Charles Proteus Steinmetz

An experimenter and teacher who took the guesswork out of electrical design.

Ian Sinclair

YOU CAN BE FORGIVEN if you've never heard of Charles Steinmetz, because neither his name nor his achievements are well-known today. Nevertheless, his contribution to electricity, and hence to electronics, has had a profound influence on us all, making possible advances that we now take for granted. Of all the famous names we have looked at so far, that of Steinmetz seems at first glance least connected with modern electronics, because most of his work was concerned with large electric motors, but, as often happens, a piece of research which expands useful knowledge often affects work which is carried out years later, and in an entirely different field.

Steinmetz was born in Breslau, Germany, in 1865 (the town is now called Wroclaw, and has been part of Poland since the occupation of Eastern Europe by the USSR after the Second World War). He was christened Karl August Rudolf, and was handicapped from birth by a severe spinal deformity, which may have had the effect of turning him to academic studies at times when his classmates were playing football. His education progressed to the Technical High School in Berlin, and from there, in 1892, to University, where he started to make a name for himself as a brilliant researcher and equally as a committed Social Democrat. It was this second activity which drew him to the attention of the ruling authorities, and it is ironic to think that if he were active in his home town right now, the Polish authorities would probably take the same line.

After several brushes with the Government, he emigrated, like so many others at the time, to the USA to find freedom of expression and action. Shortly after arriving, he anglicised his name to Charles Proteus — Proteus having been a college nickname.

His reputation as a researcher had preceded him, and he was employed almost at once by the firm of Eickemeyer and Osterfield, an electrical manufacturing company with interests in electric motors, transformers and power transmission. Once established, he founded a small research laboratory which soon became very well-known in the industry. It was at this laboratory that he discovered the effect of magnetic hysteresis.

Hysteresis Lesson

Now magnetic hysteresis isn't a subject you learn about nowadays unless you have specialized interests. This is a pity, because it deprives many of their first glimpse of real-life physics, as distinct from the neat and tidy world of theory. Let me explain the subject in outline.

When you stretch a spring, its length increases, and the amount of force that you need to keep the spring stretched depends on how far you have stretched it. Unless you stretch the spring too far, it will always return to its original length when you release it. This simple fact was discovered by Hooke in the seventeenth century, and is called Hooke's Law. A lot of laws in physics are like this one — one quantity is proportional to another, so that a graph of the extension of a spring for example, plotted against the stretching force, is a straight line (**Figure 1**). This type of relationship is called linear.

If you over-stretch the spring, however, its length is permanently changed, and the graph of extension plotted against force looks more complicated. The graph now has two lines, one for increasing force, the other for decreasing force (**Figure 2**). A shape of this type is called a 'hysteresis' curve, and it implies, in this example, that the spring does not return to its original length.

Until Steinmetz investigated the magnetization of iron, everyone assumed that when a coil of insulated wire was wrapped round a piece of iron, and an electric current passed through the wire, then the magnetism of the iron would depend on the amount of current through the wire, and the relationship would be linear, or almost so. They expected, in other words, that a graph of magnetic strength plotted against current would be a straight line. By the late 1880s, it was becoming obvious that this assumption just could not be sustained. There was, for example, no way in which the performance of an electric motor could be predicted using these simple ideas about magnetism, and the magnetism of the iron in the motor was the only missing link in the theory. The only way that a manufacturer could get data on the likely performance of a new electric motor design was to build a prototype and test it! At a time when the uses of electricity, and in particular the uses of electric motors, were expanding rapidly, this was unsatisfactory, rapidly becoming intolerable because the use of AC in power transmission, strongly urged by many engineers, demanded the use of transformers — and there was no theory governing the design of the most important part of a transformer, its magnetic core.

Round the Bend

Steinmetz set to work investigating the magnetism of iron and its alloys, using the type of equipment illustrated in **Figure 3**. The details have been omitted, but the principle was that a measured current was passed through the coil surrounding the magnetic specimen, and the strength of the magnetism measured (by a system which Steinmetz had devised). The measurements enabled him to draw a graph of magnetic strength (what we would now call the flux density) against the current flowing in the coil (proportional to what we now call magnetizing force). He started with com-

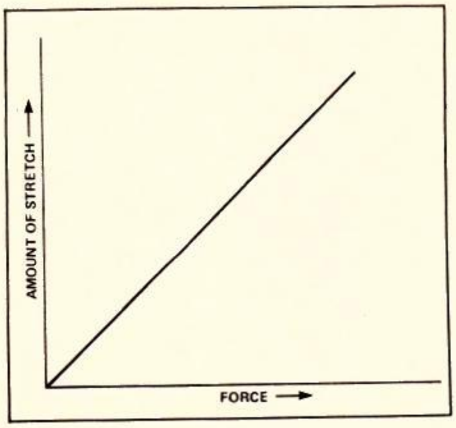

Figure 1. The graph for stretching a spring — providing you don't overstretch it!

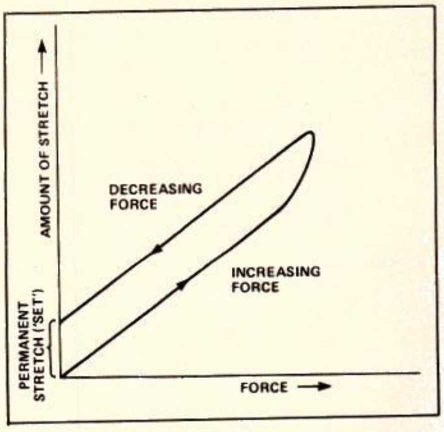

Figure 2. The 'hysteresis' graph shape that results from overstretching.

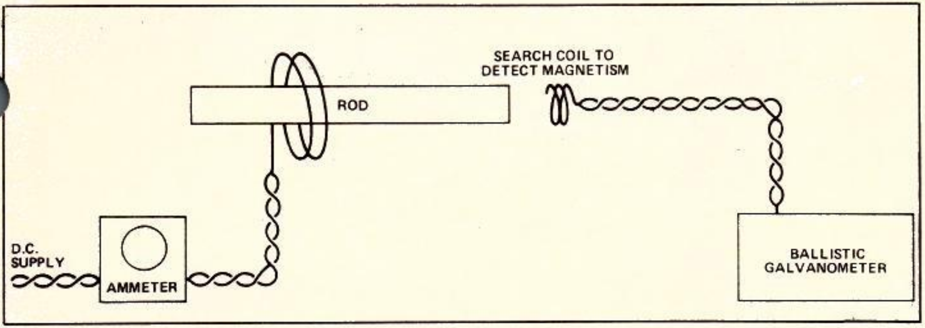

Figure 3. The Steinmetz apparatus, simplified. The rod was magnetized by the current flowing in the large coil, and the amount of magnetism detected by the smaller coil in conjunction with a ballistic galvanometer.

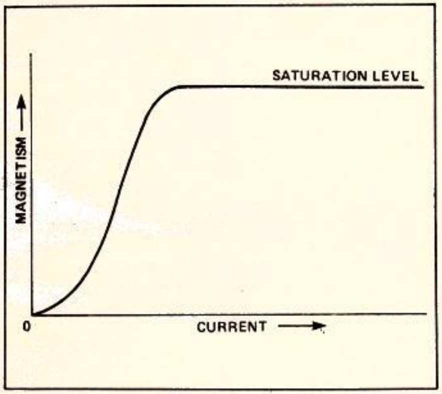

Figure 4. The first part of the magnetizing curve for iron.

pletely demagnetized iron, and found that as the current increased, the magnetic strength also increased, following a curved graph line shaped rather like an 'S', to a maximum magnetic strength, which he termed 'magnetic saturation' (**Figure 4**). When the current was reduced, however, a different set of graph points was obtained, so that the graph for decreasing current followed a different path. This path (**Figure 5**) showed that when the current was reduced to zero, the iron remained magnetized (the amount is called the 'remanence'). Steinmetz found that the magnetism could be reduced to zero only by reversing the direction of the current in the coil and holding it at some definite value, called the 'coercive force'. By taking the value of the reversed current to the amount that caused the magnetism to saturate again he produced the now-familiar hysteresis curve for iron (**Figure 6**).

The consequences of this work were enormous. The area inside the loop-shaped curve is proportional to the amount of energy that has to be used to magnetize and demagnetize the material, and this energy causes the iron to become hot. Previously, it had been thought that the heating of electric motors and transformers was due only to the current flowing through the wires (and to eddy currents), but Steinmetz's work clearly showed that the magnetic material was as much to blame. He went on to show that the shape and size (area) of the hysteresis curve could be greatly affected by the composition of an iron alloy, and, even more importantly, on its previous treatment, such as heating, previous magnetization, mechanical strain, and so on.

For the first time, electric motors could be designed and perform to specification, and transformers could be wound which would not overheat. The way was open for the invention of magnetic recording by Poulsen, and subsequent research which led to the discovery of ferrite materials such as are now used for coil cores and for aerials in pocket radios. Even if Steinmetz had done nothing more on this work, he would have deserved to be remembered, and his classic

Charles Steinmetz Continued from page 71

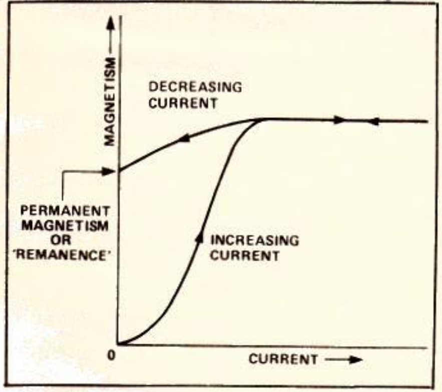

Figure 5. The hysteresis effect — as current is reduced from the saturation level, a different curve is traced, and with zero current, the iron remains magnetized.

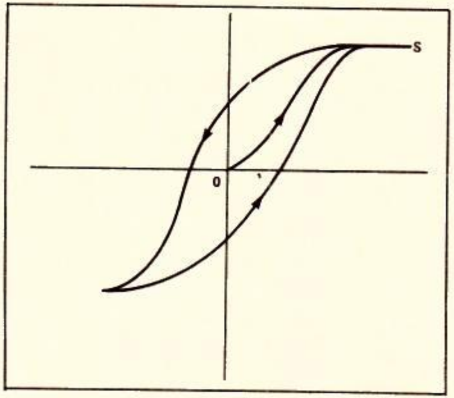

Figure 6. The complete hysteresis loop — the first part, marked OS, is seen only when starting with completely demagnetized material and is never traced again in the course of a measurement of this kind.

paper of 1892 is well worth reading in reprint form.

It Doesn't Add Up . . .

He contributed much more, however. When he arrived in the USA, he was amazed and dismayed to find that engineers, brought up in the British tradition, were almost incapable of making elementary calculations on alternating current circuits, and he undertook, virtually singlehanded, to raise the level of mathematical education to the standard which by then was common on the European continent, Britain excepted. He invented a new method of expressing AC calculations (the j-vector method) which is still in use, and, finding that engineers didn't understand it or even appreciate its advantages, he set about writing, in 1897, a textbook of Engineering Mathematics which did more to improve the education of engineers than any other single step in the decade.

Steinmetz's reputation by that time was such that when General Electric purchased the firm of Eickemeyer and Osterheld, Steinmetz was regarded as the main asset, and the most valuable single part of the deal. His work for GE included a new theory of transients (voltage pulses) which resulted in greatly improved ways of protecting transmission lines against switching surges and lightning strikes. The same theory was later used by the early workers on radar to predict the action of pulses in their circuits. Always an experimenter as well as a brilliant theorist, Steinmetz designed a pulse generator, for testing lines, which would even nowadays be regarded as someing special — 100kV at 10kA for 1 ns! This giant insulation-cracker was used to test lines for transient behaviour — and one nanosecond is as transient as you can get.

He continued working for GE, living in their bachelor accommodation surrounded by dozens of pet small animals of every kind, and a hothouse full of his special joy, orchids. He appears to have been idolised by his fellow-workers as that very rare type, a near-genius who was at the same time a very warm and friendly personality, and who would help anyone to the best of his ability. He died in 1923, having amassed no fortune, won few of the glittering prizes that most academics covet, and not even honoured by having his name used for a unit or a device. The admiration of his colleagues and the increasing value of his contributions to electrical science were reward enough for Charles Steinmetz.

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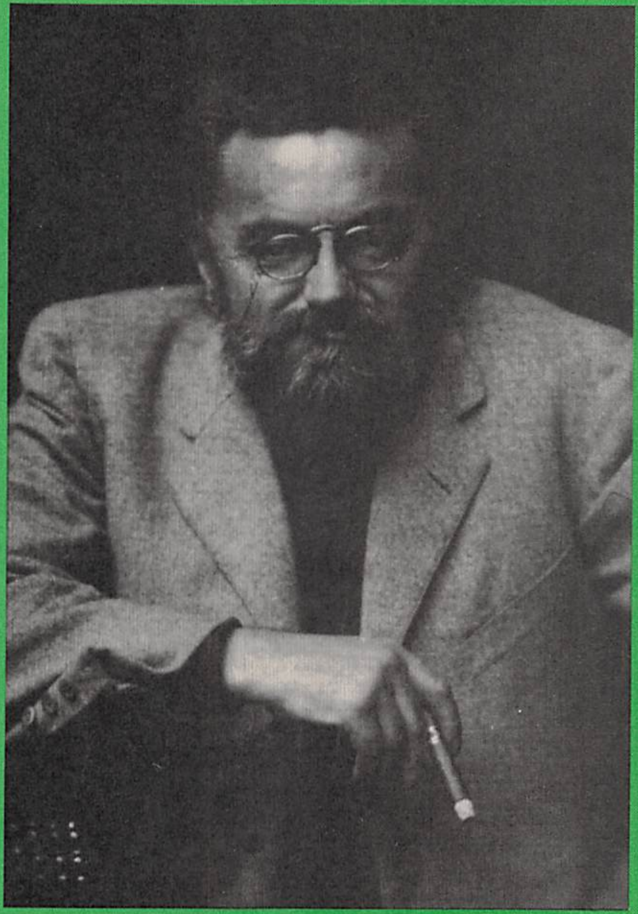

CHARLES PROTEUS STEINMETZ

BY JAMES P. RYBAK

The officials at the Castle Garden immigration center in New York City probably looked at Steinmetz with feelings of both frustration and sympathy. Standing before the officials was a person who likely already had faced rejection many times in his life. More rejection appeared imminent.

This would-be immigrant was a twenty-four year old hunchbacked dwarf who walked with a very pronounced limp. His face was swollen due to his infected teeth and his eyes were red as a result of the cold he had gotten on the steerage-class ocean voyage from Europe. To make matters worse, his clothes clearly indicated poverty. Karl Steinmetz's appearance did not make a good first impression.

The year was 1889 and immigrants from Europe were flocking to the United States by the thousands. Those seeking admittance were expected to be strong and in good health as the jobs available to immigrants virtually always required manual labor. It also would be helpful if the applicants had a basic knowledge of English.

The new arrivals were required to have some means to support themselves until they found jobs. Like most nations, the United States would not admit persons who were indigent, seriously ill, or who otherwise would become a burden to society.

In addition to his obvious physical disabilities, Steinmetz appeared destitute, spoke very little English, and had no immediate prospects for a job. He seemed to meet none of the criteria for entry to the United States. There would be no option for the immigration officials but to refuse admission to this pathetic individual and send him back to Europe.

One could not fault the officials for reaching this conclusion. They had no way of knowing that soon Steinmetz's experimentation and mathematical analyses would at last make the design of electrical equipment a mathematically precise science.

No one on that June 1 date in 1889 could possibly have predicted that within twenty-five years, the name "Steinmetz" would be a household word in America. It was simply inconceivable that this impoverished-looking man occupying a twisted body barely four feet in height would soon associate with scientific celebrities such as Edison, Marconi, and Einstein on an equal basis.

The senior official was about to stamp "Refused Entry" on the papers and send Steinmetz to a holding area to await being sent back to Europe when Oscar Asmussen stepped forward. Asmussen, whom Steinmetz had known for only a few months, had already come to the latter's aid on more than one occasion.

This young man who had befriended Steinmetz immigrated to the United States from Denmark some years earlier and lived with an uncle who was a successful San Francisco businessman. The uncle had sent Asmussen back to Europe for a university education and supplied him with a monthly living stipend. Graciously and repeatedly, Asmussen had shared his stipend with Steinmetz. His generosity even extended to taking the money his uncle had sent for purchasing a single first-class boat ticket back to America and buying steerage-class tickets for Steinmetz and himself.

Now, Asmussen would attempt to do an even greater favor for Steinmetz. Pulling a rather substantial sum of money from his pocket, Asmussen told the immigration officials that the money belonged to both Steinmetz and himself. Carrying the hopefully convincing, albeit exaggerated, argument a bit further, Asmussen assured the immigration officials that Steinmetz already was a renowned European scientist who would learn English quickly. Asmussen pledged that he would be responsible for making sure that Steinmetz did not become a public burden.

Asmussen's self-assured demeanor, good command of the English language, apparent financial resources, and familiarity with America caused the senior immigration officer to change his mind. With a sweep of his hand, the officer indicated to Steinmetz that he was allowed to enter the United States.

An Unauspicious Beginning. Karl August Rudolf Steinmetz was born on April 9, 1865, in the city of Breslau in what is called Germany today. He inherited the pronounced physical disabilities with which many of the males in the Steinmetz family, including his father, had been afflicted. What Karl lost to dwarfism and a hunched back in terms of physical abilities, however, he later would more than offset with his superior intellectual achievements.

Young Karl's early school experiences led no one to suspect he possessed the brilliant mind he later would demonstrate. He complained so bitterly and convincingly about having to go to kindergarten at the age of four that the beginning of his formal schooling was delayed for a year.

Once he finally entered school, Karl very quickly began to enjoy both learning and the school environment. Nonetheless, until he was almost nine years old, Karl Steinmetz was an undistinguished student. So mediocre was his performance at learning basic arithmetic, the teachers considered him intellectually dull. No one at that time would have ever suspected that Karl one day would develop into an exceptionally brilliant mathematician.

Looking back years later on his early school days, Steinmetz observed that his early difficulties with arithmetic arose because he never before had been required to put forth the effort and self-discipline that learning the multiplication tables required. Soon, however, Karl Steinmetz was excelling at not only arithmetic, but Latin, French, Greek, philosophy, algebra, and geometry as well. Mathematics was now his favorite subject and one at which he demonstrated the greatest ability.

Learn about a mildly eccentric but affable genius who changed the process of designing electrical equipment from a chaotic art into an orderly science.

Steinmetz Questions Everything. Early on, Karl learned to question everything, including (and especially) the commonly accepted laws of science and mathematics, before accepting anything as fact. His questioning was not done out of an attitude of audacity. Rather, he questioned so that he might develop a more complete understanding of basic scientific and mathematical principles. It was on this basis Steinmetz would later develop what to others seemed like unbelievably insightful breakthroughs.

Steinmetz completed his "gymnasium" or high school studies at the head of his class and entered the University of Breslau in 1882. His university studies consisted of mathematics, astronomy, physics, chemistry, philosophy, and classical literature.

Attendance at the lectures was totally voluntary with the exception of one at the beginning of the term and another at the end. Examinations were not a part of the courses. After a student had been at the university for at least four years, a diploma could be earned by passing an examination covering all the courses the student claimed to have attended. Steinmetz wanted more than a diploma. He intended to perform the research and write the dissertation required for a doctoral degree.

The lax policy toward attendance resulted in many students attending few lectures. Not so with Steinmetz. Every lecture was important to him and he studied late into the night. Often the attendance at lectures dwindled to the point where they became virtually private dialogues between Karl and the professor. Steinmetz could discuss topics with his professors to a depth few other students could or even wanted to approach.

The Origin of "Proteus." Although Karl was a diligent student, he also took an active part in several of the student societies that were an integral part of university life. Initially, his favorite was the mathematical society whose weekly meetings combined a business session and a technical session with several intervals of singing, drinking beer, and storytelling.

New members, or "foxes" as they were called, were required to entertain the more senior students by providing an unrehearsed lecture on an academic topic when ordered to do so. To make things more interesting, a fox would have to stop on command and change the topic of the lecture to something totally different.

The mathematical society followed the practice of conferring on each new member a "student name" that supposedly fit his personality and by which the student was then known to the other members. Steinmetz was so proficient at changing lecture topics on command that he was given the name "Proteus" after the Greek sea god who allegedly could change his shape at will. When Steinmetz later immigrated to America, he adopted Proteus as his middle name.

Politics Leads to Trouble. Karl Steinmetz soon also became interested in politics. The government of Chancellor Bismarck granted numerous privileges to the aristocracy, but virtually none to the millions of common people. For years, university students throughout Germany had agitated for social and political reform. Bismarck had retaliated by outlawing all opposing political organizations. The university students persisted in their political activities but had to do so in secrecy.

The Socialist movement's goals of a more democratic government attracted Steinmetz. Karl always worked for peaceful political change. He never used or advocated violence. When Karl temporarily became the editor of that organization's newspaper, he could not escape the scrutiny of the police.

In June of 1888, Steinmetz's doctoral thesis on a topic in synthetic geometry was nearly finished. The awarding of his doctoral degree was not far off. However, that degree would never be conferred on him. Karl's political writings had become increasingly more offensive to the government and his activities were under constant police surveillance.

Goodbye to Germany. Karl learned that the police had a warrant for his arrest. It became obvious to him that he must leave Germany immediately. His plans for the future, which had included a university professorship, now were in total disarray.

Steinmetz secretly left Breslau by train and headed for Switzerland. Although he had little money, his plan now was to study the theoretical principles of mechanical engineering, with emphasis on the technology of motors and generators, at the famous Polytechnic School in Zurich. Karl avidly read all the available textbooks and journals on the latest developments in electrical science.

The Polytechnic at first refused to admit Steinmetz because he was a non-resident of Zurich and lacked the necessary papers from his hometown police certifying that he was a person of good character. There was no chance that the Breslau police would provide him with that certification! To make matters worse, supporting himself in Zurich also turned out to be more difficult than Karl had anticipated.

The first problem was solved when Steinmetz was introduced to a prominent local political figure. The politician liked Karl and used his influence to get Steinmetz admitted to the Polytechnic.

Supporting himself remained a chronic problem. Steinmetz wrote scientific articles and tutored other students, but neither of these activities provided a reliable source of income.

Soon Karl met Oscar Asmussen and the two quickly became good friends. Asmussen was more than willing to share the modest stipend his uncle was providing. The stipend was cut off, however, and his uncle ordered him to return to the United States when Oscar announced that he planned to marry a Swiss girl.

Off to America! Steinmetz had heard many stories of the opportunities that were available to even the most common people in America and wanted to accompany Asmussen. Karl, however, still had very little money of his own. Oscar Asmussen again helped out his new friend. This time he used the money his uncle had sent him for buying a first-class return ticket to America to buy steerage-class tickets for both himself and Steinmetz.

As mentioned before, Steinmetz would have been denied permission to enter the United States had it not been for Oscar Asmussen. Not only did Asmussen convince the immigration officials that Steinmetz would not become a public burden, he made good on that promise by arranging for his own relatives in Brooklyn to house and feed his friend until Karl could find a job.

Steinmetz went to the Edison Machine Works in Manhattan to seek a job with the famous electrical inventor. The person with whom he talked there made it very clear that no more "electricians," as electrical engineers then were called, were needed.

A Lucky Letter. Before leaving Zurich, Steinmetz had received a letter of introduction to a Rudolf Eickemeyer in Yonkers who manufactured machines to make hats. Karl had no idea who Eickemeyer was, but decided it could not hurt to pay him a visit.

Eickemeyer, also an immigrant from Germany, was impressed with Steinmetz's keen intellect and desire to work. However, he had no positions available. Karl returned a week later to inquire again. Impressed now also with his persistence, Eickemeyer hired Steinmetz to do drafting for two dollars a day.

Steinmetz began his new job making drawings of the DC motors and generators Eickemeyer had also recently begun to manufacture. The design of all electrical devices at that time was done solely by trial-and-error experimentation. No one had yet been able to use mathematics to describe the operation of any but the most simple electrical circuits. Steinmetz, however, was confident that mathematics would provide the key to understanding how best to design complicated electrical equipment.

The New American. Immediately

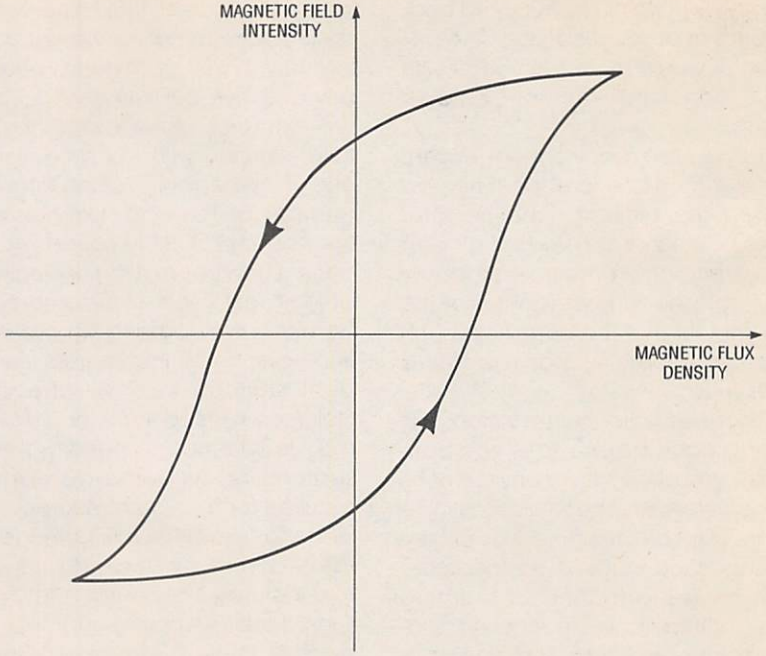

Fig. 1. Each magnetic material has a unique "hysteresis loop" that indicates that material's suitability for use in magnetic circuits.

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after obtaining a job, Steinmetz began the process of applying for American citizenship. Everything about America fascinated him and he wanted to be an integral part of this nation. He even felt that Karl August Rudolf Steinmetz was not an appropriate name for him in America.

Since "Charles" was the American equivalent of "Karl," he would call himself, simply, Charles Steinmetz. Later, Steinmetz became convinced that he had to have a middle name. As neither of his two German middle names had an American equivalent, a new middle name would have to be found. Steinmetz soon decided that his school name, "Proteus," would make a fine middle name. From that time on, he was known as Charles Proteus Steinmetz.

Steinmetz Becomes Noticed. As soon as Steinmetz learned some basic English, he began attending meetings of the American Institute of Electrical Engineers (AIEE) in New York. The electrical experts of the day presented the results of their latest experiments and research at these meetings. Steinmetz was becoming more and more fascinated by the study of electricity and wanted to be in on the forefront of electrical development.

Thorburn Reid presented a talk on "The Armature Reaction of Alternators" at one of these meetings but Steinmetz was not pleased with what he heard. Reid had not taken into account the effects of the third harmonic terms in his analysis. When questioned about this by Steinmetz, Reid pointed out that to include these effects would cause the mathematics to become extremely complicated and would serve no useful purpose.

Steinmetz was appalled at Reid's response. He was sure that the third harmonic effects were not insignificant and that workable mathematical formulas could be developed.

In a month's time, Steinmetz developed the necessary mathematical analysis and reduced it to a workable form. When he reported his results at the next AIEE meeting, Steinmetz won the respect and admiration of the membership, including Thorburn Reid, for having solved a particularly complicated problem. When Eickemeyer heard of his employee's success with the third-harmonic problem, he immediately set Steinmetz to work on solving the "hysteresis" problem, which was making the design of alternating-current motors, generators, and transformers very difficult.

Hysteresis. A current flowing in a coil wound around a soft iron core produces a magnetic field in the iron. A substantial part of the total magnetic field in the bar, however, is due to microscopic magnetic elements in the iron that become aligned with the magnetic field produced by the current in the coil.

When the direction of the current in the coil is reversed, the magnetic field in the iron also tries to reverse itself. Effects similar to friction tend to keep the magnetic particles in the iron from reversing direction easily. This resulted in the production of heat in the iron. Hysteresis effects, while moderately troublesome in the design of DC motors and generators, were holding the development of AC machines at a virtual standstill.

An alternating current flowing in the coil changes direction rapidly and repeatedly. The resulting heat from the hysteresis effects can cause the iron to become very hot. At best, the motor, generator, or transformer then exhibits low efficiency. In the worst cases, the device is destroyed by the heat. At the time, attempts by engineers to understand how to predict and minimize the losses due to hysteresis had met with very little success.

Back then, building electrical devices that operated well was more the result of luck than of design. Steinmetz himself later said: "The designer of electrical apparatus simply built it, then tested it, and when the loss was too high and the efficiency too low, or the machine too hot, he tried again. This obviously was not a satisfactory way."

Steinmetz carefully studied all the published information on hysteresis effects. Because the existing data was inconsistent and incomplete, he made numerous measurements of his own using a magnetic-bridge circuit Eickemeyer had developed. Steinmetz elegantly combined careful experimental measurements with sophisticated mathematical analysis.

The "law of hysteresis" developed by Steinmetz allowed engineers to predict the magnitude of hysteresis losses with excellent accuracy. Steinmetz was able to show which types of iron were suitable for use in alternating-current devices and which were not. His work provided a means for determining how much magnetizing current is required to produce the desired amount of magnetization in a particular piece of iron.

When Steinmetz presented his work on hysteresis to the AIEE in 1892, engineers around the world hailed it with great acclaim. The successful design of alternating-current devices was no longer a matter of luck. It now was a logical process thanks to Steinmetz. He had brought forth scientific order from chaos.

More Obstacles to Hurdle. As early as 1890, Steinmetz had realized that the understanding of how to predict and calculate hysteresis effects was not the only obstacle that was hindering the development of efficient AC equipment. Engineers at that time had no straightforward and accurate way to predict the various voltages and currents that would occur in AC networks.

The application of Ohm's law to AC circuits with inductance and capacitance as well as resistance was not well understood. The graphical techniques then in use were extremely cumbersome and provided only limited information concerning the steady-state operation of AC circuits.

A second problem was that no way existed to predict with accuracy the transient voltages and currents that occur whenever motors or generators are switched on or off. The most damaging transients, however, are caused when lightning strikes a power system and creates a brief but abnormal path to ground that permits dangerously large currents to flow.

Steinmetz believed that mathematics could provide solutions to both these problems. Few engineers at that time, however, possessed the mathematical knowledge to develop the needed techniques. Scientists who had the required mathematical ability, generally lacked a practical understanding of electrical systems. Steinmetz had both the mathematical and practical knowledge needed. Because of that, he would develop the necessary mathematical techniques himself.

Steinmetz Finds the Solutions. Complex numbers provided Steinmetz with the means needed to develop what he called his "symbolic" method for calculating steady-state AC voltage and current values. Consisting of both "real" and "imaginary" numbers, complex numbers allow not only for the calculation of the magnitudes of AC voltages and currents but also for determining how much these quantities differ in phase from other voltages and currents in the same circuit.

Steinmetz did not invent or discover complex numbers. Others before him had attempted to use these numbers to analyze circuits, but their methods lacked the clarity, elegance, and broad applicability of Steinmetz's work.

When Steinmetz presented a paper to the International Electrical Congress (IEC) in 1893 describing his use of complex numbers to solve alternating-current problems, virtually no one had the mathematical background necessary to immediately understand the importance of what he was proposing. The IEC had severe financial problems at that time and could not afford to publish Steinmetz's lengthy paper so people could study the details of his work. The significance of his work, therefore, lay unrecognized for several years. Once engineers finally understood Steinmetz's techniques, his method was universally adopted and greatly respected.

Steinmetz later addressed the problem of predicting transient voltages and currents in circuits that plagued engineers at the time. Although lasting for only small fractions of a second, these voltage and current spikes or surges could attain values of thousands of volts or amperes, respectively.

Because the magnitude of a transient changes rapidly with time, differential equations are needed to describe and predict the effects. Steinmetz solved the equations with ease but, again, few others had the mathematical background to understand his techniques and apply them to their own engineering problems.

Steinmetz now knew he needed to help educate engineers concerning the practical use of what was then considered to be advanced mathematics. To achieve this, Steinmetz wrote a series of books that became the standard texts used in most college electrical-engineering programs for many years.

Joining the G.E. Team. Shortly after Steinmetz had completed his work on hysteresis, Eickemeyer sold the electrical-equipment part of his business, which by that time had grown substantially. The newly formed General Electric Company was seeking to solidify its position in the manufacture of both AC and DC motors and generators. G.E. wanted Eickemeyer's valuable patents for electric railroad and streetcar motors, together with Steinmetz's equally valuable applied-mathematics skill. Steinmetz and the patents would go a long way toward helping G.E. achieve its goal.

Steinmetz realized that the considerable resources of G.E. would provide him with even more professional opportunities for research. He gladly joined this new corporation in 1893 and was one of those chiefly responsible for enabling G.E. to become an American industrial giant.

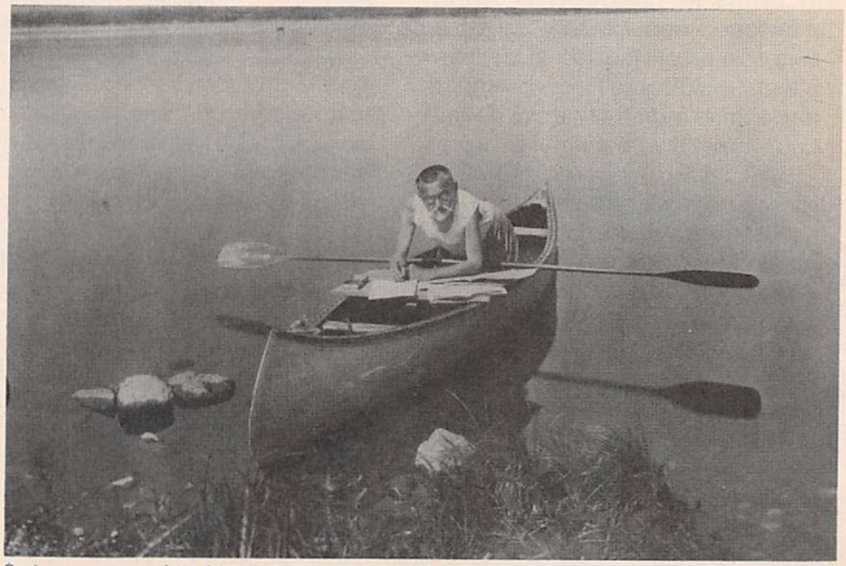
Initially, Steinmetz was sent to Lynn, Massachusetts to work in G.E.'s calculating department, which did all the mathematical computations for new equipment designs. Soon, however, that department was transferred to Schenectady, New York and Steinmetz was made its head.

The calculations were easy for Steinmetz but not so for those he directed. As a result, Steinmetz spent much of his time teaching others the details of his mathematical techniques.

Steinmetz quickly won the admiration and respect of the engineers at G.E. as one who was both exceptionally brilliant and modest at the same time. He never considered himself superior to others and never became impatient with or discourteous toward those who needed to be helped repeatedly in mastering the mathematics. The diminutive and genial Steinmetz, together with the cigars he constantly smoked and the poorly fitting, mismatched clothes he wore, soon became legendary both at G.E. and in Schenectady.

Science and engineering, not the administration of a corporate department, were Steinmetz's interests. Soon, General Electric realized this. The Company then made Steinmetz its "Senior Consulting Engineer," allowing him to choose the projects on which he would work, and to come and go on his own schedule.

Relaxations and Hobbies. Steinmetz loved to canoe along the Mohawk River, which flows through Schenectady. He leased a piece of property on one of that river's tributaries and had a one-room shelter built. Steinmetz spent nearly every summer weekend entertaining his numerous friends at his "camp." During the week, his canoe was often his "office." It was here that he often got his best scientific ideas. Thinking about



Steinmetz at work in his "office" on the Mohawk River. (Photograph courtesy of the General Electric Company) science and mathematics was Steinmetz's favorite form of relaxation.

Keeping rare varieties of live exotic animals and plants at home was a lifelong hobby for Steinmetz. In his conservatory were orchids and cacti together with crows, eagles, owls, raccoons, a gila monster, and a three-foot long alligator. This menagerie made visiting his home a fascinating adventure for his friends and for the neighborhood children, whom he especially enjoyed.

Home also was the place where Steinmetz maintained a laboratory for performing scientific experiments late into the night. In 1901, he decided that living in rent was not compatible with keeping a plant and animal conservatory as well as a laboratory.

Steinmetz then purchased some land and built a house of his own. General Electric gladly made available to him the funds for building and equipping a first-rate laboratory in his back yard. The company knew that this was a good investment. Steinmetz came up with valuable ideas virtually twenty-four hours a day.

Most neighbors would be up-in-arms if strange animal and bird noises together with odors from chemical experiments emanated from a nearby house at all hours of the day and night. The neighbors found Steinmetz to be such a genial person and such a good friend to their children that they accepted the noises and odors without serious complaint.

Steinmetz discussing his lightning generator with Thomas Alva Edison. (Photograph courtesy of the General Electric Company.)

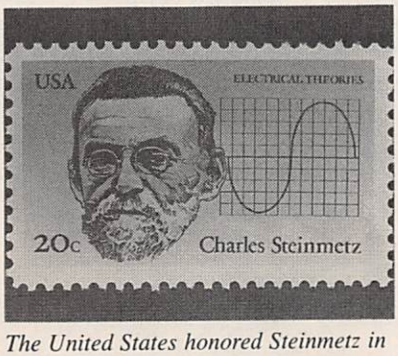
A Better Arc Lamp. Electric street lighting was rapidly becoming popular at the turn of the century. The carbon arc-lamps commonly used, however, were not efficient and required too frequent adjustment of the electrodes to keep them operating properly. Steinmetz was asked to study this situation.

Soon, Steinmetz discovered that electrodes made of magnetite, an iron oxide, were much more efficient at producing light. Furthermore, these new electrodes did not burn away rapidly during operation and, hence, did not require frequent adjustment.

The only drawback was that magnetite electrodes, unlike carbon, could operate only from DC voltage. Since inexpensive rectifiers capable of handling high power were not available, the magnetite arc-lamps had to be powered by DC generators. That was a distinct disadvantage. Soon, however, Steinmetz aided in the commercial development of mercury-arc rectifiers, which allowed the magnetite lamps to be operated from AC power.

Academic Honors. Harvard College awarded Steinmetz an M.A. degree in 1902 calling him the "foremost expert in applied electricity of this country and therefore the world." The following year Union College in Schenectady awarded Steinmetz an honorary doctoral degree completing the formal recognition of his academic achievement that was denied him when he hurriedly left Breslau fourteen years earlier. Few before or afterward have been more deserving of an honorary degree than was Steinmetz.

Union College also invited him to join the faculty as a professor of electrical engineering. This he did on a part-time basis without pay for ten years. Steinmetz earned the respect and friendship of virtually all the students despite the fact that he was exceedingly demanding in the classroom. He always emphasized the importance of liberal-arts studies as part of a sound engineering curriculum and constantly reminded students that they were merely beginning the lifelong process of learning.



The United States honored Steinmetz in 1983 with this stamp.

Public Recognition. It did not take

(Continued on page 92)

CHARLES PROTEUS STEINMETZ

(Continued from page 61)

newspaper reporters long to recognize Steinmetz as an excellent source of good copy despite the fact that most of his scientific achievements were not understandable to the average person. What made Steinmetz intriguing to newspaper readers was the man himself.

The combination of his wizard-like mind and small, twisted body together with his engaging personality and amusingly eccentric activities made Steinmetz a popular folk-hero. The rapidity with which this disabled and destitute immigrant had achieved scientific greatness while still maintaining his personal charm had won him the respect and admiration of the public.

In an article appearing in *Ladies' Home Journal* in 1915, Steinmetz fascinated his readers by describing how electricity soon would be used to cook meals, heat and cool homes, provide various new forms of entertainment at home, as well as supply power for all factory and transportation needs.

Repeatedly in talks and articles, Steinmetz urged the development of hydroelectric power-generating stations as well as other, yet unknown, energy sources because he realized that coal supplies were limited and that the burning of coal was polluting our air. He also urged the development of crops that could store the sun's energy for later conversion into alcohol-based fuels for the sake of efficiency. It wouldn't be until the 1970's (over fifty years later) that these ideas would gain popular support.

Maker of Lightning. Steinmetz's greatest public acclaim came as the result of the laboratory lightning generator he created in 1921 to test improved insulators for electric power systems. As electric power networks were growing in size, the problems caused by lightning discharges were becoming more troublesome.

Artificial lightning discharges of 120,000 volts at 10,000 amperes literally exploded around Steinmetz's laboratory. Higher voltage discharges had been produced previously by others, but not at the high current levels achieved by Steinmetz. High current is critically important if one is to truly simulate lightning's devastating effects.

Not only was Steinmetz's lightning generator successful in providing the discharges needed to develop better lightning arresters, it also provided newspaper reporters and photographers with material that captured the astonished attention of the nation. People could not believe that energy was being released at the rate of over one million horsepower, even if it were for only a hundred-thousandth of a second.

Photographs of the devastation dealt to large blocks of wood and sections of tree limbs made firm believers of everyone concerning the power of these laboratory discharges. Steinmetz was controlling energy in a manner heretofore done only by nature.

A Great Loss. In the fall of 1923, Steinmetz combined business with pleasure as he travelled for six weeks by railroad from Schenectady to California and back with numerous stops along the way. Besides visiting the Grand Canyon, Yosemite, and Hollywood, Steinmetz made personal appearances before many professional and civic groups.

Steinmetz had known for some time that his heart was weak. While he had enjoyed his trip, the schedule had been exceedingly demanding and he was exhausted. When he returned to Schenectady in mid-October, a period of rest was ordered but nothing more serious was suspected. He awoke on October 23 and asked that his breakfast be brought to him in bed. The 58 year old Steinmetz died with a physics book clutched in his hand before his breakfast arrived.

The thousands of eulogies from around the world attested to the widespread loss felt as the result of Steinmetz's death. The president of the Westinghouse Electric and Manufacturing Company, G.E.'s largest competitor, summed up the feelings of many when he stated: "He (Steinmetz) has been such an outstanding figure in engineering work for so many years and is so well known to the public that his death will be a great loss not only to the profession but to people generally." Indeed it was. ■