The Archaeology of Science in the Science of Archaeology

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A version of this paper was given verbally at the Annual Conference of the Institute for Digital Archaeology in Oxford in May of 2015. This meeting, dedicated to the theme of digital imaging in archaeology, served both as a timely celebration of recent progress in the field, and an opportunity to discuss different perspectives on this progress with colleagues from a range of specialisms. There, as here, I explore a magnetician's eye view.

REVOLUTION IS a claim which can rarely be made without controversy, but as a description of the effect of science on the discipline of archeology over the last half century its justification is beyond dispute. Of the many scientific and technological developments that have contributed to the rapid evolution in the scope and capacity of archeological and historical research, among the most significant and visible have come from the area of imaging. Off-the-shelf tools now available for application to archeological research span a remarkable range of scales and capacities. We have, for example, techniques like reflectance transformation imaging (RTI) and multi-spectral imaging (MSI) that allow the recovery and discovery of minute textural and structural information about surfaces; magnetic resonance imaging (MRI) which gives us, non-invasively, spectroscopic information about the composition of three-dimensional objects, and satellite imaging technologies which enable geophysical surveying and mapping over kilometer scales with a speed and spatial resolution which, just twenty years ago, would have passed for science fiction.

Though diverse in purpose and capability, these imaging instruments are united by a common basis: they all rely on the physics of electromagnetism.

The part of the electromagnetic spectrum that is most familiar to us is visible light. Visible light is made up of a combination of travelling electric and magnetic fields: a wave of electrical energy (red, Figure 1) together with wave of magnetic energy, propagating in the same direction, but inclined at ninety degrees to it (blue). The colour that visible light appears to the human eye is related to the distance between adjacent peaks of the waves, this length is called the wavelength and is inversely proportional to the number of undulations up and down per second, a quantity that we refer to as frequency. The term "frequency", when applied to light is exactly analogous to that we meet in the context of sound waves: the higher the frequency, or pitch, of a musical note, the shorter the acoustic wavelength, and vice versa. In the case of visible light, the longer the wavelength (that is, the lower the frequency) the redder it gets, the shorter it is, the bluer. If we change the wavelength significantly in one or other direction, the light ceases to be visible to the human eye. When we extend beyond the visible part of the spectrum in the direction of longer wavelengths, we first encounter infrared light, and in the opposite direction – the one of shorter wavelengths – ultraviolet. If we increase or decrease the wavelength further still, the electromagnetic waves start to interact with matter rather differently from optical ones. In the direction of longer wavelengths, they first become microwaves – the kind of electromagnetic radiation on which your microwave oven operates; then radio waves – the electromagnetic waves of short, medium, and long-wave radio transmission. In the opposite direction, when we increase the electromagnetic frequency above that of light, what we get are X-rays and, beyond that, their high-energy counterparts, gamma rays.

It is only in the last one hundred and fifty years that a proper understanding of how electromagnetism works has been achieved, but the process of getting there embodies one of the longest and most remarkable stories in the history of science. As a chronology alone, the tale is sufficiently nuanced and multi-dimensional to qualify as very interesting, but it is promoted into a still higher category by virtue of the fact that it provides us with a uniquely long and detailed record of the development of the intellectual machinery required to analyze, and ultimately understand, physical phenomena with visible effects, but invisible causes.

It is almost certainly the case that observations of natural rock magnetism; that is, lumps of stone that attract each other, or pieces of iron, far predate our earliest records of them. The apparent mysteriousness of magnetism is, in fact, reflected in the term we use to describe it. A pair of stories are in competition for the root of the classical Latin word magnes, and the ancient Greek μαγνῆτις. The first is that it is connected with Magnesia, the richly myth-marinated region of mainland Greece. The second, which comes to us from Pliny, is that a shepherd called Magnes was pasturing his flock on the slopes of mount Ida when the iron nails in his boots, and the iron ferule of his staff became attracted to the ground[1]. Both of these stories have such a compelling dash of the romantic about them that, even if it were possible, it would seem a shame to displace one in favour of the other.

The earliest western reference to magnetism and its relationship to electricity belongs to Thales who apparently made the observation that there was something of a commonality between the way that amber, when rubbed, attracts bits of straw, and the way that magnetic rocks attract iron[2]. This was the beginning of a controversy that would not resolve itself for almost two and a half thousand years – are electricity and magnetism somehow related, or are they two completely different things? Towards the end of the fourth century B.C., Theophrastus ponders the same problem; as part of his observations on stones, he too compares the attractive powers of amber to those of magnetic rocks[3]:

It is remarkable in its powers, and so is the *lyngourion*[4]; for seals are cut from this too, and it is very hard, like real stone. It has the power of attraction, just as amber has, and some say that it not only attracts straws and bits of wood, but also copper and iron, if the pieces are thin, as Diokles used to explain. It is cold and very transparent, and it is better when it comes from wild animals rather than tame ones and from males rather than females; for there is a difference in their food, in the exercise they take or fail to take, and in general in the nature of their bodies, so that one is drier and the other more moist. Those who are experienced find the stone by digging it up; for when the animal makes water, it conceals this by heaping earth on top. This stone needs working even more than the other kind.

And since amber is also a stone – for the kind that is dug up is found in Liguria – the power of attraction would belong to this too. The stone that attracts iron is the most remarkable and conspicuous example. This also is rare and occurs in few places. This stone too should be listed as having a similar power.

As well as a discussion of the relationship between electricity and magnetism, the extract above also gives us noteworthy insight into the way in which the physical properties of the author's subjects – the stones – were regarded. What we see is an interesting admixture of what the modern reader would describe as technical fact derived from observation: "it is cold and very transparent", and speculations which have no observational basis whatsoever "it is better when it comes from wild animals rather than tame ones and from males rather than females".

Around 50 B.C., Lucretius gives us more to think about in his account of the natural world. It is interesting to examine a few passages of this poetic translation of his *De Rerum Natura* from Leonard[5]:

And ilk one feels the stone's own power and bonds-
So over-masteringly its power flows down.
In things of this sort, much must be made sure
Ere thou account of the thing itself canst give,
And the approaches roundabout must be;
Wherefore the more do I exact of thee
A mind and ears attent.

...

Wherefore, since all these matters now have been
Established and settled well for us
As premises prepared, for what remains
'Twill not be hard to render clear account
By means of these, and the whole cause reveal
Whereby the magnet lures the strength of iron.

...

Those Samothracian iron rings leap up,
And iron filings in the brazen bowls
Seethe furiously, when underneath was set
The magnet stone. So strongly iron seems
To crave to flee that rock. Such discord great
Is gendered by the interposed brass,
Because, forsooth, when first the tide of brass
Hath seized upon and held possession of
The iron's open passage-ways, thereafter
Cometh the tide of the stone, and in that iron
Findeth all spaces full, nor now hath holes
To swim through, as before.

It is clear that the text is intended to capture the reader's imagination but, nonetheless, the dramatic pitch of the language is striking. Both the magnet and the iron attracted to it are personified, and their motions are explained through human capacities: they lure, they seethe, they crave. It is also the case though, that Lucretius very elegantly spells out the particular difficulty of the problem of magnetism, "In things of this sort, much must be made sure ere thou account of the thing itself canst give, and the approaches roundabout must be"; theatre aside, the text makes it obvious to us that understanding magnetism was considered by the author to be a serious intellectual project.

A little later, in the first century A.D., we have words on the same theme from Pliny. In Book XXXIV of his Natural History, he talks of the sympathy of magnetic stone with iron[6]:

We will speak in the appropriate place about the lodestone[7] and the sympathy which it has with iron. Iron is the only substance that catches the infection of that stone and retains it for a long period, taking hold of other iron, so that we may sometimes see a chain of rings; the ignorant lower classes call this 'live iron', and wounds inflicted with it are more severe. This sort of stone forms in Biscaya also not in a continuous rocky stratum like the genuine lodestone alluded to but in a scattered pebbly formation or 'bubbling'–that is what they call it. I do not know whether it is equally useful for glass founding, as no one has hitherto tested it, but it certainly imparts the same magnetic property to iron. The architect Timochares had begun to use lodestone for constructing the vaulting in the Temple of Arsinoe at Alexandria, so that the iron statue contained in it might have the appearance of being suspended in mid air; but the project was interrupted by his own death and that of King Ptolemy who had ordered the work to be done in honour of his sister.

Whether a suspension scheme of the kind Pliny describes in the temple of Arsinoe actually existed is, of course, a matter for debate, but factual or otherwise, the text serves to illustrate the continued relationship, or at least perceived relationship, between the miraculous, and the mysterious powers of the magnet.

It seems probable that the association between magnetism and deities, spiritualism, and religious beliefs is one which far predates our earliest surviving records of it. In his Moralia, Plutarch tells us that the bones of the ancient Egyptian god Osiris, were thought of as being made of magnetic material, and those of Typhon, of iron[8]:

The Egyptian usage is cognate to the aforesaid, for they often designate Isis by the name of *Athene*, which expresses the same meaning, "I have proceeded out of myself", and is expressive of self-communicated motion. But Typhon, as above stated, is called *Seth*, *Bebon*, and *Syn*–these names being meant to declare a certain forcible and impeding check, opposition, and turning upside down. Besides, they call a loadstone "Bone of Osiris", but iron "of Typhon" (as Manetho relates), for just as the iron is often, like something alive, attracted to and following after the loadstone, but often turns away and is repelled from it in the opposite direction, in like manner the salutary good and rational motion of the world often attracts by persuasion, draws to itself, and renders more gentle that harsh and Typhonian force; and again, when it has been driven back into itself, it upsets the latter, and plunges it once more into helplessness. . . .

It is possible, likely even, that Plutarch's report is pure fabrication but, irrespective of its truthfulness, what we can confidently take away from his account is the idea that, even in classical times, the ties between the powers of magnetism and the realms of higher beings were already thought of as being ancient ones.

Roughly three hundred years after Pliny's account of objects of worship being suspended by magnets, we have a further story along the same lines from Rufinus in his Ecclesiastical History (a translation of the fourth century Greek text of Eusebius)[9] and around 426 A.D., another written by St. Augustine in his City of God[10]:

> If, then, very many effects can be contrived by human art, of so surprising a kind that the uninitiated think them divine, as when, e.g., in a certain temple two magnets have been adjusted, one in the roof, another in the floor, so that an iron image is suspended in mid-air between them, one would suppose by the power of the divinity, were he ignorant of the magnets above and beneath; or, as in the case of that lamp of Venus which we already mentioned as being a skillful adaptation of asbestos; if, again, by the help of magicians, whom Scripture calls sorcerers and enchanters, the devils could gain such power that the noble poet Virgil should consider himself justified in describing a very powerful magician in these lines: . . .

Earlier in the same volume, we also find some general notes on St Augustine's appreciation of magnetism[11]:

> . . . We know that the loadstone has a wonderful power of attracting iron. When I first saw it I was thunderstruck, for I saw an iron ring attracted and suspended by the stone; and then, as if it had communicated its own property to the iron it attracted, and had made it a substance like itself, this ring was put near another, and lifted it up; and as the first ring clung to the magnet, so did the second ring to the first. A third and a fourth were similarly added, so that there hung from the stone a kind of chain of rings, with their hoops connected, not interlinking, but attached together by their outer surface. Who would not be amazed at this virtue of the stone, subsisting as it does not only in

itself, but transmitted through so many suspended rings, and binding them together by invisible links? . . .

There is much that could be said about the content of all three of these extracts, but, in very general terms, what is perhaps most important in the context of our discussion, is the similarity between the sense of wonder they either express or, in the case of Rufinus, reference, and that we saw in Lucretius in the first century B.C., and Pliny in the first century A.D.; as far as the intellectual's perception and understanding of magnetism goes, there has been no obvious change.

So, between the first century B.C. and the fifth century A.D., there is little apparent development in the way that magnetism is perceived or discussed. There are expressions of awe and wonder, an attempt to explain the action of magnetic systems in terms of human capacities such as desire and sympathy, but nothing material by way of *new* kinds of speculation. In fact, this remained essentially the case until the thirteenth century.

There is absolutely no doubt that the intellectual progress made on the problem of electricity and magnetism in the thirteenth century had a great deal to do with the radical empirical ideas of Bacon. However, the most important text we have on the subject is not from Bacon himself, but his contemporary and correspondent, Peregrinus. Peregrinus' letter of 1269 concerning the magnet[12] provides the first western written account of the idea of a magnetic pole, and of magnets pointing North/South (Figure 2).

In parts, the language of the Peregrinus text is in very obvious contrast to what we have seen written on the subject before. His prose is oftentimes remarkably modern: sober, and technical. The work taken as a whole though, is a blend of this new style, and a much more familiar one; Peregrinus has done experiments – experiments for which some credit him as the western inventor of the compass – but it is clear both that he is incompletely divorced from the intellectual tradition of the classical authors, and that he is of the opinion that a proper account of magnetism should be one which justifies itself in terms of natural laws, and is compatible with a fundamentally theistic world view.

It was the opinion of Peregrinus that the power of magnets came from the heavens, an idea which found significant traction during the medieval period. Celestial associations with magnetism are reflected in the etymology of the word "lodestone". The word "lode" is a medieval one meaning "way" and "lodestar" was the name given to the pole star (also known as Polaris) on account of its significance to early navigators. Curiously, there is considerable evidence to suggest that, as early as 3000 B.C., the Chinese also associated magnetism with the pole star. The earliest Chinese compasses are not navigational devices, but two-part structures comprising a board marked with geometrical graduations, and a free-floating pointer fashioned from magnetic stone in the shape of the spoon-like constellation, ursa major (the one we now know commonly as the plough, or the big dipper). The organization of the stars in ursa major is such that the constellation gives the impression of pointing to the pole star's position in neighbouring ursa minor, and for this reason, came to symbolize its path-finding qualities. Compasses of this kind were used in connection with cleromancy, in particular, the kind of divination associated with the Book of Changes[13], and the same magnetic mythology underpins the origins of the later, western concept, of the lay-, or dragon- line.

After Peregrinus, it was necessary to wait another three hundred and fifty years for the next significant development. It was then that, inspired by the philosophical advances of the late medieval period, the English physician William Gilbert sowed the seeds of a truly game-changing approach and attitude to the study, not just magnetism, but the whole of the natural world. Gilbert's text of 1600, De Magnete, is generally accepted as the first to introduce the idea of the earth originating its own magnetic field, one which has since become so firmly embedded in the way we think about magnetism that it is assumed by many to have entered into the story in a far earlier chapter.

Gilbert's theory of terrestrial magnetism is indeed a very important one, but as significant as the idea itself, is the way that it is arrived at. Gilbert does extensive experiments. He fashions, for example, little balls out of lodestone, which he calls terella – literally "little earths" – and uses short sections of iron wire to map out the magnetic field that they produce. He then compares what he sees with observations of the behaviour of a compass needle on the surface of the earth, and carefully analyzes this comparison in order to draw his conclusions; for illustration, Fig. 3 shows a two-page spread of Book V of the 1900, S. P. Thompson translation of the text, complete with reproductions of the author's original drawings. Notably, Gilbert's experiments to understand the angle of declination of a compass needle lead him to propose a new method of determining longitude. It turns out that his scheme is somewhat flawed, but its imperfections are, I would suggest, insignificant against the background of the bigger picture; what we witness in his work is the emergence both of modern scientific technique, and of a relationship between fundamental science and technology which was almost entirely absent in the classical and medieval periods. We see the beginnings of a soon-to-be-widespread recognition that understanding about how the world works of a kind that has a predictive quality, was a route to progress that could be not only philosophically fulfilling, but *useful.*

Admirable also, is Gilbert's salesmanship. He articulates the merits of his new experimental methodology with a strikingly modern variety of passion. Indeed, enthralling though the main text is, the short foreword that precedes it is one of the highlights of the volume. In this, the author is not only openly critical of those who believe myths about the action of magnetism (like, for example, the then popular notions that garlic and diamonds prevent magnets from working, that one can ascertain whether one's wife is adulterous by placing a magnet under her pillow, and that magnets eat iron, and should be fed it in order to maintain their strength), but justifies and promotes his experimental approach with impressive boldness and rhetorical flair. He writes:

> But to you alone, true philosophizers, honest men, who seek knowledge not from books only but from things themselves, have I addressed

these magnetical principles in this new sort of Philosophizing[14].

The seventeenth century was an important one for all areas of science and medicine. Throughout this time however, and indeed into the nineteenth century, though progress was made in the direction of rationalist descriptions of magnetism and electricity (that is, those that do not contain reference to human-like qualities, desires, or tendencies, or recourse to explanations with their roots in points of astrology or religion), the question of the relationship between electricity and magnetism remained an open one. It was not until the experiments of Ørsted, who showed, in 1820, that an electric current – that is, a movement of charge – gives rise to a magnetic field[15], and after him, the work of Ampère and Faraday, that we came to recognize that the two phenomena are, indeed, fundamentally linked.

Many others deserve recognition that space prevents us from giving them here for further developing our understanding of electricity and magnetism in the balance of the nineteenth century. However, the contribution of a single individual stands out. In a series of papers in the 1860s, James Clerk Maxwell described what he called, for the first time, "electromagnetic fields" and, in so doing, finally tied together electricity and magnetism in a single unified theory – that of "electromagnetism"[16]. Maxwell's description of electricity and magnetism in terms of moving "fields" paved the way for the quantum mechanical innovations of the early twentieth century, especially those of Einstein, Bohr and Pauli – work which allowed us, finally, to understand the nuts and bolts of electricity and magnetism on a truly microscopic scale.

Now, taking a step back, we see that we have been on a lengthy trip. The science that underpins today's imaging technologies took us two and a half millennia to sort out. So one might ask now whether there is more to take from the history that we have just toured though – is it anything more than a good story? In particular – against the background of the theme of digital archeology – should it inform what we do as archaeologists in the here and how? The skeptic could argue not – he might assert, perhaps, that we should focus our energy on the practical application of new technologies to archeological problems, and that the history of the science that underpins them is interesting only as the record of a means to an end. But personally, I do not think that this is quite right. I believe that to sign up to that point of view might be to somewhat misjudge the place of science in the project of human understanding.

Science and the history of science are not two separate things. It is also the case that the idea that "modern" science is somehow different from all other kinds, is an imitation one, the science of the present time – whatever that present time happens to be – is always modern, and it is not only the product of everything that has gone before it, but takes its meaning from the contents of its biography.

It is true that there are certain elements of the science of today that can be seen to be objectively superior to their analogues or counterparts from previous eras. There are practices, careful experiment being one of them, that have become better developed or more sophisticated over the years, and some historical methods and techniques that have been deemed to be wholly unscientific – that is, neither fit for the purpose they were applied to at time they were in vogue, nor proper by contemporary standards. I feel I can claim with reasonable authority, for example, that it was never productive to feed magnets iron filings. Entertaining, perhaps, but not productive.

But the apparent disparities between scientific practices and discourses of the then and the now are not solely of the kind that can be explained away with reference to some concept of progress. Or, in other words, the science of the present is not different from the science of the past simply because we are now better at doing science than we were. Rather, the contrast also has to do with the profound differences between what was understood to be the scope of science historically, and what we now consider it to be. Recognizing these differences can be of immense value to us as scientists; firstly because such a recognition emboldens us to be critical of the way that we think, and secondly, because it encourages us to question the underlying purpose of what we are doing. When we examine the story of how our understanding of electricity and magnetism has come about, I would argue that these values ring out with particular clarity. A key reason for this is that, as we have explored at in some detail, though we easily see what magnetism can *do*, it is impossible to understand *why* it does it through pure observation; to do so also requires a sophisticated imagination, and careful reasoning. So, by looking at how the treatment of the subject has evolved over the centuries, we achieve important insight into how successive generations perceived and abstracted the physical world and their relationship with it.

As a twenty-first century magnetician, it is tempting to look at some of the speculations of one's classical predecessors and find them amusing; absurd, even. And some of them are. But a great many of them are only apparently absurd. The belief that magnets have virtues and sympathies, for example, appears absurd to us now, not on account of proven intellectual deficiency on the part of those who held it, but rather as a consequence of the considerable shift in the scope of scientific thought with time. Science from classical times until the late middle ages encompassed a wide range of questions that have since been passed on to the philosophers.

Contemporary scientists spend a lot of time asking the question "why?", but in a very particular way. When we ask "why does a magnet attract iron?", what we mean is, "what physical process underpins the phenomenon of a magnet attracting a piece of iron", and possibly, "how can we systemetize our understanding of this physical process in such a way that we can achieve a general functional understanding of the process by which a piece of iron is attracted to a magnet". What we are not asking is, "why, *should* the natural world that we are a part of conspire to create the phenomenon of magnetism, and how do we reconcile its presence in the universe with our experience of our own existence?". This is exactly the question that preoccupied our scientific forebears and it is no surprise, therefore, that their investigations are infused with their enthusiasm to find an answer.

Unlike his classical predecessors, today's magnetician can give an impressive technical account of how magnetism works. But this is not because he is operating on some higher, or superior, intellectual plane. It is because he has access to knowledge that classical scientists did not have about the technicalities of how the physical world is put together. And this is not knowledge that has been acquired at first hand. I, for example, am allowed to call myself a condensed matter physicist, but have never reached out and touched an electron, seen an atom, or measured the fine-structure constant; I have simply learnt what I need to know about these things from the works of others, acquiring, through textbooks and papers, the body of accepted knowledge of the intellectual community I belong to. My job in the laboratory does not require me to engage in any way with philosophical questions about how electricity and magnetism fit into the wider universe: why there should be such things, and whether their existence has a meaning. And it would be dishonest, I believe, to claim that the absence of this engagement is any more proper than it is improper; it is simply a symptom of the fact that science has adjusted so that these questions now lie outside of its scope. Two and a half thousand years after Thales, we may have a technical description of why two magnets attract each other, but are we really materially closer to understanding why they *should*? I would suggest not.

So, what does this mean for the application of science in archaeology? What it means, I think, is that when we apply science to the study of archaeology, we should do so with a consciousness that it is a product of the past we are using it to uncover. When we do that, the simplest of observations present themselves as starting points for interesting discussions. We take for granted, for example, the fact that we do not feel the need to fully understand the physics underpinning the scientific techniques that we use. But our capacity to do this is not a trivial thing at all – it is the result of a concept of scientific authority that has developed over more than two millennia. And the value of applying these techniques as far as science is concerned does not simply lie in the satisfaction of getting some results, but the improvement in understanding it gives us of the *process* of scientific thought. And that, more than anything else at all, is key to making the best of being a scientist. Being in the laboratory doing experiments is fulfilling, but being able to explore the process of experiment and its results against the background of the wider sphere of human knowledge is a lot more than that.

Their products may be technical, material, technological, but all major scientific revolutions have begun with new ways of thinking. In the same, smaller way, progress in science is driven primarily by developments in thought. It is true that we are now capable of making sophisticated measurements of the natural world, but these can only be of value to us if we have the intellectual machinery to think about them properly. And though they may sometimes appear to be, developments in thought are not an all-of-a-sudden kind of thing: they happen over time, and they are often catalyzed by a gradual improvement in awareness of *how we are thinking*. Thinking things is easy, but understanding what parts of these thoughts belong to the thought, and which are products of the way that we are inclined to think them is really hard.

The combination of the archeological developments that today's imaging technologies give us, and the consciousness of the scientific journey that these are a part of, potentially empower us to be more aware of the intellectual processes that underpin our understanding of the universe – the physical universe, and the universe of human experience – than any other generation; we have reason, I think, to be excited.

NOTES

1. Gaius Plinius Secundus, *Natural History*, Book XXXVI, Ch. XXV.

2. An excellent account is provided in *A History of Electricity and Magnetism*, H. W. Meyer, Ch. 1. Burndy Library Publication No. 27, 1972.

3. *Theophrastus on Stones, Introduction, Greek Text, English Translation, and Commentary*, 28-30, E. R. Caley and J. F. C. Richards. Ohio State University, 1956.

4. Literally, lynx-urine stone, Caley and Richards note that this is probably a variety of amber.

5. *De Rerum Natura*, Tr. W. E. Leonard, Book VI, "Extraordinary and Para-

doxical Telluric Phenomena". Translation available online on the Internet Classics Archive http://classics.mit.edu//Carus/nature_things.html.

6. *Pliny's Natural History*, Tr. H Rackham, W. H. S. Jones, and D. E. Eichholz, Historia Naturalis, Book XXXIV, Ch. XLII. Harvard University Press, Massachusetts, 1949.

7. We might lodge an objection to the use of the word lodestone in this translation; worth mentioning, because it is an interesting illustration of how richly associative the language we use to describe magnetism is. The word "lode" is a medieval one meaning "way" and its connection with magnets has to do with the particular navigational associations they acquired in the late medieval period. At least in the western world, these post-date Pliny by at least a millennium.

8. *Plutarch's Morals: Theosophical Essays*, Tr. C. W. King, "On Isis and Osiris", LXII. George Bell and Sons, 1908.

9. Rufinus, *Historia Ecclesiastica*, "The Destruction of the Serapeum", Book XXIII.

10. St. Augustine, The City of God, Book XXI, Ch. 6, Tr. Rev. M. Dods; Ed. P. Shaff.

11. *Ibid*, Book XXI, Ch. 4.

12. Epistle of Peter Peregrinus of Maricourt to Sygerus of Foncaucourt, 1269.

13. *I Ching*. See, for example, the R. Wilhelm translation, Penguin, 1989.

14. *On the magnet, magnetic bodies also, and on the great magnet the earth; a new physiology demonstrated by many arguments and experiments*, preface, Tr. S. P. Thompson. Privately printed by The Chiswick Press,1900.

15. *Annals of Philosophy*, Vol. XVI, Article IV. "Experiments on the Effect of a Current of Electricity on the Magnetic Needle", J. C. Ørsted, October 1820.

16. *Royal Society Transactions*, Vol. CLV, "A Dynamical Theory of the Electromagnetic Field", J. C. Maxwell, 1864. Reproduced in *The Scientific Papers of James Clerk Maxwell*, Ed. W. D. Niven, Dover Publications, New York, 1965 (after an earlier, 1890, Cambridge University Press edition).

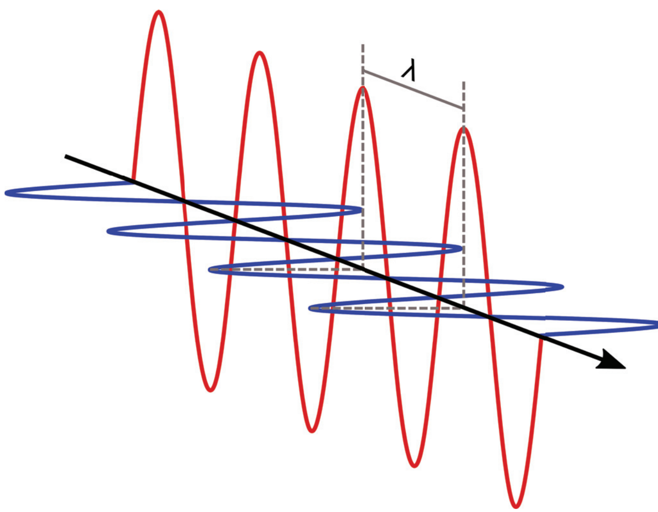
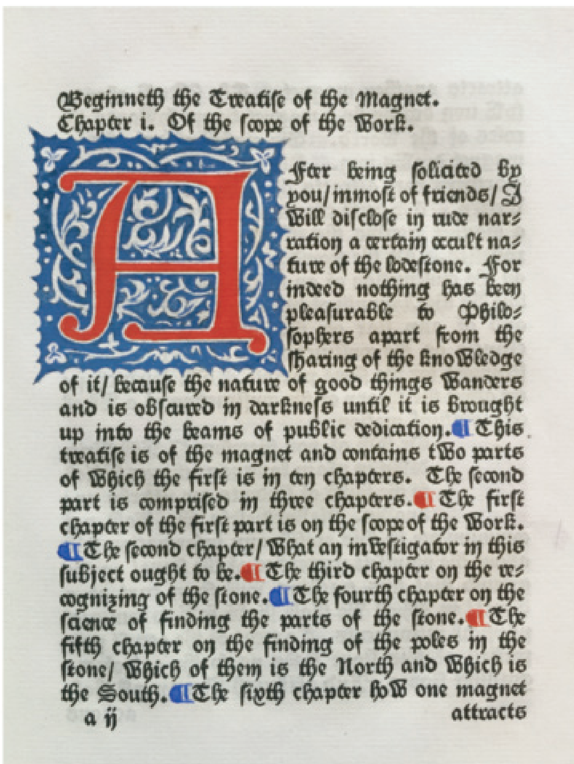


Figure 1| Electromagnetic excitations are made up of a wave of electrical energy (red) together with wave of magnetic energy (blue). The two propagate in the same direction, but are perpendicular to each other. The wavelength, usually representedby the symbol λ , is the distance between adjacent peaks of the two constituent waves and is inversely proportional to the frequency; that is, the number of undulations (or oscillations) up and down per second.


Beginneth the Treatise of the Magnet.
Chapter i. Of the scope of the Work.

After being solicited by you/ inmost of friends/ I will disclose in rude narration a certain occult nature of the lodestone. For indeed nothing has been pleasurable to Philosophers apart from the sharing of the knowledge of it/ because the nature of good things wanders and is obscured in darkness until it is brought up into the beams of public dedication. ¶ This treatise is of the magnet and contains two parts of which the first is in ten chapters. The second part is comprised in three chapters. ¶ The first chapter of the first part is on the scope of the Work. ¶ The second chapter/ what an investigator in this subject ought to be. ¶ The third chapter on the recognizing of the stone. ¶ The fourth chapter on the science of finding the parts of the stone. ¶ The fifth chapter on the finding of the poles in the stone/ which of them is the North and which is the South. ¶ The sixth chapter how one magnet attracts

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Figure 2| The opening page of a rare illuminated copy of Silvanus Thompson's translation of the 1269 epistle of Peter Peregrinus of Maricourt to Sygerus of Foncaucourt concerning the magnet (1902, The Chiswick Press). The illuminations were undertaken by Silvanus's brother, Thomas.

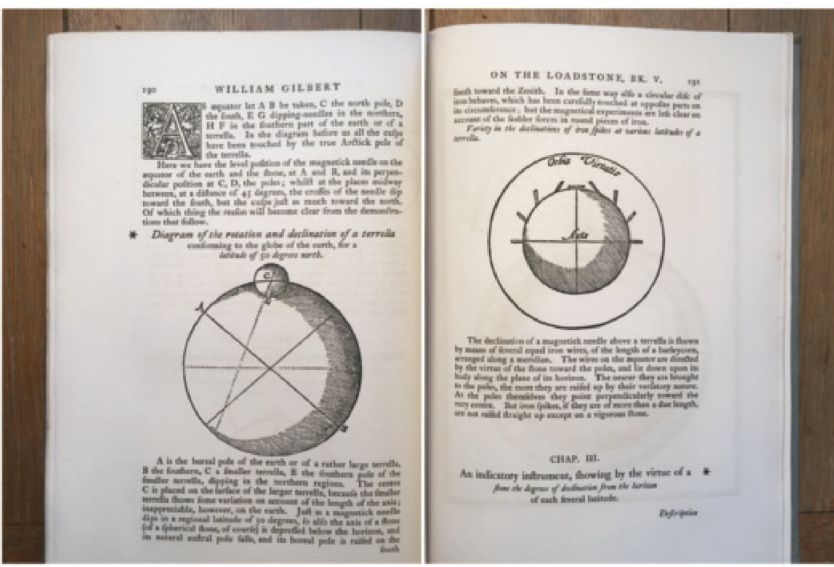
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Diagram of the rotation and declination of a terrella conforming to the globe of the earth, for a *latitude of 50 degrees north.*

ON THE LOADSTONE, BK. V. 191

CHAP. III.

An indicatory instrument, showing by the virtue of a *stone the degrees of declination from the horizon* of each several latitude.

Figure 3| Facing pages from Book V of the 1900, Silvanus Thompson translation of William Gilbert's 1600 text *On the magnet, magnetic bodies also, and on the great magnet the earth; a new physiology demonstrated by many arguments and experiment.* Complete with reproductions of the author's original drawings, this extract nicely illustrates the spirit of the volume.