Jacques-Arsène d'Arsonval: His Life and Contributions to Electrical Instrumentation in Physics and Medicine. Part I: Early Life and Activities in Physiology

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In this month's article, the author takes a look at Jacques-Arsène d'Arsonval's early life and his activities and achievements in the area of physiology and electrophysiology.

Interactions between electricity and medicine date back many centuries. The therapeutic use of electric and magnetic forces to treat diseases has continuously captured the popular imagination, as well as the interest of men of science and instrument makers, including a very little fraction of an almost always unconvinced prevailing medical establishment.

The transition from the "shocks" produced by the torpedo fish as the first electric therapeutic agent, to the evidenced extensive application of electricity in medical practice in the 19th century, was marked by multiple significant inventions and developments. The discovery of the electrical and magnetic properties of amber and magnetic rings, respectively, which were of interest since at least the time of the ancient Greeks, was followed by the invention of the first electrostatic generator in the early 1700s and an increased practicality of electric studies and demonstrations.

Although still dismissing a connection between electricity and magnetism, experimental studies of the therapeutic effects of electricity by incorporating an electrostatic generator, or a Leyden jar, to give spark and shock treatments (franklinization) were used, for example, as a cure for paralysis, blindness, deafness, headaches, and rheumatism, among others, usually on a temporary basis.

Distinct electrical shocks delivered by the use of voltaic piles (galvanization) were used in the early 1800s in patients with vision deficiencies, by applying an electrode to the eye socket, and in certain paralytic conditions, to cite only two examples. By carrying out experiments at the Royal Institution in London, Michael Faraday (1791–1867) was able to provide doctors a more manageable means of generating continuous electrical currents for medical therapy. The invention of the induction coil, the first transformer to be widely used, allowed the application of an electric current to various parts of the body (faradization) and led neurologists such as French neurologist Guillaume-Benjamin-Amand Duchenne (de Boulogne) (1806–1875) to contribute to the foundation of modern electrotherapy.

All these therapies involved controversies between very diverse positions within the medical world. Physicists and instrument makers of a new generation in the 1830s rethought the increased characteristic interest of the beginnings of the century in mathematization of the theories of electricity, magnetism, and electromagnetism. They began instead to reward experimental practice over theoretical achievements. Among various possibilities, and as a consequence of this new vocation given to physics, an important number of professionals began to carry out experiments on the relationship between electricity and living organisms, using numerous pieces of an increasingly large array of equipment available for electrotherapeutic treatment.

The Frenchman Jacques-Arsène d'Arsonval was one of these men.

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d'Arsonval is today still popularly associated with techniques of application of high-frequency currents in therapeutic rejuvenation treatments, which bear his name, by people in dermatology and cosmetology practice. His techniques sought out skincare benefits such as elimination of toxins and acne-causing bacteria; shrinking of enlarged pores; increase of collagen and elastin production; reduction in the appearance of fine lines, wrinkles, and cellulite; and even, in some reported cases, improvements in hair growth and fading of dark eye circles. A significant number of users of the related devices report even better results with this form of treatment compared with those obtained by using much more recent techniques such as dermabrasion and microdermabrasion, to cite only two examples.

d'Arsonval must certainly be considered a pioneer of this sort of "age defying therapy," as it is sometimes popularly called, because of his early examination (in the latter part of the 19th century) of the physiological effects of electrical stimulation at frequencies varying from DC up to 10 000 cycles per second (the limit obtainable with the apparatus of the day). His contributions to electrical science went far beyond this particular experimental study, however, including various branches of the emerging electrical science and its interactions with medicine and other scientific and technological areas.

Known as a brilliant physician, and considered by his contemporaries also as a physicist, physiologist, or even as an engineer, he is today much better known for his electrical engineering contributions than for those in other areas. d'Arsonval's diverse studies on the physical, electrical, and mechanical properties of striated muscles, which would become his major research interest, served as the point of departure for most of his discoveries and inventions in electrical matters. This first article on d'Arsonval deals with his early life and his first scientific achievements, focusing mainly on the most important experiences, apparatuses, and instruments devised along his studies in the fields of physiology and electrophysiology.

I. FORMATIVE YEARS

Jacques-Arsène d'Arsonval (Fig. 1) was born on June 8, 1851, in La Boire, a large state in the village of La Porcherie, in the Limousin region in west central France. He was the eighth of nine children (of which only three survived) born in a family of France's ancient nobility. His father, Pierre-Catherine d'Arsonval, was a physician, as was his father before him; and his mother, Marie-Thérèse de Beaune, was a highly intelligent and distinguished lady. After primary studies at the municipal school, d'Arsonval was sent in his 11th year to residential schools, first in Brive-la-Gaillarde, the biggest commune in the Corrèze department, and later to Limoges, the capital of the Haute-Vienne department, where he studied classics and spent many hours after-school in the physics laboratory [1]–[4].

An excellent student in all courses, including gymnastics, d'Arsonval received a baccalaureate degree in sciences from the Université de Poitiers in 1869, and traveled promptly to the college Sainte-Barbe, in Paris, seeking admission into the prestigious École Polytechnique. A cancellation of the examination due to the outbreak of the Franco-German conflict in 1870 forced him, however, to return to his homeland, where his father decided to enroll him in the Limoge's Medical School. The simultaneous exercise of functions as clinician and physicist carried out there by his professor of physiology very quickly caught d'Arsonval's attention. Having won a public contest of vocational training during his third year of studies, d'Arsonval moved again to Paris to work with the professor of internal pathology, François Sigismond Jaccoud (1830–1913), at the Lariboisière Hospital.

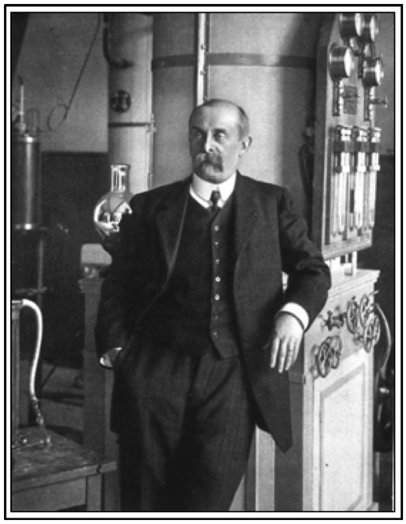

Fig. 1. **Jacques Arsène d'Arsonval (*ca*. 1890) © Coll. BIU Santé (Paris).**

A chance social encounter with the foremost physiologist of the day, Claude Bernard (1813–1878), at the Collège de France, altered the course of d'Arsonval's career [5]. Both men met for the first time on December 6, 1873, during a course on animal heat offered by Bernard, in which d'Arsonval was enrolled. The lecture aimed at showing the maintenance of a constant temperature in a normal human body, independent of the environment. When certain experiments failed owing to a defective galvanometer, d'Arsonval, who was sitting in the front row, pointed out the fault and offered to repair it, thus permitting the completion of a classroom demonstration. Bernard not only rewarded the enthusiasm and abilities of the young student, giving him the opportunity of attending the experimental physiology course he offered at the Collège, but also invited him, three months later, to be one of his assistants.

d'Arsonval was, however, still unable to decide whether to continue the scientific career he wanted, or fulfill his father's dream of completing his medical training and return home to work as his assistant. Bernard, aware of the dilemma, sent a letter to d'Arsonval's father letting him know his qualified opinion on Jacques-Arsène's possibilities, and trying to objectively contribute to the decision. After describing d'Arsonval as "the great education, a spirit of the most inventive, the taste and passion for questions related with theory and application, as well as a friendly and helpful character who make the love of his comrades and all those who know him," Bernard's letter concluded that "he had seen few young people so gifted as Jacques-Arsène for the culture of sciences, where a bright future he had reserved" [6]. The letter became crucial in what followed, and once there was a guarantee that d'Arsonval would receive enough time to complete his medical studies, he finally settled in Paris.

d'Arsonval continued his studies, with a particular emphasis on physics and physiology, and presented and defended his medical thesis on the physiological role of pulmonary elasticity on August 6, 1877, at the age of 26. His whole life was, however, completely devoted to science. He never practiced medicine.

II. D'ARSONVAL AND PHYSIOLOGY

Bernard's influence led d'Arsonval to formally give up a medical career for a life of physiological research. An underlying belief of his philosophy was that electrical potential was a property of all cells, and that whatever change they experienced was directly associated with an electrical clearance produced by a determined mechanism [7]. The three cardinal principles on which Bernard based his method, observation, experimentation, and deductive reasoning, formed the structure of experimental research used by d'Arsonval. He then combined the tradition created by his master with the preference of the already mentioned Duchenne de Boulogne for physical techniques. Bernard believed that "the mechanical, physical and chemical forces are the only effective agents of the living organism" [8]. Duchenne's preference was for physical techniques like electricity, which entered the body without destroying tissues (unlike the scalpel), thus substituting a harmless dissection for a vivisection. These two together led d'Arsonval to begin a long series of investigations that would lead him to become the founder of a new discipline—biological physics, or biophysics.

His first projects as Bernard's assistant were on animal heat and body temperature. d'Arsonval was aware that thermometric measurements in living things could provide information with exactitude about the heat distribution inside organisms, but that only a calorimetric method would allow the measurement of the oscillations of its production. He considered that the solution of issues related to thermogenesis required that the calorimeter used in the experiments remained at a substantially invariable temperature, allowing the continuation of the studies without corrections at any time. The double-chambered calorimeter he devised for studying this problem corresponded with a present day classical scheme of a heat exchanger, in which an inner chamber with the animal confined was surrounded by an ice water jacket that kept it at the required fixed temperature by absorbing the heat from the respired air as it was carried out from the chamber (Fig. 2). The constant interior temperature increased the accuracy of gas volume measurements and ensured more constant rates of breathing. The temperature and quantity of water circulating in the external chamber were measures of the produced heat. The apparatus was complemented with an automatic recorder to indirectly show the variation in the heat developed over a long time.

d'Arsonval was aware that the mercury thermometer had proved to be accurate for external parts, but not for measuring the temperature of tissues and blood in adjacent vessels. These measurements required other kinds of instruments. By believing that electricity was the most perfect and delicate means of study, which the physiologist could then dispose, he was involved in the improvement of some thermoelectric needles able to reach these hard-to-reach areas, devised by his compatriot Antoine César Becquerel (1788–1878) in 1876. The original instrument, consisting of two heterogeneous wires soldered by their end which ended in a sharp

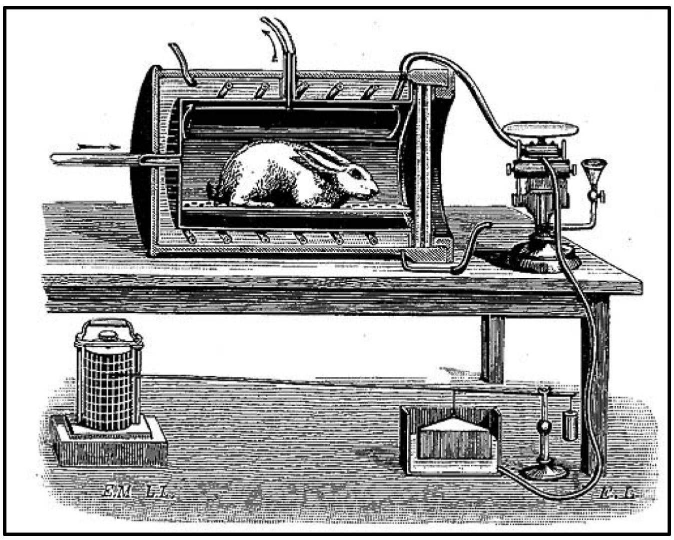

Fig. 2. d'Arsonval's calorimeter recorder.

point, presented, however, a great difficulty. Although the wires were carefully varnished, the contact with animal liquids usually removed the varnish, and the naked wires spawned hydroelectric currents, making any observation impossible and creating a constant danger. d'Arsonval fixed this by replacing one of the wires with a tube surrounding the other wire, protecting it against the dangerous contact. The coupling occurred as with sheathed probes. The needles could penetrate into the interior of the deepest organs and in tissues without causing pain, and were used, for example, to compare the temperatures of arterial and venous blood, the temperatures of blood before passing and after passing through a gland such as the liver, or the difference in temperature between a muscle at rest and the one working (Fig. 3) [9].

After two years of volunteering service in Bernard's laboratory, d'Arsonval was named *préparateur* of the Chair of Medicine at the College de France. As a consequence of getting to know many visiting scientists of all nationalities who frequented the laboratory, Jacques-Arsène was actively involved in research related to drugs, anesthetics, fermentation, thermal regulation, and, particularly, biological mechanisms involving heat and electricity.

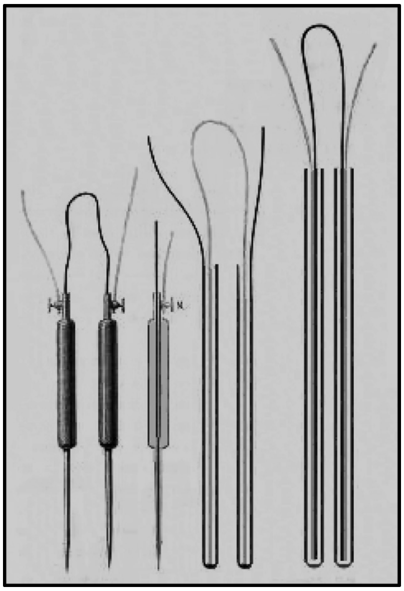

Fig. 3. **Thermocouples devised by d'Arsonval for measuring temperatures of veins, arteries, and other tissues [10].**

Following Bernard's death, on February 10, 1878, d'Arsonval became an assistant, and later a deputy, of his successor, the peripatetic and somewhat eccentric Mauritian physiologist and neurologist, Charles Edouard Brown-Séquard (1817–1894), who had previously divided his career between different appointments in his natal country, France, England, and the United States [11]–[12]. The initial collaboration between the then chair of experimental medicine at the Collège de France and the young physician in the preparation of a series of lectures devoted entirely to the nervous and circulatory systems was suddenly interrupted in late June 1879 by a misunderstanding. During a disagreement between Brown-Séquard and d'Arsonval, the latter used Bernard's name to support his case (which was unwise according to Brown-Séquard). An angry exchange followed which forced Jacques-Arsène to take refuge in the laboratory of another French physiologist and professor, Etienne Jules Marey (1830–1904), at the Collège de France for a few weeks [13].

The short time Marey and d'Arsonval worked together complemented the latter's aptitude for technical studies acquired while he was assistant to Bernard. The new mentor presented a modified vision of the physical methods required for biological studies, as well as the way to conduct investigation into the analysis of medical problems. The successful application of a new mode of analysis of physiological processes, involving recording instruments and graphic presentation of diagnostic data that characterized Marey's work, influenced d'Arsonval to implement several movement recording devices in the following years and to strengthen the linkage between biological research and techniques based on physical concepts. This fact become clear in the following decades with a growing concern for incorporating the precision and certainty of exact sciences of new apparatuses and measuring instruments that d'Arsonval began to create continuously for the physical modeling of the biological phenomena he investigated [14].

Brown-Séquard and d'Arsonval reconciled soon, and d'Arsonval returned to work as Brown-Séquard's deputy, becoming his friend and indispensable collaborator. Although both men worked together on different research (such as the noxious effects of carbon dioxide breathed out of the lungs [15], the effect of confined air on the development of tuberculosis in a guinea pig, and the design and construction of an apparatus to extract air breathed out by patients in a hospital ward and expel it outside [16], among others), d'Arsonval's primary duties were to assist Brown-Séquard in the latter's famous experiments on endocrine extracts, the starting point of opotherapy and the current endocrinology [17]. There, Brown-Séquard and d'Arsonval worked to prove that suprarenal glands were essential in life, and that all tissues give something special to blood which might be extracted and used by physicians to treat a variety of intractable diseases [18] - [20]. Their research provided beginning to the later controversial hormone theory of wound healing.

d'Arsonval took personal charge of preparing the extracts and different ways to sterilize them. Years later these studies would become the real beginning of scientific endocrinology, but it would not be his only interest. Aware as he was that a key to carry out research was to have a trustworthy and accurate system of measures, d'Arsonval was decidedly involved in the design of the tools required for his investigations and, indirectly, for the solution of diverse problems of the rapidly growing electrical industry. Sterilizing filters and autoclaves were two types of equipment he contributed, for his own

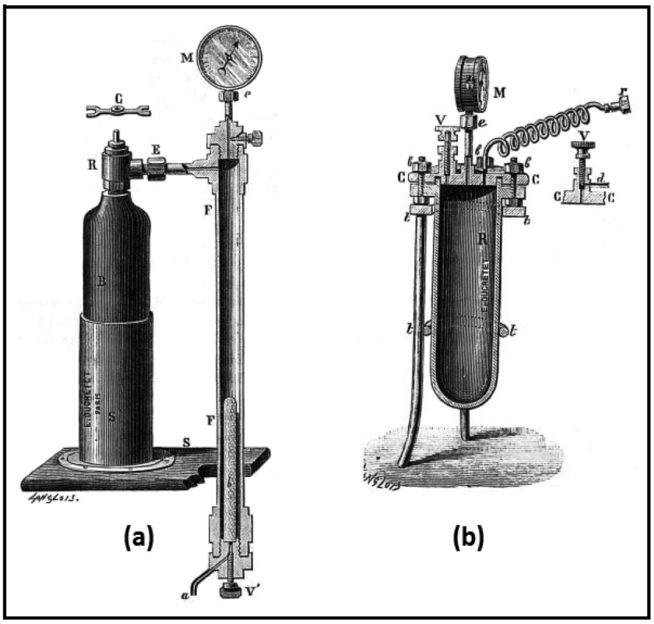

Fig. 4. **(a) Apparatus for rapid filtration and sterilization of organic liquids [21]. (b) Autoclave sterilizer with carbonic acid.**

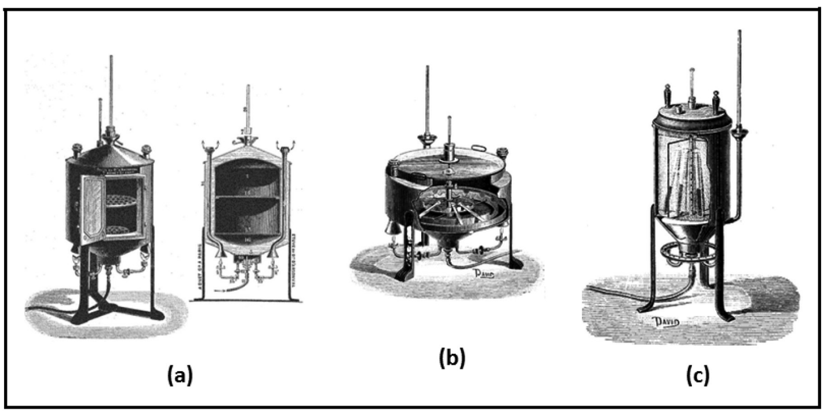

Fig. 5. **(a) Self-regulating stove of double wall for fermentations and crops [22]. (b) Stove of double wall to coagulate serum [23]. (c) Waterbath.**

use and that of other laboratories. Sterilizing filters were used to obtain liquid organic extracts absolutely free from microbes, or other dangerous pieces of solid matter in the case of the aforementioned research [Fig. 4(a)]. Aautoclaves were an alternative apparatus, for example, for the purification of animal extracts by immersion in high-pressure carbon dioxide atmospheres (a forerunner of the technique now known as extraction by supercritical carbon dioxide) [Fig. 4(b)]. His designs of self-regulating stoves, equipped with a highly sensitive controller, with temperature variations less than 1/100th of a degree [Fig. 5(a) and (b)], and "bains-Marie" (waterbaths) [Fig. 5(c)], for microbial growth and sterilizing serum, respectively, were widely used in bacteriological laboratories. Double-membrane air thermoregulators, which only worked by placing weights on the tray [Fig. 6(a)], "guillotine"-type instruments to control temperatures of gases or liquids for heating or cooling purposes [Fig. 6(b)], as well as pressure regulators of combustible gases in regenerators [Fig. 6(c)], which later facilitated the work of scientists like the French chemist and bacteriologist Louis Pasteur (1822–1895), served as forerunners of modern controllers and pressure reducing valves. For the development of these ingenious instruments, the French Academy of Sciences awarded him the prix Montyon in experimental physiology twice, in 1881 and 1889.

From 1882, although in charge of medical lectures at the Collège de France in place of Brown-Séquard during winter months, d'Arsonval was appointed Director of the Laboratory of Biological Physics, attached to the Chair of Medicine at the College. The new laboratory, which provided him additional facilities to pursue his interest in electrophysiology, had been established by the Collège de France with the assistance of another former student of Bernard, physiologist, and then Minister of Public Education Paul Bert (1830–1886), as a result of Bernard's insistence, who was convinced of the importance of physical techniques in biology. d'Arsonval directed the laboratory from 1882 until 1910. In 1887, he was officially appointed substitute teacher at the Collège de France, and seven years later, after death of Brown-Séquard, he was chosen to be his successor. In 1910, he moved to the new laboratory at Nogent-sur-Marne (which he directed until his retirement in 1931), edified on his plans and erected with funds raised by public subscription.

Simultaneously, young d'Arsonval, already known in the electrical industry for his contributions to the development of several types of apparatuses and instruments, began to be distinguished in the scientific community. At only 30 years old he assumed the heavy duties of secretary of the Electrophysiology Committee

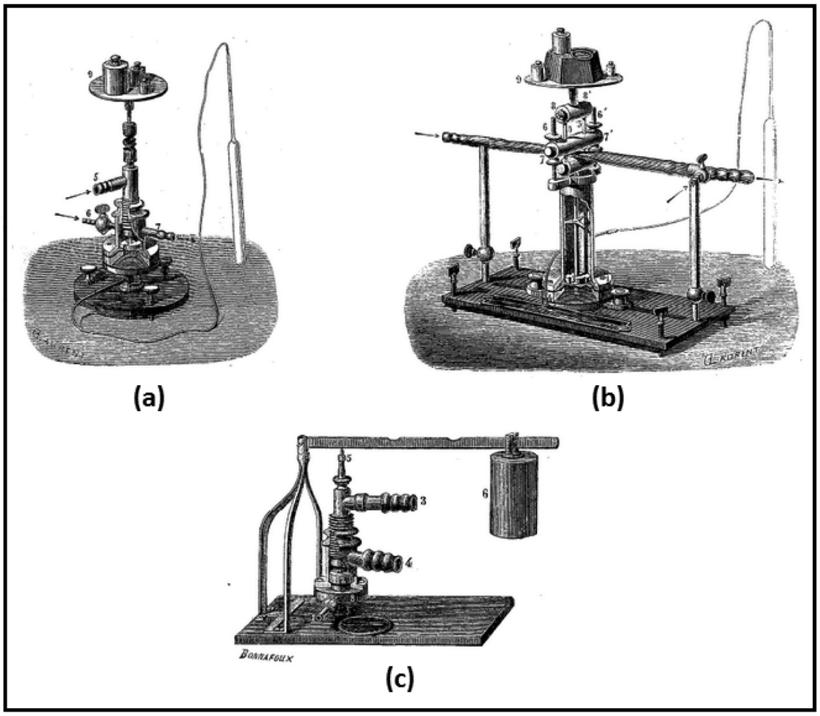

Fig. 6. **(a) Double-membrane air thermoregulators [24]. (b) Guillotine-action thermoregulator. (c) Pressure regulators [25].**

of the first International Congress of Electricians. It was held in Paris from August to November 1881, and attended by 250 delegates from 28 different countries, including leading scientists and engineers of the day. Before that year, there were different national systems of units of electricity in use. Units were primarily considered as standards adapted to the work of their own engineers. An opposition existed between the British scientists who, with the CGS system, wanted to place the electrical units in the theoretical scope of mechanics, and the German engineers, who wanted practical standards. d'Arsonval knew that a common language in both units and methods of measurement was necessary to facilitate the comparison of effects achieved in the use of electromedical devices by physicists and physicians. He played a major role in the passing of a resolution establishing a unified system of measures for practical use, based on CGS electromagnetic units, in which all the instruments should be calibrated thenceforth [26]. ■

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REFERENCES

[1] H. Bordier, "d'Arsonval," *La Nature*, vol. 59, no. 2865, pp. 241–246, 1931.

[2] A. Strohl, "Notice nécrologique sur M. Arsène d'Arsonval 1851–1941," *Bull. Acad. Nat. Med.*, vol. A105, nos. 7–8, pp. 213–222, 1941.

[3] P. Vayre, "Docteur Jacques-Arsène d'Arsonval (1851–1940): De la biophysique à l'Académie de chirurgie," *e-Mem. Acad. Nat. Chir.*, vol. 6, no. 2, pp. 62–71, 2007.

[4] A. de Gramont, "d'Arsonval physicien," in Cérémonie du Centenaire de la Naissance d'Arsène d'Arsonval à la Sorbonne le Mardi 23 Octobre 1951, *Notices et Discours—Institut de France—Académie des Sciences*, vol. 3. Paris, France: Gauthier-Villars, 1957, pp. 300–307.

[5] J.-G. Barbara, E. Broussolle, J. Poirier, and F. Clarac, "Figures and institutions of the neurological sciences in Paris from 1800 to 1950. Part II: Neurophysiology," *Revue Neurol.*, vol. 168, no. 2, pp. 106–115, Feb. 2012.

[6] P. Vayre, *Jacques-. Arsène d'Arsonval: Un Médecin Limousin à Paris—La Biophysique au Secours des Hommes*. Paris, France: Éditions Glyphe, 2006, pp. 38–39.

[7] J.-A. d'Arsonval, "Les sciences physiques en Biologie: L'Electricité (10th part)," *La Lumière Électrique*, vol. 7, no. 38, pp. 3012–3013, 1882.

[8] L. Delhoume, *De Claude Bernard à d'Arsonval*. Paris, France: J.-B. Baillière, 1939, p. 22.

[9] J. A. d'Arsonval, "La mesure des températures par l'électricité: Son importance dans les sciences biologiques," *La Lumière Électrique*, vol. 5, no. 54, pp. 40–44, 1881.

[10] C. Bernard, *Leçons de Physiologie Opératoire*. Paris, France: Bailliere et Fils, 1879, p. 470.

[11] Y. Laporte, "Charles-Édouard Brown-Séquard. An eventful life and a significant contribution to the study of the nervous system," *Comput. Rendus Biol.*, vol. 329, nos. 5–6, pp. 363–368, May/Jun. 2006.

[12] S. S. Rengachary, C. Colen, and M. Guthikonda, "Charles-Édouard Brown-Séquard: An eccentric genius," *Neurosurgery*, vol. 62, no. 4, pp. 954–964, 2008.

[13] M. E. Silverman, "Etienne-Jules Marey: 19th Century cardiovascular physiologist and inventor of cinematography," *Clin. Cardiol.*, vol. 19, no. 4, pp. 339–341, Apr. 1996.

[14] M. Borell, "Marey and d'Arsonval: The exact sciences in late nineteenth-century French medicine," in *From Ancient Omens to Statistical Mechanics: Essays on the Exact Sciences Presented to Asger Aaboe*, J. L. Berggren and B. R. Goldstein, Eds. Copenhagen, Denmark: Univ. Library, 1987, pp. 225–237.

[15] C. E. Brown-Séquard and J.-A. d'Arsonval, "Ressemblance entre l'action toxique de certaines ptomaïnes et celles du poison pulmonaire," *C. R. Seances Soc. Biol. Ses Fil.*, vol. 5, pp. 108–110, 1888.

[16] C. E. Brown-Séquard and J.-A. d'Arsonval, "Sur quelques points importants relatifs à la durée de survie des lapins après injection du liquide contenant le poison de l'air expire," *C. R. Seances Soc. Biol. Ses Fil.*, vol. 5, pp. 151–152, 1888.

[17] M. Borell, "Organotherapy and the emergence of reproductive endocrinology," *J. History Biol.*, vol. 18, no. 1, pp. 1–30, Mar. 1985.

[18] C. E. Brown-Séquard and J.-A. d'Arsonval, "De l'injection des extraits liquides provenant des glandes et des tissus de l'organisme comme méthode thérapeutique," *C. R. Seances Soc. Biol. Ses Fil.*, vol. 3, pp. 248–250, 265–268, 535–536, and 722–725, 1891.

[19] J.-A. d'Arsonval, "De l'injection des extraits liquides provenant des différents tissus de l'organisme, comme méthode thérapeutique; technique de la préparation de ces extraits," *Bull. Acad. Nat. Med.*, vol. 27, pp. 250–261, 1892.

[20] M. Borell, "Organotherapy, British physiology, and discovery of the internal secretions," *J. History Biol.*, vol. 9, no. 2, pp. 235–268, 1976.

[21] E. Ducretet, *Catalogue Raisonné des Instruments de Précision de E. Ducretet: Physique Générale*. Vannes, France: Impr. Lafolye, 1905, pp. 100–101.

[22] J.-A. d'Arsonval, "Sur une étuve auto-regulatrice," *La Lumière Électrique*, vol. 31, no. 3, pp. 106–109, 1889.

[23] M. F. L. Secrétan, *Extrait Catalogue Secrétan: Instruments de Chimie, Histologie, Microbiologie, Bactériologie, Micrographie, Météorologie, Marine*. Paris, France: Impr. J. Mersch, p. 87.

[24] P. Rousseau, *Catalogue Général Illustré des Instruments de Chimie et Ustensiles de Laboratoire, 1400 Figures: Produits Chimiques, Scientifiques et Industriels, Instruments de Physique, Verrerie, Porcelaine, Terre, Ustensiles de Laboratoires*. Compiègne, France: Impr. Henri Lefebvre, 1888, pp. 185–186.

[25] J.-A. d'Arsonval, "Régulateur de pression pour les vapeurs," *La Nature*, vol. 14, no. 402, p. 164, 1881.

[26] *Ministère des Postes et des Télégraphes, Congrès International des Électriciens Paris 1881—Comptes Rendus des Travaux*. Paris, France: G. Masson, 1882, pp. 155–157.

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