CHAPTER 7

Terra AB: Descartes's Imagery of Magnetism and Its Legacy

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In *The States and Empires of the Sun* (1662) by Cyrano de Bergerac (1619–1655), the hero of the story is suspected of heresy and one of the books in his possession, *Principles of Philosophy* (1644) by René Descartes (1596–1650), is inspected by an unlearned mob intent on further incriminating the suspect.[1] The book falls open to reveal a woodcut printed inside:

> He that held it in his Hands, seized with a panick fear, let it [the *Principles*] fall; and by mischance, it opened at a Page, where the Virtues of the Load-stone are explained: I say, by mischance; because, in the place I speak of, there is a [wood] Cut of that Metallick Stone, where the little Bodies, that are let loose from the whole, to fasten to the Iron, are represented like Arms.[2]

Within the logic of the fictional narrative, the chances of the book randomly falling open in the section on magnetism were good: it is, in fact, the longest section on one specific topic in the whole volume.[3] If we assume that it was the Latin edition that was inspected, the book probably fell open either on page 271, 273, or 274.[4] All three of these pages feature a printed woodcut showing the famous diagram related to the Cartesian theory of magnetism (Fig. 7.1).

At the centre of the diagram, the Earth is shown as big spherical magnet with the poles at A and B, surrounded by five smaller spherical magnets (I-N). Many particles in the shape of tiny screws are shown travelling on elliptical orbits around and through the magnetic bodies that are perforated by channels imagined as threads.[5] Descartes's sophisticated theory, and the "visual persuasiveness" of the diagrams used to communicate this theory, have already been the subject of a few studies.[6] Yet, the realization of this particular diagram and its conceptual underpinning has been given only cursory attention, mostly with the aim of showing how diagrams and visual references were used to elucidate Descartes's theories in general, rather than for what it tells us specifically about coeval theories of magnetism.

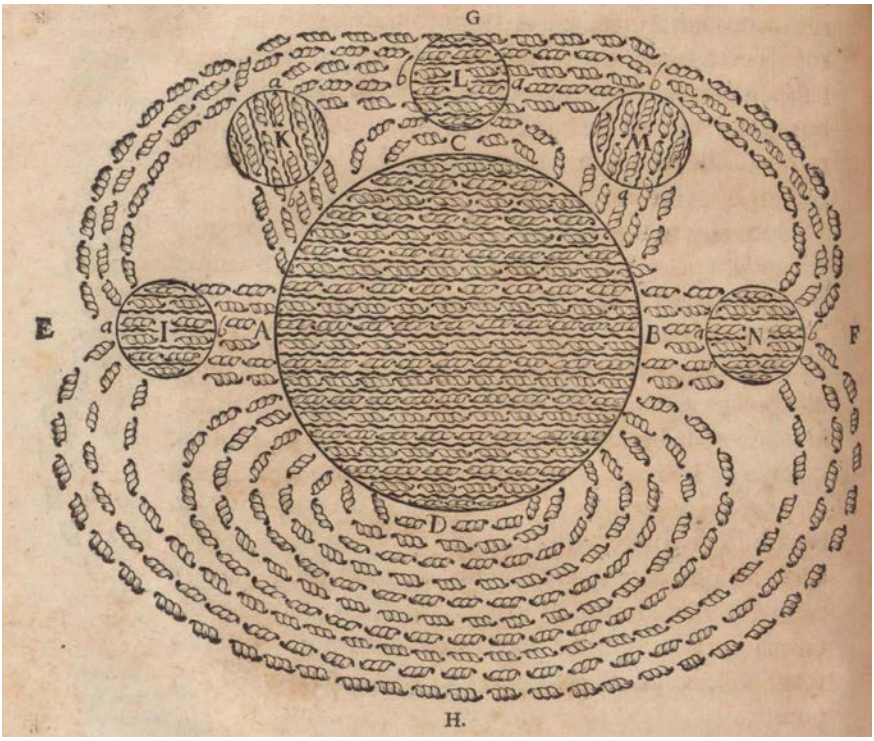

FIGURE 7.1 Descartes's "Terra AB." Descartes, *Principia philosophiae*, 271. The same woodblock (hence Fig. 7.1*) was reused in Regius, *Fundamenta physices*, 131
SOURCE: BERLIN, MAX-PLANCK-INSTITUT FÜR WISSENSCHAFTSGESCHICHTE, BIBLIOTHEK, RARA D445PR <HTTP://ECHO.MPIWG-BERLIN.MPG.DE/MPIWG:D1EAAM5H>

The true hero of this chapter is Descartes's diagram of the magnetic Earth, to which the Latin text of the *Principles* refers as "Terra AB."[7] It is well known that this magnetism diagram informed later theorists, possibly leading even to the visual structure of magnetic field lines in the nineteenth century.[8] We will sketch how this diagram came to be, how it relates to the textual description of Descartes's theory, what inherent problems the underlying idea of the diagram presents, and how later scholars engaged with the diagram or similar forms of it. Such micro-history is justified by the status of *Terra AB* as one of the most famous images in the history of early modern science not yet to have been the proper subject of any historical study. A detailed study of this image and its embedding reveals the considerable care and thought that was put into its creation and later adaptations.

1 The Creation of *Terra AB*

Before focussing on the *Terra AB* diagram, it may be instructive to briefly explain the underlying theory and its background. Within Descartes's writings, his theory of magnetism is given its first and only expression in the *Principles*.[9] In the first three parts of this book, Descartes develops a small set of explanatory principles and plausible hypotheses through which to explain all natural phenomena; the aim is to thereby develop physics in a reductionist manner.[10] In his view, the phenomena of the natural world can be explained by the mechanical interaction of invisible, yet divisible compounds of matter which have certain geometrical and kinematic properties.[11] With regard to magnetism, Descartes explicitly puts forward his theory against what he considered to be the standard Aristotelian or Galenic account of magnetic attraction. These standard accounts are oversimplified and generalized by Descartes as the theories of 'occult qualities' and 'sympathy.'[12] In opposing them, he emphasized that 'occult qualities' and 'sympathy' were nothing but names, inexplicable by definition, and thus not helpful as concepts in physics.

Descartes's own explanation, on the other hand, is grounded on the assumption that invisible mechanisms underlying natural phenomena can be inferred from visible mechanisms by analogy, because the unobservable microscopic interactions of particles obey the same physical laws that apply to all bodies.[13] According to this account of the microscopic mechanical interaction of particles, magnetism then is nothing more than the collision of tiny pieces of matter, given their geometrical and kinematic properties. Although ancient atomists argued for similar theories – as did Henricus Regius (1598–1679) and Isaac Beeckman (1588–1637) among his contemporaries – Descartes's theory is original.[14] Here, for the first time, we are presented with an account for a large set of no less than thirty-four magnetic properties. Descartes explains the precise shapes of the particles in a novel way, and, most importantly for the purposes of this chapter, he depicted his theory in diagrams. He followed William Gilbert (1544–1603) and others, moreover, in claiming that the Earth itself was a giant magnet.[15] Thus, he was particularly interested in explaining what we today would call 'geomagnetic phenomena.'[16]

But what does his theory look like more concretely? Descartes postulates a subtle matter that pervades all seemingly solid bodies.[17] In the case of magnetism, he assumes compounds of matter as screw-shaped particles which he calls "particulae striatae."[18] However, the notion of a 'screw' here must not be understood anachronistically; they are not to be construed as fastening together two things.[19] Any magnetic body, even the Earth itself, has a certain

sphere of activity limiting its interaction with other magnetic bodies. This sphere is defined by the radius in which the screw-shaped particles travel on their orbits around their 'host.' These screw-shaped particles can enter corresponding threads that run through magnetic bodies. It is magnetic bodies alone that can interact in this way, because only their interior threads fit these screw-shaped particles. The particles, for example, cannot simply enter a piece of wood since there are no matching threads. Both the screw shapes and the corresponding threads, moreover, are either left-handed or right-handed (i.e., clockwise or counter-clockwise), allowing a turning motion in one direction only. Descartes thereby tries to use the shape of the screw to explain magnetic bipolarity through the binary logic of a screw.[20] The magnetic North or South Pole of the Earth (and any magnet) is defined as the side of a magnet which either receives the left or right-handed screw-shaped particles coming from either the North Pole or the South Pole of the Earth.

The Earth in *Terra AB* (Fig. 7.1) is depicted 'on its side,' the polar axis running horizontally from left to right, contrary to the vertical orientation more familiar to us from maps. As the central piece of his visual approach to magnetism, we find in *Terra AB* many elements of the theory clearly illustrated: We see particles orbiting the Earth, building a sphere of activity; a close look also reveals the two types of particles, shaped either as right or left-handed screws. These two types of particle form two different streams, going from A to B or from B to A, traversing the surrounding air and partly penetrating the five magnets (I–N) in the periphery. These streams, and their corresponding channels, alternate longitudinally across the Earth. The threads are rendered more simply as parallel, slightly undulating lines. One detail not indicated in the *Terra AB* image itself is the direction in which the particles flow. By visualizing Descartes's theory slightly differently (Fig. 7.2), however, we see four pairs of options whereby particles may enter the alternating channels (marked ✓ in the Figure) or be unable to do so (marked × in the Figure). As can be seen, right and left-handed screw-shaped particles (coloured green and red, respectively) can enter only those threads that are correspondingly right or left-handed also. Whether or not they can penetrate depends on whether the channels are running in the apt direction, here visualized by open and closed channels (while Descartes imagined that the channels have tiny barbs that exclude the possibility of entry in the wrong direction or of backflow).

How did Descartes arrive at his *Terra AB* diagram? In early 1644, Descartes presumably met with Frans van Schooten the Younger (1615–1660). It was Schooten who made the woodcuts, the production of which even caused some delay to the publication of the *Principles*.[21] Further details about the

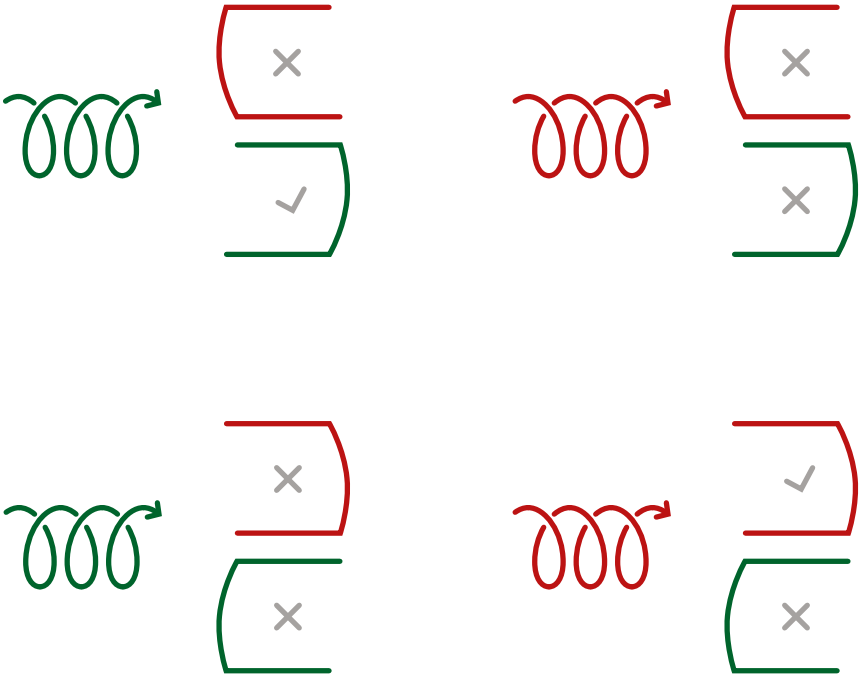

FIGURE 7.2 Left and right-handed screw-shaped particles in combination with apt threads in the magnet
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cooperation between the two men are unavailable, but we know that Descartes had drawn magnetic particles before. The earliest explanation of his theory of magnetism, including his idea of screw-shaped particles, occurs in a May 1643 letter to Constantijn Huygens (1596–1687).[22] This letter can still be found in an autograph version and includes one pen drawing (Fig. 7.3).[23] Descartes's drawing is his first attempt to depict the invisible corpuscular structure of a magnetic body.

Descartes refers to the image in his letter by way of its labelling "ACBD" and uses it to account for an experimental finding that cannot be fully described in this chapter but which has to do with an iron needle that aligns always in the same direction when placed in a C to A orientation. He assumes that the particles, depicted as short stripes, pass through the needle, shown as the rectangular bar "ACBD" in the image, in a diagonal, inclined direction, i.e., from B to A.[24] Here, he firstly drew magnetic particles, but does so in a highly abstract way, not showing any orbits or particle shapes, even though these elements of his theory are already given an introduction in the letter's text. The 1643

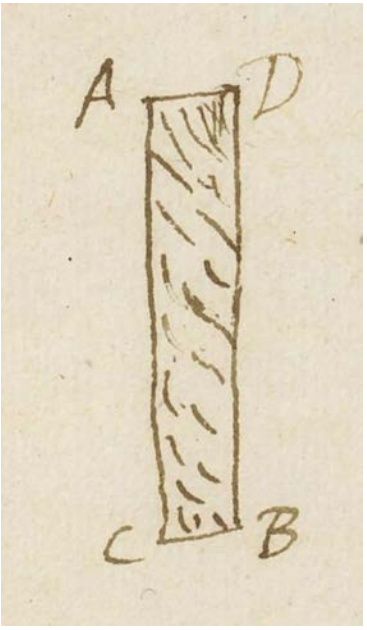

FIGURE 7.3
Descartes's pen drawing of particles in a magnetic needle (ACBD)
SOURCE: PARIS, BIBLIOTHÈQUE NATIONALE DE FRANCE, MS. 23084, FOLS. 169R–170R: *DESCARTES TO HUYGENS* (MAY 1643), FOL. 170R <HTTPS://GALLICA.BNF.FR/ARK:/12148/BTV1B525117890/F353.ITEM>

drawing thus differs from the *Terra AB* of 1644. While the latter gives a visual account of several theoretical elements, like the screw shapes and their orbits, these elements are not visually represented in the letter of 1643 but are only described in the text.

A missing link between the diagram in the letter (Fig. 7.3) and *Terra AB* (Fig. 7.1) can arguably be found in a third image (Fig. 7.4), printed as a woodcut on page 276 and again on page 290 in the *editio princeps* of the *Principles*. This diagram is particularly related to Descartes's theory of magnetic attraction and repulsion, while his *Terra AB* is mainly invoked in explanations of magnetic direction, i.e., the alignment of magnets and compass needles to the North-South axis of the Earth.

This diagram shows two magnets (O and P) with their poles at A/B and a/b aligned to attract one another. The particles are flowing through the magnets in parallel channels, but the shape of the particles is this time highly simplified – abstracted to triangles –, still indicating two different particle types (and presumably also their direction of flow) but not relating to their configurative logic, whether we are dealing with left or right-handed screws. Like in the *Terra AB*, the elliptically orbiting streams consisting of these particles alternate with regard to their direction (north-to-south vs. south-to-north, relative to the magnet's poles) and their particle type (right vs. left-handed screw-shaped particles). Leaving aside the precise mechanism of attraction,

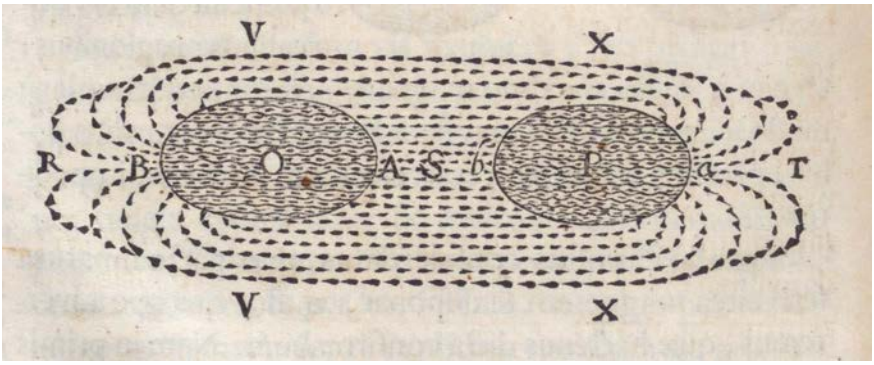

FIGURE 7.4 Two magnets surrounded by orbiting particles. Descartes, *Principia philosophiae*, 276
SOURCE: BERLIN, MAX-PLANCK-INSTITUT FÜR WISSENSCHAFTSGESCHICHTE, BIBLIOTHEK, RARA D445PR <HTTP://ECHO.MPIWG-BERLIN.MPG.DE/MPIWG:D1EAAM5H>

this diagram is of particular significance for how it relates to the accompanying text. Descartes tells the reader about an experiment that would confirm his theory and make visible the otherwise invisible paths on which the particles travel.[25] If one puts lightweight iron filings around a magnet, they settle into a pattern that matches the shape of the elliptical orbits. This is, roughly, what the diagram shows as well, especially as the experimental setting described is then, like in the diagram, extended by a second magnet, which supposedly shows that the particles move through both magnets as one (*quo pacto particulae striatae per istos duos magnetes tanquam per unicum moveantur*). In the diagram this is depicted through the parallel streams in between the two magnets. The filings are not equated with the invisible particles but are taken as a means to determine the pattern of movement of the latter.

In observance of the programme set out in the first two parts of his *Principles*, Descartes presents the relation between experiment and theory as a deductive link. The experiment does not give rise to the theory but corroborates it – the experiment is a way of confirmation not of discovery. As has often been noted, Descartes does not always quite live up to this deductive aspiration subsequently in the *Principles*.[26] While his pen drawing of 1643 (Fig. 7.3) seems entirely theoretical, insofar as the flow of the particles is deduced and not inferred from any experiment, in his imagery of 1644 (Fig. 7.1 and Fig. 7.4) it seems plausible that Descartes may have performed or read about an experiment before formulating his idea about an orbit of flying particles and making the drawing – or instructing van Schooten to make the drawing – as printed

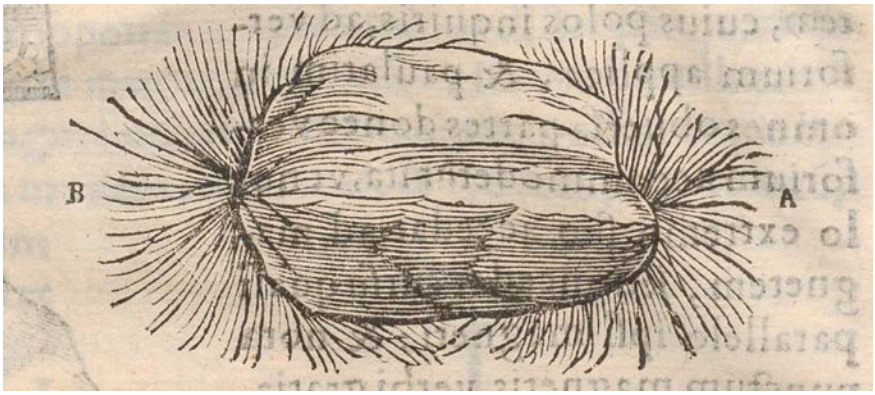

FIGURE 7.5 Magnet surrounded by iron filings. Cabeo, *Philosophia magnetica*, 18
SOURCE: ETH-BIBLIOTHEK ZÜRICH, RAR 9125
<HTTPS://DOI.ORG/10.3931/E-RARA-42143>

for the first time in the *Principles*. There is additional support for this claim beyond the text of the *Principles*.

Descartes was neither the first to describe nor depict experiments with magnets and iron filings.[27] Yet, the only publication possibly known to him and illustrating a similar experiment – the *Philosophia magnetica* (1629) by Niccolò Cabeo (1586–1650) – gave a more naturalistic visual account (Fig. 7.5) that did not show the iron filings rendered as full ellipses.[28]

The image shows a magnet – shading creates the impression of a three-dimensional object – with its poles at B and A surrounded by lines indicating the pattern into which iron filings would settle when deposited around the magnet: a much more naturalistic rendering than the discrete ellipses depicted in Descartes's *Principles*. This does not constitute an argument for or against Descartes having performed an iron filings experiment himself, but it is interesting to note that Marin Mersenne (1588–1648) compiled – probably in 1639 – a list of thirty-two magnetic phenomena and sent it to Descartes while he was already working on his *Principles*.[29] On this list, Mersenne described an experiment that might have prompted Descartes to think about or to conduct the iron filings experiment described above:

> If you attach iron filings to the north pole of a magnet and immediately the north pole of another magnet approaches, the iron filings will ruffle up and flee from its enemy, and if some wind blows strongly, when they have turned up, they likewise also move to the south pole in the opposite direction, like friends.[30]

There is another clue, moreover, to support the idea that Descartes might have used additional empirical evidence to create his *Terra AB*. If one looks more closely at the magnets K, L, and M above the big central magnet in *Terra AB* (Fig. 7.1), one finds that the channels in these surrounding magnets are inclined at variable angles with respect to the axis AB. These angles of deflection are present too in Descartes's other diagram (Fig. 7.4), but are more clearly observed in the magnets surrounding *Terra AB*, as particles within the magnets travel not on elliptical lines but on straight parallel lines. This detail has meaning and significance that was nevertheless completely overlooked in the scholarship.

Terra AB above all visualizes what is called 'magnetic inclination' – what today is understood as the angle formed between the Earth's surface and the Earth's magnetic lines which vary according to the observer's location on the Earth's surface; what in Descartes's time was understood as the inclination of a pivoted compass needle below or above the horizon, i.e., in an upward and downward direction – also called 'magnetic dip.'[31] This phenomenon, discovered early in the sixteenth century, was accounted for geometrically by William Gilbert in his *De magnete* (1600), which was clearly known to Descartes.[32] Mersenne did not discuss this in his list sent to Descartes but added it upon request when, only weeks before the publication of the *Principles*, he published his list in his *Cogitata physico-mathematica* of 1644.[33] Here, the magnetic inclination is also depicted (Fig. 7.6).

As shown in Gilbert's diagram (Fig. 7.7), iron needles moved across the surface of a spherical magnet (or the Earth) form different angles in relation to the surface depending on their latitudinal location if projected onto a plane. According to Gilbert's observation and theory, only at the poles (B and C) is the

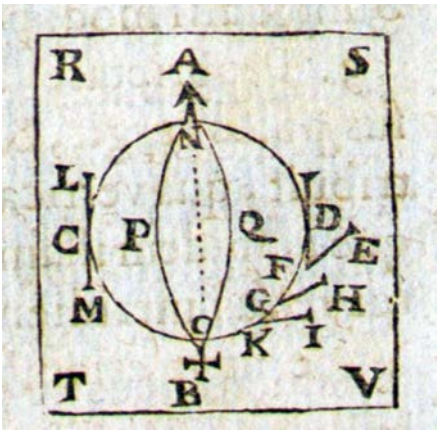

FIGURE 7.6
Diagram of magnetic dip. Mersenne, *Cogitata physico-mathematica*, 247
SOURCE: BAYERISCHE STAATSBIBLIOTHEK MÜNCHEN, 4 MATH.U. 73 <HTTP://MDZ-NBN-RESOLVING.DE/URN:NBN:DE:BVB:12-BSB10525691-7>

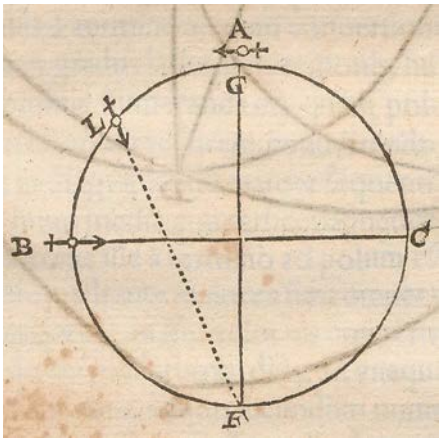

FIGURE 7.7
Diagram of magnetic dip. Gilbert, *De magnete*, 197
SOURCE: ETH-BIBLIOTHEK ZÜRICH, RAR 1253 <HTTPS://DOI.ORG/10.3931/E-RARA-8370>

needle perpendicular, hence pointing to the magnet's centre. Gilbert argues that it is at these two points, i.e., at the poles, where the attraction is the strongest. At the halfway point (L) between the equator (G) and the pole (B), a needle catches with less force and by such deflection that it aims at the opposite side of the equator (F), while at the original point on the equator (visualized at A), under minimal force, it aligns parallel to the polar axis (BC). By repositioning at different points from A through L to B, the needle rotates by 180 ° – thus a non-linear rotation with respect to the length of the circular arch. In his *Principles*, Descartes simplifies the empirico-geometrical accounts of Gilbert and Mersenne and for the first time tries to give it a corpuscular explanation.[34] He tentatively depicts this magnetic dip in his *Terra AB* (Fig. 7.1), where the magnets I and N stand perpendicular to the equator of the central magnet, but fully aligned to the poles A and B, with particles streaming right to the centre of the central magnet. At the point on the equator indicated by C, magnet L aligns parallel to the axis AB. No particles enter here at all. The channels in magnets K and M resemble the angle of point L in Gilbert's diagram (Fig. 7.7). These similarities clearly indicate the strong dependence of Descartes's diagram on Gilbert's diagram and its underlying geometrical account.

This micro-analysis reveals the *Terra AB* diagram as a complex amalgam of theoretical and empirical elements. The idea of a screw-shaped particle is derived from Descartes's natural philosophical hypothesis: this particular shape explains the principle of correspondence and polarity in a way of "visual reductionism," to use Christoph Lüthy's term.[35] Particles travelling on circular paths are somewhat a feature of theoretical traditions and were clearly prefigured by ancient theories as well as by Beeckman and Regius. The precise arrangement of their elliptical paths is not completely deduced, however, but

seems to originate from an experimental finding that Descartes had read about and that he might have reproduced himself. The same holds true for the implementation of Gilbert's account of magnetic dip.

Lüthy has already argued that it is in Descartes's imagery on magnetism that the shift from logical necessity to visual persuasion becomes most apparent.[36] Érico Andrade has argued that in order to save his theory of magnetism, Descartes's even contradicts his own laws of motion.[37] Regardless of the rhetorical ways in which he presented it, Descartes's theory of magnetism has a rudimentary empirical foundation in some of its aspects that also informs its imagery. Whilst it has empirical grounding, a key feature of his *Terra AB* is that it is used not to depict an experimental finding but to depict its explanation. Descartes's woodcut is not designed to facilitate the comprehension of an experiment but to help guide an understanding of the textual explanation of the phenomenon, adding substantial visual persuasion and fascination for his readers who were invited into a world of invisible particles made visible, the shapes and properties of which were described as underpinning the governing of all sorts of natural phenomena.

2 The Impact and Legacy of *Terra AB*

Having sketched the background of Descartes's *Terra AB*, we now trace the earliest reception of the image. This particular diagram, or, more broadly, its form and mode of depicting magnetism, had a huge impact on late-seventeenth-century theories of magnetism. Moreover, it will be shown that some of the images that might look very similar to Descartes's *Terra AB* are nonetheless embedded in theories that significantly deviate from, or even contradict, Descartes's theory of magnetism.

As is discussed elsewhere, Henricus Regius played an important role for the emergence of Descartes's theory of magnetism as presented in the *Principles*, to such an extent that Regius might have inspired Descartes or have even developed a theory of magnetism before Descartes which the latter tried to prevent from being published.[38] Considering the close collaboration between the two scholars in the years before the publication of the *Principles*, moreover, there is little wonder that Regius's own physics textbook, the *Fundamenta physices* of 1646, presents an account of magnetism which at first glance seems to be a copy of Descartes's ideas.[39] Descartes in fact accused Regius of having simply copied from his *Principles*, although he does not specify this charge by pointing to the section of magnetism.[40] This charge of plagiarism – if this term can be applied to historical cases like this – seems also justified when looking at their

respective use of images. For Regius's in-quarto edition, the Elsevier print shop re-used some of the woodcuts of the in-quarto *Principles*; for the section on magnetism, however, only the woodblock of Descartes's *Terra AB* was re-used (Fig. 7.1*).[41] All other images in the magnetism section of the *Fundamenta* were novel and depict magnetism in ways different to those presented in the *Principia*.[42]

There is, however, a peculiar difference between the diagrams used by Descartes and those used by Regius. Except for indicating the poles simply by letters, there is no graphical indication used in Descartes's diagrams (Fig. 7.1 and Fig. 7.4) to distinguish between the magnetic north pole and the magnetic south pole of any given magnet. Although we see different types of particles, their direction of flow is not indicated and the polar axis is made visible only through the parallel channels running through the magnet. Regius used the identical *Terra AB* diagram to explain the magnetic 'vortex' with reference to the "particulae striatae" and other *explanantia* unmistakeably derived from Descartes's theory. In the text, he also referred to the two types of particles and depicted these "particulae striatae" in a different section as close-ups, which is something that Descartes had not done.[43] By contrast with Descartes, however, there are some other diagrams in which Regius employed a different visual representation to indicate polarity (Fig. 7.8–Fig. 7.10). In these, the polar alignment is represented by aligned iron needles, and not by channels within the magnet. On top of each oval piece of magnet, an iron needle indicates the magnet's polar constitution, sometimes in addition to the letter labels (Fig. 7.9 and Fig. 7.10), and sometimes instead of them (Fig. 7.8). These magnets are depicted singly, not surrounded by further magnets, but by iron needles that align in correspondence to the magnetic poles. Regius also depicted the magnetic dip or inclination with the aid of iron needles arranged around the magnet (Fig. 7.9). As explained above, this is a feature which in Descartes's *Terra AB* is only implied.

Regius did not depict the single particles or the threads inside the magnet but abstracted their flow to a few dotted-line ellipses, with no symbolic or graphical information about the shape or flow direction of the particles. He did not use the arrows to indicate the direction of the flow – they are not used as symbols, but depict physical objects within the experimental setting, indicating the polar orientation of the magnet and/or of the iron needles surrounding the magnet. These arrows resolve the obscurity found in Descartes's images as to the distinction between the north and south poles; a magnetized iron needle pointing to the north pole gives an altogether more precise representation of polarity.[44] Hence, the diagrams of Regius's *Fundamenta* testify to his reassessment of Descartes's imagery, while in the text itself, he refrained from making

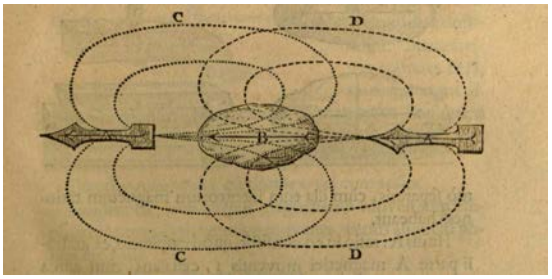

FIGURE 7.8
Magnets and compass needles surrounded by particles. Regius, *Fundamenta physices*, 133
SOURCE: BAYERISCHE STAATSBIBLIOTHEK MÜNCHEN, 4 PHYS.G. 142 <HTTP://MDZ-NBN-RESOLVING.DE/URN:NBN:DE:BVB:12-BSB10057885-8>

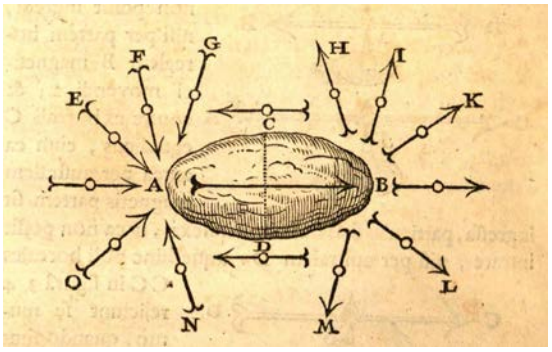

FIGURE 7.9
Magnets and compass needles surrounded by particles. Regius, *Fundamenta physices*, 136
SOURCE: BAYERISCHE STAATSBIBLIOTHEK MÜNCHEN, 4 PHYS.G. 142 <HTTP://MDZ-NBN-RESOLVING.DE/URN:NBN:DE:BVB:12-BSB10057885-8>

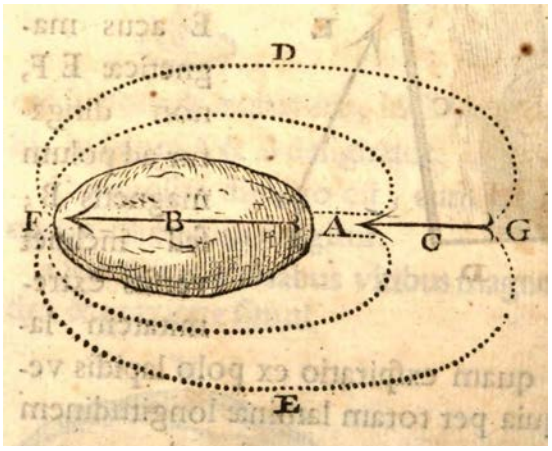

FIGURE 7.10
Magnets and compass needles surrounded by particles. Regius, *Fundamenta physices*, 140
SOURCE: BAYERISCHE STAATSBIBLIOTHEK MÜNCHEN, 4 PHYS.G. 142 <HTTP://MDZ-NBN-RESOLVING.DE/URN:NBN:DE:BVB:12-BSB10057885-8>

any mention of the work of his (former) friend.[45] Regius's diagrams are concerned less with the actual mechanisms in magnetism than with the geometrical patterns it produces. His conspicuous use of arrows, moreover, emphasizes the concept of polar alignment over the concept of the screw-shaped particles depicted in Descartes's diagrams. While a modern viewer might be tempted to see Regius's arrows as symbols indicating the direction in which the particles

flow, this interpretation has no basis in the text. Instead, the arrows must be understood as iron needles that were part of the experimental setting, as briefly outlined in text as well. The inconsistencies of Descartes's corpuscularian idea of polarity related to the flow direction, as alleged by Christiaan Huygens (1629–1695) and especially by Leonhard Euler (1707–1783) later in the eighteenth century, should not be understood as having been anticipated by Regius as part of its initial reception.[46]

Alongside Descartes's corpuscularian conception and Regius's more geometrical approach, many other forms of magnetic 'vortices' were the subject of the diagrams plentifully used by later authors in the seventeenth century.[47] This development happened by different ways of appropriation and inspiration – direct or indirect – and followed, by and large, the same patterns of the spread of Cartesian iconography as in other fields, as is richly documented in this volume and the existing literature. Philosophers sometimes copied, but more often modified, the magnetism diagrams of Descartes or Regius, by adjusting them to their particular needs or even integrated them into a slightly or completely different ontological framework. Figures 7.11–29 will give fair examples for many of these cases, without the need for more extensive discussion.

The simplest form of appropriation involved the use of plain copies. Descartes's *Terra AB* and other woodcuts of his *Principles* were, e.g., remade as engravings for use as teaching aids in Leuven.[48] These were produced by Michael Hayé (d. 1676) around 1668 and were later copied by Petrus Augustinus Denique (1683–1746) sometime in the first half of the eighteenth century. The relevant engraving (Fig. 7.13) shows Descartes's *Terra AB* together with a short verbal description referring to the letters used in the diagram. This

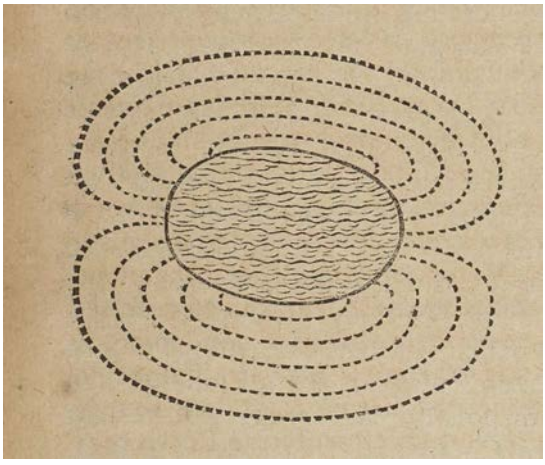

FIGURE 7.11
Magnetic Earth surrounded by orbiting particles. Descartes, *Lettres de M Descartes*, 3:605
SOURCE: PARIS, BIBLIOTHÈQUE NATIONALE DE FRANCE, DÉPARTEMENT RÉSERVE DES LIVRES RARES, R-3522 <HTTPS://GALLICA.BNF.FR/ARK:/12148/BTV1B8601520B>

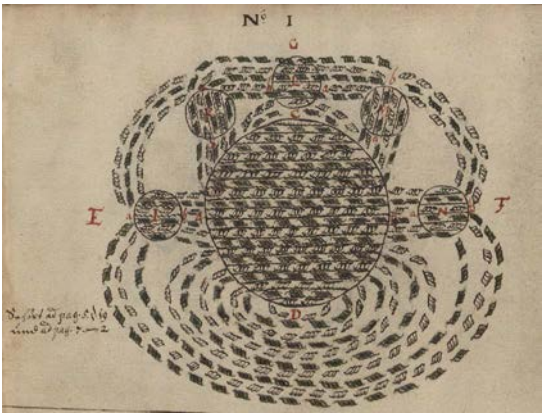

FIGURE 7.12
Magnetic Earth surrounded by orbiting particles. Copy of Descartes's "Terra AB" Anonymous, *Kürtzliche Erleuterung Etlicher Vorgaben von Der W ürkung Des MagnetSteins Nach Anleitung Und Gesetzten Grundstücken von Cartesio* (ca. 1650), 191r.
SOURCE: GOTHA, FORSCHUNGS-BIBLIOTHEK, CHART. A 7 07, FOLS. 190R–202V: <HTTPS://DOI.ORG/10.48431/HC-TRANS/E9F0-94D4>

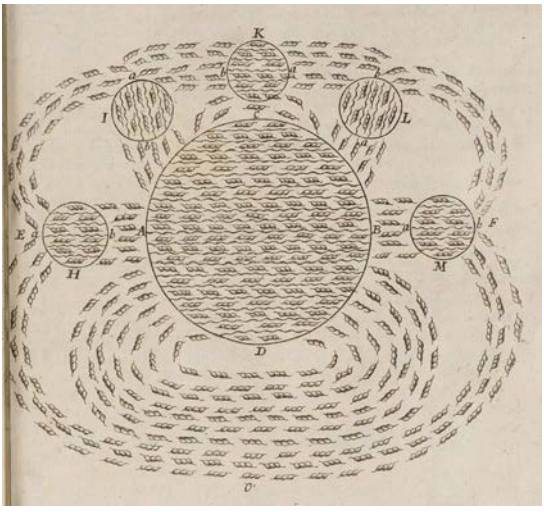

FIGURE 7.13
Descartes's "Terra AB" as engraving by Michael Hayé (ca. 1668) in a notebook of Leo Josephus Daco MS., Brussels, MS. II 10 6: Wauchier (professor) and Daco (student), *Physica* (1678), fol. 326r
SOURCE: *MAGISTER DIXIT* COLLECTION

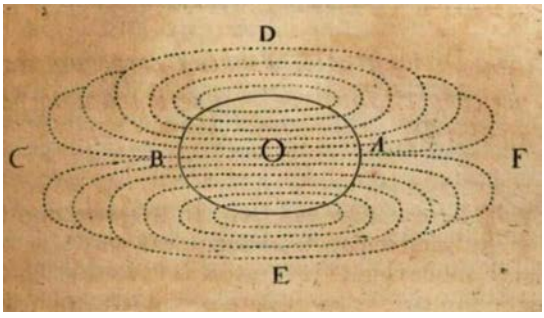

FIGURE 7.14
Magnetic Earth surrounded by orbiting particles. More, *Enchiridion metaphysicum*, 207
SOURCE: BIBLIOTHÈQUE MUNICIPALE DE LYON PART-DIEU, 339883 <HTTPS://BOOKS.GOOGLE.IT/BOOKS?ID=CJFKNIXPPY4C&HL=DE&PG=PA207#V=ONEPAGE&Q&F=FALSE>

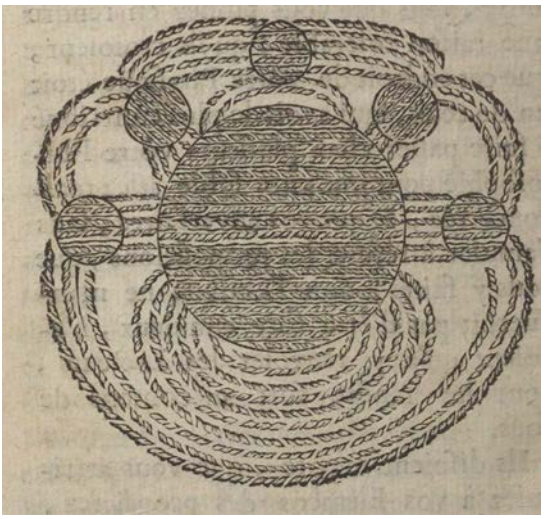

FIGURE 7.15
Magnetic Earth surrounded by orbiting particles. Copy of Descartes's "Terra AB." Daniel, *Voiage du Monde de Descartes*, 1:430
SOURCE: PARIS, BIBLIOTHÈQUE NATIONALE DE FRANCE, DÉPARTEMENT PHILOSOPHIE, HISTOIRE, SCIENCES DE L'HOMME, R-13616 <HTTPS://GALLICA.BNF.FR/ARK:/12148/BPT6K9616538K#>

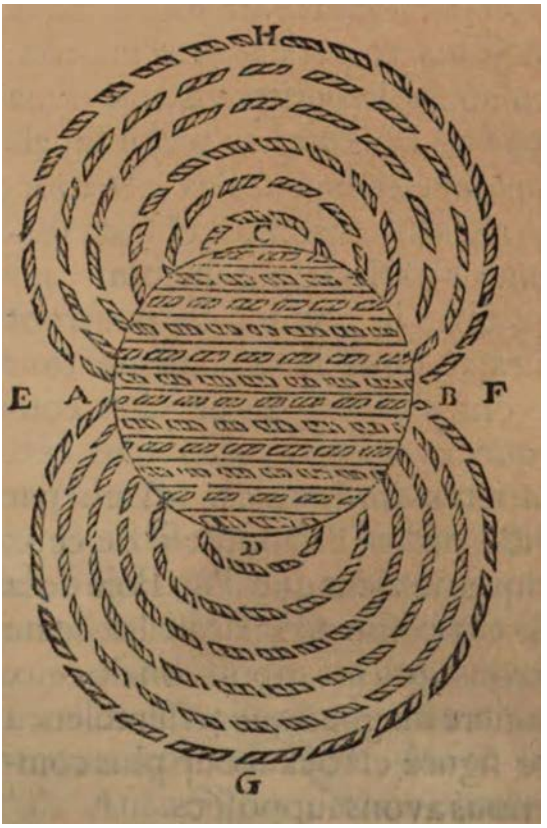

FIGURE 7.16
Magnetic Earth surrounded by orbiting particles. Regis, *Cours entier de philosophie, ou Systeme general selon les principes de M. Descartes*, 2:224
SOURCE: BAYERISCHE STAATSBIBLIOTHEK MÜNCHEN, 4 PH.U. 113-2 <HTTP://MDZ-NBN-RESOLVING.DE/URN:NBN:DE:BVB:12-BSB10008571-7>

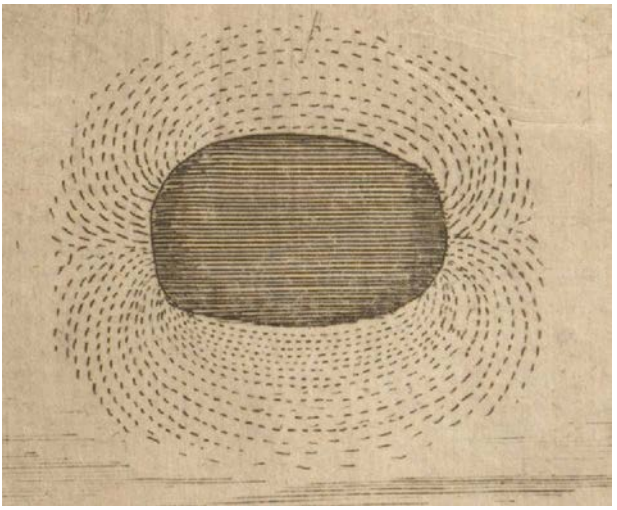

FIGURE 7.17
Magnet surrounded by orbiting particles. Hautefeuille and Aubry, *Magnetologia curiosa*
SOURCE: ZENTRALBIBLIOTHEK ZÜRICH, NP 1836,2 <HTTPS://DOI.ORG/10.3931/E-RARA-25699>

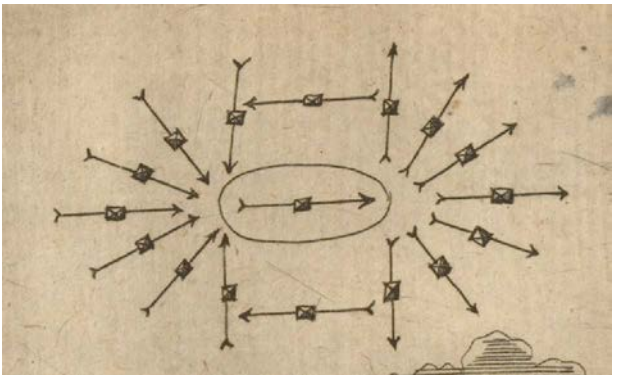

FIGURE 7.18
Magnet surrounded by orbiting particles. Hautefeuille and Aubry, *Magnetologia curiosa*
SOURCE: ZENTRALBIBLIOTHEK ZÜRICH, NP 1836,2 <HTTPS://DOI.ORG/10.3931/E-RARA-25699>

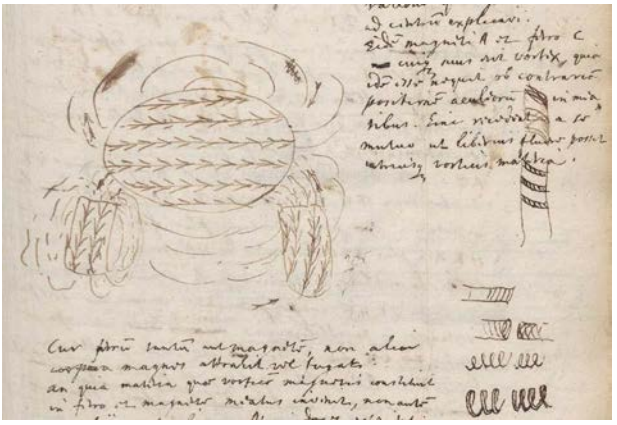

FIGURE 7.19
Magnets surrounded by orbiting particles. Small arrows indicate the particles' flow direction
Huygens: *Ponatur materia subtilis intrare tantum* (ca 1668), fol. 42r (ed. in Huygens, *Mécanique théorique et physique de 1 666 à 1695, 19*:569)
SOURCE: MS., LEIDEN UNIVERSITY LIBRARY, HUG 2

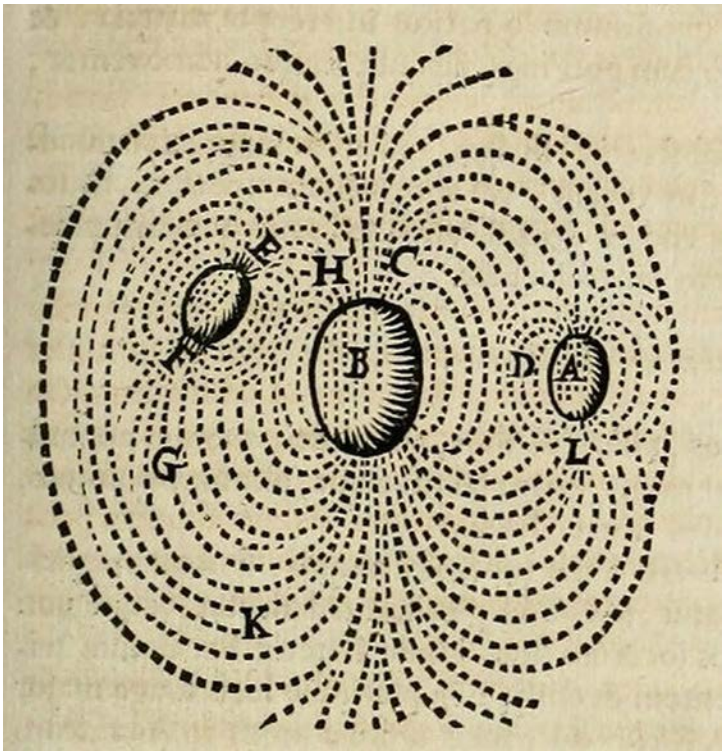

FIGURE 7.20 Magnets surrounded by orbiting particles. Du Hamel, *Philosophia vetus et nova*, 2:421
SOURCE: YOLTON LIBRARY RARE BOOK COLLECTION, OCM21396648 <HTTPS://DIGITAL.LIBRARY.YORKU.CA /YUL-1006708/PHILOSOPHIA-VETUS-ET-NOVA#PAGE/432 /MODE/2UP>

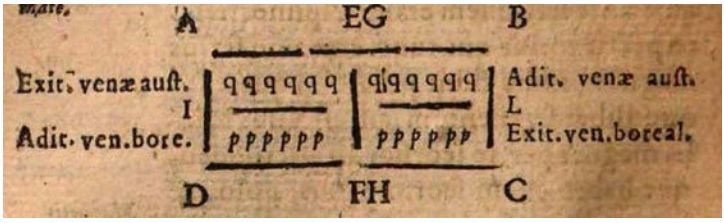

FIGURE 7.21 Diagram of entering and exiting particles. Maignan, *Cursus philosophicus*, 1418
SOURCE: AUGSBURG, STAATS- UND STADTBIBLIOTHEK, PHIL 5019 -3/4 <HTTP://MDZ-NBN-RESOLVING.DE /URN:NBN:DE:BVB:12-BSB11274361-0>

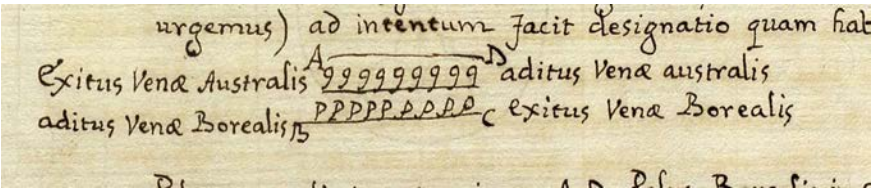

FIGURE 7.22 Diagram of entering and exiting particles. Copy of Maignan's diagram
SOURCE: ROME, BIBLIOTECA NAZIONALE CENTRALE "VITTORIO EMANUELE II," FONDO GESUITICO 1323, FOLS. 59–79: ZUCCHI, *PHILOSOPHIA MAGNETICA PER PRINCIPIA PROPRIA PROPOSITA ET AD PRIMA IN SUO GENERE PROMOTA* (CA. 1653), FOL. 66R

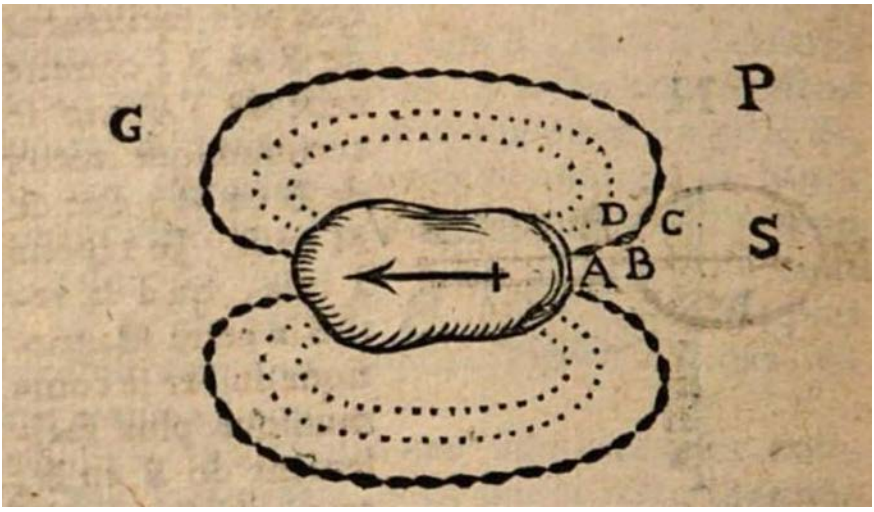

FIGURE 7.23 Magnet surrounded by particles. La Grange, *Les principes de la philosophie*, 256, 262
SOURCE: BIBLIOTECA NAZIONALE CENTRALE DI ROMA, 000024715 <HTTPS://BOOKS.GOOGLE.IT/BOOKS?ID=8KAAR4DE-JKC&PRINTSEC=FRONTCOVER&HL=IT&SOURCE=GBS_GE_SUMMARY_R&CAD=0#V=ONEPAGE&Q&F=FALSE>

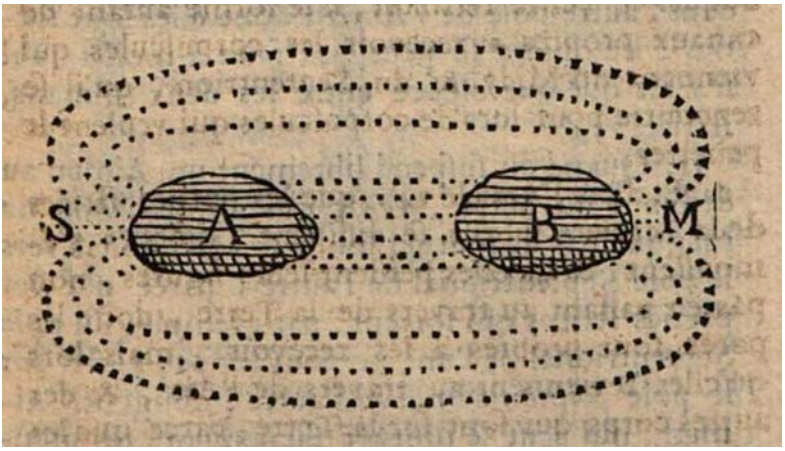

FIGURE 7.24 Magnet surrounded by particles. La Grange, *Les principes de la philosophie*, 256, 262
SOURCE: BIBLIOTECA NAZIONALE CENTRALE DI ROMA, 000024715 <HTTPS://BOOKS.GOOGLE.IT/BOOKS?ID=8KAAR4DE-JKC&PRINTSEC=FRONTCOVER&HL=IT&SOURCE=GBS_GE_SUMMARY_R&CAD=0#V=ONEPAGE&Q&F=FALSE>

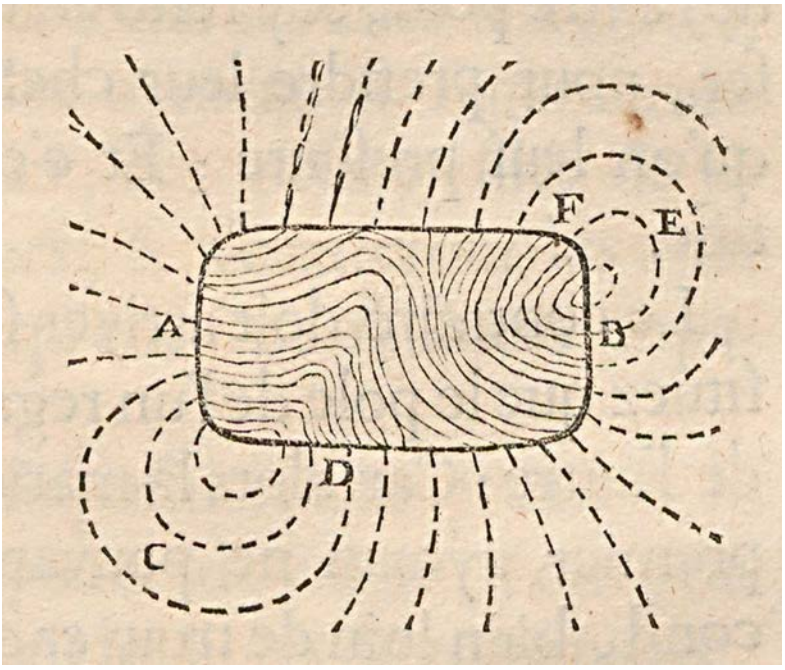

FIGURE 7.25 Magnet surrounded by particles. Rohault, *Traité de physique*, 221, 225
SOURCE: ETH-BIBLIOTHEK ZÜRICH, RAR 5463 <HTTPS://WWW.E-RARA.CH/ZUT/CONTENT/ZOOM/1435834>

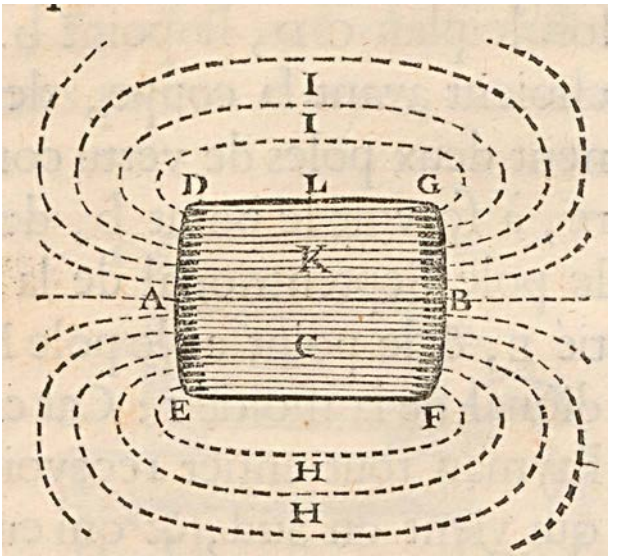

FIGURE 7.26 Magnet surrounded by particles. Rohault, *Traité de physique*, 221, 225
SOURCE: ETH-BIBLIOTHEK ZÜRICH, RAR 5463 <HTTPS://WWW.E-RARA.CH/ZUT/CONTENT/ZOOM/1435834>

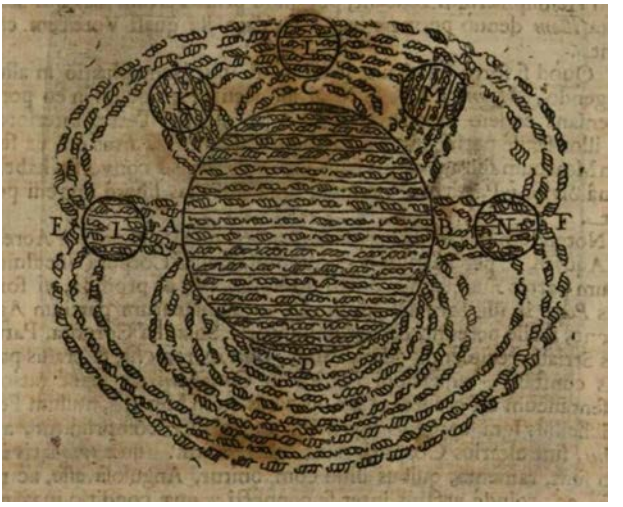

FIGURE 7.27 Magnetic Earth surrounded by orbiting particles. Copy of Descartes's "Terra AB." Le Grand, *Institutio philosophiae*, 451
SOURCE: BAYERISCHE STAATSBIBLIOTHEK MÜNCHEN, 4 PH.U. 86 <HTTP://MDZ-NBN-RESOLVING.DE/URN:NBN:DE:BVB:12-BSB10008518-3>

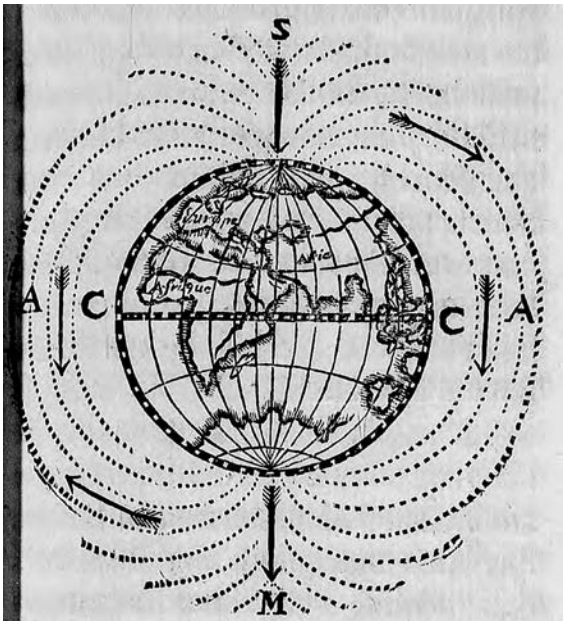

FIGURE 7.28
Magnetic Earth surrounded by orbiting particles. Le Lorrain de Vallemont, *Description de l'aimant*, 51
SOURCE: PARIS, BIBLIOTHÈQUE NATIONALE DE FRANCE, DÉPARTEMENT SCIENCES ET TECHNIQUES, S-20624 <HTTPS://GALLICA.BNF.FR/ARK:/12148/BPT6K1261880D>

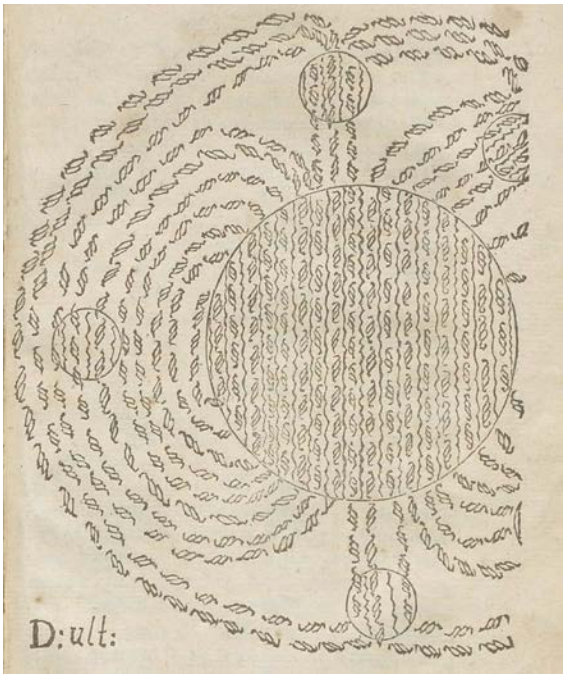

FIGURE 7.29
Mutilated "Terra AB." Hoffwenius, *Synopsis physica*, D ult
SOURCE: NATIONAL LIBRARY OF SWEDEN, F1700 3737 <HTTPS://WEBURN.KB.SE/EOD_BEST/METADATA/145/EOD_2516145.HTM>

printed sheet was then included in the sections on magnetism of many student notebooks (see Tab. 7.1), while other students even made their own copies of the *Terra AB* and other magnetism-related imagery from Descartes, faithfully redrawing these diagrams by hand.

TABLE 7.1 Imagery on magnetism in the Leuven student notebooks of lectures on *Physica*

Library	Shelfmark	Date	Professor	Student	Folia	Image(s) used
KBB	MS. II 106	1678	Wauchier	Daco	326^{r}	Hayé
AUL	MS. C165	1680	De Decker	Boonen	179^{r}	Hayé
KUL	MS. 211	1687	Werici	Cox	306^{r}	Hayé
AUL	MS. C72	1715	Bessemers	van Anderwerelt	260^{r}	drawing
KBB	MS. II 3214	1720	Bessemers	Brunin	276^{r}	drawings
KBB	MS. II 3703	1730	van Billoen	Marij	290^{r}, 291^{v}, 295^{v}	Denique, drawings
KBB	MS. II 5444	1739	Page	Van Nuffel	66^{r}, 250^{r}	Denique
AUL	MS. C75	1739	Amand	Plischart	291^{r}	Denique
AUL	MS. C28	1746	Graven	Grondel	289^{r}	drawing
KUL	MS. 326	1751	n/a	Bertrand	169^{v}, 204^{r}	Denique
KBB	MS. II 4269	1755	Lauvaux	Wauters	344^{r}	Denique
KUL	MS. 359	1755	Van Waes	Dewael	161^{r}	Denique
AUL	MS. C4	1756	Bultot	Bossart	567^{v}	drawing
KBB	MS. 21127	1757	n/a	n/a	183^{r}	Denique
KBB	MS. II 4523	1759	n/a	van Beynen	214^{r}	Denique
KBB	MS. II 5602	1761	Deckers	Lodewijckx	373^{r}	Denique
AUL	MS. C210	1761	n/a	n/a	276^{r}	Denique
KBB	MS. II 3294	1763	Heijlen	Eliart	174^{r}	drawing
KUL	MS. 302	1774	Forgeur	Jonckers	182^{r}	Denique

Referenced manuscripts are held in three libraries: Brussels, Koninklijke Bibliotheek van België (KBB), KU Leuven Libraries (KUL), Louvain-la-Neuve, Archives de l'Université catholique de Louvain (AUL). Sorted by date of composition. As for the professors, the table lists the professor responsible for the respective part on magnetism that includes images. The images included were either the engravings made by Hayé or Denique, or drawings made by the student.

A pen-drawn copy of Descartes's *Terra AB* (Fig. 7.12) by an unknown creator is also found in a German manuscript translation (unauthorized) of the section on magnetism from his *Principles*.[49] This manuscript too most likely originated from a didactic context.

Several textbooks, especially from France, drew on Descartes's theory of magnetism or argued against it – in most of them, the magnetic 'vortex' was depicted as very similar to those described by Descartes or Regius.[50] Some simply copied from Descartes (e.g., Daniel, Le Grand: Figs. 7.15 and 7.27, respectively), a few (e.g., La Grange, Hautefeuille and Aubry: Figs. 7.18 and 7.23) seem to have been inspired by Regius, while others (e.g., Rohault, Du Hamel, Regis: Figs. 7.16, 7.20, 7.25 and 7.26) advanced and modified their predecessors' diagrams considerably. Regis (Fig. 7.16) kept Descartes's corpuscular orbits of screw-shaped particles, but simplified the diagram by excluding the surrounding magnets. Du Hamel and Rohault (Fig. 7.20 and 7.25) depicted a slightly different flow of particles, e.g., by making two or more 'vortices' overlap and interact in a more complex way. Rohault depicted a non-parallel alignment on channels within the magnet (Fig. 7.25). *Terra AB* also reached textbooks outside the French context. In 1698, e.g., an anonymous printer in Stockholm prepared a second edition of the textbook *Synopsis physica* (1678) by Petrus Hoffwenius (1630–1682), and included a somehow mutilated and rotated version of *Terra AB* (Fig. 7.29) in the author's explanation of the Cartesian theory of magnetism.[51]

In general, it is noteworthy that authors depicted the 'vortex' without visualizing the shape of particles, but – and seemingly independently from Regius – abstracted the orbits to mere elliptical lines of tiny dots. In 1667, Claude Clerselier (1614–1684), editing the above-mentioned letter including the pen drawing by Descartes of 1643 (Fig. 7.3), included a woodcut (Fig. 7.11) of a different version of *Terra AB* that was not included as a drawing in the manuscript and that is thus the editor's own supplement.[52] This diagram shows neither particle types nor directionality, nor any letters; it features just one magnet. It has no parallel in Descartes's *Principles*, although Clerselier might just as well have reproduced *Terra AB* instead, especially as the text more or less matches the theory of magnetism as set out in the *Principles*. One critic of Descartes's theory of magnetism, Henry More (1614–1687) supplemented his own work with engravings (Fig. 7.14) that employ the same visual language of 'vortices' but without buying into any mechanical explanation.[53] He underlined his refusal of the Cartesian theory by using newly made diagrams instead of using Descartes's originals, elements of whose theory feature neither in the text nor

the images. By contrast, another critic of Descartes, Gabriel Daniel (1649–1728), faithfully reproduced the *Terra AB* diagram (Fig. 7.15) to explain Descartes's theory. Christiaan Huygens dealt with Descartes's theory and its imagery quite extensively.[54] He is perhaps the first to use arrows as proper symbols, i.e., to indicate the flow direction of the particles orbiting the magnet (Fig. 7.19), and he also depicted the right and left-handed screws in one of his manuscript pen drawings on the subject.

An even more sophisticated adaptation of Descartes's idea, with a highly abstract visual rendering, is to be found in the work of Emmanuel Maignan (1601–1676) (Fig. 7.21 and Fig. 7.22). Although he followed Descartes in assuming two types of particles, he rejected the idea that they should be screw-shaped and the mechanistic explanations of magnetic effects derived from the question of the shapes of the particles. Maignan depicted this aspect of his theory, combining 'sympathy and antipathy' with corpuscularian ideas, in a very abstract manner, using typographical symbols to encode the two types of particles that were the supposed non-mechanical cause of magnetism.[55] The two letters 'p' and 'q,' being mirror-images of each other, represented both types, and as in Descartes's theory of magnetism, circulated in both directions.

If Maignan's take was probably the most extreme abstraction of Descartes's idea, in 1692 Pierre Le Lorrain de Vallemont (1649–1721) reworked the image of *Terra AB* to look more vivid and concrete (Fig. 7.28). Instead of showing the world as a perforated sphere orbited by particles, he included a more naturalistic image of the globe of the Earth surrounded by the flow of magnetic particles, and given a Cartesian description in the accompanying text.[56] Le Lorrain de Vallemont's work was aimed at popularizing science; it was published in French and was not intended for use in university classes. And yet, for all of that, his image – of all the images we have explored – may be the closest approximation we have seen to a 'modern' depiction of what nowadays is known as the geomagnetic field. The flow of particles is indicated by arrows depicted like compass needles. Conspicuously, at least one arrow suggests that the flow is not unidirectional, thus formalizing an element of Descartes's original theory in a new way. None of these elements are touched upon in the text itself, unfortunately. In all of the sources we have thus far analysed, it is only Huygens and de Vallemont who put Descartes's 'vortex' into a visual scheme using arrows to indicate the direction of the emanating screw-shaped particles.

What, then, are the major and general results of the preceding synopsis? Placing all relevant images in a matrix – calculated by a neural network – of image (or, perceptual) similarity (Fig. 7.30) can help answering this question

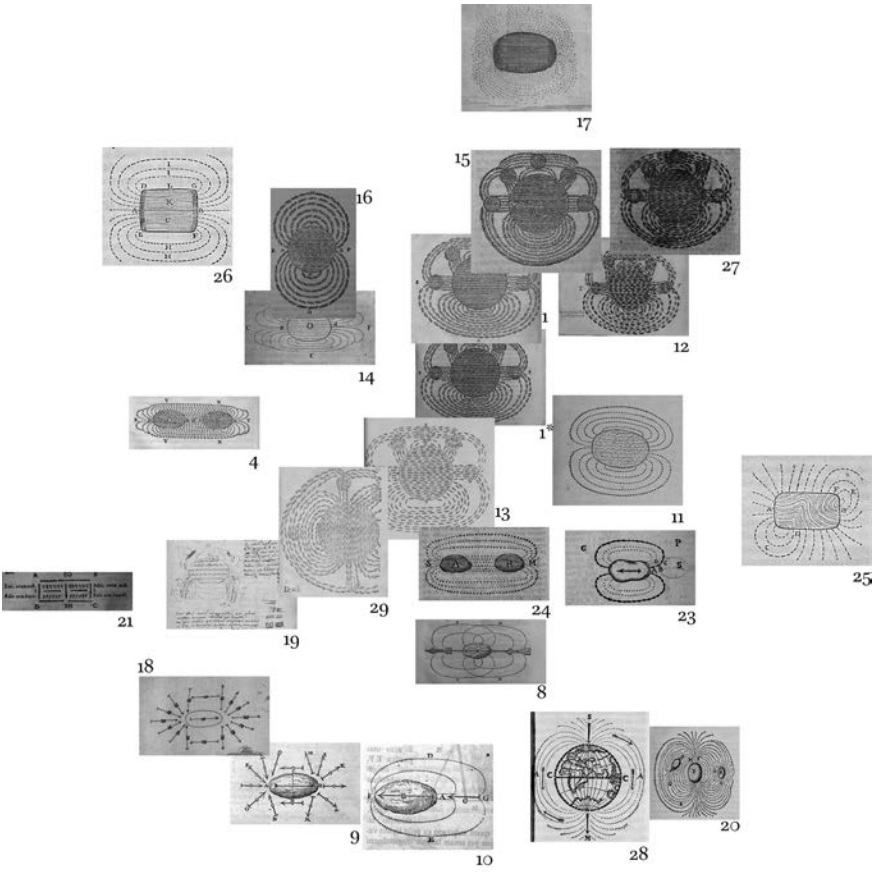

FIGURE 7.30 t-SNE image similarity matrix generated by matplot using the Convolutional Neural Network (CNN) VGG16
COPYRIGHT BY CHRISTOPH SANDER

by providing an overview of all images at a glance.[57] The spatial distance in the matrix represents the degree of similarity, i.e., the closer together two images are to each other, the more similar they are for computer vision.

Without discussing the biases of such a calculation and its arguably limited face value for historians, the matrix nonetheless matches some observations of the analyses provided in this chapter. Descartes's original *Terra AB* (Fig. 7.1) is surrounded by other images that can aptly be described as copies of different types (Fig. 7.13, 7.29, Fig. 7.1*, 7.15, 7.12 and 7.27).[58] These copies were produced by quite different means, e.g., by using the same or a new woodblock, by engraving or etching, or by redrawing the original with a pen and ink. In the case of *Terra AB*, these different techniques of production reflect some of the different contexts in which the image was used, but do not change the basic

idea expressed in the diagram, nor even introduce any variation with regard to the amount of visual detail to a relevant degree. For example, the almost identical imitations of Descartes's *Terra AB* used for teaching his theory of magnetism in Leuven (Fig. 7.13) or for translating his theory into German (Fig. 7.12) exhibit different purposes and contexts. These two examples mirror the spread of Cartesian ideas to non-specialist audiences. Regius's copy (Fig. 7.1*), and even more so, Daniel's copy (Fig. 7.15) show that the same diagram *prima facie* was also divorced from Descartes's text and its reception: Regius elaborated on the Cartesian theory while Daniel criticized it. Daniel's woodcut diagram of *Terra AB* may thus have been presented merely as a citation of the object of his criticism in a scholarly context. As different as these use cases and contexts are, so similar if not identical are the images involved. The different techniques of their production do not predetermine any particular use but natural philosophical works of the seventeenth century still tended to rely on woodcuts (as is true for most of the relevant images under discussion here) while later prints favour engravings (Fig. 7.17, Fig. 7.18, Fig. 7.13). Drawings made by hand, as done by Leuven students, and as seen in the unauthorized German translation (Fig. 7.12), and in Huygens's notebook (Fig. 7.19), reflect the private nature and use of these documents and their illustrations.

The further we get to the edges of the matrix in Fig. 7.30, and thus the further away we get from Fig. 7.1, the less similar to *Terra AB* diagrams are the images as they appear to a machine and to the human eye. This dissimilarity tends also to indicate a distance from the Cartesian text and its ideas. Yet, this distance cannot be mapped on agreement or disagreement with the Cartesian theory. In this regard, we can point particularly to French and Dutch supporters of Cartesian concepts such as particles and mechanical interactions, e.g., Regis, Rohault, Huygens, and Regius. While they followed Descartes in core elements of his theory, they were also led to different experiments (e.g., with needles) or they dispensed with the idea of screw-shaped particles for theoretical reasons. We can see this in their diagrams, although we might not be able to infer this from the imagery alone.

Other more drastic visual modifications are not due to explicit conceptual modifications but reflect again different publication contexts, such as a popularized version of the Cartesian theory (Fig. 7.28 and Fig. 7.17) in which the theory in all its subtleties was secondary. They demanded – and used – suggestive and vivid illustrations of how magnetism 'works.' Quite strong and explicit conceptual modifications, such as in More's immaterialist account, still resemble the Cartesian imagery (Fig. 7.14), although this also accounts for the fact that the diagram in More was, at least partly, meant to illustrate the Cartesian account instead of the author's own. Clerselier's attempt to depict precisely Descartes's theory of magnetism (Fig. 7.11) is visually much closer to More's

diagram than to Descartes's original *Terra AB*. Maignan's non-mechanical interpretation of some Cartesian ideas (Fig. 7.21) is clearly the most distant one in terms of similarity to the original, but not in terms of content, as his diagram depicts mainly the existence of two types of particles, very much in line with the Cartesian theory in this regard.

A one-to-one relationship between how an image looked and what it was used for is not to be established in the case of *Terra AB*. The only universal 'meaning' common to all the different diagrams is that they all refer, in one way or another, to the Cartesian theory, while this reference could mean many different things. Moreover, it must be kept in mind that not all images relate directly all the way back to Descartes's originals. It seems, for instance, clear that Le Grange was more inspired by some of Regius's diagrams than by those of Descartes. The visual reference to the Cartesian theory testifies to its visual reception and influence, comprising various modes and style of reception: teaching, translating, promoting, advancing, correcting, criticizing, and popularizing the Cartesian theory of magnetism.

Mapping the visual clusters and their relation vis-à-vis textual, institutional or geographic contexts remains tentative and preliminary if based only on this single topic of magnetism. However, these results open up an avenue of research and lead to conclusions to be confirmed or dismissed by a widening of the scope. These image clusters of magnetism not only testify to non-textual modes of influence between scholarly works, but also allow for different ways of analysing these influences. By way of studying the images, different experimental backgrounds to which some of the images relate, but which are not outlined or mentioned in the text, can be inferred and can add significantly to the understanding of the underlying scientific practices.

3 Conclusion

The imagery in Descartes's natural philosophy is notably one of the most original features of his work. This visual approach also had an impact on later natural philosophy in its own right, with consequences far beyond the reception of Descartes's natural philosophy itself. His visual aids in explaining magnetism, to which Christoph Lüthy refers as "visual reductionism," is a striking example of that approach. As argued in the first section of this chapter, the creation of these images depended to a considerable degree on experimental findings, even if Descartes presented these experiments as a confirmation – not as the basis – of his theory (and thereby of his imagery). This experimental

background, for which he most importantly drew on Mersenne, thus played a pivotal role in the creation of Descartes's *Terra AB*, showing experimental findings such as magnetic dip and the alignment of iron filings around a magnet in a highly abstracted and theory-driven manner. Nonetheless, as scholars have often pointed out, these diagrams did not depict natural objects or experimental settings, but philosophical ideas and hypotheses about the mechanical interactions of invisible particles in the natural world.[59]

Descartes's theory of magnetism and its imagery had a major influence on later natural philosophers and also on a much broader readership: Cyrano de Bergerac was clearly expecting his reader to be somewhat familiar with Descartes's *Terra AB* diagram. The image even made it into the classrooms. Whilst users did not always agree with Descartes in the finer points of detail nor on the metaphysical foundations, Descartes's images nevertheless served them not only to outline Descartes's theory but also as supports for their own theories. As Claus Zittel and Lüthy have underlined, later diagrams of magnetism images could look very similar to those of Descartes – as in the case of Regius, More, and d'Alence – but were often backed up by very different metaphysics.[60] Whether a dot of ink in a magnetic 'vortex' woodcut represents a particle or an immaterial entity cannot be seen on, or inferred from, the image itself. Whether the substance is supposed to act mechanically or in another way is not to be seen either. To interpret these images adequately, one needs not only the textual account of the respective theory of magnetism but also a more general understanding of the author's metaphysics. Some of Descartes's readers certainly ignored or misunderstood the metaphysical underpinning of his theory of magnetism, e.g., by taking his particles to be atoms. As put by Charles Sorel (1602–1674) in his *La science universelle* (1668): "[Descartes] described the sympathetical effluvia of the magnet, and also made a painting of them."[61] Descartes's aims was precisely to get rid of 'sympathy' and yet his images could not by themselves transmit that message with sufficient force to a careless reader.

It is perhaps no coincidence that the inherent theoretical complexity of the iconography of Cartesian magnetism is not always matched by its accompanying text. In fact, image and text are oftentimes decoupled in later publications. While many advanced academic discussions of the Cartesian magnetism theory, e.g., university disputations, were not illustrated at all, Cartesian imagery is used quite liberally, especially in the more introductory natural philosophical textbooks and 'popular science' publications.[62] It seems as if these richly illustrated publications take for granted that the *Terra AB* is the default way to visually understand and depict magnetism, without necessarily engaging with

the underlying theory in any sophisticated way. This holds true even for books that actually argue against certain features or the very idea of Descartes's explanation of magnetic phenomena.

This metaphysical ambiguity and openness, just like the very fact that similar or even identical images were indeed used in different philosophical frameworks, seems then to indicate that there is something more universal in Descartes's depiction of magnetism that reached beyond his particular explanation of it. It could be argued that Descartes, in some way, set the agenda with his illustrations and created a visual horizon within which other scholars constructed their own theories and their own visualizations. The visual and textual suggestions of an experimental confirmation certainly helped in that regard. By illustrating a text with images, which in fact were by no means theoretically neutral, the impression could be evoked that the miraculous phenomenon of magnetism could be represented in a visual, even geometrical way – something that had not been done to that extent and in such an abstract and yet 'graphical' way before.

Acknowledgements

I thank the editors of this volume, the anonymous referees and all members of the Max Planck Research Group "Visualizing Science in Media Revolutions" for their helpful comments to earlier versions of this chapter.

Funding for this research and its publication in Open Access was provided by the Max Planck Research Group "Visualizing Science in Media Revolutions," led by Sietske Fransen (BH-P-19-35).

Notes

1 Cf. Angelo, "Science et superstition," 131; Moreau, "Les avatars de la 'figure,'" 77; Lipking, *What Galileo Saw*, 123–124.

2 English translation from Bergerac, *The Comical History*, 21. For the French text, cf. Cyrano de Bergerac, *Les Estats et Empires*, 180–183: "Celui qui le tenoit le laissa choir d'appréhension, et par malheur en tombant il s'ouvrit dans une page où sont expliquées les vertus de l'aimant; je dis par malheur, pource qu'à l'endroit dont je parle il y a une figure de cette pierre métallique, où les petits corps qui se déprennent de sa masse pour accrocher le fer sont représentés comme des bras."

3 Cf. Descartes, *Principia philosophiae*, 259–293 (i.e., *Principia* IV 133–184, AT VIII-A 275–311). For quantification, cf. Meschini, *Indice dei* Principia philosophiae, 407.

4 In the French translation (1647), all images were added on a separate sheet at the end of the book; for the section on magnetism, cf. Descartes, *Les principes de la philosophie*, 397–452.

It thus seems unlikely that Bergerac refers to the French edition, as the folded image sheet would not have fallen open in the same way as a random page of the book.

5 The reasons for Bergerac's speaking of "arms" are touched upon in Alcover's commentary. Her explanation remains slightly unclear but the question is of little importance for the purposes of this chapter.

6 For the theory especially, cf. Hoppe, "Die Abhängigkeit der Wirbeltheorie"; Carter, "Gilbert and Descartes"; Radelet-de Grave, *Les lignes magnetiques*; Radelet-de Grave, "Vortices magnéticos"; Andrade, "O mecanicismo." Moreover, the theory is sketched in Daujat, *Origines et formation*, 293–312; Heilbron, *Electricity in the 17th and 18th Centuries*, 30–34; Schuster, *Descartes-Agonistes*, 274–280, 558–561; Gaukroger, *Descartes' System of Natural Philosophy*, 173–179; Shea, *The Magic of Numbers and Motion*, 143–144, 302–305. For analysis of the visualization, cf. esp. Radelet-de Grave, *Les lignes magnetiques*, 30–34; Zittel, *Theatrum philosophicum*, 382–395; Lüthy, "Descartes's Clear and Distinct Illustrations."

7 Descartes, *Principia* IV 146, AT VIII-A 287: "Ad quarum proprietatum caussas intelligendas, proponamus nobis ob oculos Terram AB, cuius A est polus Australis, et B Borealis."

8 This is pointed out especially by Heilbron, Zittel, and Radelet-de Grave. See note 6.

9 The theory draws on principles developed in his *Le monde*, and Descartes referred to his theory earlier in some of his letters. He also heavily relied on theories proposed by Isaac Beeckman and Henricus Regius: cf. esp. Sander, Magnes, 719–728; Strazzoni, "How Did Regius Become Regius?," 374, n. 51; Berkel, "Descartes' Debt to Beeckman."

10 See Descartes, *Principia* IV 199, AT VIII-A 323: "Nihil enim inter naturae phaenomena est recensendum, nisi quod sensu deprehenditur." See also *Principia* II 64; III 1, 15, 20, 24, 30, 46, 127, 129, and 199. On the project of the *Principia*, cf. Brockliss, "Rapports de structure et de contenu"; Ariew, *Descartes among the Scholastics*, 55–69; Gaukroger, *Descartes' System of Natural Philosophy*, 32–63; Gabbey, "The *Principia Philosophiae*"; Pitte, "Some of Descartes' Debts." On the Aristotelian background, see Des Chene, "An Aristotle for the Universities"; Brockliss, "Aristotle, Descartes and the New Science."

11 See Descartes, *Principia* I 69; IV 187, 199, and 203. See especially Garber, *Descartes' Metaphysical Physics*, 63–104; Bellis, "Le visible et l'invisible dans la pensée cartésienne."

12 See Descartes, *Principia* IV 187, AT VIII-A 314–315. On this, see, e.g., Garber, "Descartes and the Scientific Revolution"; Hutchison, "Dormitive Virtues"; Ruler, "Substituting Aristotle"; Brockliss, "The Moment of No Return"; Brockliss, "Aristotle, Descartes and the New Science." See also Sander, "Tempering Occult Qualities."

13 See, e.g., Descartes, *Principia* IV 203, AT VIII-A 325–326.

14 On the influence by Regius and Beeckman, cf. note 9.

15 Cf. Gilbert, *De magnete*; Pumfrey, "William Gilbert's Magnetic Philosophy."

16 Cf. especially Balmer, *Beiträge*; Jonkers, *Earth's Magnetism*.

17 Cf. Descartes, *Le monde* V, AT XI 24; I 176 (Descartes to Mersenne, 4 November 1630). On the postulation of subtle matter, see also Schuster and Brody, "Descartes and Sunspots," 7–18; Ariew, "The New Matter Theory." This subtle matter was deduced from a theory of elements presented earlier in his work.

18 These screw-shaped particles were introduced to account for sunspots earlier in the *Principia*. The shortest explanation of their role in magnetism is found in Descartes, *Principia* IV 133, AT VIII-A 275–276.

19 Descartes did not think about a screw fixing two things together but only invoked its shape similar to a snail shell, or, more precisely, the channelling of a column resembling the shell, as can also be inferred from the French translation (1647), reading "estre tournez à vis, ou comme une coquille". On linguistic aspects of the snail shell and the column, see

Beckmann, "The Columnae Coc(h)Lides of Trajan and Marcus Aurelius." On the "escargot," see Monet, *Abbregé du parallèle des langues Françoise et Latine*, 450. On the "piliers canalées" / "columna striata," see Monet, 165. On "striatus"/ "canalée" and "cochlea"/ "vis de pressoir," see Monet, 165, 1360. On "terebellum cochleatum," see Monet, 524. On the history of the screw and on early modern discussions, see esp. Palmieri, "Breaking the Circle"; Valleriani, *Galileo Engineer*, 101–102. Although Descartes wrote about the geometrical and mechanical application of the pressure screw and the Archimedean screw at other places (e.g., AT I 441), this more mathematical approach is not invoked in his account of magnetism. On Descartes's use of images in mechanics, see Van Besouw's chapter in this volume.

20 On the concept of polarity, cf. Steinle, "Goals and Fates of Concepts." In Descartes, cf. especially *Principia* IV 146–149, AT VIII-A 287–289.

21 Cf. Descartes to Grandami (?), 2 May 1644 (?), AT IV 122–123, 753 (to Constantijn Huygens, 20 September 1643). I thank Matthijs van Otegem, Paul Hoftijzer, and Geert Vanpaemel for pointing me to these references in Descartes.

22 It is first printed in Descartes, *Lettres De Mr Descartes*, 3:605–606; Descartes, *The Correspondence of René Descartes 1643*, 73–74. Verbeek et al. give additional references to further editions of the letter. Clerselier printed the drawing as a simplified woodcut and also added a simplified version of the *Terra AB* (see Fig. 7.11) and a circle with a compass needle in it, neither of which are to be found in the original manuscript.

23 On this pen drawing, see also Andrade, "O mecanicismo," 789.

24 The safest interpretation of the image seems to involve regarding the stripes as being the particles travelling through the magnet, although Descartes drew them sloppily; they appear to be curved in the image but are not described as curved in the text. All renderings of the drawing by later editors have made the stripes straight.

25 See Descartes, *Principia* IV 179, AT VIII-A 307: "Si paullo curiosius consideremus, quo pacto limatura ferri circa magnetem se disponat, multa ejus ope advertemus, quae hactenus dicta confirmabum. […] Quae viae ut clare ipsis occulis cerni possim, spargatur aliquid istius limaturae supra planum." Lüthy, "Descartes's Clear and Distinct Illustrations," 120, takes the experiment to be the basis for the *Terra AB* image but, as is argued here, this is an over-simplification.

26 Cf. Lüthy, "Descartes's Clear and Distinct Illustrations," 107; Hattab, "From Mechanics to Mechanism," 117; Palmerino, "Bodies in Water," 157. This point is also developed in Andrade, "O mecanicismo."

27 An early description and visual account of this experiment is given by Garzoni, *Trattati della calamita*, 273. According to Monica Ugaglia, this description was copied (without illustration) by Porta, *Magiae naturalis*, 142: see Ugaglia, "The Science of Magnetism," 73. Cf. also (and with more resemblance to Descartes's description) Porta, *Magiae naturalis*, 135, and later Aldrovandi, *Musaeum metallicum*, 561. For further details on this, see esp. Sander, "Rendering Magnetism Visible."

28 Cf. the images in Cabeo, *Philosophia magnetica*, 18, 316. Descartes knew about Cabeo's work (cf. AT I 180), although it is not clear if he read it. Cf. also Radelet-de Grave, "Vortices magnéticos," 279.

29 Descartes received the list on 25 December 1639 (cf. AT II 636). It is edited in Mersenne, *Correspondance*, VIII, 754–762, and was published in a reworked version in Mersenne, *Cogitata physico-mathematica*, 245–251.

30 Mersenne, *Correspondance*, VIII, 756: "[Hinc gratae nascuntur experientiae litem indicantes.] Si enim ferrea scobe polum Magnetis Boreum oneres, statim atque polus Boreus alterius accedit, scobs illa ferrea horret atque fugit inimicum, ac si ventus aliquis

vehemens flaret, cum erigatur ac veluti egrediatur in occursum poli meridiani, utpote amici." Cf. Descartes, *Principia* IV 145, AT VIII-A 287: "Quod limatura ferri circa unum, aut plures magnetes, certis quibusdam modis se disponat."

31 Cf. Mitchell, "Chapters in the History of Terrestrial Magnetism: Chapter III"; Sonar, "Briggs, Blundeville, Wright."

32 Cf. Sonar, "William Gilberts Neigungsinstrument."

33 Cf. Mersenne, *Correspondance*, VIII, 631; Mersenne, *Cogitata physico-mathematica*, 550. The *Cogitata* are dated 1 April 1644.

34 Cf. Descartes, *Principia* IV 151, AT VIII-A 290–291. For Descartes, the strength of the attraction is correlated to the angle at which particles are able to enter.

35 See Lüthy, "Descartes's Clear and Distinct Illustrations," 131: "What we may call 'visual reductionism,' that programme, in other words, that attempted to reduce all natural phenomena to the geometrical, and thus visualizable, aspects of ultimate particles, is one of the greatest legacies of Descartes."

36 Cf. Lüthy, "Descartes's Clear and Distinct Illustrations."

37 Cf. Andrade, "O mecanicismo."

38 On the relation between Regius and Descartes, see note 9.

39 Regius, *Fundamenta physices*, 130–145. The section is also published in Regius, *Philosophia naturalis*, 206–221; Regius, *Philosophie naturelle*, 261–276. On the project, cf. Verbeek, "Regius's *Fundamenta Physices*"; Bos, "Henricus Regius"; Bellis, "Empiricism without Metaphysics."

40 He levels this accusation in the preface of Descartes, *Les principes de la philosophie* (AT IX-B 19).

41 On the reuse of the woodblocks, cf. also Verbeek, "Regius's *Fundamenta Physices*," 547, n. 71.

42 In Smets and Lüthy, "Words, Lines, Diagrams, Images," 436, the authors state that: "Regius [...] reproduced Descartes' corpuscular physics with all its imagery, while rejecting the very metaphysics that, in Descartes' eyes, provided these images with their legitimacy." This does not hold true for the images in the section on the magnet. Regius printed the *Terra AB* image also in the section dealing with the Earth: cf. Regius, *Fundamenta physices*, 78; Regius, *Philosophia naturalis*, 144; Regius, *Philosophie naturelle*, 172. More generally, cf. also Strazzoni, "Didactic, Persuasive and Scientific Uses."

43 See Regius, *Fundamenta physices*, 53. Cf. also Lüthy, "Descartes's Clear and Distinct Illustrations," 120.

44 Cf. Regius, *Fundamenta physices*, 132: "Australis polus est ea parte, per quam particulae striatae, venientes ab australi coeli parte, E, ingrediuntur."

45 He presents his own theory following Plato and Galen, cf. Regius, *Fundamenta physices*, 141–142.

46 Cf. Radelet-de Grave, *Les lignes magnetiques*. Huygens's theory of magnetism, especially, deserves a study in its own right. Cf. here, e.g., Huygens, *Mécanique théorique et physique de 1666 à 1695, 19*.569, 571. I aim to publish on this subject in the future.

47 Cf. also Zittel, *Theatrum philosophicum*, 387. Some scholars also explicitly referred to the iron filings experiment to determine the shape of the magnetic sphere of activity. Cf., e.g., Plemp, *Ophthalmographia*, 3rd ed., 255; Du Hamel, *De meteoris et fossilibus libri duo*, 202–203; Waldschmidt and Kursner, *Disputatio physica, de magnete*, 15–16.

48 Cf. Vanpaemel, "The Louvain Printers." On imagery in student notebooks from Leuven, cf. also Sander, "Teaching Magnetism," 333; see also Mantovani, "Anatomy of a Condemnation," and Palmerino, "Descartes's Theory of Tides."

49 See MS., Gotha, Forschungsbibliothek, Chart. A 707, fols. 190^{r}–202^{v}: Anonymous, *Kürtzliche Erleuterung etlicher Vorgaben von der Würkung des MagnetSteins nach Anleitung*

und gesetzten Grundstücken von Cartesio (ca. 1650), 191r. Cf. also Sander, "Teaching Magnetism," 334. The image is reproduced in Lotze and Salatowsky, *Himmelsspektakel*, 188. Interestingly, the screw-shaped particles are alternately shaded and unshaded with respect to their shape and direction of flow.

50 Bibliographical information can be found in the captions for Figures 7.11–7.29. The figure in De Raey, *Clavis philosophiae naturalis*, 188, is not reproduced here as the text does not relate it to the magnet; it shows however a body penetrated by "particulae striatae."

51 Cf. Hoffwenius, *Synopsis physica* (1678), 112–120; Hoffwenius, *Synopsis physica* (1698), 78–84. Later editions (1699 and 1700) did not include the woodcuts. Cf. also Sander, "Teaching Magnetism," 336; Sander, "Magnetism in an Aristotelian World."

52 It is highly implausible to consider this image a first draft done by Descartes himself, however, as it is not found in his autograph version of the letter.

53 The Cambridge Platonist, More – just like Regius – referred to Plato as the inventor of the idea of a *circumpulsio* as the cause of magnetism. Cf. More, *Enchiridion metaphysicum*, 208. On More's reading of Descartes, cf. AT V 384, 389. Zittel, *Theatrum philosophicum*, 388; and Smets and Lüthy, "Words, Lines, Diagrams, Images," 435, underline the metaphysical differences between Descartes and More.

54 Cf. note 46.

55 I thank Mattia Mantovani for pointing me to Aristotle, *Metaphysics*, I, 4 (985b1–25), for a similar use of iconic letters with regard to atoms. Maignan does not refer to this passage, but he would certainly have known the Aristotelian critique of atomism as put forward in the *Metaphysics*.

56 Cf. Le Lorrain de Vallemont, *Description de l'aimant*, 51.

57 Fig. 7.30 is the result of an image t-SNE calculated from pre-trained (on more than a million images from the ImageNet database) convolutional neural network (VGG16). This Jupyter Notebook was used as a basis and adjusted to the needs of the image set of this chapter: Kogan, "Image t-SNE."

58 On this, cf., e.g., also Fransen and Reinhart, "The Practice of Copying."

59 Other images in the section on magnetism, however, depict actual experiments.

60 On this, see note 42 above.

61 See Sorel, *Science Universelle*, 4:420: "En un autre endroit il décrit mesme les effusions Sympathiques de l'Aimant, et il en a aussi fait la peinture."

62 On this, see Sander, "Teaching Magnetism"; Sander, "Rendering Magnetism Visible."