Alessandro Volta and Luigi Galvani

Nov. 20/06

Moderator:

Good day (evening), ladies and gentlemen:

Welcome to this auspicious occasion, here in the year of 1798 at the University of Pavia. Professor Volta of this university invited his colleague Professor Galvani of the University of Bologna to a public discussion about the nature of electricity. Professor Galvani has been working on electric effects in biology for more than 10 years while Professor Volta has specialized in the study of electricity, working with metals and chemicals. They have significantly different ideas or, if you will, theories for explaining electric phenomena.

Both scientists are acclaimed in their respective fields and Professor Volta's work in electricity is now placed alongside those of Benjamin Franklin and Henry Cavendish.

Signor Galvani claims that there are three different kinds of electric fluids: The first is produced by friction, the second by lightning, and the third is found in biological bodies that he calls "animal electricity". Signor Volta, on the other hand, is convinced that there is only one kind of electric fluid, that electricity produced by friction, by lightning, and electric effects found in bodies are really one and the same. They have had a lively, but friendly, exchange of ideas about the nature of electricity, for over a decade.

The main reason for this debate, however, is that Professor Volta has recently claimed to have discovered a method of producing what he calls an "inexhaustible source" of electric fluid. We are looking forward to their discussion.
Applause

Galvani:
Buon giorno, Signores a Signori.

I am pleased that so many of you are interested in the nature of this mysterious fluid called electricity. Professor Volta and I have been trying to unravel the nature of electricity for many years. He invited me to Pavia for a public discussion, to present and debate our respective views or theories. We seem to agree on many aspects of electricity but have strong disagreements about some fundamental issues.

But first let me introduce myself. I was born in Bologna, in 1737. I first wanted to study theology and enter a monastic order. But, fortunately, I was persuaded by my father to take up the study of the natural sciences, specializing in an atomy and physiology.
He stops for a moment.

I know, usually, this is the other way around. I am glad I listen to my father.

Actually, I first trained as a physician, but was offered an appointment at the University of Bologna at the age of twenty-five to teach anatomy. Later I became professor of obstetrics at the Institute of Arts and Sciences. My research began with a doctoral thesis in comparative anatomy but later drifted toward physiology. I am still at the University and presently engaged in research into what I call “animal electricity”.

In the last 10 years or so, Professor Volta and I have had a “friendly” exchange of ideas about the nature of electricity itself. This long debate was occasioned by an amazing chance discovery I made about 12 years ago in 1786. However, I did not publish my experiments until last year, but I privately reported my findings to professor Volta.

On that day in 1786 I was dissecting frogs in my lab. I remember nearby my students were experimenting with our static electricity machine. I was to make a soup for my ailing wife, who had a nasty cold. As a physician I recommended frog soup and as an anatomist I carefully dissected the frog.

Now, two things occurred simultaneously causing me to stop and wonder. One of my students was drawing a spark from the brass conductor of the electrical machine when a knife held in his hand touched the exposed sciatic nerve passing through the lower part of the spine into the frog's legs. There was an immediate twitch of the muscles and a kick of the legs as if a severe cramp had set in. Actually, all the muscles of the frog’s limbs were seen to be so contracted that they seemed to have fallen into tonic convulsions. My students were astonished and one of them cried: “La rana e viva!“, or “the frog is alive!”

For the next 10 years I conducted many experiments. I used an electrostatic machine to produce electricity and also a Leyden jar, a device to store static electricity. I systematically began experimenting with muscular stimulation by electrical means. Through numerous observations and experiments I caused muscular contraction in a frog by touching its nerves with an electrostatically charged metal. I also experimented with lightning and found the same effect. I also found out that I was able to cause muscular contraction by touching the nerve with different metals but without a source of electrostatic charge. This discovery, of course, was surprising.

Now, I knew that this was not the first time that animal electricity was discussed. I knew about the powers of the electric eel, also known as the torpedo fish, that could actually provide a lethal electric shock, not unlike the one delivered by a large charged Leyden jar. But it was the first time that, what I now call “animal electricity”, was connected to natural or man-made electricity.
He stops for a moment and then concludes his introduction.

Based on these experiments I finally concluded that animal tissue contained an innate vital force, which I called "animal electricity." I believe this is a new form of electricity in addition to the "natural" form that produced lightning and to the "artificial" form that is produced by friction (i.e., static electricity). In addition, I believe the brain secrets an "electric fluid" and that the flow of this fluid through the nerves provided a stimulus for the muscle fibers.

Grazie, professore , Signores a Signori.
He bows and looks at Volta

Volta:
Turns to Galvani and acknowledges his greeting.

Mille grazie, Professor Galvani.
Turns to the audience

I am pleased that my good friend has agreed to come to Pavia to discuss the nature of electricity. I am sad to hear that he has been forced to retire last year, because it was against his conscience to sign a document that the University required of all professors, following the occupation of Northern Italy by the Napoleonic army. Being a man of integrity, he refused to take the oath of allegiance required of him by the invader.
But I am sure that he will continue his excellent scientific work.
Galvani smiles and nods. Volta turns to the audience:

I was born in Como, Italy, in 1745. into a noble family. I actually started my education in a Jesuit school, with the intention that I would become a priest, as many of my friends did. However, my passion had always been the study of electricity, and while still a young student I even wrote a poem in Latin about this fascinating new discovery.
I will spare you the reading of this silly poem today.

My first scientific paper was published in 1769 , when I was only 24 years old: "De vi attractiva ignis electrici", which was widely read and helped me secure my first public appointment. I became a teacher of physics in a secondary school in my hometown, but was soon appointed professor of physics in the University of Como. During this time I built the first lightning rod in Como, and perhaps in all of Italy, having read about the experiments of the American natural philosopher and statesman, Benjamin Franklin.

In 1775 I invented the electrophorus, a device that produced a large static electric charge. Two years later I studied the chemistry of gases, discovered methane, and devised experiments such as the ignition of gases by an electric spark in a closed vessel. In 1779 I became professor of experimental physics at the University of Pavia. In recognition of my work, a few years ago I received the Copley medal from the British Royal Society.
A great honor for me.

On the practical side of my work, I developed gas lanterns electrically ignited, and also constructed an "electric pistol." I know that the electric pistol is just a toy but it can be used to teach important ideas to students in both electricity and chemistry.

I have been intimately acquainted with Professor Galvani's work for many years now. In fact, it was his ideas about what he calls "animal electricity" that lead me to my own

recent discovery that I think will be important for the future of science.
He stops and then continues with emphasis.

I am now announcing for the first time that I believe that I have found a method to produce a continuous flow of electric fluid. From now on we physicists will not have to store electric fluid in devices like the Leyden jar to perform experiments such as the separation of water into hydrogen and oxygen. We will have a continuous supply available.
He turns to Galvani.

But now let us start our debate, Luigi. How did you go about developing your theory of "animal electricity"?

Galvani:
Oh, dio mio**.** The phenomenon I discovered was so strange and puzzling that I immediately repeated the conditions that caused the sudden kick in the frog legs. I soon realized that this chance discovery opened up a whole new field of investigation, so I proceeded to systematically investigate this phenomenon.

Volta:
Of course, as a physicist I would have never discovered this effect. Grazie, Luigi.

Galvani:
Prego, Alessandro.
I found, for example, that there was no such action when the hand grasped the bone handle of the knife instead of holding the blade itself. I also found that there was no action if the spark was not produced by the machine. Clearly, I thought that there must be a causal relationship between the electrical stimulus and the muscular contraction.

I confirmed this by alternately touching the exposed nerve with a glass rod and an iron probe.

Volta:
So you showed that a conductor was required.

Galvani:
Exactly**.** But what puzzled me was that contact with the nerve sometimes worked and at other times failed to produce a contraction. I tried everything I could think of. I used different materials, a Leyden jar instead of the electric machine. I also used different animals for my experiments.

Volta:
I remember you writing to me that you also experimented by exposing frog legs to lightning?

Galvani:
Indeed. I did some strange experiments that must have caused my colleagues to wonder about my sanity.
He laughs.

I exposed frog legs and dissected parts of warm-blooded animals to a lightning storm by hanging them from an iron railing. I connected the lower tip of the suspended part to a grounding wire. I then watched and waited.
He stops for a moment

Volta:
What happened? Don't keep us in suspense.

Galvani:
Well, as I expected, every time I saw lightning, the legs convulsed immediately.

Volta:
And there was no delay between the lightning and the effect?

Galvani:
Now that you mention it, ….that <u>is</u> strange. When we see lightning it often takes many seconds before the effect is heard. It seems that the effect is instantaneous.

But, of course, that would only interest a physicist like you, Alessandro.

Volta:
Investigating that, would initiate a whole new field of research,
But let us not stray from the topic.

Galvani:
Alora. Anyway, an already complex set of conditions now became even more challenging. I discovered something very puzzling. I noticed that when a copper or brass hook was pressed into the frog's marrow and hung from an iron railing I saw twitching even on a sunny and cloudless day.

Volta:
Clearly then lightning was not required to produce these contractions.

Galvani:
Si. I then took the frogs indoors and I found that the legs twitched. So this eliminated electricity generated by lightning as well as by an electric machine as necessary to produce the phenomenon.

This is very exciting. You were now ready to propose a theory for the effect?

Galvani:
Well, not quite. At this point I thought that there were two possibilities. I had to decide between them. The first one was that animals possessed a special electrical property that remained with them even after they died. The second explanation was that the contact of the metals somehow produced the effect.

Volta:
Molto interessante, Luigi.
He smiles and then continues

So the legs acted like an electroscope that would show the presence of a charge by the divergence of the metallic ribbons.

Galvani:
Certo. That, of course, occurred to me, too.
But, naturally, I chose the biological interpretation: I now argued for a vital force or an "animal electricity" that is present in animal tissue in general.

Volta:
Volta scratches his head reflectively.

Let me see if I understand this, Luigi. It seems to me that you visualize a living creature as functioning like a fleshy version of a Leyden jar. The nerve and the muscle would be analogous to the inner and outer charged surfaces of the jar.

Galvani:
Seen through the eyes of a physicist!

Volta:
Certo, Luigi.

Galvani:
So… when the outer surface of the muscle received an electric charge, the nerve and inner muscular surface would then become oppositely charged and …muscular contraction would follow.

Maybe we can now hear your ideas, Alessandro.

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Volta:
Well, over the years you and I have communicated and I was more or less acquainted with your work and ideas. I tried to repeat the experiments conducted by you , as far as I could, …but I am not very adept with a scalpel!
He laughs and looks at Galvani.

Finally, I came to the conclusion that there was a third possible explanation of this phenomenon.
He pauses.

The third possibility, of course, is that the electric effect is produced by two dissimilar metals, but without contact with a biological sample. Or, as I have just written in my letter to Sir Joseph Banks, the President of the Royal Society in London: …" a mere contact of conducting substances of different kinds" .

Galvani:
But how long would this electric effect last?

Volta:
Well, not very long.
Let me show you.
He takes a piece of copper and gives it to Galvani.

Luigi, put these dissimilar metals on your tongue..

Galvani:
Alright.
He places these slowly on his tongue and then makes a face.

Actually, I have tried this, too. But that does not falsify my "animal electricity" theory. It rather confirms it, I think!

Volta:
I agree. That is, it may confirm it. But I used the tongue test not to test your theory but as a primitive electroscope to determine the strength of the electric effect.

I found that a silver zinc combination gave the best effect.
He looks at Galvani

I believe you found this, too.

Galvani:
Indeed, I did.

Volta:
But I was looking for a source of a continuous electric effect. At this point I paced a salt –moistened soft discs between the silver and zinc metal plates.

The idea then occurred to me that that I could build a vertical Pile, coupling the plates while alternating them and interpose between each of them a moistened disc. I piled them high, up to dozens in one Pile.

Galvani:
Fascinating. How did you test the size of the electric effect now?

Volta:
Good question.
Of course, a charged Leyden jar does affect the leafs of an electroscope. The tongue test is a good start for finding the strength of a week electric tension but I needed something better. What I did was connect a condenser made of two plates, much like a Leyden jar, to the electroscope. The electric fluid that was produced by the Pile then built up the charge and the leafs deflected.

Galvani:
But a charged Leyden jar will also affect an electroscope. How did you show that the electric fluid produced by your Pile flows continuously?

Volta:
You are right. What I found though was that, unlike the charged Leyden jar, my Pile continues to effect the electroscope indefinitely. Unlike the Leyden jar that has an insulating separator, the Pile consists of conductors that are separated by a salt or acid-soaked soft discs. In fact, the larger the Pile the higher is the electric tension produced.
He stops for a moment and looks at the audience

But let me hastily add that an electric Pile, no matter how many units of dissimilar plates are connected, can never produce an electric tension as high as that of a charged Leyden jar.
He pauses and then continues.

I should mention that I have been able to separate water into two gases, now known as hydrogen and oxygen, in a continuous process, rather than using the laborious approach of many applying discharges from a Leyden jar, as Cavendish accomplished about ten years ago.

Galvani:
That is very impressive, Alessandro.
But how do you explain the powers of the electric eel? There are no metallic plates inside the torpedo fish.

Volta:
I am not a biologist but I have seen dissected torpedo fishes. At least now, it seems to me that they produce electricity much like my electric Pile does. There are hundreds of small organic discs that are connected like the plates are in my Pile. So my electric Pile can be considered the artificial analogue of the natural one found in the torpedo fish.

Moderator: Gentlemen, let me summarize.
Professor Galvani, who is a biologist and physician by training, based on his work of over a decade, studying the connection between electricity and animals, has come to the conclusion that there are three identifiable forms of electricity: Electricity produced by lightning, electricity produced artificially by rubbing and electrostatic machines, and what he calls "animal electricity", that is produced organically by animals.

On the other hand, professor Volta, a natural philosopher by training, having specialized in studying electricity, is convinced that professor Galvani is mistaken when he classifies electricity as just described. He believes that there is only one kind of electricity and the classification of Professor Galvani is artificial and, -- well, simply wrong.

Based on what we have heard, I don't believe we can settle the matter now. Perhaps in the near future we will have clarification on this important topic.
Turning to the professors:

Gentlemen, thank you for the discussion. What we have heard is a clear presentation of the two views. Gentlemen, may we have brief concluding remarks:

Galvani :
Mille gracie, professor Volta, for inviting me to Pavia. I have learned a lot tonight about your work and I have a clearer idea about your method of experimentation and your theoretical thinking. I am looking forward to seeing your laboratory and the performance of your electric Pile.
He pauses and then emphatically says:

But I still think that future investigators will find that there is an "animal electricity"!.

Volta:
Gracie tanto, Professore. I, too, have learned a lot. Although I still believe that there is only one kind of electricity, your findings and the mysterious way the torpedo fish produces electric charges *is puzzling.*
They shake hands.

Volta:
Let me take you for dinner and some good wine and then we will visit my laboratory where my assistants are preparing some demonstrations for you.

Galvani:
Gracie, andiamo, Alessandro.
They leave, laughing and talking amiably.

Moderator:

Volta''s discovery was a sensation, for it enabled high electric currents to be produced for the first time. It was quickly applied to produce electrolysis, resulting in the discovery of several new chemical elements, and this led throughout the 1800s to the great discoveries of electromagnetism and electronics that culminated in the invention of the electrical machines and electronic devices that we use today.

Volta graciously honored his friend by calling electric current “galvanic fluid”. The instrument that first measured electric current, after the discovery of Oersted in 1819 that an electric current produces a magnetic effect, was named a galvanometer.

A few months later Galvani died a broken man but Volta lived a long life and died in 1827. After 1801, when he toured Europe and was celebrated (Napoleon made him a count) all over Europe, he retired and stopped his scientific work. There is a large building in Pavia called “The Volta Temple” that commemorates his work.

We now know that both Volta and Galvani were right. Biologists and physicians have mapped out how the body produces its own electricity.

As it often happens in science, when two major theories are confronting each other, it turns out that the theories are complementary ;

Wave theory and particle theory for light, for example.

And I pursued this idea, and I am pleased to announce that it lead to

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He observed that Galvani had connected brass hooks between the frog's spinal cord and an iron railing. According to Volta's interpretation, the muscle twitches were induced by current flowing between two dissimilar metals connected by the moist

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In the strange case of Galvani's frog, this twitching happened even when its legs were not in a direct circuit with the machine. Galvani had placed the lower section of a dissected frog on a table near a plate-type electrical machine.

which he called "animal electricity" - was generated in the tissue of the frog and, flowing through the metal skewer and fence, activated the frog's muscles. He distinguished this kind of electricity from "artificial electricity" generated by friction (static electricity) and from "natural electricity" such as lightning. He thought of "animal electricity" as a fluid secreted by the brain, and proposed that flow of this fluid through the nerves activated the muscles.

flesh of the frog's leg. This led him to develop the first device which demonstrated chemical production of electric current. In 1799, Volta arranged a vertical Pile of metal discs (zinc with copper or silver) and separated them from each other with paperboard discs that had been soaked in saline solution. This stack became known as the voltaic Pile and was the progenitor formodern alkaline batteries.

In 1791, while working at Bologna University, Luigi Galvani discovered that the muscle of a frog contracted when touched by a metallic object. This phenomenon became known as animal electricity — a misnomer, as the theory was later disproven. Prompted by these experiments, Volta initiated a series of experiments using zinc, lead, tin or iron as positive plates. Copper, silver, gold or graphite were used as negative plates.

The next stage of generating electricity was through electrolysis. Volta discovered in 1800 that a continuous flow of electrical force was generated when using certain fluids as conductors to promote a chemical reaction between the metals or electrodes. This led to the invention of the first voltaic cell, better know as the battery. Volta discovered further that the voltage would increase when voltaic cells were stacked on top of each other.

In his pursuit of the current generated by his primitive batteries, Volta

In seeking further experimental evidence in favour of his contact theory, Volta was led to the greatest of his inventions, the voltaic "Pile", which he described in a communication of 20 March, 1800, to Sir Joseph Banks, President of the Royal Society of London.

The twitching of frog's legs under electrical stimulus, discovered by Swammerdam in 1658 and re-discovered and described by Galvani in 1786, occasioned a memorable controversy as to the cause of the convulsive movements; after years of discussion the "animal electricity" of Galvani was superseded by the "contact theory" of Volta.

was the inventor of the voltaic Pile, the first electric battery. In 1775 he invented the electrophorus, a device that, once electrically charged by having been rubbed, could transfer charge to other objects. Between 1776 and 1778, Volta discovered and isolated methane gas.

that led Volta to build the voltaic Pile to prove that electricity did not come from the animal tissue but was generated by the contact of different metals, brass and iron, in a moist environment. Ironically, both scientists were right.

Volta, a former high school physics teacher, found that it was the presence of two dissimilar metals, not the frog leg, that was critical. In 1800, after extensive experimentation, he developed the voltaic Pile. The original **voltaic Pile** consisted of a Pile of zinc and silver discs and between alternate discs, a piece of cardboard that had been soaked in saltwater. A wire connecting the bottom zinc disc to the top silver disc could produce repeated sparks. No frogs were injured in the production of a voltaic Pile.

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He is famous more especially on account of his experiments concerning "the electrical forces in muscular movements", leading up to his theory of animal electricity. This began with the accidental observation, in 1780, of the twitching of the legs of a dissected frog when the bared crural nerve was touched with the steel scalpel, while sparks were passing from an electric machine nearby. He worked diligently along these lines, but waited for eleven years before he published the results and his ingenious and simple theory. This theory of a nervous electric fluid, secreted by the brain, conducted by the nerves, and stored in the muscles, has been abandoned by scientists on account of later discoveries, but Galvani was led to it in a very logical manner and defended it by clever experiments, which soon bore fruit. Thus he discovered that when nerve and muscle touch two dissimilar metals in contact with each other, a contraction of the muscle takes place; this led ultimately to his discussions with Volta and to the discovery of the Voltaic Pile. The name Galvanism is given to the manifestations of current electricity.

Galvani was by nature courageous and religious. It is reported by Alibert that he never ended his lessons "without exhorting his hearers and leading them back to the idea of that eternal Providence, which develops, conserves, and circulates life among so many divers beings". His works (Opere di Luigi Galvani) were collected and published by the Academy of Sciences of the Institute of Bologna (1841-42). The following are some of the titles, with the original dates of publication in the "Antichi Commentari" of the Bologna Institute: "Thesis: De Ossibus" (1762); "De Renibus atque Ureteribus Volatilium" (1767); "De Volatilium Aure" (1768-70); "De Viribus Electricitatis in motu musculari commentarius" (1791), reprinted at Modena, 1792, with a note and dissertation by Gio. Aldini; translated by Mayer into German (Prague, 1793), and again

Italian physiologist, after whom galvanism received its name, born at Bologna on the 9th of September 1737. It was his wish in early life to enter the church, but by his parents he was educated for a medical career. At the University of Bologna, in which city he practiced, he was in 1762 appointed public lecturer in anatomy, and soon gained repute as a skilled though not eloquent teacher, and, chiefly from his researches on the organs of hearing and genito-urinary tract of birds, as a comparative anatomist. His celebrated theory of animal electricity he enunciated in a treatise, "De viribus electricitatis in motu musculari commentarius", published in the 7th volume of the memoirs of the Institute of Sciences at Bologna in 1791, and separately at Modena in the following year, and elsewhere subsequently. The statement has frequently been repeated that, in 1786, Galvani had noticed that the leg of a skinned frog, on being accidentally touched by a scalpel which had lain near an electrical machine, was thrown into violent convulsions; and that it was thus that his attention was first directed to the relations Of animal functions to electricity. From documents in the pdssession of the Institute of Bologna, however, it appears that twenty years previous to the publication of his *Commentary* Galvani was already engaged in investigations as to the action of electricity upon the muscles of frogs. The observation that the suspension of certain of these animals on an iron railing by copper hooks caused twitching in the muscles of their legs led him to the invention of his metallic arc, the first experiment with which is described in the third part of the *Commentary*, with the date September 20, 1786. The arc he constructed of two different metals, which, placed in contact the one with a frog's nerve and the other with a muscle, caused contraction of the latter. In Galvani's view the motions of the muscle were the result of the union, by means of the metallic arc, of its exterior or negative electrical charge with positive electricity which proceeded along the nerve from its inner substance. Alessandro Volta, on the other hand, attributed them solely to the effect of electricity having its source in the junction of the two dissimilar metals of the arc, and regarded the nerve and muscle simply as conductors. On Galvani's refusal, from religious scruples, to take the oath of allegiance to the Cisalpine republic in 1797, he was removed from his professorship. Deprived thus of the means of livelihood, he retired to the house of his brother Giacomo, where he soon fell into a feverish decline. The republican government, in consideration of his great scientific fame, eventually, but too late, determined to reinstate him in his chair, and he died at Bologna on the 4th of December 1798.