William F. Croswell
AP-S Historian
625 Manor Place
West Melbourne, FL 32904
(407) 729-3110

Alessandro Volta and His Battery

R. Cecchini
Department of Physics
University of Florence
L.go E. Fermi 2
50125 Firenze
Italy

G. Pelosi
Department of Electronics
University of Florence
Via di S. Marta 3
50139 Firenze
Italy

The Times

1750-1770

The publication of the *Encyclopédie,* to which all the more important French thinkers contributed, began in 1750[1]. The work immediately caused harsh polemics with the clergy and the government: there were numerous attempts to interrupt its publication, while the authors formed a sort of *parti des philosophes*, in a struggle against the reactionaries and obscurantists. In this way, the Enlightenment began to express the revolt against not only the old philosophical ideas, but also the old socio-political structures.

• The expulsion of the Jesuits from many European countries (Portugal, 1759; France, 1762; Spain, Kingdom of Naples, Duchy of Parma and Piacenza, 1767-68; the order was suppressed by Clemente XIV in 1773) marked a turning point in the laicization of education. New schools, which tried to tie theoretical study to the observations of the physical phenomena, were created (e.g. *École de Lyon:* 1762).

1770-1790

• The Russian-Prussian partition of Poland (1772) showed that even the "enlightened" sovereigns (Frederick II, Catherine II) pursued a cynical policy of power, notwithstanding their sympathies for the new ideas. At the same time, the Declaration of Independence (Philadelphia, 1776) evoked enthusiasm among the European progressists, and inspired the French revolutionaries of 1789.

Figure 1: A. Volta (by G. Garavaglia). Of the many existing portraits, perhaps the most faithful.

• In 1781-83, the American Colonies achieved their independence. New intellectual circles were born: the *American Academy of Arts and Sciences* in Boston (1780), the *Royal Society* of Edinburgh (1783), the *Svenska Akademie* in Stockholm (1786), the *Linnean Society* in London (1789), etc. The center of scientific life, however, remained Paris *(Académie des Sciences, Jardin des Plantes, Observatoire Astronomique)*.

• The Estates General were convened in Paris, in 1789. On July 14, the Bastille was taken, and ten days later, the Declaration of the Rights of Man and Citizen was voted.

• Between 1785 and 1789, Coulomb published the results of his fundamental studies on electricity and magnetism in seven memoirs.

1790-1810

• The suspicions of the French revolutionaries regarding scientific institutions led to the closure of the Academie des Sciences in 1793. The next year, the *École Polytechnique* was founded, with the aim of providing a scientific background (three years) to the young people destined to become officials or engineers (the contemporary *Ecole Normale Supérieure* was devoted to the training of future teachers). These schools were often taken as examples by similar institutions in other European countries.

• In 1800, Alessandro Volta announced the invention of the battery.

• In 1802, Young formulated his theory for the explanation of interference phenomena, based on the hypothesis of the wave nature of light. In the same year, he carried out his famous diffraction experiment, and estimated the first value for the wavelength of light.

• Napoleon Buonaparte's policy of science was characterized by a great attention to national prestige and an openness toward new ideas and disciplines, if they had potential technological applications. The main instrument was the *Institut de France* (which replaced the Academie des Sciences), of which Buonaparte became a member in 1797. Napoleon (First Consul, 1799-1804; Emperor, 1804-1815) thought that scientists and their institutions should more directly serve the state. As a consequence, many scientists, more or less willingly, moved into public administration.

1810-1830

• Napoleon's defeat (Leipzig, 1813; Waterloo, 1815), the Congress of Vienna (1815), the Quadruple and Holy Alliance, and the Restoration had a great impact on scientific life, too. In all the countries, controls on culture, sciences, and arts became extremely tight, even if the return to the culture of the *ancien régime,* desired by many, was impossible.

• In 1816, Fresnel and Arago performed their famous experiments on the interference of polarized light.

• In 1820, H. C. Oersted opened the discussion on the nature of electromagnetic phenomena, with a memoir in which he described the magnetic effects of an electric current.

• A. M. Ampère presented his theory on the electrical nature of magnetism, in a fundamental memoir of 1823 (published only in 1827).

The life[2]

Alessandro Volta was born into an impoverished noble family in Como, on February 18, 1745, sixth of the seven children of Filippo (1692-*ca.* 1752) and Maddalena (*d.* 1782). His debut in life was not brilliant, as he only began to speak fluently at seven years. His first studies where humanistic: his uncle, who took care of him and his brothers when they became orphans, wanted him to be a lawyer. However, soon he showed interest for the natural sciences, helped and encouraged in this by his older friend, Gattoni.[3]

In 1763, Volta was encouraged to devote himself to experimental research by G. B. Beccaria[4] and J. A. Nollet, the chief authorities on electricity at the time. To the former, he wrote a letter in which he presented a theory–later repudiated–according to which the electrical phenomena arose entirely from an attractive force between the electrical fluid and the matter. Beccaria, a very testy man who believed in Franklin's theory of a self-repulsive electrical fluid, didn't answer until, a year later, Volta apologized for his "very frivolous chatter."

In 1774, Volta was appointed headmaster of the State Gymnasium, in Como. In 1775, he made his first great invention: the electrophorus (he called it *elettroforo perpetuo,* Figure 2).[5] The same year, he was appointed Professor of Experimental Physics at the Gymnasium–according to his request and without the usual examination–and in 1779, at the University of Pavia,[6] a post he would hold for almost forty years. He was a very popular professor and, with Beccaria, he pioneered the teaching of experimental physics in Italy. A new hall was built for his lectures, along with an important collection of instruments, which he continued to augment. In 1785, the students, as was the custom, elected him Rector of the University.

In 1776, Volta interrupted the studies on electricity to devote his attention to an inflammable gas emitted from the ground. (It

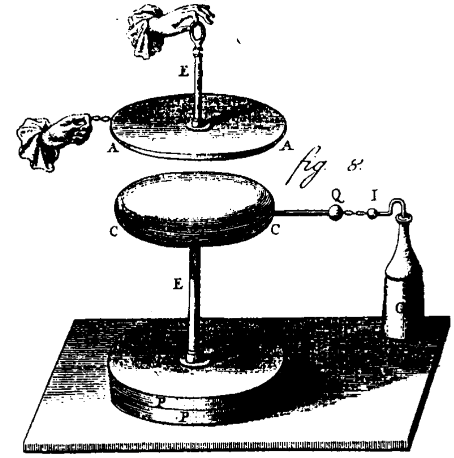

Figure 2: The *elettroforo perpetuo* [1, 3:101].

was methane, then called "inflammable air."[7]) He found it in marshy terrain (first in Lago Maggiore, then in Lago di Como), showed how it differed from hydrogen, and advanced the hypothesis of its organic origin. He even thought of using the gas as the detonant in a pistol he invented: the ignition was provoked by an electric spark.[8]

A slight modification of the pistol led to the building of the *eudiometer,* an instrument to measure the quality of air.[9]

In a letter to H. B. de Saussure–the famous naturalist, whom he had personally met during a learning trip in Switzerland and Alsace in 1777–in 1778, Volta presented his new theory on the capacity of electrical conductors. He changed the theoretical structure of his early works, and performed a complete study with the introduction of new properties, operatively defined, which he called "tension" and "electric capacity."[10]

From single conductors, Volta then went on to study the behavior of multiple conductors. His need to reveal very low quantities of electricity, originated by his meteorological studies, led him to the invention (in 1780) of the famous instrument that he called "condenser of electricity," sensitive to electricity too weak to be revealed with other instruments.[11] In the memoir to the Royal Society in which he described the instrument [2], he enunciated the principle that the quantity of electricity of a conductor is proportional to its capacity and potential ($Q=CV$).

Volta's last pneumatic studies centered on the effect of heat on gases and vapors. In 1784, in a letter to Lichtenberg, Professor of Physics at the University of Gottingen, he outlined the law usually attributed to Dalton:

> the quantity of elastic vapor is the same in a space either void of air or filled with air at any density, and depends only upon the degree of heat. [1, 1:301]

Moreover, he measured the dilation of air as a function of temperature, obtaining a value of α (the percentage increase in volume of a gas per degree of temperature) for air (about 1/216), better than the one deduced by Gay-Lussac (1/213). They measured α from the dilation between freezing and boiling points only, while Volta measured it for each degree. Since Volta published his results in a paper which was not widely read outside of Italy, his priority was ignored. However, a unanimous vote of the International Congress

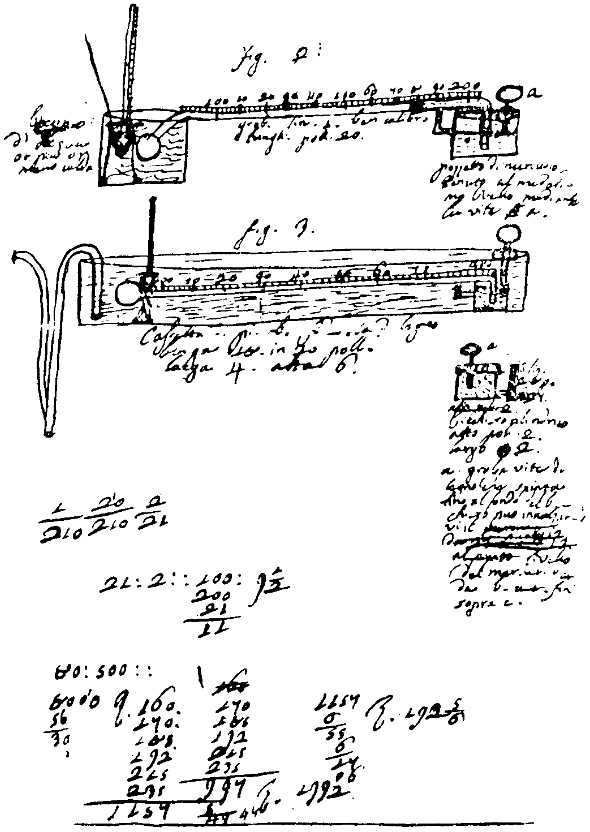

Figure 3: Volta's apparatus used for the study of the dilation of air [3].

of Physicists, held in Como in 1927, gave Volta credit for the proposition, "the coefficient of expansion of air is constant."

The controversy with Luigi Galvani (1737-1798)[12] was fundamental to the invention of the battery. Galvani thought that the phenomenon was caused by a sort of "animal" electricity, different from the usual "frictional" one, produced by the brain or another nervous center. He presented the results of his experiments in a communication to the Academy of Sciences of Bologna, in 1791 [4,5].

At first Volta was an enthusiastic supporter of Galvani's theory, and tried to determine the sign of the current produced by the frog. Soon, however, he changed his mind. After many experiments, he noted that the frog's contractions were more evident if the conductor was bimetallic. From this observation, in a memoir of 1792, he concluded that the frog's movements were caused by the effects of an ordinary current, produced by the bimetallic arc.[13] The electricity involved in the phenomenon was of the same kind as the one produced by the electrostatic machines, and the frog was just a very sensitive detector. He attributed the formation of the current to the contacts of the bimetallic conductor with the frog's body fluids.[14]

When Galvani and his disciples (his nephew, G. Aldini, Professor of Physics at the University of Bologna, and E. Valli, physician) later succeeded in provoking the contractions without the use of a metallic conductor [6], he extended his theory with the hypothesis that the electricity is created not only by the contact of metallic (he called them "first class") with humid conductors ("second class"), but also by the contact of two different second-class conductors. By a very complete set of experiments, Volta was then finally led to the conclusion that there is *always* an electrical imbalance in the contact of two different conductors: very small if both are of second class, larger if one is first class, and larger still if both are first class.

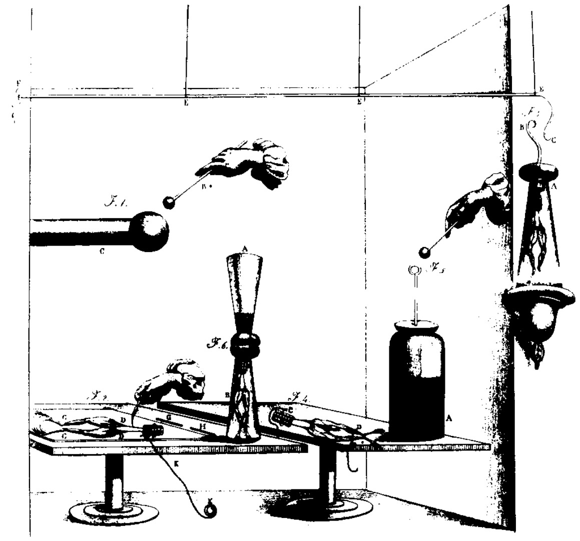

Figure 4: Galvani's experiment. The figure contains the terminal part of an electric machine (1); frogs prepared for the experiment (2, 3, 4, and 6) and a Leyden jar (5).

From this set of experiments, Volta was then led to the invention of the battery (Figure 5 shows two of the first examples), which he announced on March 20, 1800, in a letter to Sir J. Banks, President of the Royal Society [7, 8].[15] Volta's results were so stunning that they completely overshadowed Galvani's research.[16] As a consequence, the study of electrophysiology ceased for many years [9].

In 1801, he was invited to the Institut de France, upon a suggestion by Napoleon, where he read a memoir on the identity of the electrical fluid with the galvanic fluid. This was the apex of his scientific career. Following Napoleon's proposal, the Institut de France awarded Volta a gold medal and a large sum of money.[17] Napoleon's favors didn't stop: Volta was given an annuity in 1805, was appointed Senator of the kingdom of Italy in 1809, and made a Count in 1814. Buonaparte's defeat didn't mark the end of Volta's career as the Austrian government appointed him Director of the Faculty of Philosophy at the University of Pavia.

Unfortunately, Volta's success marked the end of his scientific life. In 1819, he retired to private life in Como, where his physical and intellectual decline began. He died on March 5, 1827.

Volta's behavior in private life was rather original for the times. Although he chose clerics as his favorite friends, remained close to his brothers the Canon and the Archdeacon, and was a fervent Catholic, he was far from ascetic: according to his friend Lichtenberg he "understood a lot about the electricity of women." He never showed interest in marriage until late, when he decided to marry a famous singer, Marianna Paris, whose favors he had enjoyed for many years. The opposition of the family and, in particular, of his brother the Archdeacon Luigi, obliged him to aban-

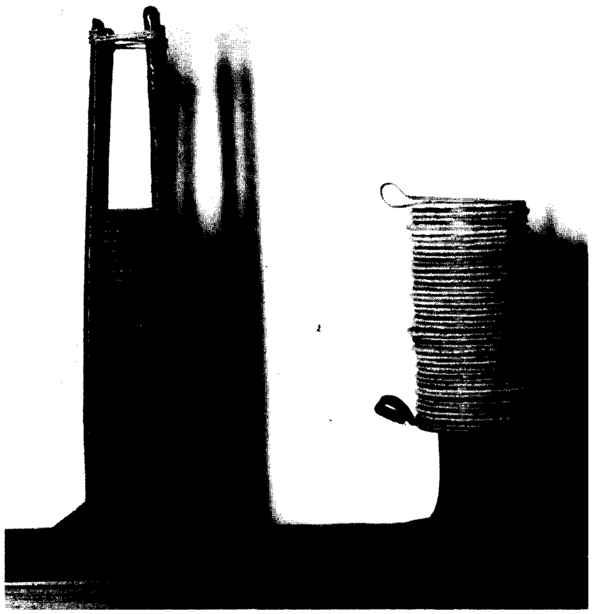

Figure 5: Two of the first batteries. (Courtesy of the National Science and Technology Museum "Leonardo da Vinci," Milan.)

don his intention. After many discussions, in 1794, he was persuaded to marry Maria Alonsa Teresa Pellegrini, daughter of a government official in Como, much more socially acceptable, who gave him three sons: Zanino, Flaminio Luigi–the favorite, whose early death, in 1814, caused the father great grief–and Luigi.

Volta's battery[18]

It is easy to understand the difficulties that Volta encountered in his experiments, if we consider that the contact of zinc and silver develops about 0.78 volt, while Volta's most-sensitive electrometer marked about 40 volts/degree [10]. He overcame these difficulties using instruments invented by others (e.g., the Bennet's [11] and Nicholson's [12] doublers, Cavallo's multiplier [13], and Bennet's gold-leaf electroscopes) and by himself: first of all, the "condensing electroscope" (Figure 7), a combination of a condenser and a straw electrometer.

Volta's notebooks don't allow a precise reconstruction of the process that led him to the construction of the battery: all of 1799 is characterized by a complete silence on it. In some letters, Volta writes of works that are giving surprising results, but hides all the details. The first announcement of the battery is in the famous letter to Sir Joseph Banks (Figure 6). The letter–of which several drafts can be found among Volta's papers–is a treatise on the battery, described in the two basic forms: the "pile" and the "crown of cups" (Figure 8).

> The apparatus to which I allude and which will, no doubt astonish you, is only the assemblage of a number of good conductors of different kinds arranged in a certain manner. Thirty, forty or more pieces of copper, or rather silver, applied each to a piece of tin, or zinc, which is much better, and as many strata of water or any other liquid which may be a better conductor, such as salt water, ley [lye], etc., or pieces of pasteboard skin etc. well soaked in the liquids; such strata are interposed between every pair or combination of two different metals in an alternate series, and always in the same order of these three kinds of conductors are all that is necessary for constituting my new instrument.
>
> [· · ·]
>
> To this new apparatus, much more familiar at bottom, as I shall show, and even such as I have constructed it, in its form to the natural electric organ of the torpedo or electric eel, etc. than to the Leyden flask, and electric batteries, I would give the name the artificial-electric organ.

The crown-of-cups version, which produced a stronger and longer-lasting electric force, instead consisted of a series of cups filled with a salt solution, each cup containing an electrode of zinc and silver (Z and A, respectively, in Figure 8). The zinc electrode in each cup was connected to the silver one of the adjacent cell, and all the cups were arranged in a circle. He also discovered that the use of a connecting wire of different metal had no effect on the strength of the battery.

In the choice of the battery structure (the pile), Volta was perhaps influenced by a detailed description by Nicholson on the electric fish [14], and his guess that a machine could be built to give a shock like the torpedo's.

The similarity of the physiological effects of the battery to those of the Leyden jar, strongly supported Volta's belief that the phenomena of the pile were of electrical nature. Moreover, he supplied another very convincing proof: a disk of copper and one of zinc, held by an insulating handle, if applied to each other for a brief time, acquire a small electric charge, which can be revealed by an electroscope.

Volta explained the impossibility of building a purely metallic battery, i.e., without making use of an electrolyte. In 1801, he showed that, if disks of various metals are placed in contact, in any order, the extremes are in the same state as if they touched each other directly: the whole pile is thus equivalent to a single pair.

Volta tried to build non-metallic batteries, too. In 1804, for example, he made a battery composed of disks of bone soaked with water, sulfuric acid, and potash. The discouraging results, however, never diminished his certainty that a non-metallic battery could be made: of this the torpedo was a living proof.

Volta's classic battery--mostly metallic--had the advantages of sturdiness and power, over the wet batteries. Portable piles could be built, like the one he brought to Paris, in 1801, to show the French scientists and Napoleon, who asked Volta to supervise the construction of a powerful battery: one capable of breaking metal bars.

Volta was incapable of evaluating the importance of his invention, and didn't forecast its possible applications. When it was used to electrolyze alkali salts, it lead Humphry Davy (1778-1929), Professor of Chemistry at the Royal Institution in London, to discover the electrolysis of sodium and potassium,[19] while studies of the properties of the current led to the laws of Oersted, Ohm, and Faraday. In this, Volta played no part: he was not interested in the chemical effects of the pile, which he considered secondary phenomena. All the attention he devoted to Galvanism–even after his triumph–was aimed at rejecting the theory of animal electricity.[20] His theoretical explanation of the apparatus didn't consider the phenomenon of polarization: he attributed the source of the electromotive force to the contact between the

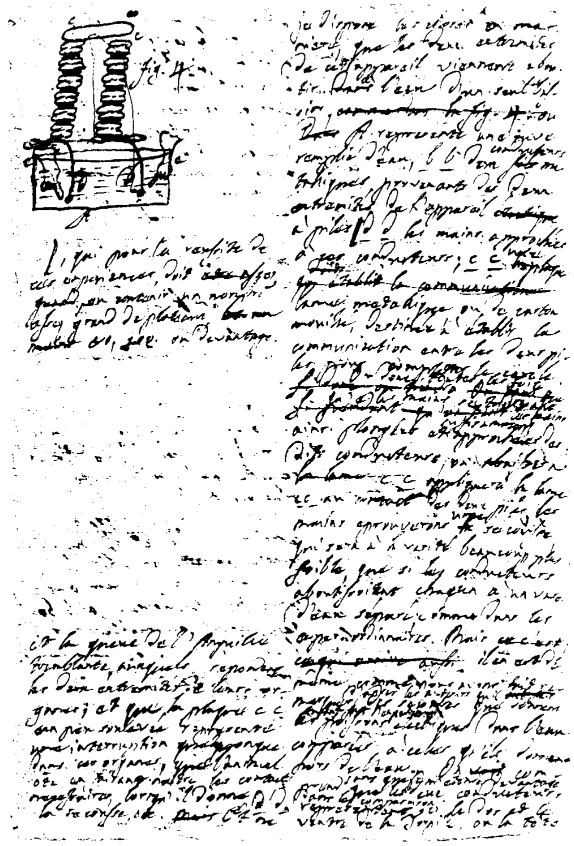

Figure 6: Manuscript of the letter from Alessandro Volta to Sir Joseph Banks, in which he announces the invention of the battery, dated from Como, March 20, 1800 [1, 1:572].

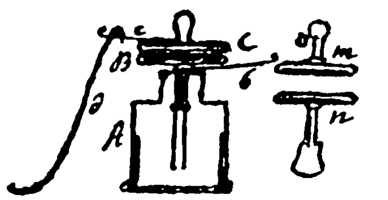

Figure 7: Volta's sketch of the "condensing electroscope," March, 1799 [1, 3:440].

different metals. He thought that the moist layers had no role beyond that of conductors (the major efficiency of the pile when the moisture is acidified was attributed solely to the better conductivity of acids),[21] and regarded the production of the electric current as something similar to perpetual motion ("an inexhaustible charge, a perpetual action or impulsion on the electric fluid" [7]).

It was Sadi Carnot, 24 years later, who pointed out the fundamental error in Volta's theory.

> Sometimes, the electromotive apparatus [Volta's battery] has been considered capable of producing perpetual motion; attempts had been made to prove this idea by building a dry battery thought to be unalterable.

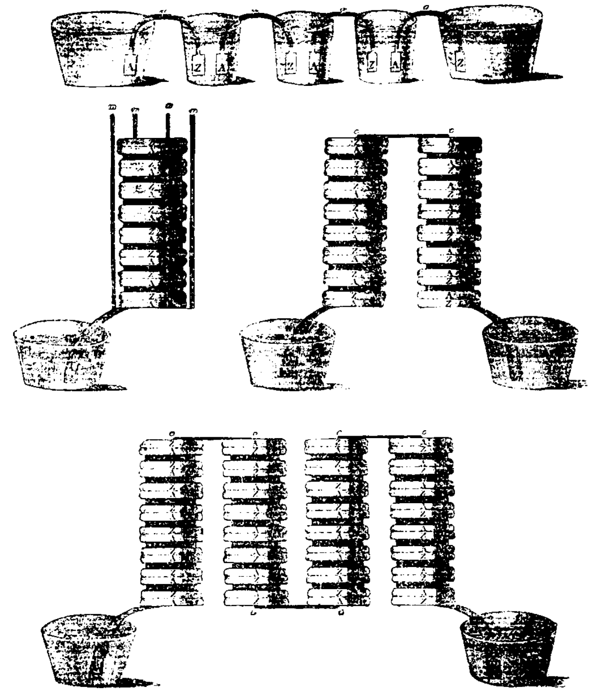

Figure 8: The "pile" and "crown" versions of the battery [1].

> However the device always wore out, when used for a certain amount of time and with some production of energy. [15]

Acknowledgments

We would like to thank Dr. A. Lumini, of the National Central Library of Florence, for her help in the collection of the source material and illustrations.

Notes

1. Diderot's *Prospectus*, in which he explained the characteristics of the work, was published in this year. The first volume–with the famous *Discours préliminaire* by d'Alembert–was published the following year.

2. There are many biographies of Alessandro Volta: the most complete is perhaps [16], but [10] and [17] are also very exhaustive. A good introduction–in English–to Volta's life and works can be found in [18].

3. Giulio Cesare Gattoni (1741-1809) lived his whole life in Como. His main interests were moral philosophy, experimental physics, and the building of scientific collections. In 1765, he set up a cabinet and a museum–which became famous for its natural history collection–and in 1785, he organized a meteorological laboratory, where, with Volta, he studied the electricity conducted by a lightning rod, which was probably the first in Como.

Strangely enough, Volta, who always showed great respect for his benefactors, never thanked him for his help [10].

4. Giovanni Battista Beccaria (1716-1781) was a Friar of the Scolopi order. In 1748, he was appointed Professor of Physics at the University of Turin, where he renewed the teaching of Physics,

emphasizing the experimental character, as opposed to the Cartesian approach of his predecessors. His innovative behavior–and his bad temper–created many enemies for him. His main interest was research in the field of electricity, revitalized in those years by the invention of the Leyden jar (1745), and by B. Franklin's works. In his main work [19, 20], he formulated the principle that "every kind of electricity remains on the free surface of the bodies, without diffusing in their interior."

5. In the letter of June, 1775, to Priestley, he wrote that his instrument "electrified just once, briefly and moderately, never loses its electricity, and although repeatedly touched, obstinately preserves the strength of its signs."

The device consisted of a metal dish containing a dielectric cake and a wooden shield, covered by tin foil, with an insulating handle. The cake was first electrified by rubbing, then the shield was set upon it and grounded. After that, it could be removed and its charge transferred to other devices (a Leyden jar in Figure 2). The operation of charge transfer could be repeated many times.

6. He was nominated by Count Carlo di Firmian, Minister of the Austrian government ("immortal Maecenas, benefactor and greatest protector of the University," in Volta's words), who was modernizing the educational institutions of the Duchy of Milan.

7. Cavendish succeed in isolating inflammable air from metals (hydrogen released from acids) in 1766. Moreover, Franklin's description of a natural source of inflammable air had just been published by Priestley.

8. Indeed, he soon discovered that hydrogen mixed with common air ignited more readily. With it, his pistol could dent a piece of wood at fifteen feet.

He hypothesized many other uses for the inflammable air, even a telegraph: "I have a lot of beautiful ideas, which make use of the trick of sending an electric spark to ignite my pistol at a distance....I don't know for how many miles an iron rod, laid on the ground, which comes back or encounters a water canal for the return, could conduct...the spark. But I foresee that...streaks of humid ground would deviate the course of the electric fluid; but if the iron rod is kept high on the ground by poles...e.g. from Como to Milan and ends in the Naviglio Canal, which is in communication with my Lago di Como, I don't think impossible to ignite a pistol in Milan by a Leyden jar discharged in Como."

9. Two of Volta's friends, Marsilio Landriani–who introduced the term "eudiometry"–and Felice Fontana–who invented a famous eudiometer–hoped that the instrument could help in identifying malarial and other unhealthy regions. For a long time after they tried, without success, to correlate the measurements of their instruments with the insalubrity of the air in hospitals, marshes, etc.

10. Probably he was influenced in this work by the famous memoir Cavendish published in the *Philosophical Transactions,* in 1771, ignored or misunderstood by the vast majority of contemporary physicists.

11. The device is simply an electrophorus with a poor conductor as its cake. To use it, one connects the probe to the shield with a wire, waits, removes the wire, and raises the shield, which can then influence an electroscope. Volta's explanation was that the electrophorus soaks all the electricity from the probe, owing to its high capacity, while the shield, with a very low capacity, can reveal the collected electricity, even if very weak.

12. Galvani's fundamental experiment is well known: a freshly-killed and stripped frog jerks if the crural nerve and the leg muscles are touched with a metallic conductor.

It seems that the discovery of the phenomenon was purely casual. Galvani and some of his friends were experimenting with an electric machine, when one of the company casually touched a knife to a skinned frog that was ready to be cooked. Galvani's wife noted that, simultaneously with the contraction of the frog's muscles, the electrical machine had produced a spark [21].

A good account of this famous controversy can be found in [22].

13. Volta noted that this current can also be revealed by the taste senses, as he felt an acid taste touching two points of his tongue, one with a bit of tin and the other with a silver spoon in contact with it. ("Fortunately, I thought that our tongue is a naked muscle..., very mobile. There are, I told myself, all the conditions necessary to excite vigorous movements.")

14. In a letter to Tiberius Cavallo, Volta wrote: "But if he [Galvani] had but a little more varied the experiments, as I have done,...he would have seen that this double contact of the nerve and muscle, this imaginary circuit, is not always necessary. He would have found, as I have done, that we can excite the same convulsions and motion in the legs, and the other members of animals, by metallic touchings, either of two parts of a nerve only, or of two muscles, and even of different points of one muscle alone....I have discovered a new law, which is not so much a law of animal electricity, as a law of common electricity." (Quoted in [22, ref. 7].)

15. Banks communicated the news to Nicholson and Carlisle; a month later they set up the first pile made in England. During their experiments, they obtained the electric decomposition of water [23].

16. The last years of Galvani's life were clouded by personal misfortune, too: the death of his beloved wife and the deprivation of his post of Professor of Anatomy at the University of Bologna, as he refused allegiance to the new Cisalpine Republic. He died of heartbreak in 1798.

17. Arago wrote: "The customs, to say nothing of the regulations, of the Academy, hardly permitted following [Napoleon's] demand; but the regulations are made for ordinary circumstances, and the Professor from Pavia had been placed over the line. The medal was voted by acclamation: and as Buonaparte never did anything halfway, the visiting savant received the same day, from state funds, 2000 *écus* for his travel expenses." (Quoted in [24, ref. 87].) The French scientists, however, avenged themselves by rejecting Volta's admission as a Fellow of the Institute for three times (until 1803).

In June, 1802, Napoleon proposed a prize for galvanic studies. He offered the annual sum of 3,000 francs and an extraordinary award of 60,000 francs for particularly important experiments or discoveries. The first "annual" prize was conceded only in 1806 to P. Erman, for his work on galvanic conduction through flame.

18. On Volta's discovery, see [10, 25]. An interesting and detailed account, although purely hypothetical, can be found in [26].

19. He built, at the Royal Institution, a battery composed of more than 500 cells, with 600 square inches of metallic surface [27]. In 1807, he was awarded the Napoleon's prize for galvanic studies.

20. His last essay on the subject was submitted under the name of a student, in a prize competition announced in 1805, by the Italian Society of the Sciences, with the theme, "Explain with clarity and dignity, and without offending anyone, the question of Galvanism disputed by our worthy members Giovanni Aldini and Alessandro Volta." None of the papers submitted won the prize.

21. Indeed Davy, in November, 1800, had showed that Volta's battery give no current if the water between the plates is pure, and that their power is "in great measure proportional to the power of the conducting fluid substance between the double plates to oxidate the zinc."[23] The result was rather in contrast with Volta's theory.

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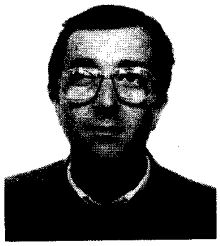
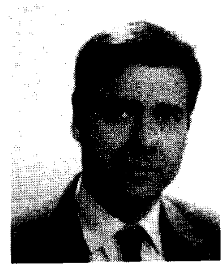


Roberto Cecchini



Giuseppe Pelosi

Roberto Cecchini was born in Pisa, Italy, on July 7, 1951. In 1975 he received the Laurea degree in Physics from the University of Florence. He first worked in the field of theoretical high energy physics, and then in private industries. At present, he is the Director of the Computing Center of the Department of Physics of the University of Florence. His main interests are in the fields of symbolic computation and image processing. R. Cecchini is a member of the IEEE and of the ACM.

Giuseppe Pelosi was born in Pisa, Italy, on December 25, 1952. He received the Laurea (Doctorate) degree in physics (cum laude) from the University of Florence, Florence, Italy, 1976. He first collaborated with the Department of Physics of the University of Florence, and then joined the Department of Electronics Engineering of the same university in 1979, where he is at present an Associate Professor. He has been involved in research related to solid state physics, radar systems, and asymptotic and numerical techniques in electromagnetic scattering. G. Pelosi is a member of the IEEE and of the Italian Electrical and Electronic Association (AEI).