**Historical Note**

# Nikola Tesla: The Man Behind the Magnetic Field Unit

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The magnetic field strength of both the magnet and gradient coils used in MR imaging equipment is measured in Tesla units, which are named for Nikola Tesla. This article presents the life and achievements of this Serbian-American inventor and researcher who discovered the rotating magnetic field, the basis of most alternating-current machinery. Nikola Tesla had 700 patents in the United States and Europe that covered every aspect of science and technology. Tesla's discoveries include the Tesla coil, AC electrical conduction, improved lighting, newer forms of turbine engines, robotics, fluorescent light, wireless transmission of electrical energy, radio, remote control, discovery of cosmic radio waves, and the use of the ionosphere for scientific purposes. He was a genius whose discoveries had a pivotal role in advancing us into the modern era.

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In the magnetic resonance (MR) community, Tesla is known as the unit of magnetic induction or magnetic flux density in the meter-kilogram-second system (SI) (1). It was named for Nikola Tesla by the International Electrotechnical Commission Committee of Action on June 27, 1956. The aim of this article is to present the life and achievements of this Serbian-American inventor and researcher whose discoveries had a pivotal role in advancing us into the modern era. He had 700 patents that covered every aspect of science and technology. Tesla's discoveries include the Tesla coil, AC electrical conduction, improved lighting, newer forms of turbine engines, robotics, fluorescent light, wireless transmission of electrical energy, radio, remote control, discovery of cosmic radio waves, and the use of the ionosphere for scientific purposes.

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## EARLY YEARS

Nikola Tesla was born on July 10, 1856, in the village of Smiljan, province of Lika, in the Austria-Hungary empire, now a part of Serbia (2–6) (Fig. 1). He was the fourth child of five. He had two older sisters and a brother and a younger sister. His father, the Reverend Milutin Tesla, was a Serbian Orthodox priest; his mother, Djuka (Mandich), was unschooled but highly intelligent with respect to creating devices and improving tools. Tesla stated, "Although I must trace to my mother's influence whatever inventiveness I possess, the training my father gave me must have been helpful. It comprised all sorts of exercises, such as guessing one another's thoughts, discovering the defects of some form of expression, repeating long sentences, or performing mental calculations. These daily lessons were intended to strengthen memory and reason, and especially to develop the critical sense, and were undoubtedly very beneficial" (7–9). Both families originally came from western Serbia, and for generations had sent their sons to serve the Church or the Army and their daughters to marry ministers or officers. Tesla was expected to follow in his father's footsteps, but he excelled in math and science during his early school years in Smiljan and in the nearby town of Gospic, where his parents moved when he was seven years old. Gradually, it became clear that the young and independent-minded Tesla was not a candidate for the seminary. He attended the Higher Real Gymnasium at Karlovac, Croatia. At the age of 17 years, he contracted cholera; for nine months he was sick and could hardly move. His father, seeing that his son wasn't recovering, promised him that if he recovered, he would send him to the finest schools to finish his education. This, according to Tesla, quickened his recovery. Tesla received his university education in mechanical and electrical engineering at the Technical University of Graz, Austria, and the University of Prague (1879–1880). At Graz, he first saw the Gramme dynamo, which operated as a generator and, when reversed, became an electric motor; and he conceived a way to use alternating current to advantage.

## EARLY WORK

In January 1881, Tesla moved to Budapest, where he worked in the Hungarian government's new central telegraph office. During his brief tenure there, Tesla

invented a telephone amplifier that intensified weak electrical current. The following year, Tesla took a position with the Continental Edison Company in Paris, France (8). His job was to correct problems encountered at Edison plants in Germany and France, and while on assignment to Strasbourg in 1883, he constructed, during after-work hours, his first induction motor—a technological advance that would soon change the world (9–10).

In Germany and France, he attempted to interest investors in his concept for an AC motor, but had no success. It was clear that in order to realize his idea, he would have to meet the greatest electrical engineer in the world: Thomas Alva Edison. In 1884, Tesla decided to move to the United States, where there were interesting developments in electrica1 engineering and more opportunities to receive funding for his research. He secured a position at the Edison research laboratory in New York City.

## MOVING TO THE UNITED STATES

At age 28, Nikola Tesla arrived in New York City and was shocked by what he discovered. "What I had left was beautiful, artistic, and fascinating in every way; what I saw here was machined, rough, and unattractive. America is a century behind Europe in civilization." The Serbian immigrant had four cents in his pocket, some mathematical computations, a drawing of an idea for a flying machine, and a letter of introduction from Charles Batchelor, one of Edison's business associates in Europe (9).

Electricity was first introduced to New York in the late 1870s. Edison's incandescent lamp had created an astonishing demand for electric power, and his direct current (DC) power station on Pearl Street in lower Manhattan was quickly becoming a monopoly. On the streets, single poles carried dozens of crooked crossbeams supporting sagging wires, and the exposed electrical wiring was a constant danger. In spite of the hazard, wealthy New Yorkers rushed to have their homes wired, the most important being the banker J.P. Morgan, who had invested heavily in Edison.

It was into this state of affairs that the 6'4" immigrant from eastern Europe entered Edison's office. Thrilled and terrified to meet his hero, Tesla handed Edison his letter of recommendation: It read: "My dear Edison: I know two great men and you are one of them. The other is this young man!" Tesla proceeded to describe the engineering work he had done, and his plans for an alternating current motor.

Both Tesla and Edison shared a common trait of genius, in that neither of them seemed to need much sleep. Edison could go for days, taking occasional catnaps on a sofa in his office. Tesla claimed that his working hours at the Edison Machine Works were 10:30 A.M. until 5 A.M. the next day. Even into old age Tesla said he only slept two or three hours a night. That's where the similarity ended, however. Tesla relied on moments of inspiration, perceiving the invention in his brain in precise detail before moving to the construction stage. Edison was a trial and error man who described invention as 5% inspiration and 95% perspiration. Edison was self-taught, while Tesla had a formal European education. Their relationship was stormy, largely due to disagreements over AC (Tesla's invention) vs. DC (Edison's invention) as the best means of generating and transmitting electrical current. It was only a matter of time until their differences would lead to conflict.


**Figure 1. A:** Tesla at 36 years old. **B:** Tesla at age 80.

Investors approached Tesla and asked him to develop an improved method for arc lighting. Although this was


**Figure 2.** Tesla stamps. **A:** The Nikola Tesla postage stamp, United States, 1983. **B:** Commemorative Croatian Postage Stamp, 50th anniversary of the death of Nikola Tesla, 1993. **C:** Yugoslavia, 1953. **D:** Yugoslavia, 1976.

not the opportunity he had hoped for, the group was willing to finance the Tesla Electric Light Company. The proud new owner set to work and invented a unique arc lamp of beautiful design and efficiency. Unfortunately, all of the money earned went to the investors, and all Tesla got was a stack of worthless stock certificates.

## INDEPENDENT LABORATORY

But Tesla's luck was about to change. Mr. A.K. Brown of the Western Union Company agreed to invest in Tesla's idea for an AC motor. In 1887, in a small laboratory just a short distance from Edison's office, Tesla quickly developed all the components for the system of AC power generation and transmission that is used universally throughout the world today. "The motors I built there," said Tesla, "were exactly as I imagined them. I made no attempt to improve the design, but merely reproduced the pictures as they appeared to my vision and the operation was always as I expected" (6). He recognized that the main advantage of the AC system was that, with transformers, it was easier and cheaper to transmit very high voltages over very long distances. He soon popularized the AC system, making it practical with out-of-step currents and rotating magnetic fields. Tesla gave exhibitions in his laboratory in which he lighted lamps without wires by allowing electricity to flow through his body, to allay fears of alternating current. He was often invited to lecture at home and abroad. The battle to produce his motor was over. But the struggle to introduce it commercially was only just beginning.

## WESTINGHOUSE-TESLA COLLABORATION

An adventurous Pittsburgh industrialist named George Westinghouse (1846–1914), inventor of railroad air brakes, heard about Tesla's invention and thought it

could be the missing link in long-distance power transmission. He came to Tesla's laboratory and made an offer, purchasing the patents for $60,000, which included $5,000 in cash and 150 shares of stock in the Westinghouse Corporation. He also agreed to pay royalties of $2.50 per horsepower of electrical capacity sold. With more inventions in mind, Tesla quickly spent half of his newfound wealth on a new laboratory. With the breakthrough provided by Tesla's patents, a full-scale industrial war erupted. At stake, in effect, was the future of industrial development in the United States, and whether Westinghouse's alternating current or Edison's direct current would be the chosen technology.

The Westinghouse Corporation won the bidding for illuminating the Chicago World's Fair, the first all-electric fair in history. The fair was also called the Columbian Exposition, in celebration of the 400th anniversary of Columbus discovering America. Up against the newly-formed General Electric (GE) Company (the company that had taken over the Edison Company), Westinghouse undercut GE's million-dollar bid by half. Much of GE's proposed expenses were tied to the amount of copper wire necessary to utilize DC power. Westinghouse's winning bid proposed a more efficient, cost-effective AC system. The Columbian Exposition opened on May 1, 1893. That evening, President Grover Cleveland pushed a button and 100,000 incandescent lamps illuminated the fairground's neoclassical buildings. This "City of Light" was the work of Tesla, Westinghouse, and 12 new 1000-horsepower AC generation units located in the Hall of Machinery. In the Great Hall of Electricity, the Tesla polyphase system of AC power generation and transmission was proudly displayed. For the 27 million people who attended the fair, it was dramatically clear that the power of the future was AC.

This success was a factor in winning the contract to install the first power machinery at Niagara Falls; this machinery bore Tesla's name and patent numbers. The project carried power to Buffalo by 1896. The Niagara power plant proved the workability of Tesla's polyphase system of AC and established the kind of power system that would eventually be used throughout the United States and the world.

## HIGH FREQUENCY ELECTRICITY AND WIRELESS TRANSMISSION OF ENERGY

Back at his laboratory on Grand Street in New York City, Tesla engrossed himself in the exploration of high-frequency electricity. In 1888, Heinrich Hertz confirmed experimentally that an electric spark propagates electromagnetic waves into space. These discoveries identified radio waves and prompted intense speculation about new possibilities for electricity. Tesla began to search for a device that could transport him to this unexplored territory. He knew that higher frequencies would have many technical advantages; lamps could glow brighter, energy could be transmitted more efficiently, and this would all be less dangerous because the energy could pass harmlessly across the body (7–10).

Tesla began his high-frequency investigations by building rotary AC generators that could run at higher speeds; but as he approached 20,000 cycles per second, the machines began to fly apart, leaving him far short of his goal. The answer came with a remarkable device still known today as a Tesla coil, still widely used in radio and television sets and other electronic equipment for wireless communication. Patented in 1891, this invention took ordinary 60-cycle-per-second household current and stepped it up to extremely high frequencies—into the hundreds of thousands of cycles per second. In addition to high frequencies, the coil could also generate extremely high voltages.

With high frequencies, Tesla developed some of the first neon and fluorescent illumination. Tesla also became involved in X-ray research. One theory at the time was that blindness might be cured by X-rays. Tesla pointed out that there was no evidence for this. He was, however, convinced he had with X-rays discovered a way of stimulating the brain, and he repeatedly exposed his head to radiation. With exposures of 20 to 40 minutes he was able to show the bony outline of the skull, the orbit, mandible, and the connection of the vertebral column to the skull. He was the first to suggest that X-rays could be used therapeutically—perhaps to "project chemicals into the human body." His experiments with shadowgraphs were similar to those that were later used by Wilhelm Roentgen when he discovered X-rays in 1895. Upon hearing the news of Roentgen's discovery of the X-ray and its remarkable utility, Tesla promptly cabled his warm congratulations to the German physicist. Tesla felt his unpublished work had been validated and promptly began work on efficient generators for X-ray machines.

But these discoveries paled when compared to his discovery of November 1890, when he illuminated a vacuum tube wirelessly, having transmitted energy through the air. This was the beginning of Tesla's lifelong obsession: the wireless transmission of energy. In 1898, Tesla announced his invention of a teleautomatic boat guided by remote control. When skepticism was voiced, Tesla proved his claims before a crowd in New York's Madison Square by demonstrating the transmission of electrical energy with several radio-controlled model boats that he had constructed.

## RADIO WAVES

With his newly-created Tesla coils, the inventor soon discovered that he could transmit and receive powerful radio signals when they were tuned to resonate at the same frequency. When a coil is tuned to a signal of a particular frequency, it literally magnifies the incoming electrical energy through resonant action. By early 1895, Tesla was ready to transmit a signal 50 miles to West Point, New York. But in that same year, disaster struck. A building fire consumed Tesla's laboratory, destroying his work. The timing could not have been worse. In England, a young Italian experimenter named Guglielmo Marconi had been hard at work building a device for wireless telegraphy. The young Marconi had taken out the first wireless telegraphy patent in England in 1896. His device had only a two-circuit system, which some said could not transmit "across a pond." Later, Marconi set up long-distance demonstrations,

using a Tesla oscillator to transmit the signals across the English Channel. Tesla filed his own basic radio patent applications in 1897. They were granted in 1900. Marconi's first patent application in America was turned down. Marconi's revised applications over the next three years were repeatedly rejected because of the priority of Tesla and other inventors.

## COLORADO SPRINGS

In Colorado Springs, where he stayed from May 1899 until early 1900, Tesla continued his experiments on electricity, but this time on a larger scale than model boats. As before, his interests focused on transmission of high energy, sending and receiving wireless messages, and related issues pertaining to high-voltage electricity. He built a 200-kW transmitting tower that could produce lightning bolts so powerful they could overload the city's electrical generator. He lit 200 lamps without wires from a distance of 25 miles and created man-made lightning, producing flashes measuring 135 feet. In fact, during one experiment, he created an artificial lightning bolt that caused the municipal generator to catch fire, plunging the town into darkness.

Tesla discovered terrestrial stationary waves (9–10). By this discovery he proved that the earth could be used as a conductor and would be as responsive as a tuning fork to electrical vibrations of a certain pitch. At one time he was certain he had received signals from another planet in his Colorado laboratory, a claim that was met with derision in some scientific journals.

## THE WARDENCLYFFE PROJECT

Returning to New York in 1900, Tesla began construction on Long Island of a wireless world broadcasting tower, the Wardenclyffe Tower, with $150,000 in capital from financier J.P. Morgan. The purpose of this wireless 187-foot tower was to serve as a worldwide communications hub for broadcasting data, pictures, and music. Tesla also planned it as a beacon for precise time, to be used freely by all countries to set their clocks, and also as a navigation beacon for ships at sea. The tower, for which construction began in 1901, was a popular destination for tourists, who admired its sheer size. The project was abandoned in 1903 because of a financial panic, labor troubles, and Morgan's withdrawal of support. It was Tesla's greatest defeat. One now sees Tesla's tower as the first infant step toward the Internet, global positioning satellites, the atomic clock (now at the National Naval Observatory), and wireless communications (manifested in today's ubiquitous cell phones and their transmission towers).

## THE RADIO PATENT

No patent is truly safe, as Tesla's career demonstrates. In 1900, the Marconi Wireless Telegraph Company Ltd., began thriving in the stock markets—due primarily to the Marconi family's connections with English aristocracy. British Marconi stock soared from $3 to $22 per share and the glamorous young Italian nobleman was internationally acclaimed. Both Edison and Andrew Carnegie invested in Marconi, and Edison became a consulting engineer of American Marconi. Then, on December 12, 1901, Marconi for the first time transmitted and received signals across the Atlantic Ocean. In 1904, the U.S. Patent Office suddenly and surprisingly reversed its previous decisions and gave Marconi a patent for the invention of radio. The reasons for this have never been fully explained, but the powerful financial backing for Marconi in the United States suggests one possible explanation.

Tesla was embroiled in other problems at the time, but when Marconi won the Nobel Prize in 1911, Tesla was furious. He sued the Marconi Company for patent infringement in 1915, but was in no financial condition to litigate a case against a major corporation. It wasn't until 1943—a few months after Tesla's death—that the U.S. Supreme Court upheld Tesla's radio patent. The court had a selfish reason for doing so. The Marconi Company was suing the United States government for use of its patents in World War I. The court simply avoided the action by restoring the priority of Tesla's patent over Marconi.

## LATE YEARS

Tesla's work shifted to turbines and other projects. Because of a lack of funds, his ideas remained in his notebooks, which are still examined by engineers for unexploited clues. Tesla was the recipient of the Edison Medal in 1917, the highest honor that the American Institute of Electrical Engineers could bestow.

Tesla was known for his elegance and singular habits. He dressed in formal attire, even while working in his various factories and laboratories. He allowed himself only a few close friends. Among them were the writers Robert Underwood Johnson, Mark Twain, and Francis Marion Crawford. He was quite impractical in financial matters. Tesla lived the greater part of his life in a suite at the Waldorf Astoria Hotel in New York. He was an eccentric, driven by compulsions and a progressive germ phobia. In fact, he didn't like to shake hands. He had a fixed routine—he always sat at the same table in the dining room. He had so many phobias that he couldn't have close relationships with women. He didn't like most of the jewelry that they wore or their perfume, and he couldn't bear to touch hair.

## TESLA AND WAR

A great American patriot, Tesla feared a new form of warfare. He foresaw remote-controlled missiles, the submarine, and the modern jet fighter. All these predictions came true. Even in retirement, Tesla continued writing, lecturing, and encouraging other young inventors. On his 78th birthday, he announced that he was able to make a death-beam–producing machine that would be able to destroy an army of one million, 200 miles away, and bring down 10,000 planes at that distance. He thought that this weapon would end war because, if every nation had it, no one would dare attack because of its destructive nature. People would be

left to pursue more noble work, such as art, music, and science. The weapon Tesla described in 1934 today sounds like the particle beam weapon planned for use in the Strategic Defense Initiative. In his last years, his interest was said to be focused in caring and feeding the pigeons in the local parks.

On January 8, 1943, Nikola Tesla died in his sleep in New York. He was 86 years old. Scores of notable people attended his funeral services at the Cathedral of St. John the Divine, such as President Franklin Roosevelt and his wife Eleanor, New York mayor Fiorello H. La Guardia, political figures from Yugoslavia, Nobel Prize winners, and leaders in science. All praised him as a visionary who provided the foundations for modern technology. In fact, as discussed above, within a year of his death, the U.S. Supreme Court ruled that Tesla, and not Guglielmo Marconi, had invented the radio.

Yugoslavia made him a national hero and established the Tesla Museum in Belgrade after World War II (Fig. 2). In addition to honorary degrees from American and other universities (including Columbia and Yale in 1894), Tesla received, during his life, the Edison Medal and the John Scott Medal. In 1975, he was inducted into the National Inventors Hall of Fame.

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