History of the electrical units.

lundi 10 septembre 2012, par Gérard Borvon

To take advantage of the first international exhibition on electricity held in Paris in 1881, it was decided that an international congress of "electricians" would be held during the exhibition.

This meeting was not just a friendly get-together. It was of paramount importance that an international system of electrical units be set up.

The day when the electricians gave birth to a universal language.

As any beginner in physical sciences would know : each physical "quantity" is necessarily linked up with its unit. In the field of electricity, the ampere, the volt, the watt are so commonplace that anyone who has changed an electric bulb or a fuse is familiar with these terms. This applies to the vast majority of people living on this planet whatever their standard of education.

Now, the question is : when, where and how these units were defined.

The decimal metric system.

The creation of the decimal system is not actually all that old. One name stood out at the time : Lavoisier. According to Lavoisier, only a decimal system would enable chemists of different nationalities to communicate together and, more generally : scientists, craftsmen, traders and professionals whose activities required a measurement system.

In his "Traité élémentaire de chimie", (Elements of chemistry), published in 1789, Lavoisier strongly advocated such a system. He had already calculated conversion tables and had had scales fitted with boxes of decimal masses. Lavoisier was a member of the committee appointed by the revolutionary authorities to create a decimal model of measures. However before achieving his mission Lavoisier was arrested and guillotined.

On April 7th 1795 (18 germinal de l'an III), the metre and the gramme became the republican units of measure, and the decimal system was established. Greek prefixes, "déca", "hecto", "kilo" were chosen for multiples and latin prefixes "déci", "centi", "milli" for submultiples. This system was to become, as Lavoisier had wished, a true universal language.

Let's come back to measures and electrical units.

In order to take a measurement, it is necessary to define a quantity (intensity, tension, etc...) and to conceive a reliable instrument to measure it.

Throughout the XVIIIth century, various devices with straw, wire, gold leaf... were made to estimate tension or electrical charge. They were considered as "electroscopes" rather than "electrometres" as it was impossible, at this time, to compare two measures carried out with different instruments.

The discovery of the electrical battery in 1800, then, of electromagnetism in 1820 made way, at last, for a study of electricity through measures. A quantity of electricity could now be properly measured through electrolyse by considering the volume of gas that emanated from the electrode or the mass of metal which settled on it. Later on, the intensity of a current would be assessed through its action on a magnetic needle or on another electrical circuit.

Throughout the XIXth century, engines, generators, lighting devices, were developed on an industrial scale. All this activity prospered thanks to a strict means of measure. It now demanded common standards. Instruments of measure were conceived and at the same time units were discussed. Initiatives were, at first, dispersed until harmonization was felt necessary.

UK in the lead.

In this field, the UK was well ahead of other European countries. Since 1863 the British Association for the advancement of science had established a unit system that was partially accepted internationally under the name : "System of the British Association" or BA System (for British Association).

Through this system British scientists were determined to rank electricity among academic sciences. The mechanic science was, as the time, the model. Electrical units should therefore be deducted from the three basic units in mechanics : the metre, the gramme, the second.

In 1873, William Thomson (who was to become Lord Kelvin) suggested that the metre be replaced by the centimetre more suited for measuring volumic masses. The system was then known as the CGS system. Let us make a point here on the "clear-sightedness" and intellectual courage of British "electricians" who accepted the centimetre and the gramme, both continental and revolutionary measures, in a country so proud of its insular traditions.

In 1875, the "metre convention", signed by diplomats of seventeen states, gave this document its official character. At the same time the "General Convention for Weights and Measures" (GCWM) and the "International Bureau of Weights and Measures" (IBWM) were created. Their head office was based at the "Pavillon of Breteuil" in Sevres near Paris.

Beside the theorical CGS system, the British Association defined a system of practical unit in which the unit of resistance was called "ohm", the unit of electromotive force "volt" and the unit of intensity "weber". This was a tribute paid to three scientists who contributed to the advancement of electric science. These three units were linked by the formula "I = E/R " which translated the relation established by Ohm between the tension of the resistance terminals and the intensity of the current passing through it. One weber is, consequently, the intensity of the current that circulates in a resistance of one ohm under the action of an electromotive force of one volt.

Both France and Germany use resistance, voltage and intensity as basic concepts. In the two countries though, the units are primarily considered as standards adapted to the work of their own engineers. Electricians do not speak one single language.

Before 1881 : there were different national systems.

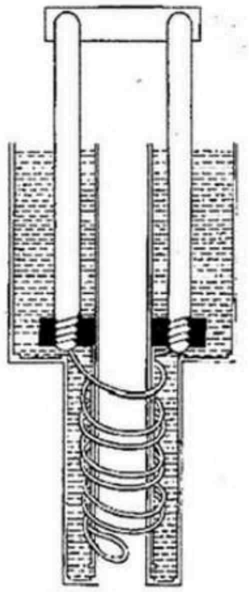
Units of resistance.

In the UK we have already noted the choice, by the British Society, of a theorical unit, a practical unit and standards. Let's be more precise in the matter.

The theorical unit : There is a problem with the coexistence of two possible theorical systems : the electrostatic system and the electromagnetic system (cf : how to build a coherent system of electrical units). For practical reasons in connection with industrial applications, it was the CGS electromagnetic system which was chosen. In this system the resistance had the dimension of speed. Its theorical unit was therefore the cm/s.

The practical unit : The value of the CGS theorical unit (cm/s) corresponded to a very low resistance. The British Association, therefore, selected a practical unit more convenient to measure ordinary resistances. It corresponded to 10 million metres per second (109 CGS units). It was then called ohm. It is to be remembered that 10 million metres correspond to a quarter of the length of the earth meridian, the universal value which is used to define the metre.

The standards : Once this practical unit was defined, standards had to be made. These were made from metallic resistances deposited in London. Maxwell, who was in charge of the committee, was tasked to determine these standards, describing them as "made of an alloy of two parts of silver and one of platinum in the form of wires from 5 millimetres to 8 millimetres diameter, and from one two metres in length. These wires were soldered to stout copper electrodes. The wire itself was covered with two layers of silk, imbedded in solid parafin, and enclosed in a thin brass case, so that it can be easily brought to a temperature at which its resistance is accurately one Ohm. This temperature is marked on the insulating support of the coil." (See Fig. 27.)".



In France, one calculates in kilometres of resistance. This unit, established by Breguet with the telegraphists in mind, was represented by the resistance of a telegraphic wire 4 millimetres in diametre and one thousand metres long. This unit was approximately worth 10 ohms. Standards were made but their values depended largely on the quality of the iron used.

In Germany they used the Siemens unit (SU symbol) which is the resistance of a mercury column, one metre long and one square millimetre in section. Its value is approximately 0,9536 ohm.

Units of electromotive force.

The CGS unit of electromotive force (which should be cm3/2.g1/2.s-2) has a very low value too. The British Association chose, therefore, as their practical unit of electromotive, the volt, which has a value of 108 CGS units. It is, more or less, represented by the electromotive force of the Daniell cell. Let's bear in mind that this cell developped by Daniell, in 1836, had a copper electrode immersed into a saturated solution of copper sulphate associated with a zinc electrode immersed into a solution of zinc sulphate. This "impolarisable" cell had a constant f.e.m of 1,079 volt. The Daniell battery was a standard reference in France and Germany.

Intensity units.

The practical unit of the British Association is the weber, intensity of a current crossing a resistance of one ohm with an electromotive force of one volt between its extremities. Its value corresponds to 0,1 CGS units (the CGS unit being cm1/2.g1/2.s-1).

This unit is very convenient for it gives us a tool to write the whole range of current intensities used in industry. At the very bottom of the scale, the intensity of phone currents is only a few microwebers and that of the telegraphic currents is a few milliwebers. At the other end of the scale the currents produced by the "Gramme machines" oscillate between twenty to thirty webers or the currents which "feed" the plating tanks can reach values up to one hundred webers.

The electromagnetic appliances used to measure currents were spreading. They were graduated according to their purpose in webers or milliwebers. In normal use, a current of one weber deposits 1,19 grammes of copper per hour on the cathode of a copper sulphate electrolyser.

In Germany the intensity unit was the one that crosses a siemens resistance linked to the terminals of a Daniell battery. It has a value of 1,16 weber.

France did not make a definite choice. The British and the German units were references but the traditional galvanometer was also used : an electrolyser was inserted in the circuit, and the intensity of the current was expressed in cm3 of gas emitted per minute at the terminals of a sulphuric acid electrolyser or in grammes of copper deposited per hour onto the cathode of a copper sulphate electrolyser.

It was obvious that a common language was necessary. That was the objective set to the first congress of "electricians"" in Paris.

1881 : first international congress of electricians, first International system.

Une date importante : l'exposition internationale d'électricité de 1881 à Paris.

An important date : the International Exhibition of Electricity in Paris in 1881.

The congress was held under the patronage of Adolphe Cochery, the postmaster general, who wanted it to be a major international event. The presidency was carried out by Jean Baptiste Dumas, a chemist. The 250 delegates came from 28 different countries. Scientists and engineers, such as the famous William Thomson (who was to be made Lord Kelvin), Tyndall, Crookes, Helmholtz, Kirchhoff, Siemens, Mach, Gramme, Rowland, Becquerel, Fizeau, Planté, Lord Rayleigh, Lenz, gathered together for the first time.

One subject to be dealt with as a priority was the electrical units and standards. An opposition existed between the British scientists who, with the CGS system, wanted to place the electrical units in the theorical scope of mechanics and the German engineers who wanted practical standards.

The French physicist Eleuthère Mascart who acted as the secretary of the congress gave us a picture of what the backstage was like.

"The congress, he said, had set up a committee on electrical units with lots of members who met on September 16th and 17th 1881. The first session boiled down to a general statement of principles. In the second, the question was more closely dealt with. The point was to know whether the units would be based on a logical system or would it be possible to accept, in particular for the measurement of resistances, the arbitrary unit known as "Siemens Unit".

The discussion proved to be difficult and confused ; propositions and objections came "out of the blue", especially from persons who were not aware of the importance of the resolutions to be achieved. Mr Dumas, who chaired the commitee with admirable tact and authority, interrupted the debate telling the audience that it was late (4.30 a.m) and that a new meeting would be held later.

On the Saturday night, as I walked out of the premises with our chairman, I told him : "My dear Professor, I think the whole affair isn't working properly" – "I am convinced, he said, that we aren't going to come to a resolution and you gathered, I suppose, why I interrupted the session". I can't remember what we talked about afterwards.
The next day, in the morning, I met, on the Solferino bridge, William Siemens who asked me if Lord Kelvin (called Sir William Thomson at the time) had called upon me, adding that I was invited to dinner to try and reach an agreement. I immediately walked back home and found Lord Kelvin's card with the words : "Hôtel Chatham, 6.30" written on it.

I was, as expected, on time for the appointment. There, I was confronted, in a small waiting lounge, with an impressive panel : Lord Kelvin, William Siemens, from the UK, then Von Helmholz, Clausius, Kirchhoff, Wiedemann and Werner Siemens. The discussion started again *and, after much hesitation, Werner Siemens ultimately accepted the proposed solution provided that the system of measure would be established "for practical use". I accepted readily this qualification and wrote down with a pencil, on the piano, the text of the convention.*

The system of measures for practical use was based on CGS electromagnetic units.

The ohm and the volt were defined and an international commission was left in charge of fixing the size of the column representing the ohm.

A great weight off my mind, I dined heartily and after the meal, on my way back, I rang the bell at Mr Dumas's notwithstanding that it was already 10.30 p.m. He was in the living-room surrounded by his family and my first words were : "The agreement on electrical units has been made". I'll never forget the true elation felt by Mr Dumas on hearing a piece of news he was far from expecting.

If the unit system finally came into existence it must be credited, firstly, to the authority of Mr Dumas whose remarkable talent commanded respect and prevented the discussion from turning into offensive words, secondly, to the influence on Werner Siemens of his brother William Siemens who lived among British scientific circles bound by the initiative of the British Association.

We were looking forward to submitting these proposals to the congress at the general session on Tuesday September 10th, but in the meantime we were informed of the death of President Garfield, so the meeting was immediately postponed as a mark of mourning.

As we only disposed of two units, the ohm and the volt and, as it was necessary to complete the system, I asked President Cochery if, at least, the committee could meet. I was compelled to accept his refusal so we stayed with Von Helmholtz by Lord an Lady Kelvin who, as they hadn't had lunch, were dining at the restaurant Chiboust by the congress hall. It was, with this restrained committee, around a plain table in white marble, that were agreed upon the three following units : ampère (instead of weber), coulomb and farad. I was to read the text the following day September 21st at the general session. Quite a number of members of the commission, who had not heard about the Saturday session, were slightly surprised but the comments of Lord Kelvin and Von Helmholtz were straight and convincing. The practical system of units was founded".

At the end of the congress Jean Baptiste Dumas delivered a speech revealing his utter satisfaction.

"The agreement was obtained through a unanimous decision. You have connected on the one hand, the absolute electrical units to the metric system by adopting for the bases, the centimetre, the mass of the gramme and the second and, on the other hand, you have created

practical units closer to the "grandeurs" which we were used to considering in practice. In so doing you have connected them through solid links to absolute units. The system is now fully-fledged".

A noticeable success.

The report of this session can be read in the French review "La Nature" (second semestre p.282). "The work of the congress could be considered as completed on Saturday September 24th. Only four general sessions had been necessary and, among them, only three had been focused on the study of questions on the agenda".

The conclusions of the congress could be summed up in seven points :

1° The CGS system was adopted.

2° The resistance unit will be designed by the name ohm with a value of 108 CGS unit.

3° The practical resistance unit (ohm) will be constituted by a column of mercury with one square millimetre section at the temperature of 0° centigrade.

4° An international committee will determine the length of the column of mercury representing one ohm.

5° The unit of current intensity will be called "ampere" : the current intensity generated by one volt in one ohm.

6° The quantity of electricity unit will be called "coulomb" or quantity of electricity produced by the current of one ampere for one second (according to the relation Q=I.t).

7° The capacity unit will be the "farad" defined by the condition that "one coulomb in one farad produces one volt" (according to the relation Q/C = V)

Ampère and Coulomb, as citizens of the inviting country, were honoured with the choice of their names for intensity and charge units. Weber was left aside but... the congress congratulated him on the fiftieth anniversary of his first entry at the university of Göttingen. His name will be later given to the magnetic flux unit.

This new way of attributing names of famous scientists to units was emphasized through JB Dumas in a somewhat lyrical closing speach of the congress.

"The British Association had the bright idea of naming these different units after scientists to whom we owe the main discoveries which gave birth to modern electricity. You carried on in the same way and from now on, the names of Coulomb, Volta, Ampère, Ohm and Faraday will be tightly linked to daily applications of the doctrines they successfully conceived. The industry, getting used to repeating daily these names, worthy of century-long veneration, will testify to the gratitude the whole mankind owes to these enlightened spirits".

A new fashion was born : scientific vulgarization came to public notice in museums, international exhibitions, reviews superbly illustrated, in particular those dealing with electricity, in France : L'Electricité (1876), La Lumière électrique (1879), L'Electricien (1881). The scientist had become a character to be popularized.

The decision to give the names of scientific celebrities to units wasn't unanimous. During the 1889 congress, Marcelin Berthelot deplored it : "Poncelet, Ampere, Watt, Volta, Ohm are now roots of names that, for most of them, don't have any necessary or immediate connection with the men who made them known. The contrast, he added, is striking with the mainly impersonal nature of the scientific nomenclature some eighty years back". Moreover, he forecasted, "It's to be feared that the next century, through the strength of the momentum and the modifications of sciences, will abandon this terminology".

Yet, the names of Kelvin, Hertz, Siemens, Tesla, Henry and many others will join the list of units in the following decades. The name of Ampère will even appear on the list of the four fundamental units of our present International system.

The next episode of the congress of 1881 : the joule, the watt...

In 1882, the British Association, made a proposition for energy and power units. The CGS system had already got a work unit, the erg (1 erg = 981 g.cm2.s-1) deduced from a force unit, the dyne (1 dyne : 981 g.cm.s-2) and a power unit : the erg/s.

For the practical unit of energy it was suggested to call "joule" the "coulomb.volt", in use previously. The British electricians considered Joule (1818-1889) as a member of their community. His first scientific works in 1838 dealt with magnetism and, in his early twenties, he discovered the "magnetic saturation" that is to say the limit value reached through the "magnetization" of a steel magnetic core excited by a magnetic field.

In 1842 he discovered the law that bears his name : it relates the calorific energy, W, emitted during a set time, t, by a resistance R crossed by a current I. A law which can be written as follows : W = R.I2.t. He was only in his mid twenties at the time and he would now on concentrate on etablishing the relation showing the direct transformation of mechanical work into heat.

For power, the Association proposed the "watt" instead of the "ampere.volt". In so doing, it encroached upon the field of "mechanicians" among whom Watt was a distinguished member.

The conversion with the work and power units used by the "mechanicians" were as follows :

1 kilogrammettre = 9,81 joules.

1 horsepower = 736 watts.

In 1884, the "international conference for determination of electrical units" met in Paris. It fixed the value of the ohm : resistance of a column of mercury of one square millimetre in section and 106 cm in length at the temperature of melting ice. Standards will be made.

The ampere was defined as the current whose absolute value was 0,1 CGS electromagnetic unit.

The volt was the electromotive force which "supported" a one ampere current in a conductor whose resistance was the legal ohm.

In 1889 the international congress of electricians came back to Paris during the international exhibition. The joule and the watt were confirmed as energy and power units. The kilowatt was accepted in replacement of horse power for the power measure of electric engines.

In a slightly challenging way, the congress of electricians invited the congress of "mechanicians", that was held at the same time to abandon the "horse power" and adopt the CGS system and to clarify the notions of "force" and "work" too often mixed up in mechanicians' texts.

Outdistanced "mechanicians"

The "mechanicians" accepted to clarify the notions of force and work and decided that :

. The word "force" would only be used, henceforth, as a synonym for effort.

. The word "work" would designate the product of a force by the distance that its point of application covers in its own direction.

. The word "power" would exclusively be used to designate the quotient of a work by the time used to produce it.

Yet they wouldn't abandon their own units, as outdated as they might appear, to their electrician colleagues :

. The unit of force remains the kilogrammeforce (weight in Paris of a mass of one kilogramme).

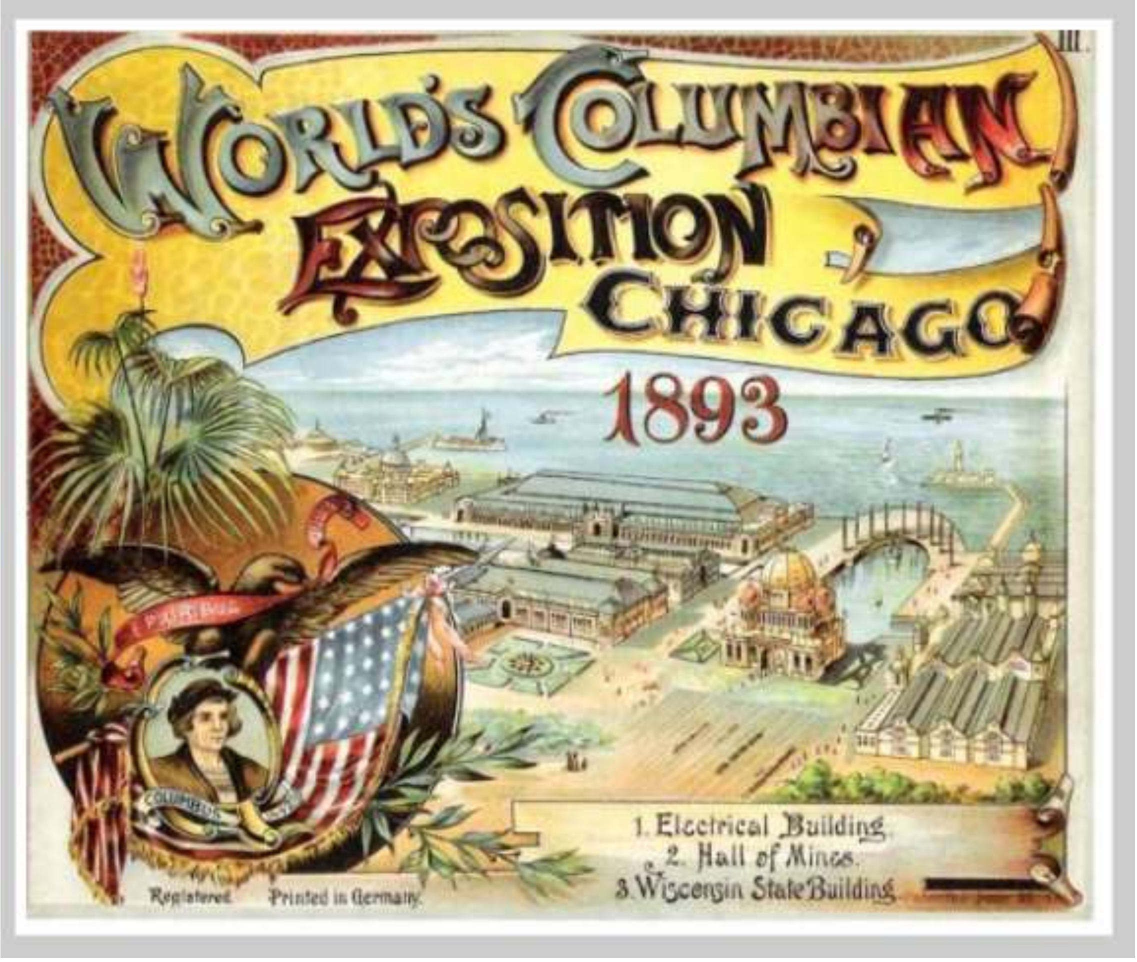
. The unit of work is the kilogrammetre (work of a force of one kilogrammeforce which moves its application point of one metre in its direction).

. The unit of power is left to one's own choice : the horse-power of 75 kilogrammetres per second and the "poncelet" of 100 kilogrammetres per second.

The word energy is kept in the language as a very convenient generalization including the similar different forms : work, kinetic force, heat. There isn't any special unit for energy considered in general : it is numerically valued according to circumstances by means of the joule, the kilogrammetre, the calory etc...

The stubborness of the mechanicians would compel French secondary school students to go on learning, up to the sixties, that a force is expressed in "kilogrammeforce", a weight in "kilogrammepoids", a work in "killogrammetre" and mechanic power in "cheval-vapeur".

On 1893, a congress of electricians was held in Chicago and was considered the second official congress following the first one in 1881.



The governments of the countries taking part in this international meeting were represented and the decisions would have the force of international law. The units already chosen were confirmed and clarified.

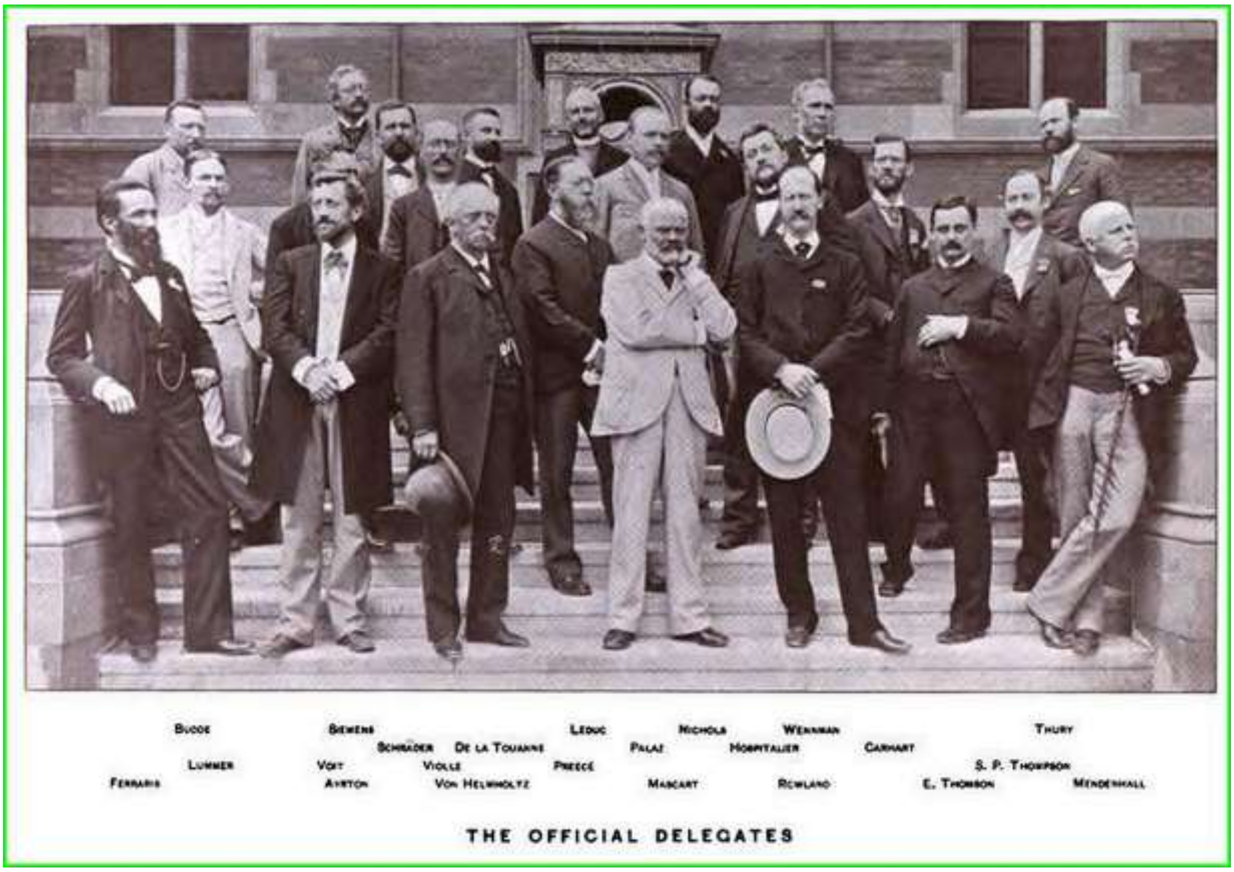
. The international ohm will be defined, in a practical way, by a column of mercury one square millimetre in section, 106,3 cm long and of a mass of 14,4521 gramme.

. The international ampere will be the current that will deposit 0,00118 grammes of silver par second on the cathode of a silver nitrate electrolyser.

. The international volt will be the electromotive force corresponding to 1000/1434 of a Clark battery, a "depolarizer battery" which at this time had replaced the Daniell battery.

. The joule and the watt were confirmed.

The host country was not forgotten. The henry was accepted as the international unit of measure of the magnetic inductance of an electric circuit.



On 1893, the congress of electricians in Chicago.

On the way to the MKSA system.

The British electricians, and in particular Maxwell, had felt the necessity, as soon as the eighteen sixties, to complete the CGS system with a specific unit of electricity as an electric charge unit or a unit of current intensity.

We must notice that two competing systems, one coming from electrostatics and the law of Coulomb and the other from electromagnetism and the law of Laplace, give different dimensions for the units.

In the electromagnetic system, for instance, the resistance has the dimension of a speed (it’s expressed by the quotient of a length L by a time T). In the electrostatic system the resistance has the dimension of the reverse of a speed (quotient of a time T by a length L).

Likewise, all the units of charge (quantity), intensity (current), tension (potential), capacity... have different dimensions in the two systems. It's to be observed, as well, that the ratio between the dimensions of the electric magnitudes in each system involved a "C" speed, a remark whose importance had already been mentioned in the Maxwell theory.

Dimensions des cinq unités principales.

DÉSIGNATION.	DIMENSIONS dans le système ÉLECTRO-STATIQUE.	DIMENSIONS dans le système ÉLECTRO-MAGNÉTIQUE.	RAPPORT $\frac{\text{Dim. électro-statique}}{\text{Dim. électro-magnétique}}$
QUANTITÉ...........	$\frac{L^{\frac{3}{2}} M^{\frac{1}{2}}}{T}$	$L^{\frac{1}{2}} M^{\frac{1}{2}}$	v
COURANT.	$\frac{L^{\frac{3}{2}} M^{\frac{1}{2}}}{T^2}$	$\frac{L^{\frac{1}{2}} M^{\frac{1}{2}}}{T}$	v
CAPACITÉ...........	L	$\frac{T^2}{L}$	v^2
POTENTIEL........... FORCE ÉLECTRO-MOTRICE.	$\frac{L^{\frac{1}{2}} M^{\frac{1}{2}}}{T}$	$\frac{L^{\frac{3}{2}} M^{\frac{1}{2}}}{T^2}$	$\frac{1}{v}$
RÉSISTANCE.	$\frac{T}{L}$	$\frac{L}{T}$	$\frac{1}{v^2}$

$v \times 3 \times 10^{10}$ centimètres par seconde.

Picture : Chart fixing the dimensions of units in the two electrostatic and electromagnetic systems . ([Maxwell : A Treatise on electricity and magnetism](#))

The CGS system which had been created exclusively from the electromagnetic system was ill-adapted to the electrostatic system.

In 1901 the Italian electrical engineer Giovanni Giorgi suggested a solution aimed at reconciling these two systems which ultimately lead to the choice of the ampere as the basic electrical unit, the metre as the unit of length and the second as the unit of time. For masses, even though the prefixe kilo is not proper to designate a unit, it was the kilogramme which was chosen (one more scar inherited from the living past of sciences).

This system was given the name of Giorgi system or MKSA system. In 1906 was created the "International Electrotechnical Commission" (IEC) with one specific mission : normalization of the system of measures to be used for industrial electricity. The MKSA system wasn't finally accepted by the International Commitee of Weights and Measures until 1946.

In 1948, the general conference of weights and measures proposed the newton as the force unit (a force which could give to a mass of one kg an acceleration of one metre/s2. The mechanic and electrical units were finally unified.

The joule which was, up to then, defined as the energy produced, for one second, by a current of one ampere conveyed through a resistance of one ohm, corresponds, as well, to the work of a force of one newton moving its point of application of one metre in its direction.

The MKSA system then got the name of International System (I.S) adopted by the eleventh General Conference of Weights and Measures (GCWM) in 1960. On the 3rd of May 1961 the French republic published the decret n°61-501 legalizing the IS in France.

It was the final victory of the "electricians" system over the "mechanicians".

Translated from : Histoire de l'électricité : l'histoire des unités électriques.

See also : "Une histoire de l'électricité, de l'ambre à l'électron"

See : The International System of Units. Its History and Use in Science and Industry, by Robert A. Nelson, president of Satellite Engineering Research Corporation.

volt or Volta farad or Faraday ?

The volt, ohm and farad were introduced by the same person, Latimer Clark, a cable engineer, in a paper in 1861. He started the tradition of naming units after scientists. He initially distorted all names: the unit names ohma, volt, galvat (from Galvani), and farad (from Faraday). In his words, he "neglected etymological rules".

In that same year, a committee of the British Association for the Advancement of Science began developing a coherent system of electrical units, the cgs system. Varley, a committee member, liked Clark's proposal, but he advocated adding a French name such as Ampere, to facilitate the international acceptance of the new units ("I should like to introduce a French name into the list. We have Germany, England and Italy represented"). For the same reason he may have pleaded for not distorting the French and German names. In addition, Varley objected to the galvat "because Galvani discovered next to nothing".

Latimer Clark adapted the unit names in his 'Elementary treatise on electrical measurement' (1868). He changed ohma to ohm, and dropped the galvat. Maxwell acknowledged Clark's practical units and their names in his 'Treatise on electricity and magnetism' (1873). In 1881, at the International Electrical Congress in Paris), two French names, ampere and coulomb, were added. The diplomacy worked, and the new system of electrical units was adopted by all countries. The only units that kept the initial name distortion were the volt and the farad.