in several key ways. Electric substances required friction to produce attraction, the attraction was lessened by damp and humidity, and "if a sheet of paper or a linen cloth be interposed" it blocked electrical attraction; none of these limitations were true of magnets and magnetic attraction.[42] James Clerk Maxwell would later disprove Gilbert's separation by showing that electricity and magnetism were two aspects of a shared phenomenon (electromagnetism), however, throughout the seventeenth century, Gilbert's view was the foundation of electrical studies.[43]

Gilbert and subsequent thinkers established an inventory of electric materials analogous to those of light-emitting substances, and the two lists featured a significant degree of overlap. Diamonds, resins, glass, "carbuncles," alum, salt, sulfur, gypsum, antimony, and various crystals or "spars" had been linked to both, and both electricity and light were produced by rubbing the various materials listed.[44] There were also similarities in the best conditions for producing each phenomenon. The rarity (barometric pressure) and coolness of surrounding air, for instance, was known to facilitate electrical attraction and the light emitted by ignis lambens, and both phenomena were frequently taken to consist of "unctuous" or "oily" emanations from the agitated body.

Despite the points of overlap between them, the seventeenth-century literature does not make a clear connection between light and electricity. To contemporary thinking, the link between the two was far from clear. For example, in a series of experiments Robert Boyle showed that rubbing diamonds produced both electric and luminous phenomena.[45] While this was certainly suggestive, not every diamond produced light, and many substances, including rotting wood, putrefying fish, seawater, and artificial phosphors, emitted light with very similar luminous qualities but no electrical effects.

Further, as Boyle's studies made clear, rubbing was only one of several ways in which light could be drawn from a stone. Others included heat and pressure—neither of which were known to elicit electrical attraction—and when the matter was tested directly by placing a small hair beside a diamond that had been heated "till it was qualify'd to shine pretty well in the dark," no attraction was observed between the diamond and the hair.[46]

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[41] Pliny the Elder, *The Natural History*, translated by John Bostock and H. T. Riley, vol. 6 (London, 1857), 397-401.
[42] Gilbert, 52-53.
[43] James Clerk Maxwell, *A Treatise on Electricity and Magnetism* (Oxford: Clarendon Press, 1873).
[44] William Gilbert, *De Magnete* (London, 1600), 48; Niccolo Cabeo, *Philosophia Magnetica* (1628); Thomas Browne, *Pseudodoxia Epidemica* (London, 1650), 61; Athanasius Kircher, *Magnes sive de arte magnetica* (Rome, 1654), book 3, part 3, chapter 3.
[45] Boyle, "Oberservations Upon Diamonds."
[46] Robert Boyle, "Observations Made this 27 of October 1663 about Mr. Clayton's Diamond," *Experiments and Considerations Touching Colours*, London, 1670, 416.

Ambiguities surrounded other materials as well, such as sulfur. Throughout the 1660s, Otto von Guericke, the former mayor of Magdeburg, pursued a series of experiments based around a hollow globe he had made from sulfur. By attaching this globe to a rod, Guericke was able to rotate it, and found that rubbing the specially constructed orb produced not only light and electrical attraction, but also repulsion and a phenomenon that future authors would identify as electrical conduction.[47] However, Guericke did not draw a connection between the electricity and light he observed. He was building on Gilbert's work to try to demonstrate his belief that the world was a large magnet. He saw his globe as a microcosm of the earth; the sulfur and other minerals in the orb were those found in the earth itself (Guericke believed), and should therefore react to stimuli in the same way that the earth itself did. The light, sound, movement, and other behaviors of the apparatus were, in turn, taken as examples of the planet's "mundane virtues."

Sulfur was a known electric substance, and one associated with light. The fact that the substance possessed the "virtues" of both light and attraction was noteworthy, but not conclusive. The material presented many other qualities, such as the capacity to produce heat, sound, and (possibly) fermentation, many of which were associated with non-electric light sources.[48] On its face, the light and attraction of sulfur seemed no more closely related than its light and combustibility or light and heat. These ideas were also not taken up after Guericke's work, as his experiments were both difficult to reproduce and theoretically out of step with broader trends in natural philosophy.[49] Neither Boyle nor Guericke made an explicit connection between light and electricity beyond the observations that the phenomena occurred together under certain experimental conditions.

The diversity of electric substances made it difficult to draw connections of this kind. For example, amber was the best-known electric substance of the era, so much so that the word "electric" is derived from the Greek word for amber. Despite its electrical nature, when experimenters at the Accademia del Cimento in Florence attempted to draw light from amber by sustained grinding, it produced none.[50] Nor, after more than a century of friction-based electrical studies, had a single investigator reported sparks or glowing from amber. The most well-known electrical experimenters of the day, such as William Gilbert, Niccolo Cabeo, and Sir Thomas Browne, are all silent on the matter of amber producing light. Much of the early progress in studies related to light came from experimentation concerned with optics, color, and natural phenomena, such as bioluminescent plants and animals.

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[47] Otto von Guericke, *The New (So-Called) Magdeburg Experiments of Otto Von Guericke* (Springer Science & Business Media, 2012), bk. 4, ch. 15.
[48] In still other portions of the text, he cites such virtues as smell, fermentation, and the influence of the stars, see Guericke, *The New (So-Called) Magdeburg Experiments*, bk.4, chs. 15–16.
[49]Leibniz informed Guericke in a letter that "nowadays, one despises everything said about virtues and qualities and wants to explain everything in terms of size, shape, and local motion" in Leibniz to Guericke, 17/27 August, 1671, cited in Heilbron, *Electricity in the 17th and 18th Centuries*, 218.
[50] Accademia del Cimento, *Essayes of natural experiments made in the Academie del cimento*, 159.

By the late seventeenth century, those interested in the nature of light had an unprecedented body of evidence at their disposal, including: a lengthy inventory of objects and events known to generate light (table 1); accounts describing the characteristics of luminous phenomena and the

Class	Description	Exemplars
Culinary fire	Light accompanied by heat and/or destruction of the illuminated body	Burning wood, coals
Reflected and refracted light	Light redirected from an external body	Sparkling gems, snake scales, shimmering water, moonlight
Light from putrefaction	Light emitted by decaying organic substances	Rotting fish, oak, and veal
Imbibed light	Light that is captured from an external source and released at a later time, typically in the form of a glow	After images on the retina, phosphorescent stones, twilight
Ignis Lambens	An inconstant, “licking” flame that produces no discernable heat; typically associated with oily substrates and friction	Sparks issued from a shirt or beddings
Ignis Fatuus	A form of glowing light canonically seen in humid outdoor regions	Will-o-the wisp, light surrounding sepulchers and gallows
Spiritual light	A flash or glow of light associated with the soul	Phosphenes seen after violent coughs or vomiting, various biblical references
Meteors	Sublunary environmental lights	Aurora borealis, lightning, shooting stars, Ignis Fatuus (in some sources)
Celestial bodies	A constant light from heavenly objects	The sun and stars, other planets
Animal light	A glow or flashing light emitted by living animals	Jellyfish, glow worms, fireflies, oysters
Luminescence of stones	Light emitted by certain stones	Carbuncles, phosphorescent stones, heated or rubbed diamonds
Castor and Pollux, St Elmo’s Fire	A glow seen atop elevated bodies; sometimes classed alongside meteors, other times with Ignis Fatuus	Light on ships masts, spear tips, mountain tops
Perpetual lamps	A form of perpetual fire created by a special alchemical procedure	Attested to in Roman sources

Table 1. Common Examples of Light Emission[51]

circumstances under which they emerged (table 2); and results from parallel literatures on the non-luminous properties of those same objects and events (e.g., analyses of chemical composition in the case of materials).

Taken together, this evidence allowed investigators to form simple taxonomies, novel questions, and integrated theories. Researchers noted a strong connection between light and agitation, with many pointing to friction, heat, turbulent weather, and (in the case of animal light) motion of the "vital spirits" as causes of light.[52] They also observed patterns in the types of materials that gave rise to light. Sulfur and salts were the most commonly cited, as both were known to produce light in relatively refined forms and thought to be present in other light-giving substances (sulfur in hair, fur, putrefying substances, and pyrite; salts in seawater, marine animals, and the so-called "volatile salts" of ammonium carbonate; and both in gunpowder and several artificial phosphors).[53] Other substances such as antimony and "viscous" or "oily matter," a material sometimes but not invariably identified with sulfur, also received attention.[54]

In an effort to differentiate between luminescent phenomena, researchers tracked how different materials and events responded to the introduction of water, oil, and spirits. They also investigated each phenomenon's relation to external light sources, such as whether it required prior exposure to an outside source to light, as artificial phosphors typically did, or if it emitted light "of itself," as in the case of ignis lambens or the glowing of scraped sugar. A few also noted interesting relations to the surrounding air, including its temperature, density, humidity, and acidity, among other things. Athanasius Kircher, for instance, argued that the rarified air (that is, air under vacuum) of the upper atmosphere was responsible for meteorological phenomena such as falling stars, St. Elmo's Fire, and other "fiery impressions," substantiating his point with the

[51] See Conrad Gesner, *De lunariis* (Copenhagen, 1669), 3–23; Kircher, *Ars Magna Lucis et Umbræ*, book 1, part 1; Boyle, "the Aerial Noctiluca," *The Philosophical Works of the Honourable Robert Boyle Esq.*, 2nd ed., vol. 3, ed. Peter Shaw (London, 1738), 173–213; Jonstonus, *An History of the Wonderful Things of Nature*, ch. 5, ch. 8, ch. 9; Daniel Puerarius, De Carnibus Lucentibus (Copenhagen, 1667), 116–36; Paolo Casato, *De Igne* (Venice, 1686), 344–49; Pierre Borel, *Historiarum, et observationum medico physicarum* (Paris, 1656), obs. 3; Antoine Furetiere, "Lumiere," in *Dictionaire universel* (Rotterdam, 1690).

[52] Robert Hooke, 'Considerations upon Mr. Newton's discourse on light and colours' in *The History of the Royal Society*, vol. 3, ed. Thomas Birch (London: 1757), 10–15.

[53] That sulfur glowed when rubbed was reported by Guericke in 1672, while the propensity of rocksalt to emit flashes when ground was noted by the Accademia del Cimento in the middle of the century; Accademia del Cimento, *Essayes of natural experiments made in the Academie del cimento*, tr. Richard Waller, 158–59). Both substances had long been known to emit light when burned, as well.

[54] Jacques-Rudolphe Camerarius, "Sur des linges qui jettent de la lumiere pendant la nuit," *Collection académique, composée de mémoires, actes ou journaux des plus célèbre académies et sociétés litteraires de l'Europe: Partie étrangère*, vol;. 6, 316–317; Camerarius, "Sur des linges qui rendoient de la lumiere dans l'obſcurité," *Collection académique, composée de mémoires, actes ou journaux des plus célèbre académies et sociétés litteraires de l'Europe: Partie étrangère*, vol. 6, 320; Jonstonus, *An History of the Wonderful Things of Nature*, ch. 1, article 5; ch. 4.

observation that in the high Andes one could often "see travelers…wholly fiery, and also horses and beasts spewing flames with their mouths and nostrils."[55] Although many light phenomena were only observable when they occurred naturally, there were some that could be reproduced through human intervention.

Differentiating Feature	**Contrasts**
Physical state	Liquid, Vaporous
Animacy	Organic and living, Organic and dead, Inorganic
Composition	Sulfur, Acid, Salt.
Location	Sublunary, Superlunary
Mode of production	Heating, Striking, Rubbing, Exposure to light
Duration	Perpetual, Extended, Brief
Interaction with water	Diminution, Facilitation, Non-interaction
Interaction with spirits	Diminution, Facilitation, Non-interaction
Interaction with oils	Diminution, Facilitation, Non-interaction
Interaction with flame	Diminution, Facilitation, Non-interaction
Morphology	Lightning-like, Flame-like, Diffuse glow
Color	White, Purple, Blue, Green

Table 2. Dimensions of Intervention

The "mercurial phosphorous," first reported by the astronomer Jean Picard, was one of these. Picard had observed one night when transporting a standard mercury barometer from his observatory to Port Saint Michel that the mercury barometer glowed. "When moved enough to make the quicksilver jump," the barometer "flashe[d] like lightning & thr[ew] a certain intermittent light."[56] Unsure what to make of it, Picard showed the barometer to several associates and attempted to reproduce the behavior in other barometers. Results were mixed, but the observation was noteworthy enough to be published in a brief 1675 letter to the *Journal des Sçavans*.

[55] Kircher, *Ars Magna Lucis et Umbræ*, ch. 5.
[56] Jean Picard, "Experience faite à l'Observatoire sur le Barometre simple touchant un nouveau Phenomene qu-on y a découvert" *Journal des Sçavans de l'An M.DC.LXXVI.* (Amsterdam: Chez Pierre le Grand, 1683), 126.

Broadly speaking, the effect depended on a couple of factors. The first was the instrument's composition. The barometer's thin glass tubing worked in a manner similar to the glass-rod generators of later decades, with the stick-slip friction of the mercury running along the vessel's interior wall creating a small measure of voltage between them. Unlike the rods, however, the barometer's interior was not an open-air environment but a low-pressure one. As Kircher noted in the case of ignis lambens a few decades earlier, the phenomenon we now know as electrical discharge is far easier to produce in moderately low-pressure conditions.[57] While the light was subtle enough to require dark viewing conditions, then, the degree of friction needed to produce it was small enough for the phenomenon to be discovered accidentally, as Picard did, particularly given the fact that barometers were fairly common at that point (Figure 1).[58]

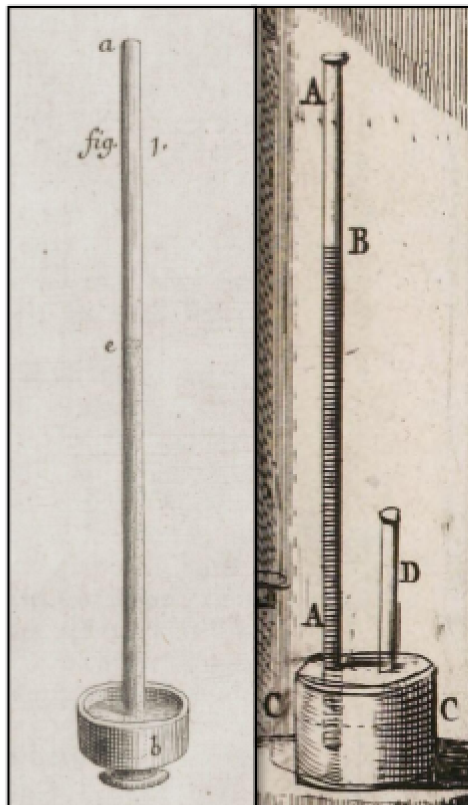

Figure 1. Left: simple form barometer Right: closed form barometer

Initial reactions to the finding were somewhat muted. The letter published in the *Journal des Sçavans* itself was quite brief, and as with similar phenomena, the result proved difficult to recreate. Picard and his associates promised to relay more information as their investigations unfolded. Only one of several barometers tried (other than Picard's own) showed the phenomenon. As a 1694 discussion indicates, moreover, the original instrument became unreliable after a few years, ceasing to produce light entirely after the astronomer's death in 1682 (though it was subsequently revived by a colleague).[59]

The result was not entirely without replications, though, as the same report indicates that Giovanni Cassini, the Italian mathematician, had succeeded in producing light with his own barometer, and between 1700 and 1701, Johann Bernoulli reported a series of studies to the

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[57] More precisely, discharge follows a relation known as Paschen's law according to which the breakdown voltage of a gas (i.e., the point at which discharge occurs) varies as a function of its pressure and the distance between the charged surfaces. More precisely: $V = BPD/(\ln(APD) - \ln(\ln(1 - 1/G))$ where V is the breakdown voltage, B is an empirically derived constant, P is the pressure, D is the distance separating the charged surfaces, A is the saturation ionization for a given electric field/pressure, and G is the secondary electron emission coefficient.
[58] R. P. Cherubin, *Effets de La Force de Contiguité Des Corps, Par Laquelle on Répond Aux Expériences de La Crainte Du Vuide et à Celles de La Pesanteur de l'air* (Paris, 1688), 48; Joachim d' Alencé, *Traité Des Baromètres, Thermomètres et Notiomètres Ou Hygromètres* (Amsterdam, 1688), figure 2.
[59] Though difficult to say, the issue with Picard's barometer may have resulted from the mercury coating the instrument's inner surface over time, reducing the resulting voltage.

French Academy that covered the effect in detail.[60] By thoroughly cleaning the interior of the barometer and eliminating surface contamination from the upper portion of the mercury, he was able to obtain the result far more reliably, rendering it a more promising topic of research.[61]

In contrast to Picard and his associates, Bernoulli went out of his way to sell the phenomenon, describing it as "very easy" and stating "the curious to whom I have shown [a refined version of the effect] have confessed that that they have seen nothing rarer; indeed, the entire capacity of the phial is in flames, and the mercury resembles a burning liquor."[62] He even suggests that the phenomenon could represent a practically endless source of light, claiming that his techniques offered a way of "making mercury a portable and perpetual Phosphorus, which I can transport and send conveniently and without danger wherever I want and all the time"—a significant claim in an era when artificial phosphori sold for large sums on the open market.[63] Shortly after Bernoulli's intervention, then, the area witnessed an influx of new experimenters attempting their own dark-room tests, and it is from this influx that the first clear demonstrations of electric light emerged.

Studies of light and investigations of electricity developed separately throughout the sixteenth century. Luminescent phenomena were defined by simple observation of light, and were classified based on the purported underlying mechanism by which that light was produced. Light could be caused by fire, reflection, movement, heat, or various atmospheric events, but there was little understanding of the essential nature of light.

Electricity, on the other hand, was not seen as a form of energy, but rather as an effluvial force. The theory held that certain materials emitted "effluvia" which were invisible strands which remained connected to those materials. Manipulating a material or its conditions in specific ways could cause it to emit more or less effluvia, and when an effluvium returned naturally to the material from which it came, it carried surrounding objects with it. This resulted in the observable attractive force of electric bodies. These effects were measured by using light objects, like a thread, which would be pulled toward a piece of amber when that amber was rubbed, thus demonstrating the presence of electricity. The underlying theoretical mechanisms of luminescence and electrical attraction were of such different categories that they were rarely studied together and most people saw them as unrelated.

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[60] Picard, 126; Johan Bernoulli, "Nouvelle maniere de rendre les Barometres lumineux," *Memoires de l'Academie Royale des Sciences de l'Annee 1700* (1703).
[61] Bernoulli, "Nouvelle maniere de rendre les Barometres lumineux," 185.
[62] Johann Bernoulli, "Nouveau Phosphore," *Memoires de l'Academie Royale des Sciences de l'Année 1701* (1743): 8.
[63] See Gad Freudenthal, "Early Electricity between Chemistry and Physics: The Simultaneous Itineraries of Francis Hauksbee, Samuel Wall, and Pierre Poliniere," *Historical Studies in the Physical Sciences* 11, no. 2 (1981): 203–29.

Hauksbee's Contemporaries

There were, however, some experimenters who did recognize and explore some form of connection between electricity and light. Samuel Wall, a longtime assistant to Robert Boyle, believed that phosphors derived their light-giving properties in part from the sulfur and salts within them, as urine and feces contained both sulfur and salts, and were associated with light in their purest forms. This was based in part on Boyle's own experiments with phosphorescence and urine – which led him to comment that he "really pitty'd his Chymist, who was forc'd to evaporate so prodigious a Quantity of Urine, to get a very little of the Phosphorus."[64] This eventually drew Wall's attention to amber, which he took to be a coagulated "mineral oleosum" (i.e., an "oily," sulfurous substance).[65] On this hunch, he set about conducting various experiments at night with a piece of amber embedded on the head of his cane. After some time, he found that rubbing the amber could produce light. Using "a pretty large piece of Amber, which [he] caused to be made long" and a piece of wool, he found that the light was still more noticeable and that, when rubbed quite rapidly, the substance emitted a crackling sound similar to burning coals.[66]

Wall then turned to diamonds, which he knew from Boyle's work were both a natural phosphor and an electric material. After finding similar results with diamonds to those he found with amber, Wall experimented with gum lac and red sealing wax, which produced the effect as well. By the end of his trials, he had convinced himself that "all or most of the Bodies which have an Electricity yield Light" and that it was "the Light that is in 'em, which is the cause of their being Electral [sic]."[67]

Although Wall connected electricks and light, he misunderstood the connection in a number of ways. He believed light was the root cause of electrical activity, and that he was describing a chemical phenomenon. According to him, light was an inherent quality of sulfur and salts within substances, and various reactions of those materials produced electrical attraction as well as the release of their inherent light. Based on his description of light as a causal precedent to electrical attraction, it seems he believed that the light and electricity produced were separate phenomena resulting from chemical reaction.

Pierre Poliniere, working at the same time as Hauksbee in 1705 and 1706, also uncovered a connection between light and electricity, but he did not pursue this connection and believed the

[64] Samuel Wall, "Experiments of the Luminous Qualities of Amber, Diamonds, and Gum Lac, by Dr. Wall, in a Letter to Dr. Sloane, R. S. Secr," *Philosophical Transactions of the Royal Society of London* 26, no. 314 (1708): 69–76, 69.
[65] Ibid., 71.
[66] Ibid., 71; Pierre Poliniere, *Experiences de physique* (Paris, 1709), 98.
[67] Wall, 74.

light was produced by the physics of a vacuum, not by electricity.[68] In the years following Bernoulli's letters, Poliniere took an interest in the mercurial phosphorus, thinking, as most French observers did at the time, that the light resulted from a subtle matter in the upper portion of the barometer, in which the air was "rarified," under light vacuum.[69] In contrast with earlier authors, however, he came to suspect that the key variable in the release of light was not the presence of mercury per se but the agitation of the rarified air. To test this, he exhausted a glass tube and set about rubbing and striking it in a darkened cellar, finding that the vessel produced a light "the size & shape of a branch of coral, or the figure of stag horns."[70] Having successfully produced light in the absence of mercury, he then turned to the efficacy of friction in open air, coming eventually to the topic of electricity.

Poliniere never states the reasoning behind this shift in his focus, but he was likely aware of Bernoulli's 1701 claim that pure mercury sparked in open air and his 1707 collaboration with Cassini showing that copper, gold, silver, and different cuts of diamond also produced light when rubbed on glass. The shift from experimenting in vacuo to open-air conditions would have been fairly natural in this case. As for electricity, it is possible that the connection was made because of the known electric properties of glass and diamonds. It is also possible that Poliniere experienced electric attraction when rubbing one of the barometers used in his experiments, though no such observation is mentioned. Whatever the cause, Poliniere found himself rubbing, striking, or scraping a host of electric substances, including red wax, amber, sulfur, glass, flint, and "pebbles" (likely quartz).[71] In each case, the substances emitted light when tested in darkness. His conclusion from these experiments was more measured than Wall's, but pointed in the same direction: "bodies which, being rubbed, have the property of attracting neighboring straws or other light bodies toward them, give off light when this friction is made in a dark place."[72] Although he noted a connection between electric bodies and light, Poliniere was clear in his theoretical explanation of light:

> …light consists of the agitation and pressure of a matter much more subtle than the coarse air we breathe. This subtle matter, passing freely through the pores of the glass, is found more clearly in the place which is free from coarse air, and the shock that is communicated to it by rubbing the exterior surface of the glass is perpetuated on all sides, at a certain distance, because of the contiguity of its parts.[73]

[68] David Corson, "Pierre Poliniere, Francis Hauksbee, and Electroluminescence: A Case of Simultaneous Discovery," *Isis* 59:4 (1968), 402-413.
[69] Poliniere, 469-470.
[70] Ibid., 467-474.
[71] Ibid., 471-476.
[72] Ibid., 473.
[73] Pierre Polinière, "Nouvelle decouverte sur la lumière, espece de phosphore," *Procès-Verbaux de l'Academie des Sciences*, 17 Nov. 1706, p. 351r - original "la lumière consiste dans l'agitation et la pression d'une matiere beaucoup plus subtile que l'air grossier que nous respirons. Cette matiere subtile passant librement par les pores du verre, se trouve plus dégagée dans le lieu qui est vuide d'air grossier, et l'ébranlement qu'on luy comunique en frotant la surface extérieure du verre se perpetiie de toutes parts, a une certaine distance, 'a cause de la contiguite de ses parties."

This explanation of a contiguous subtle matter which produces light when set in motion by rubbing a glass vessel fit with prevailing effluvial theories of light in the early eighteenth century.[74]

The explanations offered by Samuel Wall and Pierre Poliniere represent two distinct schools of thought related to electricity and light, each of which inspired its own research program. Samuel Wall represents the first approach, which looked to chemical composition and the inherent qualities of minerals for explanation. Otto von Guericke believed the material makeup of the earth was responsible for a number of phenomena, and experimented extensively with his sulfur globe (which was essentially an early static generator) as well as with an air pump he designed. His air pump was copied and improved by Robert Boyle, who pursued a number of his own experiments both with the air pump and with the luminous qualities of electric bodies (such as his work with diamonds). He too believed these phenomena were explained by the constituent elements of the substances involved. Finally, Samuel Wall, Boyle's assistant, believed that the expression of light and electricity was the result of substances containing light through their mineral composition.

Poliniere represents the second approach, which looked to the ways in which variations in air pressure impact chemical and physical qualities. Jean Picard believed the mercury in his barometer produced light. Johann Bernoulli seemed to confirm this idea by creating "perpetual phosphors" from small glass containers partially filled with mercury. Although Poliniere proved that mercury was not an essential element in these phenomena, his work grew out of a set of beliefs that light was caused by the physics of subtle matter. Each of these experimenters understood the phenomena they observed and recorded differently. Wall's commitment to a chemical explanation of light production led him to associate electric bodies with light, but to misunderstand the causation involved, and gave him no reason to explore electrical experimentation any further. Poliniere's commitment to a Cartesian explanation of effluvial physics seemed to provide a satisfactory explanation without reference to electrical activity, making any electrical experimentation a moot point in his view. Although Hauksbee was working shortly after Wall, and at the same time as Poliniere, his ability as an instrument maker, and his own theoretical focus led him to pursue a deeper, and ultimately more impactful, course of experimentation.

[74] It is possible that Poliniere's claim that a *single* subtle matter was the cause of light was challenging the Cartesian idea (supported by Bernoulli) that two aetherial elements moving around each other were responsible for creating light in the mercurial phosphorus. However, he did retain the Cartesian ideal that subtle matter filled in perceived space creating a "contiguity of parts" between all matter.

Francis Hauksbee and Electric Light

Born in 1660 to a family of textile makers, Francis Hauksbee was representative of economic trends which gave more opportunities to artisans within a growing middle-class. The England of Hauksbee's youth, while sharply stratified along class lines, was nevertheless one of rising literacy rates and expanding education. At the age of "twelve years old, more or less," Hauksbee was admitted to the Colchester Royal Grammar School, a state endowed school that had taken his brother Charles on scholarship two years prior.[75] Though originally founded for the instruction of classical Latin, by the latter half of the seventeenth century, the curriculum expanded to include arithmetic, English, and other subjects of use to the increasing number of students slated for work in the trades. It is also likely that Hauksbee received at least an elementary education in the record keeping and compositional skills he ultimately put to use at the Royal Society.

In keeping with tradition, he was apprenticed in 1678 to his elder brother John, where he learned the craft of textile making and gained skill in machining.[76] Membership in the Draper's Company of London was passed down to both Francis and John through their father, allowing them to work in the city, and in previous eras, Francis would most likely have remained in this trade.[77] By the late seventeenth century, however, the guilds had begun to function more as general licensing institutions, with many members going into unclaimed domains such as instrument making, which Hauksbee did.[78]

The timing of Hauksbee's decision to pursue instrument making is difficult to place, but advertising records indicate that he was actively manufacturing glass tools by 1699 and likely for some time before that.[79] Hauksbee's first advertisement comes in a copy of *The Post Man* from January 31st, 1699, which lists Hauksbee as the inventor of a novel cupping glass.

Cupping was a medical procedure that used the suction generated by heated cups to draw blood toward the skin or out of small incisions, helping to balance bodily humors.[80] Early versions of the procedure involved cups of bronze or horn, but by Hauksbee's time, the standard instrument

[75] John Horace Round, *Register of the Scholars Admitted to Colchester School, 1637-1740* (Colchester: Wiles and son, 1897), 63, 68. Specifically, the entry states that Charles was "to be taught without reward" (63). The record also includes an entry for a "Richard Hawksbee," listed as one of twelve free pupils in 1663 (61).
[76] The importance of machine work in John's business is indicated by a patent petition in his name for a "new engine for fulling" (*Calendar of State Papers*, 352, 382).
[77] That is, to work in London generally, not specifically in the City of London.
[78] Lesley B. Cormack, Steven A. Walton, and John A. Schuster, *Mathematical Practitioners and the Transformation of Natural Knowledge in Early Modern Europe* (Springer, 2017), 79.
[79] Terje Brundtland, "Francis Hauksbee and His Air Pump," *Notes and Records of the Royal Society* 66, no. 3 (2012): 253–72 (255).
[80] Terje Brundtland, "From Medicine to Natural Philosophy: Francis Hauksbee's Way to the Air-Pump," *The British Journal for the History of Science* 41, no. 2 (2008): 213–14.

was made of glass, as the material allowed for inspection of the application site during use.[81] The simplest cupping glasses could be blown by anyone familiar with glassmaking, but over the years, various conveniences were added to the design in the hopes of capturing more of the market.

In Hauksbee's case, the major additions appear to have centered on pressure regulation. Instead of using heat to produce suction, Hauksbee's design employed a removable syringe, simplifying the process by removing the need for flame and any concern about burning the patient's body.[82] As the apparatus could be removed and replaced without destroying the seal, moreover, it allowed for multiple glasses to be affixed with the same syringe and for cups to be re-pumped after they had been applied to the skin, increasing the potential duration of a treatment.[83]

In addition to being more convenient, the device also seems to have produced far better results in terms of pressure, allowing, by Hauksbee's estimates of a similar syringe years later, for values as low as 5% of the surrounding atmosphere.[84] If the number of advertisements is any indication, Hauksbee's wares sold well. Between 1699 and 1703, he published no fewer than 25 advertisements in various posts and almanacs, including advertisements for mail-order instruments, and in 1701, we find his first recorded entry into the domain of philosophical instrumentation proper: "an engine which serves as an air-pump for making experiments in vacuo."[85]

The step was, in many ways, a natural one to make. Air-pumps were often compared to cupping glasses in the philosophical literature, and the latter had even been used in experiments where the full-sized pump proved too large.[86] Though less widely used than the smaller devices, air-pumps would have had some marketability, at least in a metropole like London.

Early on, pumps had been constructed by specific experimenters for specific ends. The first versions were developed by Guericke in 1649 and Robert Hooke in 1658. Excepting the earliest versions used by Guericke, which employed either wooden barrels or large brass kettles, they consisted of a piston-based pump and a transparent glass chamber, or "receiver" in which objects could be deposited (figure 2).[87]

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[81] Celsus, *On Medicine*, II, 11.
[82] Means of avoiding the burning of skin were a common part of medical texts of the time; see, e.g., John Pechey, *A Plain Introduction to the Art of Physick* (London, 1697), 149.
[83] Brundtland, "From Medicine to Natural Philosophy," 214–216.
[84] Terje Brundtland, "Pneumatics Established: Francis Hauksbee and the Air-Pump" (PhD Thesis, University of Oxford, 2006), 47.
[85] *The Post Man*, 13 November 1701 cited in Brundtland, "From Medicine to Natural Philosophy," 224.
[86] Robert Boyle, *The Philosophical Works of the Honourable Robert Boyle Esq.*, 2nd ed., vol. 2, ed. Peter Shaw (London, 1738), 502–3.
[87] Robert Boyle, *New Experiments Physico-Mechanical, Touching the Spring of the Air, and Its Effects, Made, for the Most Part, in a New Pneumatical Engine* (Oxford, 1660), Figure 1.

Most of the studies in which they were employed concerned debates over the existence of vacuums and the nature of air.[88] As time went on, however, the tool came to be used in an increasing number of domains. Boyle, for instance, employed one of the pumps Hooke had made for him to investigate the effect of air on burning coals, artificial phosphors, and the light of rotting wood.[89]

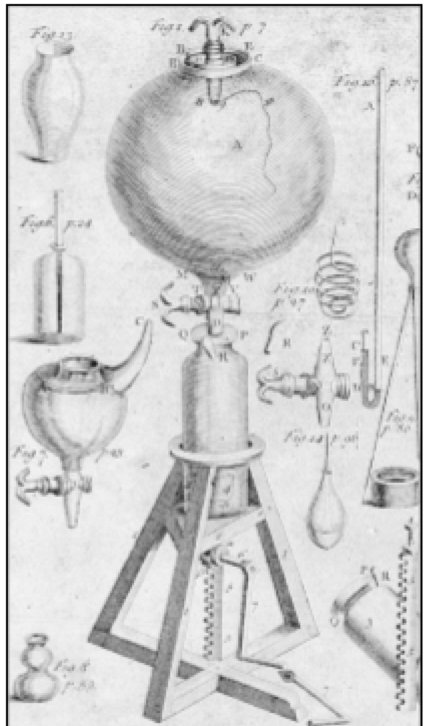

Figure 2. Hooke-Boyle Pump from *New Experiments Physico-Mechanicall*

Though this was not yet realized, the air-pump was an ideal instrument for studying electric light. As we noted in the case of barometric light, lowering the air pressure of an environment dramatically increases one's ability to create luminous discharge, and in fact, there is reason to believe that air-pump operators had encountered the phenomenon almost as soon as they began working with the instrument. In *the Spring of the Air*, for instance, Boyle notes that, when operating the pump, one would sometimes see a "kinde of light in the receiver, almost like a faint flash of lightning in the day-time."[90] The unpredictable flashes reportedly came when adjusting the metal valve leading into the glass chamber, and presumably resulted from static electricity being communicated thereby.

As significant as they were, however, the first designs were quite difficult to work with. To exhaust the receiver, which was the process of pumping out the air to create a vacuum, experimenters opened a small passageway between it and the piston barrel using a valve-control mechanism known as a stopcock. The piston would then be pulled outward, drawing air from the receiver into the barrel. From here, the stopcock would be turned again to close the receiver off and seal the air inside the piston barrel. Next, a separate valve would be opened leading from the piston barrel to the outside. The piston would then be compressed, driving the captured air. Finally, the valve to the outside would be closed back, allowing the experimenters to begin the cycle anew. To minimize leakage, seals at each of the pump's joints had to be carefully maintained with wax and cement, which would be mixed and applied to the base of the receiver before each experiment.

Without a measurement system or a means of regulating air inflow beyond the primitive stopcock, moreover, the pressure inside the receiver was difficult to set with any precision.

[88] See Boyle, *New Experiments Physico-Mechanicall*, A Summary of the chief Matters treated of in this Epistolical Discourse.
[89] Robert Boyle, "New Experiments Concerning the Relation between Light and Air (in Shining Wood and Fish)," *Philosophical Transactions of the Royal Society of London* 2, no. 31 (1671/1672): 581–600.
[90] Boyle, *New Experiments Physico-Mechanical, Touching the Air*, 1660, experiment XXVII.

Replicating results thus proved trickier than might otherwise be expected. Most importantly for electricity, experimenters were limited in the kinds of interventions they could perform. The use of removable glass chambers allowed objects to be placed inside, but these had to be introduced before pumping began, and relatively little could be done to them afterward. To study the behavior of pendulums, for example, Boyle and Hooke were forced to put the whole instrument in motion instead of simply releasing the weight from a desired height.[91] Experimenters' ability to study frictional phenomena was limited. Either, they could agitate the entire pump, as Picard did with his barometers, or they could rub an item and subsequently enclose it in the pump's register, as Boyle did. When the first attempts were made to study electricity in vacuo, the most that could be done was to place an already excited piece of amber in the register and see if it remained so in vacuo.[92]

There was, in short, ample room for improvement, and given the instrument's prominence, a market for improved air-pumps. Though one could hardly make a living producing pumps alone, the production of simplified or improved designs could provide a worthwhile stream of revenue for someone living in a major city. Such a path had already been traveled by Johan Musschenbroek in Leiden, and given the pre-existing commonalities between air-pumps and cupping (which were routinely compared to one another at the time), Hauksbee's decision to enter the market is unsurprising.

Hauksbee was effectively the sole producer of these goods in the area, and more importantly, the improvements he'd developed in constructing his cupping devices transferred readily to the larger pump designs.[93] By transferring the one-way flap valve system he'd developed for his syringes, Hauksbee was able to eliminate the cumbersome process of opening and closing valves that had characterized the stopcock system.

The process of securing the apparatus' joints was streamlined as well. Instead of using cement, which was less effective and had to be mixed and re-applied with each experiment, he employed wet leather gaskets and screw-on joints similar to those on his detachable syringes (figure 3).[94] To assess the receiver's pressure, he attached an external barometer (figure 3, G), and to regulate it, he gradually unscrewed the joint attaching the piston/cylinder to the receiver (considerably more precise than the stopcock, which went from fully closed to fully open with a 90 degree turn). Although many other electrical studies made use of stopcocks, these typically used a flexible cement to form gaskets, which needed to be reapplied each time the device was used. Hauksbee's design was more efficient and easier to use.

[91] Boyle, *New Experiments Physico-Mechanical, Touching the Air*, 1660, experiment XXVI.
[92] Robert Boyle, "Experiments and Notes about the Mechanical Origin and Production of Electricity," in *The Works of the Honourable Robert Boyle* (London: J. and F. Rivington, 1772), vol. 4, 352 footnote.
[93] Brundtland argues for Hauksbee's unique role in producing cupping equipment, and explains the transition to other pneumatic instruments; see Brundtland "From Medicine to Natural Philosophy."
[94] "Air-Pumps," in *Lexicon Technicum: Or, An Universal English Dictionary of Arts and Sciences: Explaining Not Only the Terms of Art, But the Arts Themselves*, ed. John Harris, 1st ed. (Newborough, 1704), 44–52, plate 1.

Finally, at some point between 1701 and 1702, he incorporated features "for making all sorts of experiments proper" inside the receiver, making use of the same leather gasket system he'd applied to the joints. The first recorded feature was a simple adjustable brass hook that passed through a cap on the receiver's top (inspired, perhaps, by an earlier string used by Boyle).[95] This allowed objects inside to be moved and rotated at will. Instead of rocking the whole pump, as Boyle and Hooke did, one could lift or prod the pendular machinery directly, as the Reverend William Derham did in a 1704 study of motion in a vacuum.[96]

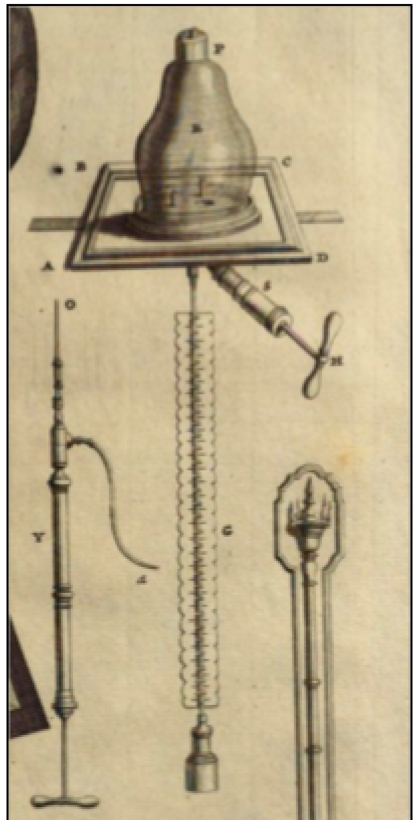

Figure 3. Early Hauksbee Air Pump, from *Lexicon Technicum*. Note the syringe (lower left) and attached barometer below.

Taken individually, Hauksbee's additions can appear like simple improvements. Collectively, however, they allowed a far greater number and range of experiments. Whereas experimenters using Hooke's model typically required the labor of multiple people to operate and a long period of preparation to set in place, Hauksbee's air pump could be operated by an individual with minimal set-up and only a moderate level of skill. Experiments could be run successively, involve active manipulation of objects in vacuo, and be tailored to specific conditions (to half-atmosphere pressure, a quarter-atmosphere pressure, and so on). Given the improvements in gasket sealing and the new barometer and air-inlet features, moreover, experimenters could be confident in their measurements and effective in the control of their experimental conditions.

The Hauksbee pump was a much better machine, and his contemporaries were quick to recognize this. In the 1704 edition of Harris' *Lexicon Technicum*, for example, Hauksbee's works are described as "the best air-pumps, and all pneumatick engines that ever [the author] saw," a sentiment echoed in Derham's paper on pendular motion, which describes him as "the best maker of [air-pumps] in the world."[97] As late as 1738, in fact—after

[95] Harris, "Air-Pumps," 51.
[96] William Derham, "Experiments about the Motion Pendulums in Vacuo," *Philosophical Transactions of the Royal Society of London* 24, no. 294 (1704): 1785–89. Specifically, Derham describes opening and closing the pallets on a pendular clock.
[97] Harris, "Cucurbitula," *Lexicon Technicum*; William Derham, "Experiments about the Motion Pendulums in Vacuo," *Philosophical Transactions of the Royal Society of London* 24, no. 294 (1704): 1785–89.

many improvements beyond Hauksbee's own—his designs were still being described as having "the utmost degree of simplicity and perfection" attained by the device.[98]

The growing notoriety of these instruments almost certainly earned him his eventual position at the Royal Society, where he served as a paid experimenter from 1703 until his death in 1713. It is unclear who at the Royal Society first noticed Hauksbee, or what the exact terms of employment were, but a 1704 record indicates that "he would be gratified according to the proportion of his services."[99]

The vast majority of his work seems to have involved the air-pump in one respect or another. His work included both self-proposed experiments, and demonstrations "ordered" or "desired" by the society. During his first two years, most of the displays involved previously reported effects. The first, presented on December 15th 1703, dealt with the mercurial phosphor. "Mr. Hauksbee shewed a new invented air pump & in it upon the Mercury descending a light &c," the brief entry notes, "he was thanked."[100] This was followed by a December 22nd demonstration of his valve systems and "new way of cupping by the air pump" and in 1704 by a series of classic demonstrations that included dropping feathers and pieces of lead in vacuo, showing that a bell would not ring when the receiver had been exhausted, and firing gunpowder in the pump (a crowd favorite, it seems, as it "was desired to repeat the experiment").[101] As time went on, Hauksbee would expand upon such displays, experimenting on rolling marbles, sound in condensed air, and the difficulty of breaking a vacuum seal.[102]

Intermixed with these frequently overlooked experiments, however, one finds an identifiable series of investigations beginning in 1705. On April 18th of that year, the record book of the Royal Society indicates that Hauksbee "shewed some on experim[ents] with the phosphorus in Vacuo of which he promised an account in writing and to repeat the experiments next meeting," and that following autumn, Hauksbee presented a considerably expanded series of demonstrations relating to the mercurial phosphorous.[103] By late November, his researches had

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[98] The Philosophical Works of Robert Boyle, 409, footnote. Note that this passage refers to a still later design implemented by Hauksbee in 1705—a double-barreled pump that operated much faster and pumped much easier than the earlier single-barrel design.
[99] Council Minutes of the Royal Society, December 7 1704 cited in Pumfrey, "Who Did the Work?," 138, footnote 29.
[100] Meetings of the Royal Society, 1702-1707, December 15, 1703.
[101] Meetings of the Royal Society, 1702-1707, December 22, 1703; January 26, 1703 (1704); March 8, 1703 (1704); June 28, 1704; October 25, 1704.
[102] Meetings of the Royal Society, May 16 1705; June 20 1705; May 28 1707. Francis Hauksbee, "An Account of an Experiment Made at a Meeting of the Royal Society at Gresham College, upon the Propagation of Sound in Condensed Air. Together with a Repetition of the Same in the Open Field, by Mr F. Hauksbee," *Philosophical Transactions of the Royal Society of London* 24, no. 297 (1705): 1902–4; Francis Hauksbee, "Experiments on the Resilition of Bodies in Common Air, in Vacuo and in Air Condens'd, Made at a Meeting of the Royal Society at Gresham College," *Philosophical Transactions of the Royal Society of London* 24, no. 298 (1705): 1946–48.
[103] Meeting of the Royal Society, 1702-1707, April 18, 1705.

led him to amber and wool, and thence to a host of further experiments isolating what would come to be known as electric light.

The impetus behind this series of experiments is difficult to say for certain. Judging from the corresponding papers in the *Philosophical Transactions*, the initial tests on phosphorus had been made at the behest of the Society.[104] The specifics of the experiments were almost certainly Hauksbee's invention, however, and we know from the 1703 records that he had been working with phosphori for at least two years prior.

Plausibly, the experiments were chosen because they were impressive, and the experimental demonstrations were at least in part meant to be a performance. Both the elemental phosphorus and the mercurial phosphorus created vivid displays of light and offered Hauksbee the opportunity to display the ends to which his finely crafted apparatuses could be put. The elemental phosphorus experiments, for instance, included one display in which the substance was placed inside a high-necked bottle with various oils and a bit of water. When the pump began to be exhausted, the bottle emitted a luminous vapor "in a pyramidical form" that rose in "vivid steams" to the top of the receiver and descended along the glass walls to the base. The new demonstrations on mercurial phosphorous, meanwhile, included remarkable displays in which air was shot through a pool of mercury into the exhausted receiver, "blowing [the mercury] up with violence against the sides of the glass that held it, appearing all round as a body of fire, made up of abundance of glowing globules, descending again into itself," as well as a version in which mercury was injected into the receiver from without, creating "a shower of fire" that "resemble[d] the falling of snow."[105]

Whatever the reasons behind the choice of experimental set-ups, the results proved suggestive, with the mercurial phosphorous in particular indicating an important role for friction. Speaking of the experiment just described, Hauksbee noted that "none of [the mercury] appear'd luminous but what descended contiguous to the sides of the glasses" and that light was emitted specifically from the larger globules "continually tearing from the sides of the glasses" along their descent. By contrast, the smaller globules, whose weight were not sufficient to cause their descent, "remain'd opake, there being (in this as well as all other mercurial experiments) no light to be obtain'd without motion."[106]

Within a month, Hauksbee had taken this lead and expanded his researches to include "the attrition of bodies" more generally, developing a special addition to his apparatus allowing him

[104] Francis Hauksbee, "Experiments on the Production and Propagation of Light from the Phosphorus in Vacuo, Made before the Royal Society by Mr. Fra. Hauksbee," *Philosophical Transactions of the Royal Society of London* 24, no. 296 (1705): 1865–66 (1865).
[105] Francis Hauksbee, "Several Experiments on the Mercurial Phosphorus, Made before the Royal Society, at Gresham-College, by Mr Fra. Hauksbee, F. R. S," *Philosophical Transactions of the Royal Society of London* 24, no. 303 (1705): 2129–30.
[106] Hauksbee, "Several Experiments on the Mercurial Phosphorus," 2131.

to rotate bodies at high speed inside (figure 4). Building on his older, wire-based system, Hauksbee inserted a long wooden shaft into a receiver using a series of oiled leather gaskets to ensure the seal remained unbroken. Inside, a small wheel was attached horizontal to the shaft (figure 4, 3). Along the wheel's exterior stood two brass plates arranged such that materials placed on the outer rim of the wheel would rub against materials affixed to the plates (figure 4, 4). Outside, the shaft was attached to a winch system that allowed the interior wheel to be rotated at comparatively high speeds "equal to something more than one third of a mile in a minute."[107]

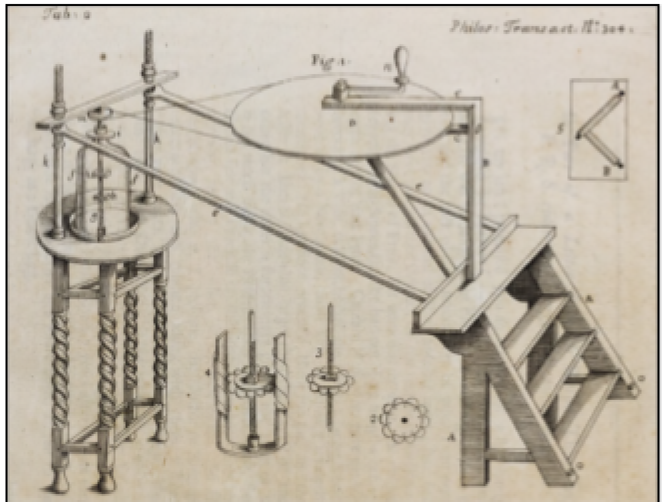

Figure 4. mechanism for producing friction in vacuo. Materials were attached to a wheel inside the register (2, 3, and 4), the objects against which they were rubbed were fixed to two adjacent plates (4). A glass orb was used in place of a wheel for studies of friction on glass.

Between November 1705 and February that following year, Hauksbee used this apparatus to investigate a series of pairings (outlined in table 3 below) on light generation. The most important pairing as concerns electricity was, of course, the one involving amber. Judging from the Royal Society record books and Hauksbee's own presentation, the pairing appears to have been the first of the arrangements to follow the mercurial phosphorus. When one examines the other pairings, they accord reasonably well with existing inventories of luminous bodies. Flint and steel were obviously a well-known pair, while oysters—a seemingly strange choice for the uninitiated—were often included in lists of luminous animals because they played host to glowing sea worms and could, upon calcination, form a certain kind of phosphorus.[108] Glass, meanwhile, would have followed quite naturally from Hauksbee's observation that light only occurred when the mercury ran against it. The inclusion of amber and wool only makes sense if they too were considered a potentially light-generating pair—or, in other words, if Hauksbee already had a strong suspicion of the light-electricity connection he was to establish.

[107] Francis Hauksbee, "Several Experiments on the Attrition of Bodies in Vacuo. Made before the Royal Society at Gresham College," *Philosophical Transactions of the Royal Society of London* 24, no. 304 (1705): 2168.
[108] Harvey, *A History of Luminescence*, 35, 111, 119, 188. That oysters could, in fact, be made into a phosphor was confirmed only later, but the suggestion can be found in English as early as 1700, when the naturalist Charles Leigh suggested it in his *Natural History of Lancashire, Cheshire and the Peak in Derbyshire* [(Oxford, 1700), 138–139.].

Pairing	Quality of Light	Relation to Air
Amber on Wool	Bright and "discernible at-three or four foot distance" in vacuo, "very little light" in open air.	Enhanced in vacuo
Flint on Steel	Described as "sparks of fire"	Diminished or eliminated in vacuo. Can be revived with fresh air.
Glass on Wool	Described as "a fine purple light" in vacuo and paler with the admission of air. Different glasses yielded different results.	Enhanced in vacuo
Glass on Wool Soaked in Wine Spirits and dried	Described as having a tendency "to break from the agitated glass, in as odd a form as lightning"	No mention (presumed same as standard wool)
Glass on Wool Steeped in Water with Saltpeter and dried	Same lightning-form tendency as spirits	No mention (presumed same as standard wool)
Glass on Oyster Shells	Described as "a fierce flaming spark"	Reported in vacuo, results of air admission unreported
Oyster Shells on Wool	Described as "dim and gloomy"	Reported in vacuo, results of air admission unreported
Wool on Wool	Described as "a small glimmering"	Present in vacuo, absent above ¼ atmosphere
Glass on glass	Described as "considerable" and having the color of melted glass	Unaffected

Table 3. Material Pairings in Order of Presentation[109]

Hauksbee investigated a series of phenomena under vacuum, many of which pertained to frictionally-generated light. The decision to include amber in these investigations may indicate that the light-generating properties of wool and amber were commonly known but had yet to appear in print;[110] it may have grown out of earlier experimental work Hauksbee conducted, or building on Boyle's earlier work with electricks under vacuum; or, Hauksbee may have been unconcerned with electricity in his early experiments and directed future research in that direction because of his earlier findings.

On this account, the impetus behind Hauksbee's investigations would have been the discovery of frictionally generated light. Coming off of the studies with mercury and elemental phosphorus, it

[109] Hauksbee, "Several Experiments on the Attrition of Bodies in Vacuo", 2165-2175.
[110] Freudenthal, "Early Electricity between Chemistry and Physics," 218.

was clear that certain substances would release light when agitated in vacuo but not in open air, and given the era's most prominent ways of framing such questions, this would have been thought of in terms of "exhalations" or the release of some subtle, effluvial matter. Working within this worldview, one of the immediate questions to follow would be what other materials had this hidden property.

Though amber had yet to be reported as a light-giving body, there was good reason to believe that it might fall into this category. Whether there was any deeper relationship between the properties of light and electricity, natural philosophers of the time would take the fact that amber was an electrick to mean that it had a clear tendency to emit effluvia when rubbed. Furthermore, amber was widely thought of as an oleous material (Thomas Browne memorably labeled it "the fat of the earth") as well as a salt-containing one, and substances which combined the sulfurous oils and salts were strongly associated with fire and light.[111] Samuel Wall built his entire theory of amber's light production around its mineral composition based on this idea. Yet, it would still be possible to consider light and electricity as separate, though frequently co-occurring, phenomena, as Samuel Wall and Pierre Poliniere did.

Hauksbee set his work apart from his contemporaries by continuing his experiments to refine his understanding of the mechanisms by which light could be generated and increased. As the studies continued, the light produced by the amber appeared more and more to represent a new class of light. In particular, it appeared that the removal of air from the air-pump had very different effects on different kinds of light. In the case of amber, increasing the strength of vacuum increased the sparks from an exceedingly subtle flicker in open air to a distinct light surrounding the amber and wool's region of contact. Clear enhancement of emission was also observed with the attrition of glass on wool, wool on wool, and, drawing on the older results, the friction of mercury on glass and the agitation of phosphorus.

The sparks produced by flint and steel, by contrast, were diminished and eventually extinguished by operating the pump, much as culinary fire (flame) was. The same diminution was observed for glowing wood, as Boyle noted a few decades earlier and as Hauksbee confirmed in a report published in September of 1706.[112] Working with Boyle's report, moreover, one could infer that the same went for other organically produced light, such as that produced by rotting fish and glow worms.[113] Finally, there were pairings that seemed more or less unaffected by the removal or admission of air. Such was the light emitted by rubbing glass on glass and, perhaps, the

[111] Sir Thomas Browne, *Nature's Cabinet Unlock'd* (London, 1657), 64. Freudenthal argues that Hauksbee would have needed outside help to note such a connection, but the oily nature of amber and the connection between oily substances and light were hardly arcane knowledge at the time.
[112] Francis Hauksbee, "An Account of an Experiment Made before the Royal Society at Gresham College, Together with a Repetition of the Same, Touching the Production of a Considerable Light upon a Slight Attrition of the Hands on a Glass Globe Exhausted of Its Air: With Other Remarkable Occurrences," *Philosophical Transactions of the Royal Society of London* 25, no. 307 (1706): 2277–82 (2280); Boyle, "Observations Upon Diamonds," 156.
[113] Boyle, "Observations Upon Diamonds," 156–71.

friction of glass on oyster shells.[114] Though the number of materials examined was relatively few, the results were quite striking—the difference, in some cases, between a light bright enough to illuminate the whole apparatus and a barely perceptible flicker—and could be adjusted upwards or downwards at the experimenters' convenience. The ability to directly manipulate the intensity of light phenomena gave them a sense of reality and tangibility.

It is clear from the course of his continued experimentation that Hauksbee recognized electricity as an important aspect of light generation. He designed a series of experiments and specialized instruments to generate electric light and to monitor the presence of electrical attraction. In his 1706 experiments, Hauksbee employed a glass orb similar to the ones he had used in his 1705 experiments, removed the air from inside the glass by placing it inside the receiver of his air-pump and closing off a stopcock attached to the orb after the pump had been thoroughly emptied. After filling and removing the receiver, Hauksbee proceeded to rotate the orb while holding his hand to the outer surface, producing an interior light bright enough to read by and illuminate an entire room ten feet wide. The most significant finding, though, was that upon the admission of air into the moving globe, Hauksbee and several other participants observed a transition from the bright light inside the apparatus to smaller sparks outside. "Certain specks of light" appeared near Hauksbee's fingers, and "if any person approach'd his fingers towards any part of the glass in the same horizontal plain with [his] hand, within an inch or thereabouts, a light would appear to stick to the fingers, notwithstanding they did not touch the glass, as was confirm'd by several then present." More curiously still, Hauksbee reported that his neckcloth, separated from the globe by a distance of over an inch or two, "appear'd of the colour of fire, without any communication of light from the globe."[115] Hauksbee had, in effect, developed the first frictional glass generator.

The September paper does not mention electricity specifically, but it is likely that the discharges described in the paper were accompanied by clear signs of electric attraction, as a few months later, Hauksbee reported a pair of follow-up investigations, one using a mechanical spinning device similar to the one from his earlier investigation, and a second employing a glass tube. The glass tube was approximately thirty inches long and one inch in diameter—far larger than any glass previously used for electrical study—and the surface area showed itself in the object's attractive power, which readily drew objects from nine to ten inches away. The additional force of the rod also made clear the repulsive power of electricity, with light bodies being attracted and then repelled as far as four or five inches away from the instrument. As with the earlier experiments, however, the effects were eliminated when the tube was exhausted of air. So tight

[114] The case of oyster shells and glass is not detailed specifically, but the sparks are described as "flaming" and there is, in contrast with the immediately following discussion of wool on wool attrition, no mention of the light abating with the admission of air.

[115] Hauksbee, "An Account of an Experiment Made…Touching the Production of a Considerable Light upon a Slight Attrition of the Hands on a Glass Globe Exhausted of Its Air," 2280-81.

was the correlation that a tube rubbed while exhausted of air would become attractive merely by the readmission of air, there being no need to rub the instrument again.

Having had such successes in the electrical domain, Hauksbee proceeded to undertake the same process at night, finding that "when the glass became warm [from rubbing], a light would continually follow the motion of the hand, backward and forwards and at the same time, if another hand was held near the tube, a light would be seen to break from it with noise, much like that of a green leaf in the fire." The snaps could be heard from seven or eight feet away, and the approach of brass, ivory, or any number of other materials drew prominent sparks.[116] These external lights ceased when the rod was emptied of air, just as the electrical effects observed in earlier experiments ceased when the rod was emptied of air. Upon being placed under vacuum, the external lights were replaced with the glowing internal light characteristic of the 1703-1705 results.

Turning to the larger mechanical device—a glass cylinder seven inches in length and diameter attached to a horizontal lathe—Hauksbee found further evidence. The sparks produced by the apparatus could be seen not only at night or in the early evening, the times at which most of his earlier experiments had been conducted, but in the mid-afternoon in "a very light room." These sparks were accompanied by the same pattern of noises and naturally coincided with signs of electrical attraction. Both the electric and luminous phenomena were readily displayed by attaching samples of fabric to a wire arch placed over the spinning cylinder, with pieces of packthread gravitating toward the rubbed portion of the glass and a muslin cloth producing a "multitude of small sparks of light" along its fringe.[117] The threads of this additional apparatus showed the presence and direction of electrical attraction, and clearly demonstrated that the visible light produced by the generator was accompanied by electrical activity.

Hauksbee would expand upon these results to show that other recognized electricks presented the pattern of light emission seen with amber and glass. In his report of September 1706, he indicates that mercury held in a glazed earthenware container produces a similar light in vacuo to mercury in glass, suggesting that the light of the latter interaction was not solely attributable to the glass. To bolster this conclusion, he further cited reports from "several persons of credit" that *mercurius dulcis*, a powdery medicine consisting of mercury and chloride, emitted similar flashes when broken in open air, promising in future works to test both it and purified salt in vacuo.[118]

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[116] Hauksbee, "An Account of an Experiment…Touching the Extraordinary Elistricity of Glass, Produceable on a Smart Attrition of It; with a Continuation of Experiments on the Same Subject, and Other Phenomena," 2330.
[117] Hauksbee, "An Account of an Experiment…Touching the Extraordinary Elistricity of Glass, Produceable on a Smart Attrition of It; with a Continuation of Experiments on the Same Subject, and Other Phenomena," 2333.
[118] Hauksbee, "An Account of an Experiment…Touching the Production of a Considerable Light upon a Slight Attrition of the Hands on a Glass Globe Exhausted of Its Air," 2279–80.

As the prior wool on glass study indicated, however, the light was not solely attributable to the mercury either, and here again, evidence could be drawn from other studies. As sequential experiments contained in the September and December 1706 *Proceedings* demonstrated, large glass bodies produced such lights not only when rubbed with wool but when rubbed against paper or a bare hand in open air.[119] Once rubbed, moreover, light would also "fix upon" objects brought close to the glass' surface, including pieces of gold, silver, brass, ivory, and wood. The pattern was further solidified by a series of investigations published between June of 1708 and October of 1709 in which Hauksbee demonstrated that sealing wax, pitch, and, after some difficulty, sulfur each displayed the same pattern of light production he'd established for amber, glass, and the mercurial preparations.[120]

In March 1707, Hauksbee traced both electrical attraction and luminescence to a common material effluvia released by the glass.[121] His experiments with wax brought him to a similar view, and given the observation that the electricity of wax passed easily through the glass barrier of the air-pump's receiver, he was inclined to see the effluvia of the two materials as similar in some key structural way. By June of 1708, he was confident enough to declare that the light and attraction produced across bodies resulted "from the number and strength of their respective *effluvia*, and so of all bodies reciprocally falling under the same classis [class]."[122] In other words, attraction and light were manifestations of an underlying material type that different bodies possessed to differing amounts, and that were most obviously present in wax, glass, and other classically electric substances.

His view shifted in his *Physico-Mechanical Experiments* of 1709, in which he asserted that the luminous and electrical effluvia had a "real difference" between them, "at least in some cases," as the two phenomena interacted somewhat differently with friction and the surrounding environment. In particular, attraction seemed to act through the air and scale with friction

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[119] Francis Hauksbee, "An Account of an Experiment Made before the Royal Society at Gresham-Colledge, Touching the Extraordinary Elistricity of Glass, Produceable on a Smart Attrition of It; with a Continuation of Experiments on the Same Subject, and Other Phenomena," *Philosophical Transactions of the Royal Society of London* 25, no. 308 (1706): 2327–35.

[120] Francis Hauksbee, "An Account of Some Experiments, Touching the Electricity and Light Producible on the Attrition of Several Bodies," *Philosophical Transactions of the Royal Society of London* 26, no. 315 (1708): 87–92; Francis Hauksbee, "An Account of an Experiment, Touching the Production of Light within a Globe Glass, Whose Inward Surface Is Lin'd with Sealing-Wax, upon an Attrition of Its Outside," *Philosophical Transactions of the Royal Society of London* 26, no. 318 (1708): 219–21; Francis Hauksbee, "An Account of an Experiment, Shewing That an Object May Become Visible through Such an Opake Body as Pitch in the Dark, While It Is under the Ctrcumstances of Attrition and a Vacuum," *Philosophical Transactions of the Royal Society of London* 26, no. 322 (1709): 391–92; Francis Hauksbee, "An Account of an Experiments, Touching an Attempt to Produce Light on the inside of a Globe-Glass Lin'd with Melted Flowers of Sulphur, as in the Experiments of Sealing-Wax and Pitch," *Philosophical Transactions of the Royal Society of London* 26, no. 323 (1709): 439–43.

[121] Francis Hauksbee, "Several Experiments Shewing the Strange Effects of the Effluvia of Glass, Produceable on the Motion and Attrition of It," *Philosophical Transactions of the Royal Society of London* 25, no. 309 (March 1707): 2372–77 (2376–77); Cf. Meetings of the Royal Society, 1702-1707, March 26, 1707.

[122] Hauksbee, "An Account of Some Experiments, Touching the Electricity and Light Producible on the Attrition of Several Bodies," 88.

whereas light came in seemingly all or nothing fashion and proved most intense in vacuo. The two were evidently bound in a significant way, however, as light was readily produced in vacuo by approaching the exterior surface of an exhausted globe with a rubbed electrical body and the two phenomena so closely related in other respects (including their material substrates, relation to friction, and facilitation by heating, among others). Although Hauksbee misunderstood both the nature of electricity, and that light was a manifestation of electricity rather than a separate effluvia, he nevertheless isolated electric light in his experiments. He provided the tools and procedures for future studies of electricity, and set a foundation upon which later scientists would build.

The Reception and Impact of Hauksbee's Work

Hauksbee did not work on electricity after 1709, and as he lived only a few years more, he never returned to the topic. The methods and phenomena that he exposed were amply taken up by his peers and followers, though, bringing with them a new language of "electrical light" and "electric fire." In the 1717 edition of his *Physico-Mechanical Lectures*, for instance, one finds Hauksbee's successor at the Royal Society, John Desaguliers, observing "that phosphorus and electrical light [are] help'd by the absence of air," and similar terminology can be found in a later course of lectures touching on "the electrical phosphorus."[123] Likewise, in a notable 1716 paper on the aurora borealis, Edmund Halley speculated that the strange phenomenon might result from a subtle magnetic matter giving rise to light "after the same manner as we see the effluvia of electrick bodies by a strong and quick friction emit light in the dark: to which sort of light this seems to have a great affinity."[124]

Some discussion of the results even made it into the second edition of Newton's *Opticks*. In the midst of an extended discussion, or "query," on the relationships between matter, heat and light, Newton comes to the question of electricity, noting that:

> A globe of glass about 8 or 10 inches in diameter, being put into a frame where it may be swiftly turn'd round its axis, will in turning shine where it rubs against the palm of ones hand apply'd to it: and if at the same time a piece of white paper or white cloth, or the end of one's finger be held at a distance of about a quarter of an Inch or half an inch from that part of the glass where it is most in motion, the electrick vapour which is excited by the friction of the glass against the hand, will by dashing against the white paper, cloth or

[123] John Desaguliers, *A Course of Mechanical and Experimental Philosophy* (London, 1717), Lecture XIV; Desaguliers, *A Course of Mechanical and Experimental Philosophy/Cours de philosophie mécanique & expérimentale*, 5.

[124] Edmund Halley, "An Account of the Late Surprizing Appearance of the Lights Seen in the Air, on the Sixth of March Last ; with an Attempt to Explain the Principal Phænomena Thereof ; as It Was Laid before the Royal Society by Edmund Halley, J. V. D. Savilian Professor of Geom. Oxon, and Reg. Soc. Secr," *Philosophical Transactions of the Royal Society of London* 29, no. 347 (March 31, 1716): 406–28 (423).

finger, be put into such an agitation as to emit light, and make the white paper, cloth or finger, appear lucid like a glow-worm.[125]

In England, Hauksbee's assertions about electric light had already taken root. Hauksbee's theory that electricity and light were material effluvia fit with Newton's own ideas about a universal aether, so the experimental report in Newton's *Opticks* was understood as an endorsement of Hauksbee's theory and experimental work.[126]

Hauksbee's work spread to the continent with similar speed. His experiments can be found in the travelogues of Conrad von Uffenbach and various reviews of his work.[127] Indeed, one can find explicit mention of "the electricity of light" in reviews published as early as 1710.[128] More in-depth engagements with the work emerged only later, however, with the 1716 translation of the book into Italian and the 1721 incorporation of his experiments into the second volume of Willem 's Gravesande's *Physices Elementa Mathematica*, which used them to argue for the existence of a light and electricity eliciting "atmosphere" in and around glass.[129]

Over the next several years, Hauksbee's ideas would find additional review and discussion in outlets such as the *Acta Eruditorum* and *Miscellanea Berolinensia*, with some undertaking replications as 's Gravesande had.[130] These, in turn, helped to establish the phenomenon as a replicable and familiar pattern. "Experience," as a 1727 publication in the later journal reports, "testifies that all electric bodies glow in the dark when rubbed, and the light is greater or less if the electric force is greater or less" (the author was in this case speaking of unexhausted glass).[131] Although the theoretical understanding of electricity and light was flawed, by the early 1730s electric lights were familiar in England, and the two forces were understood to be connected.

In the years following Hauksbee's death, the instruments and apparatus he developed for his own experiments were adopted and adapted widely to other experimental pursuits in the study of

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[125] Isaac Newton, *Opticks: Or, A Treatise of the Reflections, Refractions, Inflections and Colours of Light,* 2nd ed. (London, 1718) 315.
[126] Early in his life Newton espoused a belief in aetherial matter, but distanced himself from both this view and Cartesian ideas of effluvia for several years. Following Hauksbee's experiments, however, he seems to have readopted his aetherial views, which appear in the second edition of *Opticks* (1718) but not in the first edition of 1704. See Henry Guerlac, "Newton's Optical Aether: His Draft of a Proposed Addition to His Opticks," *Notes and Records of the Royal Society of London*, 22 (1967): 45-57.
[127] Zacharias Conrad von Uffenbach, *Herrn Zaccharias Conrad von Uffenbach merkwürdige Reisen durch Niedersachsen Holland und Engelland* (Frankfurt, 1753), 518; Anonymous, "Physico-Mechanical Experiments on Various Subjects," *Bibliotheque choisie pour servir de suite a la Bibliotheque universelle* 22 (1711): 101–18.
[128] Anonymous, "Physico-Mechanical Experiments," *Nouvelles de la republique des lettres* 51 (1710/1720): 420.
[129] Francis Hauksbee, *Esperienze fisico-meccaniche sopra varj soggetti* (Florence, 1716); Willem Jacob 's Gravesande, *Physices Elementa Mathematica, Experimentis Confirmata. Sive Introductio ad Philosophiam Newtonianam* (Lugdunum Batavorum, 1721), book 3, chapter 2, experiment 7.
[130] Anonymous, "Physices Elementa Mathematica," *Nova Acta Eruditorum* 33 (1722): 19–23; J. Schilling, "Observationes & Experimenta de vi electrica Vitri aliorumque Corporum," *Miscellanea Berolinensia ad incrementum scientiarum ex scriptis Societati regiae scientiarum exhibitis edita* 3 (1727): 314–43.
[131] Schilling, "Observationes & Experimenta,"

electricity. The glass tube described in Hauksbee's report from December of 1706 went on to become the principal tool for electricians of the 1720s and 1730s and a significant contributor to the popularity of electricity. It was simple and compact enough to be used by traveling lecturers, and, in stark contrast to the air-pump, could be manufactured by workers with less technical skill. Its simplicity also made it inexpensive, allowing for still greater participation from those who, like Hauksbee himself, were of comparatively modest means. At the same time, the tube was reliable. Though subject to the vicissitudes of climate, the glass rod was able, in most circumstances, to produce attraction, repulsion, and light – all the electrical phenomena Hauksbee identified and observed in his experiments. Rods of this type were used by Stephen Gray to discover electrical conduction, and Charles Dufay would use them to outline the principal regularities of electrostatics. Glass rods were involved in significant discoveries as late as 1746, when Benjamin Franklin began developing the first elements of his electrical theory with a series of glass rod experiments.[132]

When the glass rod was finally superseded, it was by another of Hauksbee's instruments, the globe generator. Though the final product would require additional elements available only after the discovery of conduction—specifically, the addition of an insulated "prime conductor" (typically a bar of iron suspended by silk bands)—the globe generators of the 1740s were essentially the same as Hauksbee's design, as authors at the time freely admitted.[133] These enhanced generators would, in turn, underwrite most electrical research for the remainder of the century. Appropriately enough, a significant part of their development seems to have been driven by an interest in more and larger effects for potential audiences, such as the desire to see bright sparks of various colors. Throwing off sparks from one's hands and lighting up a crown adorning the head of a volunteer would become celebrated entertainments during this era.

Hauksbee's successors in electrical study clearly credited him with having discovered electric light, electric repulsion, and with having developed uniquely reliable instruments for generating electric effects. The fact that eighteenth-century scientists recognized the extent of Hauksbee's contributions to the field are perhaps best illustrated by Joseph Priestley's 1767 publication, *The History and Present State of Electricity*. Priestley's account of Hauksbee's work agrees with other contemporary records in affirming that he discovered electric light. Yet, even more telling of Hauksbee's significance, Priestley divides the early history of electricity into periods titled "Experiments and discoveries in electricity prior to Mr. Hauksbee" and "The Experiments and discoveries of Mr. Hauksbee."[134] Based on an educated and informed survey of electrical study in the eighteenth century, Priestley, himself a renowned chemist and pioneer in data visualization,

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[132] See David Pence, "The Development and Spread of Franklinian Theory," 5–6.
[133] Johann Heinrich Winkler, *Gedanken von den Eigenschaften, Wirkungen und Ursachen der Electricität: nebst einer Beschreibung zwo neuer Electrischen Maschinen* (Breitkopf, 1744), 10.
[134] Joseph Priestley, *The History and Present State of Electricity, with Original Experiments* (London, 1767), xxiv, 1-25.

believed Hauksbee's work to be, literally, the defining point in the history of electricity to that point.

Conclusion

Through his experiments, Francis Hauksbee created a set of instruments and followed a specific procedure which allowed him to isolate electric light. Although some earlier figures had experimented with electricks and noted luminous effects, none recognized, nor enabled others to recognize, electric light as a special phenomena. Otto von Guericke believed the light produced in his sulfur globe was a magnetic occurrence caused by the mineral composition of his instrument which he had modeled on the earth itself. Jean Picard believed that light was produced by the mercury in his barometer. Samuel Wall believed that sulfurous substances contained light, which could be released through agitation. Pierre Poliniere believed light and electricity were produced by reactions between glass and the surrounding atmosphere. In all of these instances, a phenomenon was observed and fit into a theoretical framework in which light from electricks was not distinctive. Hauksbee's experimental program, enabled by a new instrument, gave him access to evidence that electric light was a distinctive phenomena, and led him to design new experiments to determine the likely nature of that light. He first recognized that amber could generate light, and then designed new experiments to test other electricks for the same capability. Upon recognizing that electricks could produce light, he designed new experiments to monitor the presence of electrical activity while generating light. Through his experiments, electric light was visibly distinguished from other types of light.

Hauksbee's work relied on a number of factors, some institutional, some personal. The funding and access provided by the Royal Society gave Hauksbee the time, space, and financial means to pursue his experiments – which likely would have been unavailable to him had he continued in any of his previous occupations. However, Hauksbee's background as an instrument maker was also a crucial contributor. Without his improved design of Boyle's air pump, Hauksbee's vacuum experiments would have been impossible, just as his triboelectric generator would have been impossible without his ability to design machinery and create glass globes. The ability to design and fabricate entirely novel instruments allowed Hauksbee to pursue a unique and original experimental program. Technological advances in other fields, such as glass manufacturing, created the necessary material preconditions, but Hauksbee's unique skills and approach allowed him to capitalize on those advances to pursue his experimental program.

The significance of Hauksbee's discoveries and contributions were immediately appreciated by other experimenters and natural philosophers. Records of his experiments were published, reprinted multiple times, and issued in translation throughout Europe. Other respected scientific figures referenced his work and findings in their own experimental accounts. Many of the instruments he developed became the accepted standard for experimenting with electricity. Finally, in 1767, 54 years after his death, Francis Hauksbee was understood as *the* defining figure in eighteenth-century electrical studies — far from an unsung hero. His work was then a key inspiration for the later discoveries made by people like Stephen Gray and Charles Dufay, whose work related to electrical charge and conduction opened new vistas for scientific exploration.

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