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Nikola Tesla (1856–1943) Scientist & inventor

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This paper presents a short review of the life and work of Nikola Tesla (1856–1943) commencing with his early life and education in Eastern Europe. The Tesla coil is described. His early work with alternating current (AC) is detailed together with his disagreements with Thomas Edison and the so-called *War of the Currents*. As with many X-ray experimenters in the year after Röntgen's discovery in November 1895, Tesla lost interest in X-rays and moved his attention to radio transmission. He was able to obtain financial backing for his projects in the years at the end of the 19th century and in the early 20th century, but thereafter eventually found it impossible. It was to be Marconi who made huge profits from radio transmission becoming standard science, and not Tesla who died virtually penniless. Although acknowledged as one of the world's greatest inventors, his lack of financial acumen and some fantastic claims, also led him to be regarded as a mad scientist. His name is perpetuated with the Système International (SI) unit of magnetic flux density, the Tesla, denoted by the capital letter T.

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Introduction

Nikola Tesla (1856–1943), Figure 1, was a famous scientist and inventor who became a naturalised American in 1891. He was an ethnic Serbian born in Smiljan (now in modern-day Croatia) in the then Austro-Hungarian Empire. He was involved in so many projects that his work with X-rays which lasted only a few years, is seldom mentioned. As an electrical and mechanical engineer his major experimental studies and inventions were related to alternating current, high-voltage high-frequency power, the induction motor, the rotating magnetic field and what is now universally known as the Tesla coil.

Tesla was at various times in his life, most famously involved with Thomas Edison (1847–1931), Guglielmo Marconi (1874–1937) and George Westinghouse (1846–1914). His major work was achieved at the end of the 19th century and in the early years of the 20th century. Many of his problems revolved around trying to obtain finance to put his ideas into practice, which were often colossal. He was also not careful with money for normal living and died almost penniless whereas the ideas he had put forward for radio communication were taken over and patented by Marconi making Marconi rather than Tesla, a fortune. Tesla did though earn money from patents but this was invested in his own projects, which were not always successful.

Towards the end of his life he became devoted to pigeons, fed them in a local park every day and even brought injured ones to his hotel room. It was in this hotel room in New York City that he died in 1943. His name is perhaps most associated today with the naming in 1960 of the Système International (SI) unit of magnetic flux density (or magnetic inductivity), the Tesla, denoted by the capital letter T [1–5].

The Tesla family

Nikola Tesla's father, Milutin, was a priest in the Serbian Orthodox Church who expected Nikola to follow him as a priest. However, when in 1873, Nikola was seriously ill with

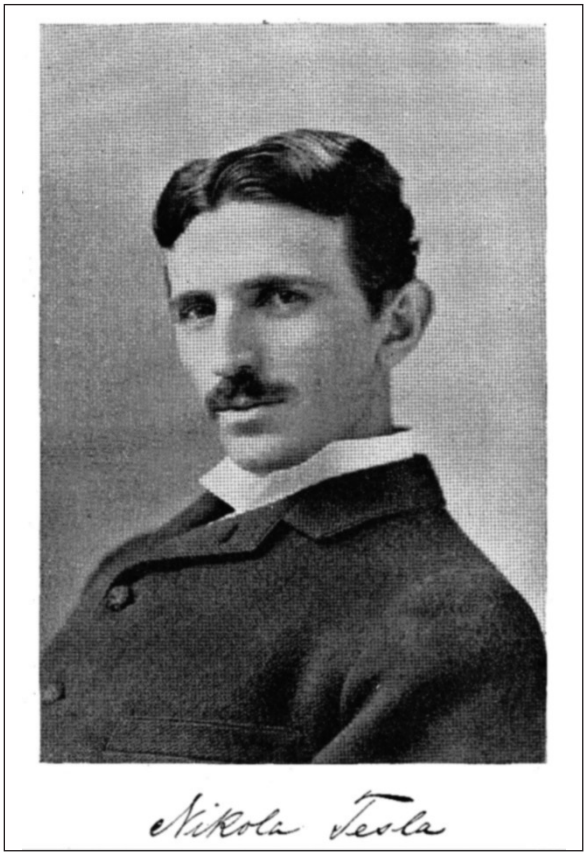

Figure 1. Nikola Tesla at the age of 36 years

cholera for at least nine months, he persuaded his father that if he survived, he could take up a technical education rather than enter the church. His mother never received any formal education but was credited by her son with a phenomenal memory and creative abilities which he claimed were passed to him via genetics.

His elder brother, Dane, was killed in an accident when he fractured his skull after being thrown from a horse when only 12 years of age. He had three sisters, but no other brother, Figure 2. His grandfather fought in Napoleon's army and his uncle Josip taught at a military academy. Nikola, however, avoided being enlisted in the military. His uncle Petar was Serbian Orthodox Bishop of Bosnia.

Education 1861–1880

In 1861 he attended the primary school in Smiljan, studying German, arithmetic and religion. Then in 1862 when the Tesla family moved to Gospić, Nikola attended primary school and then the Lower Real Gymnasium. This was followed by a move to Karlovac where he attended the Higher Real Gymnasium, graduating in 1873. It was here that his teachers thought he was cheating when he was able to perform integral calculus in his head. (Karlovac was in the Austro-Hungarian Military Frontier district.) In 1874 he avoided being drafted into the Austro-Hungarian army by running away to Tomingaj, near Gračac in the mountains. He read much during this time, including works by Mark Twain (1835–1910).

In 1875 Tesla enrolled at the Austrian Polytechnic in Graz on a Military Frontier scholarship. In the first year he never missed a lecture and the Dean of the Technical Faculty wrote to Milutin "Your son is a star of first rank". He claimed that he worked seven days a week from 3 am till 7 pm. This can be corroborated in a package of letters from his professors to his father warning that unless he was removed from the school Tesla would be killed through overwork. Also, it was whilst in Graz that Tesla made his first attempts to invent an alternating current (AC) motor, in contrast to the direct current (DC) motors that were in use at the time.

However, at the end of his second year in Graz, Tesla lost his scholarship and became addicted to gambling, losing all his tuition money and his allowance, although he later gambled back these losses. He was unprepared for his examinations and never graduated from the university and did not obtain grades for the last semester. In December 1878 he left Graz and broke off all contact with his family to hide the fact he had dropped out of school. Some of his friends even thought he had been drowned in the Mur river.

In fact Tesla was in Maribor (not in Slovenia) working as a draughtsman for 60 florins a month and spending his spare time playing cards on the street with local men. In March 1879 Tesla was returned to Gospić under police guard for not having a residence permit. His father died a month later in April 1879. Also in 1879, Tesla taught students at his old school, the Higher Real Gymnasium.

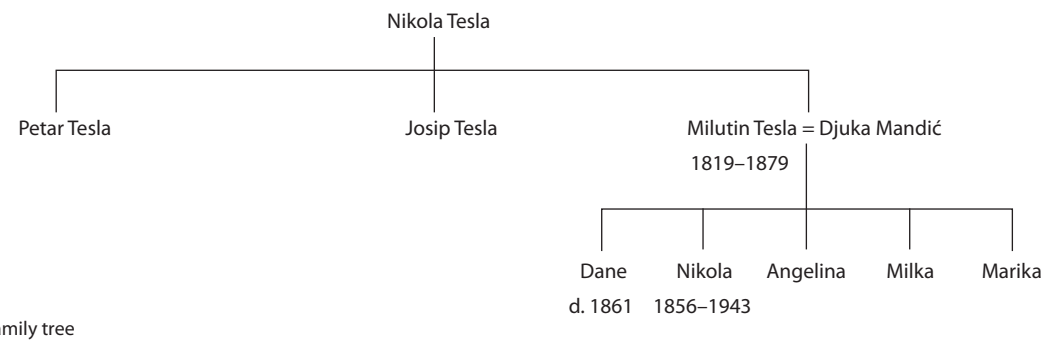

Figure 2. The Tesla family tree

In January 1880 two of his uncles put together enough money for Tesla to leave for Prague to continue his studies. He arrived too late to enrol at Charles-Ferdinand University but in any event he was required to be literate in Greek and Czech, in both of which he was not. He attended the university lectures but received no grades for the courses.

Budapest 1881

Tesla moved to Budapest in early 1881 and began working for the American Telephone Company, being hired by Tivador Puskas who had previous worked with Thomas Edison at the Edison laboratories in Menlo Park, USA. Tesla's friend and co-worker in Budapest was Anital Szigety, was the first person to whom Tesla explained his groundbreaking idea for how a motor using an alternating source could be realised.

Prior to Tesla's ideas the problem was that AC motors kept losing momentum during the course of a cycle and could not maintain continuous action. It was thought impossible in practice to overcome this problem by getting the magnetic fields to rotate although theoretically this was the solution. Tesla postulated that if the motor incorporated different circuits placed out of phase, that is, at 90 degrees to each other, then when the first was at its lowest ebb, the second would be at full strength. Continuity could then be obtained with no periods of loss of power.

Electromagnetic induction

In the 1830s Michael Faraday (1791–1867) studied the interaction of electric and magnetic fields. He demonstrated that a moving magnetic field, or a fluctuating electric field, could induce a current in a nearby circuit. This is the principle of electromagnetic induction. These discoveries led to the invention of the magneto-electric generator (or dynamo) which uses a moving magnet to generate an alternating current. It also led to the induction coil which induces an alternating high voltage current from an interrupted low voltage current.

Commutator

The *commutator* is a moving part of a rotary switch that periodically reverses the current direction between the rotor and the electrical circuit. It is a cylinder made up of multiple metal contact segments and there are two or more electrical contacts called *brushes* made of a substance such as carbon. Commutators, which are used in dynamos (DC generators) and DC motors are relatively inefficient and require periodic maintenance such as brush replacement. Tesla's AC motor had the advantage of not requiring a commutator.

Paris 1882

Tesla left for Paris in the Spring of 1882 on the recommendation of Puskas, to work for Edison's European operation, the Continental Edison Company which had been set up in 1880 under the management of an Englishman, Charles Batchelor (1845–1910) who had worked with Edison from 1870. The firm supplied electrical distribution and generating equipment throughout Europe. Tesla who was fluent in five languages including German, was assigned to work on installations in Strasbourg and during this period had time to develop a model for his induction motor. Unfortunately the local worthies had no interest in the motor when it was demonstrated to them by Tesla. His personal financial situation was no better and he spent his wages very quickly. Tesla wrote to Puskas that "the last 29 days of the month are the toughest".

New York 1884

Batchelor gave Tesla an excellent reference for him to give to Edison after he reached New York in June 1884. It said that he had known two great men in his lifetime, on was Edison and he considered that Tesla was the other. Tesla sought employment with Edison who agreed to hire him. Tesla told Edison of his ideas for an AC motor but Edison considered that AC was too dangerous and not really efficient enough to make it useful.

It is rumoured that Edison offered Tesla US$ 50,000 to make improvements to Edison's DC system but that when this was achieved Edison failed to pay US$ 50,000 claiming it was meant only as a joke. Tesla resigned immediately and for the remainder of their lives the two engineers were sworn enemies.

Tesla Electric Light Company 1885

After leaving Edison, with the financial help of two investors (Robert Lane & Benjamin Vail) Tesla then set up the Tesla Electric Light Company to produce arc lighting equipment. Tesla, though, demanded too much money from his backers, which would continue to be a feature of his life, and with the use of an AC system proved too much of a financial gamble. Tesla was removed from the company, even though he had been the founder. He even lost control of the patents he had generated. For the next year, 1885, Tesla was forced to take whatever work he could get, including electrical repair jobs and manual labour digging ditches for US$ 2 per day.

Tesla Electric Company 1886–1888

In 1886 Alfred S. Brown, a Western Union superintendent, and Charles F. Peck a New York attorney, gave Tesla financial backing and the three men set up the Tesla Electric Company at 89, Liberty Street, Manhattan. Tesla's aim included work on improving and developing new types of electric motors and generators. For example, he developed his polyphase induction motor which ran on AC. It was patented in 1888 and in the same year, was demonstrated at the American Institute of Electrical Engineers.

War of the currents 1888–1892

The fact that Tesla had a viable AC motor and related power system interested George Westinghouse (1846–1914) an American entrepreneur and engineer who invented the railway air brake (using compressed air to slow down trains) and ran the Westinghouse Electric & Manufacturing Company. A licensing deal was arranged and Westinghouse hired Tesla for 12 months to be a consultant to the Westinghouse company's Pittsburgh laboratories. It was decided that the best way to implement AC power was to use a 60 cycle AC current system.

An electrical distribution battle was waged between Westinghouse and Edison, following Westinghouse's first AC system in 1886. This conflict became known as the *War of the Currents*. In principle an electrical power system based on AC had one enormous advantage over using DC. AC could be carried for greater distances than DC: hundreds of kilometres versus a couple of kilometres. Edison did not wish to abandon DC as he had invested greatly and he set about trying to influence the public using articles and flyers that AC was unsafe and should not be used. However, Edison was not always truthful in his claims about the dangers of AC and this sometimes backfired on Edison! It affected the major backer of Edison General Electric, the Wall Street magnate John Pierpoint Morgan (1837–1913) who did not care about DC or AC but did care about being in a position in the USA to sell electricity. In 1892 Morgan merged Edison General Electric with the Thomas Houston Company which had abandoned DC and moved to AC. These two companies became General Electric with Edison's name no longer used in the company's name and with him pushed out of the new GE company.

During this period, in July 1891, Tesla became a naturalised American citizen. Also in 1891, he established laboratories in New York, first in South Fifth Avenue and then in East Houston Street.

World's Columbian Exposition 1893

Whilst the *War of the Currents* was taking place Westinghouse delayed development of Tesla's induction motor. However, by 1893 an efficient version was available, with Westinghouse believing that Tesla's patents gave him patent priority. It was also in 1893 that Westinghouse won the bid to light the 1893 World's Columbian Exposition (a World's Fair) in Chicago with AC. He beat General Electric by bidding one million dollars.

Niagara Falls 1893

Westinghouse won the contract to produce the AC system electrical generators for the first hydroelectric plant to be built in the USA: at Niagara Falls in 1893. This represented the peak of Tesla's achievements which was never matched with by later work when many of his ideas failed to become practicable.

Tesla's AC patents 1897

Westinghouse's financial outlay during the *War of the Currents*, and his support of Tesla against Edison, became a strain on the company such that had to satisfy his backers by reducing his commitments. He achieved this convincing Tesla to forgo future royalties (Brown, Peck and Tesla had already received some US$ 200,000 in licence payments and royalties) and instead accept US$ 216,000 as a lump source payment from the Westinghouse Electric Company to purchase the patents.

X-rays 1896

As with many other scientists and entrepreneurs in the early months of 1896, Tesla experimented with X-rays but his interest was short-lived. Although he may have inadvertently made an X-ray image prior to Röntgen's discovery when he was experimenting with Crookes tubes, but this can never be proven. In March 1895 much of Tesla's early work was destroyed in a fire at his Fifth Avenue laboratory. Losses included hundreds of invention models, plans, notes, laboratory data, tools and photographs valued at US$ 50,000.

Tesla is mentioned four times in Otto Glasser's 1933 biography of Röntgen [6]. These four brief texts are now detailed, with the relevant page numbers from this reference [6]. They describe X-ray topics considered by Tesla during the first year after the discovery of X-rays.

{p. 295} The American scientist N. Tesla reported [7] in June 1896, that "exposure of the head to a powerful X--radiation produced a general soothing effect, a sensation of warmth in the cerebral lobes, and a tendency to sleep." He also stated, however, that very often the eyes became inflamed, and "that one should not go too close to the tube".

{p. 313} Oliver B. Schallenberger did not use his tube with an induction coil as Röntgen did, but following Tesla's suggestion, connected it to one pole of a Tesla high-frequency apparatus.

Glasser [6] discusses various theories concerning X-rays. {p. 329}. One theory was suggested by the American inventor, N. Tesla [8], who believed that X-rays were small particles, shot into space.

{p .336} The phenomenon of scattered radiation was studied carefully within a relatively short time by Tesla [8], Edison, Pupin, Imbert and others.

Other references to Tesla's X-ray work include mention in the paper by the eminent American surgeon William Williams Keen (1837–1932) which was published in April 1896 [9]. Keen was discussing X-ray imaging of soft tissues and bones and the problems associated with the thicker portions of the body, e.g. shoulder, thigh and trunk. He notes that Tesla had "to some extent overcome the imaging difficulties by his improved apparatus and has skiagraphed, though rather obscurely the shoulder and the trunk" [10].

That Tesla was aware of dangers when using X-rays are seen from his June 1896 warning about "inflamed eyes" [7] and his May 1897 more general paper on radiation hazards [11].

Tesla, and many others, experimented with X-ray tube designs. One of the difficulties experienced with tubes were sparking and breakdown. Tesla (as well as John Trowbridge of Harvard) used oil-immersed tubes. He began his experiments with such a tube in February 1896 and obtained his skiagraphs with a calcium tungstate screen at a distance of 45 foot from the tube (the distance used by Röntgen was less than 7 foot) and an exposure of a few minutes [12].

Tesla coil

The Tesla coil was developed in 1891 and therefore it was not specifically developed for X-ray technology. The coil is an air-core transformer with primary and secondary coils tuned to resonate. It was widely used as a means of generating the high voltage needed for the production of X-rays. A circuit diagram from an 1897 issue of the *Journal of the Franklin Institute* is shown in Figure 3 [13]. A Leyden jar battery is shown in the diagram where G denotes the spark gap. In 1896 John Trowbridge, Professor of Physics at Harvard, used this system to make an X-ray image in 1.5 minutes, as contrasted with the 15 minutes or 30 minutes or even longer, used by other X-ray pioneers. However, there were problems with the Tesla apparatus as it delivered AC rather than DC and it frequently blew out the tubes [14].

Theory of X-ray burns

The theory of X-ray burns was proposed by many investigators, one of whom was Tesla, and like many of his colleagues, he got it wrong! William Rollins (1852–1929) tested Tesla's theory was that "if a tube was exhausted to such a degree that no X-light could be produced with the potential employed, the discharge going around the tube, by exposing a hand it was severely burned." Tesla recommended shielding by means of a thin layer of aluminium between the tube and the body [15, 16]. A burn by high frequency electrical induction was not disproved until 1901 [17, 18] when a group of guinea pigs, placed in a double Faraday cylinder made of thick aluminium (thus definitely excluding all electrical disturbances) was found to be injured by the radiation passing through the aluminium walls of the container.

Radio transmission 1896–1904

Tesla's theories about the possible transmission by radio waves go back as far as 1893 and by 1896 he was conducting experiments in the Gerlach Hotel, New York, where he lived. In 1898 at an electrical exhibition in Madison Squares Gardens he demonstrated a radio-controlled boat, which he called a *Telautomaton*. However, remote radio-control was a novelty until after World War I and Tesla failed in his earlier attempts to interest the American military in his idea of a radio-controlled torpedo.

In 1900 Tesla was granted patents for "a system of transmitting electrical energy" and an "electrical transmitter". When in 1901 Marconi, Figure 4, made the first transatlantic radio transmission, Tesla is supposed to have joked that it had been done with Tesla's patents: but there is not much to support this claim. However, this was the start of a long series of patent battles over radio between Tesla and Marconi with Tesla's patents being upheld in 1903, but with this decision reversed in favour of Marconi in 1904. It was not until 1943 that the US Supreme Court restored the prior patents of Tesla although they emphasised that their decision did not destroy Marconi's claim to be the first to demonstrate radio transmission. Marconi made a fortune out of radio whereas Tesla died penniless.

Colorado Springs 1899–1900

In May 1899 Tesla relocated his laboratory to Colorado Springs to give himself enough room for his high-voltage, high-frequency experiments. He studied atmospheric electricity, observing lightening via his receivers. He also produ-

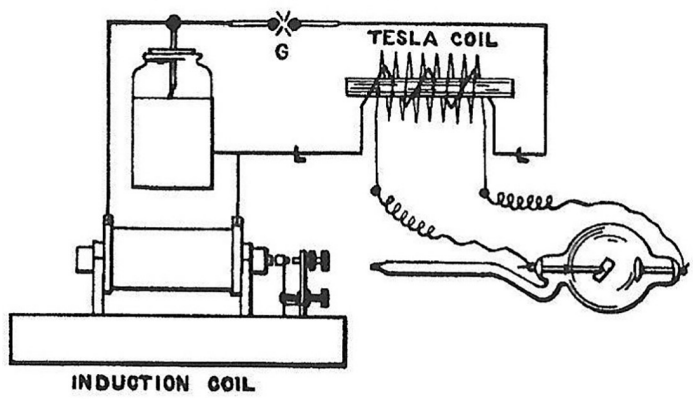

Figure 3. 1897 X-ray tube circuit [13]. The Tesla coil is a series of coils designed to step up the voltage to very high potentials, and simultaneously to increase the frequency of current alternation to millions of cycles per second by passing the current through condensers and spark gaps

Figure 4. Cartoon of Guglielmo Marconi (1874–1937) in a 1905 issue of Vanity Fair

ced artificial lightening, with discharges of millions of volts up to 135 feet in length. Thunder from the released energy was heard 15 miles away in Cripple Creek, Colorado. Sparks sprang from water line taps when touched and light bulbs within 100 feet of the laboratory glowed even when turned off. During one experiment he also blew the generators of the local power station and caused a power outage. The funding for his experiments was from John Jacob Astor IV (1864–1912 in the Titanic disaster) who had invested US$ 100,000 for Tesla to develop a new lighting system. The entrepreneur used the funding instead for these experiments!

Always a showman, Tesla is seen in Figure 5 sitting in his Colorado Springs laboratory with his so-called *magnifying transmitter* generating millions of volts. This is a multiple exposure picture created for the *Century Magazine* by the photographer Dickenson Alley. Tesla's handwritten note at the bottom on the image states "To my illustrious friend Sir William Crookes of whom I always think and whose kind letters I never answer! June 17. 1901. Nikola Tesla". He left Colorado Springs in January 1900, the laboratory was demolished and the contents sold to pay off some of Tesla's debts.

Wardenclyffe, Long Island 1900–1917

In 1900 with US$ 150,000 of which 51% was from J. Pierpoint Morgan, Tesla started on a project to build a gigantic transmitter, known as the Wardenclyffe tower, Figure 6, for trans-Atlantic wireless communications. However, as usual, Tesla ran out of money for the project and not surprisingly Pierpoint Morgan refused to make any further financial investment. The 187 foot tower was erected during 1901–1903 as part of Tesla's planned but never completed "World Wireless System". The tower was finally demolished in 1917.

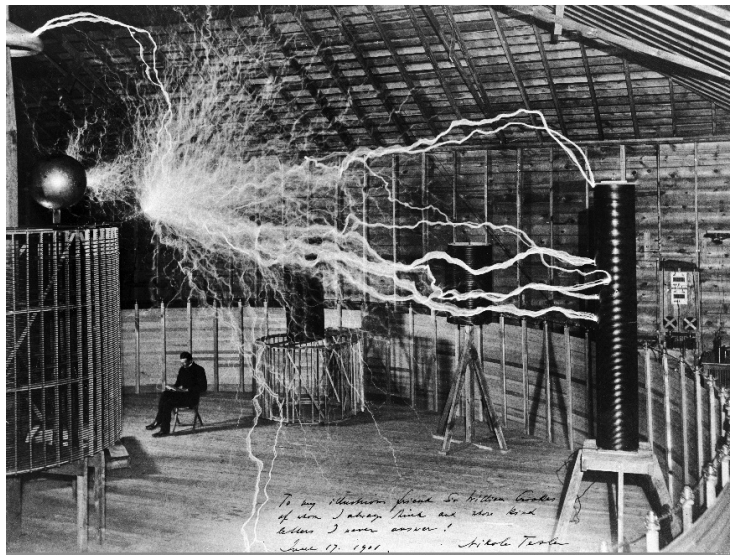

Figure 5. Multiple exposure picture. Tesla is sitting reading a book. The handwritten dedication is to Sir William Crookes

Figure 6. The Wardenclyffe tower [2]

Declining Years

After the failed Wardencliffe tower project, it became impossible for Tesla to obtain any significant financial backing for any further projects. This prompted the start of Tesla's decline. He was to increasingly become out of touch with the reality of wireless communications. During the Wardencliffe years he claimed to be aware of radio transmissions from outer space and proclaimed that alien forms of life were trying to contact earth. Much later it was found that the signals he had picked up were electromagnetic waves emitted from distant stars. He also claimed that he could use resonant oscillations to split the world in two if he so wished. This talk of earthquake machines and of death rays did not do Tesla any favours and he was increasingly considered to be some kind of mad scientist.

Eventually he spent his time caring for sick and wounded pigeons, taking them back to his New York hotel room. Not only had his financial backers vanished but even hotels were refusing him credit. In 1934 he moved into the New Yorker Hotel in downtown Manhattan which was a lower class of hotel than he was used to in his glory days. He collapsed on the evening of 7 January 1943 in his hotel room. He had suffered a heart attack. The *New York Times* obituary [19] described him as 'one of the world's greatest inventors 'but also stated that his ideas 'bordered increasingly on the fantastical' as he grew older.

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References

Much has been written about Nikola Tesla and this current short review of his life has drawn on five references [1–5]. These five references provide useful further reading. Relatively little has been written on Tesla's work with X-rays, which in any event only lasted for about a year.

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