Right: Nikola Tesla's invention of AC generators, motors and a power distribution system laid the foundations of modern industry.

Edison, pictured with some of his early light bulbs. The two were to become bitter rivals in the AC versus DC controversy.

The inventive genius

Nikola Tesla has been called "possibly the greatest inventor the world has ever known". His discoveries form the basis of modern industry yet he remains one of the least recognised scientific pioneers in history.

by J. L. ELKHORNE

Through the years, power stations have generated as much controversy as electricity. Let us examine the problems men faced a hundred years ago.

The 1870s was an era of gas light and horse-drawn vehicles; what little electricity was used in industry originated on site. Before long, new forms of power generation and transmission would transform the nature of life – and two titans of electrical power would find themselves locked in a mortal combat that came to be known as "the battle of the currents."

The electric light in our homes and business which we take for granted today eluded scientific men for three-quarters of the 19th century. Humphry Davy demonstrated an electric carbon-arc lamp in 1808 but further development awaited a better power source. Then the dynamo emerged in 1831, based on Michael Faraday's discovery of magnetic induction.

15 Myella Drive Chigwell, Tasmania, 7011.

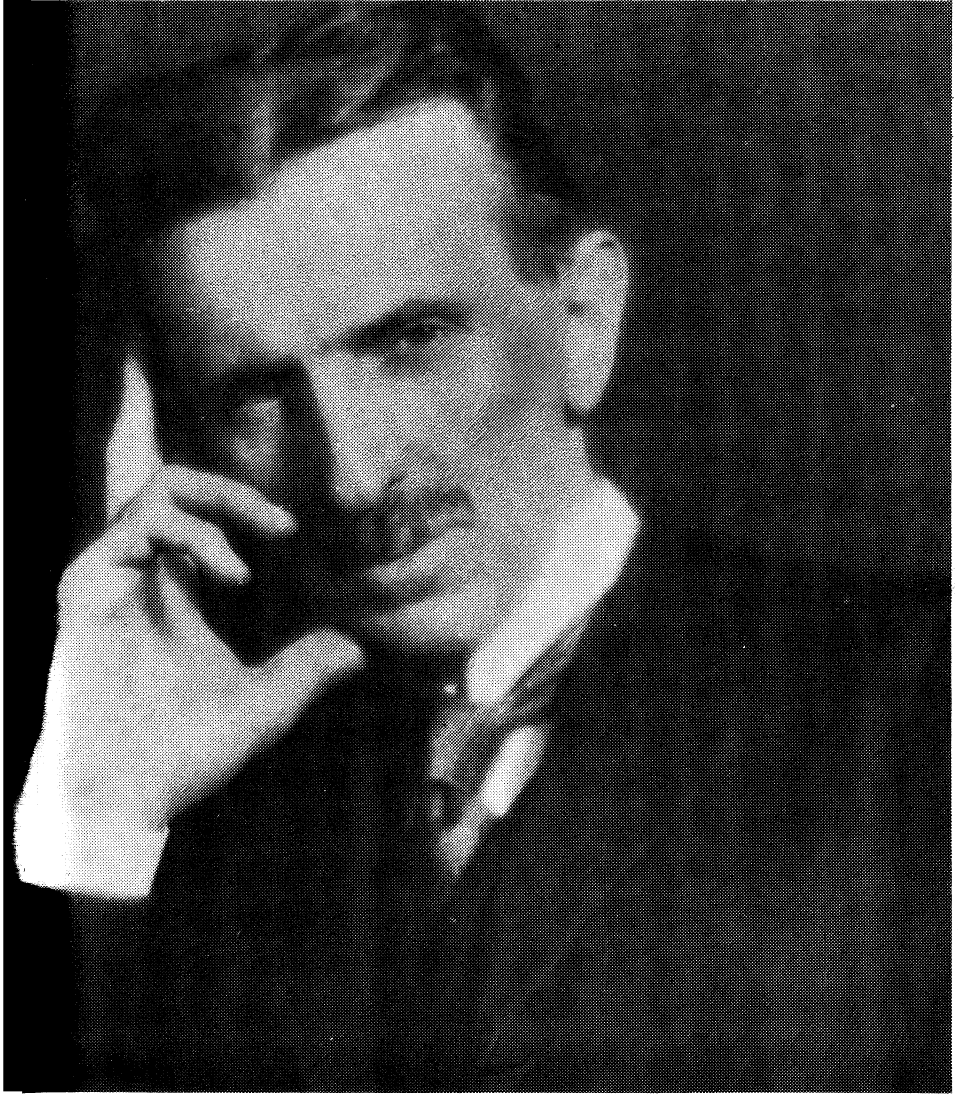
The availability of ready power helped progress, but it was not enough. Scores of scientists and inventors tried to capture the elusive principle of incandescence; De La Rive in 1820, De Moleyns in 1841 and J. W. Starr in 1845.

Joseph W. Swan, in England, gave up in 1860 after 12 years of experiments. Arc lamps were developed by various practitioners of the electrical art, and became common in the 1880s.

Thomas Alva Edison superseded Farmer, Brush, Sawyer, Hiram Maxim, St George Lane-Fox, and Wallace. The "Wizard of Menlo Park", already wealthy and famous from previous work, turned his attention actively to the problem in September, 1878. Having witnessed the Wallace-Farmer arc light system, Edison told Wallace: "I do not think you are working in the right direction." He proceeded to work on the problem in his own fashion for two nights and said: "I discovered the necessary secret, so simple that a bootblack could understand it."

Edison realised that intense arc lights could not fulfill the requirements of ordinary household use. He also recognised that a corollary of practical home lighting was a distribution system running from a central station.

He outlined his grand plan – to electrify New York City – to a repórter and reckoned he could have his electric light invention finished in six weeks. His electric distribution system would duplicate the gas-distribution industry which then lit the cities. The true value in his skill lay not in developing an incandescent lamp, so much, as in the



# of Nikola Tesla

concept of electric distribution.

Putting the cart before the horse, Edison launched an elaborate press campaign, essentially stating that the problem of electric lighting had been solved. In October, he carefully demonstrated a platinum-wire lamp. He had realised early on the necessity of a good vacuum for his lamp. He also knew, secretly, that his platinum-wire lamp was not the answer. Had he not turned it off after a short period of illumination, it would have burned out. But his showmanship convinced the public that the time had come.

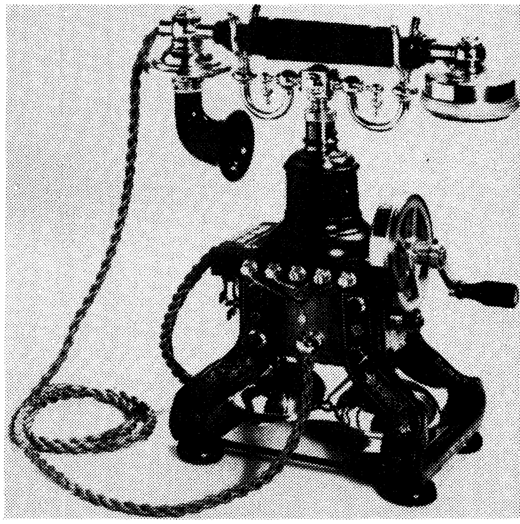
Years later, one of his associates remarked: "Edison got himself into trouble purposely, by premature publication so that he would have a full incentive to get himself out of trouble."

That trouble of his own making brought him the backing of a syndicate of financiers. Even though no electric distribution system stood ready, gas company shares dropped some 12% during this hectic time. The capitalists who took a paper loss quickly lined up to support Edison in his quest for success and profit with the new idea.

By April, 1879, Edison found his platinum-wire lamps quite encouraging, "burning an hour or two" but tried many other substances. A demonstration for his backers was not a success, however. One of the financiers remarked that Edison "would have been better off to spend a few dollars for Starr's book on carbon vacuum lamps, rather than coming to the same stopping point after spending $50,000."

The breakthrough came on October 21, 1879, with a test of carbonised ordinary cotton thread – Coats cord No. 29. Notebooks attest to a continuous run of 13½ hours. Edison coined the term *filament* for his carbonised threads, and before long, had a filament of Bristol cardboard that burned 170 hours.

Although Menlo Park neighbours and railway passengers out of New York had seen brilliant lights at night, the public announcement of success waited until December 21, 1879. Almost three years of work on the principles of distribution followed. Edison's Pearl Street power plant officially opened on September 4, 1882 and initially had 59 household subscribers. The Pearl Street Station generated electricity from steam, but a hydroelectric plant also started operation in Appleton, Wisconsin in that year.



Tesla's first work was with telephones somewhat less advanced than this 1900 model.

Had Thomas Alva Edison but known it his troubles were just beginning. His "marvel of the century" would soon prove to be an expensive white elephant, obsolescent almost before it began, and surpassed within a decade by a man whom Edison would characterise as a continental playboy.

Nikola Tesla, Croatian-born engineer and scientist, had long sought the secret of alternating current. In February of 1882, a fateful year, Tesla hit upon the brilliant concept of the rotating magnetic field.

Alternating current seemed to ordinary men of the day as nothing more than a laboratory curiosity. Just as with the electric incandescent light, scores of inventors had tried and failed with it. To understand why Nikola Tesla succeeded, analysis of the man and his time is worthwhile.

Tesla was born on the night of July 9-10, 1856, the second son of a Serbian Orthodox clergyman. His birthplace, Smiljan, Lika, Croatia, lies within the borders of modern Yugoslavia.

Nikola's father, Milutin Tesla, had started a career in the military only to enter the church shortly after he married. As the Tesla line had always given a son to the church the family expected that Nikola would eventually become a clergyman. His older brother, Dane, had evidenced a brilliant mind, and would bring honour to the family as a scientist or engineer. However, Dane

Continued on page 24

The inventive genius of Nikola Tesla

Continued from page 23

died at the age of 12, the result of an accidental fall from a horse.

Nikola had proved to have an equally find mind and a keen insight. Although his inclinations were secular, Milutin Tesla remained adamant that Nikola would enter the church.

His work in school continually astounded his teachers, for he had the ability to do lightning calculations mentally. At one point he received a failing mark in an examination, for it was assumed that he had surely cheated. Only when he demanded another examination from the director of the school, and solved problems far in advance of his years did his mentors accept his astonishing talent.

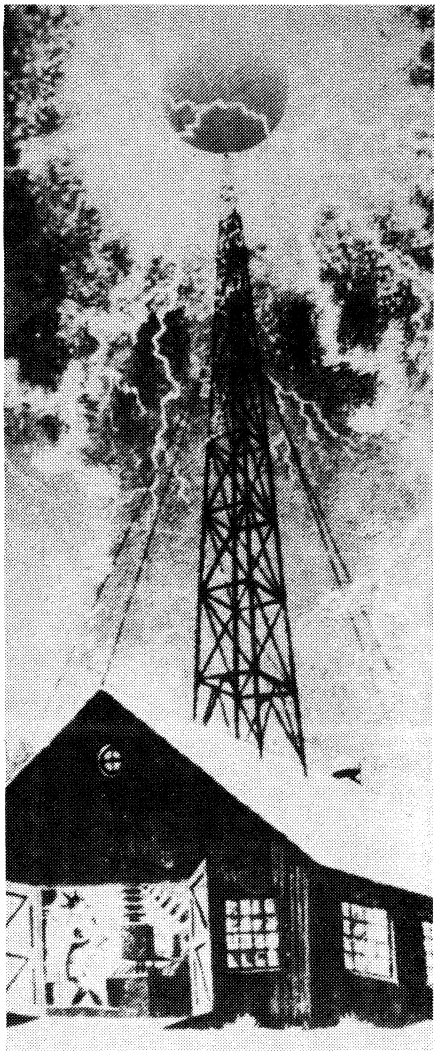
Academic work filled only part of his life. He haunted the woods near his home. It is said that he built a water wheel at a nearby stream when he was only four years old – perhaps foreshadowing his inventive abilities. On seeing a picture of the mighty cascade, he prophesied that he would "someday go to America and harness Niagara Falls."

Another of his childhood inventions was a popgun that fired a ball of wet hemp. These proved so successful that he manufactured and sold a number to his mates. A rash of broken windows ended this foray into business. His attentions were then captured by archery. He went from longbow to crossbows and arbalests of his own design.

At the age of 12, he made an unsuccessful parachute jump from the barn, using an umbrella. He proved the same as Leonardo da Vinci had, several hundred years earlier – the relative strength of materials can let you down rather abruptly. Despite his misadventures he devoured his lessons and when he was 15, continued his academic work at the Higher Real Gymnasium in Karlovac, Croatia.

He completed the four year course in three years. Whilst there, he lived with an aunt and her husband, a retired army officer. His aunt thought his slight frame a sign of delicate health and believed that heavy meals would harm him. Tesla remembered this period as the hungriest of his life and possibly this experience gave him a preference for lavish meals and fine wines in later life.

Nikola Tesla loved to take hikes along the snow-covered trails near Karlovac. One day, he began rolling snowballs down a snowy slope, trying to see how large one could get. He succeeded only too well, and watched in horror as an avalanche roared down the

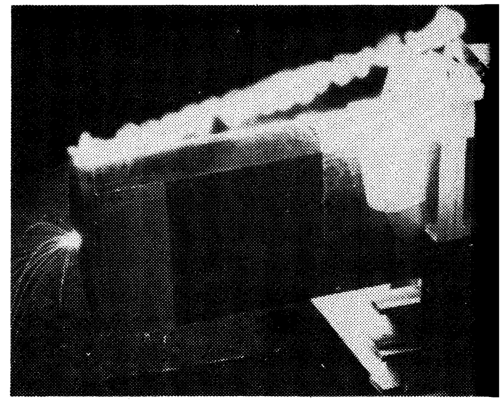


In 1899 Tesla began experiments in Colorado on wireless transmission of power, shown in this artist's impression.

moutainside. It diverted itself harmlessly in a field, narrowly missing some farm buildings. The young man was horrified at the near damage he had unwittingly caused – but recognised that a small action by a man could have great influence on natural forces. The thought that the tremendous power of nature could be harnessed and controlled by the relatively small efforts of men became a guiding force in his life.

During this period, he observed that lightning strikes preceded torrents of rainfall from the dark cloud masses, and speculated that the lightning itself triggered the rain directly. He would eventually succeed in creating an atmospheric mist artificially. In writing about the electrical control of the atmosphere, he would state: "The time is very near when we shall have the precipitation of the moisture of the atmosphere under complete control. . ."

On his graduation, he received a letter



Tesla coils are put to work today in simulating lightning strikes on aircraft.

from his father, urging him to take a hunting trip and relax from his three years of effort. Instead, he returned home and found the area in the grip of a cholera epidemic.

Worse than this, he also found that his father still expected him to enter the church. Now, Milutin Tesla knew that if his son did not do that, he would be expected to serve three years in the army. Too, he was concerned at Nikola's precarious health. But Nikola could not understand his father's worries. He only knew that he wanted to continue his technical training. He felt the army would be a waste of his education – and the obligations of the church would leave him no time to unlock nature's secrets. He fell ill.

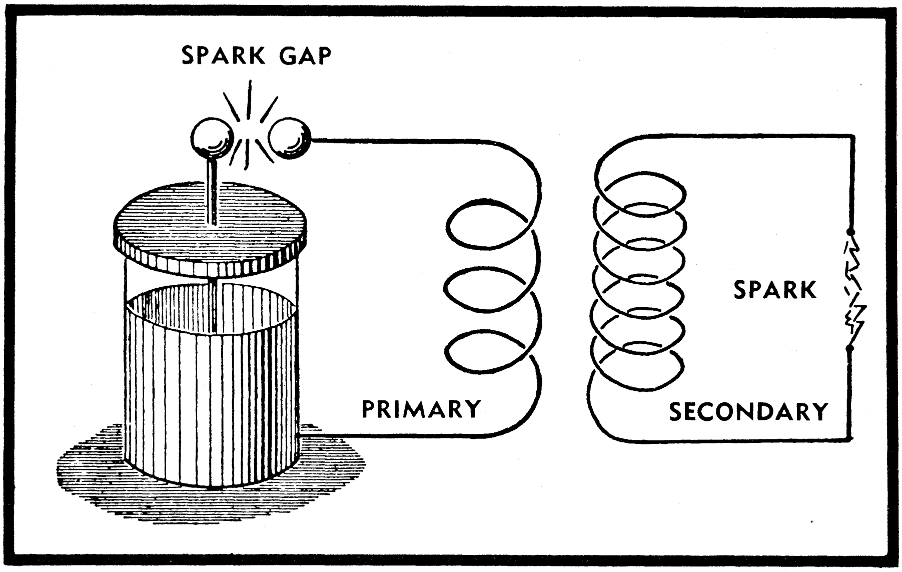
For week after week, one sinking spell led to another. Three years of undernourishment and his present spiritual anguish left him with no will to live. Doctors told the family that they should prepare themselves for his imminent death.

Milutin Tesla faced his own crisis. True, he had pledged Nikola to the church; but if the young man died, the pledge would be unfulfilled. Knowing the answer, he begged his son to tell him what would help him.

"I could get well," Nikola whispered, "if I could study engineering." His father made a solemn promise and in a short time, Nikola began to recover. In later years, he wrote that no magical event had taken place – instead, his mother had mixed a potent but unpleasant medicine so revolting that it forced his recovery.

Milutin Tesla sent Nikola away to the mountains to convalesce for some time. When he returned, the army had declared the young man unfit for military service on medical grounds. Whether the father's influence on family members in the army had anything to do with the decision is not known.

In 1875, Nikola enrolled in the



A contemporary drawing illustrates the principle of Tesla's high voltage transformers.

Polytechnic Institute at Graz, Austria. Chafing under all the lost time, he took twice the normal number of subjects, limiting himself to four hours' rest a night. In a year, he returned home with the highest possible marks. Instead of praise, his father reviled him for endangering his health. Years later, Nikola learned that the dean of the technical faculty had written to his father: "Nikola is a star of the first rank, but will kill himself from overwork."

Respecting his father's wishes, he returned to a second year at the Institute, limiting himself to a study of physics, mechanics, and mathematics. When he saw a demonstration of a Gramme dynamo, he remarked that the sparking at the commutator surely was a sign of power loss. His instructor, Professor Poeschl, patiently elaborated on the necessity of using a commutator to provide the useful direct current output.

Tesla responded that, by discarding the inefficient commutator, the inherent alternating current could provide more power. Everyone laughed, for they knew that AC was useless. Possibly, this belief dated back to Faraday's experiments, using a galvanometer. The indicator could only detect steady currents or momentary currents which reversed very slowly. It would remain perfectly quiescent (in the words of a 19th century academic) whilst to-and-fro currents of tremendous energy were circulating through the circuit to which it was connected.

Yet, Professor Poeschl took Tesla's intellect seriously enough to devote the next lecture to the young man's speculations on alternating currents. He concluded, however: "Mr Tesla may accomplish great things, but he certainly never will do this."

Popular wisdom went so far as to state that "the positive and negative cancel one another." Certainly, efforts by some inventors had not succeeded in developing a workable AC motor.

Tesla' conjectures were put in the same category as perpetual motion machines. Even though Tesla pointed out that AC would drive a passive load, such as a street arc lamp, and thus was doing work, no one accepted any further ideas

continued on page 26

The inventive genius of Nikola Tesla

Continued from page 25

of utility. Though Tesla bowed to the authority of his professor, the concept tantalised him. He imagined plan after plan and discarded them.

From his earliest years, Tesla had possessed an amazing gift of visualisation. As a child, anything he imagined seemed to appear before him, solid and as real as any object in the material world. It came as quite a shock to the little boy to discover that other people could not see his images. The unique talent had worried him and he'd tried to suppress it. Later, he discovered that he could put it to good use, although he no longer tried to get other people to see his projections.

Later autobiographical writings reveal that he perfected his engineering models in his mind. He claimed that "they were so real that he could see signs of wear, and in the case of rotating machinery, could actually tell whether or not it might be out of balance."

With a mind that could visualise a machine part to the thousandth-of-an-inch, it is not surprising that he disliked drawing. Along with this talent, he perfected what we would call a photographic memory. He could quote Goethe's Faust, and a great deal of Shakespeare and other classics. In school, he committed the logarithm tables to memory, so he would not waste time in calculation. These abilities helped him in his leisure, too. He developed a fondness for chess and started a school team which challenged other schools. He rounded out his activities with billiards – and poker.

His first game was unforgettable. A mate had promised a lamb for the fleecing. Instead, by the end of the evening, the lamb had won all – and then confounded everyone by returning, to the cent, what each had lost.

Tesla looked on cards simply as a relaxation. Time after time, he returned to the tables. One night, for some reason, his luck or his ability let him down. He lost hand after hand, and ended up betting the next term's tuition money. When he was broke, he had learned a good lesson: no one offered to return his money.

Although he felt reluctant to do so, he returned to him home and confessed his crime to his mother. Djouka Tesla understood only too well. "Take this," she said, giving him what remained of their savings. "You have yet a lesson to learn. If you cannot conquer gambling, gambling will conquer you." Where his father would have scorned him for immoral activities, his mother understood her son's obsession.

Her practical psychology – and money – helped Tesla to know himself. He did return to the poker table, and played as never before. After the final hand, his "friends" expected their losses to be returned, as usual. This time, Tesla kept the lot. He had won back what he had lost. The money his mother had advanced him was returned gratefully and he made a solemn oath never to play cards again.

A little later, he completed his studies at Graz and took a job at a tool-and-die works in Maribor which manufactured electrical equipment. The money he saved enabled him to take a further year's study at the Unversity of Prague.

In 1881, he travelled to Budapest, in hopes of getting a position at the new telephone central office being built. His excellent academic credentials opened no doors for him.. Instead, he was offered a lowly job at the Hungarian Government Telegraph Office. Forty years later, he wrote that it was "at a salary I deem it my privilege not to disclose."

"By an irony of fate, my first employment was as a draughtsman. I hated drawing; it was for me the very worst of annoyances."

Yet, Nikola Tesla's ability made itself evident; soon, he was promoted to more responsible work and finally made chief electrician to the telephone company. At the age of 25, he stood as engineer-in-charge of an entire system. His arduous schedule did include five hours of rest a night, two of them in sleep ... He relaxed for three hours keeping up with the technical journals.

At this time, he invented what might be thought of as a "speakerphone," a type of loudspeaker device by which a number of people could listen to a telephone conversation. Tesla never bothered to patent this invention, although the telephone company did utilize it. Thirty years later, he remarked that it compared favourably with the current loudspeakers.

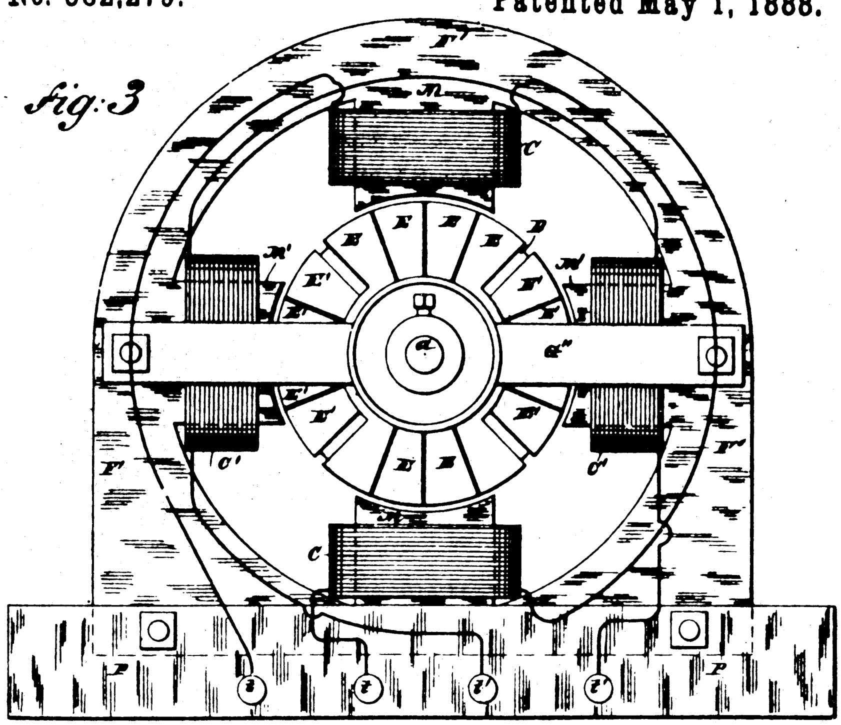
20

(No Model.) 2 Sheets—Sheet 2.

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 382,279. Patented May 1, 1888.



The principle of operation of three-phase AC motors is unchanged since Tesla's 1888 patent. Simultaneously he was issued patents for an AC generator, transformer and power distribution system.

Next issue: Tesla meets Edison.

The inventive genius

"The battle of the currents" — DC versus AC — raged throughout the 1880s. On one side was Edison, already famous, while on the other was an unknown newcomer, Nikola Tesla. Tesla's concepts of AC power generation and distribution eventually carried the day, but not without controversy.

While Tesla worked at the Hungarian Telegraph office thoughts of alternating current never left his mind. Every spare moment was used in creating his unique mental constructs. Eventually, the toll became too much and Tesla had a breakdown. Doctors professed themselves mystified by his weird symptoms.

Tesla wrote: "I could hear the ticking of a watch with three rooms between myself and the timepiece. A fly alighting on a table in the room would cause a dull thud in my ear . . . the roaring noises from near and far often produced the effect of spoken words which would have frightened me had I not been able to resolve them into their accidental components.

"In the dark I had the sense of a bat and could detect the presence of an object 12 feet away by a creepy sensation on my forehead. My pulse varied from a few to 260 beats."

The physicians' cures did nothing for him, but slowly the malady ebbed. Tesla was pleased that his memory had not been affected, for his ability to quote from the classics remained as sure as ever.

One afternoon in February, 1882, whilst walking in a park with his assistant, Szigeti, he spoke some lines from Goethe:

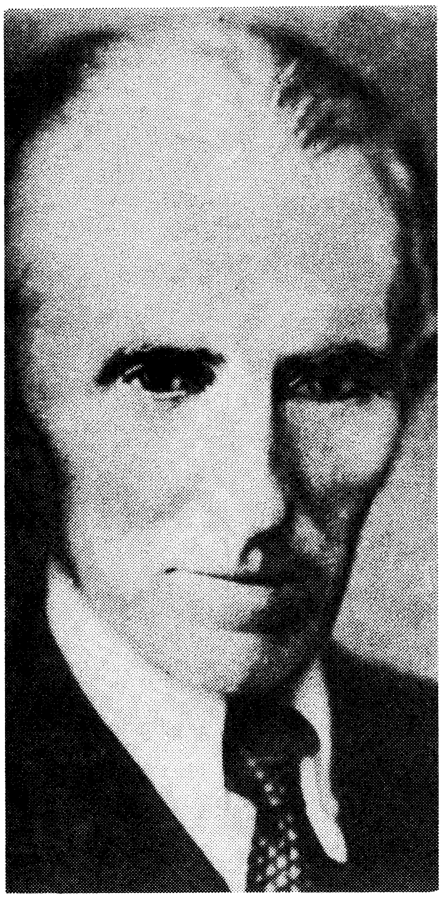
The glow retreats, done is the day of toil;
It yonder hastes, new fields of life exploring;
Ah, that no wing can lift me from the soil;
Upon its track to follow, follow soaring . . .

Suddenly he fell silent. There, before him, was the device he had thought about so long.

"Watch me reverse it," he told Szigeti. His assistant, naturally seeing nothing, feared that Tesla had had a relapse.

Impatiently, Tesla described the concept that had flashed into his mind when he quoted those lines of poetry: a two-phase circuit — two magnetic fields — that would create a rotating force to puli a rotor by induction. Quickly, he picked up a stick and sketched the circuit in the dust of the path. His exposition was so

Photo courtesy Westinghouse Electric Corp.



One of the few photographs of Tesla, taken late in life.

lucid that Szigeti immediately grasped the principle.

On his return to his job, however, other tasks awaited him and he had no time to devote to this marvellous discovery. It did not worry him, for he could build his mental constructs and set them running, to be examined at some future date. Soon, the telephone centrai office was completed.

In the spring of 1882, Tesla travelled to Paris, securing employment with the Continental Edison Co. After some design work, a power plant assignment took him to Strassburg. A physical example of the rotary field AC motor was constructed there in the summer of 1883. When not wasting time with the Germanic bureaucracy, he tried to raise interest and capital for his AC discovery but had no luck.

Returning to Paris early in 1884, he found the same situation. What is more, the large bonus he had been promised for earlier design work and his efforts as trouble-shooter in Strassburg never materialised. At that point, he determined to go to "The Land of Golden Promise" — America.

Armed with a letter from Charles Batchellor, a company director, and a personal friend of Thomas Edison, Tesla prepared to depart Europe, perhaps for good. On his way to the docks, someone picked his pocket. He convinced ship's personnel that he had booked a passage by quoting the ticket number. He arrived in the United States with a book of his poems, a couple of technical articles, some notes on a mathematical problem, a design for a flying machine — and four cents in his pocket.

Nikola Tesla presented himself to Edison straight away. The famous Yankee inventor looked suspiciously at this dapper foreigner before him, but read the letter of recommendation from Batchellor:

"I know two famous men and you are one of them," it said. "The other is this young man."

On the strength of that, Edison offered the excellently educated and well-experienced engineer $18 a week — hardly more than he paid one of his mechanics. Tesla, for his part, was quite impressed by Thomas Alva Edison, almost a legend in his own lifetime.

He was to write: "The meeting with Edison was a memorable event in my life. I was amazed at this wonderful man who, without early advantages and scientific training, had accomplished so much. I had studied a dozen languages, delved in literature and art . . . and felt that most of my life had been squandered."

At first, Tesla was given very junior tasks but soon he had won Edison's confidence. On one occasion, Tesla was despatched to the steamship *Oregon*, which had missed its sailing date, due to a problem with Edison generating equipment on board. At five o'clock the next

# of Nikola Tesla *Part 2*

by J. L. ELKHORNE

morning, Tesla, with the assistance of the crew, had effected major repairs and was returning to the shop, when he met Edison and Batchellor, recently returned from Europe.

"Here is our Parisian running around at night," Edison commented. Tesla informed him that the repairs on the *Oregon* had just been completed. As he left, he heard Edison tell Batchellor: "This is a damn good man."

The good relationship would soon deteriorate, however. As soon as Tesla mentioned his ideas about alternating current, Edison silenced him. Then, in one of those little incidents that grow all out of proportion, Nikola Tesla would misunderstand a casual statement.

He had suggested some significant improvements to the Edison equipment. The American inventor remarked: "There's $50,000 in it for you, if it works."

Soon, Tesla had completed his calculations and tests. His improvements were put into practice. Time passed, and the reward he envisaged did not occur.

"The American inventor remarked: "There's $50,000 in it for you, if it works"

Finally, he questioned Edison about it, and learned that it was "a practical joke". Tesla could not laugh, however. He had designed 24 different types of machines, in a workday which went from 10.30 in the morning to 5am the next morning — without a day's exception — for nearly a year.

Tesla resigned.

His initial impression of Edison had been tempered by observation of the great man at work: "If Edison had a needle to find in a haystack, he would proceed at once with the diligence of the bee to examine straw after straw until he found the object of his search. I was a sorry witness of such doings, knowing that a little theory and calculation would have saved him 90% of his labour."

Edison relied on his "intuition" and trial-and-error methods. After 10,000 trials for a new type of storage battery had proved fruitless, Edison bragged that he had not failed. "I now know 10,000 ways that won't work," he said.

Unfortunately, Edison had the reputation — and the money to follow his own path. Tesla, only a year in America, had no money, no contacts, and no prospects. Still, a group of entrepreneurs approached him with an idea to start yet another street lighting company, still a money-maker in the big cities. Tesla worked for some time, designing new types of arc lights and regulators, and eventually found himself the possessor of a stock certificate of doubtful value.

Edison, bitter over their differences, told anyone who would listen that the foreigner was not to be trusted. Tesla went through such hardship during the next year that he seldom spoke of it afterwards. He did occasional electrical repair jobs and during the bitter winter of '86-7, worked as a common labourer. His foreman, a stockbroker who had lost everything in the market, maintained contacts in the business world. After listening to Nikola Tesla at length, he approached an executive, A. K. Brown, of the Western Union Telegraph Co.

Brown and an associate were favourably impressed by Tesla and financed a laboratory for the inventor, not far from the Edison works. The concepts Tesla had developed five years earlier were on file — in his head. His original motor lay forgotten in Europe; the later work had all been intellectual. By October of 1887, Tesla built his engine models. He filed for patent on an alternating current system, of which the motor was only a part.

Photo courtesy Westinghouse Electric Corp.

This tower was built on Long Island in 1904 while Tesla was experimenting with power distribution by wireless.

The inventive genius of Nikola Tesla

Just as Edison had foreseen that the electric light without a distribution system was of little import, so Tesla regarded his discovery of the rotating magnetic field. To him, the motor provided only a piece of a unified system. The US Patent Office, however, reacted with horror at his sweeping approach. They broke the original application down into seven sections, and by the end of the year, had issued 30 basic patents.

As his work began to receive publicity, he was hailed as the scientific genius of the age. On invitation, he delivered a lecture before the American Institute of Electrical Engineers on May 16, 1888. The theory and practice he presented are the basis of the system we still use today. Improvements have been made, to be sure, but offer no radical departures to his central concept. In one stroke, he accomplished an engineering breakthrough of such magnitude that no comparable development has been presented since – especially by a single individual.

The group of patents included single and multi-phase motors, polyphase distribution and transformers, alternating current generators, AC to DC conversion, condensers, insulators and meters.

Five years before, Edison had electrified New York City, a remarkable achievement – with remarkable limitations. Even with his feeder-and-main distribution system, there was about a 30 volt drop overall. The nominal 110 volt adopted by Edison was compensated for by generating at 120 or even 130 volts. Those closest to the central station had brighter light – and quicker burnouts; those people at the far end had light that left much to be desired. The Edison system was predicted on an arrangement of a power house every mile or so. Although men had actually made DC generators that emitted as much as 6kV, outside the laboratory such machines were not practical, nor was long-distance transmission feasible with them. Line loss remained a significant factor of DC operation.

With Tesla's polyphase system, however, power could be generated anywhere, transformed, sent down a transmission line, and then stepped down at the point of use, all with a very high efficiency.

Fortunately for Tesla – and for mankind – a man of commerce who could bring this scientific feat out of the laboratory and to the world of everyday engineering practice made his approach. George Westinghouse, inventor and head of his own company, had succeeded after the American Civil War in marketing a portable device for getting derailed cars back on the tracks.

His invention of the railroad air brake though, established him as one of the giants of American business. He went on to become a pioneer of the gas-distribution and lighting industry. When Edison's electric distribution system began making itself felt, Westinghouse knew he needed to get involved in electricity to remain competitive. He swiftly mastered the state-of-the-art and bought the patent rights of various inventions. He designed a transformer, after study of the recent Gaulard-Gibbs unit, in three weeks. Having invented one of the first steam turbines in the world, he was quick to realise that a practical AC motor would be the key to a new and profitable system.

"I will give you a million dollars for the use of your AC patents."

When he heard of the Tesla patents in the latter part of 1887, he had already organised the Westinghouse Electric Company. He saw the importance of the rotating magnetic field concept. He approached Tesla in 1888 with an offer that could not be refused: "I will give you a million dollars for the use of your AC patents," he told the gaunt inventor, 10 years his junior. Tesla later admitted that such an astounding figure shocked him speechless. After a long pause, he replied, "Accepted – if you will also offer a royalty on manufacture."

At this point legend appears to take over from known fact. A popular story has it that Tesla and Westinghouse agreed on certain sum per horsepower of equipment sold; a sum which varies – apparently depending on the re-teller of the story – from one dollar to two dollars fifty. And, according to the story, it was a handshake agreement.

Whether this was ever ratified by a formal contract is not known, and no such contract has ever been found. But the story goes on to tell how the Westinghouse board, who had provided most of the money, refused to honour the agreement and threatened to withdraw their support on the basis that it would bankrupt the company.

At this stage Tesla reputedly tore up the contract rather than see the company, and his work fail.

By all accounts, including that of Westinghouse historian Charles A. Ruch, this legend is just that; a legend arising out of a royalty discussion which was documented but which never went beyond that stage.

At any rate, the initial payment for patent rights (which one writer states was only $200,000) was split with Tesla's backers. With a small fortune at his fingertips, Tesla found himself eager to pursue remarkable new areas on the frontier of science. Westinghouse, however, convinced him that immediate practical work on the problem at hand was necessary.

Edison, extremely worried over his two million dollar investment in the New York City generating system, launched a vitriolic attack on the new system. With his usual publicity machine in action, he raised the horrors of imminent electrocution of the general public exposed to the AC system.

He wrote: "Just as certain as death Westinghouse will kill a customer within six months after he puts in a system of any size. He has got a new thing and it will require a great deal of experimenting to get it working practically. It will never be free from danger."

Edison men distributed pamphlets, warning the populace that it would be a matter of taking one's life in his hands to merely walk the streets, constantly at the mercy of the lethal high-tension wires. The fact that a lineman a month on the Edison system was killed was ignored. Convinced by their boss's propaganda the DC was inherently safe, they failed to take adequate safety precautions.

Half a mile from his estate at West Orange, New Jersey, Edison had built a large laboratory, replacing the facilities at Menlo Park. As part of his propaganda campaign, he and his associates regularly electrocuted "stray" cats and dogs in public demonstrations.

Animals were purchased at 25 cents a head from local schoolboys. Immediately after their acquisition, they were thrown onto a contrivance powered by a 1kV alternator, possibly manufactured by the Westinghouse Electric Company. The pet population of the New Jersey community was nearly wiped out.

Charles Batchellor, who had unleashed Tesla on Edison and America, suffered an unfortunate experience while helping his boss in these enlightenments. One large dog, having deduced no good was about to be done him, wriggled out of Batchellor's grasp, knocking the man

In one stroke, he accomplished an engineering breakthrough of such

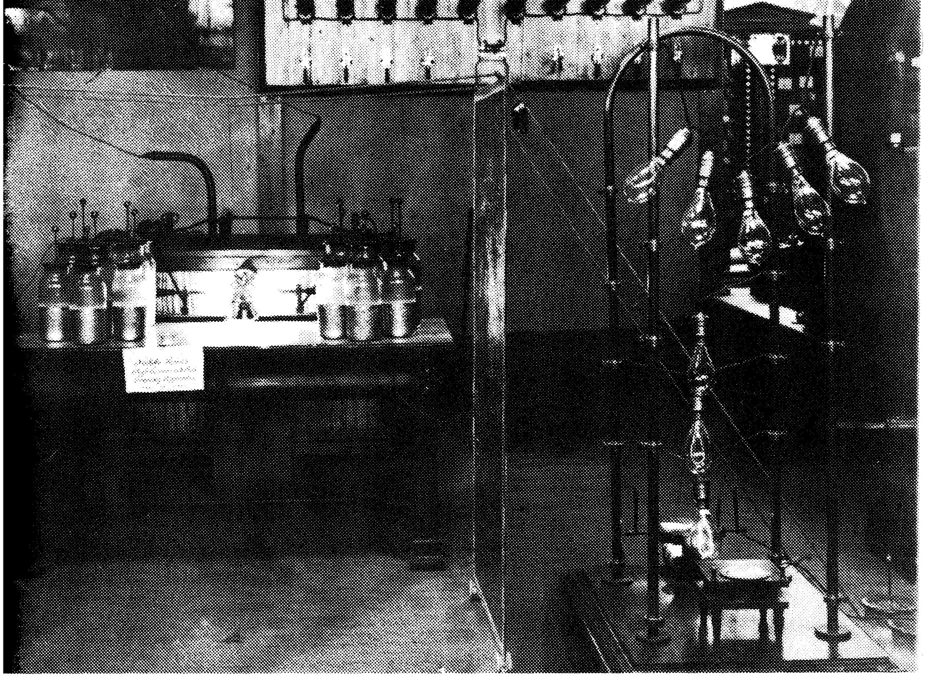


Photo courtesy Westinghouse Electric Corp.

A high voltage, high frequency set-up at Tesla's Westinghouse Laboratory.

himself onto the electrocution platform. Although he was not killed, he described the sensation: "(as) the sensation of an immense rough file thrust through the quivering fibres of the body."

Edison published an article defending his cruelty to animals, saying: "I have taken life – not human life – in the belief that the end justifies the means."

H. P. Brown, who had been a laboratory assistant at West Orange, himself began public execution of cats and dogs. He claimed to be demonstrating that such a death was "instantaneous, painless and humane." He became a lobbyist and independant consultant to the New York State legislature, helping to usher in a bill allowing capital punishment by electrocution. As soon as the statute became law, he made a well-publicised purchase of Westinghouse equipment, which was installed at Sing Sing Prison.

Westinghouse appealed to common sense, issuing a public statement that no deaths by electrocution had previously been caused by his company's equipment. He managed to counter a suggestion that the term "to Westinghouse" be used to refer to electrocution of condemned criminals.

Over strenuous objections by Westinghouse and his associates, the authorities finally decided to give the new statute – and equipment – a test. On the night of August 6, 1890, convicted wife murderer, William Kemmler, was led from his cell. Moments later, he found himself vibrating to a jolt of Westinghouse alternating current. To the chagrin of the prison officials, the shock did not kill him – the voltage was too low. He was unstrapped from the chair, marched back to his cell, and the electric chair examined. A wiring fault was found. (The electrician was probably another Edison man – fearful of his proximity to such a devilish machine.)

Hasty modifications were effected – and William Kemmler brought once again to face his punishment. This time, death was instantaneous, but called by one observer "an awful spectacle, far worse than hanging." Apparently, the optimum high-tension had been far exceeded . . .

Tesla found himself fighting Westinghouse engineers in Pittsburgh during the year 1889. He had selected 60 Hertz as the best compromise frequency for commercial power applications. Westinghouse engineers (or company accountants) had decided that 133 cycles a second would be the standard – it would decrease the cost of core materials. Even though George Westinghouse offered Tesla a $24,000 per annum salary to stay, the younger man argued he wasted his time in minor design work, disagreements, and was not free for creative work.

"He built an alternator with 384 poles which generated 10,000 Hertz."

"At the close of 1889, my services in Pittsburgh being no longer essential, I returned to New York and resumed experimental work in a laboratory on Grand St." Tesla later wrote.

Back in New York City, he began spending lavishly. He embarked on a program of research into a number of areas simultaneously. Familiar with the work of James Clark Maxwell and Heinrich Hertz, he proceeded to research apparatus working on higher and higher frequencies. He built an alternator with 384 poles which generated 10,000 Hertz. Although he finally achieved a stable rotary machine working at 30,000 Hertz, he abandoned such equipment for new apparatus capable of far higher frequencies. At the same time, he delved into the areas of mechanics, pneumatics, hydraulics and resonance phenomena.

His first high-frequency experiments culminated in a lecture at Columbia College on May 20, 1891. In it, he demonstrated the high-frequency alternator, as a power source for induction coils of his own design. He showed many curious electrostatic effects, so-called bush discharges, unique forms of incandescent lamps, and the first demonstration of wireless lighting. He achieved the phenomenon of stationary waves in a large copper bar, lighting various types of lamps at the maximum potential nodes of what seemed in conventional terms to be a short-circuit.

From the mundane world of low-frequency alternations, he had leaped into a strange, new frontier where each discovery was more unbelievable than the last – except for the fact that he was able to show experimental proofs to an astounded audience.

These investigations were the predecessor to the development of the Tesla coil. At this time, he was working with closely-coupled coils, sometimes cored, and immersed in oil or insulated with paraffin to prevent arc-over.

One of the more curious effects he demonstrated was the illumination of a carbon filament lamp, in which the globe itself was incandescent, whilst the filament remained dark! He also developed a lamp with a single button of ruby which emitted light.

His unique research so fired the imagination of scientific men that he was invited to England. In February, 1892, he gave a more advanced lecture before the Institution of Electrical Engineers, London, titled "Experiments with Alternate Currents of High Potential and High Frequency." Work he had done the previous year had been added to considerably. He had worked with Crookes tubes, precursors of the cathode ray tube. As the electron was not yet known to scientists, a great many puzzles manifested themselves in this research. Tesla was still working with relatively small, oil-insulated coils, but had made considerable advances in the types of sparkgaps employed. Dozens of fantastic luminescent effects were displayed: A group of incandescent lamps that had solid buttons of various materials instead

Continued on page 134

magnitude that no comparable development has been presented since –

Nikola Tesla . . . ctd from p25

of filaments – the forerunners of modern fluorescent lamps – of much greater efficiency than the Edison lamp.

This lecture was so successful that Sir James Dewar called on Tesla and asked him to repeat it before the Royal Institution. Tesla replied that he never duplicated his lectures, preferring to always present new and original material. Sir James then escorted Tesla to a room, pushed him into a chair and "poured out half a glass of a wonderful brown fluid which sparkled in all sorts of iridescent colours and tasted like nectar."

"Now," the Scotsman said, "you are sitting in Faraday's chair and you are enjoying whiskey he used to drink."

This singular honour convinced Tesla to accede and he repeated the lecture before the Royal Institution the next evening. Following that, he gave other lectures in Paris and Berlin. On his return to the United States, he became actively involved in the realisation of a boyhood dream – the harnessing of Niagara Falls.

The inventive genius

By 1983, Tesla's alternating current system was established as the preferred method of transmitting electrical power. After supervising the construction and installation of the first generators at Niagara Falls, Tesla turned his attention to an ambitious scheme for broadcasting power around the world.

by J. L. ELKHORNE

In 1886, Edward Dean Adams, head of the Cataract Construction Company, organised the International Niagara Commission. He asked Lord Kelvin to serve as chairman, to find a means of using the untapped power of the falls. Numerous ideas were studied and discarded: mechanical, hydraulic, and compressed air systems.

Lord Kelvin – William Thomson – had been engineer-in-charge of the first successful transatlantic cable. For this achievement, he was knighted. In 1890, his committee offered a $3000 prize for the best plan – of any kind – to utilise the power of Niagara. Some 20 plans were submitted, none by the large companies. Westinghouse demurred on the basis that the commission would get a hundred thousand dollars worth of value for a paltry prize.

By 1893, the commission had recognised that a businesslike approach was necessary and asked for bids from manufacturers. Also in that year, Westinghouse won the contract to light the Columbian Exposition. Originally planned as a celebration of the 400th anniversary of Columbus' discovery of the New World, the opening was delayed due to the extravagant plans made. The Building of Manufacturers and Liberal Arts spanned some 16 hectares, for example – the largest exposition building ever erected to that time. The Ferris wheel was invented for the occasion. The Exposition itself used more electricity than the city of Chicago – all produced by the Tesla system.

Tesla himself spent a week there, giving public demonstrations of his more unusual experiments. He had designed a graphic display of the rotating magnetic field, a modern-day parallel of the egg of Columbus. As Columbus was supposed to have stood an egg on end to challenge his critics, Tesla allowed a copper egg to stand on end and rotate around a platform, drawn by the invisible and revolving magnetic field created in the coils underneath.

He put on a veritable magic show of electrical technology, amazing thousands of onlookers with wireless lights, corona effects, high-frequency and high-potential wizardry – and culminated his performance by passing one million volts "through" his body. This feat, perhaps more than anything, convinced the doubting public that the horrors of alternating-current which Edison portrayed were greatly exaggerated.

Of course, Tesla had discovered early on that the nerves did not respond to frequencies above about 700Hz. He also became aware of skin effect – that a high-frequency current would pass across the body. And his megavolt had very little current behind it. Still, seeing a man grasp the high-tension terminal of a conical coil, reach out and vaporise a copper disc, was truly overwhelming.

Tesla's personal exhibit remained at the Exposition, as part of the Westinghouse Company display in Electricity Building. Untold numbers of people saw the marvels of Tesla's casual handling of greater voltages than any other man had ever produced.

His equipment represented 10 years' work. It included early polyphase motors, displays such as the "egg of Columbus," the 384-pole alternator, some of the "disruptive discharge" coils, fluorescent tubes, various forms of the "wireless" light, and the original oscillator.

By now, Edison's attempt at adverse influence having failed, an exchange of patent rights was arranged between the Westinghouse Electric Co and the General Electric Co. Lord Kelvin, having studied the proposals submitted for Niagara, reluctantly agreed that alternating current seemed to be the answer.

In October, the Westinghouse tender for two-phase generating equipment was accepted. Initially, three 5000 horsepower machines would be installed, and the first large-scale hydroelectric facility was born. The General Electric bid to build the transmission line found favour and the two bitter rivals collaborated on the largest electrical engineering project to that time.

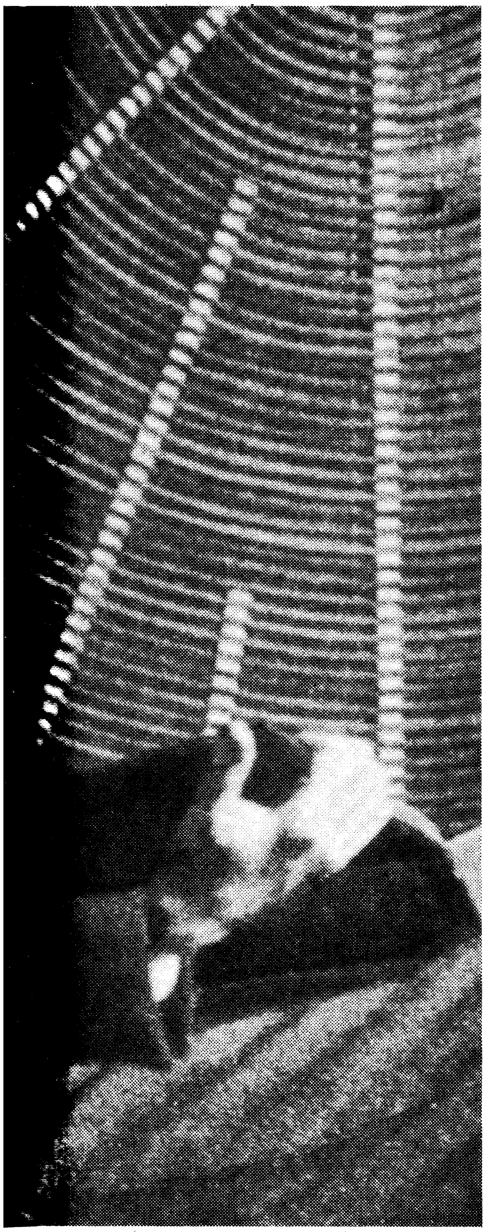
Westinghouse completed Power House Number One in 1895, and the transmission system went on-line in 1896.

In 1885, three years after the opening of Edison's Pearl Street Station, several thousand power plants, supplying some 20 different direct current systems, operated throughout the United States. Most of them were steam plants, deriving their energy from coal-fired boilers.

Dr Charles F. Scott, of Yale University, commented that single powerhouses (now) supply more power than all of the thousands of central stations and isolated plants of 1890.

# of Nikola Tesla

Part 3



Power from the Niagara plant went to Buffalo, 22 miles away. The first industrial customer for Tesla electricity was the Pittsburgh Reduction Company. The aluminium plant, founded by Charles Hall in 1888, had been based on his discovery of a workable smelting process two years earlier. Cheap, long-distance power from Niagara turned the expensive novelty metal into commercial practicality.

The second industrial user connected to the Niagara system was Dr E. G. Acheson's carborundum plant. His artificial abrasive had been a commercial failure, until the advent of the Tesla polyphase electric system. Following these two modern industries came a whole host of other products that became commercially viable with cheap and efficient electricity: acetylene, nitric acid, explosives, fertiliser, artificial graphite, furnace electrodes, battery carbons, lubrication, ferrosilicon, ferrochromium, ferrotitanium chlorine, phosphorus, caustics and ammonia.

Tesla had fulfilled that boyhood dream. His electricity and his motors – driven by the power of Niagara and harnessed to men's will – turned the wheels of industry as never before. And, as is so often the case, a host of claimants immediately sprang forth to announce loudly to the world that *they* were responsible for the new system. Von Dobrowolsky was one such – he claimed the invention of the rotary field motor, as used in a pioneer electrical transmission scheme in Frankfurt, Germany. After argument erupted in scientific journals, he reduced his claim. Even then, the chief engineer of the project published a statement: "The three phase current as applied at Frankfurt is due to the labours of Mr Tesla and will be found clearly specified in his patents."

Opponents of Tesla turned to obscure academic curiosities to prove priority. But even the authorities they quoted supported the Tesla patents. Finally, a judgment was rendered by Judge Townsend of the United States Circuit Court of Connecticut, on May 1, 1900. Townsend studied the state-of-the-art as of 1888, the year of the Tesla patents. "Prior to Tesla invention," he wrote, "no alternating-current motors were in use.

He referred to concepts of Siemens, Baily, and Bradley, and to the principle of the Arago rotation; and concluded:

"It remained to the genius of Tesla to capture the unruly, unrestrained and hitherto opposing elements in the field of nature and art and to harness them to draw the machines of man. It was he who first showed how to transform the toy of Arago into a engine of power; the 'laboratory experiment' of Baily into a practically successful motor; the indicator into a driver; he first conceived the idea that the very impediments of reversal in direction, the contradictions of alternations might be transformed into power producing rotations, a whirling field of force.

"What others looked upon as only invincible barriers, impassable currents and contradictory forces, he seized, and by harmonising their directions utilised in practical motors in distant cities the power of Niagara."

Tesla, when he left Pittsburgh, had vowed to work only for himself. His landmark lectures in 1891, 1892 and 1893, led him ever further into virgin fields of exploration. His closely coupled coils had been superseded by air coils and tuned circuits. By 1893, during his lecture before the Franklin Institute, he could speak with some assurance of the goal of his researches as "(to) transmit intelligible signals and perhaps power."

In 1895, when he was seeing the fruits of earlier efforts culminated in the Niagara Falls Power Plant Number One, a fire in his laboratory completely wrecked his progress. Every bit of apparatus he had built over the past six years was destroyed. His World's Fair display, numerous awards and personal mementos, all went up in smoke.

That fire at 33-35 South Fifth Avenue destroyed a unique site for the elite of New York City. Tesla, always an accomplished gourmet, had fulfilled social obligations with lavish dinners at the best of New York hotels. These feasts were followed by demonstrations of his latest work at the laboratory for some of the most famous people of the day.

Now, all was ashes.

With the support of Edward Adams and others, Tesla equipped a laboratory at 46 East Houston Street, taking about a year to duplicate what had been lost. A series of patents on the new technology began in April, 1896. These included various means of producing and regulating high-frequency and high-potential currents; techniques of tuning and selective signalling; wireless transmission of signals and energy; and control of moving vessels or vehicles. Some 30 patents were issued over a 15-month period.

His successful experiments in wireless telegraphy – over a distance of 20 miles – were announced in "Scientific American" for June 19, 1897.

Tesla had constructed a gigantic tank in Madison Square Garden, which his friend Stanford White, the eminent society architect, had designed. In this tank, Tesla placed the model boat which is specified in US Patent 613,809.

The inventor wrote: "When first shown in the beginning of 1898, it created a sensation such as no other invention of mine has ever produced. In November, 1898, a basic patent on the novel art was granted to me, but only after the Examiner-in-Chief had come to New York and witnessed the performance, for what I claimed seemed unbelievable."

This was the first of what Tesla called "telautomatons" – machines capable of

The Inventive genius of Nikola Tesla

carrying out operations at a distance, under the control of the operator. He built a larger example of this boat, with loop antennas, which was capable of operating as a submarine. He foresaw a whole new race of robots; machines which "would perform a great variety of operations involving something akin to judgment."

The boat was battery powered and used a number of tuned circuits controlling relays and servos. It had rudder control, forward and reverse, and could flash a pair of lights in response to questions from the audience, the answers being supplied by Tesla at the controls.

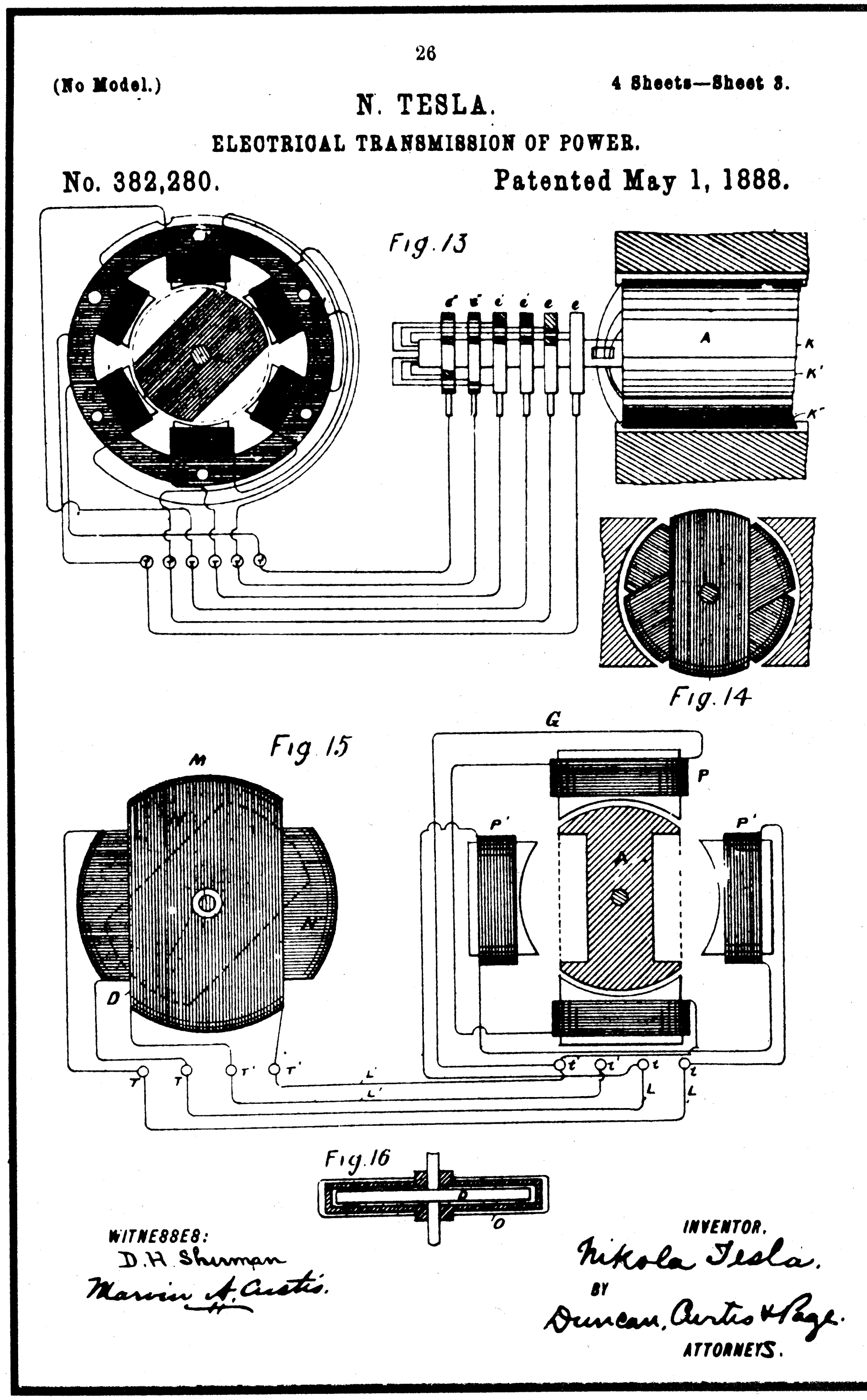
As a result of this exhibition, he was invited to organise a wireless reporting of an international yacht race, by Lloyds of London. Even though he could well have used the generous amount of money offered, he was too deeply engrossed in his researches to take the time and effort – or to allow anyone else to work with apparatus which he had, as yet, not wholly protected by patent. In any case, short distance signalling seemed insignificant to him.

His use of inductive coupling and multiple-tuned circuits to allay interference seems to predate work by Marconi, Lodge, and other fathers of wireless. Yet he did not pursue this area and put into solid engineering practice the discoveries he had made. If he had devoted himself or confined himself to this one area for even a year, he might well be known today as the father of radio.

One of the side issues he researched concurrent with high-frequency work was mechanical resonance. Some of this study had led to the "mechanical and electrical oscillator" first demonstrated in 1893. Another of the devices was an offshoot of air compression experiments. His goal in this area is not known.

One of the little toys he developed during this period was the scalp massager, often used by barbers in future years. Another item was a vibrating platform. Samuel Clemens, a good friend, used to regularly call on the inventor at the Houston Street laboratory, and is shown in one photograph holding one of the wireless lamps Tesla had developed.

The author – better known to the world as Mark Twain – once tried out the vibrating platform. He found the sensation quite soothing and refused to get off when advised to do so. After a couple more minutes of this gentle shaking, he leaped down and asked the way to the toilet. The laxative qualities of this machine were well known . . .



Tesla had a steel link delivered one day, and set up on sawhorses. It was two feet long and two inches thick. He attached a mechanical vibrator, powered by his special air compressor. This device was described later as "small enough to put in your pocket" and apparently had to be tuned by the operator. Once it achieved resonance, it reinforced the vibration until that steel link, capable of supporting tons of weight, snapped.

Next, Tesla found the 10-storey framework of a steel building going up on Wall Street. He attached his vibrator and set it going.

"In a few minutes," he wrote, "I could feel the beam trembling. Gradually, the trembling increased in intensity and extended through the whole great mass of steel. Finally, the structure began to creak and weave, and the steel-workers came to the ground panic-stricken, believing that there had been an earthquake ... if I had kept on 10 minutes more, I could have laid that building flat in the street. And, with the same vibrator, I could drop Brooklyn Bridge into the East River in less than an hour."

If this seems unlikely, study the newsreel film of the collapse of the Tacoma Narrows bridge. The third longest suspension bridge in the US in 1940, it achieved resonance during a gusting storm – with a wave motion of 10 metres along its length. The 200 metre central span dropped into the Narrows after about four hours, followed a short time later by the 300 metre end spans.

"It is a fortunate circumstance," Tesla had written in his 1893 lecture, "that pure resonance is not producible, for if it were, there is no telling what dangers might not lie in wait for the innocent experimenter."

The main thrust of his research, though, was still toward the wireless transmission of power. He had reached a safe limit, he felt, of four million volts in his Houston Street laboratory. He organised finance for the building of an experimental laboratory at Colorado Springs, Colorado, in 1899 and began developing the next phase of his work, which he called a "magnifying transmitter."

In a large, barn-like structure, he constructed an enormous Tesla coil. The primary was 17 metres in diameter, of only a few turns. This coil was beneath the floor of the building, and many researchers have been misled by examination of photographs from that period.

The secondary of the system, of the same diameter, was connected to a coil centrally mounted, six metres in diameter and some 10 metres high. This third coil was tuned, at least in one instance, to 100 kilohertz. Tesla achieved an output of 12 million volts, which was not duplicated until 1976.

From this latter coil, a cable led to a copper sphere on a mast almost 200 feet tall. At full power of about 300 kilowatts, Tesla noted sparks in excess of 30 metres, until the system stabilised. He recorded peak antenna currents of 1100 amperes in his diary of that period.

Although modern engineers claim that Tesla attempted the impossible, it appears that he did prove the transmission of 10 kilowatts to a circuit 35 kilometres away – at a fraction of full power. He also recorded detection of signals from the magnifying transmitter some 1000 kilometres distant.

In electromagnetic radiation, the inverse square law holds – when the distance is double, the energy received is quartered, as it were. Yet, Tesla himself wrote of the principle being "the diametrical opposite of ... electromagnetic radiation." He seemed to be pursuing the goal of altering the natural electrostatic equilibrium of the globe.

On July 3, he had established, using one of his unique devices for recording lightning strikes, which are plentiful in Colorado, that stationary waves occurred in the Earth.

He also commented: "I never saw fire balls, but as a compensation for my disappointment I succeeded later in determining the mode of their formation and producing them artificially."

This latter statement, almost an aside, prompted Robert K. Golka, of Brockton, Massachusetts, to duplicate the Tesla magnifying transmitter in 1976. Ball lightning is now accepted as a plasma phenomenon – and the creation of a stable plasma is one of the keys to fusion power. Golka rejects completely the Tesla theory of power transmission, believing that the abnormal ground conductivity in Colorado influenced Tesla's results.

Tesla, however, returned to New York City in 1900, published some articles and filed for a patent on his magnifying transmitter. This was finally granted in 1914. On the strength of his results thus far, he received some money from J. P. Morgan and other financiers. At Shoreham, on Long Island, a monster tower began to grow. W. D. Crow, an associate of Stanford White, designed this 200-foot tower which would have been topped by a 68-foot copper hemisphere.

This plant was designed to transmit 10,000hp, in the form of power, radio broadcasts, time and navigation signals, facsimile, and private messages to individual receivers. The grand plan was never finished, however, for the money ran out. Despite rumours that the US government destroyed the tower in World War I, the fact is that Tesla surrendered the property as payment of outstanding debts and a contractor dismantled the wooden tower for scrap. The laboratory building remains today as a sort of national trust site.

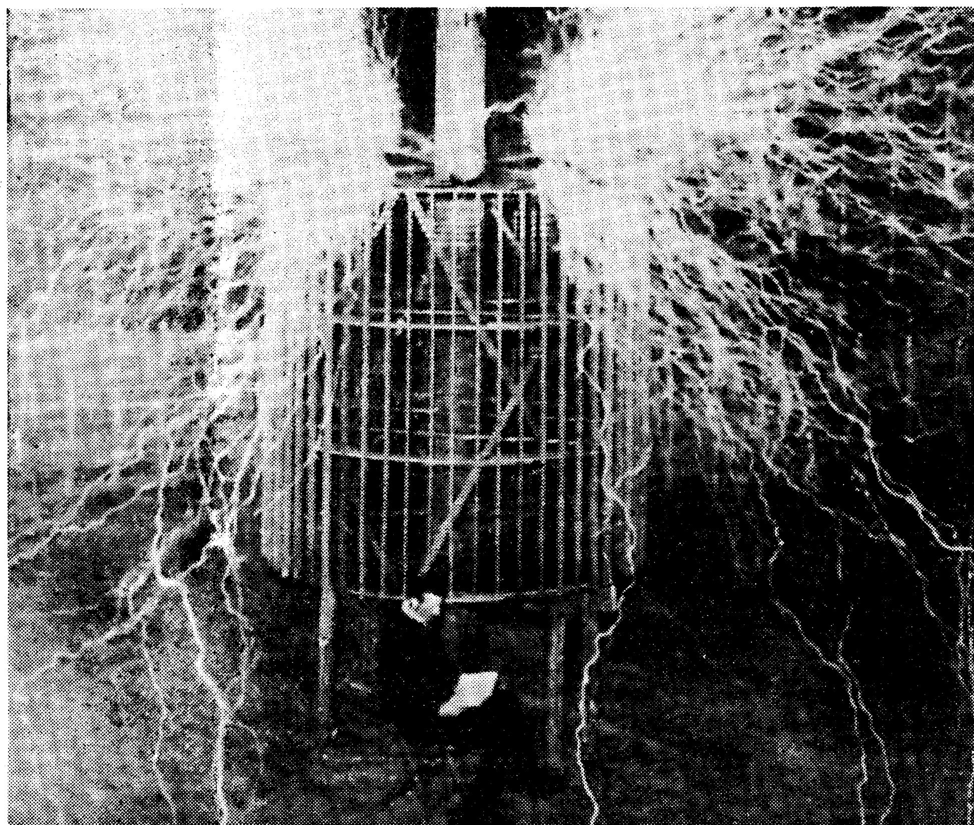
By 1911, Tesla was flogging a radical new turbine he had designed. Although Allis-Chalmers Co put some effort into it, Tesla's inability to work with other people doomed the project to failure. From then on, he declined into obscurity.

He died, alone and virtually forgotten, in the world he had helped create, in New York City. He was 86.

His legacy remains in the power system we use today, a host of patents – over 700, worldwide, credited to him – and diverse articles in magazines. And, perhaps, a hint toward the power generation system of the future.

Genius with power at his fingertips

By ADRIENNE RIDDELL



Bright spark Tesla amid a discharge of several million volts at his Colorado Springs laboratory

IN HIS VAST studio, just off Broadway, New York, the tall, thin man stood stock still while his three guests were expectantly hushed. His eyes flickered briefly over his audience and then he snapped his fingers.

A ball of red flame appeared, as though from nowhere and flickered on his fingertips.

To gasps of disbelief, the "fire" danced across his clothing and hair but caused no harm to the intense, dark-haired man, who finally extinguished the flame in a box.

It was May, 1899, and near midnight. Legendary author Mark Twain – a close friend of the enigmatic fire-man – stood in awe, as did English journalist Chauncey McGovern and actor Joseph Jefferson.

Scientists, even today, have been unable to either explain or repeat this amazing fire show.

Nikola Tesla is considered by many to have been one of the world's greatest scientists – and one of its great eccentrics.

Many of his inventions are part of modern-day living, others were abject failures – but all demonstrated an unparalleled genius.

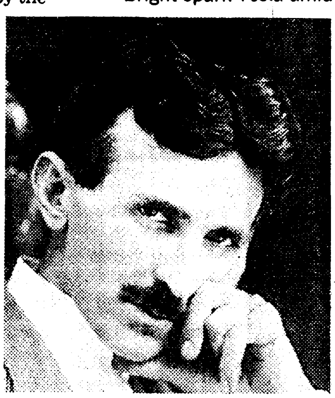
The man who was born in the village of Smiljan, Croatia, in 1856, to a poor family, carved himself a path to America and into history with amazing inventions and scientific principles still being taught today.

Tesla's father was an orthodox priest and his mother an un-schooled but highly intelligent woman. As a child, he was a dreamer and a poet but his brilliance was in evidence early.

At the age of five, he invented a waterwheel which, without paddles, was able to spin evenly in the current.

In 1884, aged 28, he uprooted himself from Paris, where he had been working, and headed for New York, arriving with four cents and some poems.

There, while gaslights still glowed yellow on the streets of young America, he drew complex designs for flying machines, robots and radio transmissions. Tesla was first employed by the great Thomas Edison, already a respected inventor, but the two soon parted company, despite each recognising the genius of the other.



Boffin and eccentric Nikola Tesla

'To gasps of disbelief, fire danced across his clothing'

A year later, Tesla had his first real success. Westinghouse Electric Company bought the rights to his polyphase system of alternating current dynamos, transformers and motors.

This spurred a titanic struggle between Edison, who used direct current electricity, and Westinghouse, using Tesla's alternating current.

Edison's direct current lighting was the first to be used in homes and on streets, helped by scare campaigns devised by Edison, including the public electrocution of animals, to put the public off Tesla's system.

To counter this, Tesla began a series of riveting public exhibitions. In one, he lit lamps without wires by allowing the electricity to flow through his body.

In 1893, Westinghouse used Tesla's alternating current system to light the World's Columbian Exhibition in Chicago. This success led the Niagara Power Company to use his system to generate America's first major power station at the falls.

That plant laid the foundations for America's power system today and alternating current is the main source of electricity worldwide.

Meanwhile, in 1891, he had invented the Tesla coil, now widely used in electrical equipment, including radio and television.

Between frantic periods of inspiration and production, Tesla remained a private man. He shunned company, preferring the solitude of his workshop where his incredible brain gave forth idea after idea.

He was plagued by phobias including a dire fear of germs. And like a child, he counted each step he took.

Tesla eventually came to think of humans as "meat machines" because he believed anything a person did had been influenced by real events – and anything a human could do could be taught to a machine.

This led Tesla to study what he called "teleautomatics" or robots. In 1898, at the age of 42, he announced his invention of a teleautomatic boat guided by remote control.

In 1900, he began working on his greatest project – the Wardenclyffe Wireless World Broadcasting Tower.

The tower would be used to broadcast pictures, messages, stock and weather reports but financial panic and labour problems meant it was never finished. It was Tesla's worst defeat, but his life was a constant struggle against poverty.

His need to finance his many creations was at war with an almost infantile awareness of money. He created hundreds of inventions, yet forgot to patent some of his most important ones, while others were brazenly stolen.

In 1943, after his death, the US Supreme Court found Tesla had anticipated all other scientists with his fundamental radio patents.

In a 1904 article, Tesla described in detail his concept of world radio, laying down his first specific radio patents years ahead of Guglielmo Marconi. He went beyond the basic transmit-and-receive principle – already thinking of pocket-sized transistor radios.

In his heyday, Tesla was heralded by the world press as the "Wizard of the West". He provided journalists with sensational copy but was the bane of editors who could not decide if his amazing prophecies were serious.

Among his wilder claims, he said he could communicate with other planets and split the earth like an apple.

Tesla regarded terrestrial stationary waves as his most important discovery. Through this, he proved the Earth could be used as a conductor and would respond as a tuning fork to electrical vibrations of a certain frequency.

After his death on January 7, 1943, in New York, Tesla was honoured by hundreds.

Three Nobel Prize winners said at his funeral that he was "one of the outstanding intellects of the world, who paved the way for many of the technological developments of modern times".