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From Thales to Lauterbur, or From the Lodestone to MR Imaging: Magnetism and Medicine¹

then, from the heart of one of those new lights,/there came a voice that drew me to itself,/(I was the needle pointing to the star) [DANTE, *The Divine Comedy*, Vol III: Paradise, xii, 28–30]

PEOPLE have been aware of magnetism from the earliest times. Their attempts to understand, and explain, this phenomenon have engendered and/or abetted religious persecution, a proof that the earth is round, elixirs of life, cures for epilepsy, devices to explore the earth and navigate its seas, the French Revolution, and an instrument that can generate three-dimensional views of the internal organs of living creatures. Quite often, those searchers were physicians . . . and other odd characters.

The record of the discovery in the Western world of the first magnetic substance—a poem by Nicander of Colophon (2nd century BC)—is known from a footnote in *Historiae Naturalis* XXXVII, the 37-volume work of the Roman naturalist Pliny the Elder (23–79 AD). Circa 1000 BC, the shepherd Magnes, the eponymous progenitor of the Magnetes (Magnetians), was walking on Mount Ida in the Troad in Mysia (now Turkey). Suddenly, he was strongly drawn to the earth by the tacks in his sandals. He dug to ascertain the cause and discovered magnetite (the mineral lode-

stone—a magnetic oxide of iron: Fe_3O_4). This, legend has it, is how the inhabitants of the foothills of Mount Ida, consecrated to the Mother of the Gods (Ida), came to be the first to discover and work iron and why, in the ancient world, Magnesia ad Sipylum (home of the Magnetes) was a source of magnets (ἡ Μαγνητὶς λίθος [magnetis lithos], meaning the Magnesian stone) or lodestones (lead stones—stones that point the way).

For over 2,000 years the ability of lodestones to attract iron filings and the ability of amber rods when rubbed with fur to attract small pieces of paper, foil, and other lightweight objects were considered manifestations of the same phenomenon. The mechanisms of magnetism and electrostatics were considered to be substantial. The consequences of this have reverberated throughout history.

What is the nature of the lodestone according to the early Greeks and Romans? The answer is in *De Rerum Natura* (On the nature of things), the only surviving work of the Roman poet Titus Lucretius Carus (96–55 BC); the theme is the atomistic theory formed by the Greek philosophers Leukippos (ca 500 BC), Demokritos (460–370 BC), and Epicurus (341–270 BC). Within that theory, the atomus (Latin for the Greek, a [not] + temon [cut])—the uncuttable, innumerable, indivisible, ever-moving unit of matter—was the ultimate constituent of the world. In *De Rerum Natura*, Lucretius states that “if you think atoms can stop their course, refrain from movement, and by cessation cause new kinds of motion, you are far astray indeed. Since there is void through which they move, all fundamental motes must be impelled, either by their own weight or by some force outside them.” Thus, for a lodestone to attract iron it must “emit a dense stream or emanation of atoms, which dispels by a process of bombardment all the air that lies be-

tween the [lode]stone and the iron. When this space is emptied and a large tract in the middle is left void, then atoms of the iron . . . slide and tumble into the vacuum . . . the [whole mass] itself follows . . . the air situated at the back of the [whole mass] pushes and shoves it forward from behind.” Why are some materials immune from the lodestone’s effects? “Some are held fast by their weight . . . gold. Others cannot be moved anywhere, because their loose texture [due to the large air spaces between the atoms that form them] allows the effluence [emanation of atoms from the lodestone] to pass through intact . . . wood.”

The “stream of atoms” from the lodestone was put to artistic use in Egypt in one of the most grandiose building projects ever. Deinokrates (ca ?–278 BC)—the Macedonian or, possibly, Rhodian architect to Alexander the Great (356–323 BC)—is credited by Pliny the Elder in *Historiae Naturalis* XXXVII with designing for the Pharaoh of Egypt Ptolemy II (309–247 BC), the Arsinoeon, a temple in honor of his full sister/second wife/sister-in-law/stepmother-to-his-first-wife Arsinoe II Philadelphos (ca 316–270 BC). In it, her iron cult statue was to be levitated by means of a vault of lodestone (she did, after all, love [φιλέο, phileo] her brother [ἀδελφός, adelphos] well). According to Pliny, Deinokrate’s death put a halt to that phase of the project. His demise may have been opportune. It is highly improbable (in fact, inconceivable) that naturally occurring lodestone could be arranged in the form of a vault to accomplish this architect’s vision. Who knows how Ptolemy II would have reacted to Deinokrate’s failure?

The Arsinoeon was not the first of Deinokrate’s building projects that

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Abbreviations: NMR = nuclear magnetic resonance, RF = radio frequency.

was associated with, or marred by, death. He created the plan for the foundation of the city in which Alexander would eventually be entombed—Alexandria (332 BC). The hecatomb, or funeral pyre, that he constructed in Babylon for Hephaestion (ca 356–324 BC, Alexander's lover) has itself become legend. His program to transform Mount Athos in the Chalcidice Peninsula in northeastern Greece into a colossal statue of Alexander (height, 6,670 feet [2,032 m]), holding in one hand a city and in the other a goblet from which the mountain streams might flow into the sea, was halted (only!) by Alexander's death.

The Greeks and the Romans sensed that lodestones could be put to practical use. They also knew that they could be dangerous. The Alexandrian astronomer Ptolemy (2nd century) writes in *Geography*: "And there are reported to be as well ten more islands in a row, called the Manoliai [that is to say, beyond the island of Iabadiou, which is generally taken to be Sumatra or Java, or perhaps Malay mistaken for an island], amid which they say that boats having iron nails are held in check, perhaps because the Stone of Heracles [Hercules, the lodestone] is native there, and for this reason shipbuilding is done in trenches." A similar phenomenon is reported in *The Arabian Nights—The Tale of the Third Kalendar* (Beggart): "tomorrow we will come to an isle of black rocks called the Magnetic Mountain, against which the force of the water will dash us and destroy our ship. All her nails will fly from her and cleave to the sides of the Magnetic Mountain . . . and all the thousands of nails on our ten ships were suddenly wrenched away and flew to join themselves to the mountain. The ship opened out and fell asunder, and we were thrown into the sea."

One could build with lodestones. One could destroy with them. Could one use them to heal? Thales of Miletus (636?–546? BC), generally considered to be one of the founders of Western philosophy, regarded the soul as somehow producing motion. Hence, he postulated (if one believes Aristotle [384–322 BC]) that both the magnet, which moves iron, and amber, which attracts cloth and paper, possess a soul. This is the first tenuous link between man's nature and these inanimate materials, and it is the primum mobile of the uncountable claims that have appeared throughout history of the medical properties of the lodestone and amber. By 200

AD, Greek physicians were prescribing amber pills to stop hemorrhages, and the priests of Samothrace were selling magnetic rings as a cure for arthritis. Many more medical cures based on these two materials were to follow, but first, lodestones had to be put to the service of the True Faith.

Saint Augustine (354–430), the great philosopher of the early Christian church, included a factual summary of the early knowledge of electrostatics and magnetism in his magnum opus *De Civitate Dei* (The city of God), which he finished writing in 428. In it, he says that his "observation . . . [that] . . . the magnet, which by its mysterious and sensible suction attracts the iron . . . has no effect on straw," puzzled him greatly and led him to the conclusion that "if such common phenomena be inexplicable . . . why should it be demanded of man that he explain miracles by human reason?" Given that the book *De Civitate Dei* was one of the fundamental theological works of the early Christian church, it has been argued that magnetic phenomena were one of the reasons empirical scientific research was suppressed in the Western world until the flourishing of religious pluralism in the 16th century.

In 1289, Peter Peregrinus wrote the first great treatise on magnetism, *Epistola Petri Peregrini de Maricourt ad Sygerum de Foucaucourt, Militem, De Magnete* (Fig 1). In it he tells the reader to perform the following experiment: Round a lodestone; take an iron needle and place it over the stone; draw a line on the stone along the direction of the needle, thus dividing the stone along the middle; repeat this procedure at many other places over the surface of the stone. If the reader does this, Peregrinus says that the reader will find the lines will concentrate at two points on the stone, just as the meridians of the earth come together at opposite geographic points. By analogy to astronomy, he named the convergence points after the axis of revolution of a sphere (as in the firmament): $\pi\acute{o}\lambda o\sigma$ (polos), or poles. The one that pointed to the north celestial pole (or so he thought) he named the "north pole"; its complement he named the "south pole." The *Epistola* also contains the first description in the Western world of a compass and how it can be used for sea navigation. Peregrinus' manuscript is the first extant example of the scientific or experimental method. In it, all questioning of a phenomenon is done without calling on any supernatural agencies. The *Epistola* became

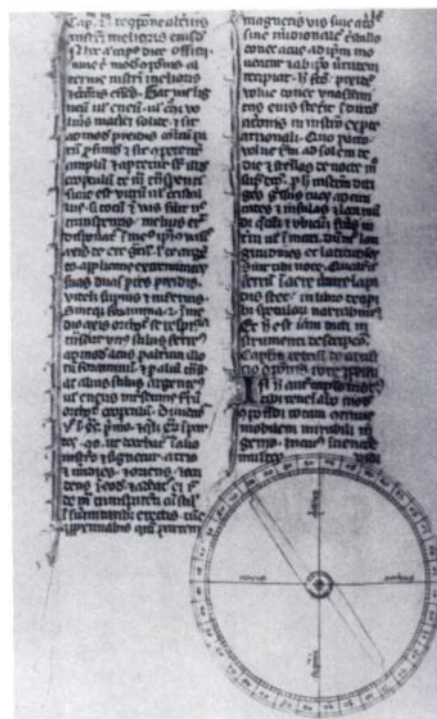


Figure 1. A page from Peregrinus' treatise on magnetism. It contains the first drawing and description of the compass in the Western world. The compass points, Septemtriones, Meridiens, Oriens, and Occidens, refer, respectively, to what we now call the Little Bear (Ursa Minor) constellation (in Roman times, the seven [septem] plough-oxen [tri-ones]), whose brightest star is Polaris (the North Star); noon or midday (Latin, medius/dies), as the sun at its zenith (noon), always appears due south in the northern hemisphere; the constellation Orion (Latin, Oriens), whose brightest star, Betelgeuse, appears in the northern hemisphere in the geographical east, in the winter before sunset, and in the summertime before dawn; and evening (Latin, occidens—sunset, the west). The modern names of the compass points—north, south, east, and west—are of Teutonic origin and first appear in Old English texts circa 800 AD.

the paradigm for all of the scientific treatises that followed it. The date of publication of this great work we know only because at its end, Peregrinus states, "Completed in camp, at the siege of Lucera, in the year of our Lord 1289, eighth day of August." It has been conjectured that at the time he wrote this he was an engineer in the employ of the King of Sicily—the man who was laying siege to Lucera. Most probably then, the honorific title "Peregrinus" or "Pilgrim" (his full name appears to have been Pierre de Maricourt) was given to him by the Pope for his participation in that siege (as a Crusader) and not for having gone on a pilgrimage to the Holy Land. Nothing else is known of his life.



Figure 2. Theophrastus Bombast von Hohenheim, or Philippus Aureolus Paracelsus. This portrait was done by his contemporary, the Venetian painter and Mannerist master Tintoretto (Jacopo Robusti, 1518–1594).

A contemporary of Peregrinus, the scholar and Franciscan monk Roger Bacon (1220–1292) greatly praised the *Epistola*. For his scientific teachings, heresies, and attempts to bring the sciences into the curriculum of university studies, Bacon was tortured and imprisoned by the Catholic church. No one knows how the Church responded to Peregrinus' *Epistola*.

An astonishing number of beliefs had adhered to magnetism by the end of the Middle Ages: Magnets could draw gold from wells; garlic had the power to destroy magnetism; a magnet carried on a person could cure arthritis and gout, draw poison from wounds, and cure baldness; when sprinkled on water, magnets spoke with a voice like that of an infant. These myths, and many more, were codified, amplified, and brought to bear on the systematic treatment of disease by a man whose name has become synonymous with hyperbole—Theophrastus Bombast von Hohenheim (aka Philippus Aureolus Paracelsus, 1493–1541) (Fig 2), doctor and alchemist. Paracelsus denounced Galenic medicine (he and his students publicly burned the works of the physician Galen [129–199 or 130–200]). He introduced the use of arsenic, mercury, sulfur, and other chemicals into the treatment of disease (especially mercury treatments for syphilis). Asepsis during surgery was one of his teachings. For these actions and views (and many others), he was widely



AUTHORIS CARMEN:

**Non me terra teget, coelo sed raptus in alto
Illustris uiuam docta per ora uirum:
Quicquid uenturis spectabit Phoebus in annis,
Cardano noscet, nomen & usq meum.**

Figure 3. Girolamo Cardano. Astrology led him to believe that he would not live to see 45 years of age, and hence he spent his early life in riotous living. Later he wrote books discussing why the prediction had been wrong: "It was when I ought to have died that I really began to live." His writings on mathematics are a major contribution to the development of algebra. A contradictory soul, he presumed to cast the horoscope of Christ; yet, in the fall of 1575—near the end of his life—he wrote in his autobiography, "One thing alone provides satisfaction to me: to understand and grasp the meaning of all the wonders of the world would be more precious to me than the everlasting dominion of the universe; this I swear by all that is holy." This engraving and its pendant poem are the frontispiece of an edition of *De Subtilitate* that appeared in 1560. The poem's sentiments express Cardano's sense of self-worth: "The earth will not cover me, but carried off into high heaven shall I be/Celebrated will I live through the mouths of learned men:/ Wherever The Sun shall look in the years to come,/ There He will see Cardano and his name."

criticized and mockingly referred to as "Paracelsus," meaning "greater than Celsus" (ca 25 BC–50 AD, an early Roman medical authority). He liked the nickname and adopted it. Paracelsus combined mysticism with his practical, empirical medical treatments. In his work *Volumen Medicinae Paramirum*, he writes that every person is a magnet, "possessing a magnetic power by which he may attract certain effluvia of a good and evil quantity in the same manner as a magnet will attract iron." Elsewhere, he asserts that the lodestone "attracts all martial humours that are in the human system." Thus, for example, since the front (north) pole of a magnet attracts and its back (south) pole repels, in cases of nervous "epilepsy where there is a greater determina-

tion of nervous fluid towards the brain, the repulsing pole of a magnet is [should be] applied to the spine and to the head, and the attracting pole of other magnets to the abdominal region" in order to effect a cure. Paracelsus' teachings in the form of "animal magnetism" appear in the scientific works of the 16th, 17th, and 18th centuries. Attempts to prove them correct, and Paracelsus' claim that magnets were a prime ingredient in his "elixir of life," spurred much research during those times. Paracelsus died in poverty at age 48. One story states that he died of a stroke; another states that he was murdered by agents of the physicians and apothecaries he had denounced. Considering the man's nature, it is likely he would prefer us to believe the latter version.

By the middle of the 16th century, attempts were being made to understand and to separate magnetic phenomena and the "amber effect." In his treatise *De Subtilitate* (On subtlety) (1550), the Italian mathematician and physician Girolamo Cardano (1501–1576) (Fig 3) listed his evidence of why "the magnet stone and the amber do not attract in the same way." His studies were driven by his interest in the claim that amber had medicinal properties and led him to postulate that all matter contains "humours" and that the absorption and exudation of these humours by matter accounts for its attraction or repulsion to another type of matter. The principle of humours was applied to the body's organs (eg, in the context of magnetism: animal magnetism) and to the treatment of disease (eg, again, in the context of magnetism: mesmerism) well into the 18th century. Cardano's career as a physician was filled with tribulation. At one point in his life he was deprived of the legal right to practice medicine by the Milanese medical association. Many of his trials were of his own making. That this is so can be deduced from the title of the first of the 200-odd books that he wrote: *De Malo Recentiorum Medicorum Usu Libellus* (On the bad practice of medicine in common use) (Venice, 1536).

William Gilbert (1544–1603) (Fig 4)—fellow and president of the Royal College of Physicians and the personal physician of Queen Elizabeth I of England (1533–1603)—built on Cardano's work and in 1600 produced his book *De Magnete Magneticisque Corporibus et de Magno Magnete Tellure Physiologia Nova* (On the lodestone, magnetic bodies, and on the great magnet

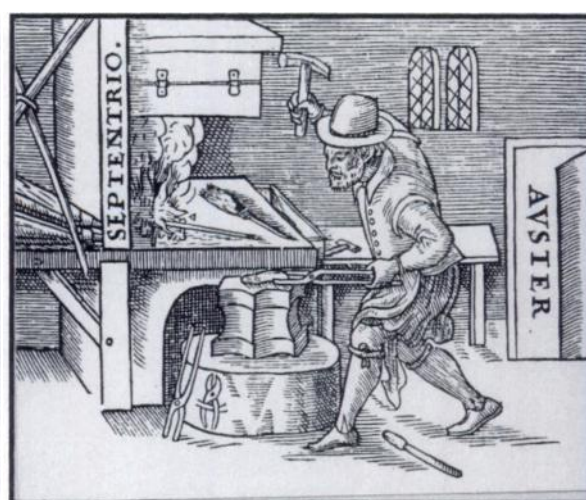


Figure 4. William Gilbert, writer of *De Magnete*, of whom the English scientist Joseph Priestly (1733–1804, discoverer of oxygen) said, “may justly be called the father of modern electricity, though it be true that he left his child in its very infancy.” In truth, he also inspired a novel method of seduction. The English dramatist and poet Ben Jonson (c 1572–1637) wrote his most famous play, *The Alchemist*, not long after the publication of *De Magnete*. In it, he advises that “Beneath your threshold, bury me a load-stone./To draw in gallants, that wear spurres: the rest,/They’ll seeme to follow.” This portrait of Gilbert by an unknown artist is based on the engraving made in 1796 by R. Clamp (late 18th century), which itself is copy of a portrait of Gilbert (now lost) that is said to have been painted in 1591 by Cornelis Janssens (1593–1661, not very likely). Thomas Fuller (1608–1661), in his *History of the Worthies of England* (1662), writes of Gilbert that “such his loyalty to the Queen that as if unwilling to survive, he dyed in the same year with her 1603. His stature was Tall, Complexion Cheerfull, an Happiness not ordinary in so hard a Student and retired a Person . . . Mahomet’s tomb at Mecha is said strangely to hang up, attracted by some invisible Loadstone; but the Memory of this Doctor will never fall to the Ground, which his incomparable book *De Magnete* will support to Eternity.”

the earth) (Fig 5). This book was the first important work in physical science to be published in England and can be regarded as the beginning of the modern science of electricity. Gilbert, like Cardano, makes a very strong distinction between magnetism and the “amber effect.” When he found that a large number of substances when rubbed with silk or fur will attract light objects, he gave them the generic name “electrics.” He coined this term from the Greek name for amber, ἤλεκτρον, or electron. One of the principal pieces of apparatus that Gilbert used in his researches was a large spherical lodestone, which he called a “terella”—a miniature earth.



a.



b.

Figure 5. (a) Frontispiece of Gilbert’s book *De Magnete*. The drawing of a serpent twined about a tau cross that appears on this page was then used extensively by physicians as a sort of identifying crest. Its origin are two biblical quotes. The first—Numbers 21:4–9—details the origin of the serpent: “the people complained . . . In punishment the Lord sent among the people saraph serpents [horned vipers?], which bit the people so that many of them died . . . Moses prayed . . . the Lord said to Moses, ‘Make a saraph serpent and mount it on a pole, and if anyone who has been bitten looks at it, he will recover’ . . .” The second—John 3:14–15—makes the link between the serpent and the image of the True Cross: “And as Moses lifted up the serpent in the desert, even so must the Son of Man be lifted up, that those who believe in him may not perish, but may have life everlasting.” Over time, and in a fashion that is not clear—possibly influenced by the Renaissance alchemical association of Christ with the Egyptian god Thoth (in Greek, Hermes Trismegistus [Hermes the Thrice Greatest])—this symbol became conflated with two forms of the caduceus: the Asklepiian caduceus, which is a clublike staff with a single serpent coiled about it (the true symbol of the medical profession), and the badge of the Greek god—and herald for the gods—Hermes, originally a straight branch from whose tip two curling, twisted twigs grew (in form, a dowser’s rod), which, through orientaling influences, was transformed into a snake-entwined branch. Hermes’ caduceus—the American symbol of the medical profession—has no medical relevance whatsoever. In *De Magnete*, Gilbert illustrates (b) the method then used for making artificial (iron) lodestones: “Get a smith to shape a mass [of iron] . . . on the anvil . . . Let the smith stand facing north [Septentrio, cf Fig 1], with back to the south [Auster, the Austral [Southern] Winds], so that as he hammers the red-hot iron it may have a motion of extension northward . . . have him keep the same point of the iron looking north, and lay the finished bar aside in the same direction . . . when [the bar is] afloat [being passed through suitable pieces of cork, it] will move about the water, and, when the end is duly reached, will point north.”

With this lodestone and a compass, he demonstrated that the behavior of a mariner’s compass could be explained by assuming that the earth is itself a large magnet. With this hypothesis and his experiments, Gilbert created the science of terrestrial magnetism. On his death, Gilbert’s lessers tried to place their escutcheon on his accomplishments. He was fortunate—a fellow physician preserved his honor.

William Barlow (ca 1540–1625) entered holy orders in 1573 and had a brilliant ministerial career—when he died he was Archdeacon of Salisbury. The numerous ecclesiastical favors that he received throughout his life were due, in part, to his being the son of a bishop and to his four sisters being married to bishops. He was literally deeply ensconced in the bosom of the Church of England. Barlow’s two scientific interests were complementary: navigation and magnetism. The first product of his scientific pursuits

was the book *The Navigator’s Supply: Containing many things of principall importance belonging to Navigation, with the description and use of diverse instruments framed chiefly for that purpose; but serving also for sundry other of cosmography in generall: The particular instruments are specified on the next page* (London, 1597). In it, he describes in clear technical prose geographic terms (meridian, equator, latitude, longitude, etc), the use of the compass, and the use of early forms of the quadrant and the sextant. Barlow’s second book was *Magneticall advertisements: or, Divers pertinent observations, and approved experiments concerning the nature and properties of the load-stone: Very pleasant for knowledge, and most needfull for practise, of travelling, or framing of instruments fit for travellers both by sea and land* (London, 1616) (Fig 6). It is an important contribution to the development of artificial magnets, for in it he points out a basic difference be-

MAGNETICALL
Aduertifements :
OR
DIVERS PERTINENT
obferuations, and approued ex-
periments concerning the nature and pro-
perities of the Load-stone :

*Very pleasant for knowledge, and most
needfull for practise, of traueilling, or fra-
ming of Instruments fit for Trauellers
both by Sea and Land.*

ACT. 17. 26.
*He hath made of new blind all nations of men for to dwell
on the face of the earth, and hath determined the times be-
fore appeared, and the bounds of their habitation, that they
should seek the Lord, &c.:*



LONDON,
Printed by Edward Griffin for Timothy Barlow, and
are to be sold at his Shop in Pauls Church-yard at
the signe of the Bull-head. J. 1616. L.

A
BREIFE DIS-
COVERY OF THE
IDLE ANIMADVER-
SIONS OF MARKE RIDLEY
Doctor in PHISICKE vpon
a Treatise entitled,

Magnetickall Aduertifements.

*moneat Cornicula risum.
Furtinis nudata celoribus*



LONDON,
Printed by Edward Griffin for Timothy Barlow,
at the signe of Time in Pauls Church-
yard. 1618.

a. Figure 6. William Barlow's contributions to magnetic lore could be easily missed except for the notoriety he achieved with his attempt to usurp Gilbert's eminence in the field of magnetism. (a) In his book *Magnetickall aduertifements*, he notes the difference in the magnetic properties of iron and steel; by mistranslating from the Latin text of *De Magnete* the word "electric" as "electricall," he coined a new word; through his dedication of the book to a courtier, whom he compares to a magnet because the courtier is of "so pleasing a carriage toward euerie man, as causeth al good men which know [him] to love [him] by force of a natural sympathy," he hatched one of the most fearsome creatures that has ever been—the politician with a "magnetic personality." The symbolism of the escutcheon on the book's title page is obscure. One of the twinned snakes (left) wears a crown on its head. This identifies it as a basilisk—a creature whose breath was so foul that inhaling one puff of it meant death. The only method of killing a basilisk was to make it see its own hideous reflection. Is Barlow making an indirect reference to M(arke) Ridley with this distorted form of a physician's crest—identifying him with the basilisk? Are we to interpret the escutcheon as Barlow's intent of vanquishing Ridley by making him see in the reflecting mirror of knowledge (represented by the owl) his heinous act (and self)? We will never be completely certain. (b) However, the title page of his answer to Ridley's charges, *A Brief discovery of the idle animadversions of Marke Ridley*, contains a quote—"moneat Cornicula risum, Furtinis nudata celoribus," or, "let the Horned One beware of ridicule, for the theft which was hidden is exposed"—which leaves one in no doubt of his perception of Ridley at the time of its publication.

tween steel and iron: "steele is farre better than yron, and receiveth a farre stronger touch [magnetization] . . . The purer the steele, so much the better . . ." Barlow's impetus for publishing this book appears to have been a mixture of anxiety, jealousy, and pride. In the book's dedicatory passages he alludes to early drafts of the book having been "either mislaied or embeseled" and that as a consequence he has "met with many por-
traits of [his] Magnetickall imple-
ments . . . in print in another mans name." He goes on to list those men who urged him to publish his work, naming among them Gilbert. Indeed, he states that he "may be bold to chal-
lenge a right, as having endeouored
to get some insight in this argument

[magnetism] . . . above the space of
twenty years ere Doctor Gilberts book
saw light." The degree of truth in this
claim will never be known. He never
challenged Gilbert's priority while *De
Magnete*'s author lived, and with the
exception of the description of the
differences in the properties of steel
and iron, all of the topics that Barlow
discusses in his book—how to magne-
tize needles, cap magnets, cement
(join) loadstones, and use the com-
pass—form a subset of those dealt
with in Gilbert's book. For example,
Barlow singles out for censure only
one magnetic medical cure—the one
that Gilbert criticizes in his book. Bar-
low deplores the " . . . great error of
those Phisitions and Surgeons, which
to remedy ruptures, doe prescribe

unto their Patients to take powder of a
Lodestone inwardly, and the small
filings of iron mingled in some
plaister outwardly: supposing that
herein the magnetickall drawing
should do great wonders." Gilbert
attributes whatever medicinal effect
this remedy has to the poultice which
"heal[s] . . . the ruptured tissues by
excitation [drying out]." The only
concrete evidence that Barlow offers
to establish his right to precedence is
a letter from Gilbert to Barlow (in-
cluded in the book!) that contains this
passage: "you [Barlow] have shewed
me [Gilbert] more; and brought more
light than any man hath done." The
Oxford antiquarian and historian An-
thony à Wood (1632–1695) says that
Barlow was "accounted superior, or at
least equal, to that doctor [Gilbert] for
a happy finder out of many rare and
magnetickall secrets." Unfortunately for
Barlow, Wood's support was posthu-
mous, and it was said of Wood "that
he'd never spake well of any man." However, his chief detractor was im-
mediate; his nemesis—the wrongdoer
he alludes to in *Magnetickall Aduertise-
ments*' dedication—the physician
Mark Ridley (1560–1624).

Barlow's life was the antithesis of
Ridley's. The cleric led a sedentary
life, never venturing out onto the sea
the charting and navigation of which
became his true life's work. The
healer began his medical career as
physician to the English merchants
resident in Muscovy (Moscow). Then
he was appointed the chief physician
of the tsar, Theodore (1584–1598). His
medical skills and personal charm
must have been considerable, for not
only did he survive the tsar's death
but he also returned to England in
1598 with many compliments from
the new tsar, Boris Fedorovich Go-
dunov (1552–1605). He settled in prac-
tice in London, where he achieved
professional renown. In 1613, Ridley
published a book that greatly alarmed
Barlow: *A Short treatise of magnetickall
bodies and motions* (London, 1613) (Fig
7). It is a practical review and an am-
plification of the magnetic experi-
ments in Gilbert's book written in an
articulate and straightforward prose
style. Barlow published *Magnetickall
aduertifements*—and his thinly veiled
charge of plagiarism by Ridley—3
years after the appearance of Ridley's
book. The return volley came in the
form of *Magnetickall animadversions*
(criticisms) upon certaine magnetickall
aduertifements from W. Barlow (Lon-
don, 1617), in which Ridley accuses
Barlow of plagiarizing all that appears
in his book from *De Magnete* and from

Ridley's own work. The reply was *A Brief discovery of the idle animadversions of Marke Ridley* (Fig 6) (London, 1618)—a 13-page salvo in which Barlow shrieks out his charge against Ridley, points out all that he perceives to be in error in Ridley's book, lists his own unique discoveries on the nature of magnetism (unlisted are the different magnetic properties of steel and iron), slyly accuses Ridley of heresy (like Gilbert, Ridley was a Copernican, something which the religious Barlow was definitely not: "[Gilbert's] sixt Booke, entreating of the motion of the earth, I thinke there is no man living farther from beleieving it, than my selfe . . ."), and questions Ridley's title of chief physician to the tsar! In Barlow's words, "except this Ridley, has ploughed with my Heifor, hee had not knowne my Riddle [a sieve to separate chaff from grain]."

Who was telling the truth? Gilbert, the one person who could have answered this question, had died 12 years before the beginning of this argument. Both men lay claim to fraternizing with "Doctor Gilbert, our friend and Collegiat" (a phrase from Ridley's book). The difference in the spirit in which the two authors wrote their books makes one hope that Ridley was telling the truth. Whereas Barlow marshalls the powers of heaven into his ranks—"To the Reader: This booke was written by a Bishops sonne,/And by affinitie to many Bishops kinne:/Himself a godly Pastour, prayse hath wonne,/In being diligent to conquer sinne"—(from the introductory verses to *Navigators Supply*), Ridley advises his readers that "when [they] readest this booke, that [they] should provide [themselves] of such . . . Magnets as I have described . . . as also of needles, wiers and waightes of iron and steel . . . then [they] mayest reade and practice the operations and demonstration in this booke." Who won the argument? If one assigns significance to the etiquette of introductions, a clue is found in these lines from Ben Jonson's comedy *The Magnetic Lady* (1632), wherein the heroine—"Lady Lodestone"—"Draws and draws unto you guests of all sorts,/The courtiers, and the soldiers, and the scholars,/The travelers, physicians and divines,/As Doctor Ridley wrote, and Doctor Barlowe."

Gilbert's book was widely disseminated (it reached Italy in only 2 years), and with its publication a great period of scientific research and inquiry on the nature of electrostatics and magnetism began—ominously.



Figure 7. Dr Mark Ridley appears to have been a very good self-promoter. The title page of his book *A Short treatise of magneticall bodies and motions* (a) declares him to be a "Doctor in phisicke and Philosophie Lately Physition to the Emperour of Russia, and one of eight principals or Elects of the Colledge of Physitions in London." In case the book's readers missed the message, it was repeated on the frontispiece of the book (b), which displays Ridley's handsome likeness at age 34 years on a shield with a border that proclaims him to be "Mark Ridley of Cambridge (Cantabrigiensis), Doctor (Archiatrus) to the Russian Emperour." His coat of arms is emblazoned in the shield, which itself is surrounded by scientific instruments and symbols of learning. Below this imposing composition are inscribed the words "Missus ab Elisa Ruthenis quinque per annos Anglia in aethra te vocat illa aedum/Tute mathematicis clarus magnetica calles/Promas laudes doctus ubique capis." ("Sent by Elizabeth to the Russians for five years/In order that you not fail in your duty to the English she called you home/You are famous in mathematics and skilled in magnets/May you prove [?] your praises wherever you receive them.") Clearly, Ridley had much in common with Cardan (cf Fig 3).

Among *De Magnete's* readers in Italy were Giordano Bruno (1548–1600), Galileo Galilei (1564–1642), and Gilbert's rival Giambattista Della Porta (1535–1615) (Fig 8). The former two incorporated its contents into their arguments in support of the heliocentric model of the solar system that had been proposed by Nicolaus Copernicus (1473–1543):

Simplicio: Then you are one of those people who adhere to the magnetic philosophy of William Gilbert? . . .

Salviati: I have the highest praise, admiration, and envy for the author, who framed such a stupendous concept regarding an object which innumerable men of splendid intellect had handled without paying any attention to it . . . I might have wished for in Gilbert would be a little more of the mathematician . . . I do not doubt that in the course of time this new science will be improved with still further observations, and

even more by true and conclusive demonstrations. But this need not diminish the glory of the first observer . . .

(Galileo Galilei, *Dialogue Concerning the Two Chief World Systems—Ptolemaic & Copernican*) (Florence, 1630). Porta called Gilbert a "barbarous Englishman . . . who took the whole seventh book of my *Magiae Naturalis Libri XX* [Natural magick in 20 books] [Naples, 1558] and split it into many books, making some changes; . . . the material which he adds on his own account is false, perverse and melancholy; and towards the end he arrives at the mad idea that the earth is in motion." Bruno was burnt at the stake in Italy for promoting the Copernican system. Galileo was condemned by the Inquisition for his belief in the heliocentric system and was under house arrest until his death. Porta was examined by the Inquisition, and in 1592 all further publication of his works was prohibited. This ban was not lifted until 1598.

The treatment of Gilbert's fellow



Figure 8. (a) Giambattista Della Porta (bottom center)—autodidact, playwright, and writer of books on philosophy, geometry, optics, military architecture, cryptography, mathematics, meteorology, physiognomy, and chemistry. His book *Magiae Naturalis Libri XX* (Natural magick in 20 books) (Naples, 1589), a mixture of useful recipes, half-truths, observations, and experiments, was a best-seller from its first appearance. It went through 12 editions in Latin, four in Italian, seven in French, two in German, two in English, and, possibly, one in Spanish and another in Arabic. The frontispiece (a) and title page (b)—engraved by Richard Gaywood (ca 1650–1680)—of the English translation of the book, which was printed in London in 1658 (almost 100 years after the original publication date of the book!), give evidence to the complex nature of this man. They accommodate both the fantastic (alchemy) and the practical (*Of Tempering Steel*). The seventh chapter of *Natural Magick* deals with the “Load-stone.” Much in that chapter is comparable to Gilbert’s statements in *De Magnete*, hence his hostility toward Gilbert. Porta was a curious, and contrary, man. He includes in this book chapters on perfumes and cosmetics, and then goes on to describe how to turn women’s faces red, green, or pimply. His dedication to experiment, and his contemplation of the natural world, freed him from many false perceptions and brought him to the verge of greatness, but in the end he was overwhelmed by the lure of the occult and the fabulous.

savants in France was no better than that in Italy. In 1634, the celebrated philosopher and mathematician René Descartes (1596–1650, inventor of analytic geometry) (Fig 9) was ready to publish his treatise *Le Monde, ou Traité de la Lumière* when the news came to him of Galileo’s persecution. He decided to suppress his quasi-atomistic (corpuscular) physical theories (amongst them the first mechanical theory of magnetism) until he had secured the patronage of Cardinal Richelieu (1585–1642), chief minister of King Louis XIII of France (1601–1643). *Le Monde* was not published in its entirety until after Descartes’ death. In fact, in France, through the first half of the 17th century, it was a crime to publish any thesis that disagreed with the teachings of the Catholic Church (and Aristotle) without the consent of the theological faculty of the University of Paris. The

punishment was death—a sentence meted out to the Huguenot scholar, philosopher, mathematician, and pedagogue Pierre de La Ramée (Peter Ramus, 1515–1572). His attacks on Aristotelian (non-atomistic) logic led to his being shot, stabbed, thrown from a window, dragged by his heels to the Seine, decapitated, and thrown into the river during the St Bartholomew’s Day Massacre (August 26, 1572).

History shows that the Catholic Church in the 17th century did not give up its intellectual primacy without a fight. And yet, the main impetus for objective scientific research was provided by the teachings of a French priest, Pierre Gassendi (1592–1655) (Fig 10), which rehabilitated the atomic doctrines of the ancient Greeks. How he contrived to get ecclesiastical approval to publish *De Vitae et Moribus Epicuri Libri Octo* (Lyons,

1647)—a life of Epicurus—is a minor mystery in the history of science. Epicurus taught that in the beginning there existed merely atoms and a void (vacuum) and that the universe (and, by inference, human beings) had originated in the chance accretion of atoms moving about in a random fashion. There is no room for God and Creation in such a theory. Nevertheless, Gassendi managed it and thus made heretical atomism fashionable. By teaching that “the human soul is immaterial” and that “the Creator is the first cause of things but, once the moment of Creation was over, He removed Himself from active control of natural phenomena,” he clothed atomism in the vestments of religious orthodoxy. Science’s claim for dominion over the world was advanced, and its champion in England was the one-time Paracelsian, and physician, Walter Charleton (1620–1707).

The extreme swings of fortune in Walter Charleton’s medical and scientific careers find echoes in the historical events of the transitional period into which he was born. To understand the vast alterations that Charleton’s perception of science suffered, we must first consider another physician and chemist of his time: the Belgian, Johannes Baptista Van Helmont (1579–1644). He was a Paracelsian and a brethren of the Ancient Mystical Order of the Rosy Cross—a Rosicrucian. This order was an offshoot of Paracelsian teachings and arose in Germany in the very early 17th century. Helmont was most interested in one aspect of Rosicrucian teachings: the “Unguentum Armarium,” or weapon salve. Some of the ingredients of this salve were human blood, human fat, dried Egyptian mummy, armeniac, oil of roses, and linseed oil. In short, it contained everything but lodestone! When a person was wounded by a weapon—for example, by an arrow—this salve was applied to the weapon—in our example, the blood-covered arrowhead—and not to the wound. The wound itself was cleaned and dressed with clean lint. Then “the blood effused doth send out subtle streams to its fount [the body],” and with these streams, or “Magnetic Nuntii,” are carried “the Balsamick [healing] Emanations of the Sympathetic Unguent or Powder.” Helmont’s troubles began when he published a treatise on the weapon salve and the method for effecting sympathetic cures, *De Magnetica Vulnerum Naturali et Legitima Curatione Contra* (The magnetic cure of wounds) (Paris, 1621). The General Inquisition

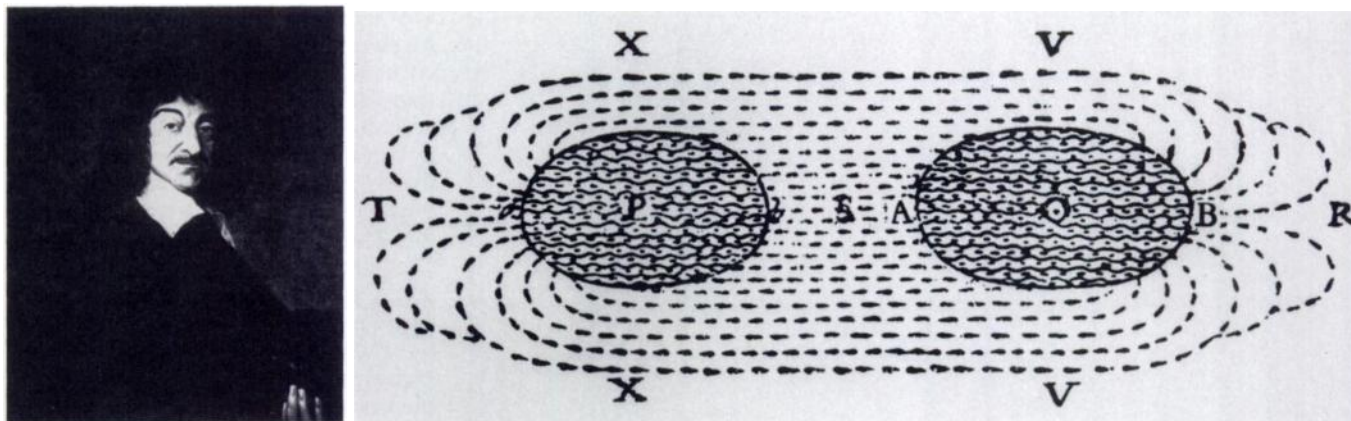


Figure 9. (a) René Du Perron Descartes (or Renatus des Cartes). His goal in life was to present all the phenomena of nature (including man) as the necessary consequences of a few first (mechanical) principles. Unfortunately for him, his excellent powers of observation and superior experimental technique, provided him with endless examples of nature behaving in ways that belied his first principles. Nevertheless, Descartes' conceptions were to affect the course of science. In the field of medicine, his "beast-machine" provided the mechanical framework that guided the development of physiology in the 17th century. Descartes' theory of magnetism is ingenious. He could not bring himself to believe in the atom and the vacuum, yet elements of the epicurean explanation of magnetism appealed to him. Hence, he postulated that all matter contained microscopic pores, that these pores were all threaded with same sense, and that the degree to which an object can be magnetized depends on the size and arrangement of its pores (b, from *Principia Philosophiae* [Principles of philosophy], Amsterdam, 1644). Why? Because all space is permeated with screw-shaped particles (vortices). Thus, two objects attract each other strongly because these vortices can travel through one object, emerge from it in a straight line, enter the other, and drive away the air between the two objects (in Archimedian screw fashion). As there can be no void (vacuum), the objects move toward each other. Descartes' theory of magnetism made a profound impression on the illuminati and the literati of his time—to the extent that they appear in an unfinished poem of the great English poet Samuel Butler (1612–1680), *A Satire on the Royal Society*: "Or what's the strange magnetic cause/The steel or loadstone's drawn or draws?/The star the needle, which the stone/Has only been but touch'd upon?/Whether the North-star's influence/With both does hold intelligence?/(For red-hot ir'n, held tow'rds the pole,/Turns of itself to 't when 'tis cool:)/Or whether male and female screws/In th' iron and stone th' effect produce?" The manner of Descartes' death is an anticlimax to his brilliant and restless life. In 1649 he accepted an offer to become tutor to Queen Christina of Sweden (1626–1689). The queen, no mean scholar herself, chose the hour of 5 AM to receive her daily lesson from Descartes. On February 1, 1650, he caught a chill while making his way to her palace to give the lesson. Ten days later he died of an inflammation of the lungs.

in Spain condemned the work in 1625. A year later, it was impounded. In 1627 Helmont asserted his innocence and submission to the Church. He acknowledged his errors again in 1630. Condemned in 1633–1634 for adhering to the "monstrous superstitions" of the school of Paracelsus, he was placed under house arrest until 1636. Church proceedings against him were not lifted until 1642, 2 years before his death. In 1646 he received an official religious rehabilitation, and permission was given for *De Magnetica* to be reprinted.

Helmont was not the charlatan that his dabbling in alchemy would lead one to believe. Amongst his achievements in medicine are the demonstration that acid is the digestive agent in the stomach, that the rhythmic movement of the pylorus exerts a directing action on digestion, and (most important) that diseases have a discrete and unique nature. Amongst his achievements in chemistry are improved chemical medicines, the proof that metals reduced by acid are recoverable, and the discovery of "specific smoke." Helmont burned solids and fluids and applied chemical analysis to the smoke that resulted. He found its nature to be different from air and water vapor and to be specific to its source material. This "specific smoke"

he gave the Greek name $\chi\acute{\alpha}\omicron\varsigma$ (chaos) or gas.

The complex mixture of advanced science and medicine, cosmology, alchemy, and metaphysics that is Helmont's healing doctrine is couched in Hermetic prose. Its translation from Latin into English was accomplished by Walter Charleton (Fig 11). His humble origins required him to enter a profession—his choice was medicine. Charleton's genius was quickly recognized, and, through the favor of King Charles II of England (1630–1685), he was awarded the degree of Doctor of Physick in 1643, at the young age of 23. Shortly afterward he was made Physician-in-Ordinary to the King. When Oliver Cromwell's (1599–1658) Roundheads overthrew the monarchy, Charleton moved to London. There, he was unable to obtain admission to the College of Physicians until 1676 due, it is said, to the envy and resentment that his precocity generated—a more likely cause was his unrepentant royalism. During the interregnum Charleton turned to writing. His first work was a translation and expansion of Helmont's oeuvre (including *De Magnetica*), which he titled *A Ternary of Paradoxes* (London, 1650) (Fig 11). There, while considering the healing powers of amber, he states that "the phansy of Amber

delights to allect [draw in] strawes, chaffe, and other festucous bodies, by an attraction, we confesse, obscure and weake enough, yet sufficiently manifest and strong to attest an Electricity, or attractive signature: for married to the mumie of our bodies, it appears superior to the humane Magnet." Charleton appears to be the coiner of the word "electricity." Note that he uses it in the context of an electrostatic charge causing two bodies to move together, instead of to denote a moving line of charge (a current).

A confirmed Helmontian, Charleton experimented with magnetic cures. Their failure, and his growing awareness of the new atomic doctrine, ensured that he would turn away from Helmont and toward Gas-sendi. In 1654 his most important work on atomic natural philosophy appeared, *Physiologia Epicuro-Gassendo-Charlotiana* (London, 1654) (Fig 11). Through it, the mechanical philosophy of atomism was disseminated in England, influencing the country's leading scientists—among them Isaac Newton (1642–1727). Charleton enjoyed his greatest prosperity and influence in the years following the restoration of the monarchy in 1660. He was again appointed physician to the king, was made a member of the



Figure 10. Pierre Gassendi, defender of atomism. This is a reproduction of the engraved portrait executed by Jacques Lubin (1637–1695?), which was published by Charles Perrault (1628–1703, critic and author of the Mother Goose fairy tales) in his book *Les Hommes Illustres qui ont Paru en France Pendant ce Cicle* (Paris, 1696). Gassendi's writings touched all fields of knowledge: metaphysics, mathematics, astronomy, physics, and medicine. A chronic disease of the chest undermined his health. A few days before his death, he was bled nine times in a single day in an effort to break his intermittent fever and to relieve the congestion in his chest. Though weak and protesting that he could not withstand another bleeding, he submitted to the decision of the best physicians in Paris and allowed himself to be bled four more times. He died on October 24, 1655.

Royal Society, and achieved fame as a prolific and brilliant author. However, by the 1690s the scientific beliefs and methods that had preceded his *Physiologia* were obsolescent. His medical practice declined. Charleton spent the last years of his life in poverty, undone in part by the scientific ideas that he had helped popularize.

The scholars of the 17th century—Bruno, Galileo, Della Porta, Voltaire, Gassendi, Charleton, Van Helmont, and many more—debated and wrote lengthy refutations of each other's work and theories. They were preparing the intellectual climate of Europe for the coming age of Enlightenment through public, and vociferous, argument. It was in a more gentle spirit that the English physician Thomas Browne (1605–1682) (Fig 12)—a shy and retiring man, always on the fringe of the scientific world, and a self-defined “enquirer after truth”—began the first systematic and deliberate onslaught on the magnetic salves,

medicines, and talismans that were prevalent at that time. Browne was singularly suited for that task. While he was in his twenties, he traveled throughout Italy, France, and Germany, studying many subjects, learning several languages (Greek, Latin, French, Spanish, Dutch, Italian, Hebrew, Danish, and Portuguese!), and receiving his MD in Leiden in 1633. When he returned to England, he practiced for 4 years with an established doctor in Oxford in order to satisfy English regulations. He took his MD in Oxford in 1637. During this period, and throughout his life, he read extensively on travel, philosophy, medicine, and science. He also conducted many experiments in physics, electricity, biology, coagulation, and comparative anatomy. All that was remarkable that he learned or read in any book, he set down in notebooks. These were to be his intellectual quarry until his death.

Browne's fame results from three books that he wrote: *Religio Medici* (A physician's religion) (London, 1643), *Pseudodoxia Epidemica* (Enquiries into vulgar and common errors) (London, 1646), and *Hidriotaphia, or, Urne-buriall* (London, 1658). The first book is the story of Browne's resolution of “the divided and distinguished worlds that he inhabited.” In it, he deals with a doctor's relation to his God and to the secular world of his profession. It was read in England and, in translation, everywhere in Europe. Few books in any age have caused such a commotion. The last book is a consideration of the discovery of some supposed Roman (really Saxon) burial urns near Norwich, England. Portions of this text are considered to be some of the greatest prose in the English language. The second book is the longest, most difficult to read, and most important. It is a critique—a reevaluation—of the popular ideas of his time. Browne did not mean for this book to be the final arbiter on these ideas, but rather, that it should clear the grounds for those who were to follow him and who would “test the things [ideas] themselves: opinions [on our conceptions] are free; and open it is for any to think or declare the contrary . . . [we] shall only take notice of such, whose experimental and judicious knowledge shall solemnly look upon it . . . ready to be swallowed [by] any worthy enlarger.” *Pseudodoxia* comprises seven sections, or books. The first is devoted to the causes of error, while the others encompass topics as varied as “mineral and Vegetable bodies” and “things

questionable as they are described in Pictures.” Over 200 separate topics are treated in the 200 leaves of the book. The amount of writing in it devoted to any topic is related to the importance that Browne assigned to that topic. Thus, in mere paragraphs he deals with the devil's cloven hoof and why dogs can search out a Jew in the dark; consumes a page or so to refute the belief that a badger's right legs are shortened so that he can run comfortably along a hillside (what would happen if he ran across the same ground in the opposite direction is not sufficient grounds to dismiss this “fact”); and consigns more than a dozen pages to a consideration of a central problem to the concept of matter: magnetism.

Scrutiny of the lodestone occurs in the second book of *Pseudodoxia*. Browne begins on a materialistic note: “And first we conceive the earth to be a Magneticall body . . . exciting and impregnating magneticall bodyes within its surface or without it, and performing in a secret and invisible way what we evidently behold effected by the Loadstone.” Then, he goes on to describe the two contemporary theories of the cause of magnetism: the Epicurean (the stream of atoms) and the Cartesian (the corpuscular theory; see Fig 9). He doesn't commit himself to either theory, but he attempts to test some of the better-known facts associated with magnetism by observing the behavior of a simple magnetized needle compass (a magnetized needle piercing a cork that is suspended in a bowl of water), magnetization of iron by heating, the attraction of unlike magnetic poles, and so on. He arrives at several false conclusions—for example, “the Northern pole of the Loadstone attracteth a greater weight then the Southerne on this side of the Equator”—due in part to the primitive nature of the experiments he was able to perform. However, he also makes some shrewd observations: “there may be some fraud in the weighing of precious commodities . . . by placing a powerful Loadstone above or below [the scale], according as we intend to depresse or elevate one extreame” and “[the Loadstone] may serve as a tryall of good Steel . . . taking up a greater masse of that which is most pure . . . may also decide the conversion of wood into Iron, as is pretended . . . and the commone conversion of Iron into Copper.” Browne then goes on to outline the “sundry . . . Naturall, Historicall, Medicall [and], Magicall . . . common opin-



Figure 12. Thomas Browne, whose answer to the great error of his age—the obsequious acceptance of traditional accounts of things as they were—was to write the book *Pseudodoxia Epidemica*. This is a detail from a contemporary painting done by an unknown artist circa 1641–1650. The whole work shows both Browne and his wife, Dorothy. To Browne, “the three determinators of truth (are) authority, sense, and reason.” In the prefatory note of *Pseudodoxia Epidemica* he says that existing errors in thinking must be removed before men will be ready to receive new knowledge. For that reason he had prepared a “large and copious List” of commonly presumed truths. The task was very difficult, as some of the subjects were obscure; he had to work alone—cut off from the universities and from London—and he could do it only in snatches of time, “as medical vacations, and the fruitless importunity of Uroscopy would permit” him.

consigns to man’s instinct for “the hopeful enlargements of its [the loadstone’s] allowed attraction.” Browne dismisses as nonsense a report of a young man who had swallowed a knife and who was cured when the knife was attracted to a convenient location by applying “a plaister made up with the powder of Loadstone” and then cut from his stomach.

All that Browne attests to in *Pseudodoxia* is not correct. Much of what he sets down in it is not original—he borrows extensively from Gilbert, Gassendi, Descartes, and others. The great merit in this work lies not in its originality of thought but in its demonstration that dogmatic assertions about phenomena will break down in the face of experience. And so, at the end of the 17th century, what little was known and could be quantified about magnets and magnetic phe-



Figure 13. Allegorical frontispiece of the *Traité de l'Aiman* by Joachim Dalencé. It shows a mariner holding a rudder in one hand and a compass in the other, about to board his ship. A goddess points with her left hand to a compass and with her right hand to the constellation Ursa Minor (the Little Bear), the brightest star of which is Polaris (the Pole, or North, Star). She holds in her left hand a sounding (depth) line. In front of the mariner’s ship floats a boat-shaped vessel containing a lodestone. On the left, a suspended lodestone supports a series of keys and weights, possibly a display of a lodestone’s strength. On the ground, next to the plinth, lies a series of mining tools (picks, shovels, etc), indicating the source of lodestones.

nomena could be summarized in the 33 overwrought plates that form the curious work *Traité de l'Aiman* (Amsterdam, 1687) (Fig 13) by Joachim Dalencé (ca 1640–1707). It is proof that in the nearly 100 years after the publication of Gilbert’s great book no advancement had been made in the study of magnetism. All that is known of Dalencé comes from archival material and correspondence. Besides the treatise on the magnet, he wrote two other important works: *La Reconnaissance des Temps, ou Calendrier et Ephemerides du Lever et de Coucher de la Lune et des Autres Planètes, avec les Eclipses pour l’Année* (Paris, 1679–1684) (a set of astronomical tables on the daily rising and setting times of the moon and planets [ephemeris tables]) and *Traitez des Barometres, Thermometres et Notiomètres ou Hygrometres* (Amsterdam, 1688) (a book on meteorologic instruments). In the latter work, he was the first to suggest the calibration of ther-

mometers on the basis of two points of change: one, the freezing point of water, and the other, unfortunately, the melting point of butter (he was probably from Normandy). The publication of *Traité de l'Aiman* was one more step in the transition of man’s perception of the world as a place controlled by philosophical principles to one governed by measurable, intangible, forces. The tangled skein of magnetism, electrostatics, medicine, chemistry, and the then infant science of physics was beginning to be unravelled into separate strands.

In the 18th century, a passionate interest in electricity and magnetism enveloped all of Europe’s peoples, especially the French and the Germans—fire in the form of sparks could be forced out of the human body. Man was surrounded by astonishing, invisible forces. Rubbed glass machines, which could produce a constant source of electrical charge, were invented (Fig 14). Contemporary demonstrations of the electrical/magnetic fluids in the body proceeded in this manner: An urchin was caught, suspended in mid-air by insulating cords, and then electrified by contact with a rubbed glass machine. Sparks would then be drawn from his nose and he would be made to attract small bits of paper and metal leaf (Fig 15). The first man to perform the electrified boy experiment was also the first to demonstrate the transmission of charge—the English electrician Stephen Gray (1666–1736). Born to a family of artisans, Gray, a shy and self-effacing man, followed in his father’s footsteps and became a dyer. His omnivorous interest in the sciences was fed by self-education. Indeed, he was not to devote himself completely to science until a bad back made him unable to practice his trade. Then, in 1711, he asked to be admitted as a “poor brethren” (pensioner) to Sutton’s Hospital (the London Charterhouse—an extant institution that provides schooling for boys who are “gentlemen by descent and in poverty” and a living for poor brethren who were preferably “soldiers that had borne arms by sea or land, merchants decayed by piracy or shipwreck, or servants in household to the King or Queen’s Majesty”). He was admitted in June 1719. There, he found a more than adequate number of urchins on which to experiment. He first tried the electrified boy experiment in his chamber on April 8, 1730, although he did not describe it in the *Philosophical Transactions of the Royal Society* until 1731. In Gray’s own

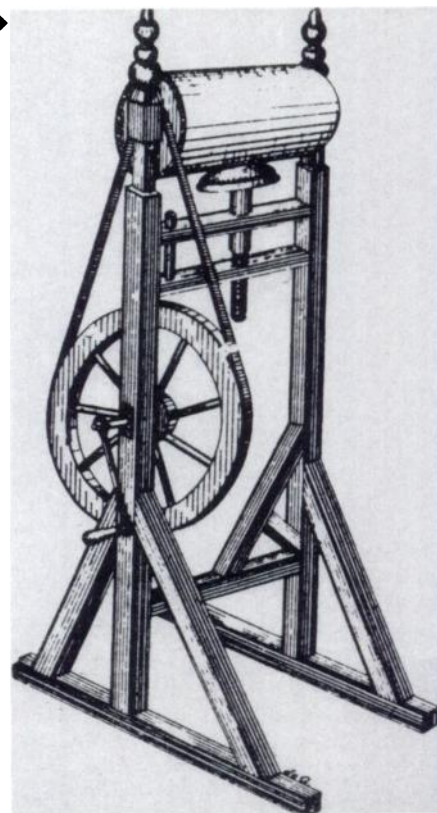
words, "a Boy between eight and nine Years of Age. His weight, with his Cloaths on, was forty-seven Pounds ten Ounces. I suspended him in a horizontal Position . . . Upon the [glass] Tube's being rubbed, and held near his Feet . . . the Leaf-Brass was attracted to the Boy's face with much Vigour . . ." On Gray's death, the writer and critic Samuel Johnson (1709–1784) co-wrote "Now, hoary Sage, pursue thy happy flight,/With swifter motion haste to purer light,/Where Bacon waits with Newton and with Boyle/To hail thy genius, and applaud thy toil,"

By 1743 showmen were traveling with their electrical machines to the English New World Colonies, giving people shocks for a small fee. In that year, Benjamin Franklin (1706–1790) (Fig 16) observed in Boston an electrified boy exhibition by the itinerant electrician (and practicing male midwife) Archibald Spencer (MD, ?–1760) of Edinburgh, Scotland, lecturer on natural philosophy. The man was a popular lecturer, who, Franklin wrote "was lately arrived from Scotland, and showed me some electrical experiments. These were imperfectly perform'd, as he was not very expert; but being on a subject quite new to me, they equally surpris'd and pleased me." Franklin was in the process of retiring from the printing trade. His business interests were yielding him an income of £1,000 a year—equal to the salary of the royal governor of the province of Pennsylvania. It is to be expected that this restless man would seek an outlet for his intellectual energies. Spencer's lecture, although flawed by Boston's humidity, roused Franklin's interest in electrical and magnetic phenomena. He acquired some simple equipment from Europe and began their study. In 1744, Spencer performed his lecture-demonstration in Philadelphia. At some time after that, Franklin bought Spencer's equipment, and his research began in earnest (Spencer took holy orders and spent the rest of his life as minister to All Hallows Parish, Anne Arundel County, Maryland). Within a few years he had teased out the basic principles of electrostatics (Fig 17). Much of present electrical terminology originates with Franklin: charge, discharge, condenser, electrical shock, electrician, positive, negative, plus, and minus. As a graphic expression to describe the shock produced by combining a number of Leyden jars (condensers or capacitors), he took over the military term "battery."

Figure 14. The electrostatic engine was invented in 1705 by Francis Hauksbee (1666–1713), demonstrator and curator of experiments for the Royal Society of London. He was investigating the blue glow given off by rubbed evacuated glass tubes. In reality, the tubes were only partially evacuated, and the phenomenon he was observing we now call ionization. To produce the glow, he mounted an evacuated glass globe on a spindle and rotated it with great speed while a woollen cloth was pressed against it by a strong brass spring. He discovered that this apparatus could produce a strong electric charge that could be transferred to other objects by means of a metal chain (wire) connected to fine metal points suspended just above the glass globe's surface. Such an instrument was used by Benjamin Franklin for his own scientific investigations. Hauksbee was an experimental genius but a scientific autodidact. He derived his theoretical principles from the president of the Royal Society, Isaac Newton. In turn, Newton relied on Hauksbee to test his conjectures. At his request, Hauksbee tried without much success to discover the law of magnetic attraction. Their collaboration, which continued until Hauksbee's death, enabled Newton to make extensions and revisions to his theories: "The power of gravity is of a different nature from the power of magnetism . . . The power of magnetism in one and the same body may be increased and diminished; and is sometimes far stronger, for the quantity of matter, than the power of gravity; and in receding from the magnet decreases not as the square but almost as the cube of the distance, as nearly as I could judge from some rude observations" (*Principia* III, 6—he almost got it right).

It is to Franklin that we owe one of the most (to this author) annoying concepts in physics. The kind of charge that accumulates on a glass rod that has been rubbed with silk he named "positive." That which accumulates on amber that has been rubbed with fur he named "negative." He defined the sense of current as positive charge moving from a positively charged battery electrode to a negatively charged electrode. We now know that when a glass rod is rubbed with silk some of the rod's mobile electrons (negative charge) are taken up by the silk, "charging" it positively, and that an amber rod rubbed with fur has some of the fur's mobile electrons transferred to it, "charging" it negatively. But the true nature of current is electron flow. Because of Franklin, current flows in the opposite sense to that of the particles that carry it.

Magnetism is not a research area in which Franklin distinguished himself. He tried to describe magnetism in terms of a magnetic fluid the properties of which were analogous to those of his electrical fluid (charge). Thus, according to him, all matter contains a



magnetic fluid that is uniformly distributed throughout it. When an object is magnetized the fluid condenses in one of its extremities. That extremity becomes positively magnetized while the donor region of the object becomes negatively magnetized. The degree to which an object can be magnetized depends on the force necessary to start the fluid moving within it. Whether it remains so is indicative of how easy it is for the magnetic fluid to flow on its own back to the negative magnetic pole. An electrical shock (current) passing through an object renders it a magnet because it puts the object's magnetic fluid in motion. At the same moment that solid connections were being established between electricity and magnetism—"[a tradesman in Wakefield] having put up a great number of knives and forks in a large box . . . in a large room . . . a sudden storm of thunder, lightening . . . the Box split . . . many knives and forks melted . . . emptying the box upon a Counter where some Nails lay . . . the knives, that lay upon the Nails . . . took up the Nails" (*Philosophical Transactions of the Royal Society for 1735*)—Franklin turns around and says "As to the magnetism, which seems produced by electricity, my real opinion is, that these two powers of nature have no



a.

affinity with each other, and that the apparent production of magnetism is purely accidental."

The variety of medical matters that Franklin took an interest in makes one gasp. Possibly inspired by reports of new therapies based on placing the ill in a tub of water containing an electric eel, he experimented with electric shocks as a cure for paralysis: "I sent the united shock . . . through the affected limb or limbs . . . the next morning the patients usually related . . . a prickling sensation . . . The limbs . . . seemed to receive strength . . . I do not remember that I ever saw any amendment after the fifth day . . . [the patients] became discouraged, went home, and in a short time relapsed." He appears to be the first man to outline (at least in writing) the concept of a craft-related disease: lead poisoning. When his sister contracted breast cancer, Franklin compiled a list of the then-known therapies for it. He made the observation that colds could be spread by contagion but not through *cold* itself. Considering the breadth of his endeavors, is it any wonder that he had to invent bifocals so that he could work with greater efficiency?

In one area of medicine Franklin truly erred, and this had tragic consequences for him. Cotton Mather (1663–1728)—author, Bostonian Congregational minister, and American Puritan—was to most of his contemporaries the embodiment of outdated ideology. To Franklin, he was an in-



b.

Figure 15. The electrified boy was a dramatic, and popular, demonstration of electrical fluids. In a, we see the electrician Abbé Jean-Antoine Nollet (1700–1770) performing it for the ladies of the French court in the mid-1740s. He holds a rubbed glass tube over the boy's head, which induces in the boy a distribution of charge. A woman raises her finger to the boy's nose and draws a spark from it. The boy's hands attract bits of paper from the small table in front of him. Nollet made his living from the construction and sale of scientific apparatus, and his "cour de physique" was a set of carefully orchestrated science demonstrations performed for wealthy and enthusiastic auditors. His most illustrious audience was the king of France, Louis XV (1710–1774), and the dauphin and dauphine of France, the future Louis XVI and Marie Antoinette. It is said that to demonstrate to them the transmission of static charge (he was the dauphin's preceptor), he made a line of several hundred Cistercian monks hold hands. Then, the last monk in the line was handed a metal pole driven into the ground, while the first touched a charged electrostatic machine. All of the monks leaped simultaneously into the air. The king was most amused. Nollet disagreed strongly with Franklin's theories on the nature of electricity. Although wrong in his challenge, through the prodding of his objections electrostatic theory was refined. This illustration comes from Nollet's treatise on his electrical experiments, *Essai sur l'électricité des corps* (Paris, 1746). (b) An illustration from the book of the German astronomer and mathematician Johann Gabriel Doppelmayr (1671–1750), *Neu-entdeckte Phaenomena* (Neuremberg, 1744), which shows his version of the electrified boy demonstration. This book was instrumental in creating the popular interest in electrical phenomena that spread throughout Germany in the mid-1740s. The son of a merchant who made a hobby of physics, Doppelmayr devoted his life to lecturing (he was a professor of mathematics), writing, astronomical and meteorological observation, and physical experimentation. He died of a severe electrical shock that he received while experimenting with the just-invented condenser (capacitor).

fluential figure, as Mather, the first man from the New World Colonies to be elected a member of the Royal Society of London (1713), was one of the best-informed men in the colonies. Franklin attributed his own penchant for practical schemes to notions derived from Mather's essays. Whatever energies Mather could spare from producing those writings—over 450

separate works of scriptural explanation, scientific education (he once considered a career in medicine), and political morality—he used to lead a campaign that he began in 1721 for inoculation against smallpox. Popular sentiment was so high against this procedure that on one occasion a (dud) grenade was thrown into Mather's house (the note attached read "Cotton Mather, you Dog; Dam you; I'll enoculate you with this, with a pox on you"). Franklin joined the popular attack on Mather, lampooning him in his brother's paper *The New England Courant*. Mather's father, Increase Mather, expressed his family's opinion of Franklin's writing: "I cannot but pity poor Franklin, who, tho' but a young Man it may be speedily he must appear before the Judgement Seat of God, and what answer will he give for printing things so vile and abominable?" In 1736, one of Franklin's sons—his beloved Francis—died of smallpox at the age of 4 because he had not been inoculated. Franklin would later sorrowfully acknowledge his youthful folly: "I long regretted bitterly, and still regret that I had not given it to him by inoculation. This I mention for the sake of parents who omit that operation, on the supposition that they should never forgive themselves if a child died under it; my example showing that the regret may be the same either way, and that, therefore, the safer should be chosen."

His medical interests gave Franklin an entrée to some of his most devoted paladins: the learned physicians of his day. They were to serve Franklin well during his life. One notorious incident comes to mind. The standard defense in his time against lightning was the ringing of bells. Now, the incineration of bellringers by lightning was a much-noted phenomenon. Franklin advocated replacing bellringers by spiked, or pointed, lightning rods (an invention of his) placed on building towers. English savants favored knobbed, or blunt, ones. At the time of this disagreement the disobedient New World Colonies, which Franklin represented, were in full revolution, and the shape of lightning rods became a matter of politics. In 1778, King George III of England (1738–1820) instructed the president of the Royal Society, the eminent military doctor John Pringle (1707–1782)—coiner of the words "septic" and "antiseptic"—that henceforth lightning rods would end in knobs. Pringle, a good friend of Franklin, replied that "the prerogatives of the

President of the Royal Society do not extend to altering the laws of nature," and forthwith resigned (or so goes the tale, which may have been concocted by the French).

Franklin's involvement in medical research and his investigations of magnetism can be portrayed as paving the way for one of the great bloodbaths of history—the French Revolution. Franz Anton Mesmer (Fig 18) was born in 1734 in Germany. In his early life he was an uninspired, but diligent, student. He studied medicine in Vienna and received his doctorate of medicine from the University of Vienna in 1766. His thesis, *De Planetarium Influx*, extends to paracelsian medicine the gravitational theory of Isaac Newton! For the next 8 years, Mesmer practiced medicine in Vienna, spending his spare time experimenting in physics and practicing on the glass harmonica (a musical instrument perfected by Franklin). He was known for his modesty, lack of ambition, and kindness. A recipient of that beneficence was the young Wolfgang Amadeus Mozart (1756–1791). At the age of 12, Mozart was commissioned by Emperor Joseph II of Austria (1741–1790) to write an opera. The court intrigues of the time sabotaged this commission. To make amends, Mesmer ordered from Mozart an opera for himself. This work, *Bastien et Bastienne*—Mozart's first opera—made its debut in September of 1768 in Mesmer's private theater. Mozart later repaid Mesmer's generosity by mocking him in the opera *Così fan Tutte*.

In 1774, Mesmer made the acquaintance of Father Maximilian Höll (1720–1792), Jesuit priest, professor of astronomy at the University of Vienna, and court astrologer to the mother of both Joseph II and Queen Marie Antoinette of France, the Empress Maria Theresa of Austria (1717–1780). Father Höll was affecting medical cures with artificial lodestones—pieces of iron that had been strongly magnetized through a process developed during the period 1743–1751 (Fig 19). Mesmer obtained a supply of these magnets from Father Höll and began to apply them to his patients (many of whom had numerous symptoms that today would be recognized as having hysterical or psychosomatic origins) to assist the flow of the universal "fluidum" from the atmosphere to their bodies. Mesmer knew from Paracelsian teachings that this fluidum (a form of magnetic flux from the stars) had curative powers. The cures he achieved were astounding. However, since the true agency for

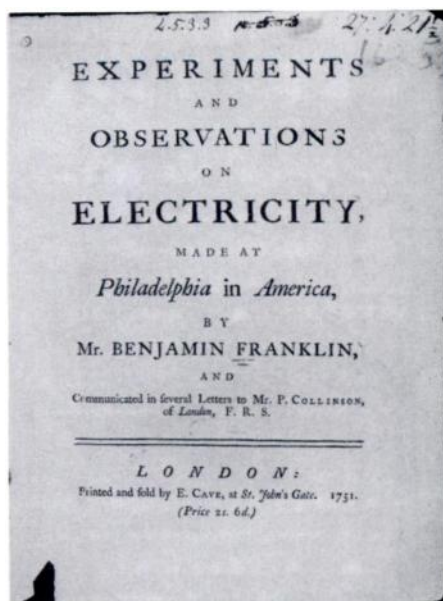


Figure 16. Benjamin Franklin, the intellectual "beau ideal" of his time, achieved world renown at age 45 with his experiments on electrical phenomena. A brilliant scientist and experimentalist, Franklin was thought by his contemporaries to be the "Father of Electricity" (many people now do also). (a) This portrait of Franklin at age 40 by Roger Fexe (1724–1769) explains his fame as a courtier and lady's man. At age 26, however, he created one of the great comic literary creations—Richard Saunders, a bumbling old savant, poor, saddled with a shrewish wife, given to making pious observations and to ogling pretty girls—and gave him a home in *Poor Richard's Almanac* (Philadelphia, 1732). Succeeding generations have confused Franklin with his creation. (b) Popular images of Franklin, such as this mezzotint by Edward Fisher (1730–1785) after an oil painting executed by Mason Chamberlin (?–1787) in 1762, do not help prevent this. The pair of bells on Franklin's right were installed in his study. One was grounded and the other connected to a form of lightning rod, and they would ring during a lightning discharge.

these cures was the power of suggestion, Mesmer soon found that he could obtain cures with such non-magnetic stuffs as paper, wool, silk, stone, and even animals and human beings. He therefore reasoned that he was not dealing with ordinary "mineral" magnetism, but with a special kind that he named "animal" magnetism. Disease resulted from an "obstacle" to the natural flow in the body of the fluidum channeled from the stars to the body by the body's own "animal" magnetism. Ill people could overcome this "obstacle" by "mesmerizing" their body's magnetic poles to induce a "crisis" (often in the form of convulsions) and so restore their health or "harmony." In a single short year, mesmerism and mesmeric cures became the rage of Vienna. Needless to say, the medical faculty of the University of Vienna was skeptical of Mesmer's theory. They were also alarmed by his increasing fame and the royal favor he was beginning to achieve. This was to be his undoing.

In January 1777, Mesmer undertook the cure of Maria Theresia von Paradies (1759–1824)—a child piano virtuoso and protégée of Empress

Maria Theresa. Maria had been blind since the age of 3. It is certain from the records of the time that her blindness was due entirely to hysteria. Mesmer's treatments restored Maria's sight but induced another hysterical symptom: She lost her equilibrium. Mesmerizing therapy for this condition replaced it with depression. The treatments and counter-treatments went on and on, and what was worse, Maria began to lose her musical talents. Maria's parents, envisioning a future devoid of the income provided to them by the empress and fearful of her displeasure when she learned of their child's newfound unremarkable normalcy, demanded at a melodramatic meeting that Mesmer stop tampering with their daughter's health. The girl's reaction to this meeting was spectacular. She fell to the floor writhing in convulsions and promptly became totally blind (again). As a result, an official committee of investigation was set up to evaluate the efficacy of Mesmer's magnetic cures. On May 2, 1777, Mesmer was ordered to "make an end of this fraudulent practice," was expelled from the fraternity of medicine of the city of Vienna, and was ordered to leave the city.



a.

Figure 17. (a) Franklin's book *Experiments and Observations on Electricity, made at Philadelphia in America* (London, 1751) is one of the most widely read and discussed books ever written on a scientific subject. The influence of his writings on the affairs of the world extended beyond such mundane matters as government, medicine, and science—to the rarified regions of couture. (b) His invention of the lightning rod engendered the most daring fashion ever: lightning rod hats. Ladies were able to promenade about Paris safe in the knowledge that the long conducting wires that trailed behind them to the ground would keep their heads free of excess electrical "fluidum."



b.



Figure 18. Franz Anton Mesmer (1734–1815). The public's opinion of the man took two extreme forms: "Mille jaloux esprits en vain l'ont voulu nuire,/Mesmer, par tes soins généreux,/Nos maux ont disparus, l'humanité respire./A thousand jealous spirits have vainly tried to harm you./Mesmer; by your generous care./Our ills have disappeared, humanity breathes" and "Vieilles, jeunes, laides, belles,/Toutes aiment le docteur,/Et toutes lui sont fidèles./Young or old, plain or bold,/All women love the doctor,/And they onto him, all cling and hold."

The Paris that Mesmer entered in 1781 was fertile ground for his theories. Sir Isaac Newton's (1642–1727) gravity, Voltaire's (1694–1778) discourses on Newton's theories, Franklin's electricity, the De Montgolfière brothers' (Étienne Jacques [1745–1799] and Michel Joseph [1740–1810]) mysterious gas and the "expérience aerostatique" that it produced (the first hot-air balloon flight occurred on June 15, 1783)—these, not revolution, were to be the topics of discussion in the salons of Paris for the next few years. Indeed, Maximilien Robespierre's (1758–1794) first public statements were in defense of lightning rods (*pointed* ones). The popular enthusiasm for science was so strong that the wall between science and pseudoscience began to crumble into the chasm of occultism, where mesmerism would dwell.

Mesmer set up a medical practice in Paris. His rise to fame and notoriety and the backlash of his success retrace the paths they followed in Vienna. Mesmer left Paris late in 1781 to "recuperate from the wounds that had been inflicted on him by officialdom" while his followers remained behind to organize a popular front. A lawyer, Nicolas Bergasse (1750–1832), oversaw the establishment of "magnetic clubs" throughout all of France—allegedly, for the purpose of disseminating Mes-

mer's teachings. The Paris branch, the Society of Harmony, was the most prestigious and exclusive. The Marquis de La Fayette (1757–1834) signed his membership contract to it on April 5, 1784 (initiation fee, 100 louis d'or—about 50,000 U. S. 1991 dollars!). Shortly afterward, he traveled to the New World Colonies to visit George Washington (1732–1799). He carried a letter from Mesmer to Washington; thus began a correspondence between these two men. Washington's perceptions on mesmerism combine enthusiasm with a healthy skepticism. To Mesmer he wrote that "the discovery of [magnetism] . . . if it should prove as extensively beneficial as it is said, must be fortunate indeed for mankind, and rebound very highly to the genius to whom it owes its birth."

As time went on, the distinction between a follower of mesmerism and an opponent of the status quo (by definition, then, a political revolutionary) became blurred. Under Bergasse's direction, mesmerism became a camouflaged political theory, and the "magnetic clubs," revolutionary cells. That this was his intention all along can be surmised from this statement that he made at one of the Society of Harmony's, by then, closed meetings: "The time has now come, for the revolution that France needs. But to attempt to produce one openly

is to doom it to failure. To succeed it is necessary to wrap oneself in mystery. It is necessary to unite men under the pretext of experiment in physics, but, in reality, for the overthrow of despotism."

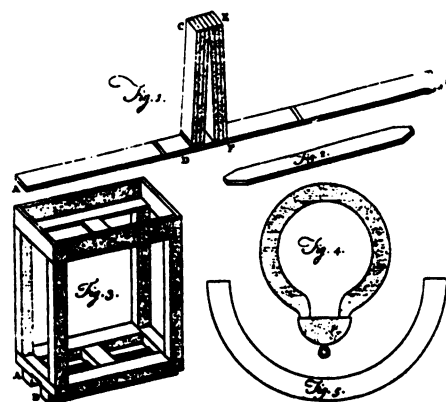
By the time Mesmer had reestablished himself in Paris in 1785 (partly at Marie Antoinette's request), he had lost all control over his theories. His medical practice degenerated into the extravagant, ludicrous, cultic displays and rituals that we now associate with him. Dozens of mesmerists claimed that they alone held the "true secrets" of mesmerism. A royal commission to investigate mesmerism was created by King Louis XVI of France (1754–1793) on March 12, 1784. It was composed of nine members: Four came from the medical faculty of the University of Paris (including Doctor Guillotin [1738–1814], inventor of a "humane" method for execution—the guillotine), and five came from l'Académie des Sciences (including Antoine Lavoisier [1743–1794] and the ambassador from the newly founded United States of America, Benjamin Franklin). The commission met at Franklin's house in Passy, on the outskirts of Paris. On August 11, 1784, its work was completed, and a report was drawn up by Franklin. It was sent

to the king in the form of the *Rapport des Commissaires Chargés par le Roi de l'Examen du Magnétisme Animal* (Fig 20). Mesmer's theories were declared fraudulent.

The French Revolution came in 1789. Robespierre's retaliation for the rejection of his application to membership to l'Académie des Sciences (for lack of scientific credentials—he was, after all, a mesmerist) was to introduce as many of its members as he could to “Madame la Guillotine” (especially those, among them Lavoisier, who had been on his credentials committee). Mesmer left France in 1789, wandered throughout Europe, lived out the final years of his life a few miles from his birthplace, and died in 1815. The last years of Father Höll, Mesmer's first instructor on the properties of magnets, were also troubled. The Jesuit order was abolished (again) in 1773, signaling a campaign of public defamation of the Jesuits. Doubts about Höll's astronomical observations and scientific credibility were raised. These accusations pursued and hurt him through the last 20 years of his life. His scientific reputation was not rehabilitated until almost a century after his death. In this, he is more fortunate than Mesmer.

The credit for discovering the true nature of electromagnetism goes to Hans Christian Oersted (1777–1851), a professor of physics at the University of Copenhagen. The (possibly apocryphal) moment occurred there in the winter of 1820 during a lecture demonstration, when he noticed that a compass needle was deflected when a current flowed through a nearby wire. He carried out some experiments and found to his astonishment that not only did a current-carrying wire exert a force on a magnet, but a magnet also exerted a force on a coil of wire carrying an electric current. The coil acted like a magnet, behaving as if it possessed magnetic north and south poles. Magnetism and electricity were somehow connected. Oersted published his results on July 21, 1820, in a four-page article written in Latin. Such was Oersted's fame after this article appeared that to avoid confusion (?) the illustrious Danish storyteller Hans Christian Andersen (1805–1875) began to refer to Oersted as the “Great Hans Christian” and to himself as the “Little Hans Christian.”

The pace of scientific research on magnetism skyrocketed. Within a few years the properties of electromagnetism were worked out by André Marie Ampère (1775–1836), Jean-Baptiste Biot (1774–1862), and Félix Savart



b.

Figure 19. It is not clear who was the first to produce a strong artificial magnet. Three Englishmen can stake a claim to this achievement: the physician Gowin Knight (1713–1772), the schoolmaster and amateur physicist John Canton (1718–1772), and the astronomer John Michell (1724–1793). Dr Knight's claim is based on precedence. Accounts of his bar magnets made of laminated steel and their superiority over the then available natural and artificial magnets first appear in the *Philosophical Transactions of the Royal Society* in 1744. Unfortunately, Dr Knight never revealed his magnet-making process. His rival was Canton, a good friend of Franklin. Canton's fields of research were magnets and meteorology. He hoped to profit from the manufacture and sale of artificial magnets. Accounts of his magnets begin to appear in 1747, but he delayed publishing his technique in the *Philosophical Transactions of the Royal Society* until 1751. Canton was to rue his reticence, for the first published description of the manufacture of artificial magnets is a book written by Michell in 1750: *A Treatise of Artificial Magnets* (Cambridge, 1750) (a). The similarity between Michell's technique and Canton's led the latter to cry foul, but his accusations came to naught. One achievement is Michell's alone: He introduced the term “Horse Shoe” magnet (b, magnet labeled Fig 4). Patients undergoing mesmeric treatments would have such magnets placed about their neck or they would be given bar magnets to hold (b, magnet labeled Fig 2). Perhaps we should let the last word on the topic of magnet design be Franklin's: “Dr. Knight, inventor of steel magnets, has wrote largely on that subject; but I have not yet had leisure to pursue his writings with the attention necessary to become master of his doctrine.”

(1791–1841). The classical edifice of electromagnetism was capped in 1865 by James Clerk Maxwell (1831–1879) with the publication of his electromagnetic wave theory of light.

The first “magnetic image” was created in 1838 by Dr John Elliotson (1791–1868) (Fig 21), professor of the theory and practice of medicine at London University, president of the Royal Medical and Chirurgical Society, founding member of the University Hospital, and disciple of Mesmer. Elliotson was one of the first doctors

A T R E A T I S E O F *Artificial Magnets;*

In which is shown
An easy and expeditious METHOD
of making them,
Superior to the best *Natural Ones*:

AND ALSO,
A Way of improving the *Natural Ones*,
and of changing or converting their POLES.

Directions are likewise given
For making the *Mariner's Needles* in the best Form,
and for touching them most advantageously, &c.

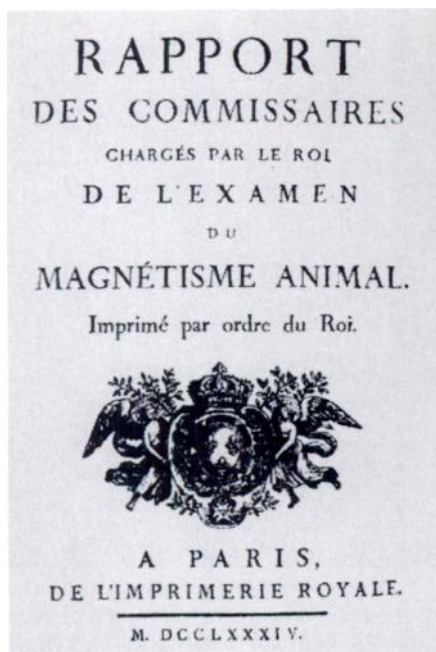
By J. MICHELL, B.A.
Fellow of *Queen's College, Cambridge*.

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— M D C C L — (P r i n t e d)

a.

to use a stethoscope and to practice percussion and auscultation. His book *Human Physiology* was for many years the standard university text. Elliotson became interested in magnetism sometime in 1829. By 1837 he was performing at the University College Hospital “painless” surgery on patients anesthetized (hypnotized) with “magnetic sleep.” His most famous medical case occurred in 1838 and involved two hysterics, the sisters Elizabeth and Jane Okey. Not only did magnetic treatments cure them, but they also gave them “clear [clair] sight [voyant]” or clairvoyance—the ability to visualize their internal organs and those of others. Elliotson had the sisters accompany him on his medical rounds. Through magnets, he would place them in a trance-like state. They then evaluated the state of the organs of his patients, and he would prescribe appropriate treatments for their ailments. This early imaging technique and the idiosyncratic behavior of Elizabeth Okey brought him into conflict with his colleagues. Elizabeth had a habit of approaching certain patients, giving a convulsive shudder, and screaming, “Great Jacky [the angel of death] is sitting on the bedclothes!” It was believed that the precipitous end of some dying patients was provoked by her oracular zeal. The University Hos-



a.

pital passed the following resolution in 1838: "That the Hospital Committee be instructed to take such steps as they shall deem most advisable to prevent the practice of mesmerism within the hospital." Elliotson abandoned his medical practice and devoted his life to the publication of *The Zoist, A Journal of Cerebral Physiology [phrenology] and Mesmerism and their Applications to Human Welfare* (1843–1856). His use of magnetism as a diagnostic tool was not to be vindicated for 150 years.

At the birth of the 20th century came both Wilhelm Konrad Röntgen's (1845–1923) discovery of x rays (1895) and the quantum theory. That magnetic fields affected atomic phenomena was immediately observed by the Dutch physicist Pieter Zeeman (1865–1943). He demonstrated that the optical spectrum of the sodium atom could be affected by placing the atom in a strong magnetic field (1) (the Zeeman effect). To the scientists of that time, this implied that atoms possessed a magnetic field. It became essential that the quantum theory be able to describe the behavior of an atomic nucleus immersed in a strong magnetic field. Once the theory was formulated it was necessary to confirm it through experiment. The existence of the intrinsic magnetic moment (field) of the atom was demonstrated (2) by Otto Stern (1888–1969) and Walter Gerlach (1889–1979) in 1924. Subsequent research (3–5) by Isidor Rabi (1898–1988) and his colleagues led to the first direct measure-



b.

Figure 20. (a) The report to King Louis XVI of France from the commission he established to examine mesmerism caused quite a sensation. It provided much material for the public imagination and for doggerels. (b) This print from that time, entitled *Le Magnétisme Dévoilé (Magnetism Unveiled)*, shows Franklin leading the commission members in an attack on mesmerists. He holds aloft the commission's report. The mesmerists flee (literally, fly) from its glow of truth. They leave behind their gullible patients and a smashed mesmeric tub, emptied of its magnetic fluid. The following is the punchline of one of the most widely reproduced epigrams of the time: "Si quelqu'un esprit original/Persiste encore dans son délire,/Il sera permis de lui dire:/Crois au magnétisme . . . animal!/Of any mind so fanatical/That it persists in this delusion,/One must say as a conclusion:/Believes in magnetism . . . animal!" Franklin was not opposed to cures based on patient psychology. In 1784, he wrote "my Sentiments concerning the Cures perform'd . . . Mesmer . . . I cannot but fear that the Expectation of great Advantage from the new Method of treating Diseases, will prove a Delusion. That Delusion may however in some cases be of use while it lasts. There are in every great City a Number of Persons who are never in health, because they are fond of Medicines and always taking them, whereby they derange the natural Functions, and hurt their Constitutions. If these people can be persuaded to forbear their Drugs in Expectation of being cured by only the Physician's Finger or an Iron Rod pointing at them, they may possibly find good Effects tho' they mistake the Cause."

ment of nuclear magnetic resonance (NMR) (a term coined by Rabi) in atomic and molecular beams in 1938. The Nobel Prize for physics was awarded to Stern in 1943 and to Rabi in 1944 for work on atomic and nuclear magnetic phenomena.

NMR has been the subject of intense research since 1936. A pioneer in this field was the physicist Cornelis Gorter (b 1907), who published several articles (6–10) on his unsuccessful attempts to detect the phenomenon (it was his bad luck to use a difficult experimental technique and an inappropriate sample in his studies). NMR in a solid was first reported in 1946 by

two research teams: One comprised Felix Bloch (1905–1983) (Fig 22a), Wilford Hansen (b 1928), and Martin Packard (b 1921) (11–14); the other, Edward Purcell (b 1912) (Fig 22b), Henry Torrey (b 1911), and Robert Pound (b 1919) (15). These two teams worked independently on this phenomenon, unaware of the other's research, at universities on opposite coasts of the United States (respectively, Stanford and Harvard). For their NMR work, Bloch and Purcell were jointly awarded the Nobel prize for physics in 1952.

It is interesting that Bloch and Purcell perceived NMR in very different ways. To describe how so, we will give a short exposition of NMR. When a group of atoms whose nuclei possess a magnetic moment is placed in a strong static magnetic field, their nuclei can be conceived of as magnetic dipoles precessing about this field at a frequency f , which is defined by the multiple of a constant that is unique to those atoms (their gyromagnetic ratio, γ) and the magnitude of the field (call it B). This results in the Larmor equation— $f = \gamma B/2\pi$ —named for the Irish physicist Joseph Larmor (1857–1942), who introduced the equation in 1896 in connection with a classical analysis of the Zeeman effect (16,17). If these dipoles are simultaneously irradiated by an electromagnetic radio-frequency (RF) field of a frequency matching—in resonance—that of their precession, they will interact with that field. Physically, this means that the nuclei will absorb energy from the RF field and change their nuclear state. This change can be experimentally detected in either of one of two ways: first, by fixing the RF frequency and monitoring the amount of power the atoms absorb from it as a function of the strength of the static field in which they are immersed (ie, their precession frequency), and second, by fixing the strength of the static field (the nuclei's precession frequency) and monitoring with an antenna the strength of the interaction of the magnetic dipoles with the RF field as a function of the frequency of the RF field. The former experiment can be described in terms of quantum physics as the resonance absorption of energy—Purcell's experiment, done on paraffin. The latter experiment can be described in terms of the precession of a magnetic dipole and the induction of an electromotive force or voltage in a detection coil (antenna)—Bloch's experiment, done on water. At the time that these two men almost simultaneously reported



Figure 21. Dr John Elliotson. A brilliant clinician and, by all accounts, one of the ablest physicians in London. Among his friends were Charles Dickens (1812–1870) and William Makepeace Thackeray (1811–1863). The latter dedicated his work *Pendennis* to Elliotson:

To Dr John Elliotson

My Dear Doctor,

Thirteen months ago when it seemed likely that this story had come to a close a kind friend brought you to my bedside, whence in all probability I should never have risen but for your constant watchfulness and skill. I like to recall your great goodness and kindness (as well as many acts of others, showing quite a surprising friendship and sympathy) at that time, when kindness and friendship were most needed and welcome.

And as you would take no other fee but thanks, let me record here in behalf of me and mine, and subscribe myself

Yours, most sincerely and gratefully,
W.M. Thackeray

their experiments it was not apparent to them, or to anyone else, that they were presenting the same effect. This realization came only when the two research groups met in the summer of 1946. The terminology of the two experiments had fused over time; thus, we speak about both nuclear magnetic resonance and free induction decay.

NMR developed quickly as a scientific discipline. Bloch introduced the concepts of a "thermal" or "longitudinal" relaxation time (T_1) and a "transversal" relaxation time (T_2) in a seminal article (12) he wrote in 1946. In that same article he derived the "Bloch equations," which are still the basis of all analyses of NMR experiments. He also provided the rationale for the use in NMR of those substances that are called contrast agents in magnetic resonance imaging: "...



a.



b.

Figure 22. (a) Felix Bloch and (b) Edward Purcell, corecipients of the Nobel Prize for physics in 1952 for their independent discovery of NMR. This history would be different except for an accident. Bloch has said that his group's first attempts to see the NMR signal were in vain because of his miscalibration of the electromagnet they were using. It was while they were turning off the magnet (14) to make some adjustments that they first saw the NMR signal "drifting across the oscilloscope screen." (Reprinted with permission of the AIP Meggers Gallery of Nobel Laureates.)

such long relaxation times can be inconvenient for the observation of the induction effect. It is recommendable, in this case, to add to the substance a certain percentage of paramagnetic atoms or molecules. They will essentially act as catalysts ... greatly shortening the relaxation time ... even if they are present in a small percentage and do not otherwise affect the nuclei under consideration." Six weeks after Purcell first detected NMR, a new graduate assistant began work at his laboratory: Nicolaas Bloembergen (b 1920), a Dutch physicist displaced by the devastation of the European research laboratories caused by World War II. Two years after Bloembergen's arrival, he, Purcell, and Pound published a theory of nuclear magnetic relaxation (18). So widespread has been its application that, over time, the theory and its expository article have taken as their name the initials of their three authors: BPP. Bloembergen was one of the recipients of the 1981 Nobel prize in physics "for his contribution to the development of laser spectroscopy."

The need to sustain the NMR signal over extended periods of time for the measurement of NMR phenomena spurred Erwin Hahn (19) (b 1921) to the development of the spin echo in 1950. This technique was subsequently improved in 1954 by Herman Carr (b 1924) and Edward Purcell (20). The variation on their work, which

was done by Saul Meiboom (b 1916) and David Gill (21) in 1958 would one day produce one of the standard imaging pulse sequences—what we now call the Carr-Purcell-Meiboom-Gill spin-echo pulse sequence. The introduction in 1966 by Richard Ernst (b 1933) and Weston Anderson (22) (b 1928) of Fourier transform techniques to the analysis of magnetic resonance phenomena marks the moment when the technical and analytic armamentarium necessary for nuclear magnetic resonance imaging became complete. Fourier transform NMR was employed in the study of molecular dynamics by Robert Vold (23) (b 1942) in 1968 and by Raymond Freeman (24–26) (b 1924) in 1969. The application to magnetic resonance imaging of their experimental technique would yield the second standard imaging pulse sequence, the inversion-recovery pulse sequence.

The NMR techniques that led inexorably to imaging research were applied to biologic systems as quickly as they were ushered in. Thomas Shaw et al (27–32) used NMR to monitor the water content of foods as early as 1951. Complementary work on biologic samples was done concurrently by Erik Odeblad (33–45) at the Karolinska Institute in Sweden. For 30 years, this tenacious investigator produced about 20 articles on his inquiries into the NMR properties of every conceivable human tissue, fluid, and secretion,



Figure 23. Paul Lauterbur. The technique that he formulated to produce an NMR image couples, within the body, magnetic field gradients and RF fields; therefore, he decided to name it *zeugmatography*, from the Greek word *ζεύγμα* (*zeugma*), meaning "the result of joining together." The technique has flourished—the name has not. (Photograph courtesy of Dr Lauterbur.)

including blood serum (34), cervical mucus (35), human milk (36), vitreous fluid (37), eye tissue (37), vaginal cells (38), uterine glandular secretions (39), and sputum (44). In 1959, Jerome Singer (46,47) (b 1921) created a method for the measurement of blood flow rates, which he named "spin tagging." It was used in 1970 by him and Oliver Morse (48) to quantitate the blood flow in the arm of a child (Singer's daughter). It is the basis of several magnetic resonance imaging techniques now under development for angiographic and pseudo-Doppler imaging.

While Shaw, Odeblad, their collaborators, and other researchers were employing NMR to quantitate the water content and the NMR "signatures" (T1 and T2) of tissues, another group of scientists pressed NMR to the analysis of the physico-chemical characteristics, behavior, and dynamics of water in living systems. One of the earliest reports demonstrating that NMR could be used to study the structure of water in living microorganisms was written in 1964 by the Mexican scientist Jorge Cerbón (b 1930) (49). His investigation of the water NMR signal from suspensions of microorganisms suggested to him "that the water spectrum in microorganisms appears similar to those in

inorganic gels that have an oriented structure of water with mobility limited by adsorption processes"—possibly the first allusion in the NMR literature to the theory of "free" and "bound" water in living cells, the perceived source of contrast in magnetic resonance images. Subsequent research in that same year by Cerbón enabled him to observe the lipid NMR signal in microorganisms and that ionic concentration affects the behavior of the lipid phase (50). Ionic complexing in muscle tissue soon became a separate line of NMR research (51–54).

NMR evidence for the existence of "ordered water" in living cells was the research goal for many scientists (55–66) during 1965–1971. It emerged from the NMR spectra of water in systems as varied as relaxed and contracted frog skeletal muscle (55), partially dried yeast cells (57), decomposing fish muscle (58), oriented (with respect to the NMR spectrometer magnetic field) rabbit sciatic nerve (59), and rat skeletal muscle (63). It was only a matter of time before someone would try to see what, if any, differences appeared in the NMR "signature" of a tissue as a consequence of disease—and there hangs the tale of the origin of magnetic resonance imaging.

In 1971, Raymond Damadian (b 1936) reported (67) that NMR could be used to discriminate between malignant tumors and normal tissue. Efforts to reproduce this work were quickly set in motion (68–71). In September 1971, Paul Lauterbur (b 1928) (Fig 23) watched Leon Saryan as he compiled the NMR spectra of different rat tissues (71,72). In Lauterbur's own words (73), "although there were clear differences . . . there seemed no plausible reason for the differences . . . even normal tissues differed markedly among themselves in NMR relaxation times, and I wondered whether there might be some way to noninvasively map out such quantities within the body. The principle upon which a technique might be based, the encoding of spatial coordinates by known magnetic field shapes, occurred to me the same evening. Over the next several days, a general method . . . to generate a true image . . . became clear." The terse paper that he sent to *Nature* describing his methods was rejected because "it was not of sufficiently wide significance for inclusion in *Nature*" (a statement to be pondered when one considers that *Nature* rejected the first paper describing the Krebs cycle). By writing a lengthy rejoinder to this judg-

ment and rewriting his manuscript in a more exuberant style, he produced the result that he desired—the paper (74) was accepted by *Nature* and published in its March 16, 1973, issue.

The field of NMR was prepared to incarnate Lauterbur's idea. Programs to enlarge and refine NMR spectrometers for biologic research had been in existence for some time. It had been demonstrated in 1966 that it was possible to simultaneously monitor in vitro the electric activity and the NMR spectrum of a beating turtle heart (75)—an amazing feat for its time. In 1967 Thomas Lingon (b 1941) constructed an NMR spectrometer large enough to surround a human arm (76). One that could contain an anesthetized rat (77) was built by Jasper Jackson (b 1926) in 1968. Irwin Weisman did his 1972 tumor research (70) on rat tails in vivo. Thus, Lauterbur was able to publish his first image—a cross-sectional image of two vials of water—in 1973. Within a year of the appearance of that image, four methods of NMR imaging had been demonstrated by four geographically disparate groups (78–81); the race to produce the first NMR image of a human had begun. But *that* is another story. ■

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