History of Magnetism

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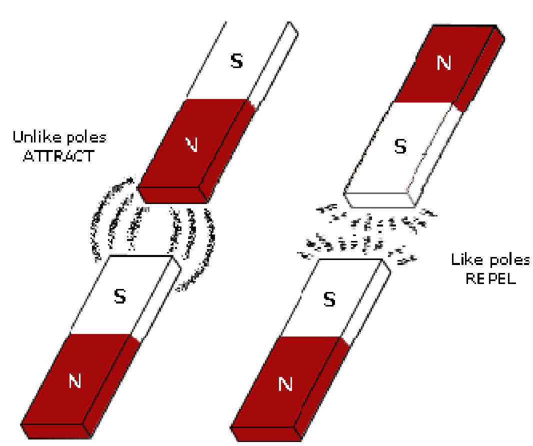
The magnet starts with the lodestone. Lodestones have magnetite which is an iron oxide mineral. When lightning strikes close enough to magnetite, the magnetic field created by the lightning is strong enough to magnetize the lodestone. It is the only naturally occurring magnet on earth. The first recordings of lodestones can be traced back to early Greeks and Chinese. In 600 B.C. Thales commented that the attractive power of the lodestone meant that it had a soul because it caused movement to iron. The Chinese were the first to use the lodestone's properties of magnetism [6]. They were the first to use a "compass" which pointed south as opposed to western compasses which pointed north. There were many superstitions regarding lodestones. They supposedly cured many illnesses including headaches, forced wives to tell the truth in their dreams if laid on their pillow, improved fertility in women, and could be used as a love potion. Their attractive power was supposedly negated by garlic, onions, and diamonds. These would later be tested by Gilbert and others and be proved false

Dr. William Gilbert, born in 1544 in Colchester, England, did much in the history of both magnetism and Electricity. He got his MD from Cambridge in 1569 and in 1600 as elected president of the College of Physicians. He was the first to introduce "electricity" as a word but he said "electricus."[3] Gilbert undertook a direct study of magnetism. He realized that a piece of iron had a north and south pole and when cut, he had two sets of poles.



Peter Peregrinus was the first to discover the existence to two poles and he coined the term “polus” to refer to the north and south ends of a magnet [8]. He also discovered that the magnetic attraction was somewhere in the earth which convinced him that the Earth was a giant lodestone. He liked to use the term coition instead of attraction because according to him attraction meant a “stronger” force while coition was something gentler in meaning. Gilbert though that the lodestone had to give off something vaporous to leave the stone and enter, lift the iron, and pull it back. He said that Thales was not far off in believing that a lodestone had a soul.

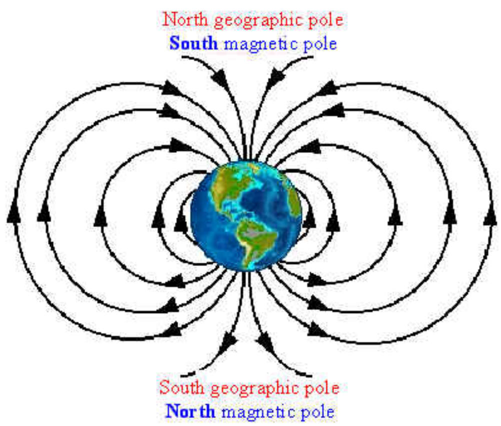
He ran countless tests to learn what the limits of a lodestone were. He learned that when heated beyond a certain point, magnetized iron would lose its magnetism. Lodestones would attract a piece of iron with one end and repel it with the other. Repeated beating of a piece of iron caused it to magnetize. He called what we today call the field around the magnet the orb of virtue. He realized that unlike heat which starts on one end of a piece of iron and has to travel in time to the other end, magnetism was instantaneous throughout the rod. If you magnetized one end, the other was instantly magnetized as well.

Gilbert published what he learned in *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure* (*On the Magnet and Magnetic Bodies, and on the Great Magnet the Earth*) which was published in 1600[5]. It described all of his experiments concerning magnetism and his argument that the center of the Earth was iron which was why it was a large magnet. His studies of electricity using amber also were in his book. He invented the first electrical measuring instrument, the electroscope, which he called the versorium. “Gilbert recorded three ways to magnetize a steel needle: by touch with a loadstone; by cold drawing in a North-South direction; and by exposure for a long time to the Earth's magnetic field while in a North-South orientation.” [2]

In between Gilbert and Gauss nothing major happens. Servigton Savery makes the first compound magnet in1730 by binding together multiple magnets in a pole to pole fashion [2]. Gowen Knight is the first person to make artificial magnets for sale to scientists and explorers [7]. And John Mitchell writes a book about how to make steel magnets.

Carl Friedrich Gauss is the next big name on the magnetic history line. He was interested mostly in mathematics but when Wilhelm Weber got a job at the University of Göttingen as physics professor in 1831, they began working on magnetism. He had worked on physics before 1831 publishing two papers *Über ein neues allgemeines Grundgesetz der Mechanik* and *Principia generalia theoriae figurae fluidorum in statu aequilibrii.* The first included the principle of least constraint and the second went over the forces of attraction. His potential theory which he had developed earlier is what helped him in physics the most.

Gauss and Weber began their magnetic studies in 1832 when Alexander von Humboldt asked for Gauss's assistance in making a grid of magnetic observation points around the world. By 1840 he had written three papers dealing with magnetism. In *Allgemeine Theorie des Erdmagnetismus* (1839), Gauss showed that there can only be two poles in the globe and proved an important theorem about the determination of the intensity of the horizontal component of the magnetic force along with the angle of inclination of the earth's magnetic field. (Probability Distributions…) He used the Laplace equation to help him with the calculations and was able to calculate the location for the magnetic south pole.



Gauss had a magnetic observatory built which was completed in 1833 and completely free from magnetic metals. He used this observatory to alter and change Humboldt's procedures when making a calendar for observations of magnetic declination getting better and easier results than Humboldt himself did. He also figured out to the separate the inner and outer sources of the Earth's magnetic field in mathematical theory.

Charles Coulomb was a Frenchman born in 1736 from two wealthy families which allowed him to have a privileged and well educated life. His early interests were astronomy and mathematics but later turned to engineering and went to the Royal School of Engineering in Paris, graduating in 1762. Coulomb submitted a paper to the Academy of Sciences in Paris in 1777 that discussed the compass and he was awarded grand prize for it. He published several papers on electricity and magnetism throughout the next phase of his life. In 1784 he published his most important paper *Recherches théoriques et expérimentales sur la force de torsion et sur l'élasticité des fils de metal* which covered his invention the torsion balance used to investigate distribution of change on surfaces, and he also used it to investigate the laws of electrical and magnetic force. In 1785 he wrote three papers on electricity and magnetism dealing with his torsion balance and the attraction and repulsion of magnetic and electric fluids. He wrote 4 more papers in the next four years. His studies into electricity and magnetism were a big foundation for electromagnetism and how electricity and magnetism were related.

Hans Christian Oersted was born in Rudkøbing, Denmark in 1777 to a poor apothecary. He substituted for an apothecary he worked for at the University of Copenhagen and received a travel grant after making a good impression there. In 1806 he became professor of physics at the university.

Oersted thought that a small wire would be best for seeing the relationship between magnetism and electricity. He also thought that electricity flowed in a non-uniform stream. During a lecture he performed an experiment to see if current running through a wire would deflect a compass needle. It was such a slight deflection that nobody was impressed, not even he was impressed, and he left the idea alone for several months before picking it up again. Later that year, with several colleagues, he picked up the idea and started running with it. He discovered that a thicker wire worked better than a thin wire. He made a report of his discovery and sent it to several journals to spread the news. The reason why he got a response from the needle and others hadn't is that others had placed the compass at right angles to the wire thinking that the magnetism would flow in the same direction of the current which would mean the needle would swing parallel to the wire. Instead the needle moved away from the axis of the wire[4]. He did not neutralize the effect of the earth's pull on the compass so the current in the wire only pulled the compass needle slightly before coming to a rest not perpendicular to the wire. What he did learn was that "the magnetic effect of an electrical current has a circular motion around it." (Stauffer, "Speculation") His breakthrough destroyed several roadblocks in the progress to understanding magnetism and allowed others to build off what he had discovered.

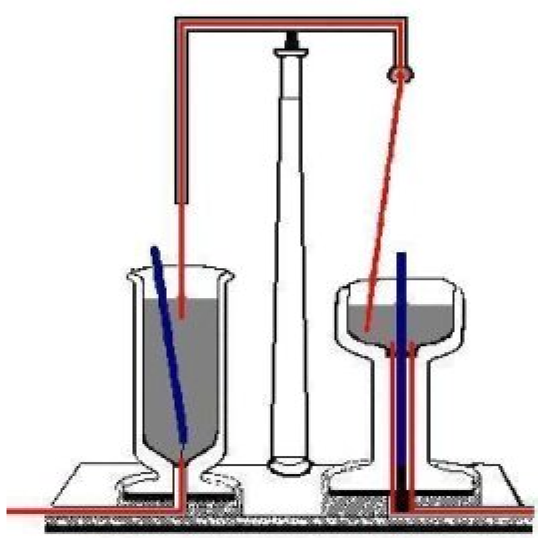
Andre Marie Ampere, son of a silk merchant, studied as he saw fit in a library. His father thought the best education was to let him study what he felt like studying through a library. Despite a life filled with 2 deaths and a bad marriage, Ampere was elected chair of experimental physics at the College de France in 1824. Ampere was driven by a desire to not be forgotten. This ability would eventually hinder him from seeing things in his experiments that he wasn't looking for but still Andre was very influential to the advancement of electromagnetism.

Ampere was in a meeting of the Academie des Sciences in Paris when Oersted's discovery that electricity created magnetic effects surrounding a wire carrying current was announced [8]. Ampere immediately began to explore ideas based off this statement while the others debated its validity. Two weeks later Ampere was ready to tell the rest of the world his discoveries. He repeated Oersted's experiments but enhanced them by neutralizing the Earth's magnetic field by placing magnets to oppose the earth's pull. This allowed the compass to freely spin to 90 degree angles with the current induced wire. It pointed in opposite directions on top and on bottom of the wire supporting Oersted's suspicions that the magnetic force formed a circle around the wire. His next idea was to wrap wire around a glass tube, something that would eventually be called a solenoid, and see if an iron bar inside the tube would act as a bar magnet when the current was running in the wire. He suspected that the Earth must have currents running inside it which would account for the earth's magnetism.

Ampere also experiments with parallel wires and their current inducing effects. These wires attracted or repelled each other depending on if both currents were in the same direction or in opposite directions. This allowed him to state what is now Ampere's law which states that the electric current through a loop (wire) is related to the magnetic field it induces. This was Ampere's greatest legacy: Magnetism was produced by electricity in motion [8]. He invented a device for detecting current and called it a galvanometer which he used to prove that electricity ran through voltaic piles.

These currents inside permanent magnets intrigued Ampere. He wanted to know what caused them. Augustin-Jean Freasnel suggested that the metal was made of molecules and that maybe the molecules had currents flowing around themselves since current couldn't flow through the whole piece of metal or it would heat up, something that it didn't do. Ampere liked this idea and after tinkering with it, he used it to determine Coulomb's inverse square law of magnetic attraction. This stated that the force of attraction or repulsion between two current induced wires was directly related to the inverse square of the distance separating them.

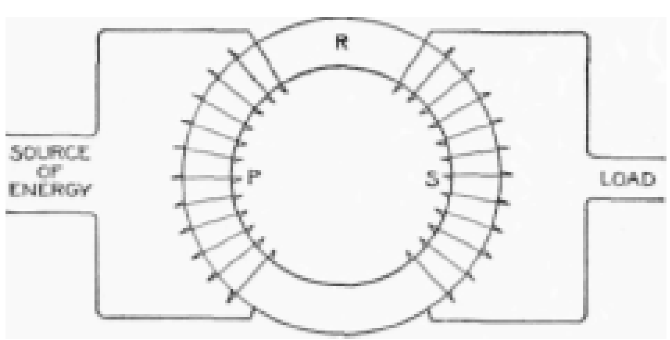
Faraday had no formal education and only got a once in a lifetime chance to study science and magnetism and the sorts. He was very fond of hard evidence. He ran experiments instead of theorizing and some of Ampere's theories Faraday denied because Ampere had no evidence to support them.



Faraday's first major experiment was his rotation experiment seen right. He created this experiment to show that a current-carrying wire produced a circular magnetic force. When current ran through his setup, the magnet on one end rotated around the wire while the free wire on the other end rotated around the fixed magnet. The current caused mechanical motion. This was a huge step toward the modern world filled with electric motors. His experiment showed that the lines of force created by a magnet were circular. That statement did not go along with what other physicists of the age thought could happen but Faraday didn't let that stop him.

Faraday's next experiment was to discover how circular forces emerged from a current carrying straight wire. He reversed the problem just like Ampere. And half submerged a solenoid in water with a compass needle floating in the water. With current moving in the solenoid, the compass needle only came to rest when its north pole came next to the north pole of the field inside the tube. He postulated that if there could be a monopole magnet, it would move endlessly about the solenoid.

Between 1824 and 1831, Faraday tried to find a way to make magnetism produce electricity. Then once he heard about Joseph Henry's electromagnet and that switching current direction switched the polarity of the magnet (1830), Faraday knew what to do. He coiled to wires around an iron ring, one on each side. One of the wires would have a current run through it which would magnetize the ring which would hopefully produce current in the other wire.



When he turned on the current, his compass he was using to measure any current in the second wire flicked but then went back to its original position. He realized that current was only produced when the magnetic field moved through the wire. The magnetic force had to be change in order to produce a current. This came to be known as electromagnetic induction. A continuously moving magnetic field would create a steady current he found out. His experiment used to support this hypothesis was moving a bar magnet up and down inside a coil of wire and measuring the current induced by the wire. His results were summed up in two laws: 1. when magnetic flux is changing, electromotive force is induced in the circuit, and 2. the magnitude of this e.m.f. is proportional to the rate of change of the flux. [1]

Faraday discovered two important things. Electricity could make things move, and movement of magnets could create electricity. These two ideas would lead to the electric generator and the motor which would have an everlasting effect on society.

James Clerk Maxwell (1831-1879) is the next big name in magnetism. After graduating from Cambridge University he began his work on fields of magnetism and electricity. He relied heavily on the ideas and experiments of other scientists working in magnetism, but he was able to piece together what everyone was learning to create a whole new playing field on top of which electricity and magnetism as we know it today rests. His biggest contribution was his four field equations. Most of his work came from studying the fields themselves and not the objects that creates those fields.

Name	Integral form
Gauss's law:	$\oiint_{\partial V} \mathbf{D} \cdot \mathrm{d}\mathbf{A} = Q_f(V)$
Gauss's law for magnetism:	$\oiint_{\partial V} \mathbf{B} \cdot \mathrm{d}\mathbf{A} = 0$
Maxwell-Faraday equation (Faraday's law of induction):	$\oint_{\partial S} \mathbf{E} \cdot \mathrm{d}\mathbf{l} = -\frac{\partial \Phi_{B,S}}{\partial t}$
Ampère's circuital law (with Maxwell's correction):	$\oint_{\partial S} \mathbf{H} \cdot \mathrm{d}\mathbf{l} = I_{f,S} + \frac{\partial \Phi_{D,S}}{\partial t}$

By looking at William Thomson's work on the flow of heat, Maxwell decided that electrical and magnetic forces had to be related to the flow of something. This something would later be called flux. He related Faraday's force lines to lines of flow of flux.

There are 5 concepts that can be examined out of Maxwell's work. The first of which is *potential* which refers to something that doesn't actually exist but could exist given the right conditions. This concept allowed calculations to be made about fields and what would happen if charges were placed in certain points around fields. The fields had potential to do something to the charge but didn't do anything until it was actually placed there. Another notion is the *vector* which displayed the direction the potential acts. The vector potential of a field had a strength and direction of the field at any point. If lots of these vectors were placed in a field, they would form circles, just as Faraday learned from his experiments. A third idea he used was *gradient*.

Gradient is the slope of something and in relation to magnetism he talked about the negative slope of the force of magnetism inversely proportional to the square of distance. This made it possible to describe the decrease of force due to increasing distance. *Divergence* dealt with the way the field was shaped. Close to a pole of a magnet the field lines are very close to each other and the field is stronger. As those lines get farther from the magnetic they are allowed to separate more (diverge) and the field gets weaker. The final concept Maxwell introduced to magnetism was *circulation*. Maxwell wanted to use swirling vortices in thought process to help come up with theory on how magnetic lines are what they are. This required a magnetic description of a whirlpool which needed circulation as a concept.

In discovering that the key to understanding electricity and magnetism was the change in a magnetic field caused a current, Maxwell set the foundations for electromagnetism, envelops electricity and magnetism in a huge umbrella.

Magnetism's history is intertwined with these men's lives. Without them, we would know almost nothing about magnetism. These men poured their lives into studying and learning about magnetism, through experiments and postulation, they began to learn how our world worked and magnetism's contribution to it.

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