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Magnetism and electricity

With this volume we arrive at what was the greatest Chinese contribution to physics, the discovery of magnetism. It is a subject that has given rise to a vast literature because the attractive power of the lodestone was known, both in China and the West, from at least the middle of the first millennium BC. There is no doubt about this, but there is doubt about the discovery of the lodestone itself and of the fact that pieces of iron could become magnetised by contact with it. Knowledge of this appeared rather suddenly in Europe at the very end of the twelfth century AD, and search for immediate antecedents in Arabia and India has not proved successful.

That the Chinese were the first to understand and utilise the directive property of the lodestone has traditionally been admitted, but strangely enough for entirely the wrong reasons. From Han times (late third century BC) onwards Chinese texts speak of the ‘south-pointing carriage’ (*ting nan chhê* [*dìng nan che*] or *chih nan chhê* [*zhi nan che*]), the art of making which was continually being lost and revived. From the time of the Jesuit missionaries in the early seventeenth century onwards, it was assumed that these were references to some form of magnetic compass, but it may now be considered solidly established that the south-pointing carriage had nothing whatever to do with magnetic directions. It was essentially a self-regulating mechanical device with a system of gear-wheels to ensure that a pointer always pointed to the south, irrespective of the motion of the carriage. Some contemporary historians of science, unaware of this, have criticised Chinese literature for what they have taken to be claims for discovery, whereas what they have come across are legends concerning the south-pointing carriage. Moreover, as we have had occasion to remark before in other volumes of this abridgement, some historians of science have even gone so far as to doubt whether anything having a bearing on Western science could have come from China. Yet none have been able to discover any precursors of European knowledge of the lodestone’s direction-seeking power before the turning point of AD 1190.

The story of the magnetic compass in China was revolutionised in the

late 1940s and early 1950s by Wang Chen-To [Wang Chen-Duo] who managed to explain a fundamental text in the *Lun Hêng* [*Lun Heng*] (Discourses Weighed in the Balance) of AD 83. This revealed a probable connection between the magnetic compass and the diviner's board of the Han people. In what follows we shall seek to show (a) that the first text clearly describing the magnetic needle compass is undeniably of about AD 1080, i.e. a century earlier than the first European mention of this instrument; (b) that magnetic declination (i.e. the failure of the magnetic needle to point to true or geographical north), as well as the magnet's directivity, is mentioned there; and (c) that the declination was discovered in China some time between the seventh and tenth centuries AD. It will also become evident, (d) that the use of the needle, which alone permitted the construction of an accurate pointer-reading instrument, was the limiting factor in discovering declination, and belongs to the beginning of this period; and (e) that the original Chinese compass was probably a kind of spoon carefully carved from lodestone and revolving on the smooth surface of a diviner's board. Lastly we shall arrive at Dr Needham's suggestion that there is a detectable connection not only with divination practices but also with games such as chess. The original form, the lodestone spoon, was certainly known and used in the first century AD, and may go back, as a secret of court magicians, two centuries earlier. The failure to elucidate this before has been partly due to scholars searching for traces of a south-pointing vehicle when they ought to have been looking for a 'south-controlling spoon' (*ssu nan shao*) [*si nan shao*].

The case of the earliest magnetic compass in navigation is somewhat similar. It is certain that by AD 1190 it was in use in the Mediterranean, but its use is also spoken of in a Chinese text just under a century previously. A mistranslation of this text by earlier scholars led to the persistent statement that it was then found only on foreign (Arab) ships trading to Canton [Guangzhou], but this idea, as we shall see, has no basis. Something will be said later as to possible means of transmission; the famous Elizabethan investigator of terrestrial magnetism, William Gilbert, thought that Marco Polo or someone else of his time brought it, but this would have been a century too late. 'If the Chinese', wrote the historian Edward Gibbon, 'with the knowledge of the compass, had possessed the genius of the Greeks and Phoenicians, they might have spread their discoveries over the southern hemisphere'. In fact, this is just what they did.

MAGNETIC ATTRACTION

What was known of magnetic attraction in the medieval West? By the beginning of the Middle Ages it had been established (a) that the lodestone attracts pieces of iron; (b) that it does so across a distance; (c) the attracted iron

adheres to the magnet; (*d*) the magnet induces a power of attraction in the attracted iron, which (*e*) it retains for some time. It had also been observed that (*f*) the magnetic influence would act through substances other than iron, and (*g*) some magnets would repel pieces of iron as well as attract them. Tradition by way of Aristotle tells us that Thales (sixth century BC) studied the magnet using animistic explanations based on animal or human attraction, while another tradition refers to later philosophers taking an interest in the subject, and certainly Democritus (fifth century BC) discussed it. Lastly, all the fundamental properties mentioned above were described in the first century BC by Lucretius, who suggested that attraction was due to a vacuum being established between the iron and the magnet.

In China, as in Europe, the magnet went by many names. The most usual was *tzhu shih* [*ci shi*], the ‘loving stone’, generally combined in the ideograph *tzhu* [*ci*] (磁). Another derivative *tzhu* [*ci*] (孽) means copulation or breeding, and those who first observed magnetism in China seem, like Thales, to have thought of attraction animistically. Again, *hsüan shih* [*xuan shi*], the ‘mysterious stone’, though it later signified non-magnetic iron ore, seems likely, in view of other phrases involving *shih* [*shi*], to have originally referred to the lodestone. Most of these and other names and phrases go back to the Chin [Jin] (second to fifth centuries AD) or at least to the Tang [Tang] (seventh to tenth centuries).

Chinese literature between the third century BC and the sixth century AD is as full of references to the attractive power of the magnet as the European. Though there is nothing as early as Thales, nor contemporary with Aristotle, the *Lü Shih Chhun Chhiu* [*Lü Shi Chun Qiu*] (Master Lü’s Spring and Autumn Annals) – a compendium of science which mentions attraction – would be late third century BC, about contemporary with Archimedes. And shortly before Lucretius was writing, the *Huai Nan Tzu* [*Huai Nan Zi*] (The Book of (the Prince of) Huai-Nan) – another compendium of science – said:

If you think that because the lodestone can attract iron you can also make it attract pieces of pottery, you will find yourself mistaken. . . .

The lodestone can attract iron but has no effect on copper. Such is the motion of the Tao [Dao].

Elsewhere the writer also says that ‘the lodestone flies upwards’, meaning that a small piece of magnetite could be attracted by iron held above it. By AD 83 the *Discourses Weighed in the Balance* was commenting that both magnetic attraction and the attraction exhibited by amber were examples of ‘sympathetically attracting things’. Wang Chhung [Wang Chong] who wrote the book, also refers to the ‘mutual influence’ displayed by amber and the lodestone on various bodies, remarks which echo the general Chinese concept of ‘resonance’ and action at a distance.

In the fifth century AD the Chinese had already begun to undertake measurements of magnetic force. The medicinal properties of lodestone were considered to be different from those of non-magnetic iron ore, and it was necessary to distinguish between the two, particularly as the latter was sometimes rather toxic. So in the *Lei Kung Phao Chih* [*Lei Gong Pao Zhi*] ((Handbook based on the) Venerable Master Lei's (Treatise on) the Preparation (of Drugs)) we read:

If you want to make a test take one catty (about 600 gm) of the stone and see whether using all four sides it can attract an equal weight of pieces of iron – if so this is the best, and may be called *yen mien sha* [*yan mian sha*]. The sort which (in the same conditions) on all four faces attracts 200 gm is called *hsü tshai shih* [*xu cai shi*]. Again that which will only attract about 100 or 140 gm is termed (ordinary) lodestone (*tzhu shih* [ci shi]).

Presumably stones of less power were graded into the category of non-magnetic ore. The method of estimation, involving as it did the use of the balance cannot be later than the twelfth century AD, texts of which often quote it, and may well be more than five hundred years earlier.

In both East and West numerous legends grew up about the lodestone. They took various forms: there were certain islands which ships could not pass if they were constructed with iron nails, or gates which men could not get through if armed with iron weapons; alternatively it was thought that somewhere or other statues of iron floated in mid-air, suspended by magnetic attraction. In the second century AD Ptolemy, the Greek astronomer and geographer, placed such magnetic islands between Ceylon and Malaya, while we find the same story in the *Nan Chou I Wu Chih* [*Nan Zhou Yi Wu Zhi*] (Strange things of the South) two centuries later. But probably the idea had its own forms of purely Chinese origin, for a palace at Chhang-an (Sian) was long supposed to have magnetic gates to deter invaders, while such gates were also connected with myths about ordeals and escape from the mundane world. Similar stories occur in Arabic texts.

It was natural that the lodestone should find application both in alchemy and medicine. Sung [Song] medical books (fifth century AD) often speak of opening blocked passages or extracting foreign bodies such as needles or arrow fragments by the use of lodestones – which suggests that even if the processes were more imaginative than successful, it was clearly realised that magnetic attraction acted through intervening substances other than iron. Magnets only became much used in European medicine in the seventeenth and eighteenth centuries AD.

On the whole it may be said that between ancient and medieval knowledge of attraction in Europe and China there was nothing to choose. One finds

less theory about it in China, perhaps because action at a distance fitted in better with the Chinese world-view than with the Greek. Indeed, in Greece things were thought to have their 'natural places' in the cosmos and magnetic behaviour was difficult to reconcile with this concept, as also with Aristotle's doctrines of the 'natural' and violent' motion of bodies.

Nevertheless a particular Chinese conception was due to the Greek heretic Hermogenes (second century AD), who believed that God had created the world from nothing, but had organised all matter by acting upon it like a magnet. If this patterning principle had been brought down to earth as a physical reality, instead of being transcendent, there would have been no difference between it and the Chinese doctrine of the Tao [Dao].

Lastly we may note that while Pliny (first century AD) and later writers in the West referred to the fact that sometimes the lodestone would repel iron, the Chinese were also aware of this. There is a curious story of magnetised chess-men (p. 47) which has come down to us in several versions, while words meaning 'push away' and 'repel' were also used and, in the first century BC, the *Shih Chi* [*Shi Ji*] (Memoirs of the Historiographer(-Royal) down to 99 BC) says the pieces 'mutually hit' each other. We have then a hint that in China repulsion was also observed.

ELECTROSTATICS

Just as ancient and medieval Chinese knowledge of the lodestone paralleled that of the West, so also with the fact that certain substances like amber will, when rubbed, acquire the ability to attract small objects such as dried plant fragments. It is again Thales who is credited with the first of such observations, and whereas the electrum of Homer (ninth or eighth century BC) was an alloy of gold and silver, certainly after the time of Herodotus (fifth century BC) the word generally refers to amber, and our 'electricity' derives from it. Plato mentioned it, but only Plutarch and Pliny (first century AD) state that it must be rubbed beforehand.

Greek amber was probably of Baltic origin, but most Chinese amber came from deposits of burmite in Upper Burma. This has slightly different chemical and physical properties from succinite, the common amber, though both are the fossil gum from conifers. Wang Chhung [Wang Chong], a contemporary of Plutarch and Pliny, is one of the first to mention it; he used the term *tun mou* [*dun mou*] which is likely to have been formed from some Shan or Thai language. Such is also supposed to be the derivation of the more usual term *hu pho* [*hu po*]. About AD 500, the physician and alchemist Thao Hung-Ching [Tao Hong-Jing] wrote that amber was fir-tree resin which had been buried for a thousand years, and in which entrapped insects might be seen, adding that there was a method of imitating it by heating hen's eggs with

dark fish roe. But, he points out,

... only that kind which, when rubbed with the palm of the hand, and thus made warm, attracts mustard-seeds, is genuine.

The electrostatic test for genuine amber is still used. And though Wang Chhung had not mentioned the need for rubbing, after the Han practically all pharmacopoeias mention amber and its properties. After this there was no real advance in China, any more than in Europe, until the study of electricity really began in the eighteenth century.

MAGNETIC DIRECTIVITY AND POLARITY

The magnetic compass is the oldest representative of all those dials and pointer-readings which play so great a part in modern science. The sun-dial was of course far older, but there only a shadow moved, not part of the instrument itself. The wind-vane was older, but there the possibility of precise readings on a circular graduated scale was absent in all its ancient forms. The magnetic compass was also self-registering. Furthermore, its development, in which a needle allowing accurate readings replaced a piece of lodestone, and the later use of pointers for precise indications on a scale, displays the process of induction – reasoning from the particular to the general. No apology is needed, therefore, to consider in some detail what was the oldest form of compass developed by the Chinese, and when it was that successive developments were introduced. That so fundamental an instrument spread so slowly is not difficult to understand once we realise that its original discovery was connected with a divination process by imperial magicians, and that since it then developed in an agrarian rather than a primarily maritime civilisation, its use was for centuries limited to a specifically Chinese pseudo-science, Taoist [Daoist] geomancy, details of which reached a high level of refinement. The adoption of the compass by Chinese sailors was probably long retarded also because all through the Middle Ages, river and canal traffic predominated over ocean voyages.

Geomancy was mentioned in volume 1 of this abridgement, but a brief reference to its main points may be desirable all the same. For the Chinese the term meant ‘the art of adapting residences of the living and tombs for the dead so as to co-operate and harmonise with the local currents of the cosmic breath’. Known as the science of ‘winds and waters’ (*fêng shui* [*feng shui*]), it referred not merely to physical winds but rather the *chhi* [*qi*] or *pneuma* (spirit) of the earth circulating through the veins and vessels of the earthly macrocosm. The waters too were not only the visible streams and rivers but also those passing to and fro out of sight, removing impurities, depositing minerals, and like the

chi, affecting for good or evil the houses and families of the living, as also the descendants of those who lay in the tombs. The history of the magnetic compass is only understandable in the context of this system of ideas, for this is the matrix in which it was generated.

Of all forms of divination, geomancy was perhaps that which became most deeply rooted in Chinese culture throughout the traditional period. It led to a minute appreciation of topographical features, because the protection of a site from harmful influences was always a matter of great importance. Purely superstitious in many respects though the subject sometimes became, the system as a whole undoubtedly contributed to the exceptional beauty of positioning of buildings, villages and cities throughout the realm of Chinese civilisation (Fig. 166).

The system seems certainly to have developed during the fourth century BC in the Warring States period when the natural philosopher Tsou Yen [Zou Yan] and schools of philosophical magic were flourishing. Thus the *Kuan Tzu* [*Guan Zi*] (The Book of Master Kuan) speaks of water as the blood and breath of the earth, 'flowing and communicating within its body as if in sinews and veins'. And a century later, just before his death in 210 BC, Mêng Thien [Meng Tian], the builder of the Great Wall, claimed that he could not have built it 'without cutting through the veins of the earth'. In the Han then, the system was well under way, and was consolidated during the San Kuo [San Guo] period (AD 221–65).

From the Thang [Tang] (seventh to ninth centuries) onwards, the rise of the compass seems to have led to a division of the geomancers into two schools. Those who came from Chiangsi [Jiangxi] province held fast to many of the older principles, reasoning their way on the shapes of mountains and the courses of rivers, no doubt much as their Han predecessors had done. On the other hand, the men of the maritime region of Fukien [Fujian] regarded the compass as all important for determining changes in topography, though besides this they also made much use of the symbols in the *Book of Changes* (see volume 1 of this abridgement) and paid more attention to astrology. The marks of this division are still evident in Ming and Chhing [Qing] works.

The surviving literature on geomancy and the compass is quite large, but even so there are still gaps and obscurities. Indeed, it is to be feared that some of the most interesting facts about the development of one of the most important of all scientific instruments have perished for ever. Some items, it seems, were wilfully destroyed, for while there may be a much doubt about the traditional burning of books attributed to the first emperor Chhin Shih Huang Ti [Qin Shi Huang Di], there is clear evidence for destruction among Jesuit converts in the seventeenth century. This was tragic and paradoxical in view of the learned nature of the Jesuit mission.

Cambridge University Press

978-0-521-31560-9 - The Shorter Science and Civilisation in China, Volume 3

Colin A. Ronan

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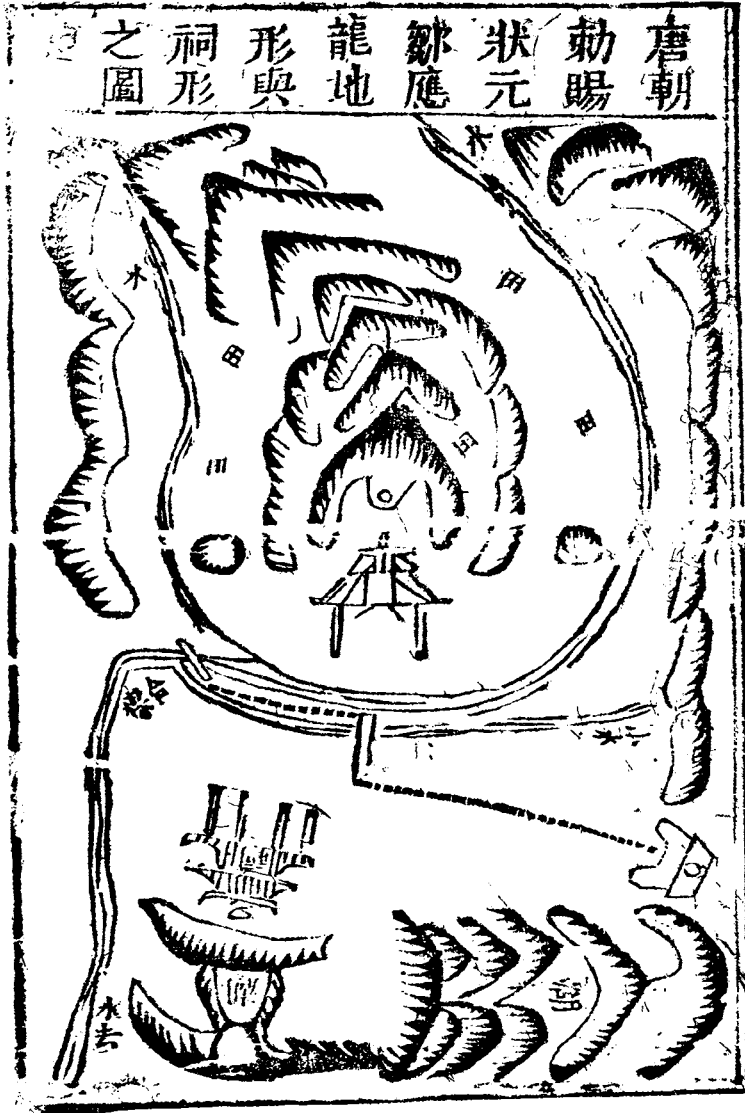


Fig. 166. Geomancy as the background to the science of magnetism: a selected layout of buildings and environment in the early thirteenth century AD. The caption at the top says: 'Map of the Grounds and Family Temple donated by Imperial Rescript to Tsou Ying-Lung [Zou Ying-Long], Optimus Graduate in the Palace Examinations'. In a region of hills three streams join together at a point left of centre to form a small river, which flows away at the left bottom corner. The temple, backed by two small lakes, faces the upper part of the plan, with a view of the auspicious point (marked by a pavilion) at the tip of the hilly ridge separating the two upper valleys, each of which contains numerous rice-fields. Two bridges and a gateway in the hills are also marked. From *Ti Li Cho Yu Fu* [*Di Li Zhou Yu Fu*] (*Precious Tools of Geomancy*) c. AD. 1570.

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Appearance of the magnetic compass in Europe and Islam

The first thing to be done is to note the exact dates at which knowledge of the magnetic compass first appears among Europeans and Arabs. As far as Europe was concerned, we find that the property of the lodestone to point in a given direction was unknown to Adelard of Bath in AD 1117, but was mentioned by Alexander Neckham in 1190. Many others then wrote about it, most notably Petrus Peregrinus (Peter the Wayfarer, or Peter de Maricourt) in 1269 in a text that is one of the finest contributions to physics of the whole medieval period. There have, of course, been claims for earlier European references, but all have been discredited, as too have suggestions that the Norsemen or Vikings had the magnetic compass earlier than 1190, though they do seem to have known of it by 1225. The suggestion has also been made that medieval European churches were orientated by means of the compass, but this is highly controversial and the fact has not yet been established.

The earliest Arabic references are all somewhat later than the European ones. The first mention is of sailors finding their way by means of a fish-shaped piece of iron rubbed with a magnet; it appears in a collection of anecdotes in Persian and compiled about 1232 by Muhammad al-'Awfi. Half a century later, in a treatise on precious stones, Bailak al-Qabajaqi described how in 1242 he had witnessed the use of a floating compass needle, and added that the captains who sailed the Indian seas employed a floating iron leaf shaped like a fish. No other books of the thirteenth century discuss it, however; even the encyclopaedia by the geographer al-Qazwini is silent. There is no earlier mention of the compass, neither by tenth-century astronomers or geographers, though there is a treatise on love written early in the next century by Ibn Hazm that has been thought to refer to magnetism. Nevertheless this speaks only of magnetic attraction, not of the polarity of the compass. It may be noted, incidentally, that no Indian reference of any importance has been discovered.

Development of the magnetic compass in China

What then happened in China? To discover this it will be most convenient to take the basic text of the astronomer, engineer and high official, Shen Kua [Shen Gua], and then work back from it. This important passage appeared in the *Mêng Chhi Pi Than* [*Meng Qi Bi Tan*] (Dream Pool Essays) written about AD 1088, i.e. a little over a century before the earliest European mention of the magnetic compass. It runs as follows:

Magicians rub the point of a needle with the lodestone; then it is able to point to the south. But it always inclines slightly to the east, and does not point directly to the south. (It may be made to) float on the surface of water, but then it is rather unsteady. It may be balanced on the finger-nail, or on the rim of a cup, where it can be

Cambridge University Press

978-0-521-31560-9 - The Shorter Science and Civilisation in China, Volume 3

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made to turn more easily, but these supports being hard and smooth, it is liable to fall off. It is best to suspend it by a single cocoon fibre of new silk attached to the centre of the needle by a piece of wax the size of a mustard-seed – then, hanging in a windless place, it will always point to the south.

Among such needles there are some which, after being rubbed, point to the north. I have needles of both kinds by me.

Moreover, the same book contains another, less well-known, passage:

When the point of a needle is rubbed with the lodestone, the sharp end always points south, but some needles point to the north. I suppose the nature of the stones are not all alike. Just so, at the summer solstice the deer shed their horns, and at the winter solstice the elks do. Since the south and the north are two opposites, there must be a fundamental difference between them.

This has not yet been investigated deeply enough.

Here, then, we have not only undeniably the earliest clear description of the magnetic needle compass in any language, but also a definite statement about magnetic declination. It greatly antedates the traditional discovery of magnetic declination by Columbus in 1492. The two kinds of needles mentioned by Shen Kua may of course have been magnetised at different poles of the lodestone, but there may also have been another origin for this traditional idea as we shall see (p. 21) when we discuss the divining board.

The modern scholar Wang Chen-To [Wang Zhen-Duo] has pointed out that some of Shen Kua's [Shen Gua's] experimental conditions indicate a considerable amount of careful investigation. For example, the use of new silk thread for suspension meant that a single fibre rather than one of twisted hempen yarn had finally been chosen, and its newness implied an appreciation that its elasticity should be evenly distributed.

We must now turn to earlier texts though, before doing so, it is necessary to refer to one just a little later than that of Shen Kua [Shen Gua], but still many decades before the first European mention.

Sung compasses, wet and dry

In the *Pên Tshao Yen I* [*Ben Cao Yan Yi*] (The Meaning of the Pharmacopoeia Elucidated), a work which dates from 1116, there is a passage that seems on first sight to be but a repetition of what Shen Kua [Shen Gua] had said thirty years earlier, yet we find two things have been added. These read as follows:

Again if one pierces a small piece of wick (pith or rush) transversely with this needle (i.e. the magnetic needle), and floats it on water, it