Jacques Arsene d'Arsonval: His Life and Contributions to Electrical Instrumentation in Physics and Medicine. Part III: High-Frequency Experiences and the Beginnings of Diathermy

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I. "LIVING THINGS ARE TRUE ELECTRIC MACHINES": D'ARSONVAL WORKS ON HIGH FREQUENCIES

In this article, the author focuses on Jacques Arsene d'Arsonval's experiences in the field of electrical instrumentation in physics and medicine.

d'Arsonval's main contributions were in the electrical stimulation of muscles and nerves and the application of high-frequency currents to medicine, which was the most important part of his medical work. The interplay between technical developments and their applications in medicine was not at all new as clearly evidenced by relevant literature on the subject [1]. It was by the middle of the 18th century that the therapeutic effects of electricity became an intriguing and controversial topic of investigation, and, as a consequence of a logical effort to understand the nature and properties of the still "mysterious" physical phenomenon, the idea that it might have a welcome place in medicine was beginning to be given serious consideration. By recognizing its market potential, a heterogeneous group of people, including natural philosophers, physicians, apothecaries, and instrument makers, began to work, jointly or separately, on various technological innovations that made administering electrical therapy easier [2].

A few isolated examples can be mentioned. Soon after the presentation in 1746 by the Dutch scientist Petrus van Musschenbroek (1692–1761) of what would become known as the Leyden jar [3], it was applied by different people, among them the Italian professor of physics and mathematics in Geneva, Jean Jallabert (1712–1768), to muscular stimulation and treatment of various conditions associated with loss of movement. Some separate electrical accidents in the 1780s, involving the American polymath Benjamin Franklin (1706–1790) and the Dutch physiologist, biologist, and chemist, Jan Ingenhousz (1730–1799), showed that people could survive intense shocks to the head in which electricity clearly spread to the brain, without serious ill effects, other than amnesia. This encouraged leading French and English electricians to try it on melancholic and other mentally challenged patients in their respective cities [4]. In the 1780s, the Italian physician, physicist, biologist, and philosopher Luigi Aloisio Galvani (1737–1798) discovered the contractions of a muscle when that muscle and the nerve of a frog were simultaneously touched with a bimetallic arch of copper and zinc. His nephew and student, also the Italian, Giovanni (Joannis) Aldini (1762–1834), proceeded in 1801 to apply, with limited success, stimulating current from voltaic piles to try to cure melancholia with cranial electricity [5].

A few years after his invention of the lead-acid battery in 1859, the French physicist Gaston Planté (1834–1889) suggested galvanocautery, which means cauterization by a galvanic current, as its first application [6]. Then, in 1872, the British surgeon Thomas Green applied 300 V, generated by a battery of up to 200 cells, to stimulate the

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phrenic nerve and resuscitate surgical patients who were anesthetized with chloroform, an anesthetic with the side effect of depressing respiration and the cardiac pulse [7].

By the time d'Arsonval became interested in the subject, more than 200 patients had been treated daily in many hospitals, both in Paris and the provinces, using static electricity with collective electric baths and induced currents applied individually. The French community of electrotherapists (only some of whom were medical doctors) was well aware of the special nature of this situation compared to other countries such as the United States, where medical electricity was rarely taught at universities and was still not recognized as a medical specialty.

d'Arsonval's research on electrophysiological activity of muscles and nerves led him to explore the effects of low- and high-frequency currents. Since the completion of his experiments on this subject with condenser discharges in 1878, by which he was able to obtain two currents of equal value but with reverse sense, he was worried about the lack of uniformity in the results of experiments arising from the irregular action of induction coils and the need for standard measurements. If it was true that, by using his devices, muscular contractions could be obtained without the sensory nerves being affected, and replicable excitations could be obtained for given charges on the condensers and given positions of the secondary coil, it was also true that the results of one worker could hardly be compared with those of another.

The first important contribution was a study of the physiological effects of varying currents. d'Arsonval learned that a recording apparatus was required to know how the current varied from moment to moment, and what the waveform, or the "excitation characteristic" as he called it, of the current was [8]. To get the duration and intensity of any electric wave of low periodicity he used the principle of his moving-coil galvanometer. Deflections produced by the continuous variation of the currents sent through the coil suspended in a magnetic field were automatically transmitted by diaphragm and recorded on a revolving cylinder (Fig. 1). As very rapid oscillations impaired the curve's accuracy because of the inertia of the apparatus, d'Arsonval ingeniously replaced it with an optical diagram. A ray of light fell on a small concave mirror, attached to a membrane midway between the center and the circumference. The oscillating spot of light was received on a screen, and if the whole system was rotated about an axis to cause a displacement of the spot perpendicular to the oscillation, the current curve was then depicted on the screen [9].

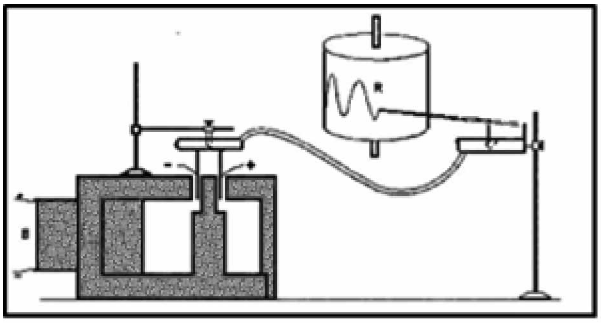

Fig. 1. **d'Arsonval's apparatus for recording waveform of alternating currents.**

Once d'Arsonval learned that the physiological effect of any current was the same whatever electrical source was used as long as the waveform was the same, and that the contractions produced by sinusoidal currents were less painful and more voluntary than those from interrupted faradic or galvanic currents, he focused immediately on finding the best way to obtain such currents and avoid factors such as variations in the magnetic field, which prevented the alternating currents from being truly sinusoidal. The first device he used to obtain smooth sinusoidal currents consisted of a movable circular magnet revolving in front of and very near a fixed electromagnet (Fig. 2). The currents produced during the rotation of the magnet changed their direction with each half-revolution.

The machine was later replaced by a modified version of one of the dynamos designed by the Belgian technician Zénobe Théophile Gramme (1826–1901) in order to obtain currents whose frequency and voltage could be changed by varying the speed of the rotation or by bringing the fixed coil more or less close to the magnet (Fig. 3) [11]. In this way, d'Arsonval introduced what he called "sinusoidal voltaization" into practice, and later, more specifically, in medicine [12].

By 1888, d'Arsonval began to use sinusoidal currents and other forms of electricity being used in electrotherapy to determine the comparative effects on metabolism, as well as on sensibility and neuromuscular excitability. While the metabolic rate showed no effect at all on galvanic currents, only a slight increase for static electricity, and a more marked (though insufficient to cause obvious muscular contractions) effect for

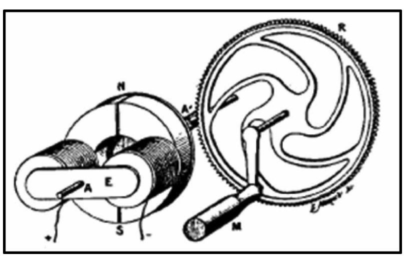

Fig. 2. **Apparatus used by d'Arsonval to obtain sinusoidal currents [10].**

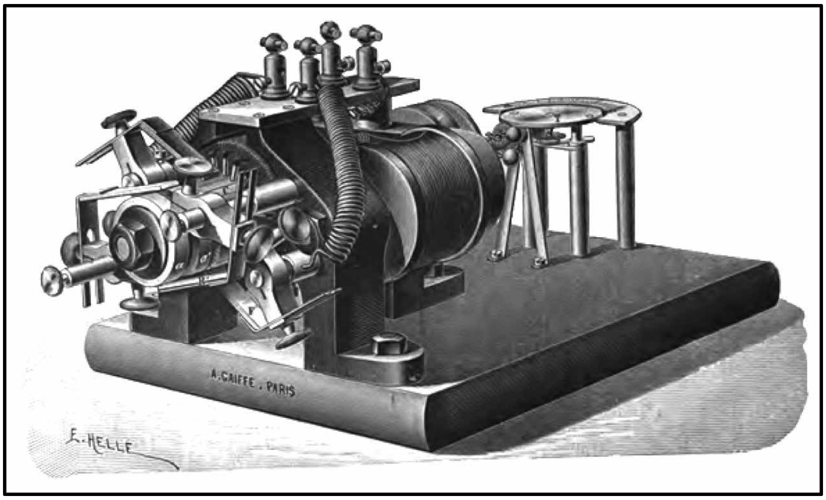

Fig. 3. Gramme dynamo modified by d'Arsonval to produce sinusoidal currents [13].

induced electrical currents, astonishing results were obtained for sinusoidal currents. At the lowest frequencies there were no contractions or pain, but increases of about 20% in the oxygen absorption, as well as in the production of carbon dioxide in the tissues resulting from the increase in metabolic rates. d'Arsonval also learned that when the entire body was submitted to the action of these currents, the circulation accelerated and the urine's analysis evidenced increases in the organic exchanges of the body. With respect to the effect of frequency, he determined that at about ten cycles, there were individual muscular contractions, two for every cycle, and then at around 25 cycles, the contractions fused and the muscle contracted all the time, or, as it was then called, tetanized. The intensity of this excitation increased with the frequency up to a maximum of about 5000 Hz, and then decreased until it was hardly noticeable at the highest frequency his machine could achieve, about 10 kHz [14], [15]. The Rühmkorff's coil d'Arsonval was using at that time did not allow him to obtain a sufficient frequency of oscillation to entirely suppress muscular contraction, because of the time lost in magnetizing and demagnetizing the core. In December 1890, after the public announcement of his results, the use of sinusoidal currents in electrotherapy was disseminated, first in France, and later elsewhere.

The study of sinusoidal currents was, however, only the beginning of what would be d'Arsonval's lead role in the field. His suspicions about the extension of the effects studied at still higher frequencies appeared to be well founded, but the work that required to confirm this was not yet technologically feasible.

II. THE BEGINNINGS OF MODERN ELECTROTHERAPY AND DIATHERMY

In 1887 and 1888, the German physicist Heinrich Rudolf Hertz (1857–1894) used an oscillator to carry out the famous experiments demonstrating the existence of electromagnetic waves, first theoretically proposed by the Scottish mathematical physicist James Clerk Maxwell (1831–1879) almost a quarter of a century before [16]. Although his findings stimulated a lot of research that led several years later to the realization of wireless telegraphy, Hertz's main interest was to broaden the base of general knowledge by showing how the mysterious "ether" transmitted Maxwell's waves, and, in this way, furnished the background of a fundamental theory to modern physics.

The apparatus employed by Hertz produced stationary electric waves with oscillations, each one lasting about 1/100 000 000 of a second, the period being determined by the capacity and self-induction of the apparatus. Such a circuit formed by the combination of a condenser and a coil had been known for some time. Several investigators had already suspected that the discharge of a Leyden jar could be oscillatory [17]. Discharges of a Leyden jar had been studied by Helmholtz in 1847, its frequency calculated by Thomson six years later, and its oscillatory character demonstrated experimentally by German physicist Behrend Wilhelm Feddersen (1832–1918) in 1858 [18]. The increase in the spark length due to an appropriate set of circuit dimensions was responsible for the high-frequency oscillations.

d'Arsonval became aware of the Hertz's experiments and, in December 1890, he used a modified oscillator of about 1-MHz frequency. However, the oscillator did not provide enough intense currents, forcing him to look for other possibilities. At about the same time, two men, the English-born American engineer Elihu Thomson (1853–1937) and the Serbian-born inventor Nikola Tesla (1856–1943), were making similar experiments in North America. With a primary purpose of making fundamental studies of high-frequency discharges in order to identify the new characteristics of those alternating currents, and without entering directly into the field of Hertz's experiments, Thomson was able to develop some alternating current machinery and patent, in about 1890, a high-frequency transformer without an iron core, which provided frequencies 30 to 40 times greater than any previous similar machine [19], [20].

After studying in Graz and Prague, and working in Budapest and Paris, Tesla immigrated to the United States in 1884, where he devised the first alternating current motor and patented many developments related to commercial production, distribution,

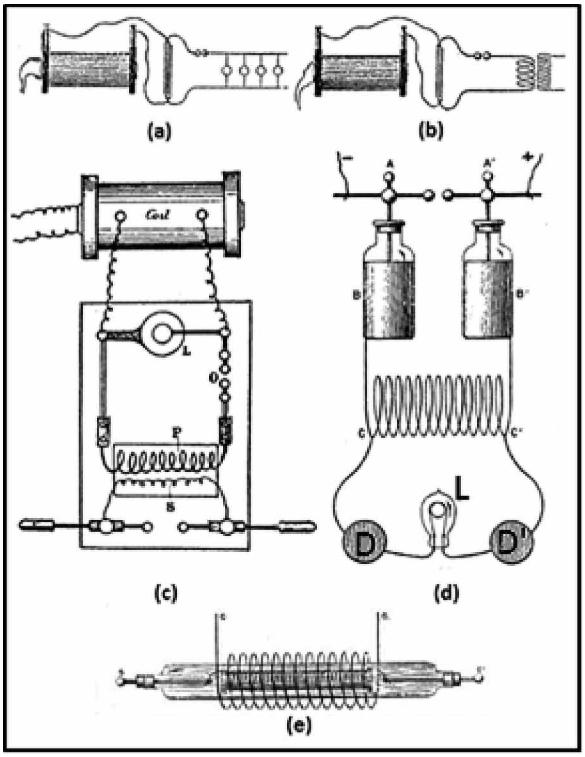

Fig. 4. **Circuits used for high-frequency currents. (a) and (b) Tesla's circuits for illumination of electric lamps by high-frequency current and for raising its potential [24]. (c) Thomson's modification of Tesla's circuit [25]. (d) and (e) d'Arsonval's modification of Thomson's circuit and fine wire coil enclosed in an oil-filled glass cylinder for increasing the spark's length [26].**

and use of electrical energy. To increase the frequency of alternating current, a subject in which he became pioneer of the technology, around 1890, he built high-speed generators capable of creating currents of about 15 000 Hz. To reach even higher frequencies, he then designed an oscillator transformer that bears his name [Fig. 4(a)]. The device consists of a capacitor connected to a spark gap and a coil (the primary). This primary coil was surrounded by a coaxial coil of a very large number of turns (the secondary). When the capacitor discharged into the primary coil, a damped alternating current of high-frequency passed through the primary and created in the secondary coil an induced current of the same frequency but of very high voltage [Fig. 4(b)] [21]. The spectacular, although still poorly understood, effects of these induced currents included the absence of the classic physiological effects of low-frequency currents.

Tesla's amazing experiences on the application of alternating currents of high-frequency and high potential to methods of artificial lighting were presented in New York in May 1891, then nine months later in Europe, first at the Institution of Electrical Engineers and the Royal Institution in London, and then in Paris at a joint session of the French Physical Society and the Society of Electrical Engineers, and finally, in February 1893, before the Franklin Institute of Philadelphia. All audiences were very impressed with the performances shown, and the following day each one was described in newspapers and journals with abundant detail.

Although not a doctor, Tesla carried out experiments in order to observe the effects of high-frequency currents on the human body. In an article published in December 1891, although unable to conclude whether it was beneficial, he discussed a person who did not experience heating after being connected to a source of high-frequency currents. Regarding high frequencies, however, he stated that it should not be surprising "that progressive physicians expected to find in it a powerful tool and help in new curative processes" [22]. Tesla did not venture further into the field of electrotherapy and he just improved and patented oscillators and high-frequency transformers that were used by manufacturers of electromedical devices.

d'Arsonval had doubtless heard Tesla's lecture in Paris. The provisional news about some tingling as the only apparent effect caused by electrical sparks and tens of thousands of volts hitting the body in Tesla's demonstration, as he previously had suspected, encouraged him to continue working on the subject. While Tesla devoted himself more particularly to the problems of electric lighting, d'Arsonval's main interest was focused on the physiological effects of the currents. After adopting in 1891, for a short time, Thomson's modification of Tesla's circuit [Fig. 4(c)], he realized that it could become dangerous if the condenser was disrupted and a large low-frequency current would be short circuited, seriously damaging both the experimenter and the transformer. d'Arsonval subsequently in 1893 devised an instrument based on the design of an apparatus used by the British physicist Oliver Joseph Lodge (1851–1940) for his experiments on lightning conductors, which added a further condenser in the series [23].

The apparatus was comparatively simple [Fig. 4(d)], but achieved a lower range of frequencies than that of Tesla. The internal armatures of two Leyden jars were connected with the terminals of the secondary circuit of an induction coil. The external armatures, in turn, were connected to one another by means of a solenoid composed of about 15–20 turns of a thick copper wire. A metal rod terminating in a ball was attached to each internal armature placed to form a spark gap. Each time a spark crossed the spark gap, a

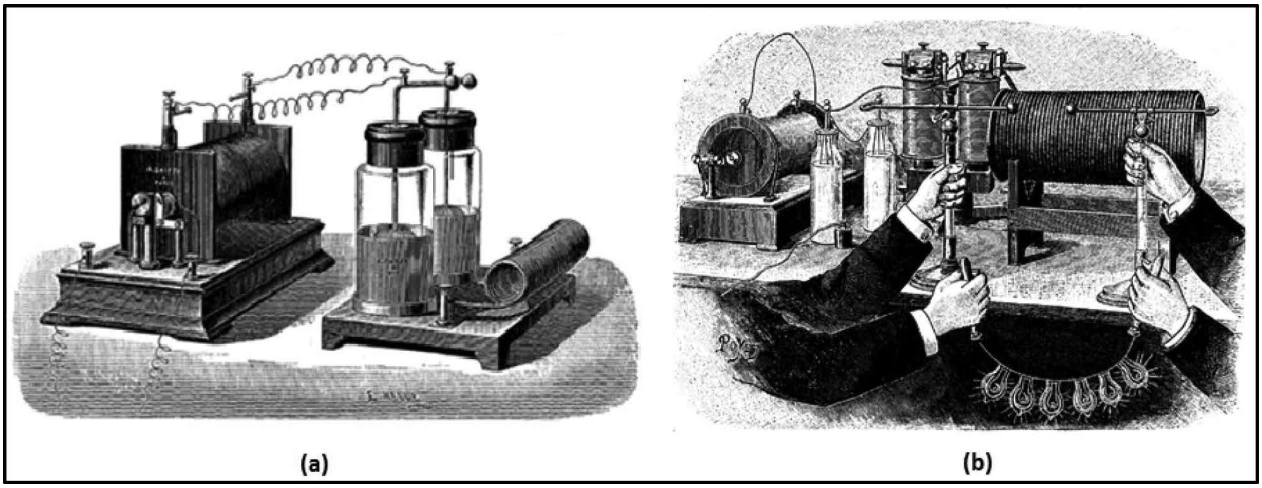

Fig. 5. **d'Arsonval's apparatus used in the experiments on high frequencies. (a) Dispositive view [27]. (b) Application for demonstrative uses [28].**

current of a very high potential and a very high frequency of oscillations was set up in the solenoid, and could be collected from its two ends. The distance between the knobs where the inner coatings of the jars terminated could be adjusted to suit the sparking distance of the charging electromotive force.

Figs. 4(d), 5(a), and 5(b) show a typical arrangement he utilized to demonstrate the high-frequency effects in courses at the College de France, societies of electricians, and to different scientific commissions. In one particular case, a set of six lamps (each one 150 V and 0.8 A) were made luminous when a current flew through a circuit formed by the arms of two people identified as D and D', the circuit being derived from the ends of a solenoid induced by oscillating discharges. The significant 720 W, or about 1 horsepower, which crossed the two bodies, were clearly manifested either by the luminosity of the lamps or by the lively and numerous sparks produced once the circuit was broken. While such an amount of energy could have been enough to hurt both men as if they were struck by lightning, under the above stated conditions it produced no appreciable sensation.

d'Arsonval reported his first results on February 24, 1891 [29]. The paper he sent to the French Academy of Medicine in 1892 was regarded so skeptically that it was nearly rejected, and he decided to never send the academy another paper. He explained the absence of muscle reaction and sensation, either to the disharmony between this vibratory frequency and the nerve terminals, or because of the fact that such currents could only flow on the surface of a conductor, and not through it. d'Arsonval believed that motor and sensory nerves did not respond to frequencies of the order of 30 million per second, while others did it at higher frequencies of heat and light. The observed skin flushing with increased sweating which was present for up to a half an hour was attributed to vasodilation rather than the heating reaction. He further noted not only an analgesic effect due to currents, but also a drop in blood pressure and an increase in the organic combustion, with "loss of heat to the periphery." By experimenting with currents of 1 A traversing living bodies, d'Arsonval was able to point out that while frequencies from 100 to 150 oscillations per second could kill, the same current at frequencies from 400 000 to more than 10 million oscillations per second, giving sparks of up to 10-cm length, passed through bodies with almost no perceptible physical sensation.

At d'Arsonval's suggestion, the French instrument maker Georges Gaifee (1857–1943) improved the original arrangement by incorporating a transformer with a closed magnetic circuit, which allowed increasing the potential from 0 to 15 000 V. This high tension alternating current could be used directly to charge the high-frequency condensers. A main disadvantage of the arrangement was the backward flow of the high-frequency waves, which injured the transformer, limiting the subsequent possibilities of higher potentials and more satisfactory results. By solving this inconvenience, the potential of the current supplied by the alternating current main reached 60 000 V. The improved apparatus was suitable not only for high frequencies, but also for X-ray work, in this way becoming a real advancement in the construction of the apparatus for medical purposes (Fig. 6). Some years later, as an outstanding development in medicine, it was implemented as part of the full portable equipment required by campaign hospitals (Fig. 7).

In 1893, d'Arsonval described his method of "autoconduction" in applying high-frequency currents to living bodies [32]. After having used the technique of connecting the person directly with the equipment, he moved to induction. The animals

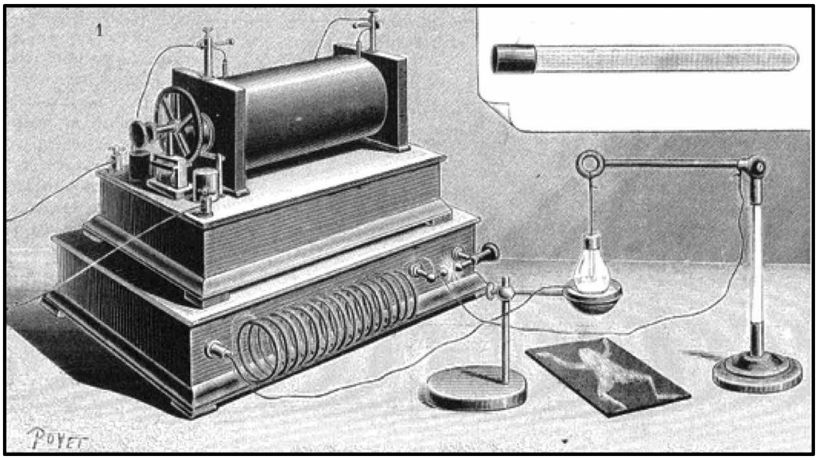

Fig. 6. **d'Arsonval—Gaiffe's apparatus assembly for the production of high-frequency oscillations and their employment in X-rays [30].**

used in the first experiments were quickly replaced by humans. The person, standing or sitting, was completely enclosed in a large, man-sized solenoid coil such as a cage, with big gaps between the turns, and separated from all contact with it [Fig. 8(a)]. Smaller cages were used for arms, legs, etc. [Fig.8(b)]. Owing to the high-frequency oscillating magnetic field within the solenoid, strong currents were induced within the subject's body. The person felt neither pain nor any other sensation, but if a 20-V lamp bulb was used to close the circuit, it was illuminated.

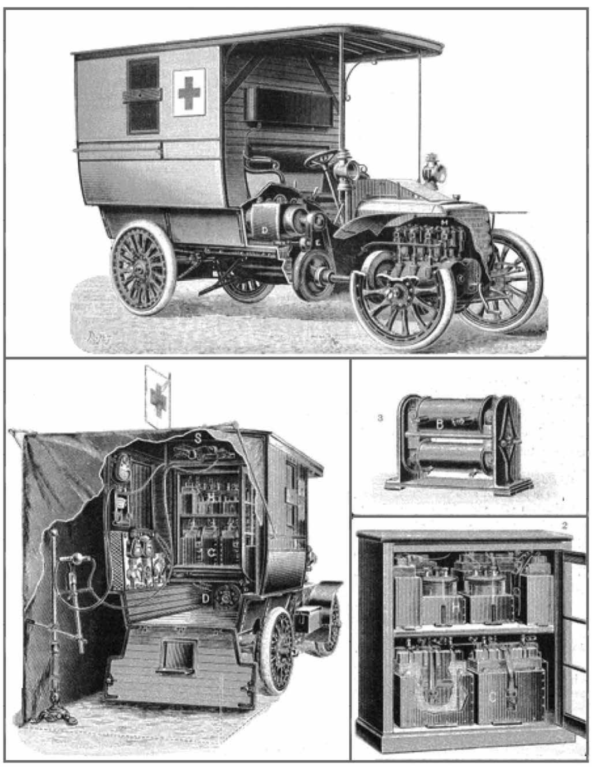

Fig. 7. **Campaign hospital vehicle incorporating d'Aronval—Gaiffe's apparatus and several instruments [31].**

Also in 1893, d'Arsonval collaborated with the French doctor Paul Marie Oudin (1851–1923) in both the required increasing of the voltage and the clinical applications of high-frequency currents [35]. A secondary coil, with a large number of turns of thin wire enclosed in an oil-filled glass cylinder [Fig. 4(e)], was used to solve the problem of the only voltage provided to him, a stream of sparks, each 15–20 cm long. An improved assembly in which the thick copper wire of the primary coil was mounted so that its position around the secondary one wound on a large hollow cylinder of ebonite, allowed adjustment to provide the required tension. It was, however, still insufficient. Oudin had found in 1892 that by connecting one end of the large d'Arsonval's solenoid with one end of a similar, small solenoid, and having the lengths of the two wires carefully adjusted in such a way that both circuits were in resonance, he was able to obtain a powerful brush discharge across the secondary by self-inductance. By adding his second large "resonator" coil, very high voltages from several hundred thousand to a million volts at lower currents and frequencies between 200 kHz and 2 MHz could be generated. The only significant difference between the Tesla and Oudin apparatuses was that while the former was bipolar, the latter was unipolar, with one end grounded. While in the early version of Oudin's resonator the two coils were separated and not magnetically coupled, in the version he introduced in 1897 both coils became one single length of wire wound on an insulating cylinder [36] (Fig. 9). With an apparatus which proved to be particularly suitable for the production of long sparks (for fulguration) and egrets (for effluviation), Oudin used it extensively in the treatment of skin diseases, as well as gynecology, or for the extraction of teeth through the numbing power of sparks [37].

During 1894 and 1895, d'Arsonval, his staff, and his disciples researched the therapeutic effects of high

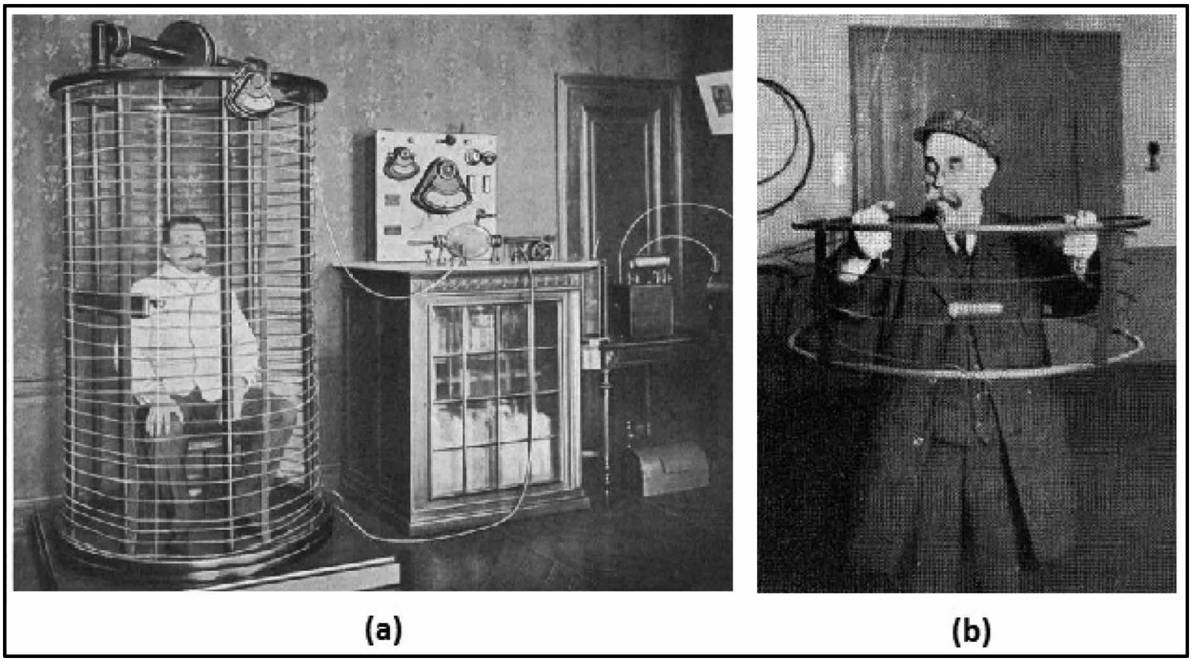

Fig. 8. **Solenoid used by d'Arsonval for autoconduction. (a) Full body person sitting [33]. (b) d'Arsonval experimenting with the technique on a part of his own body [34].**

frequencies and reported their results during one year of practice. Georges Apostoli (1847–1900) and Augustin Joseph Berlioz (1853–1922) studied 75 patients suffering from various ailments who submitted to autoconduction [40]. Each one was placed in the solenoid for 15–20 min daily, completing in total around 2500 treatments. Most types of hysteria and certain forms of local neuralgia received absolutely no benefit, but arthritic, rheumatic, and gouty conditions showed very marked amelioration. In another report presented the following year, the same doctors highlighted the valuable therapeutic properties of high-frequency currents in the treatment of some classes of chronic afflictions. While static currents became the treatment par excellence of acute diseases and nervous afflictions, in which the high frequencies seemed not to be well supported, they concluded that d'Arsonval's recently discovered currents seemed to be most helpful to patients suffering from debility and became the greatest modifier in problems associated with nutrition [41].

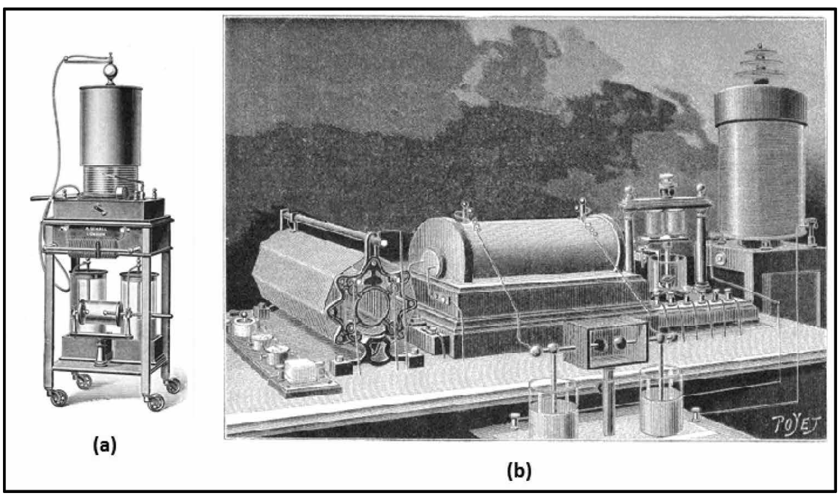

Fig. 9. **(a) Early Oudin coil apparatus [38]. (b) Early 20th century assembly of an apparatus for producing high frequencies incorporating d'Arsonval's dispositive and Oudin's resonator [39].**

In 1896, d'Arsonval gave an account of his first series of hospital trials of high-frequency treatment. The trials had been carried out at the Hotel-Dieu in Paris, originally a hospital for the poor and needy. There he had collaborated with the French doctor and associate professor of the Faculty of Medicine of Paris, Albert Charrin (1857–1907). It was so early in the development of electrical engineering that the hospital did not yet have a connection to an electric power supply, and d'Arsonval was forced to transport batteries to the hospital as a prime source of energy. In addition to the already discussed methods of direct application and autoconduction, he also used there the so-called electrification by condensation. In the latter, the patient was attached to one end of a solenoid, while the other was joined to a plate or a sheet of metal brought near, although not attached to, the patient. In this way, the metal plate and the body formed an arrangement similar to the two coats of a condenser, which was alternately charged and discharged as voltage at the ends of the solenoid rose and fell. The apparatus was arranged in the form of a couch, and the patient lay down on insulating cushions which separated him from the metal sheet underneath (Fig. 10).

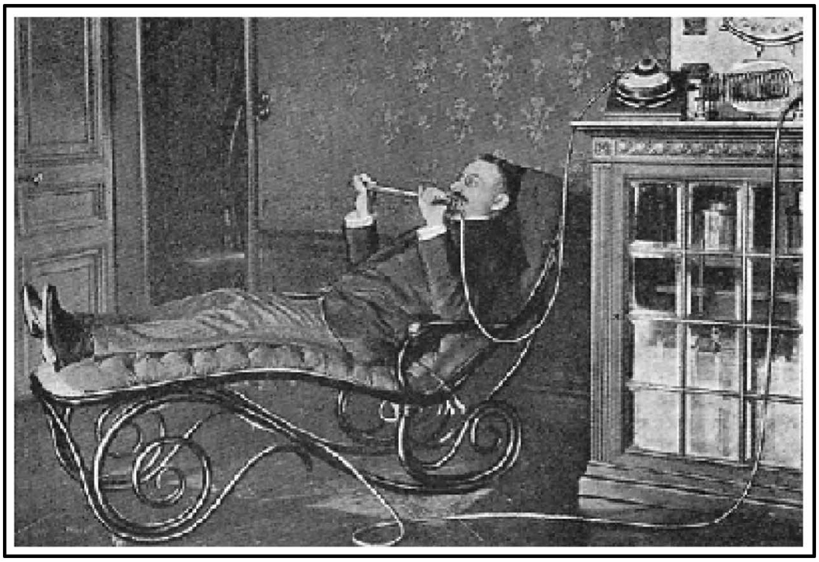

Fig. 10. Treatment by the condensation method.

The therapeutic results of these studies seemed so very promising that they led d'Arsonval, who, as has already been mentioned did not practice medicine himself, to say: "By communicating these facts to physicians, by providing equipment that allows them to get them, my role as physiologist is over. It is now they who correspond to take part in therapy" [42]. Similar studies were subsequently separately carried out by Oudin, the military doctor Jean-Alban Bergonié (1857–1925), and the also French electro-radiologist, director of the medical physics laboratory of the Lyon's university, and later by the developer of the technique of thermolysis, Henri Bordier (1863–1942).

d'Arsonval's work was generally acknowledged and, in 1899, the Austrian neurologist Moritz Benedikt (1835–1920) suggested the term "d'Arsonvalization" in his honor to denote application of high-frequency currents, in a similar way as terms "galvanization" and "faradization" had become standard. The new therapy was rapidly gaining interest in other countries, prompting an increasing number of articles and specialized treaties, and gaining more and more followers in the medical profession in Europe and the United States. Although d'Arsonvalisation was also used outside the medical community by so-called therapists and "quacks," and some doctors considered its effects as only the result of suggestion, not a proven method, the technique was widely practiced until the 1930s.

The actual heating mechanism of the high-frequency currents was first elucidated by Von Zeynech in 1899, who believed that the heat phenomenon reported by d'Arsonval was "ohmic" in nature, and that the passing of current through tissues had a similar behavior as current flowing through resistors.

The most direct legacy of d'arsonvalisation was diathermy, which aimed specifically at the tissue heating by using unamortized sine waves, with higher intensities and frequencies [43]. This technique, developed by German physician Franz Karl Nagelschmidt (1875–1952), who coined the term diathermy and designed the first unit in 1906, effectively allowed new applications of electricity in medicine and surgery still in use today [44]. By 1910, diathermy machines were beginning to make their appearance in supply houses, and only a decade later came to be recognized as convenient instruments in electrosurgery.

Although d'Arsonval's high-frequency current generators were originally devised for use in physiology laboratories and clinics, they had been also used in areas other than medicine. The generator model built by the French instrument-maker Eugène Ducretet (1844–1915) participated in the first wireless telegraphy experiments carried out in Paris in 1898 by the French radio pioneer and Captain Gustave-Auguste Ferrié (1868–1932), between the Eiffel Tower and the Pantheon [45]. In the early 20th century in Europe and the United States, electrifying vegetable gardens or orchards with cables, cages, or solenoids were driven by high-frequency currents. Although some results were encouraging, they were not enough to introduce electroculture in agricultural practice [46].

III. THE MAN BEHIND THE SCIENTIST

Recognized by some of his contemporaries as a physicist, by others as a physiologist, by some communities as a physician, and by a few as an engineer, d'Arsonval was actually a brilliant scientist. His contributions to science and technology are far from being reduced to those few briefly presented in these series of papers. His joint work with one of his favorite students, the French engineer and inventor George Claude (1870–1960) on the liquefaction of gases, ultimately led them to start the

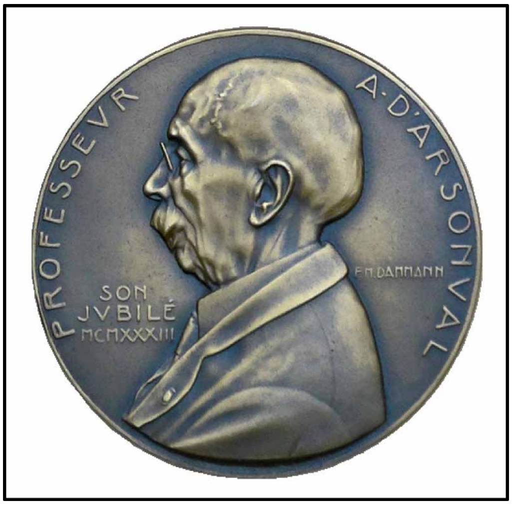

Fig. 11. **Commemorative Medal on the occasion of the Professor d'Arsonval's retirement on May 27, 1933 [47].**

liquid air industry in France and the development of a technique to store liquids in a bottle surrounded by a vacuum jacket, an invention later improved by the Scottish chemist and physicist James Dewar (1842–1923), who used a vacuum jacket with reflecting walls to keep a liquid hot or cold. His association with the French physician and hygienist Frederic Bordas (1860–1936), about the dehydration technique involving cold and vacuum today known as lyophilization; the design of the first electrically controlled constant temperature incubator for embryological and bacterial research, well used into the 20th century; the studies on the possibility of resuscitation by artificial respiration after high-voltage electric shocks; the invention of a chronoscope for measuring the speed of the sensations of the nerves; and the development of the idea of converting the thermal difference between the warm surface water and the cold subsurface water into electrical energy, are other, still very important, contributions of d'Arsonval.

d'Arsonval was indifferent to priority claims and received honors he never solicited (Fig. 11). In 1884, he was named Knight of the Legion of Honour in recognition of his work in the field of telephony, and he received the Grand Cross in 1931. In 1893, he was awarded the Lacaze Prize for his research in physiology, and seven years later received the Great Gold Medal granted by the Industrial Company of Northern France for services to science and industry. In 1888, he was elected Member of the French Academy of Medicine, and six years later Member of the French Academy of Sciences. For many years, he was also one of the editors of *La Lumière électrique*, one of the earliest journals devoted to electricity.

d'Arsonval was instrumental in founding national and international societies for electrical science in 1881 and 1897, respectively, a government-supported laboratory for electrical research in 1888, the École Supérieure d'Électricité in 1894, an international society for cryogenic studies in 1908, and the Compagnie Générale d'Électro-Céramique in 1923, to name only a few.

He was happily married twice, although he did not have children. At the age of 20, he married a young widow with a three-year-old girl. Thirty years later, after his first wife's death, d'Arsonval married his stepdaughter. Because such a union was not legal under the French law, the wedding took place in Spain in 1902, and d'Arsonval and his new wife were forced to break all contact with their families. His wife was a talented musician who shared her husband's love of music, often accompanying him as he played the flute.

From 1892 until the turn of the century, d'Arsonval mixed physics and medicine with politics, being elected as mayor of his native town. After striving for and realizing the construction of a school, a town hall, and a railway station, as well as securing the construction of roads, water canals, and the electrification of the town, he resigned from politics in 1900 to join Alfred Picard in planning the great Exposition Universelle held that year in Paris from April 14 to November 12. He died at the age of 89 in La Boire on December 31, 1940.

According to his biographers, d'Arsonval was an acutely inventive mind, skillful experimenter, hard worker, kind and fair in dealing with peers and subordinates, had a warm sense of humor and held sparkling conversations enameled of witty anecdotes [48]. A prestigious award bearing his name, consisting of a silver medallion, a silver lapel pin, an illuminated testimonial, and a $2000 honorarium, is granted from time to time by the International Bioelectromagnetics Society (BEMS) to recognize outstanding achievements in research on the subject.

"The advancement of science," d'Arsonval said, "has always been consequence of the intuitive and the imaginative. To be a great scientist, one must, first, be a very sensitive man and, at bottom, an artist, if not a poet." Regarding the role of the physical sciences in biology, and specifically electricity, he stated in the first years of his career: "Electricity must become, in my opinion, one of our most powerful means of action to change the living beings. I am convinced that the therapy of the future will employ such means as physical healing modifiers (heat, light, electricity, cold, hot, etc.) … The barbarian means that, under the pretext of curing us, are contaminated us with the most poisonous drugs of chemistry, will give way to physical agents whose employment have at least the advantage of any foreign object in the body" [49].

The way in which he imagined the role of electricity in future is clearly presented in the following speech he gave at the International Congress of Electricians of 1881:

"Channeling electricity is democratizing the energy … transporting it through long distances means to be able to switch from coal whose reserves are running out and the use the natural forces so far lost. In the near future […] we will see the waters of our rivers, winds and tides putting in movement powerful electric machines from where will leave a network of wires crossing the country and distributing on its journey energy for the industry and the agriculture. Remember […] *it will be thanks to the science that the yesterday's impossibilities will become the tomorrow's trivialities.*" ■

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