THE DISCOVERY OF THE MAGNETIC COMPASS AND ITS USE IN NAVIGATION

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This chapter is concerned with the magnetic compass, its use in maritime navigation, and its theory of operation. First, it attempts to determine the origin of the discovery that a slender iron rod or needle has the property of alignment with the geometric poles of the earth; ie, it has the power of giving direction. Then its technical development by exploiting its directional property as an instrument in navigation or scientific research is discussed. Finally, the later discoveries of navigation are described within the context of the great European explorations. The main purpose is to show how the discovery of the directive property of a magnetic needle led to the technical development of the compass and the discovery of new magnetic phenomena.

Today, it is an accepted fact that the Chinese invented the magnetic compass. But, the evidence that supports this claim is slim and controversial. Although there is good evidence, that is now accepted to conclusively prove the claim that the Chinese knew of the directive property of a magnetized iron needle, there is very little evidence that proves the directive property of the magnetic needle was extensively used by them in maritime or terrestrial navigation. Additional fragmentary evidence suggests that knowledge of the directive property was transmitted to the European west during the crusades as a result of contact with the Arabs. Here the controversy regarding the origin of the compass in Europe will not be addressed, because it is really a fine point for scholars. The important point is to realize that by the 13th century the directive property is widely recognized and used in navigation.

In this chapter the history of the magnetic compass will be addressed beginning with its origin in China. But, this is really a relatively unimportant part of the story. The true significance of the magnetic compass is its technical development as a navigational instrument, coupled with the technologies of navigation, seamanship, shipbuilding, and map making, combined with the sciences of mathematics and geography. This collaboration of scholarly sciences combined with the skills of the artisan classes, which stressed the economic applications of the directive property of the magnetized needle, was the crucial development that led to the widespread scientific interest in magnetism as a science. This collaboration was a development that profoundly changed western civilization. It led to European economic dominance of the world and then later to the scientific revolution.

Our story is primarily concerned with the period of the later middle ages when the compass appears. Unfortunately its origin is shrouded in mystery. Its discovery and technical development is crucial to the development of magnetic science. The high point in our story are the descriptions for the construction of two types of magnetic compasses by Peter Peregrinus in a letter written in 1269. This letter contains the first technically detailed description of the compass. It is significant because it includes both a theoretical discussion of magnetism and a technical description of two different types of compass. Following this there was a further development of terrestrial magnetism, which occurred during the age of ocean navigation and the discovery and exploitation of the new world that was facilitated by the navigational compass. Here the important point is that the new magnetic science derived its economic importance and

support from the economic gains of the Portuguese and Spanish worldwide trade empires: which the English of the 16th century envied and sought to emulate.

The development of navigational technology using the compass, is probably the greatest achievement of the middle ages. It gave birth to the renaissance of European civilization. It facilitated a tremendous increase in wealth, which further encouraged the investigation of science and its technical innovations. By the time of the publication of On the Magnet by William Gilbert in 1600, a renaissance in western science and technology was well under way. Francis Bacon attributed this to three major technical developments in his book Novum organum published in 1620:

"it is well to observe the force and virtue and consequences of discoveries; and these are to be seen nowhere more conspicuously than in those three which were unknown to the ancients...; namely, printing, gunpowder and the magnet. For these three have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes; insomuch that no empire, no sect, no star seems to have exerted greater power and influence in human affairs that these mechanical discoveries."[1]

The development of the compass and its use in navigation is therefore a major technical development of the first magnitude. This will take the place which it deserves in this history of the science of electricity and magnetism.

Historians of Chinese civilization have noticed that all three of these technological developments can be traced to China. Joseph Needham, who has written the most complete history of science and technology in China, advocates the origin of the compass in China in the following manner:

"Medieval Europe had done something in dynamics, but knew nothing of magnetism till the end of the twelfth century. All the work on that had been done in China, where people were worrying about the cause of declination before Europeans even knew of the existence of polarity...Here and again with the magnetic compass that China knew as the "South-Pointing Needle", there is clear evidence that something happens in the East, and a little later something happens in the West."[2]

This chapter will not address the impact that its development had on the theoretical interpretation of magnetism. This will be considered in detail in the following chapter. Here the development will be considered primarily as a prelude to the work of Peter Peregrinus. This is a major landmark in science history and concerns us for two reasons. It is considered by many experts as the first scientific work that has survived, and second it is a model of the experimental approach in the scientific method. As such it appears to be the first scientific work that utilizes the experimental approach to knowledge. But, his most important contribution was a magnetic theory which explained the origin of the directive property of the magnetic needle.

The Chinese Discovery of The Mariner's Compass

The mariner's magnetic compass is the first technological application of magnetism and, one of the oldest scientific instruments. The invention or discovery of the mariners compass is a controversial historical problem, which remains unsolved. The inventors and discovers of the principle of the compass are lost to history. The facts are complicated in historical controversy. The origins of this significant scientific development are therefore unknown to us. Here a reconstruction of what is known is attempted as unclear as it is.

In The Bibliographical History of Electricity and Magnetism Mottelay presents evidence that the principle of the compass was in active use in China as early as 2637 B.C. :

"This date has been conclusively shown to be the earliest one at which history notes anything resembling the application of the magnetic influence....Hoang- ti constructed a chariot upon which stood erect a prominent female figure which indicated the four cardinal points, and which always turned to the south whatever might be the direction taken by the chariot." [3]

This opinion derives from a treatise on the history of China published in 1736 by Jean Baptiste Du Halde, who was a missionary in China. In it, Du Halde writes:

"about the year 2643 B.C., the Emperor Hoang-te, being at war, an instrument was invented, which being placed in a car, it pointed to the south and enabled the imperial army to direct its march and surprise the enemy during a thick fog."[4]

Du Halde further observes that the chariot story would "indicate the use of the compass, or something similar to it ... and it is unfortunate that the device has not been explained more fully." Indeed the conclusion has not been accepted by historians as a conclusive use of magnetism to indicate direction.

In the encylopeadic work Cosmos published in 1849, Alexander von Humboldt cites another example of the apparent use of a magnetic compass in China in the year 1110 B.C.:

"As the ambassadors sent from Cochin China and Tonquin were about to take their departure, Tcheou-Koung gave them an instrument which upon one side always turned toward the north and on the opposite side to the south, the better to direct them upon their homeward voyage. This instrument was called tchi-nan (chariot of the south), and it is still the name given to the compass which leads to the belief that Tcheou-Koung invented the latter."[5]

These opinions are controversial. There are those who object and claim that the directional carts were unknown prior to the fifth century A.D. The modern opinion is that the south pointing carriages were mechanical devices.

"...once erroneously believed to represent a step in the development of the magnet compass. A two-wheeled horse-drawn chariot on which a figure was mounted with its arm preset to point due south, the vehicle had gears so arranged that whichever way it turned, the figure pivoted to hold its south-pointing posture....The magnet compass, however did originate in China in the early middle ages. Both European and Chinese antiquity were aware of the ability of the

loadstone (a variety of magnetite) to attract and repel iron, and of its inductive property-the power to magnetize iron, to impart the same attraction and repulsion to it. Discovery of the directive possibilities of the magnet, however, belonged to China, as did the invention of the magnetic needle, to make readings more accurate."[6]

Lyons in a technical book on the compass reports that in a Chinese dictionary dated to about 121 A.D. there is a description of the loadstone which describes it as:

"A stone with which an attraction can be given to the needle."[4]

In quoting from a work published about 400 A.D. Lyons tells us regarding the Chinese:

"They had ships which directed their course to the south by the magnetized needle.. the fortune tellers rub the points of the needle with the stone of love for rendering it proper to indicate the south."[4]

Mottelay reports that about 265 A.D.:

" What by many is believed to be the earliest, reliable, distinct mention or actually printed record of the use of the magnet for navigation, appears in the justly prominent Chinese dictionary or encyclopedia, 'Poei-wen-yun-fou', wherein it is mentioned that there were during this period ships directed to the south by the ching or needle."[7]

In 419 A.D. Mottelay reports, that a much more detailed description of the magnetic needle is given in a Chinese work titled Mung-khi-py-than:

"The soothsayers rub a needle with the magnet stone, so that it may mark the south; however it declines constantly a little to the east. It does not indicate the south exactly. When the needle floats on water it is much agitated...It is preferable...to suspend it as follows: Take a single filament from a piece of new cotton and attach it exactly to the middle of the needle by a bit of wax as large as a mustard seed. Hang it up in a place where there is no wind. Then the needle always shows the south; but among such needles there are some which, being rubbed, indicate the north. Our soothsayers have some which show the south and some which show the north. Of this property of the magnet to indicate the south, like that of the cypress to show the west, no one can tell the origin.**"**[8]

These passages clearly show that the Chinese had knowledge that the magnetic needle was influenced to indicate either the north or south, but had no conception of the role of the magnetic poles. Further, they understood that the direction indicated was not to the true north or south, a phenomenon we call the magnetic declination. The passages also show why the magnetic needle had a slow development as an instrument of navigation. It needed to be used in a stable environment free from the disturbances of wind and waves. In this form is possessed a crude but limited utility for navigation. But, a further difficulty was that there was no proof that it indicated the actual north or south. There was no theory to account for its action. Finally, there is disagreement regarding the dates. Lyons states that this passage was written in the eleventh century A.D. in disagreement with Mollelay who gives 419 A.D. and also states that: "There is

no statement, however that the needle thus prepared, was used for any guiding purpose."[4] This points out the problem of accurately establishing the dates. A problem which has not been completely resolved.

The modern belief that the magnetic compass originated in China is based on the descriptions of primitive devices used in a form of divination. Lodestones formed into the shape of a primitive ladle or spoon were observed to have a wonderfully mysterious directive property when placed on a cooper plate and spun around. The spoon was balanced so that it could be spun around in a circle, pivoting on the smooth concave surface of the spoon. When the spinning stopped, the handle was seen to point towards the south. In a book, apparently written about 83 AD, we are told: "But when the south-controlling spoon is thrown upon the ground, it comes to rest pointing at the south." But, was this device a compass? Probably not, even though it was used to mark the cardinal directions, because it didn't have a direct application to direction finding in navigation.

In the Chinese book called the Wu Ching Tsung Yao (The Gist of Military Experiences), written about 1040 AD there is a description of a primitive compass made into the shape of a fish, and designed to float on the surface in a bowl of water. The fish was made from a thin iron sheet, which was magnetized by heating and then cooling while oriented in a north-south direction. When cooled in the presence of the earth's magnetic field, the fish became magnetized, and when placed in a bowl of water the fish floated on the surface and turned to point with its head towards the south. Although clearly a primitive form of magnetic compass, which indicates a knowledge of the directive property of magnetized iron, the device could not be used in navigation. It was too unstable. Being subject to disturbances of the wind and external motions, it certainly had only a limited use in navigation.

Although the Chinese are thought to have had a knowledge of the directional properties of lodestone from around the first century AD, the first mention of the use of a compass in navigation doesn't appear until the 12th century. The reference reads "The ships pilots are acquainted with the configuration of the coasts; at night they steer by the stars, and in the daytime by the sun. In dark weather they look at the south-pointing needle." This passage, which is from the book Phing-Chou Kho T'an, written between 1111 to 1117 AD, is not unlike similar references found in European records written about the same time.

The modern historical opinion is that beginning around 1000 AD the Chinese were users of a magnetized needle in the form of a compass. They knew and understood long before the middle ages that the directional property of a piece of iron was acquired when stroked or touched by a loadstone. This property was used in divination, necromancy, and fortune telling. The directional relation to the sphere of the heavens was used in these rituals. During the period from 850 to 1050 A.D. this property began to be used for navigation aboard ships. Lyons reports that some authors say that it was only towards the end of the thirteenth century that reliable records indicate the use of the compass for marine navigation. This agrees with the evidence from European history which records the use of magnetic needles sometime prior to the twelfth or thirteenth century A.D. The thesis is that the device was transmitted to the Europeans from the Arabs at about the time of the crusades. However, these devices can not be considered instruments suitable for marine navigation. This development occurred in the thirteenth century with the publication in 1269 A.D. of the earliest known description of a magnetic compass suitable for

use in navigation. This description occurs in the Epistola de Magnete of Petrus Peregrinus de Maricourt.[4]

The European Invention Of The Mariner's Compass

The idea that the Europeans derived the use of the compass from the Arabs is derived from a Frenchman Cardinal Jacques de Vitry, who after being engaged in the crusades, published a History of the Crusaders and Their Voyages to the Holy Land in 1204 A.D. This history describes a primitive compass being in regular use among the saracens on the coast of Syria. A detailed description of this navigational method was given by an Arabian manuscript written in 1240 A.D.:

"The captains who navigate the Syrian Sea, when the night is so obscure that they cannot perceive any star to direct them according to the determination of the four cardinal points, take a vessel full of water which they place in a sheltered from the wind within the ship. Then they take a needle, which they enclose in a piece of wood or reed formed in the shape of a cross. They throw it in the water contained in the vase, so that it floats. Then they take the magnet stone large enough to fill the palm of the hand or smaller. They bring it to the surface of the water, and give to the hand a movement of rotation toward the right, so that the needle turns on the surface of the water. Then they withdraw the hand suddenly, and at once the needle, by its two points, faces to the south and to the north, I have seen them, with my own eyes, do that during my voyages at sea from Tripoli to Alexandria in the (Arab) year 640 (or 1240 A.D.)."[4]

The device is clearly not a navigational instrument, but a method or procedure for direction finding during unsuitable weather conditions. It lacked these essential features of the modern compass: a permanent method of suspending the needle, a container to shelter it from the wind, a sighting device to align the compass in a specific direction and a graduated circle to allow measurement in the sighted direction. These are specific innovations that were provided by the design invented by Petrus Peregrinus in 1269 A.D.[4]

There is abundant evidence that the mariner's compass was developed in europe around the thirteenth century. Prior to this, there is no description of a mariner's compass that would justify the claim that the Chinese invented it. Further, the Chinese were not a maritime nation. Additionally, the devices described by Petrus Peregrinus are also not instruments suitable for use in navigation. One indication that the device was invented in Italy is the fact that Peregrinus letter was written there in 1259 AD, another is the emergence of the Italian maritime trading states of Venice and Amalfi at about this time. The later emergence of Portugal and Spain as overseas maritime powers demonstrated that it was the combination of the compass with the other navigational arts which was the truly decisive factor.

Flavio Goia an italian is credited with inventing the method of suspending the magnetic needle upon a perpendicular pivot so that it would remain horizontal despite the movements of a ship. This is the decisively crucial invention that makes its use as an instrument of maritime navigation possible. Gilbert tells us: "The people of Amalfi, in the kingdom of Naples first, 'tis said constructed a mariner's compass; and as Flavius Blondus says the townsmen do not without reason boast, they were taught by one Johannes Goia."[24] This story is sometimes thought to be a

myth. There is no evidence that Flavio Goia ever existed. His name is disputed. But, it is likely that significant technical development of the mariner's compass occurred in Amalfi. This is a significant advancement for two reasons. It improved the ability to perform the observations, and it revealed the pointing of the needle below the horizon. A phenomenon known as the dip.

Certainly one of the most important scientific endeavors during the 15th and 16th centuries was the theory of the compass and its use in ocean navigation by the great explorers Christopher Columbus, Sebastian Cabot, and others which revealed that the compass direction varied from true north and south. The explanation of this variation was an important and economically valuable concern. It was a European discovery that the variation of the needle from true, varied with location on the earths surface. A phenomena which introduced a large error if navigation by compass alone was used. Hence it became important to understand the deviation of the compass from true, a phenomena which is called the declination.

The first record of the declination of the compass comes from a Chinese source. A Chinese medical natural history written between 1111 and 1117 A.D. by Keou-tsoungchy, gives the following description of the Chinese water compass, and proves that the declination from the true South was known at this time in China:

"The magnet is covered over with little bristles slightly red, and its superficies is rough. It attracts iron and unites itself with it; and for this reason, it is commonly called the stone that licks up iron. When an iron point is rubbed upon the magnet, it acquires the property of pointing to the south, yet it declines always to the east, and is not perfectly true to the south...If the needle be passed through a wick or a small tube of a thin reed , and placed upon water, it will indicate the south, but with a continual inclination towards the point ping, that is to say East five-sixths South."(Mottelay p29)

The attribution of the discovery of the declination from the north in western europe is unknown. It probably was not known to Petrus Peregrinus in 1269, who does not mention it. A manuscript of the letter found in Leyden contains a passage which warns about the declination from the north:

"Take note that the magnet, as well as the needle that has been touched by it, does not point exactly to the poles, but that part of it which is supposed to point to the South sometimes declines a little to the West, and that part which looks towards the North sometimes inclines to the east. The exact quantity of this declination I have ascertained after numerous experiments to be five degrees. However, this declination is no obstacle to our guidance, because we make the needle itself decline from the true south by nearly one point and a half towards the West. A point contains five degrees."

Mottelay says that this passage is "unquestionably a late addition" entered at a later date, because the entry is in a different handwriting inside a circle of one of the original drawings. (Mottelay page 54)

In 1492 during his first voyage to America, Christopher Columbus is credited with being the first to determine astronomically the coincidence of a magnetic and geographic meridian. On this

meridian there is no magnetic variation from the true north-south direction. The magnetic variation, the divergence of the compass direction from true north-south, was known before his voyage to America. Columbus is credited with discovering that the magnetic variation changed with geographic location. On September 13, 1492, he was 2.5 degrees east of the island of Corvo in the Azores when he noted in his logbook that the magnetic variation changed from being northeast of true north to northwest of it. The variation continued to change as he proceeded westward, so that day by day the error increased. This was a source of alarm for his pilots and crew when they learned of it. But, Columbus managed to allay their fears by explaining that the error was due to a change in position of the north star, and not to a fault of the compass.[25]

In 1497 after returning from his voyage of discovery to Labrador, Sebastion Cabot "...represented to the King of England that the variation of the compass was different in many places, and was not absolutely regulated by distance from any particular meridian; that he could point to a spot of no variation..."[26]Later the idea occurred to him and Jean Rotz that this phenomena might be useful in the determination of a ship's longitude at sea. Measurement of longitude via the variation of the compass is known as mecometry. This idea was not successfully applied, because the variation in the deviation from true was found to be vary too irregularly from place to place to be useful for determining longitude. Later in 1635 an English mathematican, Henry Gellibrand published a book, which proved that the variation from true varied with time as well as place. Gellibrand was able to compare his contempory measurements with ones obtained 12 and 50 years earlier. The results put an end to attempts to use the variation as a method of determining longitude.

In 1544, Greog Hartmann discovered the magnetic dip. He describes the phenomenon in a letter written March 4th of that year. "Besides, I find also this in the magnet, that it not only turns from the north and deflects to the east about nine degrees, more or less, as I have reported, but it points downward." Hartmann found that the north pole of the compass deviated about 9 degrees from the horizontal so that it "dipped" below the horizontal plane.[27]

The discovery of the dip is often attributed the Robert Norman who manufactured compass needles. In 1576 he designed an instrument and measured the magnetic dip in London. In 1581 he published a pamphlet titled "The Newe Attractive" in which he announced his discovery. The title reads:

"The Newe Attractive, containing a short discourse of the Magnes or Loadstone, and amongst other his virtues, of a newe discoured secret, and subtil propertie concerning the Declinyng Needle, touched therewith, under the plaine of the Horizon..."

In this pamphlet, Norman describes the design of his instrument and the results of his measurement of the dip "which for this citie of London, I finde, by exact obseruations to be about 71 degrees 50 mynutes". The charming description of his discovery is described as":

"Hauing made many and diurs compasses and using alwaies to finish and end them before I touched the needle, I found continuallie that after I had touched the irons with the stone, that presentlie the north point thereof woulde bend or decline downwards under the horizon in

some quantitie so much that to the flie of the compass, which was before levell, I was still constrained to put some small piece of ware on the south point and make it equall againe..."[28]

William Gilbert believed that there was a correlation between dip and latitude as a result of his measurements on spherical loadstones. He suggested that this method could be used to determine latitude under cloudy conditions. Gilbert's theory assumed that the dip would be vertical or ninety degrees at the north pole. Henry Hudson attempted to verify the utility of this method during one of his northern voyages in 1608. He obtained the surprising result that the dip was nearly vertical at a latitude of 75 degrees. A result which indicated that Gilbert's method could not be applied to determine latitude.

We can examine the problem in two ways. The first is theoretical while the second practical. The theoretical issue was concerned with the theory of magnetism. If it could be definitely established the nature of the magnetic movement towards north and south, then the reason for the deviations could be explained. But the primary theory was that established by Peregrinus, that the directional power was drawn from the celestial poles. Since these were astronomically known to be fixed, the cause of the variation was sought elsewhere.

Summary and Conclusions

The discovery that a steel needle rubbed by the loadstone acquired the power to point north and south was profound. The evidence does indicate that the Chinese were the first to recognize this fact, but in connection with ritual magic. The decisive invention was the suspension of the needle on a pivot in combination with a compass card indicating the wind directions. This invention opened up an entirely new field of magnetic inquiry through the discovery of the declination and it's variation. The discovery of the dip was also decisive. It argued against the idea that the compass needle pointed towards the north pole as the source of magnetic influence. Hence the stage is set for the decisive theory, presented by William Gilbert, that the origin of the magnetic force is within the earth.

Finally, it is very important to realize that the invention of the compass and its technical and scientific investigation is one of the unrecognized roots of modern science. Traditionally, the development of modern science has been claimed to arise from the old science of Ptolemaic astronomy with the publication of Copernicus' heliocentric theory. But equally important was the technical development of the compass and the practical navigational arts based on the magnetic compass. This opened the age of exploration, and the discovery of the new world. These changes shook the authoritarian foundations of the academic world of the renaissance; because the new world, discovered by Columbus, was unknown to the ancients. Hence their authority in matters of geography and geometry was undermined. Opening the door to the possibility that other new discoveries would lead to new knowledge about the natural world.

Because the compass was unknown in antiquity, along with the printing press and gunpowder, the huge success of these inventions led to the modern movement that aspired to obtain new knowledge. The acquisition of this knowledge was identified with the rejection of ancient knowledge and the application of the new procedures of experimental science which would lead in the same way to the discoveries brought about by the technical and scientific development of

the compass. The two main ingredients of this new method were the combination of the experimental arts of the artisan and the new idea of a science based on an inductive or experimental method of proof.

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