Stephen Gray and the Discovery of Electrical Repulsion and Conduction

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Abstract

This article reexamines Stephen Gray's unpublished 1708 letter to Hans Sloane to explain why Gray's discoveries of electrical conduction, insulation, and repulsion failed to gain immediate acceptance despite their experimental significance. Rather than attributing this delay to shortcomings in Gray's methods, the article argues that his findings conflicted with prevailing theories of electricity and with contemporary standards of scientific proof. By tracing the development of electrical thought from classical antiquity through William Gilbert's influential theory of electrical attraction, the study demonstrates how effluvial explanations and Gilbert's distinction between electricity and magnetism established an intellectual framework within which Gray's observations were considered implausible. The article further situates Gray's work within broader methodological debates concerning the relationship between experiment and theory, showing how Isaac Newton's evolving philosophy of science helped redefine acceptable standards of evidence by separating the demonstration of phenomena from complete explanations of their causes. This shift enabled later natural philosophers, including John Theophilus Desaguliers and Charles François de Cisternay du Fay, to reinterpret Gray's experiments and incorporate electrical conduction and repulsion into the emerging science of electricity. Gray's experience illustrates that the acceptance of scientific discoveries depended not only on empirical observation but also on changing epistemological assumptions about what constituted convincing scientific proof.

Keywords: history of electricity, electric effluvia, Stephen Gray, repulsion, conduction, insulation, scientific proof.

Introduction

In 1708, Stephen Gray wrote a letter to Hans Sloane, the Secretary of the Royal Society of London. Sloane was responsible for compiling the *Philosophical Transactions*, the foremost scientific journal in the English-speaking world at that time. Gray was a cloth dyer from Canterbury and an amateur natural philosopher who had previously sent Sloane letters related to optics, fossils, and astronomy, several of which had been published. In this latest letter, Gray broached a new field of experimental study: electricity. Gray had been inspired by the electrical experiments of Francis Hauksbee. Hauksbee had been appointed Demonstrator of Experiments for the Royal Society in 1703, and the Society's President, Sir Isaac Newton, had directed him to pursue experiments related to electricity. Accounts of many of these experiments were published, and Gray had followed Hauksbee's work closely for years. In his letter, Gray described twelve electrical experiments and arrived at two new hypotheses that would inspire his discovery of electrical conduction, insulation, and repulsion.

Stephen Gray is generally credited with discovering electrical conduction and insulation in 1729, and generally not credited with discovering electrical repulsion at all, despite each of these phenomena being demonstrated in his unpublished experimental account from 1708. To understand when, or if, Gray was given credit for these discoveries, we must consider why electrical conduction, insulation, and repulsion were considered controversial, unlikely, or impossible prior to Gray's work, and what factors changed after 1708 that influenced the later acceptance of some of Gray's findings. We do not know why Hans Sloane decided not to publish Gray's letter in 1708, so we must begin by situating Gray's work within the larger context of electrical studies at that time. Theories of electricity were rooted in classical antiquity, but in

England were strongly influenced by William Gilbert. Gray also sent his letter in the midst of a larger intellectual renegotiation of methodologies. In 1708, Gray did not offer any theoretical explanation for repulsion, and offered only a vague explanation of conduction (that it seemed non-electrical objects were capable of absorbing and emitting electrical effluvia). The lack of theoretical foundation to explain or accommodate his experimental results may have been reason enough to not publish his letter. However, in the years following his letter, many natural philosophers in Britain, including Isaac Newton, became willing to accept the reality of certain phenomena without a full understanding of the mechanisms by which those phenomena operated. This shift in acceptable standards of proof was taking place during Gray's lifetime, and explains why some of his findings were rejected in 1708 and embraced by 1729.

To understand the significance of Gray's work, and the process by which his ideas gained acceptance, this paper will begin by addressing the social and intellectual context within which Gray operated. To do so, it will begin by describing theories of electricity from classical antiquity through the early modern period. The paper will pay particular attention to William Gilbert, whose book *De Magnete* was foundational to electrical and magnetic science in Britain. The paper will then examine debates around Gilbert's findings, using this as an example to understand broader questions of methodology and standards of proof that were being contested at the time. Next, the paper will consider ongoing intellectual shifts related to methodology and standards of proof, illustrated through the work of Isaac Newton. These shifts are essential to understanding why Stephen Gray's demonstrations of repulsion and conduction were considered controversial in 1708, but were broadly accepted by 1720 in the case of repulsion and 1731 in the case of conduction. The paper will then consider Stephen Gray more directly, beginning with

Gray's first electrical experiments, communicated to the Royal Society in 1708 though never published. Next it will examine the reception of Gray's work after 1708, with particular attention to his published works in 1720 and 1731, in which he returned to the question of electrical conduction raised in 1708, designed new experiments to demonstrate the reality of electrical conduction, and successfully popularized that understanding throughout Europe. This examination of Stephen Gray's scientific career illustrates that the acceptance of his work was driven by shifting cultural norms within the scientific community related to methodology and standards of proof.

Effluvial Theories from Classical Antiquity to 1600

Going back to Aristotle's physics, it was accepted that any physical effect must have a physical cause, but in the case of electrical attraction, magnetism, gravity, and numerous other forces, there was no apparent physical connection to explain how one object could affect another. Natural philosophers therefore theorized an invisible, but nevertheless physical, matter that could explain electrical, magnetic, and gravitational effects. In theory, certain materials like amber and glass contained "effluvia," which were vaporous strands, invisible to the eye, that could flow out, create a physical connection with some other object, and then cause observable effects, like electrical attraction. A wide variety of thinkers from classical antiquity, through the medieval period, and into the eighteenth century relied on effluvia to explain the indiscernible causes of observable effects. By theorizing a physical connection between two objects, even if that connection was invisible, earlier thinkers created a consistent and intelligible paradigm of physics that accommodated effects like electricity and magnetism.[1]

[1] Silvia Parigi, "Effluvia," in *Encyclopedia of Early Modern Philosophy and the Sciences* (Cham, Switzerland: Springer, 2020), 543-546.

The first recorded explanations of this kind of invisible force were related to magnetism. The fourth century B.C.E. Greek atomist philosopher Epicurus believed that all physical things were in a constant state of discharging and scattering minute bits of themselves. He believed that the emissions of lodestones displaced surrounding air to create a void, or vacuum, into which bits of iron would fall and be drawn toward the magnetic lodestone.[2] This theory was adopted and expanded by the first century B.C.E. Roman poet and philosopher Lucretius. In *De Rerum Natura*, Lucretius explained his understanding of the physical world and these curious effects of lodestones. Like Epicurus and earlier atomists, he held that all matter emitted parts of itself. These "streams" of matter were the cause of sensory experiences, as sight, smell, taste, and hearing resulted from subtle material emissions being taken up by sensory organs.[3] Matter could absorb the emissions of other matter, which Lucretius demonstrated through the example of temperature. He observed that "cold and heat pass through brass," meaning that the cold or heat of one object was absorbed and transmitted by another object.[4] This example also illustrated that some emissions could only be absorbed by compatible forms of matter; wood, for example, did not absorb and emit temperature in the same way that brass did. To explain this selective absorption of qualities, Lucretius theorized that all matter is porous, but that these pores are "assigned" by nature to absorb some material qualities while remaining impervious to others.[5] Lodestones would emit a constant stream or "current" (in the sense of a river or ocean current) which would affect compatible objects nearby.[6] Like Epicurus, Lucretius believed that the

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[2] Duane Roller and Duane H. D. Roller, *The Development of the Concept of Electric Charge: Electricity from the Greeks to Coulomb* (London: Oxford University Press, 1954), 3.
[3] Lucretius, *De Rerum Natura*, book 6, translated by H. A. J. Munro (London: George Bell and Sons, 1903), 175.
[4] Lucretius, *De Rerum Natura*, 175.
[5] Lucretius, *De Rerum Natura*, 176.
[6] Lucretius, *De Rerum Natura*, 176

magnetic emissions of a lodestone displaced surrounding air, which created a vacuum. Pieces of iron would then be drawn into this vacuum.[7] The movement of the iron to the magnet was supposed to be made possible by the force of "all the air which lies behind" the iron, which "carries and pushes it on" through the void to the lodestone.[8]

Although this explanation accounted for magnetic attraction, Lucretius also observed instances of iron being pushed away from a lodestone, and could not explain this by reference to a vacuum. Instead Lucretius returned to his idea of the porous nature of matter. When magnetic emissions encounter iron, he proposed, they seek to fill the pores of that iron, creating a link that can facilitate attraction and causes iron to cling to a lodestone when the two meet. But, if the magnetic emission "has no opening to swim through as before," it will be "forced therefore to dash against and beat… the iron… by which means it repels from it."[9] The process by which attraction or repulsion occurs is not observable to the naked eye, according to Lucretius, because the natural combinations of magnetic emissions and iron are not discernible or distinguishable from each other. Lucretius compares the combination of magnetic emissions and iron to the combinations of smelted metals or dyed wool in which the constituent elements are inseparable and indistinguishable.[10] The word "effluvium" first appeared in print in Pliny the Elder's *Historia Naturalis*, over a century after Lucretius' death, but Lucretius had put forward a classic effluvial theory.[11] Invisible emanations from certain materials explained physical effects where the

[7] Lucretius, *De Rerum Natura*, 176. Lucretius writes that a lodestone "dispels… all the air which lies between the [lodestone] and iron… When this space is emptied and much left void between, forthwith the first-beginnings of iron fall headlong forward in the void." He adds that iron is then held to the lodestone by some "unseen bonds of connexion."
[8] Lucretius, *De Rerum Natura*, 177.
[9] Lucretius, *De Rerum Natura*, 178.
[10] Lucretius, *De Rerum Natura*, 178.
[11] Parigi, "Effluvia," 543-546.

mechanism of that effect was imperceptible. Many later thinkers adopted the atomist view that effluvia displacing air and creating vacuums explained magnetic attraction and repulsion.

Plato and Platonists disagreed, however. Writing roughly a century after Lucretius, the Platonist philosopher and historian Plutarch sought a new explanation for magnetic effects. Like Plato, Plutarch did not believe a void or vacuum was physically possible. The universe was full of matter. Any displaced matter would be replaced by other matter. There could not be a space devoid of matter. Plutarch's detractors argued that this made motion impossible; if all space was full how could anything shift?[12] In general, Plutarch thought that things simply exchanged places with air.[13] In his essay collection *Moralia*, Plutarch addressed several forms of motion in the natural world, including the attractive power of lodestones and amber.

Plutarch believed that lodestones emit "strong exhalations" which are invisible but nevertheless move the surrounding air. But, instead of creating a vacuum, these air currents move outward to some distance and then change direction to return to the lodestone. This creates a whirlwind, like an eddy formed in water. As the air is "carried round" in this whirlwind, it "forcibly draws the iron in the same direction."[14] For Plutarch, this explanation accounted for magnetic attraction and repulsion. At different stages in this process, or under differing circumstances, the magnetic effluvia are moving in opposite directions and can therefore move iron either toward or away from a lodestone.[15] To address why lodestones only attracted iron, rather than all matter, Plutarch explained that iron had "certain pores and asperities" which allowed air to be "received" in the

[12] This issue of "motion in a plenum" (a completely filled space) would be taken up by many later thinkers, notably René Descartes.
[13] William Goodwin, editor, *Plutarch's Morals*, vol. 5 (Boston: Little, Brown, and Company, 1883), 435-436.
[14] Goodwin, *Plutarch's Morals*, 436.
[15] Goodwin, *Plutarch's Morals*, 436.

iron in such a way that the air could grip and move the iron. Other materials were less porous, so these exhalations simply slipped over them.[16]

Plutarch also addressed the attractive force exerted by amber. He believed amber had a weaker effluvial force because it needed to be rubbed to attract anything, and could only draw light objects, unlike lodestones that were constantly exerting force and affecting dense pieces of iron. This led Plutarch to theorize that amber had a "flammeous and spirituous nature," that it was in some way less substantial than a lodestone.[17] Although he deemed this force weaker than that of the lodestone, he believed that the exhalations of amber could attach to more kinds of matter because they were thinner and more tenuous than those of a lodestone. Thinner exhalations could attach to smaller pores that magnetic exhalations would simply wash over. Although amber emitted its exhalations through more "recluse passages" it otherwise operated along the same principles as the lodestone.[18] Like Lucretius and Pliny the Elder, Plutarch was espousing an effluvial theory of matter: matter emits some kind of exhalation which, although invisible, impacts other objects and aspects of the physical world.

Ironically, the figure from classical antiquity that would have the most significant impact on later theories of magnetism and electricity, Aristotle, said very little about either phenomena directly. Aristotle proposed that all terrestrial matter was composed of four elements: earth, water, air, and fire. There was also a fifth celestial element, aether, which was unchanging and exclusive to the heavens. Terrestrial elements were defined by two essential dichotomies: each element was either dry or wet, and either hot or cold. Earth was inherently cold and dry, water was inherently cold

[16] Goodwin, *Plutarch's Morals*, 437.
[17] Goodwin, *Plutarch's Morals*, 436-437.
[18] Goodwin, *Plutarch's Morals*, 437.

and wet, air was inherently hot and wet, fire was inherently hot and dry. These elements also constituted the physical material of every substance, a concept Aristotle called "Matter." Elemental Matter on its own could only move in the direction of its natural tendency, downward for earth and water, upward for air and fire. However, added to this Matter, there was another feature of substance which Aristotle called "Form." The Form of an object provided a cogent arrangement, and a unifying or animating force that could make something greater than the sum of its material parts. Form gave some objects the ability to move in directions different from their elemental tendencies, gave animals the ability to move voluntarily, and gave humans the ability to make rational choices.[19] For Aristotle, any object capable of causing motion must possess a unique Form, a spiritual essence that enables motion beyond the simple downward pull of earth and water or upward lift of air and fire. The only mention Aristotle made of magnets or magnetism was to comment that Thales of Miletus (a pre-Socratic philosopher who died more than 150 years before Aristotle's birth) believed magnets must possess a soul to be able to impart motion to other objects.[20] Aristotle discusses amber in one work, noting that it appears to have been liquid at one point, suggesting that certain material properties can change over time, but he makes no mention of its electrical effects.[21]

The writings of classical antiquity were largely lost in Europe following the collapse of the Western Roman Empire. They survived in the Arabic speaking world and were reintroduced to European audiences in the twelfth and thirteenth centuries. When medieval Christian philosophers looked to this body of work to inform their own worldviews, they readily adopted

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[19] Aristotle, *On Generation and Corruption*, Book I, translated by H. H. Joachim, https://classics.mit.edu/Aristotle/gener_corr.1.i.html
[20] Aristotle, *On the Soul*, translated by J.A. Smith, https://faculty.georgetown.edu/jod/texts/aristotle.soul.html
[21] Aristotle, *Meterology*, Book IV, translated by E.W. Webster, https://classics.mit.edu/Aristotle/meteorology.4.iv.html

Aristotelianism, conflating his concept of Form with their own religious ideas of the immortal soul. The adoption of Aristotle's writing for thinking about the natural world became pervasive in Christian Europe during the medieval period, and formed the curricular foundation for the universities that were being established at that time.[22] The tradition of Christian Aristotelianism came to be called Scholasticism (from *schola*, Latin for school) because of its close connection to European universities. The Scholastic curriculum was based on learning the scripture, the works of Aristotle, and commentaries on each, so that you could then apply logical reasoning to debates and disputations. Most of these debates were concerned with abstract and theological matters, such as the nature of free will, or proving God's existence. Although questions about the natural world and physical phenomena were permitted, scholars proceeded with caution and sensitivity in such matters. What could be considered a celebration of God's creation by some, might be seen as a sacreligious attempt to uncover divine mysteries by others. Scholastic natural histories served to catalog a wide range of flora, fauna, and phenomena, although they rarely ventured beyond observation. For a belief about the natural world to be justified and accepted, scholastic philosophers needed to record their observations and explain how that phenomena fit within scriptural and Aristotelian cosmology, or at least show that it did not contradict either of those canons.[23] If some phenomenon could not be explained within the framework of scripture or Aristotelian physics, or if its causes were unintelligible, it was labeled as hidden, secret, occult, or a mystery. These terms were not necessarily considered pejorative within Scholasticism, as there were many things that people were not meant to know, theologically or practically.[24]

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[22] Peter J. Bowler and Iwan Rhys Morus, *Making Modern Science: A Historical Survey*, 2nd Edition (University of Chicago Press, 2020), 356-7.
[23] David C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, Prehistory to A.D. 1450*, 2nd edition (University of Chicago Press, 2007), 254-285.
[24] Xiona Wang, *Handling "Occult Qualities" in the Scientific Revolution: Disciplines and New Approaches to Natural Philosophy, from John Dee to Isaac Newton* (Leiden: Brill, 2023), 3.

Magnetism, the electrical effects of amber, and whatever force caused planetary motions were all broadly accepted as occult qualities. For some this was a divine mystery that should be accepted rather than explored, while others believed that a combination of study and ceremonial practices (i.e. magic) would allow them to understand these mysteries and manipulate the world around them at will.[25] Sympathy and antipathy were also commonly recognized occult qualities. The theory was that throughout the natural world, things related to each other in terms of "friendly affection, or coordination" called sympathy.[26] In contrast, Antipathy was a connection between two objects based on their aversion or incompatibility. In either instance, it was commonly believed these imperceptible connections between objects could be used by acting upon one object so as to affect a different object connected to the first through occult bonds of sympathy or antipathy. These occult qualities were conceptualized in a way consistent with Aristotle. As Giambattista della Porta explained "the world is interconnected just like an organism, each part with its sympathies and antipathies." For figures like Della Porta, or Gaspar Schott, Aristotelian elements explained the connections of sympathy and antipathy. The sympathetic connection between things spoke to an affinity of their matter, such as "The Moon draws up fire to it, the Earth moves to the center, the lodestone attracts iron, amber draws chaff, brimstone [sulfur] draws fire, the Sun attracts flowers and leaves, and the Moon the waters."[27] Like Della Porta, many saw magnetic attraction as an example of sympathy, and magnetic repulsion as an example of antipathy.

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[25] Steven P. Marrone, *A History of Science, Magic & Belief: From Medieval to Early Modern Europe* (New York: Bloomsbury Academic, 2025), 1-8.
[26] Gaspar Schott, *Thaumaturgus physicus sive Magiae universalis naturae et artis pars quarta et ultima*, Johann Gottfried Schonwetter, 1659, quoted in J. L. Heilbron, *Electricity in the 17th and 18th Centuries: A Study of Early Modern Physics* (Los Angeles: University of California Press, 1979), 26.
[27] Giambattista della Porta, *Magiae Naturalis*, 1584, translated by Joseph Muscat, https://staff.um.edu.mt/jmus1/dellaPorta.pdf, 3.

For others, like Roger Bacon, occult qualities and Aristotelian elements did not provide an adequate explanation of the mechanism by which an effect happened. In 1260, he revived earlier atomist ideas and theorized that all objects emanated unseen rays, which he called "species." Although these were invisible, they were physical and therefore did not rely on occult explanations of sympathy or antipathy to account for phenomena like sensory experiences or magnetism. In 1489, Marsilio Ficino introduced a related concept called "spirit" which he explained as a universal medium which connected all things together and facilitated unseen interactions between them. Late medieval thinkers increasingly applied the term "effluvia" to describe the theoretical emanations of objects and tried to understand the limits of "spirit" through new experiments comparing effluvial transmissions through air, vacuum, and water.[28] Bacon and Ficino proposed effluvial theories as a more rigorous alternative to occult qualities, indicating that a shift away from the methodology and epistemology or Scholasticism was underway.

An effluvial understanding of matter was applied to understanding electrical attraction by the Italian mathematician Gerolamo Cardano, particularly in his 1550 publication *De Subtilitate Rerum*. In *De Subtilitate*, Cardano laid out an extensive theory of the material world and its interactions, based in large part on effluvial theories like those of Lucretius and Plutarch, but with the addition of Aristotelian physics. Amber and lodestones were both capable of attracting objects across distance without a perceptible connection to those objects. Cardano began with Aristotle's observation that amber was fossilized tree resin that had at one point been liquid. Amber would therefore be wet within Aristotle's primary dichotomies. While lodestones only

[28] Parigi, "Effluvia," 543-546.

attract iron, amber would attract "anything light."[29] For Cardano, the fact that amber needed heat to attract was consistent with the fact that it attracted small light objects, such as pieces of straw, which were also quite dry. Fire, an obvious example of elemental heat, would move toward and through dry matter as it burned, suggesting an attractive connection between hot things and dry things. Cardano associated the wet nature of amber with secondary qualities like oiliness and stickiness, which, in his estimation, were qualities common to materials that burned well, including amber which was popularly burned as an aromatic.[30] So it made logical sense to Cardano and his contemporaries that amber would emit a moist, oily, sticky effluvia, and that this effluvia would behave like fire in certain ways. Cardano explained amber's attraction as light, dry objects being naturally drawn by moist effluvia, just as fire is drawn towards its fuel.[31] Because the emission of amber's effluvia was driven by heat and moisture on an elemental level, it was inherently related to air (elementally hot and moist) in keeping with those ancient theories that explained attractive forces as being caused by the movement of air, and a ready explanation for the effluvia being invisible.

Thinkers in classical antiquity observed natural phenomena and argued with one another about the underlying causes and characteristics of the natural world, based on their contradictory observations and cosmologies. Of these ancient thinkers, Aristotle had the largest influence on later thinking because his ideas were adopted and institutionalized in medieval universities. The Scholastic tradition of these universities was based on cataloging observations and confirming

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[29] John M. Forester, editor, *The De Subtilitate of Girolamo Cardano* (Tempe, AZ: Arizona Center for Medieval and Renaissance Studies, 2013), 306.
[30] Forester, *De Subtilitate*, 306; The association with bituminous materials also created an association with sulfur and phosphorescence which drove earlier explanations of and investigations of electric light – for more see Daniel P. Graham and David Evan Pence "Making Light: Francis Hauksbee and the Isolation of Electric Fire," Leverage, Dec. 2023. https://www.leverage.institute/program/metascience
[31] Forester, *De Subtilitate*, 306.

the truth of ideas about the natural world by arguing for their congruence with scripture, Aristotle, and their internal consistency or elegance. Accepted standards of proof continued to change as some figures introduced more mechanistic arguments based on their understanding of elemental characteristics. The shifting basis of justification for ideas about natural phenomena can be seen in the changing meaning of "occult qualities" throughout the medieval period. Many natural philosophers accepted effluvia as a valid, non-occult explanation of various phenomena, because effluvia was a physical, if invisible, connection between objects. In the seventeenth century, embracing mathematical and experimental methods that focused on explaining how phenomena occurred without recourse to magical thinking or indefinable occult qualities became the norm among natural philosophers.

William Gilbert and the New Science

In the seventeenth century, several natural philosophers adopted new approaches to studying the natural world which generally fell into two categories. They could focus on the power of experience and experimentation, allowing their observations, rather than Aristotelian dogma, to shape conclusions. Or they could adopt radical rationalism and a mathematical approach that guaranteed the truth of their conclusions through the *a priori* truth of numbers and self-evident axioms. Eventually, most natural philosophers would adopt a combination of experimental and mathematical methods in their work, but at the beginning of the seventeenth century these methods were applied more exclusively. The English physician and natural philosopher William Gilbert was representative of the experimental approach, and the French polymath René Descartes was representative of the mathematical, rationalist approach. Both were dissatisfied

with Aristotelian explanations for various phenomena, so they shared a commitment to overturning the norms of medieval Scholasticism, despite the difference in their methodologies.

William Gilbert dominated the theoretical understanding of electricity and magnetism in Britain in the seventeenth century.[32] He described the study of magnetism and electricity prior to his own work, writing that although many earlier figures showed "occult causes and wonders," like "amber and jet… attracting chaff" they "never [gave] a proof from experiments," instead these authors "treat the subject esoterically, miracle-mongeringly, abstrusely, reconditely, mystically."[33] For Gilbert, the standards of proof that were considered adequate by natural philosophers in the medieval period were insufficient to establish the truth of their theories. He believed that carefully crafted experiments would reveal truths about the natural world, and these should be used to attribute mechanisms to natural phenomena.

Robert Norman, a mariner and compass maker of the late 1500s, had noted a series of anomalies with magnetic compasses. He was particularly concerned with the fact that compasses regularly diverged from true north, and that compass needles often dipped horizontally when pointing north.[34] Gilbert read Norman's work, and was inspired to begin a thorough, systematic, and experimentally driven study of lodestones and their effects. His experiments and the behavior of magnetic compasses led Gilbert to propose that the earth itself was magnetic, and that it was in

[32] For a more thorough explanation of William Gilbert's ideas and experiments, see Mindy McTeigue and Geoff Anders, "William Gilbert and the Discovery of 'Electricks'," Leverage, Sept. 2020. https://www.leverage.institute/program/metascience

[33] William Gilbert, *On the Loadstone and Magnetic Bodies and on the Great Magnet of the Earth*, translated by P. Fleury Mottelay (New York: John Wiley & Sons, 1893), 77, originally published as William Gilbert, *De Magnete* (London: Petrus Short, 1600).

[34] Robert Norman, *The Newe Attractive, Shewing The Nature, Property, and Manifold Vertues of the Loadstone; with the Declination of the Needle, Touched Therewith, under the Plaine of the Horizon* (London, 1720). The first edition was published in 1581.

motion. These ideas formed the basis for his landmark work, *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure*, published in 1600. In advocating these views, Gilbert was challenging Aristotelian cosmology and the Catholic Church while establishing the validity of his experimental methodology.

Aristotle believed each of the four elements had a natural place in the universe. Earth was the heaviest and would move to the lowest point available, on a local as well as a universal scale. Water also tended to low points, but rested above earth, as evidenced by the fact that rivers, lakes, and seas had earthen beds. Air and fire moved upwards. The natural tendencies of the elements led Aristotle to posit a series of concentric cosmological spheres, which explained the position of the Earth relative to other astronomical bodies. According to Aristotle, elemental earth settled at the center of the universe, forming the planet Earth. Because the Earth was at its settled natural point, Aristotle believed it must be stationary. The Papacy also took a hard line in favor of a geocentric universe, based in part on a literalist reading of the Bible.[35] Despite Catholic doctrine being consistent with non-literal readings of scripture, they enforced a geocentric view of the universe, spelled out most clearly in 1616 when Pope Paul V directed the Roman Inquisition under Cardinal Bellarmine to punish Galileo for supporting Copernican views of a heliocentric universe and publishing works that spread those ideas. Heliocentrism was officially declared heretical.[36] Gilbert saw Copernicus as the "restorer of astronomy," and

[35] This stance was based on a literal reading of several biblical passages which mentioned the earth being set on its foundations, which implied its immobility, such as Psalm 104, verse 5, which in the Geneva Bible (the most popular English translation prior to the King James Version published in 1611) reads "He set the earth upon her foundations, so that it shall never move."

[36] Maurice A. Finocchiaro, "Galileo's First Confrontation with the Inquisition (1616): Four Orders and Three Issues," *Galilaeana: Studies in Renaissance and Early Modern Science* 13: 29-60.

believed that magnetism was the key to explaining how and why the earth moved in its orbit around the sun.[37]

While ancient thinkers believed that magnetic attraction and electrical attraction were essentially the same force with different degrees of strength, Gilbert offered a more systematic explanation of the differences between magnetism and electricity. In *De Magnete*, Gilbert identified electrical materials by bringing them near to a non-magnetic needle, which he called a versorium, to see if they caused it to move by the force of their attraction. Amber was among the first and most strongly attractive materials Gilbert tested, so he called this class of attractive materials "electricks" after the Greek (ἤλεκτρον / elektron) and Latin (electrum) words for amber. Gilbert identified amber, jet, and many precious stones such as diamond and sapphire as possessing attractive force when rubbed.[38]

Throughout these studies, Gilbert would present a theory of electrical attraction put forward by someone else and then present experiments designed to scrutinize that explanation. He began with Cardano, who had identified some key differences between magnetism and electricity. Cardano had noted that amber attracted anything light, was made more strongly attractive by warmth and friction, did not have an external direction in which attraction occurred, and that electrical attraction was blocked by imposing a barrier. Lodestones, on the other hand, only attract iron, are unaffected by heat and friction, are drawn mutually to the iron they attract, align with planetary poles, and can attract iron through barriers.[39] Gilbert added two more criteria:

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[37] Gilbert, *On the Lodestone and Magnetic Bodies*, 358.
[38] Charles Du Fay, "Premiere Mémoire sur l'Électricité," *Histoire de l'Academie Royale des Sciences Annee MDCCXXXIII* (Paris: L'Imprimerie Royale, 1735), 23-24.
[39] Forester, *De Subtilitate*, 306.

magnets can pull heavier objects than electricks can, and moisture inhibits electrical activity but not magnetic activity.[40] And he concluded that rubbing, not the heat created by that rubbing, was the cause of electrical attraction in amber. When amber was warmed by any other means it did not attract light objects.

Gilbert also showed that electrically attracted objects had the same weight before, during, and after interaction with amber, thereby refuting Cardano's idea that light objects absorbed the effluvia of amber. Gilbert challenged Plutarch's interpretation that a current of air was pushed away from, and then returned to, the electrick, pointing out that rubbed amber had no impact on candle flames, torches, or live coals, all of which would react to a moving current of air. He also recognized that some things were not capable of being made electrical by rubbing, establishing two broad categories which would shape electrical study for over a century: electricks and non-electricks. He noted that electrical attraction did not arise spontaneously, because amber required rubbing to exhibit attraction. It was not uniquely innate, because many different materials, including jet, diamonds, and sealing wax, could all exhibit electrical attraction. It did not operate by sympathy or similitude, because many different and unrelated materials were attracted by electricks.[41] Based on his deduction and experiments, Gilbert concluded that electricks operated by effluvia.

Gilbert expressed the problem that even though "electric bodies do not appear to touch," there must be "something… given out from the one to the other to come into close contact therewith,

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[40] Joseph Priestley, *The History and Present State of Electricity, with Original Experiments* (London, 1767), 5; Gilbert, *On the Loadstone and Magnetic Bodies*, 74-97.
[41] J. L. Heilbron, *Electricity in the 17th and 18th Centuries: A Study of Early Modern Physics* (Los Angeles: University of California Press, 1979), 176.

and be a cause of incitation to it."[42] Early in *De Magnete*, Gilbert introduced the idea of "humors," which he defined as "exudations from the earth" which possessed different qualities than earth, and may have been caused by some process of elemental decomposition or corruption.[43] Gilbert asserted that all things were composed of elemental earth, which decomposed into two humors, one "fluid and humid," the other "firm and dry."[44] He believed amber, and by extension other electricks, to have a preponderance of the first humor, and to be fundamentally fluid in nature as a result.[45] Here, Gilbert adopted an effluvial theory in conjunction with his larger cosmology. When friction was applied to an electrick, he believed it would cause that solid body "to release a subtle vapor," because of its moist composition.[46] This vapor, or effluvium, was invisible, and would spread from the electrick. If the effluvium encountered a light object it would form a physical connection to it, due to its inherent moisture, which Gilbert believed was the basis for its adhesion. When the effect of the friction faded, the electrical effluvium would naturally return to its point of origin, but because it had formed a physical connection with that light object, the light object would be carried with the effluvium back to the electrick, resulting in electrical attraction.[47]

Gilbert's theory of moist effluvia being the mechanism of electrical attraction was supported by a series of idiosyncrasies he observed in his various experiments. Electricks could attract many different substances, but had no effect on flames, which Gilbert believed was because a moist effluvium would be consumed by fire. Electrical attraction was hindered by moisture or ambient

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[42] Gilbert, *On the Loadstone and Magnetic Bodies*, 92.
[43] Gilbert, *On the Loadstone and Magnetic Bodies*, 19-20; McTeigue and Anders, "William Gilbert," 57.
[44] Heilbron, *Electricity in the 17th and 18th Centuries*, 177; Gilbert, *On the Loadstone and Magnetic Bodies*, 83-84.
[45] Roller and Roller, *Electric Charge*, 9-10.
[46] Heilbron, *Electricity in the 17th and 18th Centuries*, 177.
[47] Gilbert, *On the Loadstone and Magnetic Bodies*, 95-97.

humidity, which Gilbert saw as evidence that there were pores in attracted objects which would receive an electric effluvium, but could also be filled, and therefore blocked, by other forms of moisture. Barriers, even of something as insubstantial as cloth, could interrupt electrical attraction, just as they could block moisture and ambient humidity.[48] All of these results supported Gilbert's idea that electricity was essentially a moist effluvia.

This was further demonstrated by another experiment. Gilbert took two sticks, one of which was inserted through a piece of cork, and placed them in a pool of water. The stick with the cork was wet on one side, and dry on the other, as the cork floated and kept one side of the stick above the water level. The second stick was entirely wetted in the pool. Gilbert observed that the dry portion of the first stick was drawn to the second stick, which he interpreted as an instance of attraction driven by a dry object being drawn to a wet one.[49] Gilbert noted that "wet bodies on the surface of water attract wet bodies," and concluded that "all bodies are united and, as it were, cemented together by moisture."[50] Gilbert saw this as analogous to electrical attraction, and upheld his theory that a sticky, moist effluvia was the physical mechanism of electrical attraction.

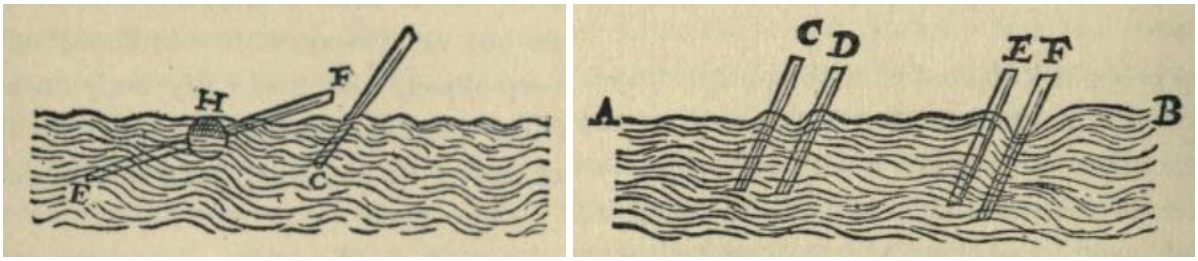


Figure 1: illustrations of William Gilbert's stick experiments, which he believed demonstrated an inherent attractive quality associated with moisture, underpinning his theory that electrical effluvia were moist and sticky. From Gilbert, *On the Lodestone*, 93-94.

[48] Gilbert, *On the Loadstone and Magnetic Bodies*, 95-97.
[49] Gilbert, *On the Loadstone and Magnetic Bodies*, 92-94.
[50] Gilbert, *On the Loadstone and Magnetic Bodies*, 92.

Gilbert maintained that magnets operated on a fundamentally different principle to electricks, although like electricks he was adamant that magnetism was not caused by any "occult qualities."[51] He believed the inherent magnetic nature of the earth itself explained all instances of magnetism on the earth, and that by demonstrating this through experiment its cause should no longer be labeled "occult."[52] He saw this terrestrial magnetism as a new form, like the Aristotelian forms of fire, water, earth, and air, though one Aristotle had not identified. Gilbert believed that the Earth itself was a giant rotating magnet, and formed his own cosmology, contrary to that of Aristotle, around his understanding of magnetism. For Gilbert, there was a single terrestrial element, earth, and it was inherently magnetic. Lodestones were elementally pure fragments of the earth, so they retained this characteristic magnetism.

Although Gilbert disagreed with Aristotle on many issues, he agreed that motion could not occur spontaneously. The fact that magnetic and electrical attraction caused motion demanded explanation. Gilbert demonstrated that lodestones rotated to orient themselves in accordance with planetary poles, which he extrapolated to explain that the earth itself rotates in accordance with some larger universal alignment. For Gilbert, lodestones had a Form that imparted motion, and their need to align with the planet itself explained the impetus for this motion. Magnetic Form and elemental composition explained the motions caused by magnets, and moist effluvia explained the motion caused by electricks.

Gilbert's theoretical explanations of the differences between magnetic and electrical attraction informed his beliefs about the nature of magnetic repulsion and the nonexistence of electrical

[51] Gilbert, *On the Loadstone and Magnetic Bodies*, 105.
[52] Gilbert, *On the Loadstone and Magnetic Bodies*, 105.

repulsion. Magnetic repulsion was readily observable and consistent with Gilbert's understanding of magnetism. Lodestones clearly had opposing poles, one of which would attract while the other repelled. Gilbert explained that the pole of one lodestone repels another "that does not agree naturally with it," but in so doing "makes it turn round so that they may come together perfectly according to nature."[53] Gilbert believed that magnets had a natural order and direction, and that they moved to align with the magnetism of the planet and its poles.[54] The position of a given magnet was what caused it to repel or attract in turn, and repulsion only occurred when one magnet was in an "unnatural" position relative to the planet, with that repulsion serving to correct that unnatural position by moving the magnet into correct alignment.[55] The inherent nature of magnets was to align with the earth, which facilitated and explained both attraction and repulsion. Based on his effluvial understanding of electricks, there was no reason they should be able to repel anything.

The mechanism of electrical activity Gilbert theorized on the basis of his experiments made sense of attraction but did not explain electrical repulsion. He described how an electric body drew objects to it, and held them "till their force is spent or vanishes," at which point the previously attracted objects "being set free again, are attracted by the earth itself and fall to the ground."[56] Lodestones forcibly separated themselves in an obvious manner; electricks seemed to simply lose their attractive power and allow objects to return to their regular tendency of motion (usually downward). Furthermore, the moist and humid nature of electricks suggested a tendency to "enfold," "hold," and pull, which justified attraction, but not repulsion.[57] In his opposition to

[53] Gilbert, *On the Loadstone and Magnetic Bodies*, 176.
[54] Gilbert, *On the Loadstone and Magnetic Bodies*, 182.
[55] Gilbert, *On the Loadstone and Magnetic Bodies*, 182-183.
[56] Heilbron, *Electricity in the 17th and 18th Centuries*, 97.
[57] Heilbron, *Electricity in the 17th and 18th Centuries*, 94-95.

occult explanations and insistence on being guided by experimental observation, Gilbert observed and justified magnetic attraction and repulsion, but he only observed and justified electrical attraction. With no discernible reason or evidence to support the idea of electrical repulsion, Gilbert believed he had found another criteria to differentiate magnetism from electricity and declared that while magnetic bodies were capable of both attraction and repulsion, electrical bodies only exerted attraction, and did not repel objects.[58] He was clear in his statement that "all electrics attract objects… they never repel or propel."[59]

Gilbert's theories provided an explanation for electrical attraction that was supported by experimental observation, but which also fit with an intuitive understanding of the world. Amber's fluid nature was widely accepted. It was often found on seashores, some pieces had insects trapped inside suggesting it had been liquid at some point. It was also easily observed that water would wick through dry objects, like cloth or straw, moving on its own, even against gravity. Although we now understand this process of capillary action to be different than electrical attraction, for a seventeenth-century observer the relevant detail would be that wet elements were capable of movement through certain other objects. For some, Gilbert's theory was convincing on the basis of his lengthy treatise and detailed experiments; for many others, Gilbert's theory was convincing simply because it fit within their observations and experiences of analogous phenomena. Unlike earlier thinkers, Gilbert also explained his experiments in such a way that they could be reproduced, so that others could verify his conclusions for themselves.[60]

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[58] Gilbert, *On the Loadstone and Magnetic Bodies*, 176; Priestley, *History and Present State of Electricity*, 5.
[59] Gilbert, *On the Loadstone and Magnetic Bodies*, 176
[60] See McTeigue and Anders, "William Gilbert," 65-67; This experimental tradition was built on by Francis Bacon (who published his *Novum Organum* in 1620), and the creation of the Royal Society in 1660.

In the century following *De Magnete*, any theory of electricity had to contend with Gilbert's own, whether in support, opposition, or adaptation of his ideas. His systematic differentiation between magnetism and electricity formed the definitional criteria for both magnets and electricks. Electricity was understood to be an effluvial force that could be drawn out of certain materials by rubbing them and could attract light objects. It was also, by definition, incapable of repulsion or operating through barriers. Subsequent generations reproduced Gilbert's experiments, observed similar results, and endorsed his conclusions that electrical repulsion did not exist and electricity could not move through barriers.

Responding to Gilbert and Debating Standards of Proof

Throughout the seventeenth century, many in Britain adopted and defended Gilbert's conclusions and experimental methodology, while some on the continent contested both, illustrating how changing standards of proof developed differently. René Descartes, for example, saw the universe as something like a clockwork mechanism, in which every physical effect (apart from mind) caused by matter pushing against and moving around other matter. Descartes considered any explanation outside of matter pushing against other matter to be unnecessary.

While Descartes had fundamental issues with Gilbert's non-mathematical, non-mechanistic explanations, others accepted the validity of elemental explanations but disagreed with his specific conclusions. Writing a few decades after Gilbert, Niccolo Cabeo, an Italian Jesuit polymath, responded directly to Gilbert's theory in his own work, *Philosophia Magnetica*. Cabeo posited four kinds of attraction, each with its own underlying cause. The first of these attractions is that caused by natural resemblance between objects ("propter similtudinem naturae"),

essentially a restatement of the earlier theory of sympathetic attraction. Cabeo claimed this form of attraction was the basis of magnetism.[61] Second was attraction caused by gravity and levity ("attractio ex vi qualitatis elementaris grauitatis aut leuitatis") by which things tended towards their natural place by virtue of their elemental composition, whether that be downward (for earthy matter) or upward (for airy matter).[62] The third variety of attraction was a revival of Plutarch's theory – attraction caused by a vacuum ("attraction ratione vacui").[63] In keeping with Plutarch, Cabeo explained that electric bodies emit a thin effluvium which displaces and rarefies the air; this void space is then filled by an inflow of surrounding air, the movement of which causes attraction. Cabeo believed this form of attraction explained electrical activity. The fourth form of attraction is caused by physical attachment to an object, like when a boat is pulled by a rope.[64] On the basis of these causes, and his own experiments, Cabeo raised objections to several of Gilbert's ideas about electricity.

In reasoning through the cause of electrical attraction, Cabeo, like Gilbert, ruled out sympathy because electricks attract too many disparate objects. Gravity and levity were also ruled out, on the grounds that electrical attraction can cause an object to defy gravity. Cabeo's category of attraction by physical attachment could have fit with Gilbert's effluvial theory, which posited an invisible but nonetheless physical link. Cabeo, however, dismissed the possibility of effluvia facilitating attraction because of what he described as a rebounding effect in electrical attraction.[65] Occasionally, when an object was attracted to an electric body, it would encounter

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[61] Niccolo Cabeo, *Philosophia Magnetica* (1629), 192.
[62] Cabeo, *Philosophia Magnetica*, 192.
[63] Cabeo, *Philosophia Magnetica*, 192.
[64] Cabeo, *Philosophia Magnetica*, 192.
[65] Heilbron, *Electricity in the 17th and 18th Centuries*, 182-183.

the charged electrick and then bounce away from it "to a distance of three or four inches."[66] Gilbert explained this phenomenon as the electric effluvium being exhausted and gravity taking over; Cabeo, however, believed the distance to which the previously attracted object moved was too great for gravity to explain. He theorized that this was the result of attracted objects rebounding, or bouncing off of the electric body which had attracted them. This was a simple mechanical explanation, which also relied on the forcefulness of attraction within Cabeo's theory. It also precluded Gilbert's effluvial theory. If sticky effluvia were the cause of electrical attraction, they would not allow an object to bounce away once attracted. A vacuum being rapidly filled with surrounding air, on the other hand, could account for this rebound effect.[67] Cabeo encountered electrical repulsion, and noted it, but did not identify it as a distinct phenomenon. Instead, he explained the observed repulsion as a secondary effect of electrical attraction.

Cabeo also repeated Gilbert's stick experiment. Gilbert saw this experiment as a demonstration of the attractive power of moist effluvia, but Cabeo interpreted the results as a demonstration of attraction by gravity. Cabeo explained that when a dry stick was put on the surface of water, its dryness could not mix with the wetness of the water, as they were opposite qualities according to Aristotelian theory. The stick therefore created a depression in the surface of the water, and other sticks simply fell into that depression as a result of gravity.[68]

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[66] Heilbron, *Electricity in the 17th and 18th Centuries*, 183.
[67] Heilbron, *Electricity in the 17th and 18th Centuries*, 183.
[68] Gilbert, *On the Loadstone and Magnetic Bodies*, 92-94; Cabeo, *Philosophia Magnetica*, 190-192. Although Cabeo did not understand the modern idea of surface tension, his explanation of Gilbert's stick experiment was, coincidentally, much more accurate than any other contemporary explanations.

Although some of Cabeo's objections to Gilbert were dogmatic, his reinterpretation of Gilbert's experiments highlighted real gaps in Gilbert's theory and explanations.[69] Gilbert's theory of moist effluvia could not explain the rebound effect Cabeo and others observed. He tried to give a better explanation of Gilbert's evidence, like his stick experiment, in terms of a vacuum theory, which to his mind offered the best alternative explanation. However, Cabeo's explanation obscured the underlying phenomenon within another theoretical framework that could not account for all the observed phenomena and, for his part, Cabeo ignored Gilbert's refutations of Plutarch's air-based theory (electricks did not affect candle flames, etc.).

Gilbert himself died in 1603, and so could offer no reply to Cabeo's commentaries on his work. However, other thinkers, particularly in England, such as Kenelm Digby and Thomas Browne, wrote in support of Gilbert's theories. Others, like Otto von Guericke, ignored these debates surrounding electricity and magnetism, but largely adopted Gilbert's assumptions and understanding of magnetic effects, suggesting that many thinkers adopted Gilbert's view because it was plausible and consistent with experimental results.

In 1645, Kenelm Digby, an adherent of Gilbert's theory, published his *Two Treatises*, in which he addressed a wide variety of physical and metaphysical phenomena, including all types of motion.[70] He divided the motion of attraction into several types. Water being drawn up a pipe by suction, or fire causing an inrush of air, were both treated as attraction by vacuum.[71] This was based on the maxim, from Aristotle, that "nature abhors a vacuum." Digby interpreted this to

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[69] Gilbert suggested a magnetic explanation for the earth's rotation, but Cabeo, in keeping with Aristotle and the official stance of the papacy, maintained that the earth was immobile. See Roller and Roller, *Electric Charge*, 14.
[70] Kenelm Digby, *Two Treatises: In the one of which, the Nature of Bodies; in the other The Nature of Mans Soule it Looked into In Way of Discovery of the Immortality of Reasonable Soules* (London: John Williams, 1645).
[71] Digby, *Two Treatises*, 196-202.

mean that any potential void had to be instantly filled by surrounding matter. He considered it "a great mistake" to suppose that a vacuum could properly exist.[72] Although his general theory of attraction was based on nature working to fill any potential vacuum, Digby considered electrical attraction to be fundamentally different. His explanation held that electricks were solid bodies of an "unctuous" or oily nature, based in part on his categorization of amber as a bituminous material.[73] Because oily things were easily burned, which was also true of amber, Digby believed they had an affinity with fire.[74] He believed that anything with a hot or fiery nature was likely to rarefy surrounding air and create attraction in the same manner that fire itself would do.[75] As proof of the idea that anything connected to fire was likely to attract, Digby cited the commonly held beliefs that loaves of bread which were still hot from the oven, and onions "which by their smell shew much heat in them," will draw any infection from the air into themselves.[76] Digby also explained how a variety of animals were used medicinally to draw infection from a person into that animal, which was explained by virtue of the warmth of living animals, and consistent with a belief in the humoral system of health and medicine.[77]

The ability of fire to create attraction by vacuum provided the justification for Digby's theory of electrical attraction, which he insisted was separate from attraction by vacuum. He explained that electric bodies, when warmed by rubbing, released "steams," which were imperceptible, but were emitted into the surrounding air. Contact with the cold air caused these inherently hot

[72] Digby, *Two Treatises*, 197.
[73] This classification came from Gilbert, who also identified other "unctuous" materials as being electricks see Gilbert, *On the Loadstone and Magnetic Bodies*, 76, 79.
[74] Digby, *Two Treatises*, 214.
[75] Digby, *Two Treatises*, 202-203.
[76] Digby, *Two Treatises*, 203; there is still a popular belief in many cultures throughout the world that placing a cut onion in the room of a sick person, or putting onions in the socks of a sick person, will help them recover more quickly. This is an outgrowth of early modern ideas like Digby's, although modern adherents likely do not realize this belief has its origins in seventeenth-century interpretations of Aristotelian physics.
[77] Digby, *Two Treatises*, 203.

emissions to condense and return to their point of origin. Digby compared the condensation of these vapors to "the little tender horns of snails" which "shrink back if any thing touch them, till they settle in little lumps upon their heads."[78] When these subtle vapors encounter any light body, they enter its pores, connect to it, and if it is light enough "would carry it with them" when they naturally return to their point of origin.[79] Electrical attraction was simply the result of these vapors encountering and latching onto light objects, and then carrying those objects with them as they condense and return to their object of origin, the electrick.

Digby was clear in expressing his respect for Gilbert and many of his ideas. When discussing magnetism, Digby explained that the "admirable" Dr. Gilbert had given the clearest understanding of the lodestone through his experiments and observations.[80] The starting point for Digby's explanation of electricity was to cite his "learned countryman Dr. Gilbert."[81] Digby was also clear in identifying magnetism as having both attractive and repulsive forces, what he refers to as the "double virtue" of lodestones, but never acknowledged the existence or possibility of electrical repulsion.[82] Despite this general endorsement of Gilbert, Digby was also negotiating with and willing to alter Gilbert's theory in some significant ways. They both believed effluvia created a physical connection between electricks and the objects they attracted. They differed, however, in their explanations of how that connection formed. Gilbert saw a connection between electrical phenomena and water. Because he believed that water had an inherently adhesive quality, this was a sufficient explanation: electricks emit moist effluvia, which adhere to objects and create an attractive effect when they return to their point of origin. Digby drew a connection

[78] Digby, *Two Treatises*, 214.
[79] Digby, *Two Treatises*, 214.
[80] Digby, *Two Treatises*, 225.
[81] Digby, *Two Treatises*, 215.
[82] Digby, *Two Treatises*, 234.

between electricks and fire. Based on his association of fire with things that are oily and hot, it made sense to Digby that electricks would create attraction by emitting oily effluvia that stick to light objects and drag them along when they naturally cool and condense. While there are meaningful differences between Gilbert's and Digby's explanations of electrical attraction, Digby saw his effluvial theory as being aligned with Gilbert's. He also adopted Gilbert's experimental methodology, and shared Gilbert's belief that experimental observations were an acceptable standard of proof. Like Gilbert, Digby believed that everything emitted effluvia, and that those emanations were the cause for a wide range of phenomena ranging from infections, to the ability of dogs to track deer, to magnetism and electrical attraction.[83]

Digby also aligned himself with Gilbert through his opposition to Cabeo. Even though Digby's general theory of attraction seems consistent with Cabeo's theory of electrical attraction, Digby saw the two as fundamentally different. Through *Two Treatises*, Digby calls out Cabeo by name multiple times, rejecting Cabeo's ideas in favor of Gilbert's in each instance.[84] In particular, Digby argued that if Cabeo's theory were true, the effluvial force of an electrick would create a wind that would push objects away from it, and therefore had no reason to cause attraction. This wind would also not cause light bodies to stick to an electrick once they were attracted.[85] This was essentially a restatement of Gilbert's objection to Plutarch's theories, just as Cabeo's work was a revival of them. Digby also saw Cabeo's explanation as inconsistent with the rebounding effect Cabeo himself described. If attraction were driven by the force of air, objects would not attract and rebound and attract again, in a pattern both Cabeo and Digby observed. However, in offering his own explanation of this phenomenon, Digby is more speculative. Cabeo observed

[83] Digby, *Two Treatises*, 205.
[84] Digby, *Two Treatises*, 216, 234.
[85] Digby, *Two Treatises*, 217.

pieces of sawdust attracted to an electric body and then thrown from it "sidewayes," i.e., not in the direction of gravity. Digby reasoned that this effect might be caused by "new emanations" of effluvia from the electrick, like successive waves.[86] These waves could potentially interfere with previously established attractions, and create the effect that Cabeo believed was a rebound of attractive force without admitting vacuum as the underlying mechanism of electrical activity.

Writing a year after Digby, Sir Thomas Browne also endorsed Gilbert's methods and conclusions. In discussing Gilbert's work with compasses, Browne declared that "England produced the Father Philosopher" of magnetism, and that "Dr. Gilbert" discovered more of magnetism through his experiments than either "Columbus or Americus" ever did through their maritime exploration and use of the compass.[87] Browne cites Gilbert's explanations of magnetism and electricity favorably throughout his work, and adopts Gilbert's theories of each phenomenon.[88] Browne defined electricks by their power to attract other bodies, excepting fire, which he maintained would consume the moist effluvia responsible for attraction.[89] Gilbert himself noted this exception, and explained it in the same way – moist effluvia could not affect flames because the heat of fire consumed and dissipated moisture, including that of the effluvia itself. Browne asserts that the effluvial nature of electricks is "plaine and granted by most," which is demonstrated by the facts that electricks require heat to exhibit attraction and that anything interposed between an electric and a light body breaks the attraction as it "intercepts the

[86] Digby, *Two Treatises*, 217-218.
[87] Thomas Browne, *Pseudodoxia Epidemica: Or Enquiries into Very Many Received Tenets, and Commonly Presumed Truths* (London: Tho. Harper, 1646), 64; this is referencing Christopher Columbus and Amerigo Vespucci, both noted explorers who travelled across the Atlantic and mapped areas of the Americas (which were named after Vespucci).
[88] Browne, *Pseudodoxia Epidemica*, 61, 64, 66, 70, 72, 74, 78, 80.
[89] Browne, *Pseudodoxia Epidemica*, 78.

effluvium."[90] Browne also described the effluvia as "viscous" and compared them to syrups and oils, in keeping with Gilbert's theory of a moist, sticky effluvia.

Like Digby, Browne also sought to disprove Cabeo and defend Gilbert. For Browne, Cabeo's theory is disproved by the variability of electrical attraction. When an electric body is rubbed and brought near to a pile of many straws, only some of these will rise toward the electric body. If a void were created into which air rushed, as Cabeo theorized, all of the straws in a given space would be equally affected by it.[91] Browne did accept Cabeo's idea that air moved in vortices in reaction to effluvia, but did not believe these effluvia created a void or vacuum. Observing the movement of dust in sunlight, Browne noted that it often moves in circular pathways when disturbed by breath, and he believed effluvial movement would cause a similar effect. The "gyration and whirling" of air was "evident… from the Atomes or moates in the Sun," i.e., dust in the sunlight.[92] Browne also observed the same effect Cabeo had: objects attracted to an electric body are sometimes thrown from that electrick. What Cabeo explained as a rebounding or bouncing effect arising from the strength of attraction, Browne called a "discharging" which he attributed to "the breath of the effluvium issuing with agility," in other words, new effluvia moving outward.[93] What Digby had proposed as a possibility, Browne stated as a reality. In Browne's view, any movement of a light object away from a charged electrick was a side effect of the effluvial activity which causes attraction and should not be considered a separate force or effect. This meant that Browne also had to contend with the key question of why effluvia did not always push objects away prior to attracting them. Browne explained that when effluvia are

[90] Browne, *Pseudodoxia Epidemica*, 79.
[91] Browne, *Pseudodoxia Epidemica*, 80.
[92] Browne, *Pseudodoxia Epidemica*, 80.
[93] Browne, *Pseudodoxia Epidemica*, 80.

emitted from an electrick they do so as an "enlengthened filament," and when they whirl about to return to the electrick they become thicker and stronger because they double back on themselves. Most objects are too heavy to be moved by a thin filament, but in the process of doubling back, the thin filaments of effluvia are combined, like a rope composed of several strands. As the effluvia accumulate and combine in this way, according to Browne, they become strong enough to move objects, thereby creating attraction. Objects were not constantly pushed away by the waves of effluvia because at the point of emanation, Browne maintained, those effluvia were too attenuated to move anything.[94] He also endorsed Gilbert's assertion that electricity would be blocked "if a body be interposed," because any object easily "intercepts the effluvium" of an electrick.[95]

Both Digby and Browne were convinced that Gilbert's effluvial theory was true. They endorsed the ideas that electricity could only attract objects, and that it could not operate through any barrier. By rejecting Cabeo and his challenges to Gilbert's theory, Digby and Browne helped to establish Gilbert as the authority on magnetism and electricity in Britain. On the continent, however, others took inspiration from Cabeo's work. The Academy of Experiments (Academia del Cimento) in Florence, in particular, investigated both the possibility of a vacuum around an electrick and the question of whether electrical attraction was mutual. On the former question, Cabeo's theory seemed to imply that there should be no air around an electrick, as it would all be displaced by effluvia. In 1666, members of the Academy took a recently invented barometer, which consisted of a glass tube partially filled with mercury, and in the empty space of this sealed tube above the mercury, created a light vacuum. In order to test the power of electrical

[94] Browne, *Pseudodoxia Epidemica*, 80.
[95] Browne, *Pseudodoxia Epidemica*, 79.

attraction through a void, they attached a small, sealed chamber to the top of a barometer and attempted to cause electrical attraction within that space.[96] This experiment proved inconclusive, though it did inspire later experiments with mercury barometers, which contributed to the discovery of electric light.[97] With respect to the mutuality of electrical attraction, the Florentine Academy succeeded in showing that electrical attraction was, in fact, mutual, contrary to Gilbert's belief. By suspending a piece of amber from a thread like a pendulum, rubbing it, and bringing another object near to it, the amber itself was moved.[98]

Otto von Guericke was another adherent of Gilbert's theories of magnetism and electricity. He did not write a pointed defense of Gilbert's work or address any objections to Gilbert's theory, but he did adopt Gilbert's assumptions regarding magnetism as well as his experimental techniques. Guericke attempted to recreate and build on the work of earlier natural philosophers throughout the 1650s, 1660s, and 1670s, and was especially interested in Gilbert's theories of terrestrial magnetism. Like Gilbert, Guericke created a *terrella*, an experimental model meant to represent the earth. While Gilbert's *terrella* was simply a spherical lodestone, Guericke made his out of a collection of minerals, predominantly sulfur, which he believed would mimic the qualities of the Earth due to its mineral composition and spherical shape. Guericke's *terrella* was attached to a stick in such a way that it could be rotated rapidly upon its axis. With this instrument Guericke conducted a wide variety of experiments.[99] Many of these failed, or only succeeded occasionally, but Guericke was able to create a number of electrical and magnetic

[96] Roller and Roller, *Electric Charge*, 15-16; *Saggi di Naturali Esperienze Fatte nell'Accademia del Cimento Sotto la Protezione del Serenissimo Principe Leooldo di Toscana* (Firenze: Giuseppi Cocchini, 1666), LXXXIV-LXXXIX.
[97] Graham and Pence, "Making Light."
[98] Roller and Roller, *Electric Charge*, 15-16.
[99] Otto Von Guericke, *Experimenta Nova (ut vocantur) Magdeburgica de Vacuo Spatio* (Amsterdam: Joannem Janssonium a Waesberge, 1672).

effects. Guericke observed a cycle of attraction, contact, and repulsion in an experiment with his *terrella*, which worked as a frictional electric generator.[100]

Guericke described a wide range of previously unacknowledged phenomena, including both attraction ("virtutem impulsivam" or "impulsive power") and repulsion ("virtus etiam expulsive" or "also an expulsive power"), as well as light generated by his sulfur globe.[101] But like Gilbert before him, Guericke believed in a strict separation between magnetism and electricity, and interpreted all of these phenomena as magnetic. This is in part due to Guericke's intentions in his experiments. He was interested in exploring a range of terrestrial events and created an experimental model of the earth to do just that. Based on his experiments and prior reading on the subject, he believed the earth was magnetic, and therefore assumed that events he investigated were the result of magnetic causes. Guericke came to the conclusion that the mineral composition of the earth and other planets provided the explanation for all motion in the universe, as well as explaining the causes of light, sound, and heat.[102] Because Guericke explained his observations in terms of terrestrial magnetism, they were largely ignored by later thinkers interested in electricity. This was compounded by the difficulty of recreating his instruments and experiments from his notes.[103] Although Otto von Guericke did observe electrical repulsion, his misattribution of that phenomenon played into the previously established theoretical understanding that magnetic repulsion was real, and electrical repulsion was not.

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[100] Joseph Priestley, writing in the 1760s, suggested that this meant Guericke had discovered that "a body once attracted by an excited electric was repelled by it, and not attracted again till it had been touched by some other body." However, Guericke interpreted it as a magnetic effect, not an electrical one, and therefore should not be credited as having discovered electrical repulsion. Priestley, *History and Present State of Electricity*, 8-9.
[101] Guericke, *Experimenta Nova*, 147.
[102] Guericke, *Experimenta Nova*, 125-151; Heilbron, *Electricity in the 17th and 18th Centuries*, 215.
[103] 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.

Gilbert's ideas about magnetism and electricity became dominant in England and influential elsewhere in Europe. Although the support of thinkers like Kenelm Digby and Thomas Browne lent further credence to Gilbert, ultimately the reasons for his popularity were simply that his theory made intuitive sense, it was supported by the evidence of his experiments, and he explained his experiments in sufficient detail that later thinkers could recreate them to observe the results directly. Digby and Browne offered minor addenda and reinterpretations that addressed specific objections raised by Cabeo, but the core understanding of electricity came from Gilbert. The key elements of this accepted view were that electricity and magnetism were separate forces with different attributes. Magnetism could both attract and repel, and could be communicated through pieces of iron. Electricity, on the other hand, could only attract, and was easily blocked by any number of barriers, moisture, or insufficient friction. Although Gilbert continued to dominate the field of electrical studies in 1708, the ongoing process of renegotiating methodologies and standards of proof that had brought Gilbert to the forefront of British experimental science would soon create an opportunity to move beyond his longstanding dominance and give an opening for Gray's theories to gain acceptance.

Isaac Newton and Changing Standards of Proof

As early as 1675, Isaac Newton observed a curious phenomenon that may have been an instance of electrical repulsion. Newton performed an experiment designed to determine if electricity could penetrate through glass, as he was generally interested in the effluvial permeability of different materials. To test this, he placed a glass disc "about two inches broad" in a brass ring and suspended it about one eighth of an inch above a table. By rubbing the upward facing side of

the glass disc, Newton observed that scraps of paper were attracted to the lower face of the disc, demonstrating that electricity could move through glass. Even after he finished rubbing the glass, Newton recorded that the paper scraps moved back and forth between the glass and the table. He described them "sometimes leaping up to the glass, and resting there a while, then leaping down and resting there, then leaping up, and perhaps down and up again," and sometimes in arcs and directions across the space between the glass and the table, moving parallel to the table.[104] In this experiment the "leaping down" of a paper scrap could be seen as gravity overcoming the attraction of electricity, or as the attractive force fading over time. However, this explanation does not fully explain the ongoing back and forth movements of the paper scraps, or their movements perpendicular to the direction of gravity, which Newton observed.

Newton did not offer a theoretical explanation of this incongruous movement of paper scraps at the time, and instead published a report on his intended experimental result (that electricity could pass through glass), and included these other details in an unpublished account of the experiment. Newton believed that electrical effluvia could pass through glass because it was itself an electrick, and did not see the results of this experiment as electricity being communicated to a non-electrick, as Gray would conclude in 1708. Newton's experiment demonstrated electricity operating through glass, and a forceful movement of paper scraps away from the electrically charged glass, but Newton only publicized those results which he could explain in a manner commensurate with preexisting theories of the physics of effluvia. Newton likely concluded that the incongruous movement of paper scraps might warrant further investigation, but should not be published until it was more fully studied and understood. In this

[104] Heilbron, *Electricity in the 17th and 18th Centuries*, 4; Thomas Birch, *The History of the Royal Society of London* vol. III (London: A. Millar, 1757), 250.

way Newton would have been endorsing a specific standard of proof as being a prerequisite of publication. Although in 1675 Newton preferred not to publish a finding he could not fully explain, he would later come to accept experimental results as sufficient and self-evident proofs even in the absence of a fully explained theoretical basis.

In 1703, Newton became President of the Royal Society of London, a post he filled until his death in 1727. Arguably more than any other individual thinker, Newton was positioned by virtue of his role and his accomplishments as a natural philosopher to influence the acceptance of scientific theories, direct experimental programs, and shape scientific understanding in Britain. In 1704, Newton published a treatise about the physics of light, called *Opticks*. In *Opticks*, Newton laid out his decades-long research project encompassing the transmission of light and color. Newton put forward a corpuscular theory of light, in which he proposed that light was made up of minute physical particles, which could be acted upon as other physical matter was. To Newton, this was clear in the phenomena of reflection, refraction, and inflection. Physical apparatus like mirrors and prisms were capable of shaping and affecting light at a distance, proving the physical composition of light. In his earlier work dealing with gravity, Newton had theorized a universal medium, much less dense than air, which allowed effluvia and other forces (especially gravity) to communicate without direct physical contact; he called this medium "aether." Newton theorized that physical effects could be transmitted at great distances through the aether. Newton expected that effluvia and corpuscular rays (like light) would behave similarly because they were both composed of physical streams which were imperceptible. Newton believed electricity was effluvial, so the behavior and limitations of electricity could serve as an example to test ideas about effluvia as a general category. Therefore, electrical

experiments, such as the one he conducted in 1675 to test the effluvial permeability of glass, could serve as a limited analog to better understand the transmission of light. By combining these different elements, Newton developed a theory that physical forces (like gravity) and phenomena (like light and color) could be transmitted across vast distances. Across his landmark works, *Philosophiæ Naturalis Principia Mathematica* first published in 1687, and *Opticks* first published in 1704, Newton's understanding of what constitutes sufficient proof shifted.

In the preface to *Principia*, Newton explained that "the basic problem of philosophy seems to be to discover the forces of nature from the phenomena of motions and then to demonstrate the other phenomena from these forces."[105] With respect to attraction and repulsion, Newton wrote:

> all phenomena may depend on certain forces by which the particles of bodies, by causes yet unknown, either are impelled toward one another and cohere… or are repelled from one another and recede. Since these forces are unknown, philosophers have hitherto made trial of nature in vain. But I hope that the principles set down here will shed some light on either this mode of philosophizing or some truer one.[106]

He believed that the unknown forces of the universe may eventually be explained more fully, but took issue with other philosophers who were unwilling to theorize about natural forces until and unless they could offer a full explanation of the characteristics and mechanisms by which those forces acted. In keeping with his stated view that the basic problem of philosophy was to discover natural forces, he was more willing than some of his contemporaries to demonstrate the existence of forces like gravity without being able to fully explain how they operated in the way they did.

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[105] Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy,* trans. I. Bernard Cohen, Anne Whitman, and Julia Budenz (Berkeley, CA, 1999), 382.
[106] Newton, *The Principia,* 382-3.

Newton's *Principia* was rapidly accepted and celebrated in Britain, but (echoing reactions to Gilbert), natural philosophers on the continent took issue with his methodology.[107] Because the *Principia* did not explain the mechanism by which gravity acted, Leibniz wrote a letter to Newton accusing him of resurrecting an "occult quality" in his work, and insisted that denying he had done so "would be to uphold something worse than occult qualities … to renounce philosophy and reason, giving refuge to ignorance and laziness by means of an irrational system."[108] Leibniz made the same accusation more publicly in 1704, the same year that Newton published his *Opticks*. Despite these attacks on his approach, Newton did not change course.

In many of his works, Newton put forward propositions he could not prove definitively in addition to those he could. He explicitly labeled the former as "conjectures," and put them in a separate section of each book to make it clear what was supported by the results of his experiments and what was speculative. In *Opticks*, these speculations took the form of queries at the end of the treatise. In the Latin edition of *Opticks,* published in 1706, Newton added a new query (the 22nd in that edition; in later editions it appeared as the 31st), in which he laid out a new idea about the origins of motion and the behavior of corpuscles, which he believed to make up all matter. This query begins:

> Have not the small particles of bodies certain powers, virtues or forces by which they act at a distance not only upon the rays of light for reflecting, refracting, and inflecting them, but also upon one another for producing a great part of the phenomena of nature? For it's well known, that Bodies act one upon another by the Attractions of Gravity, Magnetism, and Electricity.[109]

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[107] Wang, *Handling "Occult Qualities,"* 210-211.
[108] Newton to Leibniz, 16 October 1693, in Turnbull, *Correspondence*, 3, 285–6, quoted in Wang, *Handling "Occult Qualities,"* 211.
[109] Isaac Newton, *Opticks or a Treatise of the Reflections, Refractions, Inflections and Colours of Light*, 4th edition, (London: William Innys, 1730), 350-351; Arthur Quinn, "Repulsive Force in England, 1706-1744," *Historical Studies in the Physical Sciences* vol. 13, no. 1 (1982): 109-128, 110.

Based on his understanding of the accepted forces of gravity, magnetism, and electricity, Newton thought that corpuscles themselves must have some characteristic that was capable of exerting force on other corpuscles and matter. He did not address the nature and mechanism of these forces, writing simply "how these attractions may be performed, I do not here consider."[110] Newton believed these forces would naturally exist between corpuscles in general, and saw evidence of this in various chemical examples. Salt dissolved in water, for example, served as an illustration. If salt is heavier than water how can parts of it be taken up into the water rather than it all settling at the bottom of a vessel of water? For Newton, a corpuscular attraction between the water and the salt would be able to overcome the gravitational pull on the salt. However, within chemical operations, Newton also found a problem he could not solve by reference to attraction alone. For example, he noted that nitric acid (which was called "Aqua Fortis") dissolves silver, but not gold; a combination of nitric acid and hydrochloric acid (which was called "Aqua Regia") dissolves gold, but not silver.[111] Dissolution was commonly understood to be a function of attraction between a solute and a solvent, but for Newton this explanation failed to account for the fact that adding ingredients to Aqua Fortis robbed it of its ability to dissolve silver. Instead, he thought that hydrochloric acid must repel silver, so that when it was added to nitric acid it would prevent the attraction required to dissolve the silver.[112] Newton also provided simpler examples of apparent repulsion, such as water and oil not mixing together.[113] Newton's understanding of chemistry was among the factors that led him to a theory of repulsion.

[110] Newton, *Opticks,* 351.
[111] Newton, *Opticks*, 357-358.
[112] Newton, *Opticks*, 357-358.
[113] Newton, *Opticks*, 358.

These forces were also evident to Newton in the behavior of light, which he believed was made of corpuscles. Light refraction suggested "an attractive force between the rays of light and the small particles of transparent bodies."[114] In both reflection and inflection, Newton saw rays of light "repelled… without the immediate Contact of the reflecting or inflecting Body."[115] The ways in which light could be bent, shaped, and directed proved to Newton that there must be some material force influencing the material that constituted light. Although he was not certain where these forces originated or how they operated, Newton theorized that such forces must be a feature of corpuscles themselves. Newton's theory of corpuscles held that all corpuscles were essentially the same, but could differ in size. Corpuscles themselves were brought together by strong attractions to form larger particles with weaker attractive power. The larger the particle, the weaker its powers of attraction. The process of combination occurred successively to form very large particles with very weak attractive power.[116] This suggested to Newton a mathematical analogy — when you reduce positive numbers beyond zero, they become negative numbers, so if you reduced attraction enough, it should naturally become repulsion. Newton believed this applied to the physics of particles, and that "where Attraction ceases," as a result of multiple iterations of particle cohesion "a repulsive Virtue" must exist.[117]

As Newton argued throughout *Opticks*, light was material, and subject to the same mechanics as other matter, including those caused by effluvia. Newton therefore saw the forces which shaped and directed light as equally applicable to effluvia, which he referred to as "Air and Vapour" and "the Particles… shaken off from Bodies by Heat and Fermentation."[118] Although Newton did not

[114] Quinn, "Repulsive Force in England," 110.
[115] Newton, *Opticks*, 370-371.
[116] Newton, *Opticks*, 370.
[117] Newton, *Opticks*, 370.
[118] Newton, *Opticks*, 371.

explicitly identify electrical effluvia, they would fit these categories within Newtonian physics. Newton was explicit, however, in identifying this repulsive force as separate from Boyle's "Spring of Air," stating that the "vast Contraction and Expansion" of the motions he described "seems unintelligible by feigning the Particles of Air to be Springy… or rolled up like Hoops, or by any other means than a repulsive Power."[119] Differences in the size of corpuscles caused related differences in forces and manifested as different kinds of matter.[120] By ascribing these forces to particles, Newton was making a universal claim on par with his theory of gravitation. He believed that gravitation determined the motion and behavior of planetary bodies, and that there must be a similar set of forces that determined the motion and behavior of corpuscles and the matter made from corpuscles. He expressed this analogy by writing that just as "all the great Motions of the heavenly Bodies" were directed "by the Attraction of Gravity which intercedes those Bodies," that the motion of "all the small ones of their Particles" must also be directed "by some other attractive and repelling Powers which intercede the Particles."[121] A series of observations about light, filtered through a belief in a corpuscular universe, and a methodological shift that accepted the validity of forces without uncovering their mechanism of action led Newton to the conclusion there must be both attractive and repulsive forces, and that these forces must affect all matter.

Among Newtonians and members of the Royal Society, this new pronouncement created quite a stir, and some confusion. For generations, the scholarly consensus in England was that only magnets could repel one another. Supposed instances of electrical repulsion were discounted because they did not fit within preexisting theoretical frameworks. The most influential attempt

[119] Newton, *Opticks*, 371.
[120] Quinn, "Repulsive Force in England," 111.
[121] Newton, *Opticks*, 372.

of the seventeenth century to explain the apparent phenomena was offered by Niccolo Cabeo and relied on an effluvial theory of electricity, which was generally accepted, and a further theory of air displacement and vacuum-induced motion, which was controversial. Among Cartesian philosophers, Cabeo's theory was problematic because Descartes did not believe an empty space could exist. All motion occurred in a plenum, a space completely full of matter (mostly air), within which all motion involved matter trading places. In England, Cabeo's theory was controversial because it contradicted Gilbert, and suggested that repulsion should occur at all times, which it clearly did not. Newton did not expect all matter to exert attraction or repulsion, because corpuscules combined in different ways to create different effects within individual material objects. However, the idea that corpuscles were responsible for these forces was at odds with Gilbert. Although he broke with earlier theories, Newton's claim that a repulsive force (distinct from Gilbert's magnetism or Boyle's springy air) must exist eventually gained support. This is illustrated in part by the *Lexicon Technicum*, a dictionary of scientific terms published in two volumes (1708, 1710) by John Harris, a Fellow of the Royal Society. Between the publication of these two volumes, Harris adopted Newton's position.

In 1708 Harris defined air as a compressible, dilatable fluid made of three kinds of corpuscles: vapors from the earth, sea, and living bodies; subtler particles emitted from heavenly bodies and the globe's magnetism; and "Corpuscles which are constantly Elastical or Springy," describing elasticity as "an Essential Property of Air."[122] This view echoed Gilbert's effluvial theory and Boyle's theory of elastic air. Newton, though rejecting Boyle's model of spring-shaped particles, also identified three categories of air: vapors that emit from living things, vapor of a "middle

[122] John Harris, *Lexicon Technicum: Or An Universal English Dictionary of Arts and Sciences*, vol. 1 (London: 1708).

nature," and "true and permanent air," the last being stable and always present.[123] Harris's third kind of vapor closely resembles Newton's conception of permanent air. He also differentiated air from aether by noting that air refracts light, while aether does not.[124] The 1708 volume also included an entry on "Attraction," explaining Newton's law of gravitation, but offered no discussion of repulsion.[125]

By 1710 Harris revised his treatment of air to incorporate Newton's more recent work in the *Opticks*. In the entry for "Air" he reported the recent claims of "the admirable Sir *Isaac Newton*" that particles of air repel one another at a distance but attract when near.[126] Harris also repeated Newton's suggestion that true and permanent air originated from the fermentation of dense terrestrial bodies. Newton understood larger, denser particles to have less attractive power, and if a particle became large enough he reasoned its attractive power could actually become a repulsive power. This idea helped explain why air and vapors spread to fill any vessel—a phenomenon Boyle had described but attributed only to elasticity. Under the entry for "Attraction" (cross referenced from "Air") in the 1710 volume, Harris explains that the "Production of Air and Vapours" proves "that there is a *repelling Force*." Building on Newton's proposal, he writes that repulsion between particles occurs when particles leave the "Sphere of Attraction" of neighboring particles.[127] Particles are attracted to one another when they are in close proximity, and repelled from one another when they are more distant. For Newton, and

[123] Prajit K. Basu, "Newton's Physics in the Context of his Works on Chemistry and Alchemy," *Indian Journal of History of Science* 26 (3), Sept. 1990: 290-291
[124] Harris, *Lexicon Technicum* vol. 1.
[125] Harris, *Lexicon Technicum* vol. 1. There is an entry for "repellent" but this refers to medicines that address swelling by repelling humors, not a physical force.
[126] John Harris, *Lexicon Technicum: Or An Universal English Dictionary of Arts and Sciences*, vol. 2 (London: 1710)
[127] Harris, *Lexicon Technicum* vol. 2.

now for Harris, a genuine repelling force was required, especially in the dense particles of permanent air.

Harris further aligned with Newton under the entries “Attraction,” cross-referenced from “Air.” He argued that the production of air and vapors proved the existence of repulsion: particles attract within one another’s “Sphere of Attraction,” but repel once outside it.[128] He also adopted Newton’s critique of Boyle, insisting that elasticity alone could not account for air’s behavior and that particles must themselves possess repulsive force. The second volume even added a short entry for “Repelling Force,” noting simply “That there is such a thing in Nature, see *Attraction* towards the End.”[129] Through these revisions, Harris made clear that he had shifted from a synthesis of Gilbert and Boyle to a wholehearted endorsement of Newton, presenting repulsion as a fundamental property of air.

There were several authors who were otherwise aligned with Newton, but did not accept his newly theorized repulsive force. In 1710, John Freind, F. R. S., published a series of lectures on chemistry. He dedicated the book to Newton, but made no mention of repulsion beyond one instance while defining magnetism.[130] John Keill, F. R. S. wrote an article for the *Philosophical Transactions* in 1708 on the laws of attraction, and made no mention of Newton’s repulsive force either.[131] To many, even among Newton's adherents, it seemed flatly impossible that a single particle could exert both attraction and repulsion. How could opposite forces coexist within a

[128] Harris, *Lexicon Technicum* vol. 2.
[129] Harris, *Lexicon Technicum* vol. 2.
[130] John Freind, *Praelectiones Chymicae* (Amstelodami: Janssonio-Waesbergios, 1710), 2-5; an English translation was published 2 years later as John Freind, *Chymical Lectures* (London: Philip Gwillim, 1712); Quinn, “Repulsive Force in England,” 114.
[131] John Keill, “In Qua Leges Attractionis aliaque Physices Principia traduntur,” *Philosophical Transactions* vol. 26, no. 315 (June, 1708): 97-110; Quinn, “Repulsive Force in England,” 114.

single body? There was a long tradition of denying any repulsion that was not magnetic, a lively debate in the English scientific community on the nature of matter, and conflicting opinions on the possibility of a single particle exerting opposite forces. Although Newton's new query theorizing a repulsive force was published in the 1706 edition of *Opticks*, it was not included in the 1708 volume of Harris' *Lexicon Technicum*, or Keil's paper on attraction of that same year. By 1710, Newton's new idea had gained enough traction to be included in Harris' second volume, but was still not endorsed by others, like Freind. Because this universal repulsion was a force that Newton hypothesized without offering an explanation for how it might act or why it might exist, it, like gravity thirty years earlier, served as a proxy for accepting Newton's new methodology and standard of proof. Many natural philosophers were not willing to accept the existence of forces that they could not fully explain, even if their existence was demonstrated experimentally or modeled mathematically. Whether by virtue of his position in the Royal Society, or because he was participating in an intellectual shift that had taken root in Britain more so than elsewhere, Newton's approach to physics eventually gained ground among British natural philosophers. This change in methodology helps make sense of why Stephen Gray's experiments would have been deemed unpublishable in 1708, but would gain general acceptance in the 1720s and 1730s.

Stephen Gray's 1708 Letter

Stephen Gray was born in 1666, probably in Canterbury. He and his brother Thomas established themselves as dyers, a craft at which Stephen worked for most of his life. Stephen's other brother, Matthias, was made Mayor of Canterbury in 1692 and again in 1700.[132] The first record

[132] "List of Officials," *The History and Topographical Survey of the County of Kent* vol. 12.

of Gray's foray into natural philosophy was in 1696, when several of his observations on microscopy were published by the Royal Society of London in its journal, *Philosophical Transactions*. From 1696 to 1703, Gray published regularly on subjects including optics, fossils, and, most of all, astronomy.[133] Although he spent the majority of his time at his dyeworks, he formed friendships and working relationships with a number of natural philosophers, including wealthy amateurs who helped fund his work and influential professionals who brought him into the community of scientific thinkers. Among Gray's associates throughout his life were John Flamsteed (the Astronomer Royal), Roger Cotes (professor at Cambridge and personal friend of Isaac Newton), Granville Wheler (a Kentish landowner, reverend, and natural philosopher), and John Theophilus Desaguliers (an experimentalist and natural philosopher who would later become Newton's assistant). At some time between 1703 and 1708, Gray turned his attention to electricity and began a decades-long series of experimental projects to better understand its characteristics and range of effects.

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[133] Stephen Gray, "Several Microscopical Observations and Experiments," *Philosophical Transactions* vol. 19, no. 221 (August 1696): 280-287; Stephen Gray, "A letter from Mr. Stephen Gray, giving a further account of his water microscope," *Philosophical Transactions* vol. 19, no. 223 (December 1696): 353-356; Stephen Gray, "A letter from Mr. Stephen Gray, from Canterbury, May the 12th 1697, concerning making water subservient to the viewing both near and distant objects, with the description of a natural reflecting microscope," *Philosophical Transactions* vol. 19, no. 228 (May 1697): 539-542; Stephen Gray, "A letter from Mr. Stephen Gray, dated Canterbury, Dec. 8, 1697, relating some Experiments about making Concave Specula nearly of a Parabolick Figure," *Philosophical Transactions* vol. 19, no. 235 (December 1697): 787-790; Stephen Gray, "Part of a letter from Mr. Stephen Gray, about a way of measuring the heighth of the mercury in the barometer more exactly," *Philosophical Transactions* vol. 20, no. 240 (May 1698): 176-178; Stephen Gray, "An observation of some parelii seen at Canterbury," *Philosophical Transactions* vol. 21, no. 251 (April 1699): 126-127; Stephen Gray, "Part of a letter from Mr. Gray, concerning an unusual parhelion and halo," *Philosophical Transactions* vol. 22, no. 262 (March 1700): 535; Stephen Gray, "Part of a letter from Mr. Stephen Gray to the Publisher, containing his observations on the fossils of reculver clisse, and a new way of drawing the meridian line, with a note on this letter by the publisher," *Philosophical Transactions* vol. 22, no. 268 (January, 1701): 762-764; Stephen Gray, "A letter from Mr. Stephen Gray, concerning drawing the meridian line by the pole star, and finding the hour by the same," *Philosophical Transactions* vol. 22, no. 270 (April 1701): 815-819; Stephen Gray, "Part of two letters from Mr. Stephen Gray, concerning the spots of the Sun, observ'd by him in June last," *Philosophical Transactions* vol. 23, no. 288 (December 1703):1502-1504.

In a letter written on January 3, 1708, to Hans Sloane, the Secretary of the Royal Society, Stephen Gray laid out a series of electrical experiments.[134] Gray was inspired by the work of Francis Hauksbee, which was regularly published in the *Philosophical Transactions* and which Gray followed closely. In his letter, Gray described a series of experiments he had conducted using a glass tube of the same size and dimensions as the one used by Hauksbee in his own experiments, the design of which Hauksbee described in a published account in 1707.[135] Gray's stated goal was to build on Hauksbee's work by conducting new experiments related to electricity, or as he put it "to Trace out the extent and Current of the Luminous and Electrick Effluvia of Glass."[136] Gray described twelve related experiments in his letter.

In each of these experiments, Gray used an electrically charged glass rod to manipulate and affect various objects, most often a feather. This was a fairly standard experimental model. Rubbing a piece of amber or glass would produce static electricity, and a light object like a feather would be easily moved to demonstrate the presence of electricity. Gray recreated some of Hauksbee's experiments producing light from electrical bodies and made specific observations about the shape and extent of these light emissions. He then conducted a series of experiments meant to test the extent of electrical attraction, but was surprised by the results he produced. Gray's second, third, fourth, and twelfth experiments are of greatest interest. In the second, Gray observed that the feather would be attracted to and cling on to the glass rod, as expected. But, if he then brought the rod within several inches of some other object, the feather would push away from the glass rod and move back and forth between the glass rod and that other object "10 or 15

[134] Sloane Manuscript 4041, Folio 83, reproduced in Robert A. Chipman, "An Unpublished Letter of Stephen Gray on Electrical Experiments, 1707-1708," *Isis* vol. 45, no. 1 (May 1954): 33-40, 34.
[135] Francis Hauksbee, "Several Experiments Shewing the Strange Effects of the Effluvia of Glass, produceable on the Motion and Attrition of it," Philosophical Transactions vol. 25 (1707-1708): 2372-2377.
[136] Chipman, "An Unpublished Letter," 34.

times" before stopping.[137] In his third experiment, Gray looked more closely at the feather as it rested on the charged glass rod, and noted that while one side of the feather clung to the rod, the other side of the feather extended away from it. If he then touched the extended fibers of the feather, they would immediately reverse direction and cling to the glass rod as well.[138] For his fourth experiment, Gray charged a glass rod, used it to attract a feather, which was then pushed away from the glass rod as in his second experiment. He described it as being "reflected" from the rod. This force remained in effect long enough that the feather could be chased around the room, being pushed by the glass rod, until the feather came in contact with some other object, at which point it would be attracted to the rod once more.[139] This experiment closely matches one described by Otto von Guericke, which Francis Hauksbee also recreated later in 1708 (perhaps inspired by Guericke, perhaps by Gray himself). This fourth experiment is an example of the attraction-contact-repulsion cycle, in which objects are electrically attracted, come in contact with another object causing an exchange of ions and reversal of charge, and are then electrically repelled. Although Gray had no concept of electrical charge, he recognized that the direction of electrical force seemed to reverse each time the feather touched another object, and that there were clear instances of repulsive force acting on the feather.

In his twelfth experiment, Gray began as he did in the second. Using a charged glass rod, he attracted a feather which subsequently was repelled from the glass toward a wall. Gray wrote that he wanted to test if the repulsion he observed was caused by the "Reflection" of electrical effluvia off "external objects."[140] Electricity was understood as the result of effluvial emission,

[137] Chipman, "An Unpublished Letter," 34-35.
[138] Chipman, "An Unpublished Letter," 35.
[139] Chipman, "An Unpublished Letter," 35.
[140] Chipman, "An Unpublished Letter," 36

and was believed to be only an attractive force. Effluvia were invisible, vaporous strands that emitted from electrical objects, like glass, and could latch onto light things and pull them back to the glass, creating the attractive effect that Gray observed. However, sometimes electric bodies seemed to push objects away, which was inconsistent with effluvial theories. Within the effluvial paradigm, any apparent repulsion was explained as attractive effluvia being redirected by bouncing off an external object. The effluvia would still attract light objects, but because the effluvia's direction of travel had been changed, the direction of attraction would also be changed. What might look like repulsion was, therefore, just a redirected effluvial strand moving in an unexpected direction.[141] Gray was explicitly testing this accepted explanation in light of his experimental results, to see if they were consistent with the prevailing theory. To test if electrical effluvia were being redirected by external objects, Gray placed a solid object between the feather and the glass rod. He expected this solid object to cut off all electrical activity by blocking the effluvia. However, Gray observed that the feather was instead attracted to the solid, non-electrical object placed between it and the glass rod. Furthermore, the feather would move between the wall and this interposed object, two non-electric objects, just as it moved between the glass rod and another object in his second experiment.[142] Gray wrote that the hypothesis that electrical effluvia bounced off of non-electrical objects "is contradicted by the now mentioned Experiment."[143] Although he did not offer an alternative theory of electricity to explain how or why repulsion occurred, Gray's experiment showed what he saw as self-evident proof of electrical repulsion's existence.

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[141] Gilbert, *On the Loadstone and Magnetic Bodies,* 59-60; Browne, *Pseudodoxia Epidemica*, 61-64.
[142] Chipman, "An Unpublished Letter," 36.
[143] Chipman, "An Unpublished Letter," 36.

Gray recognized his results were both unexpected and unexplained. In his earlier experiments, he had not anticipated that the feather would move away from his glass rod. In 1600, William Gilbert explained that on the basis of his experiments he believed that electricity was exclusively an attractive force. The only electrical motion Francis Hauksbee ever mentioned was attraction. Gray was not trying to overturn any established theory of electricity, but he could not deny the effects he observed in his experiments. Gray observed what looked like electrical repulsion. He designed an experiment which he expected would prove that this was caused by effluvia bouncing off an external object. Instead, he encountered another unexpected and unexplained result. The feather moved between two non-electric objects as though they possessed electrical effluvia themselves. Gray offered an explanation that, in light of his experimental results seemed to him "somewhat more probable" than the explanation he had disproven. He proposed that "as all bodies Emitt soe they Receive part of the Effluvia of all other bodies that Inviron them and that the attraction is made according to the current of these Effluvia."[144] The idea that non-electric objects could absorb and emit electrical effluvia formed the basis of Gray's experimental work for the next 25 years and would form the basis for his discovery of electrical conductivity and insulation. If electricity could be absorbed and emitted by non-electrical objects, this left the question of electrical repulsion unaddressed. Gray's twelfth experiment showed that effluvia were not reflected, so Gray had no cogent explanation for why the feather in his experiments alternated the direction of its movement.

Gray was not a theorist and did not delve into the implications of his experiments beyond his hypothesis that everything could absorb and emit effluvia. He admitted in his letter that he was "far from thinking what I here offer is an Intire solution of the Phenomena," adding "this I must

[144] Chipman, "An Unpublished Letter," 36.

leave to the consideration of the Learned," by which he meant the members of the Royal Society who studied electricity, most notably Francis Hauksbee himself.[145] Despite the significance of Gray's results, his 1708 letter was not published, and the phenomena he demonstrated in these experiments were not accepted by the mainstream scientific community in Britain for over a decade. The implications of Gray's experiments were controversial. Since classical antiquity, electricity and magnetism were considered to be related forces, and magnetism was considered the more powerful of the two. Magnetic attraction and repulsion were equally self-evident, but electrical attraction was much more evident than electrical repulsion. There was no theoretical basis for electrical repulsion in antiquity, and that idea was made explicit by William Gilbert in 1600, who differentiated magnetism from electricity in part by holding that magnetism could both attract and repel, while electricity could only attract. Theories of electricity were based on the belief that electric objects emitted effluvia; effluvial theories brought with them a set of axiomatic assumptions, including that effluvial forces only worked in one direction, and that solid objects would block the flow and activity of effluvia. Gray's discoveries and ideas would eventually gain broad acceptance, but they first had to overcome the barriers of preexisting theories of effluvial action, and in particular the legacy of William Gilbert's ideas on electricity.

The Reception of Gray's Ideas After 1708

In 1708, Gray observed that electricity traveled from one object to another, and that objects were intermittently drawn to an electrically charged glass rod and then repelled from it. He concluded that all objects must be capable of absorbing and emitting electricity, and although he did not

[145] Chipman, "An Unpublished Letter," 36; Michael Ben-Chaim, "Social Mobility and Scientific Change: Stephen Gray's Contribution to Electrical Research," *The British Journal for the History of Science* vol. 23, no. 1 (March, 1990), 3-24: 9;

know what caused the repulsive force he observed, he ruled out effluvial reflection, which would have preserved the theory that electricity was an exclusively attracting force. There are several possible explanations for Hans Sloane's decision to not publish Gray's letter describing these observations and conclusions in 1708.

The decision could have been based on the letter's content. Gray's simple experiments and the hypotheses it suggested were significant, and some (both at the time and since) have interpreted them as challenges to scientific orthodoxy, which was in some ways represented by the Royal Society. However, Newton's personal support for a theoretical repulsive force and the shifting standard of proof he applied makes it unlikely that the Royal Society would penalize Gray for hypothesizing repulsion or conduction, despite these ideas still being controversial in 1708. Some scholars have interpreted Gray's letter as an attack on effluvial theory itself, which would disrupt myriad theories across natural philosophy.[146] However, Gray referenced effluvia as the mechanism of electrical activity in his 1708 letter and continued to do so in later works on electricity, suggesting he did not see his work as a challenge to that view, but rather as a demonstration of previously unknown effluvial actions. It is possible that Francis Hauksbee influenced the decision.[147] Hauksbee had been appointed Curator of Experiments in 1704, shortly after Newton became President, and focused his work on electrical experiments. Hauksbee had worked for and with Newton previously, in his role as an instrument maker and experimental demonstrator and may have seen Gray's experimental work as threatening his position or theories. Hauksbee was certainly apprised of Gray's work described in the letter, because he was

[146] Michael Ben-Chaim interprets Gray's statement here as disputing the idea that "the electric emitted 'its own effluvia'" and therefore a direct challenge to the effluvial theory of electricity. This is an overstatement of Gray's point. Ben-Chaim, "Social Mobility and Scientific Change," 10-11.
[147] Ben-Chaim, "Social Mobility and Scientific Change," 14-15; Chipman, "Unpublished Letter," 37-38; Heilbron, *Electricity in the 17th and 18th Centuries*, 234-236.

directed by the Society to recreate Gray's experiments later in 1708, in order to "try what is new in them."[148] Some have suggested that Gray was even the inspiration for similar experiments carried out by Hauksbee.[149] This possibility remains speculative, however, as none of Hauksbee's surviving writings suggest any relationship, preoccupation, or ill-will toward Stephen Gray.

Another possible explanation put forward by some scholars is that Gray's earlier friendship and association with John Flamsteed may have created some friction with Isaac Newton. Gray's first correspondence with Flamsteed was in 1699,[150] and Gray had at least a good working relationship with Flamsteed for many years.[151] Newton and Flamsteed, on the other hand, were on notoriously bad terms with one another.[152] Between 1699 and 1701, several of Gray's letters to the Royal Society were published in the *Philosophical Transactions*. These focused primarily on astronomy, and several were written in collaboration with Flamsteed, which likely did not endear him to Newton. Newton became President of the Royal Society in 1703. From 1701 to 1713, Gray wrote seven letters to Hans Sloane, none of which was published. Gray's only publication during this time was an astronomical report in 1706, and was written by Flamsteed with contributions from Gray. It is possible, though there is no definitive evidence, that Flamsteed, as Astronomer Royal, possessed enough social clout that his letters were regularly

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[148] Heilbron, *Electricity in the 17th and 18th Centuries*, 234-236; Ben-Chaim, "Social Mobility and Scientific Change," 10.
[149] Ben-Chaim, "Social Mobility and Scientific Change," 14-15; Chipman, "Unpublished Letter," 37-38; Heilbron, *Electricity in the 17th and 18th Centuries*, 234-236.
[150] Robert A. Chipman, "The Manuscript Letters of Stephen Gray F.R.S. (1666/7-1736)," *Isis* vol. 49 no. 4 (Dec. 1958), 430.
[151] Chipman, "Manuscript Letters," 423.
[152] This animosity is probably linked to the comet of 1680. Astronomers previously believed comets always appeared in pairs, Flamsteed made detailed observations of the 1680 comet and showed that there was only one. He shared his observations with Newton, at that time a professor of mathematics at Cambridge, and Newton published an account of the comet, along with the proof of its being a single comet, in the *Principia Mathematica* in 1687, without crediting Flamsteed. This comet was later dubbed "Newton's Comet." Newton was also well-known to carry a grudge, and made frequent attacks on the ideas and reputations of Robert Hooke, John Flamsteed, and Gottfried Wilhelm von Leibniz.

published despite his poor relationship with Newton,[153] while Gray's letters were not. Although the poor relationship between Newton and Flamsteed is well-documented, it does not follow necessarily that Newton's relationship with Flamsteed would motivate him to suppress Gray's work, and sources that argue this point have not been able present more than a circumstantial case based on Newton having an antagonistic personality.[154]

Contrary to arguments that either Hauksbee or Newton actively worked to suppress Gray's work, it has been suggested that Hans Sloane made decisions about the *Philosophical Transactions* independently of the rest of the Society. Sloane has no documented biases against Gray personally or scientifically.[155] Placing Gray's letter in the context of the ongoing methodological shift in British science, as shown through Newton's work in the previous section, provides an alternative explanation. In his 1708 letter, Gray explained the results of his experiments, his hypotheses based on those results, and then specifically pointed out what he perceived to be an inconsistency implied by his hypotheses. Gray noted that if all objects can absorb electrical effluvia, "it sho[u]ld in like manner affect other distant bodies," such as every other object in the room where he conducted the experiment, Gray admitted his results were "hard to conceive," and that he was "far from thinking what I here offer is an Intire solution of the Phenomena."[156] Although Newton was comfortable with asserting the existence of forces and phenomena without being able to explain how or why they existed, Sloane may not have shared this methodological and epistemological stance. Beyond presenting a challenge to Gilbert's theories of electricity and

[153] John Flamsteed "Observations of the Solar Eclipse, May 11/12 1706. At the Royal Observatory at Greenwich, &c. communicated by the Reverend Mr John Flamsted, Math. Reg. & F.R.S." *Philosophical Transactions* vol. 25, no. 306 (June 1706): 2237-2241.
[154] David H. Clark and Stephen P. H. Clark, *Newton's Tyranny: The Suppressed Scientific Discoveries of Stephen Gray and John Flamsteed* (New York: W. H. Freeman and Company, 2001).
[155] Thony Christie, "Did Isaac Really Victimise Stephen," The Renaissance Mathematicus, Dec. 25, 2012, https://thonyc.wordpress.com/2012/12/25/christmas-trilogy-2012-part-i-did-isaac-really-victimise-stephen/
[156] Chipman, "Unpublished Letter," 36.

magnetism, Gray admitted he did not understand the causes of the phenomena he observed in his experiments. Gray's explanation of conduction was sparse but theoretically consistent with existing effluvial theories, provided his audience accepted the ability to absorb and emit effluvia as a previously undiscovered quality of matter. On the other hand, Gray offered no theoretical basis for his understanding of repulsion. In 1708, Sloane may have judged Gray's work as beneath the standard of proof necessary for publication in the *Philosophical Transactions*.

There is no clear explanation for why Gray's letter, and the new discoveries therein, were not published and publicized in 1708. Gray continued to build on and develop his ideas through further experiments between 1708 and 1720. To pursue this work Gray moved to London in 1716. When he arrived, he lived with John Theophilus Desaguliers, Fellow of the Royal Society, the Society's Demonstrator of Experiments (following Hauksbee's death in 1713), and for a time, Gray's experimental collaborator.[157]

While Gray's 1708 letter was not published, his ideas did receive adoption. In 1717, Desaguliers published a book, *Physico-Mechanical Lectures*, as a companion piece to his public demonstrations of Newtonian principles.[158] In laying out the basic principles of Newtonian physics, Desaguliers defines matter as having physical extension and resistance, which he writes "are the Properties of all kinds of Bodies," and specifies that all matter has gravity proportional to its mass "as is fully Demonstrated by Sir Isaac Newton."[159] He explains Newton's inverse square law of gravity, but specifies that electrical attraction, which he calls "Cohesion," exists as

[157] Ben-Chaim, "Social Mobility and Scientific Change," 12.
[158] Ben-Chaim, "Social Mobility and Scientific Change," 12-13; J. T. Desaguliers, *Physico-Mechanical Lectures, or an Account of What is Explained and Demonstrated in the Course of Mechanical and Experimental Philosophy* (London, 1717), 1-2.
[159] Desaguliers, *Physico-Mechanical Lectures*, 1-2.

a separate force from gravity.[160] Electrical attraction operates differently than gravity, in that it "decreases… much faster" when bodies are separated.[161] Desaguliers also addresses "the repelling Force" of electricity.[162] For Desaguliers, this principle of motion is clearly demonstrated "in the Experiments made upon Cork, Lead, Glass, Iron, Feathers, Leaf-Gold, &c." He further adds, that if any light body that is attracted to a rubbed glass tube touches that tube, it will be repelled from it until it touches some other thing.[163] While Desaguliers does not credit anyone, these bear a striking resemblance to the experiments described and carried out by his friend, collaborator, and housemate, Stephen Gray.[164] In 1717, Desaguliers had fully adopted Newton's methodology, and on the basis of that method's standard of proof found electrical repulsion perfectly acceptable as a force in its own right, a stance that had been controversial in British scientific circles for a century.

Gray's 1720 Letter

In December 1720 Gray wrote a new letter to Hans Sloane, for the first time since 1713. During the years from 1708 to 1720, Gray was hard at work conducting electrical experiments, as he explained in this new letter. Gray began the letter by recounting that in a series of experiments using a glass tube and a feather tied to a stick he frequently observed that once the feather had come in contact with the glass tube, it was then attracted to other non-electrical objects, such as the stick, as if they were electrical themselves. Gray described that it was as if electricity had

[160] Desaguliers, *Physico-Mechanical Lectures*, 2
[161] In this regard Desaguliers is actually incorrect, as both electricity and gravity decrease per the square of the distance between bodies. Likely, Desaguliers simply did not recognize this because of the differences in scale between the electrical phenomena he observed and the gravitational phenomena discussed in astronomical works.
[162] Desaguliers, *Physico-Mechanical Lectures*, 2.
[163] "A Feather, or any other light Body, when once attracted by the rubb'd Tube, so as to touch it, will always be repel'd from it, till it has touch'd some other Body." Desaguliers, *Physico-Mechanical Lectures*, 2-3.
[164] Desaguliers, *Physico-Mechanical Lectures*, 2-3.

been "communicated" to the stick or the feather by the glass rod.[165] To charge the glass rod for his experiments, Gray would simply pull it between his fingers several times. To test whether a feather could be electrified, Gray applied the same method. Although he found the result to be inconsistent, it was possible to electrify a feather in some of his attempts.[166] This inspired Gray to attempt the electrification of several other materials, including hair from his wig, hair from a dog's ear, and silk threads of several different colors, all of which he found could be charged using the same method.[167] Gray found a wide variety of things that could be electrified in this way, including different cloths, ribbon, paper, wood shavings, leather, parchment, and "those thin Guts wherein Leaf-Gold is beaten" (probably the outer membrane of an ox intestine).[168] Although none of these exerted attraction as strongly as glass or other accepted electricks, they nevertheless exhibited electrical attraction "to the distance of sometimes 8 or 10 Inches."[169]

Gray noted that many electricks would emit light and crackling sounds when rubbed. Gray categorized electric light and sounds as being properties associated with glass, most likely drawing on Hauksbee's earlier accounts of generating electric light.[170] Gray related one final set of experiments in 1720, which would prove the most impactful for his later work. He tied a feather to a stick with a silk thread about six inches long, and placed the stick in a base so that it would stand vertically. He then took a piece of brown paper which he had charged by rubbing, and brought it near the feather. The paper attracted the feather to it so strongly that the thread

[165] Stephen Gray, "An Account of Some New Electrical Experiments by Mr. Stephen Gray," *Philosophical Transactions* vol. 31, no. 366 (December 1720):104-107, 104.
[166] Gray, "An Account of Some New Electrical Experiments," 105.
[167] Gray, "An Account of Some New Electrical Experiments," 105.
[168] Gray, "An Account of Some New Electrical Experiments," 106.
[169] Gray, "An Account of Some New Electrical Experiments," 106.
[170] Gray, "An Account of Some New Electrical Experiments," 106.

stretched upright in the air; Gray compared it to a "piece of Wire."[171] When the feather and thread were in this extended position, Gray brought his finger near the feather and observed that the fibers on one side of the feather were repelled by his finger while those on the opposite side were attracted to it. When he repeated this experiment without the feather, the thread itself would "avoid, or was repelled" from his finger. When he moved his finger to a section of thread about two inches from the end, it was then attracted to his finger.[172] This letter was published in the *Philosophical Transactions* within the year.

Comparing Gray's letter from 1708 to that from 1720 reveals several developments in his understanding of electricity. In 1708, Gray observed a series of effects which seemed incongruent with the prevailing theories of electrical effluvia. He referred to a feather being pushed away from a glass rod as being "reflected," in keeping with the idea that attractive effluvia were reflected and therefore changed their direction of attraction. He declined to lay out a new theory to explain the inconsistency between his experimental observations and prevailing electrical understanding, though he did not think effluvial reflection was a sufficient explanation of the results he observed in his experiments. In 1720, Gray again described a series of results that did not fit within the theory of effluvial reflection, but by that time he was definitive in his statement that in addition to attracting light bodies, electricity can also repel objects. Although he did not explicitly return in 1720 to the idea that all matter is capable of receiving and emitting effluvia, he described several scenarios in which objects that had been in close proximity to an electrically charged object exhibited electrical effects independently of that object. He also described multiple instances of light objects "avoiding," or being "pushed" or "repelled" from

[171] Gray, "An Account of Some New Electrical Experiments," 107.
[172] Gray, "An Account of Some New Electrical Experiments," 107.

his hand or other objects. He also carefully noted that in each instance of electrical repulsion, there was a simultaneous attractive force present at a different point on the object exhibiting the repulsive force. When one side of a feather is repulsive, the other side is attractive; when the end of a thread is repulsive, another section of its length is attractive. Not only did Gray explicitly state that repulsion was a real electrical effect, but he also identified that repulsion and attraction coexisted within a single object.

Gray's 1731 Letter

In 1708, Gray demonstrated electrical conductivity and repulsion, previously unacknowledged electrical effects. However, at that time, demonstrating phenomena without explaining their underlying properties and causes was not deemed a scientifically valid discovery. Standards and methods shifted within the British scientific community after 1708, and by 1720 experimental demonstration was considered a scientifically valid basis for discovery. By that time, however, other figures had already replicated Gray's experiments, and electrical repulsion was already an accepted feature of scientific lexicons, experimental demonstrations, and Newtonian physics. Gray was ahead of his time in 1708, and had missed the opportunity for recognition by 1720. Gray would return to studying electrical conductivity, also demonstrated in his 1708 experiments, in his next major scientific contribution in 1731.

Isaac Newton had died in March, 1727, at the age of 84. He was replaced as President of the Royal Society by Hans Sloane, who had previously served as the Society's Secretary. Sloane was succeeded in his prior role by Cromwell Mortimer, a physician from Essex whom Sloane had nominated to become a Fellow of the Royal Society in 1728, at the same time he was assuming

his new position as Secretary. When Gray wrote his next letter in 1731, it was not addressed to his longtime correspondent, Sloane, but to the new editor of the *Philosophical Transactions*, Mortimer. Gray's 27 page letter described dozens of experiments carried out over the course of 19 months, each of which related to electrical conduction.

Gray opened his letter by describing his latest discovery: "that the Electrick Vertue of a Glass tube may be conveyed to any other Bodies, so as to give them the same Property of attracting and repelling light Bodies, as the Tube does."[173] In 1729, Gray presented an experimental demonstration of this phenomenon to Desaguliers. Desaguliers made a report of these findings to the Royal Society, but in his letter Gray aimed to give a more detailed account of his discovery, and to lend it greater support and specificity in light of experiments he had conducted since his demonstration for Desaguliers. In February 1729, Gray repeated the experiments he had described in his letter from 1720.[174] In reflecting on his earlier work with electricity, Gray "called to Mind a Suspicion which some Years ago I had, that as the Tube communicated a Light to Bodies, when [it] was rubbed in the Dark, whether it might not at the same Time communicate an Electricity to them."[175] This "suspicion" from years earlier was Gray's observation in 1708 that electrically generated light could move from a glass rod to other objects, in keeping with his theory at that time that all objects could absorb and emit effluvia. In 1720, Gray experienced light transmissions while testing the electric qualities of several materials. Gray's understanding of Hauksbee's work connecting light and electricity suggested to him that if light was transmittable, perhaps electricity was too. Gray was finally circling back to try and explain the

[173] Stephen Gray, "A Letter to Cromwell Mortimer, M.D. Secr. R. S. Containing Several Experiments Concerning Electricity; by Mr. Stephen Gray," *Philosophical Transactions* vol. 37, no. 417 (February, 1731): 18-44, 18-19.
[174] See above; Stephen Gray, "An Account of Some New Electrical Experiments," 104-107.
[175] Gray, "A Letter to Cromwell Mortimer," 19.

incongruous movement of electricity through non-electricks that he had observed, but not explained, in 1708. He set about addressing the issue of electrical communication in a systematic and thorough way.

Working with a glass tube, as before, Gray began by inserting a cork ball into either end of the tube to see if that would alter its electrical effects. When he rubbed the glass tube he found that not only could the tube itself still attract a feather, but that the feather was "attracted and repelled many Times together" by the corks themselves, suggesting to him that the electricity was moving from the glass tube through the cork balls.[176] To see if he could extend this effect further, Gray fixed a small ivory ball onto one of the corks, and again "found that the Ball attracted and repelled the Feather… repeating its Attractions and Repulsions for many Times together."[177] He attached this ivory ball to the glass tube with a series of successively longer sticks, pieces of iron and brass wire, and eventually hung the ivory ball from a piece of packthread looped around the glass tube. In each of these instances, Gray found "the Ivory Ball attracted and repelled" small pieces of brass leaf "over which it was held."[178] Having established the basic premise that electricity could be "communicated" to non-electrical materials, Gray tested a wide range of metals, beginning with coins and working up to larger objects such as a tea kettle, as well as bricks, tiles, and chalk, concluding that all these materials "had… an Electrick Vertue communicated to them" by the electrified glass tube.[179]

[176] Gray, "A Letter to Cromwell Mortimer," 20.
[177] Gray, "A Letter to Cromwell Mortimer," 20-21.
[178] Gray, "A Letter to Cromwell Mortimer," 21.
[179] Gray, "A Letter to Cromwell Mortimer," 22.

Having established the possibility of electricity being communicated from a glass rod to a variety of other objects, Gray began testing the limits and extent of this communication. On his own, Gray was able to communicate electricity over 18 feet by connecting multiple fishing rods together, end to end, holding an electrified glass tube at one end of the connected rods, and observing electrical attraction and repulsion at the other end. He was limited in this work, however, by lack of space and materials; so he turned to two friends who had much greater resources and space at their disposal, and an interest in experimental science. From May 1729 through August 1730, Gray conducted dozens of experiments on the nature and extent of electrical communication at the country estates of his friends John Godfrey and Granvil Wheler, with their assistance. Godfrey and Wheler were both Fellows of the Royal Society, and their respective estates, Norton Court and Otterden Place, provided excellent premises for Gray's work.[180] Beginning at Norton Court, Gray and Godfrey created successively longer conduits using various materials including wood, cane, and various kinds of string, twine, and thread. The common mode of testing for electrical communication was to fix a ball of cork or ivory to one end of the conduit. Beneath this ball they would place a small stand or plate with bits of brass leaf on it. The opposite end of the conduit would then be electrically charged with a glass tube. If the ball "attracted and repelled the Leaf-Brass" this was positive proof of electrical communication.[181] As the distances involved increased, Gray used packthread lines more and more, simply for practical ease. Typically, one end of the packthread would be looped over a nail or post, and the line would be drawn across a room or field, supported as needed by silk threads. When testing indoors, the line would be wrapped around a silk thread at one end of the room and looped back and forth across the room to create a line longer than the room itself.[182] Using this

[180] Gray, "A Letter to Cromwell Mortimer," 23.
[181] Gray, "A Letter to Cromwell Mortimer," 24.
[182] Gray, "A Letter to Cromwell Mortimer," 26-29.

method, Gray and his collaborators created a line "that was 666 Feet in Length, by eight Returns" which is to say, eight loops from one end of the gallery at Otterden Place to the other.[183] This was not only remarkable for its distance, but also because it showed electricity was capable of "going and returning" rather than simply traveling continually in a single direction.[184] When testing outdoors, pairs of posts would be sunk into the ground at intervals, with a silk thread tied between them to support the line extending as far as possible.[185]

Gray's experiments were not only concerned with the distance at which communication was possible, but also addressed the nature of electricity. Gray showed that if the center of a line was charged, the electricity would travel to both sides of the line, showing it was not unidirectional or unitary.[186] He successfully charged lines without touching them with the glass rod, showing that electrical charge could travel across empty space.[187] By charging a hollow wooden cube and a solid wooden cube of the same size, he showed that mass had no effect on the power of attraction or repulsion, as it would in the case of gravitational force.[188] By charging one side of a hoop and observing attraction at all other points around that hoop, he further demonstrated that electricity was nonlinear in its communication.[189] He also repeated many of his experiments in both a vertical and horizontal orientation, and observed no difference in the electrical effects, showing that electricity was unaffected by gravity.[190] Using a tobacco pipe and some soapy water to create a bubble in the pipe's bowl, Gray was able to electrify the pipe stem and create attraction in the bubble, showing that "fluid bodies," in addition to solid ones, could "have an Electricity

[183] Gray, "A Letter to Cromwell Mortimer," 29.
[184] Gray, "A Letter to Cromwell Mortimer," 30.
[185] Gray, "A Letter to Cromwell Mortimer," 30-31.
[186] Gray, "A Letter to Cromwell Mortimer," 32-33.
[187] Gray, "A Letter to Cromwell Mortimer," 33-34.
[188] Gray, "A Letter to Cromwell Mortimer," 35.
[189] Gray, "A Letter to Cromwell Mortimer," 36-37.
[190] Gray, "A Letter to Cromwell Mortimer," 25, 37-38.

communicated to them."[191] It was also during this period that Gray developed his "dangling boy" experiment, in which a young boy, a servant at the estate, was suspended off the ground by silk threads, and became an electrical conduit himself. Gray would bring a glass rod near the boy's feet and his hands would attract and repel pieces of brass leaf, or Gray would charge one hand, and the boy's other hand showed electrical effects.[192] There were several variations on this experiment, such as having the boy hold various things (like fishing rods) to show that electricity could travel through objects and people simultaneously.[193] Although this experiment did not introduce any principles not previously established in his experiments with inanimate objects, the spectacle of electrifying people made this experiment very popular in public demonstrations that were popular at the time. The dangling boy experiment popularized electrical conduction and helped establish Gray as an accepted authority in electrical science. These accounts of Gray's extensive work on electrical conduction were published in the *Philosophical Transactions* in 1731, and were reproduced, both in English and in translation throughout Europe for decades.

When Gray demonstrated electrical repulsion and conduction in 1708, his account lacked the explanation and theoretical basis required to be considered legitimate scientific work at that time. By 1720, standards in Britain had shifted, and repulsion was already an accepted electrical effect, although not credited to Gray. In 1731, Gray laid out an exhaustive investigation of electrical conduction in which he designed experiments to specifically test dozens of hypotheses about the nature and behavior of electricity. But even in the midst of his most dedicated period of scientific work, and the longest and most in-depth scientific report he had ever written, Gray did not offer a theory of electricity to account for or explain the phenomena he observed in his experiments. By

[191] Gray, "A Letter to Cromwell Mortimer," 39.
[192] Gray, "A Letter to Cromwell Mortimer," 41-42
[193] Gray, "A Letter to Cromwell Mortimer," 40-45

1731, that kind of theoretical foundation was no longer considered a necessary feature of a scientific discovery in the scientific community in Britain.[194]

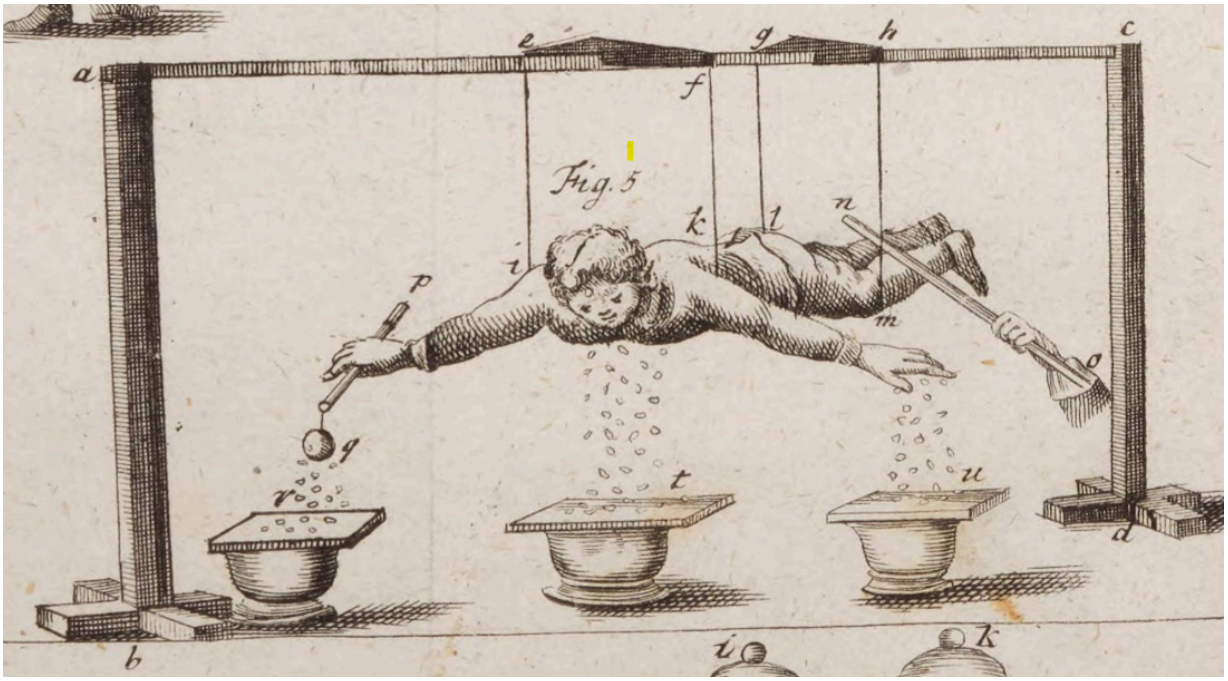


Figure 2: an illustration of Stephen Gray's "dangling boy" experiment from a 1744 German-language exposition of the discoveries of Francis Hauksbee, Stephen Gray, and Charles Du Fay, from Johann Gabriel Doppelmayr, *Neu-entdeckte Phaenomena von Bewunderns-würdigen Würckungen der Natur, welche bey der fast allen Cörpern zukommenden Electrischen Krafft* (1744), plate 2.

The most significant endorsement of Gray's work outside of Britain came from Charles François de Cisternay du Fay, a member of the French Academie Royale des Sciences. In 1732, Du Fay was appointed the Superintendent of the Jardin du Roi, the French royal botanic gardens. Although he was not a botanist, he set out to learn from established and successful botanical gardens in Holland and England. To that end, Du Fay travelled to England with Joseph Jussieu

[194] Stephen Gray, "A letter concerning the electricity of water, from Mr. Stephen Gray to Cromwell Mortimer, M.D. Secr. R.S" *Philosophical Transactions* vol. 37, no. 422: 227-230, 260; Stephen Gray, "Two Letters from Mr. Stephen Gray, F.R.S. to C. Mortimer, M.D. Secr. R.S. Containing Farther Accounts of His Experiments concerning Electricity," *Philosophical Transactions* vol. 37, no. 426: 397-407.

(who came from a long line of acclaimed botanists), to visit a series of gardens and the Royal Society. Du Fay began corresponding with a number of Dutch and English thinkers, including Stephen Gray.[195] In 1733, Du Fay published a series of "Memoires," treatises laying out new theoretical ideas about electricity based on his recreation and analysis of a series of electrical experiments, including many devised by Stephen Gray. Du Fay also wrote a letter to his friend, Charles Lennox, the Duke of Richmond, explaining "some extraordinary Discoveries" he had made "in the *Electricity* of Bodies," which he asked to be passed along to the Royal Society. This letter was subsequently published in the *Philosophical Transactions*.[196] Du Fay began his explanation of the latest discoveries in electrical science by writing that he was indebted to the Royal Society for setting him on the path of studying electricity. Specifically, he credited "the Writing of Mr. *Gray*, and the late Mr. *Hauksbee*, both of that *Society*," because it was Gray and Hauksbee that "first put me upon the Subject," of electricity, "and furnish'd me with the Hints that led me to the following Discoveries."[197]

Du Fay went on to describe a series of discoveries and the experiments he conducted to demonstrate them. Among these, he mentioned conducting an experiment originally carried out by Otto von Guericke, (and, as discussed above, recreated by both Hauksbee and Gray) in which an electrically charged sulfur globe is used to repel a feather.[198] Du Fay then laid out a new principle: any object that is initially attracted to an electric body will become electrified, and then

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[195] "Eloge de M. Du Fay," *Histoire de l'Academie Royale des Sciences* (1739): 73-83, 76, 78; Michael Bycroft, "Wonders in the Academy: The Value of Strange Facts in the Experimental Research of Charles Du Fay," *Historical Studies in the Natural Sciences* vol. 43, no. 3 (June, 2013): 334-370, 340-341.
[196] Charles Du Fay, "A Letter from Mons. Du Fay, F.R.S. and of the Royal Academy of Sciences at Paris, to His Grace Charles Duke of Richmond and Lenox, concerning Electricity," *Philosophical Transactions* vol. 38, no. 431 (March, 1734): 258-266.
[197] Du Fay, "A Letter from Mons. Du Fay," 258.
[198] Du Fay, "A Letter from Mons. Du Fay," 262.

be repelled, until it comes into contact with some other object and discharges its electricity, at which point that process will repeat.[199] Du Fay recognized that this pattern of attraction and repulsion would be difficult to align with preexisting theories, but believed it would clarify a surprising number of other points of confusion or misunderstanding.[200] For example, when Hauksbee observed this pattern, he could not make theoretical sense of it, and treated it as a curiosity. Gray observed and recounted this pattern of attraction, contact, and repulsion several times, including in his letters of 1708 and 1720, but he never stated that this pattern was a predictable feature or principle of electricity. Dufay did what Gray did not in providing clear statements of the principles by which electricity operated, lending Gray's work legitimacy in those areas and among those natural philosophers who had not adopted Newton's stance that demonstration alone was a sufficient scientific justification. In France, Du Fay's acceptance of Gray's work was enough to warrant its publication and support within the Academie Royale des Sciences.[201] In England, Gray's publications, Newton's endorsement of the idea of a repulsive force, and the ongoing support of Newtonian experimentalists like Desaguliers popularized the idea. In 1742, Desaguliers published *A Dissertation Concerning Electricity*, which was intended as a summation of the Newtonian understanding of electricity. In that work, Desaguliers defines electricity as "a Property of some Bodies, whereby they alternately attract and repel small Bodies brought near them."[202] It also introduced the terms "conductor" and "insulator" to describe Gray's discoveries and the theories drawn from that work.

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[199] Du Fay, "A Letter from Mons. Du Fay," 263.
[200] Du Fay, "A Letter from Mons. Du Fay," 263.
[201] Charles Du Fay, "Quatrième Mémoire sur l'Électricité," *Histoire de l'Academie Royale des Sciences Annee MDCCXXXIII* (Paris: L'Imprimerie Royale, 1735): 457-476.
[202] J. T. Desaguliers, *A Dissertation Concerning Electricity* (London: W. Innys and T. Longman, 1742), 1.

Conclusion

Stephen Gray's unpublished letter of 1708 is a pivotal document in the history of electricity, not because it immediately altered the scientific understanding of electricity but because it illustrates the complex relationship between experiment, theory, and scientific authority in a time of dramatic intellectual change. Long before these phenomena were accepted as features of electrical science, Gray demonstrated electrical conduction, insulation and repulsion. But his findings were not sufficient to convince the natural philosophers of his time. The significance of Gray's work is therefore not simply in the experiments he performed, but in the historical situation which determined whether the experiments could be accepted as valid evidence. In tracing the development of electrical theory from classical antiquity to Gilbert, Newton, and Gray, this study has shown that the acceptance of scientific knowledge was as much a function of shifting standards of proof as of the experimental observations themselves.

Natural philosophers had coherent explanations of electrical attraction in theories inherited from antiquity long before Gray took up the study of electricity. Effluvial theories, developed by thinkers such as Lucretius and Plutarch and adopted by medieval and early modern scholars, provided an intelligible mechanism whereby invisible forces could produce visible effects. William Gilbert transformed these traditions. He distinguished electricity from magnetism and based his conclusions on carefully designed experiments. His experimental program represented a significant break with scholastic natural philosophy rooted in a new standard of proof and experimental methodology. Gilbert’s conclusions that electricity was only attractive and could not pass through intervening bodies were upheld for more than a century. His theory was supported by convincing experiments, and later English natural philosophers, such as Digby and

Browne, maintained Gilbert's standard of proof and experimental methodology, forming a context in which Gilbert's effluvial theory of electricity was widely accepted.

Gray's experiments directly contradicted these accepted views. His observations that electrical effects could be communicated through non-electric bodies and that electrified bodies alternated between attraction and repulsion ran counter to principles that had become fundamental to British electrical science. But Gray himself could not provide a theory that adequately accounted for all the phenomena he saw. His suggestion that all bodies absorbed and emitted electrical effluvia was an important contribution to the understanding of electrical conduction, but it did not solve the problem of repulsion. In 1708, Gray's experimental work lacked two crucial factors needed for widespread acceptance: he did not give an explanation of the mechanism by which repulsion occurred, and he did not give a consistent theoretical basis upon which to believe that electrical repulsion was even possible. In contrast, Gray's understanding of conduction arguably did have these elements in 1708. He explained electrical conduction as a movement of effluvia through non-electrick objects. His explanation accepted the prevailing theory of electrical activity, and only sought to add that electrical activity could act through other objects. However, this addition was also a challenge to Gilbert's definition of electricity, and was coupled with Gray's more problematic views on repulsion. Gray did not deny that his explanation was incomplete. In that intellectual context, this led to his letter remaining unpublished, thereby denying to a wider audience one of the most important electrical discoveries of the eighteenth century.

In the decades after Gray's letter, the standards by which natural philosophers judged scientific claims began to change, slowly but significantly. In his developed philosophy Newton progressively distinguished between the demonstration of phenomena and the full explanation of their causes. He was prepared to accept the forces he had shown experimentally as real, though he did not know how they worked. This was a major break with earlier hopes that observation and explanation would go hand in hand. Newton argued that experiments could reliably establish the existence of forces, whose ultimate causes were unknown, without needing a fully worked out mechanical theory before accepting new phenomena. This change of method created an intellectual climate in which Gray's discoveries could finally be appreciated for what they showed rather than dismissed for what they did not yet explain.

Gray's eventual recognition was the result both of his own persistence, and of broader shifts in eighteenth-century natural philosophy. The publication of his later papers, the support of influential Newtonians such as Desaguliers, and the theoretical refinements given by Du Fay all helped to incorporate Gray's observations into a coherent understanding of electricity. These later natural philosophers accepted repulsion, conduction, and insulation as constitutive properties of electricity. By the middle of the eighteenth century the ideas first suggested in Gray's unpublished manuscript had developed into fundamental principles of electrical science.

Gray's story offers a larger lesson about the history of science. Scientific discoveries are not accepted solely on the basis of experimental correctness. They must also be understandable by the current criteria for assessing evidence, building theories and establishing authority. The history of electricity in the early eighteenth century shows that these standards are themselves

historical, evolving with the sciences they govern. Gray's experiments in 1708 demonstrated essential principles of electricity that were finally accepted years later, because the context in which natural philosophers interpreted Gray's work had changed. His career reminds us that the progress of science depends not just on new observations, but also on changing ideas about what counts as convincing proof.

Bibliography

Aristotle, *On Generation and Corruption*, Book I, translated by H. H. Joachim, https://classics.mit.edu/Aristotle/gener_corr.1.i.html.

_____. *On the Soul*, translated by J.A. Smith, https://faculty.georgetown.edu/jod/texts/aristotle.soul.html.

_____. *Meterology*, Book IV, translated by E.W. Webster, https://classics.mit.edu/Aristotle/meteorology.4.iv.html.

Bacon, Francis. *Novum Organum*. Edited by Joseph Devey. New York: Collier & Son, 1902.

Basu, Prajit K. "Newton's Physics in the Context of his Works on Chemistry and Alchemy." *Indian Journal of History of Science* 26 (3), Sept. 1990: 283-305.

Ben-Chaim, Michael. "Social Mobility and Scientific Change: Stephen Gray's Contribution to Electrical Research," *The British Journal for the History of Science* vol. 23, no. 1 (March, 1990): 3-24.

Birch, Thomas. *The History of the Royal Society of London*, vol. III. London: A. Millar, 1757.

Bowler, Peter J. and Iwan Rhys Morus. *Making Modern Science: A Historical Survey*, 2nd Edition. University of Chicago Press, 2020.

Browne, Thomas. *Pseudodoxia Epidemica: Or Enquiries into Very Many Received Tenets, and Commonly Presumed Truths.* London: Tho. Harper, 1646.

Bycroft, Michael. "Wonders in the Academy: The Value of Strange Facts in the Experimental Research of Charles Dufay." *Historical Studies in the Natural Sciences* vol. 43, no. 3 (June, 2013): 334-370.

Cabeo, Niccolo. *Philosophia Magnetica.* 1629.

Chipman, Robert A. "An Unpublished Letter of Stephen Gray on Electrical Experiments, 1707-1708." *Isis* vol. 45, no. 1 (May 1954): 33-40.

_____.. "The Manuscript Letters of Stephen Gray F.R.S. (1666/7-1736)." *Isis* vol. 49 no. 4 (Dec. 1958): 414-433.

Christie, Thony. "Did Isaac Really Victimise Stephen." The Renaissance Mathematicus. Dec. 25, 2012. https://thonyc.wordpress.com/2012/12/25/christmas-trilogy-2012-part-i-did-isaac-really- victimise-stephen/.

Clark, David H., and Stephen P. H. Clark. *Newton's Tyranny: The Suppressed Scientific Discoveries of Stephen Gray and John Flamsteed*. New York: W. H. Freeman and Company, 2001.

Desaguliers, J. T. *Physico-Mechanical Lectures, or an Account of What is Explained and Demonstrated in the Course of Mechanical and Experimental Philosophy.* London, 1717.

_____. *A Dissertation Concerning Electricity.* London: W. Innys and T. Longman, 1742.

Digby, Kenelm. *Two Treatises: In the one of which, the Nature of Bodies; in the other The Nature of Mans Soule it Looked into In Way of Discovery of the Immortality of Reasonable Soules.* London: John Williams, 1645.

Doppelmayr, Johann Gabriel, *Neu-entdeckte Phaenomena von Bewunderns-würdigen Würckungen der Natur, welche bey der fast allen Cörpern zukommenden Electrischen Krafft, und dem dabey in der Finstern mehrentheils Erscheinenden Liecht einige berühmte Mitglieder der preißwürdigen Königl. Engl. Societät der Wissenschafften vornemlich aber, Herr Hauksbee und Herr Gray in London und nach einer weiteren Untersuchung, Monsieur du Fay in Paris durch viele Experimenta, zu unsern Zeiten glücklich hervorgebracht, und in unterschiedlichen Wercken dem Publico mitgetheilet*. Nurnberg: 1744.

Du Fay, Charles. "A Letter from Mons. Du Fay, F.R.S. and of the Royal Academy of Sciences at Paris, to His Grace Charles Duke of Richmond and Lenox, concerning Electricity." *Philosophical Transactions* vol. 38, no. 431 (March, 1734): 258-266.

_____. "Premiere Mémoire sur l'Électricité." *Histoire de l'Academie Royale des Sciences Annee MDCCXXXIII.* Paris: L'Imprimerie Royale, 1735: 23-35.

_____. "Quatrième Mémoire sur l'Électricité." *Histoire de l'Academie Royale des Sciences Annee MDCCXXXIII*. Paris: L'Imprimerie Royale, 1735: 457-476.

"Eloge de M. Du Fay." *Histoire de l'Academie Royale des Sciences* (1739): 73-83.

Finocchiaro, Maurice A. "Galileo's First Confrontation with the Inquisition (1616): Four Orders and Three Issues." *Galilaeana: Studies in Renaissance and Early Modern Science* 13: 29-60.

Flamsteed, John. "Observations of the Solar Eclipse, May 11/12 1706. At the Royal Observatory at Greenwich, &c. communicated by the Reverend Mr John Flamsted, Math. Reg. & F.R.S." *Philosophical Transactions* vol. 25, no. 306 (June 1706): 2237-2241.

Forester, John M., editor. *The De Subtilitate of Girolamo Cardano.* Tempe, AZ: Arizona Center for Medieval and Renaissance Studies, 2013.

Freind, John. *Praelectiones Chymicae.* Amstelodami: Janssonio-Waesbergios, 1710.

Freind, John. *Chymical Lectures.* London: Philip Gwillim, 1712.

Gilbert, William. *De Magnete.* London: Petrus Short, 1600.

Gilbert, William. *On the Loadstone and Magnetic Bodies and on the Great Magnet of the Earth*, translated by P. Fleury Mottelay. New York: John Wiley & Sons, 1893.

Goodwin, William, editor. *Plutarch's Morals*, vol. 5. Boston: Little, Brown, and Company, 1883.

Graham, Daniel P. and David Evan Pence."Making Light: Francis Hauksbee and the Isolation of Electric Fire." Leverage. Dec. 2023, https://www.leverage.institute/program/metascience

Gray, Stephen. "Several Microscopical Observations and Experiments." *Philosophical Transactions* vol. 19, no. 221 (August 1696): 280-287.

_____. "A letter from Mr. Stephen Gray, giving a further account of his water microscope." *Philosophical Transactions* vol. 19, no. 223 (December 1696): 353-356.

_____. "A letter from Mr. Stephen Gray, from Canterbury, May the 12th 1697, concerning making water subservient to the viewing both near and distant objects, with the description of a natural reflecting microscope." *Philosophical Transactions* vol. 19, no. 228 (May 1697): 539-542.

_____. "A letter from Mr. Stephen Gray, dated Canterbury, Dec. 8, 1697, relating some Experiments about making Concave Specula nearly of a Parabolick Figure." *Philosophical Transactions* vol. 19, no. 235 (December 1697): 787-790.

_____. "Part of a letter from Mr. Stephen Gray, about a way of measuring the heighth of the mercury in the barometer more exactly." *Philosophical Transactions* vol. 20, no. 240 (May 1698): 176-178.

_____. "An observation of some parelii seen at Canterbury." *Philosophical Transactions* vol. 21, no. 251 (April 1699): 126-127.

_____. "Part of a letter from Mr. Gray, concerning an unusual parhelion and halo." *Philosophical Transactions* vol. 22, no. 262 (March 1700): 535.

_____. "Part of a letter from Mr. Stephen Gray to the Publisher, containing his observations on the fossils of reculver clisse, and a new way of drawing the meridian line, with a note on this letter by the publisher." *Philosophical Transactions* vol. 22, no. 268 (January, 1701): 762-764.

_____. "A letter from Mr. Stephen Gray, concerning drawing the meridian line by the pole star, and finding the hour by the same." *Philosophical Transactions* vol. 22, no. 270 (April 1701): 815-819.

_____. "Part of two letters from Mr. Stephen Gray, concerning the spots of the Sun, observ'd by him in June last." *Philosophical Transactions* vol. 23, no. 288 (December 1703):1502-1504.

_____. "An Account of Some New Electrical Experiments by Mr. Stephen Gray." *Philosophical Transactions* vol. 31, no. 366 (December 1720):104-107.

_____. "A Letter to Cromwell Mortimer, M.D. Secr. R. S. Containing Several Experiments Concerning Electricity." *Philosophical Transactions* vol. 37, no. 417 (February, 1731): 18-44.

_____. "A letter concerning the electricity of water, from Mr. Stephen Gray to Cromwell Mortimer, M.D. Secr. R.S." *Philosophical Transactions* vol. 37, no. 422: 227-260.

_____. "Two Letters from Mr. Stephen Gray, F.R.S. to C. Mortimer, M.D. Secr. R.S. Containing Farther Accounts of His Experiments concerning Electricity." *Philosophical Transactions* vol. 37, no. 426: 397-407.

von Guericke, Otto. *Experimenta Nova (ut vocantur) Magdeburgica de Vacuo Spatio*. Amsterdam: Joannem Janssonium a Waesberge, 1672.

Harris, John. *Lexicon Technicum: Or An Universal English Dictionary of Arts and Sciences*, vol. 1. London: 1708.
_____. *Lexicon Technicum: Or An Universal English Dictionary of Arts and Sciences*, vol. 2. London: 1710.

Hauksbee, Francis. "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* 25 (1706-1707): 2327-2335.
_____. "Several Experiments Shewing the Strange Effects of the Effluvia of Glass, produceable on the Motion and Attrition of it." *Philosophical Transactions* vol. 25 (1707-1708): 2372-2377.

Heilbron, J. L. *Electricity in the 17th and 18th Centuries: A Study of Early Modern Physics.* Los Angeles: University of California Press, 1979.

Höttecke, Dietmar, 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.

Keill, John. "In Qua Leges Attractionis aliaque Physices Principia traduntur." *Philosophical Transactions* vol. 26, no. 315 (June, 1708): 97-110.

Lindberg, David C. *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, Prehistory to A.D. 1450*, 2nd edition University of Chicago Press, 2007.

"List of Officials." *The History and Topographical Survey of the County of Kent* vol. 12.

Lucretius. *De Rerum Natura*. Translated by H. A. J. Munro. London: George Bell and Sons, 1903.

Marrone, Steven P. *A History of Science, Magic & Belief: From Medieval to Early Modern Europe*. New York: Bloomsbury Academic, 2025.

McTeigue, Mindy, and Geoff Anders. "William Gilbert and the Discovery of 'Electricks'." Leverage, Sept. 2020. https://www.leverage.institute/program/metascience

Newton, Issac. *The Principia: Mathematical Principles of Natural Philosophy,* trans. I. Bernard Cohen, Anne Whitman, and Julia Budenz. Berkeley, CA, 1999.
_____. *Opticks or a Treatise of the Reflections, Refractions, Inflections and Colours of Light*, 4th edition. London: William Innys, 1730.

Norman, Robert. *The Newe Attractive, Shewing The Nature, Property, and Manifold Vertues of the Loadstone; with the Declination of the Needle, Touched Therewith, under the Plaine of the Horizon.* London, 1720.

Parigi, Silvia. "Effluvia." in *Encyclopedia of Early Modern Philosophy and the Sciences.* Cham, Switzerland: Springer, 2020.

della Porta, Giambattista. *Magiae Naturalis*. 1584.

Priestley, Joseph. *The History and Present State of Electricity, with Original Experiments.* London, 1767.

Quinn, Arthur. "Repulsive Force in England, 1706-1744." *Historical Studies in the Physical Sciences* vol. 13, no. 1 (1982): 109-128.

Roller, Duane, and Duane H. D. Roller. *The Development of the Concept of Electric Charge: Electricity from the Greeks to Coulomb.* London: Oxford University Press, 1954.

Saggi di Naturali Esperienze Fatte nell'Accademia del Cimento Sotto la Protezione del Serenissimo Principe Leooldo di Toscana. Firenze: Giuseppi Cocchini, 1666.

Gaspar Schott, *Thaumaturgus physicus sive Magiae universalis naturae et artis pars quarta et ultima*. Johann Gottfried Schonwetter, 1659.

Xiona Wang, *Handling "Occult Qualities" in the Scientific Revolution: Disciplines and New Approaches to Natural Philosophy, from John Dee to Isaac Newton* (Leiden: Brill, 2023),