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# Rendering Magnetism Visible: Diagrams and Experiments Between 1300 and 1700

▼ **ARTICLE**

▼ **ABSTRACT** Human beings can neither see nor feel magnetism, although its effects can be made manifest to sense experience through experiments. Since antiquity, philosophers have therefore often viewed magnetism as an "occult" force, for whose manifest effects a hidden cause had to be sought. Around 1300, scholars began to address the seemingly occult nature of magnetism not only through experimental investigation but also visually, attempting to represent experimental results in diagrams. Historical research on diagrams has been fairly negligent about the relation between diagrams and scientific practices, including experiments. This paper will try to redress the balance, by focusing on diagrams in manuscripts and printed texts between 1300 and 1700 that were produced in response to magnetic experiments. It will be argued that naturalistic and geometrizing forms of representation were combined in order to render experiments with magnetism understandable, replicable, and meaningful. This resulted in a visual style of diagram that oscillated between the abstract representation of invisible entities or powers and the concrete and performative depiction of actual objects or operations.

▼ **KEYWORDS** Visual Culture, Experiments, Magnetism, Diagrams, Abstraction, Early Modern Period, Middle Ages

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As modern biologists have discovered, "some birds can sense the Earth's magnetic field and orientate themselves with the ease of a compass needle. … Thanks to special molecules in their retinas, birds like the European robin can even literally *see* magnetic

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fields."[1] Humans, however, have no sense that detects magnetism, and thus to them magnetism remains an invisible power. However, the effects of magnetism can be felt through the push and pull of two magnets, and scholars were able to visualize magnetic effects through instruments and experiments.

The phenomenon of magnetism has been known since antiquity. It was experimentally investigated more thoroughly in the Middle Ages and was controversially discussed among philosophers with more rigor in the early modern period.[2] Magnetism's invisibility, as will be argued, required and fostered an experimental approach.[3] Scholars of the past coped with the epistemological condition of being unable to detect magnetism (or "magnetic force") by sense experience through the use of different concepts, media, and theories. These concepts, media, and theories have their own unique historical dimensions and conditions, which are explored in this article. This case study aims to add to the ongoing discussion on "visualization" and diagrams in science.

In 1544, the sundial-maker Georg Hartmann wrote in a letter to Duke Albert of Prussia: "This virtue [*Tugend*] [of the magnet] I would right gladly explain to your Grace, as can be done by writing alone, for such things are more easily shown by manual demonstration than by writing."[4] Hartmann realized that it was difficult to describe magnetic powers by words alone and instead wanted to be able to point to them by hand in experimental demonstrations. Robert Norman, an instrument maker like Hartmann, wrote in 1580 about the magnetic power (*vertue*) extending from a magnet:

> I am of opinion that if this vertue [of the magnet] could by anie means be made visible to the eie of man, it would be found in a sphericall forme, extending round about the stone in great compasse and the dead bodie of the stone in the middle thereof .... And this I have partly proved and made visible to be seene in some manner.[5]

Norman explicitly linked his experiments to the goal of rendering the magnetic "vertue" visible.[6] But neither Hartmann nor Norman used images as a way to convey the results of their physical experiments, arguably a middle way between a descriptive text and a hands-on experiment.[7] Other scholars of their time, building

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1 Yong (2010). See, for example, Foley, Gegear, & Reppert (2011); Nießner et al. (2013); Wiltschko & Wiltschko (1995).

2 A comprehensive overview is provided by Sander (2020a). See also Balmer (1956); Daujat (1945); Weill-Parot (2013).

3 On the experimental research on magnetism in the early modern period, see, for example, Sander (2020b, p. 275).

4 Translation (modified) in Harradon (1943, p. 128). The document is edited and reprinted in Hellmann (1898, p. 65): "welche Tugend [des Magnetsteins] auch von ganzem Herzen eure fürstliche Gnad [ich] wollte mittheilen, wo ich nur das in Schriften könnte verfassen, denn solche Dinge sind viel leicher zu verständigen, so man solche mit der Handarbeit anzeigt, denn mit der Schrift."

5 Norman (1581, p. 19).

6 Unfortunately, Norman does not explain how he "proved" this.

7 Norman used diagrams but not in relation to what he refers to in the quotation given.

on 13th-century innovations, investigated magnetism experimentally and employed a specific type of imagery, the diagram, to give a visual account of magnetism.[8]

Experiments transformed into diagrams were the antidote to magnetism's invisibility, as they made its effects seeable through a process of visualization. This dynamic makes magnetism an ideal topic for a case study investigating the use and production of diagrams for two major reasons. First, the inherent invisibility of magnetism required the use of a core feature of diagrammatic visualization, namely, making something visible that was not visible before.[9] These per-se invisible entities shown in an image can be considered constitutive of the image's status as a diagram. Second, this case study draws attention to the performative basis for some diagrams used in natural philosophy that depend on or are grounded in experiments, which is often an irrelevant (or neglected) aspect of diagrams from fields like geometry or astronomy. This approach is different from the purely abstract approach of, for example, mathematical branches of knowledge, or from the predominantly observational empirical approaches in other fields, such as natural history or astronomy; the study of magnetism was wedded to manipulation and experimentation.

To start, I sketch the relevant natural philosophical framework for explaining magnetism, in which it was seen as an "occult" power that demanded an empirical approach to be investigated. Then, I show how this theoretical and experimental background established and fostered a visual approach to magnetism from the beginning of the 14th to the end of the 17th century. This period was a time of increased interest in magnetism, as it underwent the many transformations of the so-called Scientific Revolution.[10] And for large parts of this timeframe, the conceptual framework outlined remained important, either as an explicit or tacit background or as a target of criticism.[11] The guiding question of this study is, how do experiments and their conceptual goals or results interact with the abstract and more naturalistic features in imagery (most fittingly called "diagrams")? I argue that diagrams as a visual aid in scientific treatises on magnetism pursued three different, interconnected, and often consecutive functions: diagrams explained to readers how to perform the experiments, they communicated the experimental results on a more conceptual level, and sometimes they were taken as visual renderings of the very theories that are confirmed or discovered by an experiment. The visual characteristics of the diagrams used to pursue or communicate these goals are found in various shades between the naturalistic depiction of an experiment and the highly abstract, geometrical representation of an underlying cause or pattern of magnetism, forming a continuum rather than discrete categories of images.

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8 For a general overview on "scientific images" and diagrams in pre-modern science, see as a starting point: Catton & Montelle (2012); Crowther & Barker (2013); Franklin (2000); Fransen & Reinhart (2019); Hackmann (1993); Kupfer, Chajes, & Cohen (2020); Lüthy (2018); Marr (2016); North (2004); Raphael (2013); Saito (2012). More literature is provided in other notes.

9 This is addressed in the concluding section of this article.

10 See the references in Sander (2020b, p. 275 n. 3).

11 See, for example, Hutchison (1982); Clarke (1989); Copenhaver (1991).

## 1. Invisible Powers and Empirical Knowledge

The invisibility of what we today call "magnetism" was undisputed among premodern authors, who had developed a specific conceptual space for phenomena that are only accessible to the senses by their effects. They thought about these phenomena, such as magnetism and the effects of some drugs, as being in the realm of what they called "occult powers."[12] In doing so, they rendered any scientific investigation aiming at discovering the causes of magnetism a very difficult undertaking.

Natural philosophy with a traditional Aristotelian outlook, as was dominant between the 13th and 16th centuries, required sense experience as a starting point and eventually aimed at the causes of things. But how might one scientifically deal with magnetism when its cause cannot be experienced by any sense organ? In order to tackle this, Aristotelian and Galenic scholars coined the notion of "occult," which in its technical scholastic meaning simply refers to something "unsensible." One can see and feel some magnetic effects through objects, but the magnetic power or force itself, that is, the cause and coming-to-be of its effects, is entirely hidden to our senses. This magnetic power or force, mostly called *vis* or *virtus magnetica*, was grounded in one (or many) of the magnet's qualities, which human senses obviously fail to detect. One cannot simply see or feel if some stone or piece of iron is magnetic or not. Thus, these "magnetic qualities" were called "occult," introducing a metaphysical distinction into Aristotelian natural philosophy. There are, to somewhat simplify the matter, qualities that are subject to the sense of touch that were called "manifest" or "elementary qualities," as they derive from the qualities of the four elements that, in different mixtures, were held to constitute all natural things on earth.[13] Fire is hot and has the power of heating another thing; "heat" is then considered the manifest quality that grounds this power. Other powers, such as magnetic attraction, could not readily be explained by these "manifest" qualities deriving from the four elements.[14] Yet, magnetic phenomena such as attraction were well known, undisputed as such, and used in many practical contexts. Therefore, naturalists assumed a specific type of power that was not grounded in or emergent from the qualities of the elements, and they called this efficient cause an occult power originating from occult qualities. By definition, these qualities are insensible.

This notion of occult might appear to be an anthropocentric theory of causation because it seems to exclusively depend on human abilities of perception. While it was criticized from early on, it remained the default theory to account for magnetism until

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12 Much has been written on this. As a good starting point, see Bianchi (1982); Weill-Parot (2013, pp. 27–136); Wild (1906).

13 This is obviously a simplification of the Aristotelian account, leaving out, for example, the role of the "common sense." This, however, was never prominently invoked in accounting for occult phenomena, as is clear from Weill-Parot (2013). For a concise discussion of "elementary qualities," see Martin (2017); Pasnau (2011).

14 For a detailed explanation, see Sander (2020a, pp. 652–660, 684–687); Sander (in press-c).

at least the 16th century.[15] We find, for example, an early critical reflection on the notion of occult qualities in one note of Paolo Sarpi's *Pensieri* of the 1580s:

> Those that are called occult qualities are like the other qualities, but we have no sense to perceive them. This is the case with the qualities of the magnet, because we do not have an iron sense that can be moved, and wherever a sense is missing, we call the quality [of the missing sense] "occult." … The number of sensual qualities is limited to five for us, but perhaps there are other qualities that might affect other types of organs that we do not have. The magnet shows this, [because] its quality is not perceived by any of our five senses. … Therefore, if the nerve becomes one that perceives this, as the magnet [is perceived] in the iron, it would no longer be called an occult quality.[16]

Sarpi, a pioneer in the experimental investigation of magnetism, had a strong and seemingly modern point here.[17] If we could only sense magnetism, as we now know some birds can, the entire occult category would become more or less meaningless. In spite of making this fair point, Sarpi, like most of his contemporaries and predecessors, did not spell out the invisible mechanism leading to magnetic effects. Many, if not most, pre-modern authors accepted that some powers in nature were not subject to further explanation.[18]

## 2. Experiments and Diagrams

As occult qualities were inaccessible to direct sense experience, in the ancient and medieval world phenomena or effects related to those qualities were typical instances of what was called *experimentum* or *experientia*.[19] An anonymous medieval treatise, for example, states: "Although we do not know a manifest reason as to why the magnet

15 As is well known, the strongest rebuttal of the theory of occult qualities came from the camp of corpuscularian philosophers in the early 17th century, most famously by René Descartes and Pierre Gassendi. They also wanted to dissolve the metaphysical distinction between elementary and occult qualities based on the contingent condition of human sense perception. See, for example, Hutchison (1982).

16 Sarpi (1996, pp. 170, 173, 210): "Quelle che si chiamano qualità occulte, sono come l'altre, ma noi di sentirle non abbiamo senso. Così è quella della calamita, perchè un senso di ferro, che possa da lei esser mosso, non abbiamo ed a chi manca un senso, le qualità ad esso corrispondenti sono occulte. Così pure occulte son chiamate le qualità pestilenti e venefiche, le quali offendono il cuore perchè egli non le sente. … Il numero delle qualità sensibili viene da noi ristretto a cinque sensi; ma forse vi sono altre qualità atte a far impressione in altra sorta d'organi, che noi non abbiamo. La calamita lo mostra, che la sua qualità non conosciuta da alcuno de' nostri cinque sensi, … onde se il nervo degenera in quello lo sente come la calamita nel ferro, né quella si chiamerebbe più qualità occulta." See also Sander (2020a, pp. 658–659).

17 As has been argued, Sarpi's research on magnetism was closely connected to the research by the Jesuit Leonardo Garzoni, who will be introduced shortly. See Sander (2016); Ugaglia (2006). What remains of direct or indirect traces of Sarpi's interest in magnetism does not include any diagrams.

18 This is nicely elaborated in Fleming (2011); Weill-Parot (2010). See also Sander (2020b, pp. 278–280) for discussion on different explanations of magnetism.

19 See, as a starting point, Bénatouïl & Draelants (2011); Dear (2006).

attracts iron, nonetheless experience manifests it, so that nobody can deny it."[20] Yet, in the case of magnetism, this "experience" is not a passive observation, as one might, for example, experience a solar eclipse. In order to experience magnetic effects, it needs some sort of manipulation, intervention, and experimentation.

The first detailed account of magnetic experiments, and therefore a key document for this article, was authored by Petrus Peregrinus in 1269.[21] Around 70 manuscript copies, including translations, and four printed historical editions of his *Epistola de magnete* are extant; 41 of them bear illustrations, with circa 175 images in total.[22] Only a small fraction of the transmitted illustrations deal with the experiments explained in the first part of the treatise. As these diagrams are not referred to in the text, nor included in the earliest manuscripts, it seems likely that these were included by later copyists rather than by Peregrinus himself. The experiments connected to these diagrams aim at uncovering the magnet's poles and at establishing a cosmological analogy for magnetic polarity. Later authors knew Peregrinus's treatise, elaborated on its ideas, and used similar magnetic experiments to undergird different theories and applications of magnetism.[23] Most importantly here, they employed visual images as well, often similar to those originating from Peregrinus's manuscript and print tradition.

In what follows, four different experiments and their diagrammatic visualizations will be investigated. Three of these experiments have their origin in Peregrinus's *Epistola de magnete*, but early modern authors of works on magnetism and early modern copyists of Peregrinus's treatise played a major role in finding novel ways to render the experiments and their results visual. Peregrinus's text does not invoke the diagrams under investigation, and yet his experimental approach paved the way for diagrams being visual accounts of otherwise invisible magnetic phenomena. The first three examples arise from Peregrinus's experimental approach to finding the two poles on a magnet: where are the two points on a magnet that have the strongest attraction and align to the poles of the world? The fourth experiment, unknown to Peregrinus, was conducted to give insight into the spatial extension of magnetic force. It was only through experiments like these that it was possible to deepen empirical knowledge about magnetism. As will be shown, scientific images relating to these experiments dealt with the invisibility of magnetism and facilitated the communication of this empirical research in different ways.

20 Albertus Magnus (Ps.) (1973, p. 82). For the (slightly different) Latin text, see Albertus Magnus (Ps.) (2011, p. 105).

21 See Halleux (2007); Petrus Peregrinus (1995); Sander (2020a, pp. 795–798); Smith (1992).

22 For a census of all these images, see the online database Sander (2021a). The majority of these illustrations relate to the treatise's second part, dealing with practical devices such as the magnetic compass, and only this part verbally refers to the imagery. For an analysis of the imagery relating to Peregrinus's *perpetuum mobile*, see Kleinert (2003). References to the images of the instruments (referred to in the text as "descriptio") are found in Petrus Peregrinus (1995, pp. 83, 86, 88). Only one manuscript refers to a *figura* in the first treatise, but without connection to any of the diagrams discussed in this article. See Petrus Peregrinus (1995, p. 70 l. 118), in the critical apparatus.

23 See Georgescu (2013).

Before proceeding, a brief clarification of some of the terminology and concepts involved will be helpful. In pre-modern times, and even less so for the time span of 400 years covered by this study, a well-defined scientific vocabulary to describe magnetism did not exist.[24] The adjective "magnetic" (*magnetica*, and so forth), for example, was not used before the late 16th century, nor was the noun "magnetism," which at first did not even denote magnetism or magnetic effects in the modern sense at all.[25] Moreover, not all the authors discussed here attempted to define their own concepts properly, and if they do, their theories and definitions are often not as clear as one might wish. A strict application of the vocabulary used by the historical authors is neither feasible nor helpful, but references and comments in the footnotes shall make readers aware of any complications in this regard. The more fine-grained conceptual backgrounds underlying the relevant concepts cannot be dealt with in the scope of this article either, but this does not greatly affect the validity of its argument. It should also be emphasized that the authors rarely state what they think is shown in the images they provide in their works. To determine this is left to the historian, and this study will try to map the expressions and concepts used by the authors as closely as possible to the imagery.

As for vocabulary, it is justified to speak about "magnetic polarity" with regard to the sources at hand, as this concept was actually coined by Peregrinus in the Middle Ages, which Friedrich Steinle in particular has elucidated.[26] Instead of speaking about just two "sides" of a magnet, the concept of "north and south poles" not only alluded to a cosmological analogy between the magnet and the heavenly sphere, but also created two new entities in the magnet, tied to a specific bipolar power. The expression "magnetic force" or "power" will mostly translate what many authors called *vis* or *virtus magnetica*.[27] This is obviously not meant to denote a physical "force" in a modern, Newtonian sense, but rather the magnet's capacity to move another piece of iron (that is, attraction and repulsion), to align in a north–south direction, or to make another body itself magnetic. The concepts of a "magnetic field" or "lines of force," which might be relevant to some of the experiments described in what follows, are anachronistic and will therefore be avoided.[28]

### *2.1. First Experiment: Iron Needles on a Magnet*

The first experiment of Peregrinus to be discussed in this case study involves a spherical magnet and an iron needle.[29] The experiment aims to find the two poles of

24 See also Sander (2020a, pp. 875–879).

25 *Magnetismus*, especially in alchemical or cosmological contexts, was understood as all sorts of powers or effects that resemble magnetism, for example, by way of attraction or "action at a distance." See Sander (2020a, pp. 876–878).

26 See Steinle (2012).

27 References to this will be given for each author who employs the concept.

28 See Gooding (1980); Steinle (2008).

29 See Petrus Peregrinus (1995, pp. 68–69).

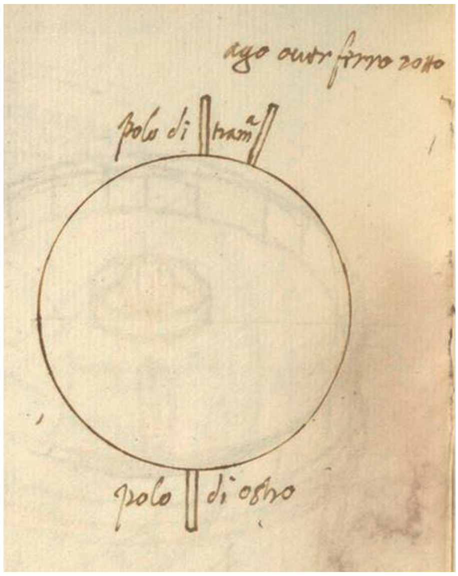


**Figure 1**. Spherical magnet with three iron pins on it. The magnetic poles are labeled by text (*polo di tramontana/ostro*). Two of the pins stand upright on the poles, a third pin declines slightly as placed at a certain distance to the pole. Although the objects are abstracted to two-dimensional shapes, no invisible entities are depicted, only the objects used in the experiment. (Illustration drawn by the scribe and added after the treatise on a separate sheet; ink on paper.) From Vienna, Österreichische Nationalbibliothek, Lat. 5969 (second half of the 16th century), fol. 196v.

the magnet by placing needles onto it; a pin's or needle's point would attach, its length protruding at an angle according to its position relative to the poles.

Figure 1, showing the idea of the experiment, is taken from a 16th-century manuscript copy of an Italian translation of Peregrinus's work made by Filippo Pigafetta.[30] Among the many illustrated copies of Peregrinus's treatise, this is the only depiction available of this experiment. The pen drawing shows a spherical magnet with its poles forming a vertical axis. In the illustration there are two pins on the magnet that stand upright at each of the poles, with an additional needle on the top right inclined toward the center. Peregrinus took the needle standing on the magnet at a right angle to its surface to indicate a magnetic pole.[31] Although the diagram shows three pins, the text does not indicate the use of multiple needles at the same time. Thus, the depicted

30 This translation is edited in Petrus Peregrinus (1995, pp. 91–109). Of the two copies, only one is illustrated and all the images were added at the end of the manuscript, see Vienna, Österreichische Nationalbibliothek (hereafter ONB), Lat. 5969, fols. 180r–199v. See also Sander (2020a, p. 797). Pigafetta's autograph (ÖNB Lat. 6256) has no diagrams, and the copyist of ÖNB Lat. 5969 is not identified.

31 It must be noted that the pin cannot have any angle to the circle's periphery, but rather to a tangent at this point where it touches the circle. This assumed tangent, however, is neither drawn in the image nor mentioned in the text. This "rectangular" alignment of the pin is also distinguished by the pin pointing to the magnet's center.

experiment has to be seen as an aggregation of three separate stages or trials of the experiment, that is, the sticking of one pin onto the magnet at three different places, one after the other.[32] This emphasizes the diachronicity that is thus synchronized in the diagram. Moreover, the diagram depicts the difficult experiment, which is anything but easy to perform, with almost geometrical clarity, and thus shows it in an idealized way. Hence, this illustration gives a complex, dynamic, and idealized visual rendering of the experiment (and some of its theoretical assumptions as well).

Peregrinus, however, did not investigate the angles of these needles in order to draw further conclusions. William Gilbert, in his famous *De magnete* of 1600, described a similar experiment with needles, but did try to discover the mathematics behind the angles of the needles on the magnet.[33] Knowing Peregrinus's *Epistola,* and thus not incidentally using spherical magnets as well, Gilbert argued experimentally and geometrically that the angle would indirectly indicate how strong attraction is at each point on the spherical magnet. He also reasoned, in relation to another very similar experiment, that the decrease of the angle of a needle moved along the surface of a magnet could be described by a mathematical equation. For Gilbert, this provided a model to calculate the geographical latitude based on the geomagnetic phenomenon known as "magnetic dip" or "inclination."[34] He considered a spherical magnet (*terrella*) to be a model of the earth, the earth being a giant magnet, and he was primarily concerned with investigating the nature of the earth's magnetism by means of downscaled experiments.

His experiments led to different diagrams visualizing magnetic effects (Figures 2, 3, 4) and, indirectly, revealing some of its geometrical patterns (Figure 5). With this latter goal, he even went one step further, as Laura Georgescu has also argued, by using these diagrams to prove and demonstrate the behavior of magnetic force in geometrical terms.[35] Gilbert's experiments, and therefore also his diagrams, are nonetheless heavily influenced by non-geometrical and non-empirical (but also rather theoretical) assumptions stemming from his Copernicanism and syncretic metaphysical ideas.[36] His spherical magnets and the geometry that many of his diagrams favor, for example, idealize round shapes.[37]

32 Notably, if this experiment was actually being performed simultaneously, the two pins at the top (that is, the north pole) would not remain separated as they appear to be in the image, but would instead be pulled together into a group.

33 See, for example, Gilbert (1600, pp. 76, 82, 96, 197–198, 206). See also Sander (2020a, pp. 457–466). See especially Bexte (2007); Georgescu (2014).

34 See especially Sonar (2016).

35 See Georgescu (2014).

36 See, for example, Henry (2001).

37 This led Gilbert to believe, for example, that the magnetic force extends spherically from the center of the magnet instead of from its poles, leading to an oval shape; see Sander (2020a, pp. 632–634). Moreover, the earth being spherical and its diurnal movement (following Copernicus) being the eventual object of demonstration motivated him to experiment with spherical magnets.

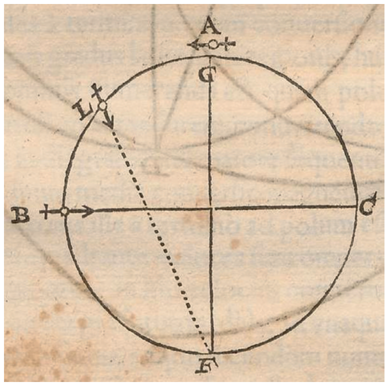


**Figure 2**. Spherical magnet with three compass needles (symbolized as arrows) at G (equator), L (halfway between A and B along the arc), and B (magnetic pole). In addition to the labeled poles (B and C), the axis (BC) and equator (GF) are made visible as lines. The dotted line LF is a virtual entity showing the compass needle aiming at F from point L. Visually, only the symbolized compass needles encode the experimental practice. (Woodcut print on paper.) From *De magnete* (p. 197), by W. Gilbert, 1600, London, England: excudebat Short (ETH-Bibliothek Zürich, Rar 1253).

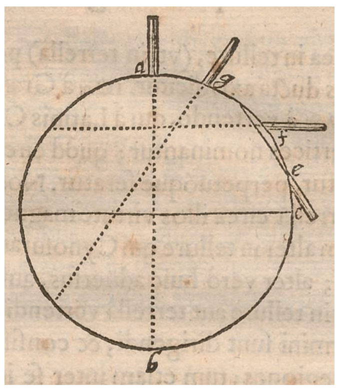


**Figure 3**. Spherical magnet with pins at a, g, f, and e. In addition to the labeled poles (a and b), the equator (line leading to c) is made visible diagrammatically. Dotted lines represent chords, and their lengths indicate the strength of the magnetic attraction at the respective point (a, g, f, and e, with a solid line by mistake), with the strongest power at poles a and b (the length being the complete diameter). Visually, the more or less naturalistically depicted pins refer to the experiment. (Woodcut print on paper.) From *De magnete* (p. 82), by W. Gilbert, 1600, London, England: excudebat Short (ETH-Bibliothek Zürich, Rar 1253).

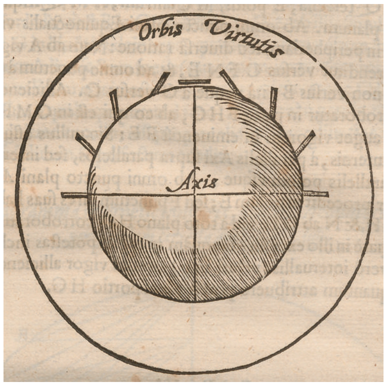


**Figure 4**. Spherical magnet with nine pins on its surface. The "sphere of influence" (*Orbis Virtutis*), axis (*Axis*), and equator (vertical diameter) are made visible diagrammatically, while the first two entities are also labeled. Visually, the more or less naturalistically depicted pins and the shadow on the spherical magnet give the impression of physical objects. (Woodcut print on paper.) From *De magnete* (p. 191), by W. Gilbert, 1600, London, England: excudebat Short (ETH-Bibliothek Zürich, Rar 1253).

In all these images related to more or less one and the same pin experiment can be seen different ways to abstract and make visible magnetic polarity, magnetic inclination, and the strength of magnetic attraction. "Abstract," here and in the following, is meant as the visual tendency of an image to minimize visual information about the actual or imagined setup of an experiment or object in favor of adding information about conceptual entities by means of letters, text, or geometrical shapes.[38] For example, the diagram connected to the *Epistola* (Figure 1) carries information about the execution of the experiment, since it follows the textual instructions and shows hardly anything more than the (labeled) objects involved in the experiment. There are no lines or other shapes that make visible something that is not visible in the experiment itself, except for the labeling of the poles on the magnet. Thus, this diagram has a low level of abstraction. In Gilbert's diagrams (Figures 2, 3, 4), by contrast, much information about the actual experimental setting is lost or schematized; instead, they include shapes that are geometric abstractions and not physical objects.[39] As in the diagram derived from Peregrinus's treatise (Figure 1), Gilbert's diagrams are dynamic in the sense that they arguably integrate different stages of the experiment (that is, sticking a pin on different sides of the magnet) into one view. However, in Gilbert's diagrams of a clear geometric nature (for example, Figure 5), as distinguished from more pictorial ones, the experiment that also formed the background for Gilbert's

38 For a recent historiographical analysis of the term "abstract" in medieval art history, see Gertsman (2021). For a more systematic approach, see Strayer (2014).

39 For example, in Figures 2 and 3 we see dotted lines as the virtual lengthening of the needles, important for the understanding of Gilbert's arguments. His theory cannot be discussed here in more detail, but the literature provided above does so to some extent.

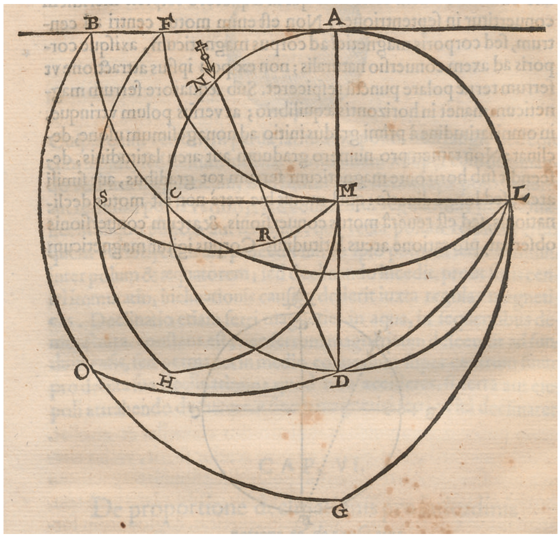


**Figure 5**. Spherical magnet with compass needle (symbolized as arrow) at N (halfway between A and C along the arc). The labeled poles (C and L), axis (CL), and equator (AD) are made visible diagrammatically. Moreover, various lines and arcs aid the geometric construction underlying a mathematical function. Visually, only the symbolized compass needle remotely alludes to any experimental practice. This is an almost purely geometrical and abstract representation of the magnetic force and the dip-latitude relation. (Woodcut print on paper.) From *De magnete* (p. 198), by W. Gilbert, 1600, London, England: excudebat Short (ETH-Bibliothek Zürich, Rar 1253).

more theoretical thoughts has disappeared entirely, and in fact allows for a more abstract representation of magnetic force reduced to lines and arcs.

How do these experiments and their depictions relate to the natural philosophical view on magnetism and the notion of occult qualities? Peregrinus himself describes the experiments but does not put forward a sophisticated visual approach to magnetism. He neither comes up with an elaborate causal explanation of the effects nor fully explains what he calls the magnet's *virtus naturalis*.[40] Although he addresses magnetism's occult nature (*natura occulta*) in the outset of his letter, he does not refer to this or occult qualities any further, and, in a way, begs the question.[41] Peregrinus was not much concerned with either the magnet's invisible qualities nor their visualization, but with experiments as a source of knowledge, a cosmological analogy between the magnet and the world, and technological applications of magnetism.[42] Later copyists

40 See, for example, Petrus Peregrinus (1995, pp. 63, 67, 74, 76, 78–80, 85–87).
41 See Petrus Peregrinus (1995, pp. 64–66).
42 His analogical reasoning and his interest in technology go beyond the scope of this article and do not directly affect the argument here. It must be said, however, that his analogical reasoning and his interest in technology also led to diagrams, which were, however, of a different nature.

and editors, however, did support the verbal description of his pin experiment by adding diagrams and, as we shall see, did so for other experiments as well. This can be seen as a step taken by these copyists to render Peregrinus's original experiment in a diagram bearing more information than just the details of how the experiment was to be performed. At first sight, Figure 1 is not concerned with invisible entities per se but with giving an account of the experiment. However, the textual labels for the (per-se invisible) magnetic poles add to this decisively and constitute an abstraction from the experiment.

In contrast to Peregrinus, Gilbert explicitly and harshly attacked the Aristotelian notion of qualities, be they manifest or occult, even while his own rather enigmatic theory invoking a magnetic *forma* remained relatively close to what might be called an Aristotelian theory.[43] Gilbert deemed the magnetic force to follow basic geometrical patterns, which can be discovered experimentally and represented in diagrams. These diagrams became almost entirely geometrical and, for the first time in this context, were also called *diagramma* in the Latin text.[44] With regard to the inclination experiment referred to above, he states:

> While some assign occult and hidden virtues [*virtutes*] of things, others a property of substance, as the causes of the astonishing magnetic effects; we have discovered the primary substantial form of globes, not from a conjectural shadow of the truth of reasons variously controverted; but we have laid hold of the true efficient cause, as from many other demonstrations, so also from this most certain diagram [*diagramma*] of magnetic forces [*vires magneticae*] effused by the form. Though this (the form) has not been brought under any of our senses, and on that account is the less perceived by the intellect, it now appears manifest and conspicuous even to the eyes through this essential activity which proceeds from it as light from a lamp.[45]

With such a statement the diagram is explicitly employed as an instrument for the manifestation and visualization of magnetic forces (*vires magneticae*) that are propagated (*effusae*) by the somewhat enigmatic "form" of the magnet.[46] Many diagrams

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43 On Gilbert's theory, compare, for example, Freudenthal (1983); Henry (2001); King (1959); Pumfrey (1990); Wang (2016). Gilbert emphasized the difference from the Aristotelian notion, however. See Gilbert (1600, p. 65).

44 Gilbert frequently uses the expressions *vis*, *virtus*, *potestas*, and *vigor* with regard to the magnet's powers. A systematic and clear-cut distinction between the expressions is not provided in his *De magnete*; subtler differences are not relevant for the matter at hand. See also note 46. On diagrams, see Gilbert (1600, pp. 42, 74, 122, 161, 189–190, 198–201, 205–207).

45 Translation (modified) in Gilbert (1900, p. 207). For the Latin, see Gilbert (1600, p. 207): "Cum alij occultas rerum & abditas virtutes, alij proprietatem substantiae ponunt mirabilium magneticorum effectuum causas; nos formam substantialem primariam globorum invenimus, non ex probabili rationum varie controversiarum veritatis umbra, sed ut ex alijs multis demonstrationibus, ita ex hoc certissimo magneticarum virium a forma effusarum diagrammate, veram efficientem causam apprehendimus. Quae (forma) cum nullis nostris sensibus subiecta sit, ideoque ab intellectu minus percipitur, nunc oculis ipsis manifesta & conspicua apparet, per formalem hunc actum qui ab ea procedit sicut lumen a luce."

46 Is it the magnetic force or the form that is effused from the magnet and thus visualized in Gilbert's diagram? In the quotation immediately above, it is clearly the forces that are being effused ("magneticarum virium a forma

in his work attest to this approach. A reader in one copy of *De magnete* even jotted down "visibilis" in the margin of the page of the geometrical diagram depicted in Figure 5.[47] It has been argued that this geometrical scheme was developed by fellow mathematicians on Gilbert's behalf, and it circulated widely in its aftermath.[48] Not all who used Gilbert's diagrams subscribed to his metaphysics or cosmology, but the visual "geometrization" of the needle experiment (and others connected to it) appealed to all of them.

### *2.2. Second Experiment: A Magnet Floating on Water*

Peregrinus's next experiment under consideration here used magnets placed on pieces of wood floating on water in a vessel.[49] These floating magnets would move and rotate in the water in order to take up their natural alignment with the poles of the world or under the influence of magnetic attraction and repulsion when a second magnet was added to the setting. As in the first experiment, a shift from naturalism to abstraction can be observed by looking at how Peregrinus's experiment was depicted in diagrams in different versions of his treatise.

In some images (Figures 7 and 9), only a pictorial description of the experimental setting is given, bearing no text or other diagrammatic modes of visualization.[50] In other illustrations (for example, Figures 6 and 8), however, we see rudimentary forms of the diagrammatic in addition to depictions of the experimental setting: just like in the first experiment, the celestial and magnetic poles cannot be seen and consequently are not "depicted" as such, but can be labeled or marked in an image. Figure 8 features a person executing the experiment by holding a magnet at the edge of the vessel, adding a performative level to the image.

While the main purpose of Peregrinus's water experiment was to determine the north and south poles of a magnet, a virtually identical experiment pursued different scientific goals in later works.[51] Leonardo Garzoni, who composed a highly original treatise on magnetism around 1580, used a similar experiment but aimed at showing something different.[52]

effusarum"). See similarly, yet with regard to other types of "forces" (*vires*, *virtutes*), Gilbert (1600, pp. 221, 224, 231). However, in other places he speaks about the form as being effused, for example, Gilbert (1600, p. 70): "de formis sphaericis effusis." See similarly Gilbert (1600, pp. 69, 207, 208, 210). Albeit an important (and possibly insolvable) question, it does not matter too much for the argument of this article: both the form and the forces are invisible per se, detected experimentally, and visualized in diagrams.

47 See the copy in QC751.G55 1600, Kelvin Smith Library, Case Western Reserve University, Cleveland, OH, on p. 198.

48 See Sander (2020a, pp. 457–476); Sonar (2016). The diffusion of Gilbert's diagrams across 17th-century publications has yet to be studied systematically.

49 See Petrus Peregrinus (1995, pp. 69–70).

50 See also the respective image in Taisnier (1575).

51 Georgescu (2013) focuses on Peregrinus, Norman, and Gilbert.

52 On Garzoni, see Sander (2016); Ugaglia (2006).


**Figure 6**. Vessel filled with water in which a smaller vessel floats, carrying a magnet. Water (*aqua*), cardinal directions (*septentrio*, *meridies*; labeled both for the vessel and for the magnet), and the magnet (*lapis*) in the center are labeled. The axis and equator of the magnet are indicated diagrammatically with lines. Visually, the drawing of the vessel has features that make it look naturalistic (for example, perspective and slight hatching), and it even depicts the probably wooden staves bound by hoops, distinguished by color. Abstract and more naturalistic features are combined in this hybrid diagram. (Illustration inserted into the text by the scribe, ink on paper.) From Rome, Biblioteca Apostolica Vaticana, Pal. lat. 1340 (14th century), fol. 31v.

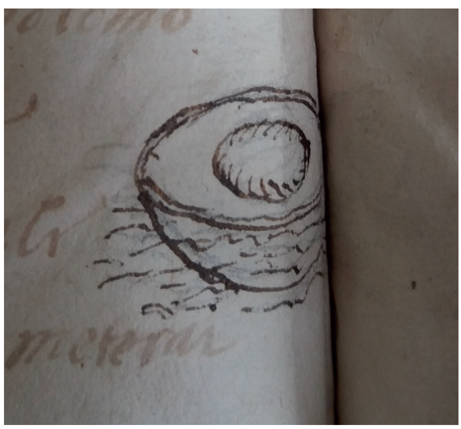

**Figure 7**. Magnet in a vessel floating on water. No labels or diagrammatic lines or shapes are drawn. Wavy lines indicate the water. Hatching on the magnet visually makes it appear as a body. This is not a diagram but a depiction of part of the experimental setting. (Illustration added to the margin by the scribe, ink on paper.) From Turin, Biblioteca Nazionale Universitaria, G.V.10 (second half of the 16th century), fol. 1v.

**Figure 8**. Vessel filled with water in which a smaller vessel carrying a magnet floats. A person holds a second magnet at the edge of the large vessel. Only cardinal directions (*tramontana*, *ostro*) are labeled; lines or geometrical shapes are not part of the image. Visually, the drawing of the vessel bears naturalistic features (for example, hatching and perspective) and depicts the probably wooden staves bound by hoops. The image has a performative aspect due to the inclusion of the person executing the experiment. (Illustration drawn by the scribe and added after the treatise on separate sheet, ink on paper.) From Vienna, Österreichische Nationalbibliothek, Lat. 5969 (second half of the 16th century), fol. 196v.

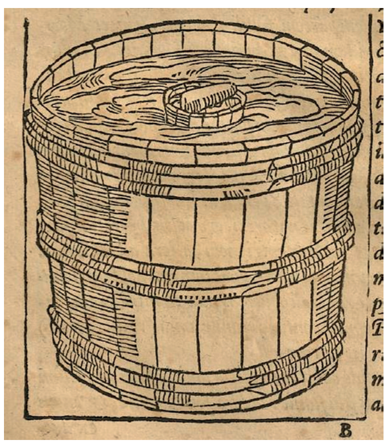

**Figure 9**. Vessel filled with water in which a smaller vessel carrying a magnet floats. No labels or diagrammatic lines or shapes are present. Wavy lines indicate the water; the hatching and other details (for example, the wooden staves bound by hoops) underline the naturalistic character of this image. This is not a diagram but a depiction of a part of the experimental setting. (Woodcut print on paper.) From *Opusculum perpetua memoria dignissimum* (p. 5), by J. Taisnier, 1562, Cologne, Germany: Apud Ioannum Birckmannum (Universitätsbibliothek Basel, Km XI 13:7).

In his experiment, as described and depicted in two surviving manuscript copies of his work (Figures 10 and 11), floating magnets were placed around a fixed magnet in order to determine the pathways in which small magnetic ships were pulled toward a magnet on the water.[53] The low frictional resistance of the water allowed the floating magnets to make visible a geometrical bipolar pattern of what Garzoni considered the actual ways along which magnetic qualities were emitted from the magnet. He openly tried to find middle ground with regard to the notion of occult qualities.[54] He remained within the Aristotelian framework, but also attempted to give a more qualified account of magnetic qualities, which he called the "quality of the two faces," alluding to the two poles of a magnet.[55] In a process of visual abstraction, many of Garzoni's diagrams depart from a depicted experiment and give a visual account of the otherwise invisible extension of magnetic power ("nella figura si dimostra il progresso et il flusso della virtù della calamita").[56] But at least one of his diagrams also testifies to a conceptual abstraction. In Figure 11, he depicts not only lines and geometrical shapes derived from an experiment but the actual qualities being emitted from a magnet on the basis of these geometrical shapes.[57] These qualities are represented by the overlapping circles in the diagram.[58] Here, the diagram does not primarily or exclusively show an experiment or a pattern governing magnetic force, but a theory of magnetism based on the diffusion of qualities instead. The actual cause is shown in a metaphysical abstraction. While Figure 10 shows lines as traces of magnetic force, Figure 11 depicts how this force is exerted, namely by the emission of qualities as a result of the magnet's specific substantial form.

53 Both manuscripts feature many other similar diagrams.

54 See Garzoni (2005, pp. 220–221); Ugaglia (2005, pp. 25–27).

55 A detailed account of Garzoni's metaphysics cannot be given here, but see Sander (2020a, pp. 691–692); Ugaglia (2006, pp. 69–70).

56 Garzoni (2005, p. 184). See also Garzoni (2005, p. 96): "il quale effetto manifestamente si vede se la calamita…" See also Garzoni (2005, p. 164): "…movendo il ferro in molta distanza è forza che ciò operi con lo stromento di qualche invisibile qualità diffusa nelli corpi mezani, la quale sia in essi prodotta dalla reale qualità che nella pietra si truova, et essendo proprio delle forme si sostantiali, come accidentali, di propagare, diffondere, et multiplicare se stesse, quanto possono, questa qualità ancora (come quella che non solo è motiva, ma alterativa insieme) ha forza di produrre et multiplicare se stessa nell'aere, et ne i corpi circostanti." See also Garzoni (2005, pp. 119, 163, 191, 229, 297), for similar phrasings.

57 It is puzzling why this diagram was not included in the later print template, the source of Figure 10.

58 See Garzoni (2005, p. 183).

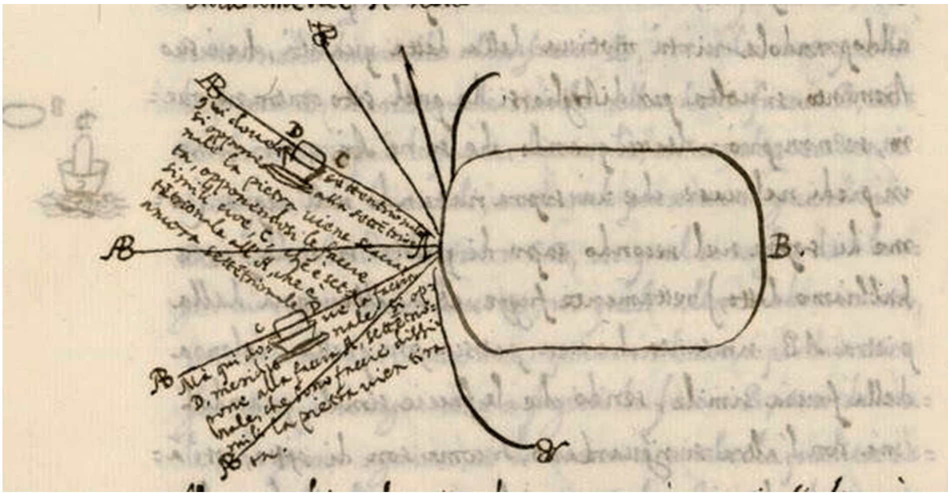

**Figure 10**. Large magnet surrounded by two magnets floating on small ships. Magnetic poles (A and B for the large magnet, C and D for the two small magnets) are labeled. Six straight and two curved lines represent the paths on which the small magnets float away from or toward the large magnet, oriented according to the polar structure of the large magnet (labeled as AB, merged into one letter symbol). The two multi-line pieces of text inserted along two of the path lines describe the experiment and its results. Only the two small ships bear faintly naturalistic features; all other information is encoded diagrammatically in an abstracted way. (Ink on paper.) From Madrid, Biblioteca Nacional de España, MS. 2020 (second half of the 16th century), fol. 124v.

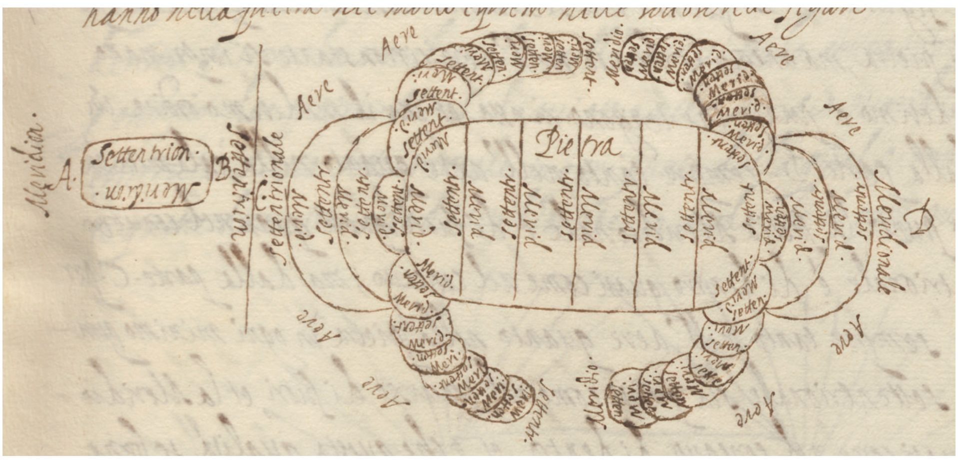


**Figure 11**. A large magnet and one smaller magnet (left) in close proximity, repelling each other. Magnetic poles (C and D for the large magnet, A and B for the small magnet), the surrounding air (*Aere*), the large magnet (*Pietra*), and several instances of the cardinal directions (*Settentrionale* and *Meridionale*) are labeled. Semicircular qualities emitting from the magnet have the same bipolar structure as the magnet, being divided into north and south. No naturalistic features and no direct visual reference to experimentation are present; all information is encoded diagrammatically in an abstracted way. (Ink on paper.) From Milan, Biblioteca Ambrosiana, S. 82 sup (second half of the 16th century), fol. 33r.

### *2.3. Third Experiment: A Magnet Divided into Two Pieces*

In the last experiment of Peregrinus to be analyzed here, he instructs the reader to divide one magnet into two pieces and then to observe the behavior of these pieces in relation to each other.[59] Peregrinus was the first author to record that a magnet split into two pieces does not lose its polarity, but instead each of the fragments becomes a new magnet with two poles. By splitting stone AD into two pieces, the two magnets AB and CD result. These two magnets attract each other when poles B and C touch. They repel each other if sides B and D are put together.

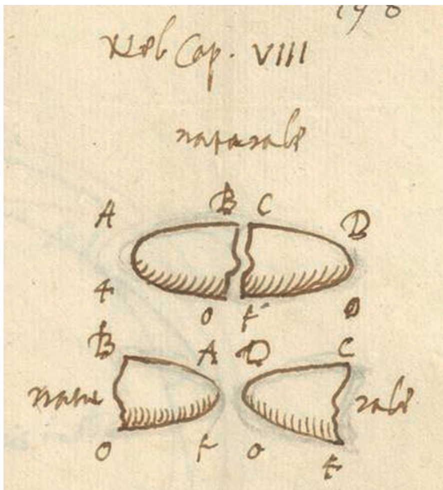


**Figure 12**. Two oval magnets, each divided into two pieces, shown in two configurations of attraction. Their alignments are qualified as "natural" (*naturale*), while all eight corners are labeled with letters (the text only refers to the capital letters A to D). Two (of four) relevant combinatory positions are shown, as instructed for the experiment in the text of the treatise. The magnets bear slightly naturalistic features due to hatching. The image is part of a set depicting further combinations of the split magnets. (Pen drawing made by the scribe and added after the treatise on separate sheet, ink on paper.) From Vienna, Österreichische Nationalbibliothek, Lat. 5969 (second half of the 16th century), fol. 198r.

The accompanying images depict this experimental result by showing the magnets with their respective labeling and in different combinations (Figure 12).[60] In no less than five annotated printed copies of Pererginus's treatise (edited in 1558 by Achilles Pirmin Gasser), several readers—among them none other than John Dee—drew the

59 See Petrus Peregrinus (1995, pp. 74–78).

60 Also in print, for example, in Taisnier (1562, p. 8). Taisnier's work uses Peregrinus's treatise here. Other editions have no images here. See Petrus Peregrinus (1558); Raimundus Lullus (1520).

attraction–repulsion combinations as diagrams (Figure 13), while the edition itself lacked any images here.[61] These readers seemingly performed the experiment by drawing the diagrams on the basis of the text, and Dee even corrected Gasser's edition in two cases where the text got north–south and the variables wrong.[62]

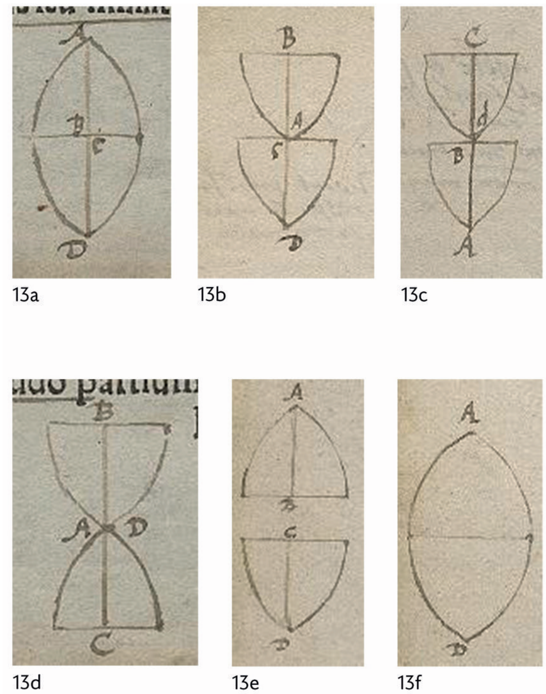


**Figure 13**. Different combinations of split magnets abstracted to half ellipses. Their poles are labeled (A, B, C, D); in most of them the axis is drawn into the diagrams. Here, the magnets hardly appear as physical bodies. (Marginal pen drawings on paper, ink on paper.) From *De magnete* (pp. C4v–D1v), by Petrus Peregrinus, 1558, Augsburg, Germany: Philipp Ulhart (London, British Library, C.54.bb.6—the copy owned by John Dee).

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61 Marginal drawings of oval magnets in different polar combinations are found in Munich, Universitätsbibliothek der LMU München, 0014/W 4 Phys. 535, fols. C4v–D1r; Rome, Biblioteca Apostolica Vaticana, Stamp. Pal. IV.508, fols. C4v–D1v; Wolfenbüttel, Herzog August Bibliothek Wolfenbüttel, A: 160.1 Quod. (1), fol. C4v; London, British Library, C.54.bb.6 (copy owned by John Dee); Cambridge (MA), Massachusetts Institute of Technology Libraries, QC751.P49 1558, fols. C4v–D1r. A total of 37 copies of this edition could be identified in libraries across the globe.

62 See Dee's superscript corrections (in London, British Library, C.54.bb.6)—on fol. D1v, line 1: "Meridionale" corrected to "Septentrionale"; line 6: "A.B." corrected to "B.D." Manuscripts neither add "Meridionale"/"Septentrionale" (line 1) nor refer to the variables (line 6). This is Gasser's (erroneous) addition, it seems.

In other works of the early modern period, the same or similar experiments are also depicted. Some of these give more concrete visual information about the experimental performance (for example, by including a performing hand), divide the magnet along the axis instead of along its equator, abstract the finding to purely geometric shapes, or put the magnet almost on display by depicting it in a naturalistic way as if it was one very specific specimen instead of a generic object (Figures 14, 15, 16).[63]

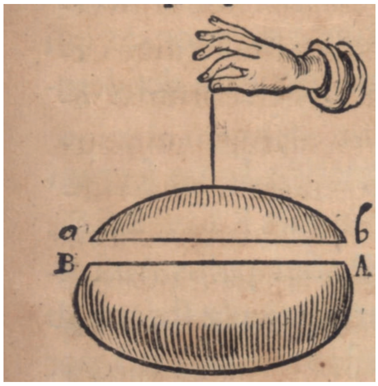


**Figure 14**. A magnet divided along the axis between the poles A and B. Upper part held by a hand using a thread to allow free rotation. Poles are labeled (a, b, A, B). The diagram is schematic but includes a performative feature (hand) and adds hatching to the egg-shaped magnet. (Woodcut print on paper.) From *Principia philosophiae* (p. 279) by R. Descartes, 1644, Amsterdam, The Netherlands: Apud Ludovicum Elzevirium (Berlin, Max-Planck-Institut für Wissenschaftsgeschichte, Bibliothek, Rara D445pr).

63 Similar examples of hands are found in: Descartes (1644, p. 278); Cabeo (1629, p. 81); Madrid, Biblioteca Nacional de España, MS. 2020, fol. 64r. An attempt to depict the split magnet as cuboid is found in Leonardi & Arlensis de Scudalupis (1610, p. 458). A scene of *putti* performing a similar experiment is found in Grandami (1645, p. 115).

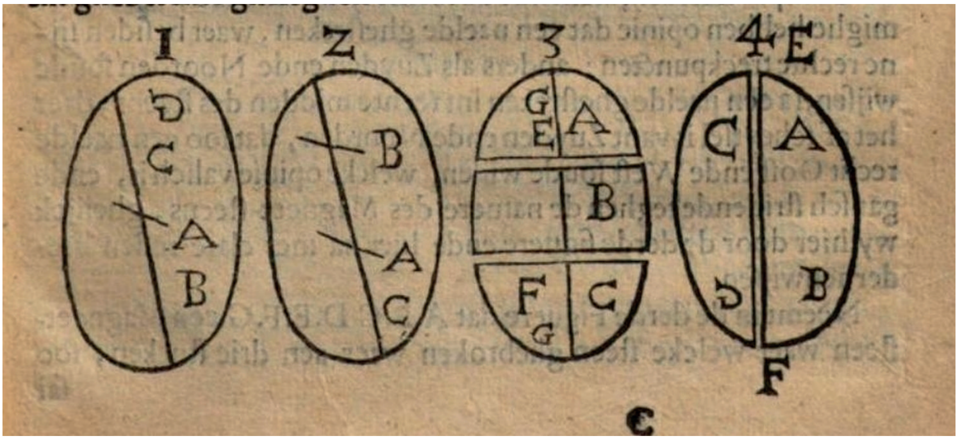


**Figure 15**. Four different modes of dividing a magnet. The magnets are abstracted to oval shapes, featuring various labels for the different parts and poles. (Woodcut print on paper.) From *Het Ghebrvyck der Naeld-vviisinge* (p. 5r), by B. E. Keteltas, 1609, Amsterdam, The Netherlands: Barent Otsz (Amsterdam, Universiteitsbibliotheek, O 60–537).

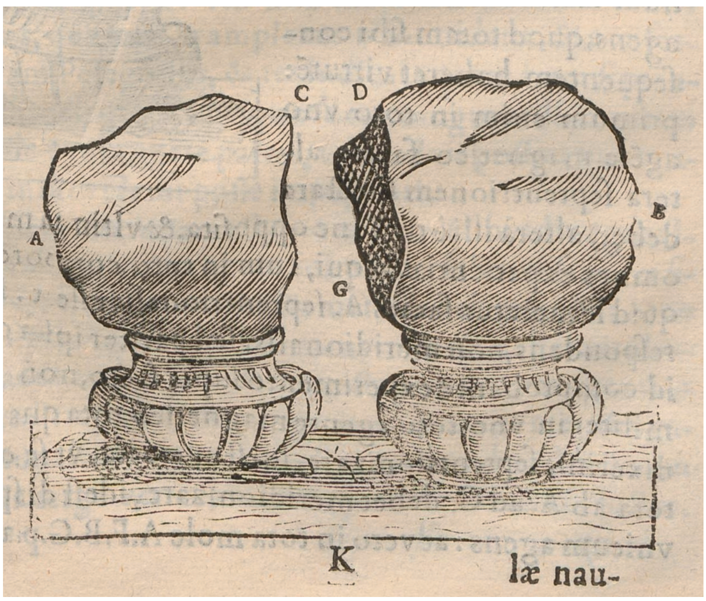


**Figure 16**. A magnet split into two pieces, with both parts placed on sockets. This image has vivid naturalistic features and gives irrelevant details, like the sockets and their ornaments. At the same time, it employs diagrammatic features such as the labeling of the poles and sides (A, B, C, D, G). (Woodcut print on paper.) From *Philosophia magnetica* (p. 109), by N. Cabeo, 1629, Ferrara, Italy: Apud Franciscum Succium (ETH-Bibliothek Zürich, Rar 9125).

But returning to the manuscript copies of Peregrinus's treatise, there is another visual format for the very same experimental finding that is much less figural. Instead of depicting actual objects, scribes abstracted the visual description of the experimental finding to a more textual style of notation (Figures 17 and 18). Pieces of magnets are mere lines that connect the letter labels for the poles. The Latin text of the treatise does not refer to any figures in this context, and the earliest copies of the treatise are not illustrated here either. Presumably, this more abstract notation emerged from the fact that the text employs variables to explain the experiment. Earlier manuscript copies use simple letters connected by lines in the margin, while later copyists have elaborated on this and included them in the main text or more generously at the bottom of the page.[64] Variables of this kind were used frequently in Aristotelian natural philosophy, and similar forms of notation are known from other fields of research at the time.[65] In these variable-based diagrams added to the text, magnetic polarity in its highest degree of visual abstraction is almost turned into a formula, giving an experimental and formal representation of what later scholars would call the "laws" of magnetic polarity.

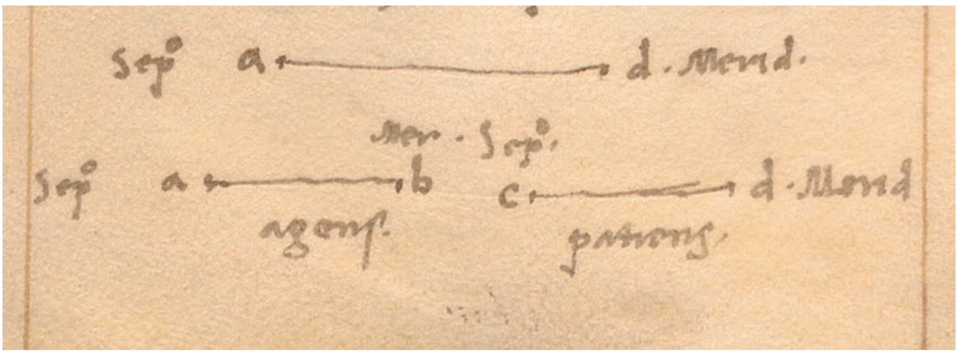

**Figure 17**. Abstracting the magnet, and a magnet split into two pieces through the variables used in the text to denote the poles (ad above, and ab and cd). There are no graphical features in this image except the lines (symbolizing the magnet) connecting the letters of the poles. Cardinal directions (*Sep*. and *Merid*.) and the active and passive role in attraction (*agens* and *patiens*) are labeled. (Pen drawing added at the bottom of the text by the scribe, ink on paper.) From Munich, Bayerische Staatsbibliothek, clm 10275 (first half of the 16th century), fol. 11v.

64 Almost the same schematic representation as in Figure 17 appears in the Peregrinus copy in Rome, Biblioteca Apostolica Vaticana, Pal. lat. 1122 (14th century), fol. 122r (pen drawing added to margin by the scribe, ink on paper). Marginal notes abstract the combination of a magnet split into two pieces through the variables used in the text to denote the poles (a, b, c, d). There are no graphical features in this image. Images bearing a close resemblance to Figure 18 can be found in the manuscripts in Modena, Biblioteca Estense Universitaria, Lat. 1235 (second half of the 16th century), fol. 25v (scheme inserted into the text by the scribe); and in Foligno, Seminario Vescovile, Biblioteca Jacobilli, C III 7 (first half of the 16th century), fol. 11.8r (scheme added to the bottom of the page by the scribe).

65 The use of letters and variables in pre-modern logic and natural philosophy is highly under-researched. See, as a starting point, and mostly focusing on Aristotle's logic or ancient mathematics, Frede (1987, p. 113); Ierodiakonou (2002, pp. 135–136); Mendell (1998, p. 182 n. 48); Netz (1999, p. 21); Wardy (2007, pp. 301, 308, 313).

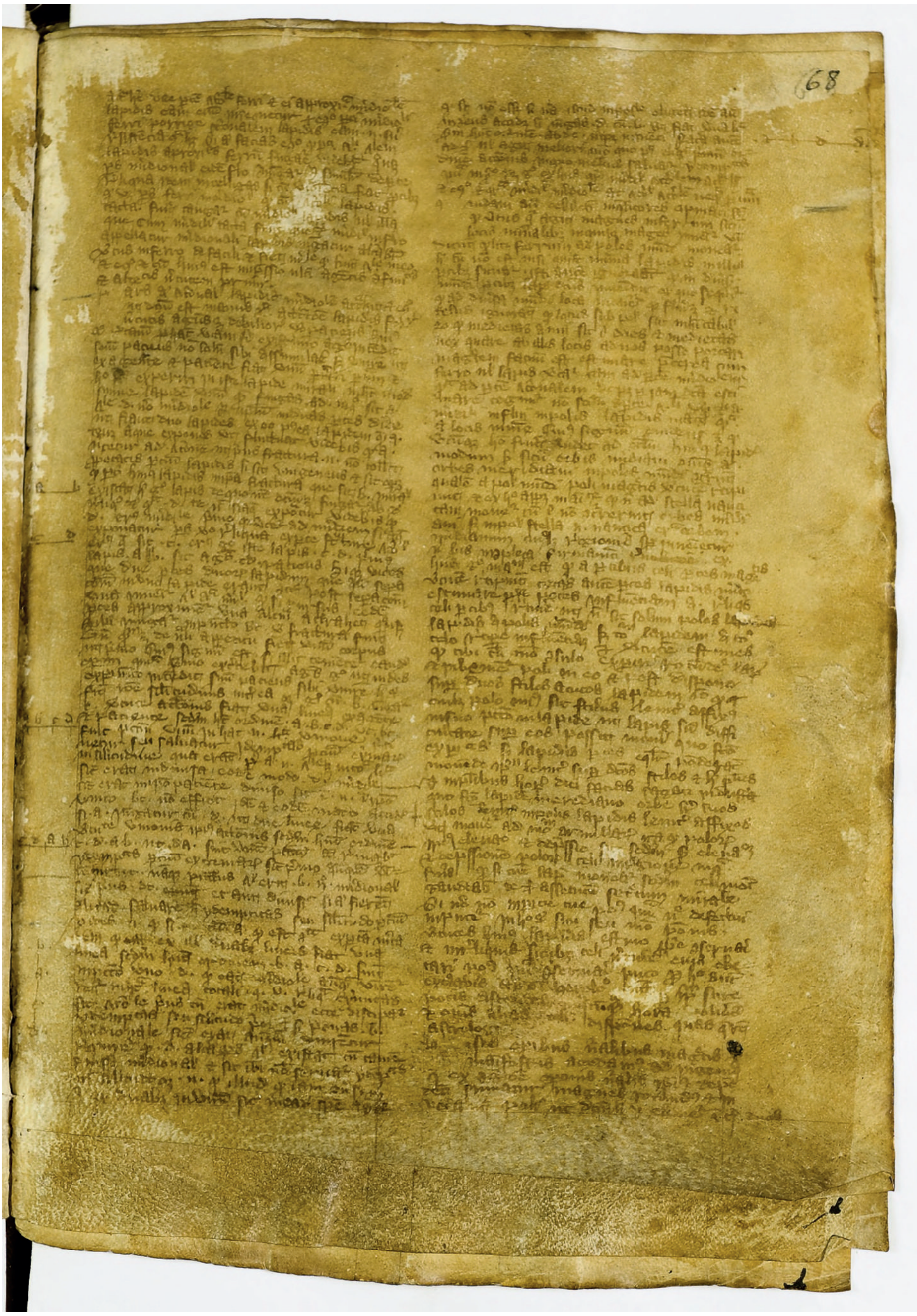

**Figure 18**. Full page with marginal notes abstracting the combination of a magnet split into two pieces through the variables used in the text to denote the poles (a, b, c, d). There are no graphical features in this image except the lines below the variables and the marks on the line for the pieces of the magnet. (Pen drawing added to margin by the scribe, ink on paper.) From Paris, Bibliothèque Nationale, lat. 7378A (14th century), fol. 68r.

### *2.4. Fourth Experiment: Iron Filings Around a Magnet*

The final example discussed in this article concerns an experiment in which iron filings are sprayed around a magnet to observe the pattern of the filings that emerge. This experiment was first concisely described in the 16th century and has no relation to Peregrinus.

The earliest (and rather naturalistic) illustration relating to something similar comes from a work on natural history by Conrad Gesner of 1565 (Figure 19).[66] Gesner does not have a precise experimental or conceptual goal related to the image.[67] He or his draftsman depicted a magnet and an iron needle surrounded by iron filings without any geometrical shape emerging. In the subsequent decades, experiments with iron filings were described verbally a few times.[68]

It was Niccolò Cabeo's *Philosophia magnetica* of 1629 that gave the first visual account of it (Figure 20).[69] His woodcut shows a rather naturalistic image as well, but Cabeo labeled the poles and clearly wanted to make an argument about the shape of the aligned iron filings. Cabeo, explicitly following Garzoni, avoided the concept of occult qualities and instead adhered to the idea of a specific magnetic quality (*qualitas duarum faciarum*) inducing polarity and magnetic effects.[70] Albeit not a quality subject to the senses, his visual and textual rhetoric downplayed the occult and instead presented a visual account of the propagation of the quality that distinguishes his position from the common scholastic approach to magnetism.[71]

Like Garzoni, though different from Gilbert, Cabeo argued that the magnetic force (*vis magnetica*) does not extend from the magnet's center but from both its poles, which is also shown (albeit indirectly) in his depiction of the experiment.[72] For Cabeo and Garzoni, the emerging shape—that is, the magnet's so-called "sphere of activity" (*sphaera activitatis*)—was therefore considered oval instead of spherical, as it was for Gilbert (see also Figures 4, 10, 11).[73]

66 See Gesner (1565, p. 84r).

67 Many sources refer to iron filings as having the ability to conserve the power of a magnet if it is stored covered by them. See Sander (2020a, pp. 65 n. 120, 72, 76, 87, 531, 664, 666, 668); Sander (2021b, p. 300 n. 49).

68 A few decades after him, three important figures of early modern research on magnetism, namely Leonardo Garzoni, Giambattista della Porta, and William Gilbert, verbally described the experiment. But they, again only verbally, also described some pattern that emerged around the magnetic poles. See Garzoni (2005, p. 273); Gilbert (1600, p. 90); Porta (1589, pp. 135, 142).

69 See Cabeo (1629, pp. 18, 316). See also Waddell (2015, pp. 78–80).

70 See Pumfrey (1990); Sander (2020a, pp. 689–693); Sander (in press-a).

71 See Bianchi (1982); Weill-Parot (2013, pp. 27–136); Wild (1906).

72 See Sander (2020a, p. 632). See especially the diagrams in Cabeo (1629, p. 144); Kircher (1641, p. 88).

73 Also explicitly in Kircher (1641, p. 91). On the notion of the "sphere of activity," see Krafft (1970); Jalobeanu (2016); Sander (2020a, pp. 629–632).

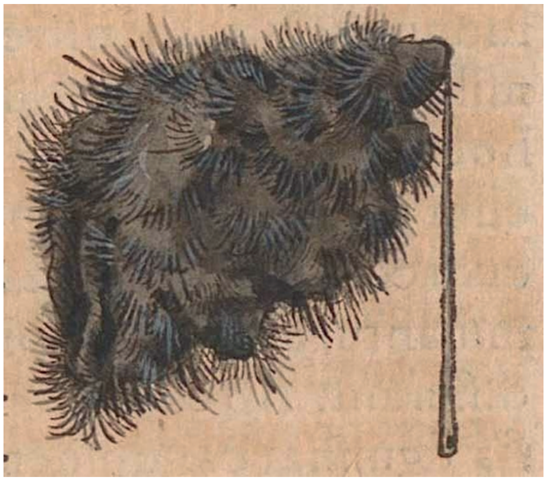

**Figure 19**. Magnet covered in iron filings touching the point of an iron needle. This seemingly naturalistic image is neither a diagram nor does it relate to a concrete experiment described in the text. It rather appears as what was called a "joke of nature," here depicted as the exaggeration of a magnetic hedgehog—the result of an experiment that Gesner or his draftsman might have made. (Woodcut print on paper.) From *De rerum fossilium* (p. 84r), by C. Gesner, 1565, Zurich, Switzerland: Apud Gesnerum (Zürich, Zentralbibliothek, FF 1264).

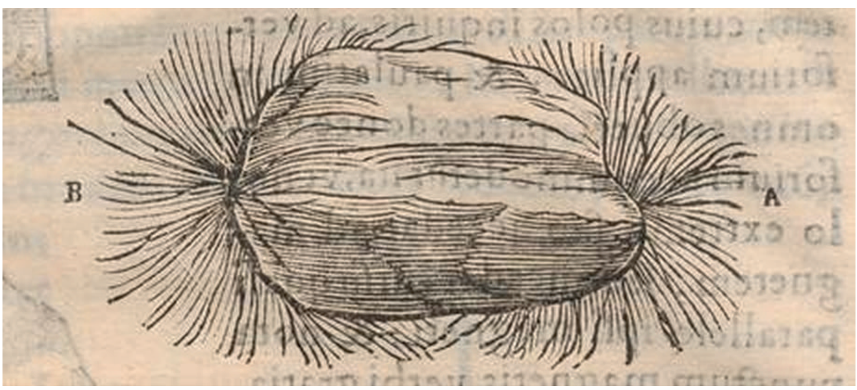


**Figure 20**. Magnet surrounded by lines along which iron filings sprayed around the magnet align. These lines neither show "lines of force" in the modern sense nor do they accurately depict the iron filings used in the experiment, but are something in between the two. While the image appears in a rather naturalistic style (note hatching, irregular shape of magnet, irregularity of lines), it has—like a diagram—labels for the magnetic poles (A and B). (Woodcut print on paper.) From *Philosophia magnetica* (p. 18), by N. Cabeo, 1629, Ferrara, Italy: Apud Franciscum Succium (ETH-Bibliothek Zürich, Rar 9125).

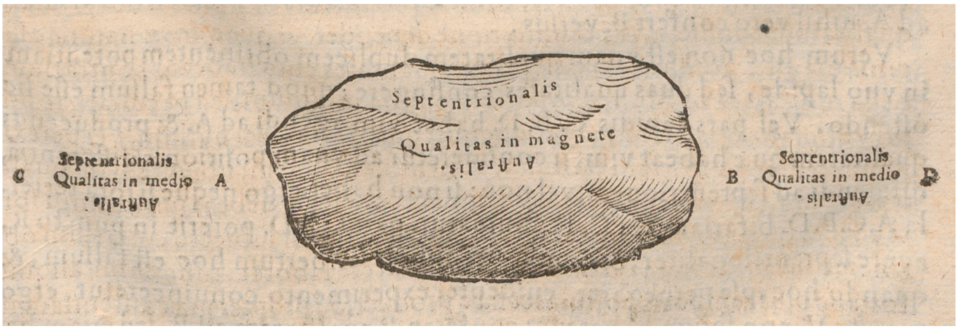


**Figure 21**. Inner structure of magnetic polarity and resulting aligned orientation of (polar) magnetic qualities. Labels distinguish between the quality within the magnet (*in magnete*) and those qualities in the surrounding medium (*in medio*). All qualities have the same orientation (from C to A, from A to B, and from B to D) and both have a north and a south pole. While the magnet in the center is of a naturalistic appearance, the qualities are only represented as text without any geometrical or pictorial aids (in contrast to, for example, Figure 11). (Woodcut print on paper.) From *Philosophia magnetica* (p. 135), by N. Cabeo, 1629, Ferrara: Apud Franciscum Succium (ETH-Bibliothek Zürich, Rar 9125).

With Figure 21, Cabeo even merged results from different experiments—including some of those discussed in this article—into a single diagram that no longer shows any of these experiments, but rather a purely theoretical idea of how magnetic qualities account for polarity and how this polarity is propagated. The diagram gives a topographical abstraction of how the polar structure of the qualities relate to their emission from a piece of magnet with a precise polar orientation. Unlike Garzoni's earlier attempt to represent the same idea (Figure 11), Cabeo gives a geometrical shape neither to the qualities themselves nor to their pattern of propagation and extension.

Cabeo did not use the iron filings experiment to visually infer the paths of the emitted qualities, but depicted the experiment and his theory in two different diagrams. It fell to René Descartes to visually and conceptually combine both the experimental and the theoretical imagery.

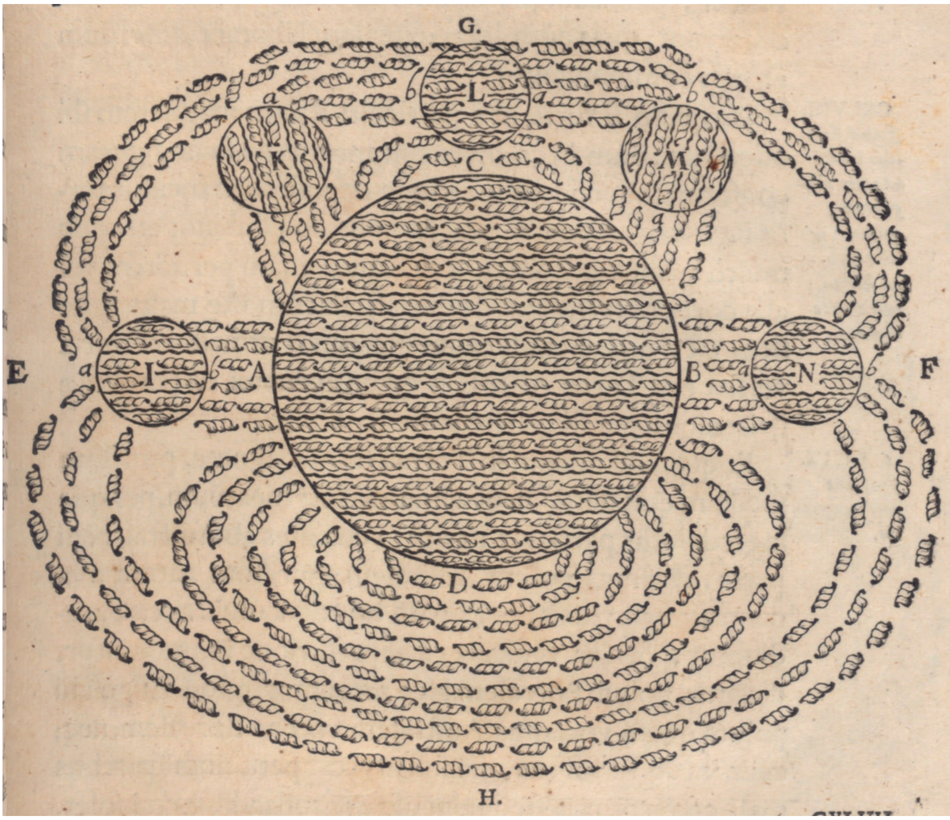


**Figure 22**. The magnetic earth surrounded by five magnetic bodies, all perfused with two symmetrical types of tiny screw-shaped particles flowing in two directions. While the particles form oval orbs outside the bodies, they are channeled into corresponding screw threads within the bodies. Labels indicate the magnetic poles of the earth (A, B and a, b), the magnetic bodies (I, K, L, M, and N), and a few virtual points (G, C, D, and H). This diagram is the visualization of a corpuscular theory of magnetic phenomena, but remotely and indirectly refers to an experiment with iron filings described in the text. (Woodcut print on paper.) From *Principia philosophiae* (p. 271), by R. Descartes, 1644, Amsterdam, The Netherlands: Apud Ludovicum Elzevirium (Berlin, Max-Planck-Institut für Wissenschaftsgeschichte, Bibliothek, Rara D445pr).

In his *Principia philosophiae* of 1644, Descartes used two diagrams showing magnets orbited by tiny screw-shaped particles to visually support his corpuscularian theory of magnetism, which was openly directed against the idea of occult qualities as the cause of magnetism (see Figure 22 for one of these).[74] It is crucial, however,

74 See Sander (2020a, pp. 717–743); Sander (in press-b; in press-d). See also Descartes (1964–1974, AT 8, 313). On Descartes and his scientific imagery, see especially Baigrie (1996); Lüthy (2006); Strazzoni (2015); Zittel (2007, pp. 382–395).

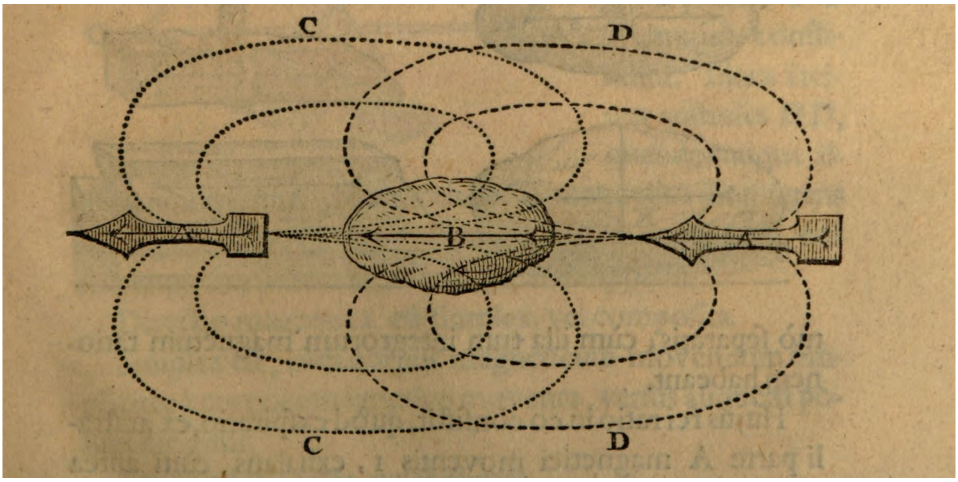


**Figure 23**. Magnet surrounded by two iron needles, with a third needle on top of the magnet. Dotted oval lines represent the flow of particles, being the major element of the causal theory. The labels A and B denote the needles, while C and D are virtual points. The needles must not be confused with arrows indicating a flow direction. They represent the needles' orientation relative to the magnet's poles. (Woodcut print on paper.) From *Fundamenta physices* (p. 133), by H. Regius, 1646, Amsterdam, The Netherlands: Apud Ludovicum Elzevirium (Bayerische Staatsbibliothek München, 4 Phys.g. 142).

that Descartes explicitly referred to an experiment with iron filings in this context.[75] He most likely knew about this experiment through Marin Mersenne.[76] Although he framed this experiment as the empirical confirmation of what is seen in the diagram and accounted for by his theory, it could also be seen as the empirical basis for the diagram. In his view, the iron filings aligned to the paths on which the invisible particles travel around and in between magnets. He abstracted considerably from the experiment in these diagrams. Iron filings would not align on such distinct oval paths. It should also be noted that Descartes depicted the invisible particles themselves and not the iron filings.[77] Moreover, he integrated this experiment and its visual transformation into a natural philosophical argument about the causal explanation of magnetism through corpuscles and their mechanical interactions. Like in Garzoni's and Cabeo's diagrams of emitted qualities (Figures 11 and 21), Descartes' diagram does not just show a magnet or an experiment but a theory of magnetism.[78]

Although not all of Descartes' readers were ready to accept his corpuscularian theory, his diagrams of magnetism became paradigmatic and were copied and adapted

75 Descartes (1964–1974, AT 8, 307–308).
76 See Mersenne (1932–1988, Vol. 8, p. 756).
77 See also Lüthy (2006, p. 120).
78 See, for example, Gabbey (2001, p. 458): “Descartes's explanatory model for the magnet does not represent a magnet: it is a magnet under a Cartesian mechanical reconstruction.”

very often in the second half of the 17th century. Henricus Regius had already advanced the magnetism diagrams of his colleague Descartes when he added compass needles to the depicted experimental setting (Figure 23).[79]

These needles are shown as arrows in the diagram to render visible the polar alignment. At the same time, Regius no longer plotted the particles in detail, but abstracted their flow to mere dotted lines. Similar approaches to abstracting the particles to dots without any distinction or indication of their flow direction are found in later imagery used by other authors.[80]

In some diagrams of this tradition (for example, Figure 24) the labeling and the arrows are omitted altogether, but the context and their by-then almost canonical status nonetheless made viewers understand what they were supposed to see: the extension of magnetic force (*vis magnetica*) or the emission of particles in an oval "sphere of activity."

In another example (Figure 25), from a 1653 work of natural philosophy influenced by Descartes' theory of magnetism, the flow of the two types of particles, which Descartes described and also meant to depict, is reduced to the letters "p" and "q," representing the particles.[81] This illustration completely loses the geometrical aspect of the magnetic vortex and could arguably be seen as a table. As in the case of magnetic polarity, the visual is reduced to something that looks more like a formula than an image of an experiment. And yet it is not to be read as a table with information arranged in rows and columns, but employs the tabular form and the letters "p" and "q" in a way that is iconic: this image resembles the spatial (and not the logical) order of the very thing it aims to represent.

The most extensive visual approach toward magnetism in the aftermath of Descartes was taken by Christiaan Huygens in the many drawings contained in his manuscript notes (for example, Figure 26).[82] His major concern was to determine the direction in which magnetic particles flow through the magnet and the surrounding air. In the example shown, the symbol of the arrow is used probably for the first time to indicate the direction in which the particles flow. These arrows in the drawing are not compass needles; they are placed on a different logical level to indicate the direction of motion.

Just as in the case of the imagery connected to magnetic polarity, in the images relating to the iron filings experiment it was often not the experiment that was depicted but a theory-laden rendering of an experimental finding. The experiment with iron filings eventually led to depictions of magnetism that were more abstract or outright geometrical. The experiment itself was most often not even mentioned

79 See Regius (1646, pp. 130–145).

80 See Sander (in press-d).

81 The quasi-diagram of Maignan (1653, p. 1418) was copied in a manuscript treatise by Niccolò Zucchi, see in Rome, Biblioteca Nazionale Centrale "Vittorio Emanuele II," Fondo Gesuitico 1323, fols. 59r–78r, at fol. 65bisr (new foliation).

82 See especially Huygens (1937, pp. 551–604). Several of his drawings of magnets and his magnetism diagrams have not yet been edited, as can be learned from Yoder (2013). The author of this article intends to publish on this topic in the near future.

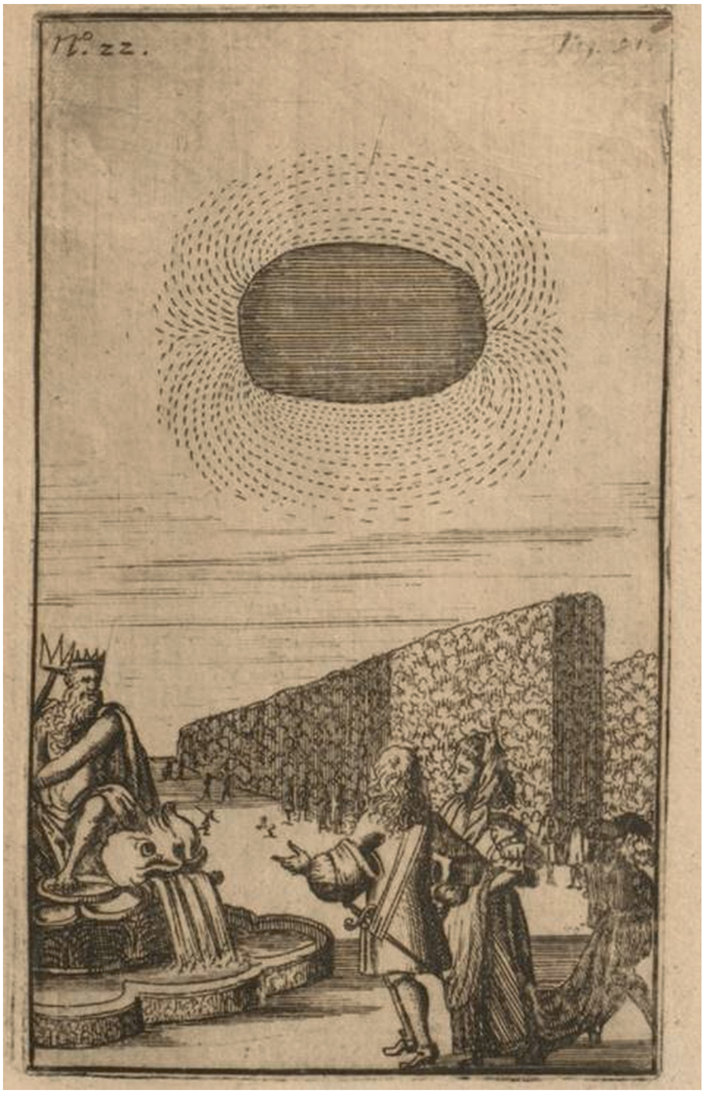


**Figure 24**. Scene of a couple going for a walk in a castle garden, stopping by a fountain, and looking at the sky. In the sky, a magnet is placed with oval orbs (dotted lines) representing the extension of magnetic force (*sphaera activitatis*), based on a corpuscular theory. The magnet has parallel channels represented by many straight vertical lines. This image has no labels but also fails to be a naturalistic account of any magnet or experiment; it rather alludes to an account of magnetism that aims to explain its effects and to render visible the invisible force involved. The work aims at explaining natural philosophy and magnetic experiments to a non-specialist audience in the vernacular. (Intaglio print on paper.) From *Magnetologia curiosa* (Plate n. 22), by J. de Hautefeuille & J. P. Aubry, 1690, Mainz, Germany: Christoph Küchlern (Zentralbibliothek Zürich, NP 1836, 2).

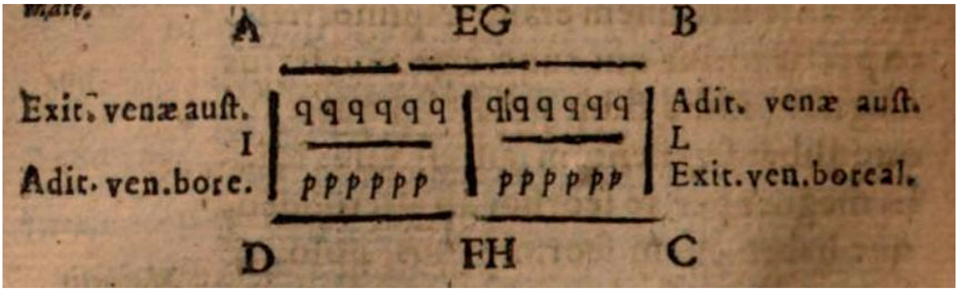


**Figure 25**. Scheme of how particles enter and exit a magnetic body. The magnet ABCD, having its poles at I and L, has two parallel horizontal channels through which the two type of particles, symbolized by 12 q's and p's, exit and enter (*Exitus/Aditus venae*), depending on whether they come from the earth's south or north pole (*australis/borealis*). This image exclusively consists of lines and letters, lacking any figurative—let alone naturalistic—features. This is also mirrored in its production, as it is printed only with moveable type, including the short line elements. (Letterpress print on paper.) From *Pars secunda philosophiae naturae* (p. 1418), by E. Maignan, 1653, Toulouse, France: Bosc (Augsburg, Staats- und Stadtbibliothek, Phil 5019–3/4).

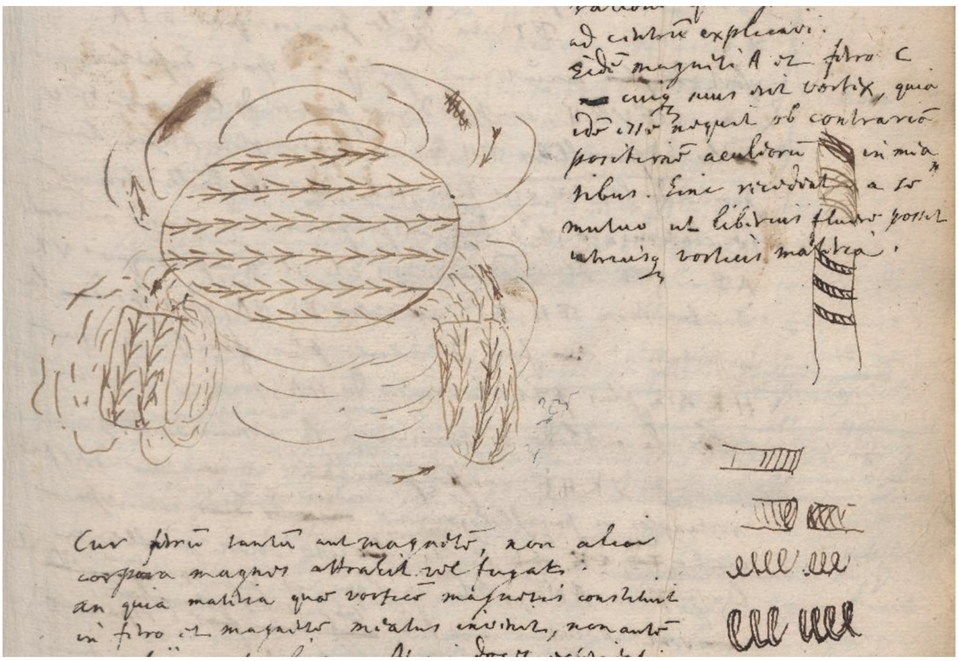

**Figure 26**. Pen drawing of three magnets (one large oval one and two smaller rectangular ones) and the interference of their "spheres of activity," consisting of orbiting particles. Flow direction is marked by five small arrows. Channels running through the magnets have barbs, allowing only one direction of flow. On the right side are detail drawings of the screw shape of the particles, possibly to explore visually how right- and left-handed threads are projected onto a cylinder. The subject of this image is the causal explanation of magnetic effects. This image has no labels but bears features of a diagram through the abstract nature of the matter and the abstract rendering of all elements. (Ink on paper.) From Leiden, University Library, HUG 2 (dated to 1668), fol. 42r.

in the later texts to which the images were added. The invisible particles themselves, their movement, or their direction of flow were not subject to experimental tests, as all of them were unobservable. The implicit rhetoric, it seems, was rather that authors wanted to make their readers understand how magnetism would look if it were visible. Although we cannot perceive magnetism directly, diagrams allowed for a depiction of the material, yet invisible, causes of magnetism.

The Cartesian and post-Cartesian vortex diagrams thereby established a somewhat canonical imagery. As shown by Christoph Lüthy and others, the visual account of invisible particles played an important role for the underlying rhetorical strategies and conceptual assumptions of the corpuscularian theories of the 17th century, and magnetism was no exception.[83] Particles emitted by the magnet were not taken to be invisible per se, but merely unobservable by the naked human eye, which is why some natural philosophers hoped to make them seen under the microscope.[84] Thus, the depictions of these particles in various woodcuts were visual glimpses into an unseen microworld, and the alignment of iron filings was considered indirect proof of their mechanical interaction.

## 3. Conclusion

Sense experience and experiments were implicit conditions for the investigation of magnetic phenomena. The manifest effects of any occult power such as magnetic attraction are only uncovered through experimentation and observation. The visual, non-verbal communication of these experiments and the theoretical conclusions drawn from them led to the emergence of a variety of diagrams in the pre-modern period, starting with the transmission of Peregrinus's *Epistola* in the 13th century. These experiments and their visible results were recorded in diagrams by adding conceptual entities such as poles or qualities by means of textual labels or schematic shapes. These diagrams, in their most complex form, encoded together the experimental performances and results, as well as their underlying forces and causal explanations.

How do these functions relate to the formal and visual features of the imagery discussed in this article? This article claims that linking both the concrete/practical (the experiment to be performed) and the abstract/theoretical (the underlying physical structure to be investigated) demands a hybrid visual language, accessible in what is called a "diagram."[85] Diagrams allow for the visual oscillation and tension between the abstract representation of magnetic force and the more concrete depiction of experiments. These diagrams still depict experiments as spatial arrangements of objects, but at the same time the objects carry markers of abstraction, such as labels (for example, for the magnetic poles) or invisible lines that indicate their movement (like the floating magnet). The variety of diagrammatic forms allows for a gradual,

83 Bellis (2010); Lüthy (2006).
84 See, for example, Smets & Lüthy (2009, p. 436); Wilson (1988).
85 Scholars have already observed this with regard to other early modern epistemic imagery; see, for example, Crowther & Barker (2013, pp. 451–453). See also Cohen (2020.

seemingly natural shift from the experiment to a more general scientific claim or idea that is developed in the text.

The epistemic functions of these diagrams are complex and only a close comparative analysis of the images can bring about a fine-grained understanding of their visual rhetoric and dominant conceptual features. Roughly, "description" and "explanation" can be distinguished as two non-exclusive features of the diagrams. Although this occurs to different degrees, a first common descriptive feature of these diagrams is abstraction. They generalize and schematize by leaving out pieces of visual information and superimposing other types of information. Take as an example the concept of magnetic polarity that had been discovered or coined in medieval times through and vis-à-vis experiments. The notion of polarity had its origins in geometry and was commonly used in astronomy for describing and explaining the rotating celestial bodies and the cosmos.[86] Seen as a metaphor, the source domain of polarity (that is, geometry) is mapped onto the domain of the experimental research on magnetism (that is, magnetic poles). Magnets then appear as bipolar objects. This geometrization is visually expressed, for example, by showing magnets as two-dimensional shapes with letters assigned to their poles (for example, Figures 5 and 13). Some of the visual material discussed even abstracts the experiment almost to the degree of a textual but still iconic formula (for example, Figure 17).

Other diagrams, in contrast, are not that abstract and instead add naturalistic accents—another common descriptive feature of many of the images discussed. Magnets, for example, are depicted as three-dimensional bodies with light and shadow (for example, Figure 16). Sometimes we see a hand or an entire person performing the experiment (for example, Figures 8 and 14). Naturalistic features in the imagery relate to the emphasis in many historical sources of the fact that real experiments were conducted. Some texts even demand the reader to repeat these experiments themselves.[87] In this context, naturalistic images employ a specific visual, "hands-on" rhetoric by claiming an actual engagement with concrete objects. A highly abstract geometrical rendering of the same idea might not evoke this engagement immediately.

The visual features of "concreteness" and "naturalism" serve as a means of virtual witnessing, adding credibility to the experiments and eventually to the theory.[88] The process of abstraction, on the contrary, enables the author or reader to conceptualize magnetism geometrically through an engagement with geometrical shapes, and thereby renders it possible to determine patterns, such as the oval shape of the extension of magnetic force as seen in the alignment of iron filings around a magnet. In different ways and with different combinations of features, diagrams allow authors to spotlight an empiricist and experimentalist rhetoric and to encode very theoretical ideas about the nature of magnetism.

86 See Steinle (2012); Sander (2020a, pp. 282–283).
87 See also Georgescu (2017).
88 See Cunningham (2001).

Both approaches (the abstract and the naturalistic) map onto the research agendas of the creators of these diagrams or of the works they appear in. In this regard, the diagrams also try to explain what is seen in the experiments or to interpret these findings against a theoretical background. Peregrinus thought of the cosmos as analogue for spherical magnets and Gilbert employed spherical magnets as models for the earth, which led both of them to advertise their magnetic experiments as sources of a deeper understanding of the respective modeled entity. In the diagrams connected to their works, and as far as discussed in this article, astronomical analogies and ideas were visually invoked by abstracting magnets to spherical, bipolar shapes, just as the spherical cosmos and the spherical earth appeared in other contemporary astronomical diagrams.[89]

The natural-philosophical causal explanation of magnetism mostly takes a back seat in many of the earlier, medieval diagrams, but is central in some of the early modern ones. In Garzoni's work, we might find the earliest systematic attempt to tie diagrams based on the depiction of experimental results to a concise causal theory of magnetism (Figures 10 and 11). Cabeo, Descartes, and others followed (for example, Figures 22 and 26). The various depictions of magnetic vortices *à la* Descartes had their origin in an experiment, but were soon taken to be the visual rendering of magnetic force and a quasi-mechanical explanation for it. Interestingly, however, similar diagrams could be based on very different metaphysics. A conceptual entity such as the "sphere of activity" could be spelled out very differently in different natural philosophies, but for their respective depictions this difference did not play a major role. Whether a diagram visualized magnetic force as conceptually understood in terms of qualities, forms, particles, or whatever else did not lead to a codified *visual* distinction. All of these entities are invisible to the human eye but could become visible through the diagram as dots and lines, independent of distinctions regarding their metaphysical nature. In the same way, almost identical geometrical diagrams (for example, in optics) depicting the principles of refraction and propagation of light could be grounded on very different ideas about the nature of light; the causal explanation of magnetism did not immediately determine its imagery.[90]

This divorce between the nature of the invisible magnetic force (that is, the "cause" of magnetism) and its visual rendering becomes even more obvious when looking at modern diagrams on magnetism. Contemporary educational imagery (Figures 27 and 28) seems strikingly similar to the historical diagrams on a superficial visual level. These didactic images instruct or even replace experiments that resemble those described by 13th-century experimenters, such as putting two bar magnets in close proximity to experience the forces of attraction and repulsion with your hands. The conceptual frameworks of pre-modern and modern physics are very different, as are the institutional and media contexts of their publications. Yet, the simple experiments and elementary findings remain more or less the same. This has apparently

89 See, for example, Müller (2011); Crowther & Barker (2013).

90 On diagrams in optics, compare, for example, Borrelli (2017); Dupré (2006); Eastwood (1989); Frosini (2013). On the intertwinement of optics and magnetism, see Sander (2020a, pp. 745–749).

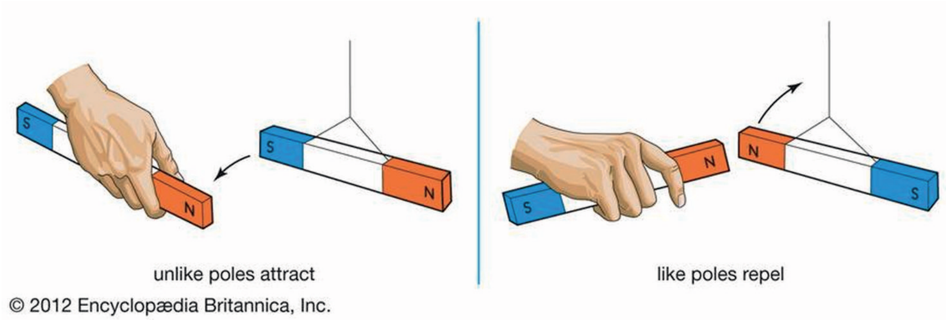


**Figure 27**. Didactic illustration of a magnetic experiment, including a hand holding a bar magnet that attracts (left) or repels (right) a second bar magnet that is hanging by a thread. The forces are indicated by two arrow symbols. Blue and red colors refer to the magnetic poles, which are also labeled on the objects themselves. The image instructs an experiment, but through the inclusion of the arrows also bears elements of a diagram. From "Magnetic Attraction and Repulsion," (n.d.), *Encyclopædia Britannica* (https://www.britannica.com/science/magnetism/images-videos#/media/1/357334/145755).

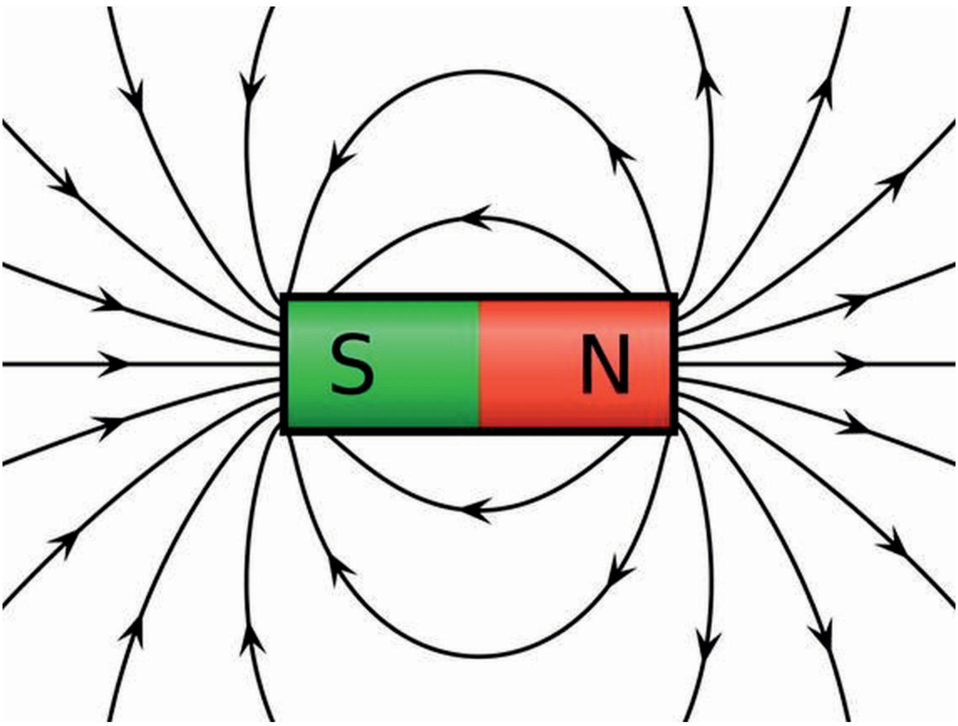


**Figure 28**. Didactic illustration of the magnetic field of a cylindrical magnet. Magnetic flux is indicated by vectors (lines with arrow points). Magnetic poles are labeled (S and N) and color coded (green and red). This is a paradigmatic diagram. From "File:VFPt cylindrical magnet thumb.svg," by Geek3, 2010 (https://commons.wikimedia.org/w/index.php?curid=10587119) (CC BY-SA 3.0).

translated into similar forms of visualization, if seen from a *longue-durée* perspective.[91] The more concrete, instructive, and performative visual features that teach about the experiments are supported by more abstract features that try to depict the underlying foundations of the effects, without being tied to one specific physical explanation of magnetism.

The visual approach needed to combine these "heuristic, expository, and didactic" functions is what we now call "a diagram."[92] The diagram can be seen as "a tool for thinking" (Bigg), as the "Bildtypus des indirekten Sehens" (Bexte), or as "Sichtbarmachung eines Unsichtbaren" (Gormans).[93] As has been shown, diagrams provide some sort of "indirect vision," insofar as you see not just a snapshot of an experiment but insight into what forces are at work and in which formal pattern they act. Thus, the diagram is a form of visual metonymy: at first glance, it shows an effect brought about in an experiment, but it actually aims at visualizing the functioning or the geometrical foundation of this effect. In the case of magnetism, this functioning is invisible per se but made visible in an experiment, which is the performative basis for a diagram. It is exactly that visual information in the diagrams that cannot be visibly seen in an experiment—be it a magnetic pole or a magnetic "quality"—that makes the diagram a diagram and thereby more than just a depiction of an experiment or an object. A diagrammatic reconstruction of an experiment can visualize the invisible and can merge diachronic processes into one synchronous image.

When diagrams loosen their link to the experiment or concrete object that occasioned them, they become independent of these, at least for the viewer. This makes these diagrams "epistemic images" in the narrow sense that Lorraine Daston employs, namely when the image itself becomes the primary object of investigation.[94] The actual object depicted becomes less important, or even dispensable by being replaced by the epistemic image. These diagrams can become a "tool for thinking" properly

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91 Highlighting the similarities should not blur the important differences between pre-modern and modern imagery in magnetism. First, Huygens introduced the arrow as a symbol in magnetism diagrams to indicate the direction in which invisible particles flow. Arrows in modern diagrams of magnetic fields of course do not relate to these particles. Moreover, arrows in modern depictions are also used to indicate attraction and repulsion. They symbolize the movement of the magnet. This use of the arrow is not found in pre-modern sources. Second, what has been compared to logical or mathematical notations or formulas appear similar in appearance but are different in meaning compared to actual formulas. The pre-modern examples are still iconic and resemble the spatial arrangement of the objects the letters refer to. The syntax of these notations is not as strictly logical as, for example, notations in formal logic or mathematics are. Moreover, they in no way exhibit any attempt to make magnetism accessible to quantification, which is done in modern physics. Third, modern illustrations almost always use the canonical color coding of the magnetic poles as red and blue. This is alien to pre-modern visualizations. Diagrams in medieval manuscripts are often colored, which sometimes includes those on magnetism. But there is no case in which color was used in order to denote a magnet's poles.

92 Bigg (2017, p. 562).

93 Bexte (2007); Bigg (2017, p. 562); Gormans (2000).

94 See Daston (2015, p. 17): "made with the intent not only of depicting the object of scientific inquiry but also of replacing it. A successful epistemic image becomes a working object of science, a stand-in for the too plentiful and too various objects of nature, and one that can be shared by a dispersed community of naturalists."

speaking, insofar as they act as models to represent reality.[95] Peregrinus, Gilbert, and others employed magnets as experimental models, and yet the diagrams connected to these experiments could also become models in their own right.[96] Diagrammatic accounts of polarity, of magnetic inclination, or causal explanations can especially perform this function: they can be used to predict, to some extent, the behavior of magnetic bodies or to provide a visual understanding of a causal theory or hypothesis.

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95 There has been much published on this aspect of diagrams. With a focus on visualization, see Downes (2012); Giere (1999; 2004); Goodwin (2012). Giere (1999, p. 44) defines models as "tools for representing the world," lists diagrams as one type of model, and rightly emphasizes the need to pay attention to actual scientific practice when reconstructing what models are for and how they are used in the sciences. With a stronger historical focus on the pre-modern sciences, see, for example, Borrelli (2017); Franklin (2000); Lattmann (2019).

96 See above: Peregrinus considered a spherical magnet to be an analogue for the cosmos, Gilbert and his followers used a spherical magnet as a miniature of the earth. Yet, these conceptions are not inherent to their diagrams. Gilbert's dip diagrams can be used as models or "visual tools" independently of his metaphysical claim—and indeed they were, for example, by Cabeo, who did not subscribe to Gilbert's thesis that the earth is a round magnet.

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