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# WILLIAM GILBERT AND 'MAGNETIZATION BY PERCUSSION'

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In his *De Magnete* William Gilbert claims that it is possible to make a magnet by hammering a red-hot bar of wrought iron arranged north–south on an anvil. This is contrary to modern ideas concerning the 'Curie temperature' (770°C for carbon steel), and to the recognized susceptibility of steel magnets to mechanical abuse. It has proved impossible to replicate Gilbert's technique experimentally. Only lengthy cold hammering of hardened carbon steel specimens on a large ferrous anvil produced weak permanent magnets.

**Keywords: magnetization; percussion; Gilbert; *De Magnete***

In 1600 William Gilbert published the pioneering scientific work based on experiment that is generally referred to as the *De Magnete*.[1] He distinguished magnetic from electrostatic attraction, discussed the naturally magnetic samples of iron oxide known as 'lodestones'[2] and their poles, and explained how 'artificial' magnets may be produced by unidirectional stroking of hardened steel bars with a powerful lodestone. In particular, he confirmed the Chinese discovery that either form of magnet would, if suspended on silk thread or floated on a cork disc, tend to come to rest with its north-seeking pole in a northerly direction.

Gilbert also claimed that a permanent magnet could be produced by heating a wrought-iron bar to incandescence in a forge and then continuously hammering it on an anvil as it cooled while oriented more or less horizontally in a north–south direction. He illustrated this procedure with the engraving reproduced as figure 1. This lively scene has become quite well known, being reproduced in many general and school-level scientific texts, but it does give the impression that a blacksmith was employed to do the work. As a gentleman and a courtier—as well as a physician—it would not have been acceptable for Gilbert to soil his own hands in this way!

A scholarly study of Gilbert's treatise was pursued by Silvanus Thompson,[3] who in 1901 pointed out similarities between Gilbert's illustration and that of a blacksmith in a work published by Cornelius Kiliani[4] in 1594. More recently, the image has been traced back still further by Ashworth,[5] proving to be an etching originated by the Flemish artist Marcus Gheeraerts for an illustrated collection of Aesop's fables first published in 1567 (figure 2).[6] Sixteenth-century artists commonly used works by their predecessors to provide information for their own pictures. The story of the smith and his dog is not one

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Figure 1. Making magnets by hammering hot iron in the meridian.[1] 'Auster' and 'Septentrio' come from an early scheme of naming cardinal points from the winds: they correspond to north and south, respectively.

of the better-known fables, but the gist of it is that the dog could sleep through the noisiest labours of his master but would be instantly aroused by the least rattle of his feeding dish. Various morals were drawn, generally to the effect that some people appear deaf to everything but that which directly concerns their own well-being.

It will be observed that Gilbert's engraver has promoted his smith through several social classes, making him appear as quite a debonair craftsman working in a remarkably clean shop. The dog, being irrelevant to the scene, has been ejected. Unfortunately, by reversing the blacksmith's stance, the artist has made it impossible for him to manipulate the bellows with his left hand and thereby control the temperature of the iron!

## Nature of the iron

It should be pointed out that the only iron available to Gilbert would have been 'wrought iron', made by the reduction of iron ore with charcoal to give a metallic sinter, followed by extended hot hammering to close the pores and extrude most of the slag. The product was a rather uncontrolled mixture of iron and carbon that could be softened by 'annealing'—heating to a bright red heat and then allowing to cool slowly. At this stage it might be hammered into bars for convenient sale to blacksmiths and the like. Reheating to a red heat followed by rapid quenching in water or oil resulted in a very hard and brittle product, so it was usual to 'temper' a hardened wrought-iron tool by gentle reheating controlled by the interference colour exhibited on an abraded surface. Knives, for example, would generally be tempered to a blue colour.

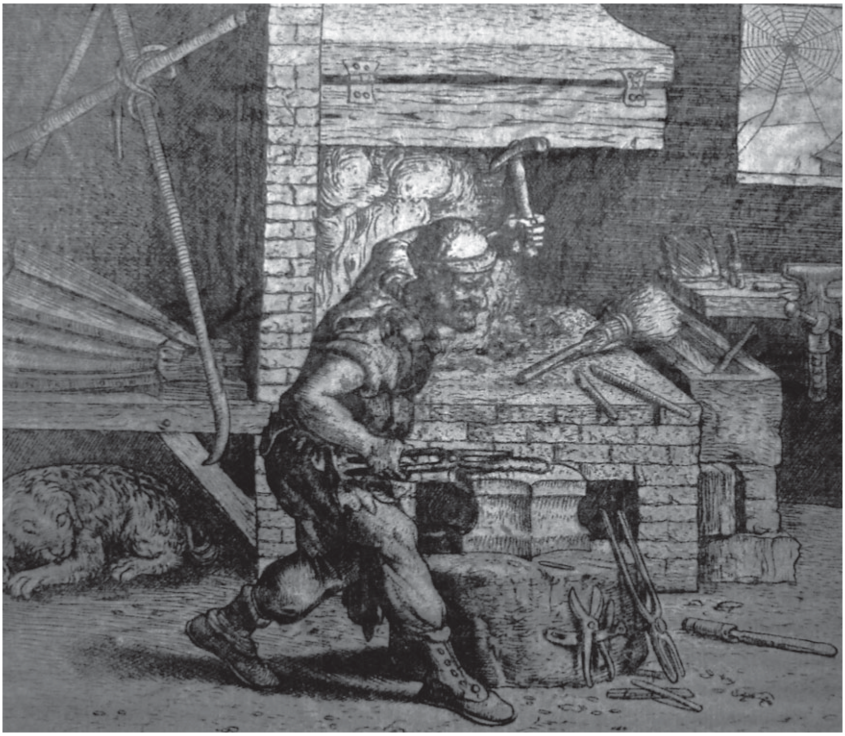

Figure 2. 'The Smith and the Dog', an etching by Marcus Gheeraerts published in Bruges in 1567.[6]

Nowadays it is virtually impossible to obtain genuine wrought iron: what is generally available in tonnage quantities is 'mild steel'—a misnomer for the remarkably pure iron obtained by blowing air through molten iron obtained from a blast furnace. It cannot be hardened. True 'steel' is an alloy of iron and carbon, made by carefully adding carbon (or a high-carbon alloy) to molten mild steel. 'Carbon steel' is available in various shapes and compositions for making ferrous tools and objects that need to be subsequently hardened and tempered.

## Further problems

The mirror-image transformation of the smith is not a particularly significant oversight: much more serious is whether hammering of a hot iron bar oriented in the Earth's field is, in fact, effective for the production of a permanent magnet. Thompson does not question it, and even today the tradition seems to be very commonly accepted. However, elementary texts usually emphasize that, for strength and longevity, permanent magnets should be made either of *hardened* high-carbon steel or of special alloys. They also commonly mention that mechanical abuse will damage a magnet, decreasing its power to lift small pieces of iron.

The 'Curie temperature' quantifies the temperature at which a magnetic material loses its magnetism, and modern reference works quote a figure of about 770°C for carbon steel. This corresponds to a mid-red heat, so the blacksmith's specimen could not begin to acquire magnetism until it had cooled below this point. Then, as it cools still further, it has been explained that wrought iron is softened (annealed). Hardening requires the *rapid* cooling associated with quenching the glowing metal in cold water or oil.

An underlying problem is that the Earth's natural magnetic field is being employed as the magnetizing influence, and it is both intrinsically weak and (in Europe) directed to be nearer vertical than horizontal. In Gilbert's London this *dip* was about 73°, but it has since diminished to be nearer 66.5°. Any procedure using the terrestrial field should therefore maximize its influence by positioning the sample along the magnetic meridian and inclining it downwards. Nevertheless, a considerable mass of iron does exert a degree of concentration of the terrestrial field, so the iron anvil in Gilbert's illustration should exert a beneficial (but unsung) effect. Better still would be a massive iron bar supported along the dip, but the difficulty of hammering at an angle suggests a vertical bar as a practical compromise.

## Experimental tests

Producing permanent magnets by percussion has been completely supplanted by electromagnetic methods, so only one modern study is known.[7] Commercial 'masonry nails' are made from hardened carbon steel, and a stock size 60 mm long and 3 mm in diameter provided reproducible small samples. Each weighed 3.37 g. A small plotting compass detected no magnetism in any of these nails, but as an extra precaution all were first passed through an alternating-current demagnetizer.

Untreated nails were magnetized by stroking them with a modern 'Alnico' magnet, and also by placing them within a coil connected briefly to a 12 V car battery. All easily picked up a dozen steel dressmakers' pins, forming stable chains. A technique involving finding the neutral point when opposed by the horizontal component of the Earth's field (known to be of an intensity about 0.18 oersted (Oe) in the UK) gave magnetic moments of 110 electromagnetic units (emu), equivalent to a saturation magnetic strength of 33 emu $g^{-1}$. (The terms oersted cm or oersted cm $g^{-1}$ do not appear to have been used.) Annealed nails magnetized by identical methods would not pick up a single pin but did repel one pole of a plotting compass. Their magnetic strength was less than 4 emu $g^{-1}$, falling to less than 1 emu $g^{-1}$ when the softened nail was dropped on the floor.

Attempts to induce permanent magnetism by supporting both hard and softened nails for 12 months in a wooden trough positioned down the dip were totally unsuccessful. So, too, were experiments in which nails were transferred directly from the furnace to an inclined refractory trough partly submerged in motor oil, so that the red-hot metal was rapidly quenched while pointing down the dip.

Magnetization of the hard steel nails by percussion at room temperature was then attempted. Specimens were held vertically in wooden tongs on a boulder of hard rock, and given up to 50 blows with a 400 g hammer. No magnetization could be detected with a plotting compass, even in nails that had become slightly bent.

Finally, hard nails were similarly hammered on the end of a mild steel bar 36 inches long and 1.5 inches in diameter, clamped in a vertical position. A very small permanent magnetic field was at last detected in these specimens, rising to a maximum moment of 4.3 emu, equivalent to 1.3 emu $g^{-1}$. The downward, pointed end of the nail was always magnetic north. Although this magnetic field possessed only 10% of the intensity required to pick up a single pin, this result encouraged controlled experiments with blows provided by a mild steel weight falling a known distance. These parameters were adjusted to put 10 kg cm of work into a nail at each blow; 50 blows injected 500 kg cm of energy, equivalent to nearly 150 kg cm per gram of steel. Nevertheless, the maximum strength achieved was only 1.3 emu $g^{-1}$—just as with hand hammering. Presumably this moment represents the best dynamic alignment of those few domains that are sufficiently delicately anchored to move in the augmented terrestrial field when disturbed by vibration.

Binding weakly magnetized nails of individual moments 4.3 emu into bundles did increase the magnetic strength of the assembly, but diminishing returns with increasing numbers of nails made it difficult to exceed a moment of 27 emu with 14 nails.

To check on the response of larger specimens, 6-inch lengths of carbon steel tool blanks 0.25 inches square were subjected to the same tests. Heating was accomplished with a blowtorch or laboratory furnace, but a forge and anvil were not available for 'drawing out' a carbon steel bar. It is not thought that this small change in scale would affect the results—namely, that only cold hammering of the hardened steel on a vertical iron bar produced a very weak permanent magnet.

## William Scoresby

A leading practitioner of the art of making large permanent magnets by percussion was the Whitby whaler William Scoresby.[8] Several of his products are on display at the Whitby Museum in Pannell Park, and I was able to examine them through the courtesy of the curators.[9]

One of the most impressive is the 'Greenland' magnet, made in 1822 when the *Baffin* was in the Greenland Sea. It consists of nine hardened laminations, each magnetized on a vertical anvil by *cold* hammering in the manner described above. They were subsequently bolted together to give a horseshoe magnet 29 cm long and 10 cm across at its widest point. It weighs 10.5 kg. Provided with a keeper, the force of attraction is, even at the present time, sufficient to necessitate its removal by being slid sideways rather than by being pulled straight off. The strength of this magnet (as well as others) was measured by the neutral-point method mentioned above and elsewhere.[10] It came out at 1.9 emu $g^{-1}$—little more than the hammered masonry nails examined above. Its impressive strength is therefore really due to its great mass.

## Conclusions

It seems to be widely accepted that one way of making a permanent magnet is to position a red-hot iron rod north–south in the Earth's magnetic field, and then hammer it continuously as it cools. This technique was first mentioned by Gilbert in his *De Magnete* of 1600, and illustrated with what has become a well-known engraving (see figure 1).

This proposal is contrary to modern theory and practice, and has been proved by experiment to be highly suspect. Only by extensive cold hammering of hardened carbon steel samples on a massive ferrous anvil has it proved possible to produce weak permanent magnets. However, if Gilbert had continued his hammering even when his wrought-iron bar was cold, he might have produced a weak magnet and fulfilled his desire to demonstrate the inductive effect of the terrestrial magnetic field. It is not expected that such a weak magnet made of partly softened iron would retain its magnetism for any great length of time.

The moral of this story is that if a statement is put forward by a respected authority, is accompanied by a memorable illustration, and is no longer particularly relevant, then it is unlikely to be challenged.

## Notes


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