William Gilbert: the first palaeomagnetist

Lodestone and iron were the only known magnetic materials in Gilbert’s day, and long thereafter. The thoughts about lodestones, and indeed about science, in Gilbert’s time might be typified by some quotations:

“Others tell that in daytime the loadstone possesses power of attracting iron, but that at night this power is feeble or rather null,” (B1, C1, 13).

“They asserted that a loadstone rubbed with garlic does not attract iron,” (B1, C1, 2).

Do I need to write that Gilbert actually tested these ideas, and many similar? Yes, I must, because testing a scientific idea experimentally was barely beginning to catch on during his lifetime. His task was not only to investigate magnetism, but also to overcome a mountain of printed ignorance.

Yet even while such nonsense persisted, the practical or technological uses of magnetism were already many: travelling (especially at sea), searching for veins of buildings, aiming cannons at night, orienting underground tunnels for war or water, for example.

However, Gilbert wanted to know the rules as well as the uses. What were his tools? Lodestone, iron, a pivoted magnetic needle (a versorium, figure 1), a home-made protractor, a balance, several fingers (he seems not to have used a ruler) and a blacksmith’s forge (figure 2). As you read this, perhaps you could consider whether you would have made his discoveries with these facilities alone. It was no hindrance that he was the physician of Queen Elizabeth I and was one of her favourites, which perhaps provided some finance for his great passion (magnetism, rather than Her Majesty). He chose to work with spheres of lodestone, turned on a lathe, which must have been quite difficult given the hardness of a lodestone. Such a sphere he called a Terrella (a “little Earth”).

Gilbert understood polarity, which in itself is commendable, given the ignorance of the time: “As Albertus Magnus says, there are two species of loadstones, one pointing north, the other south” (B1, C1, 13).

Gilbert was sure that the Earth was a giant lodestone and used the Earth as a primary reference, defining the north (magnetic) pole of a needle, or of a nail floating on a piece of cork, to be that which turns towards the Earth’s north geographic pole.

I would like to take you through several of William Gilbert’s discoveries. His book, De Magnete, was published in Latin in 1600 and not published in English until 1893 (that of P Fleurie Mottelet, which I find easier to read) and 1901 (the Gilbert Club’s translation). In the margins he placed asterisks. A small asterisk meant “this discovery is my own, and original, but is not obviously of great consequence”, but a large asterisk meant “this discovery is original to me, and it’s a big deal!”. My first reading took me 70 hours because of the difficult terminology. On my second reading (about 30 hours) I found several gems which the earlier struggle had caused me to miss, not least because Gilbert would toss these gems into one or two sentences buried in a paragraph.

**Thermal magnetization**

“The apply a red hot iron to a magnetized needle and the needle stands still, not turning to the iron; but as soon as the temperature has fallen somewhat at it at once turns to it. A piece of iron that has been magnetized [by stroking with a lodestone], if placed in a hot fire until it becomes red-hot, and permitted to remain for a little while, loses the magnetic power,” (B2, C4, 107).

He also knew that quite a strong magnetization (verticity) could be induced by heating an iron wire or rod and leaving it with one end pointing north as it cooled. Palaeomagnetists now call this a thermoremanent magnetization; it has happened to every igneous rock ever formed.

**Thermal demagnetization**

In what follows, “position” means “orientation”. That sort of terminology is why my first reading took 70 hours. Yet even today we talk of a star’s position, meaning its direction.

Why would it even have occurred to him that he could demagnetize an iron rod as follows: “Quicken the fire with bellows so that it becomes all alive, and let the glowing iron remain for a little while. After it has grown cool again (but in cooling it must not remain in one position) put iron [on] cork once more in water, and you shall see that it has lost its acquired verticity [magnetisation],” (B3, C3, 190).

That is, by flipping the iron back and forth as it cooled, he effectively demagnetized it by a randomizing process. Today this is called tumbling by the palaeomagnetists, and I believe it was never done again until 1957, by Arni Brynjolfsson in Iceland.

**Time effects**

Today we often mention viscous remnant magnetization, which is acquired slowly in magnetic materials simply by sitting for a long time in a weak magnetic field such as the Earth’s.

“Let us see what position alone, without fire and heat, and what mere giving to the iron a direction toward the Earth’s poles may do. Iron bars that for a long time – twenty years or more – have lain fixed in the north and south position, as bars are often fixed in buildings and in glass windows – such bars, in the lapse of time acquire verticity [magnetisation] … for great is the effect of the long-continued direction of a body toward the [Earth’s] poles,” (B3, C12, 214), and here he quotes an earlier Italian observation. Perhaps Thellier in the 1930s was next to look into this phenomenon systematically.

**Coercive force**

Having magnetized an iron wire (rod) by stroking it with a lodestone:

“And now merely hold for a while the north end of the stone [lodestone] near the north end of the wire … not bringing the two into con-

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1: Gilbert’s prime magnetic instrument, a pivoted magnetic iron needle. This needle would be remagnetized from time to time by stroking it with a lodestone.
If you were a scientist who was more than 200 years ahead of his time, as was William Gilbert, would anyone take notice of you? A few did — notably Galileo — but even now, 400 years later, not many have actually paid close attention to what Gilbert wrote. I have tried here to make available, particularly to geophysicists, some of Gilbert’s outstanding discoveries that should reside with honour in our geomagnetic textbooks. His book, De Magnete, was published in AD 1600.

This was the closest Gilbert could come to drawing a hysteresis loop and finding the coercive force, since he had no numerical measure of magnetic field strength or magnetic moment and it wasn’t until 1637 that Descartes’ idea of graphs was published.

In fact Gilbert came close to measuring magnetic field strength. He did know that the magnetic needle swung or vibrated more rapidly in a stronger field, and might have timed its vibration period using a water clock; however, he did not. Baptista Porta before him could compare the strengths (magnetic moments) of lodestones by placing a lodestone four finger-breadths away, “Then some iron lying on a board is brought nigh, so that it shall cleave to [under] the loadstone in the scale … into the opposite scale sand is poured gradually till the scale in which is the loadstone separates from the iron. By weighing the sand the force of the loadstone is ascertained,” (B3, C36, 168).

It may be that weighing scales were the most sensitive and accurate instrument of the time. They had been in use for centuries, and possibly millennia, for commercial purposes.

Instantaneous magnetization

“The moment the iron is touched by the loadstone it is excited throughout. For example, take an unmagnetized iron rod, 4 or 5 inches long: at the instant you simply touch with the loadstone either end, the opposite end straightway, in the twinkling of the eye, repels or attracts a needle, however quickly brought to it,” (B3, C3, 191).

As I read it, he would have carried the iron rod swiftly by hand to the versorium. Of course the process of magnetization would be 5 or 6 orders of magnitude faster than he could have detected.

Magnetic shielding

In at least three places in his book, Gilbert mentions that an iron plate interposed between, say, a versorium (magnetic needle) and a lodestone, will diminish the effect on the needle. He knew experimentally that gold, silver, glass and marble had no such effect whatsoever.

“No hindrance is offered by thick boards, or by walls of pottery or marble, or even of metals; there is naught so solid as to do away with this force or to check it, save a plate of iron,” (B3, C10, 209 and B2, C16, 132 and 134).

Phase change

This was one of the gems I missed on first reading. Gilbert was well aware that heating iron could eliminate its magnetic property altogether, but he goes further and guesses the nature of the change:

“Still, as Cardan not injudiciously remarks,
red-hot iron is not iron, but something lying outside its own nature, until it returns to itself. For just as, by the cold of the ambient air, water is changed from its own nature into ice, so iron made white-hot by fire has a confused, disordered form, and therefore is not attracted by a loadstone, and even loses its power of attracting, however acquired,” (B2, C4, 108).

This remarkable intuition about a magnetic phase change similar to the water-ice change, even down to the use of the term “disordered”, left me astounded that anyone should have grasped it 400 years ago when there was no distinction between heat and temperature, and no temperature scale beyond touch and colour. It was to be more than 300 years before the notions of a magnetic order/disorder transition and associated Curie temperature became clear.

Curie temperatures

We now know that lodestone is usually fairly pure magnetite, with a Curie temperature near to 580 °C. Iron has a Curie temperature near to 770 °C. How close did Gilbert get?

“But a red-hot loadstone does not attract iron at all, nor is iron at white heat attracted by loadstone,” (B2, C38, 173). He knew, therefore that the “Curie point” of iron was greater than that of lodestone.

Action at a distance

“The poles of iron bars are changed when a loadstone simply presents its pole to them and faces them even from some distance,” (B3, C12, 215), and Gilbert notes the same for the effect of the Earth’s magnetism without the Earth touching a compass needle.

“Surely in a like way does that great loadstone the Earth affect iron and change verticity,” (B3, C12, 215).

He had no means of speculating on how this happens through empty space, nor does he seem to have been the kind of person to dwell on unlikely theories.

It was also clear that he understood, as had Robert Norman before him, the distinction between a force and a torque. He asserted that the Earth’s magnetism exerted a torque on a compass but not a force, and that was nearly correct experimentally. Also:

“If two loadstones be set over against each other in their floats on the surface of water, they do not come together forthwith, but first they wheel round, or the smaller obeys the larger and takes a sort of circular motion; at length, when they are in their natural position [antiparallel] they come together,” (B2, C4, 110).

Gilbert the palaeomagnetist

In the now-standard textbooks on palaeomagnetism or rock magnetism, the earliest work seems to fall to Delesse in 1849 and Melloni in 1853. Gilbert preceded them by more than 250 years. Here it is:

“We once had chiselled and dug out of its vein a loadstone 20 pounds in weight, having first noted and marked its extremities; then, after it had been taken out of the earth, we placed it on a float in water so it could freely turn about; straight-way that extremity of it which in the mine looked north turned to the north in water, and after a while there abode,” (B3, C2, 184).

So he took an oriented sample from its in-situ position and measured the direction of its natural remanent magnetization. That’s palaeomagnetism. His instrument was some cork or wood on water and the Earth’s magnetic field.

Since the 1960s we have been certain that the polarity of the Earth’s magnetic field has reversed aperiodically. Half of the time throughout the Earth’s history, its magnetic poles have been inverted compared with those of today. Lodestones, or at least ironstones, have certainly been found with a reversed magnetization. Thank goodness Gilbert’s 20 pound oriented sample was normally magnetized (along the sense of today’s geomagnetic field). Otherwise, his book might have been somewhat different. Since he believed, quite reasonably, that the Earth itself was a giant permanently magnetized lodestone, I doubt that he would have been able to explain any sample that was magnetized in the opposite sense.

The dip of the Earth’s magnetic field

Gilbert and others attribute to Robert Norman the discovery, in 1576, of the inclination or dip of the geomagnetic field below or above the local horizontal. Figure 3 shows Gilbert’s apparatus for virtually friction-free demonstration of this dip. His needle is suspended in a wine glass by driving the needle through a cork, the combined system being neutrally buoyant, submerged, and finely balanced. Of course, there was no scale and I suppose this demonstration was more for his own delight, or for the Tudor equivalent of a cocktail party.

Figure 4 lets us see how he demonstrated the variation of the dip of the magnetic field with latitude. He already had a few data from both northern and southern latitudes, and he replicated this with a model Terrella, using short pieces of iron, as in the figure. We must remember that he believed that the Earth itself was a giant lodestone, apart from superficial corruption.

The dipole field

Near the end of any talk I have given about De Magnete, I have produced figure 5 and then asked for a show of hands as to how many of the hardened geophysicists in the audience have ever seen this sort of diagram before. You must imagine the Terrella that was in fact at the centre of figure 5. At the United Kingdom Geophysical Assembly a few years ago, only two, or perhaps three hands went up. Turning the diagram through 90° and placing it alongside the well-known diagram of lines of force of the Earth’s dipole field shed a little light. Surely Gilbert was by far the earliest person ever to investigate, with a magnetic needle, the configuration of a dipole field. Who was next?

Do lodestones eat iron?

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work any graces of rhetoric, and verbal ornateness, but have aimed simply at treating knotty questions about which little is known in such a style and in such terms as are needed to make what is said clearly intelligible.

One of the pleasures of De Magnete is the many pages devoted to knocking earlier people. Gilbert pulled no punches. Testable hypotheses were far more to his taste than musty books.

“Here we must express wonder at a manifest error of Baptista Porta, who, though he properly refuses assent to the invertebrate falsehood about a force the opposite of the magnetic, imparts a still falster opinion, to wit, that iron rubbed with diamond turns to the north. ’If,’ he writes, ‘we rub an iron needle on diamond, and then put it in a boat or on a straw or suspend it properly with a thread, at once it turns to the north like iron rubbed on a loadstone, or perhaps a little more sluggishly. Nay – and this is worthy of remark – the opposite part, like the loadstone itself at the south end, repels iron, and when we experimented with a multitude of small iron rods in water, they all stood at equal distances apart and pointed north.’ Now this is contrary to our magnetic rule; and hence we made the experiment ourselves with seventy-five diamonds in presence of many witnesses, employing a number of iron bars and pieces of wire, manipulating them with the greatest care while they floated in water, supported by corks; yet never was it granted me to see the effect mentioned by Porta,” (B1, C13, 217). Overkill perhaps, but he made his point.

“And errors have steadily been spread abroad and been accepted – even as evil and noxious plants ever have the most luxuriant growth – down to our day, being propagated in the writings of many authors who, to the end that their volumes might grow to the desired bulk, do write and copy all sorts about so many things of which they know naught for certain in the light of experience,” (B1, C1, 2).

You can see that he called a spade a spade and knew his own value. Perhaps a certain snobbery even creeps in, at least as viewed 400 years later. “Philosophers of the vulgar sort,” and “theories adapted to the vulgar herd” would not today get past the editor of this journal, would they?

Weaknesses?

It is tempting to ascribe Godhead to those who have done marvellous things, especially long after their deaths when they pose no professional threat to ourselves. However, we must admit that almost all Gilbert’s work was only semi-quantitative. Galileo, while honouring Gilbert, did point this out. Even before 1600, lengths could be measured better than Gilbert did.

I remember Sir Edward Bullard, at a British Conference, saying: “Let’s get the facts right. We can fix up the theories later.” I think Gilbert had Bullard’s rule in mind pretty solidly, and certainly very uncharacteristically of his times – or indeed of any previous times in all history. His digression at the end of the book can be forgiven. Here, despite his emphasis on experiment and observation, the book does become fairly speculative in places.

And then…

Most, perhaps all, of the standard palaeomagnetic textbooks credit Gilbert with having written that “the Earth itself is a giant magnet”, and then pass on. As we see here, he did very much more than that, so long ago that few could have gathered the full import of his work until at least another 200 years, and in some cases 350 years, had passed. It is at first especially surprising that translations into English from the Latin only appeared after 300 years, but given that the significance of his discoveries would have been meaningfully to so many, it is perhaps understandable, despite the praise he received from the few. Even in 1893 and 1901, the translators themselves seem not to have been so concerned about science as about literary elegance. I doubt that a working scientist of the 1890s would have translated a magnetic needle as versorium, or magnetic field strength (or sometimes magnetic moment) as virtue; these are transliterations from the Latin.

Gilbert’s book has been quite fairly credited by some as the first modern scientific textbook because, I suppose, so much was based on experiment. It is not unreasonable that modern science should have started with an obvious phenomenon with which we could easily deal at first hand – magnetic lodestones. Lodestone “exhibited that strong powerful attraction of iron – no latent or obscure property, but one easily seen of all”. This raises an interesting if hypothetical question: Lodestones are magnetized because they have gradually formed in the Earth’s magnetic field. How would science have progressed if we ourselves had evolved on Mercury, Venus or Mars? Those planets have very weak or zero magnetic fields, so that if lodestones exist on those three planets, it would quite possibly have acquired no significant magnetization during its formation. What then? A science starting from electrostatics alone might well have taken a considerably longer time to reach the notions of electric currents and then magnetic effects. We might still be using horses and buggies, gas lights, and messenger boys.