

Physics

in the Enlightenment

part 2

Electricity and magnetism from Gilbert to Volta

Important dates in the history of electricity

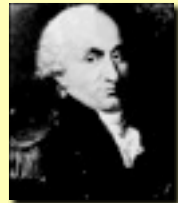
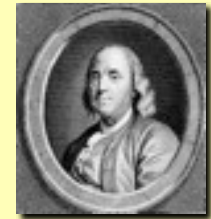
1600	Gilbert	<i>versorium</i> , electrics, non-electrics
1629	Cabeo	electric repulsion
1660	Guericke	electrostatic machine (sulphur sphere), electric repulsion and transmission
1705	Hauksbee	electrostatic machine (glass sphere),
1729	Gray	motion of electricity (to about 300 m)
1733	Dufay	two kinds of electricity: glass and resin
1739	Desaguliers	conductors and isolators



Important dates in the history of electricity



Leyden jar



$$F \sim Q_1 Q_2 / r^2$$

(1746 Kratzenstein,
1760 D. Bernoulli,
1766 Priestley,
1769 Robison,
1772 Cavendish)

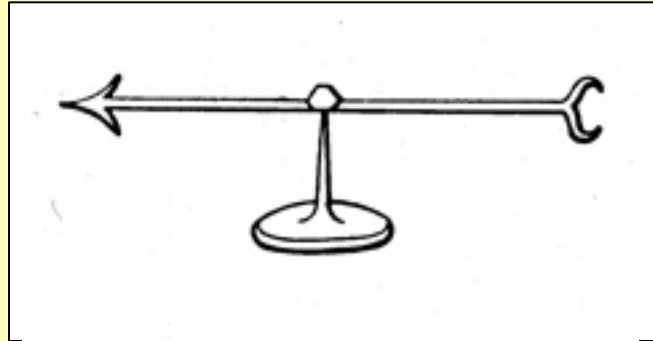


animal electricity

contact potential, electric pile

William Gilbert - *De magnete* (1600)

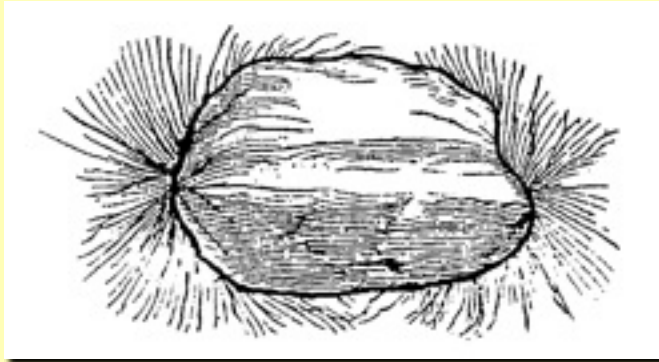
The first systematic study of electrification
by means of **versorium** (a rotating needle)



"electrics": amber, jet, diamond, sapphire, opal, amethyst, beryl, carbuncle, iris stone (quartz), rock crystal, sulphur, fluorspar, belemnites, orpiment, glass, hard resin, sal gemma, sealing wax, antimony glass, rock alum, mica...

"non-electrics": all metals, alabaster, agate, the marbles, pearls, ebony, coral, porphyre, emerald, chalcedony, jasper, bloodstone, corundum, flint, bone, the hardest woods (cedar, cypress, juniper)...

Early graphic representations of the magnetic field



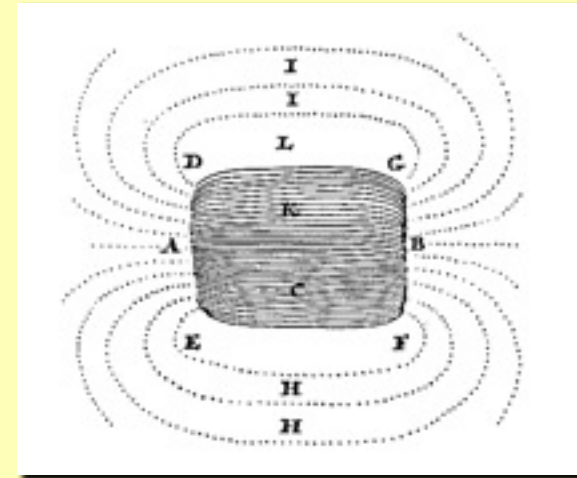
Cabeo (1629)



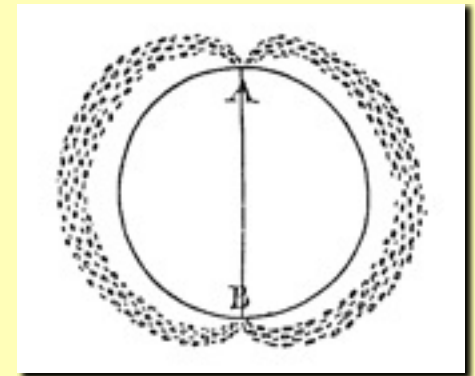
Vallemont (1696)



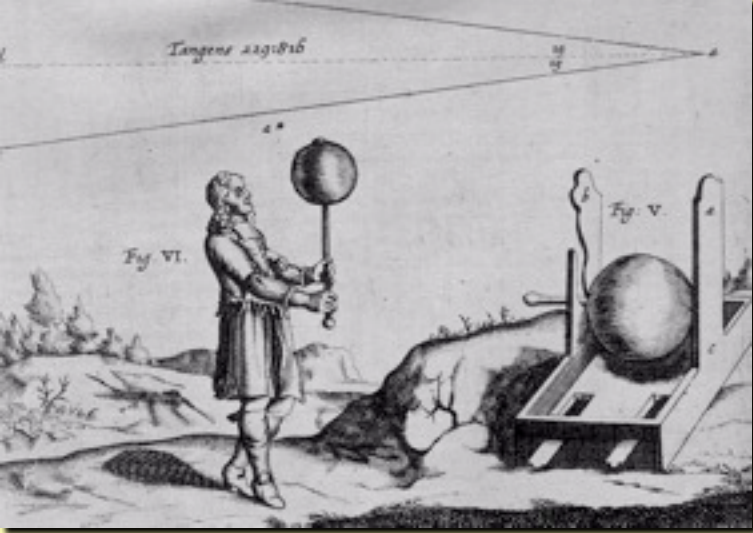
Dalencé (1687)



Rohault (1671)



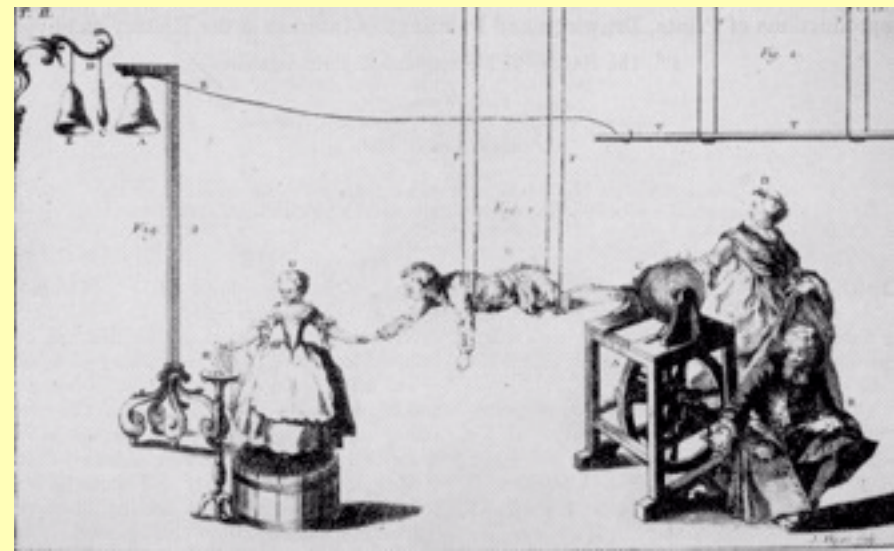
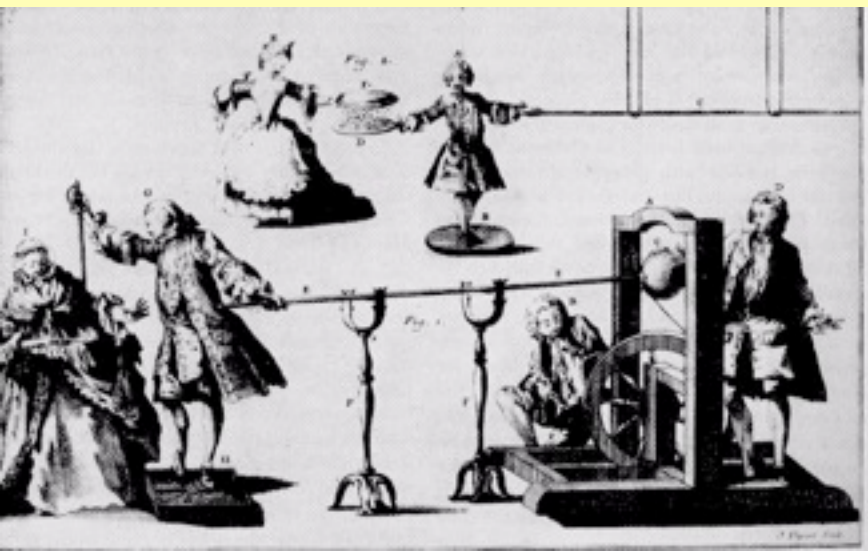
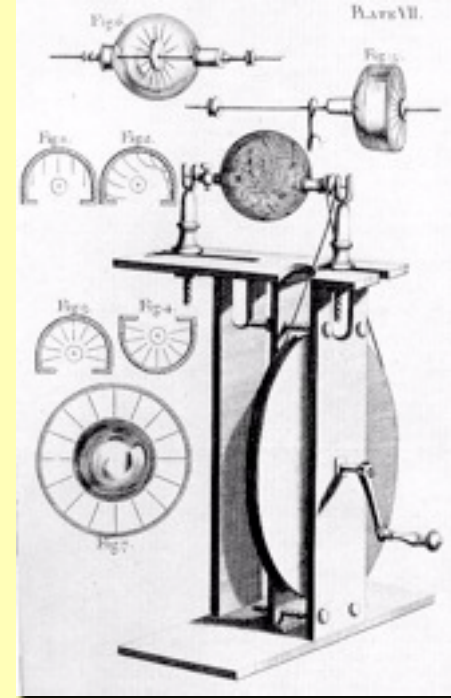
Lana (1692)



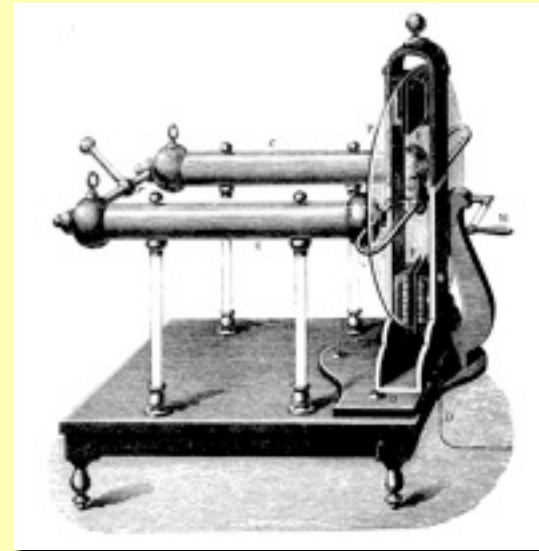
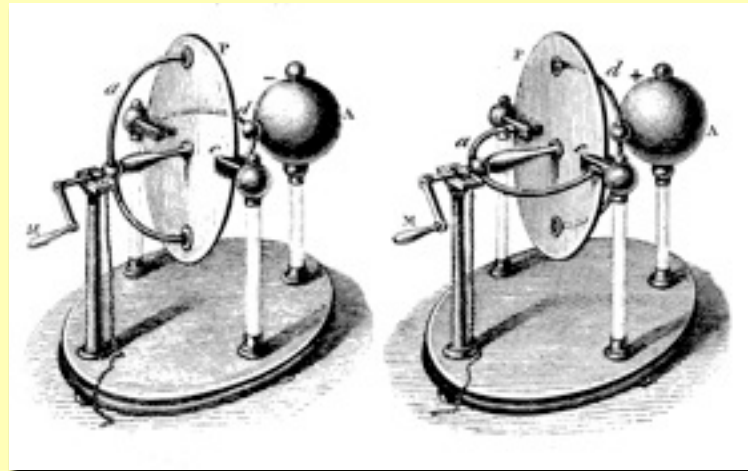
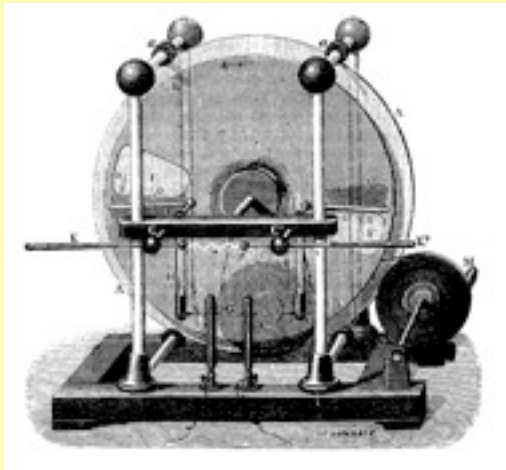
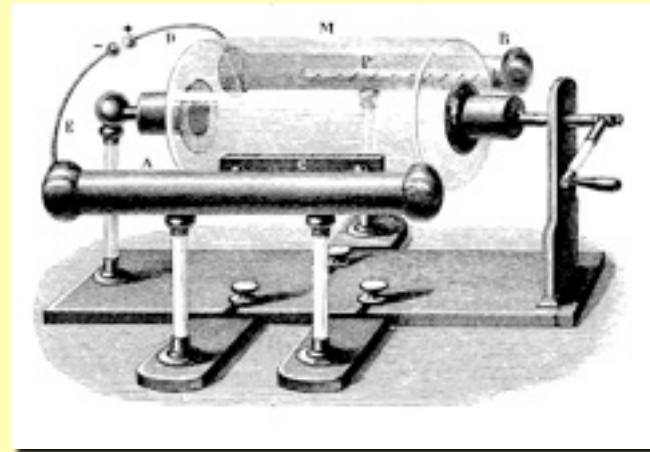
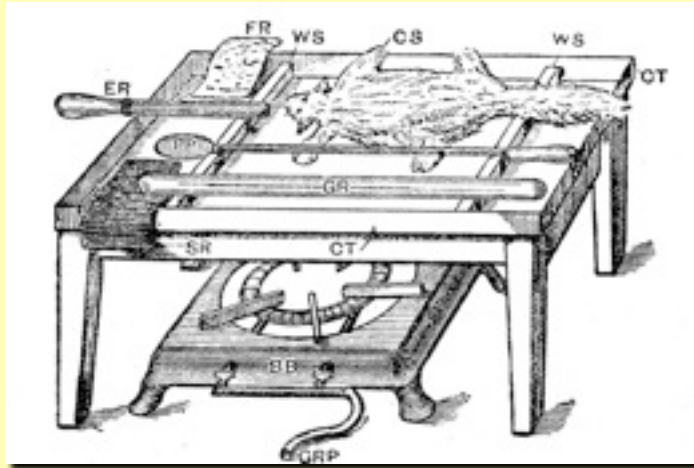
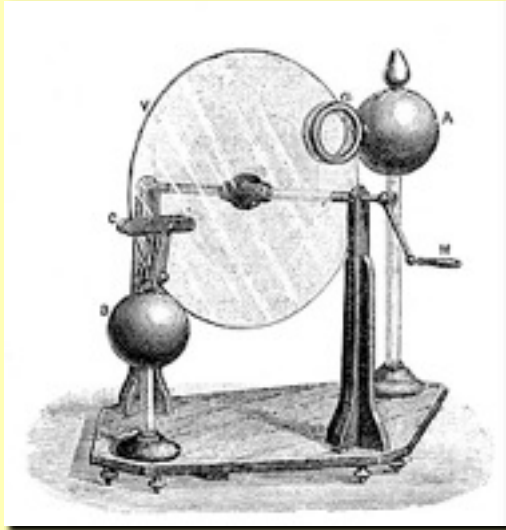
Sulphur sphere
Guericke (1660)

Electrostatic machines

Glass sphere
Hauksbee (1705)



Various types of electrostatic machines

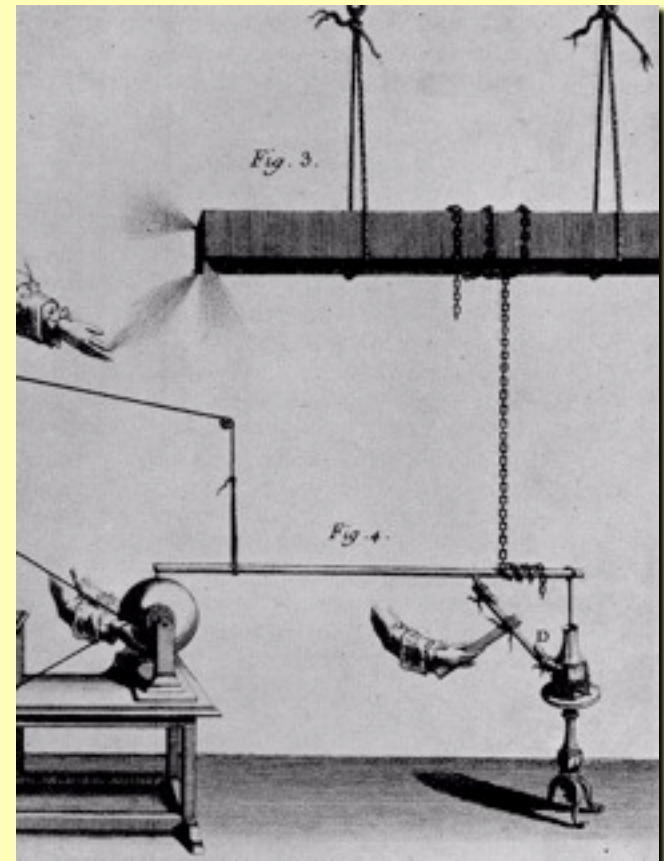
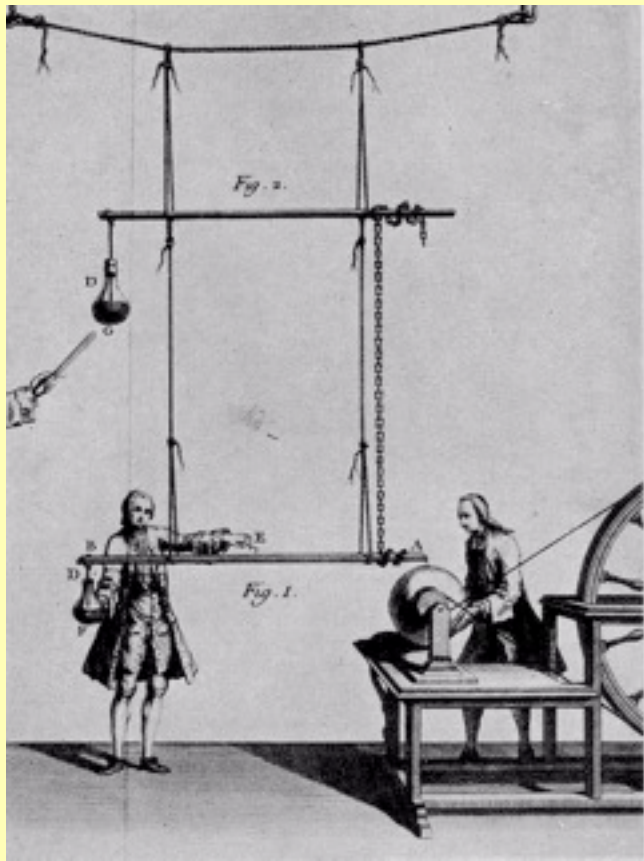


The Leyden jar (1745)

Ewald von Kleist (Kammin, then Prussia)
(now Kamień Pomorski, Poland)

Pieter van Musschenbroek

Andreas Cunaeus (Leyden)



"I am going to tell you about a new but terrible experiment which I advise you not to try yourself, nor would I, who have experienced it and survived by the grace of God, do it again for all the kingdom of France. I was making some investigations on the force of electricity; for this purpose I had suspended by two threads of blue silk a gun-barrel *AB* which received by communication the electricity of a glass globe which was turned rapidly on its axis while it was rubbed by the hands placed against it; at the other end *B* there hung freely a brass wire, the end of which passed into a round glass flask *D*, partly filled with water, which I held in my right hand *F*, and with the other hand *E*, I tried to draw sparks from the electrified gun-barrel..."



*Musschenbroek to Réaumur,
January 20, 1746*



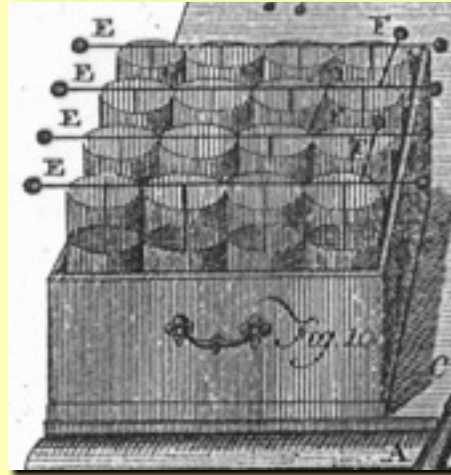
"...all at once my right hand F was struck so violently that all my body was affected as if it had been struck by lightning; ... the arm and all the body are affected in a terrible way that I cannot describe: in a word I thought that it was all up with me...

I have found out so much about electricity that I have reached the point where I understand nothing and can explain nothing."



*Musschenbroek to Réaumur,
January 20, 1746*

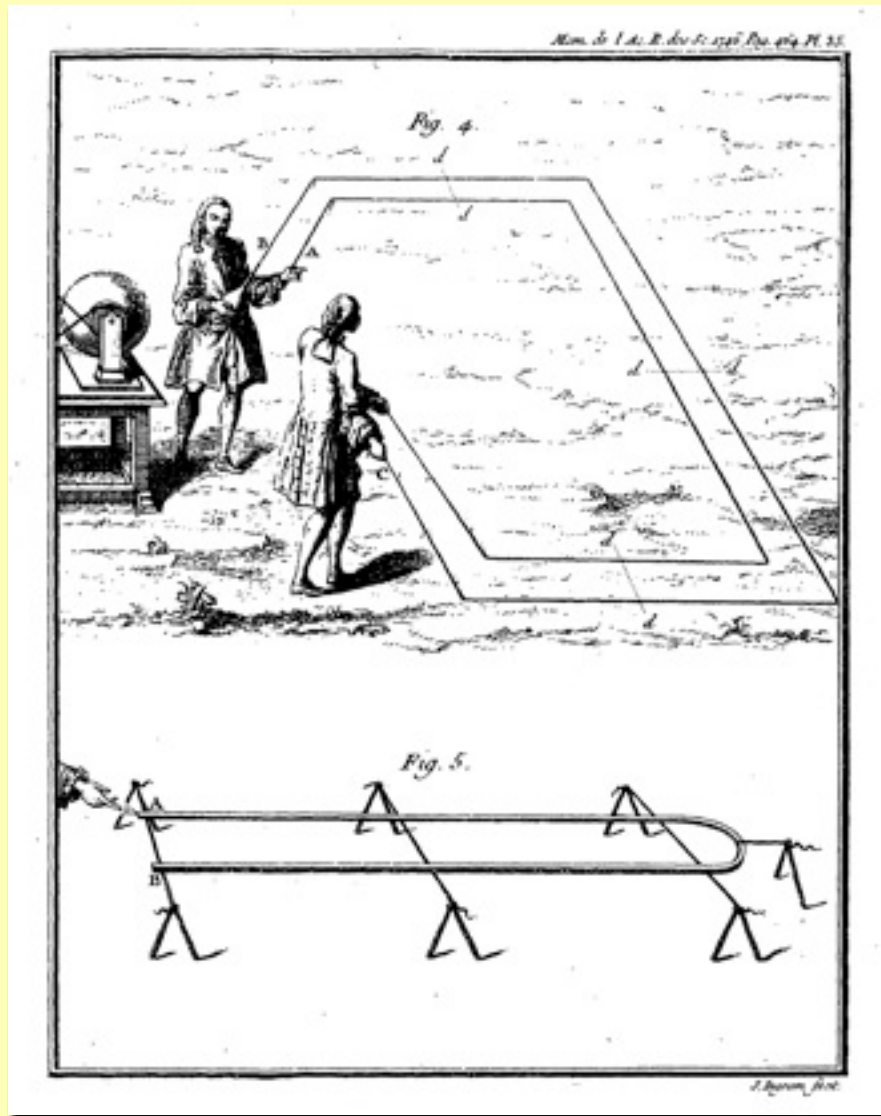




Daniel Gralath of *Societas Physicae Experimentalis* in Gdańsk made the first electric battery by connecting several jars in parallel

On April 10, 1746, he gave a shock to a chain of 20 people

Jean-Antoine Nollet in Paris in a public demonstration gave a shock to a chain of 180 King's guard soldiers and later to about 700 Carthusian monks



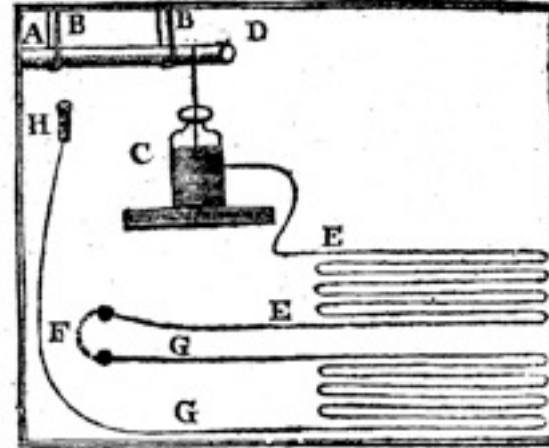
Louis Le Monnier

An attempt to measure
the speed of electricity
Paris (1746)

An attempt to measure the speed of electricity



William Watson
(1747)



- A*, The prime Conductor.
B B, The silk Lines.
C, The coated Phial.
D, Its Hook communicating with the prime Conductor.
E E, The Wire reaching from the Coating of the Phial to the left Hand of the Observer, being more than a Mile in Length.
F, The Place of the Observer.
—, A supposed Line, drawn upon the Explosion through his Body and Arms.
G G, Another Wire, of the Length of *EE*, which goes from the right Hand of the Observer to *H*.
H, The short iron Rod to make the Explosion.

total distance of 12276 feet



Benjamin Franklin
(1706-1790)

EXPERIMENTS
AND
OBSERVATIONS
ON
ELECTRICITY,

MADE AT
PHILADELPHIA in AMERICA,
BY
BENJAMIN FRANKLIN, L. L. D. and F. R. S.

To which are added,
LETTERS and PAPERS
ON
PHILOSOPHICAL SUBJECTS.

The Whole corrected, methodized, improved, and now first collected into one Volume,

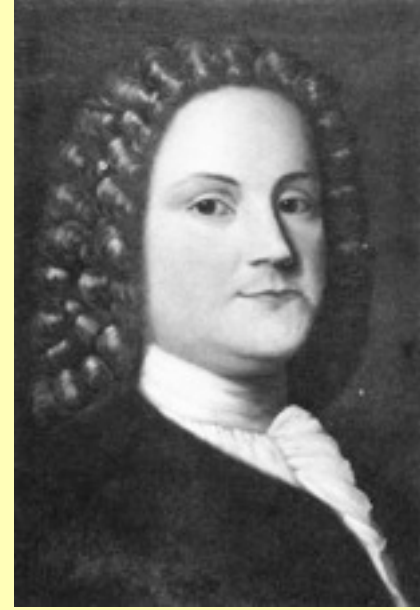
AND
Illustrated with COPPER PLATES.

L O N D O N :

Printed for DAVID HENRY ; and sold by FRANCIS NEWBURY,
at the Corner of St. Paul's Church-Yard.

MDCCLXIX.

"The electrical matter consists of particles extremely subtle, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any perceptible resistance. If any one should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him."



Franklin, *Experiments and Observations on Electricity* (1751)

”Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former mutually repel each other. Hence the appearing divergency in a stream of electrified effluvia.

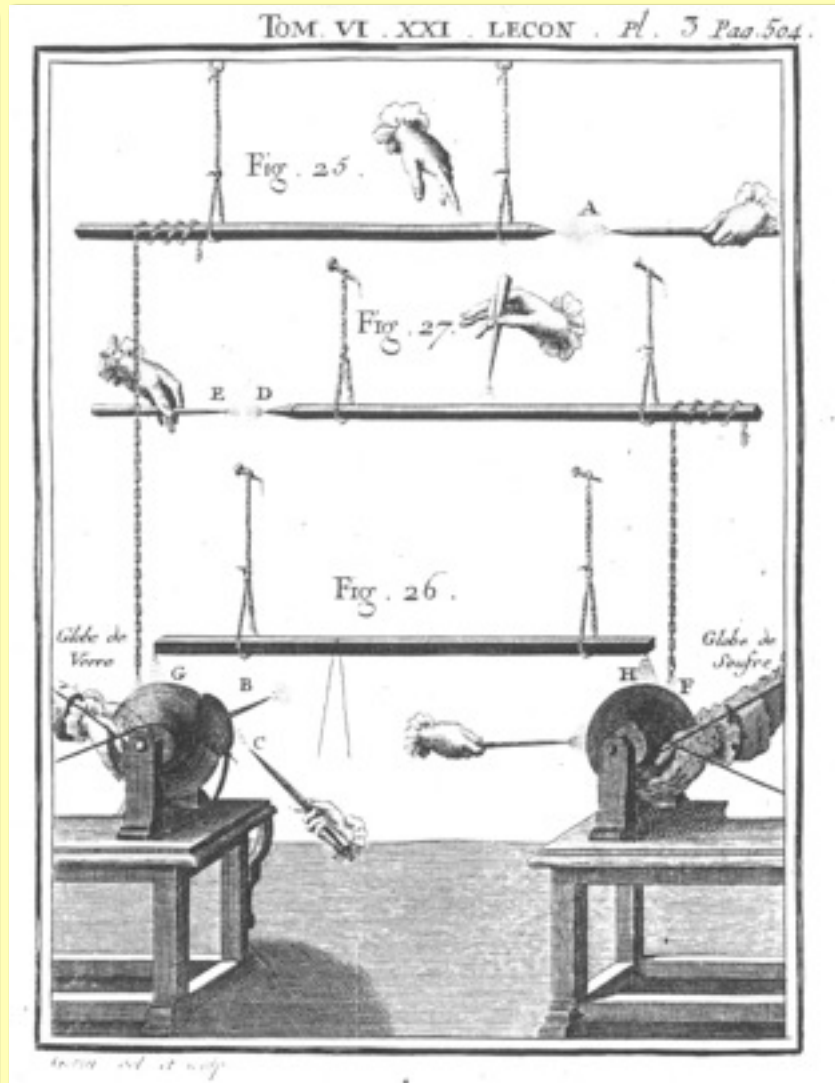
But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter.

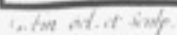
From these three things, the extreme subtlety of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arise this effect, that, when a quantity of electrical matter is applied to a mass of common matter, of any bigness or length, within our observation (which hath not already got its quantity) it is immediately and equally diffused through the whole...”

Franklin, *Experiments and Observations on Electricity* (1751)

"Thus common matter is a kind of sponge to the electrical fluid. And as a sponge would receive no water if the parts of water were not smaller than the pores of the sponge; and even then but slowly, if there were not a mutual attraction between those parts and the parts of the sponge; and would still imbibe it faster, if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts, which would act in conjunction with the attraction of the sponge. So is the case between the electrical and common matter..."

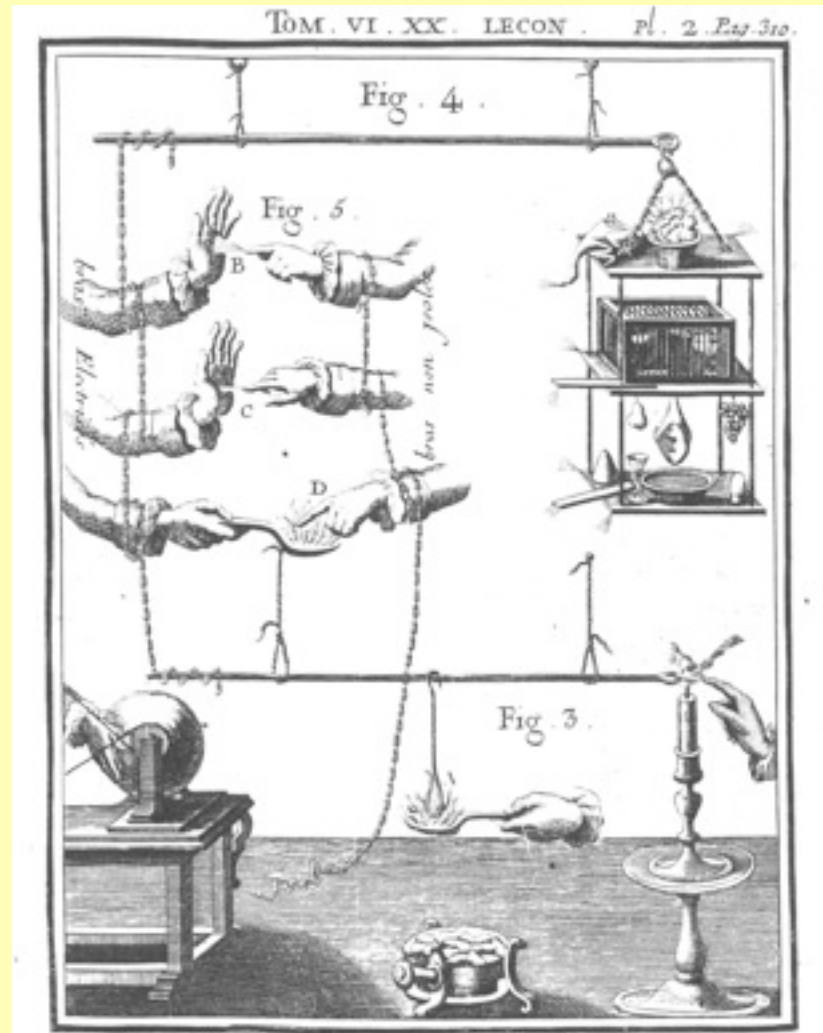
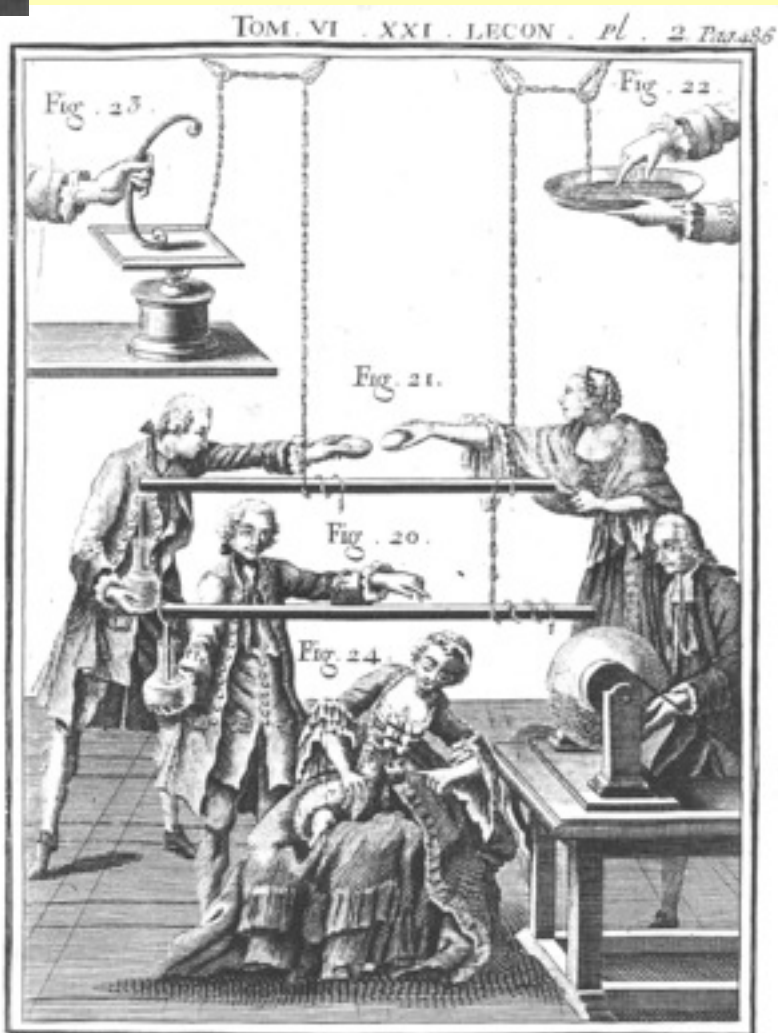
Franklin, *Experiments and Observations on Electricity* (1751), cont.





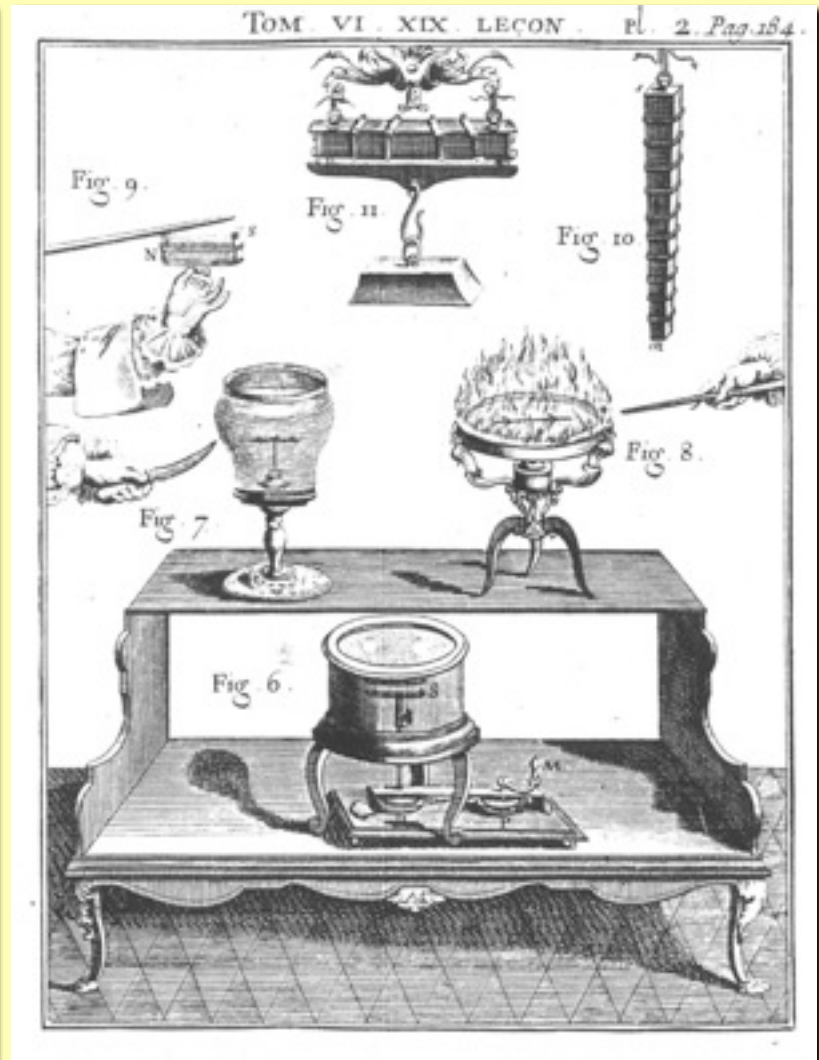
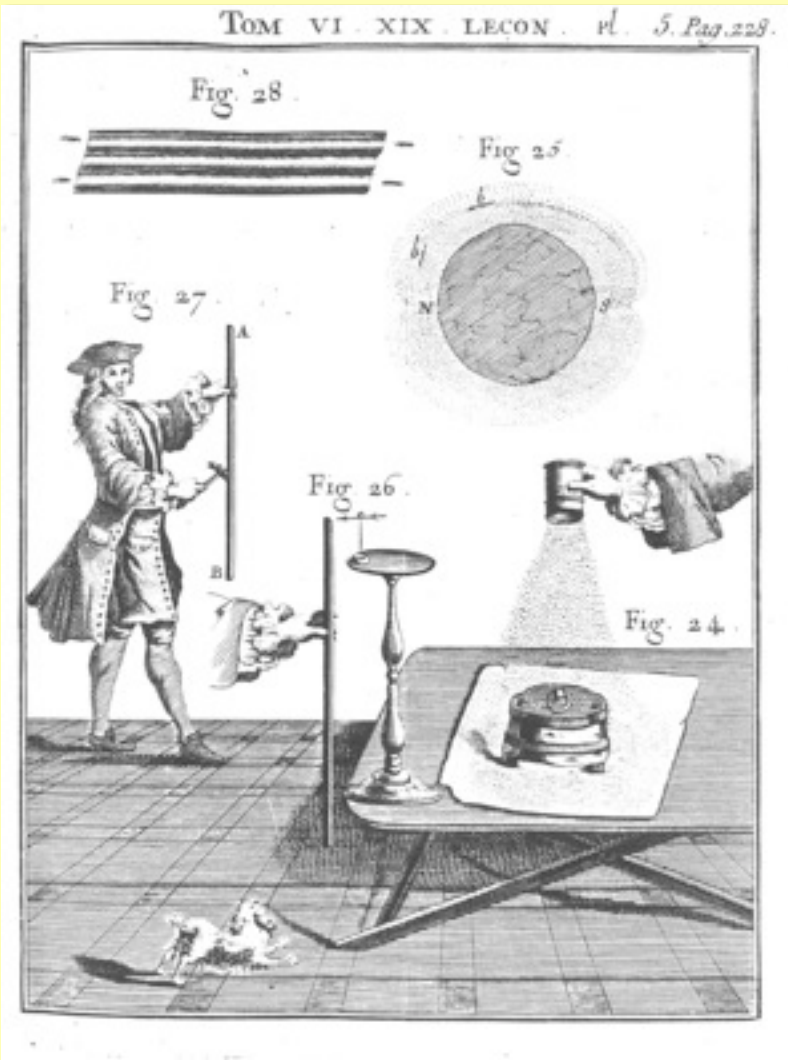


Abbé Nollet on electricity and magnetism





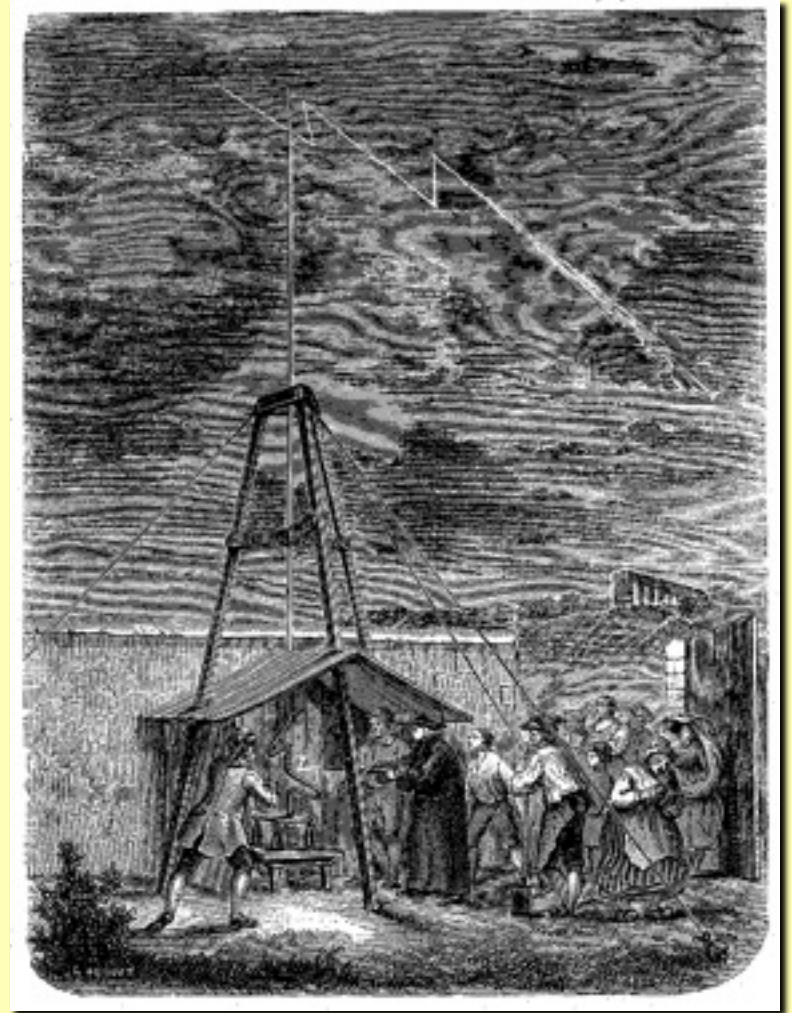
Abbé Nollet on electricity and magnetism



Lightning rod

Franklin – an idea based on similarity of lightning and electric sparks

First experiment performed
on May 10, 1752
by Thomas Dalibard
at Marly-la-ville (near Paris)



New Paris fashion – personal lightning conductors



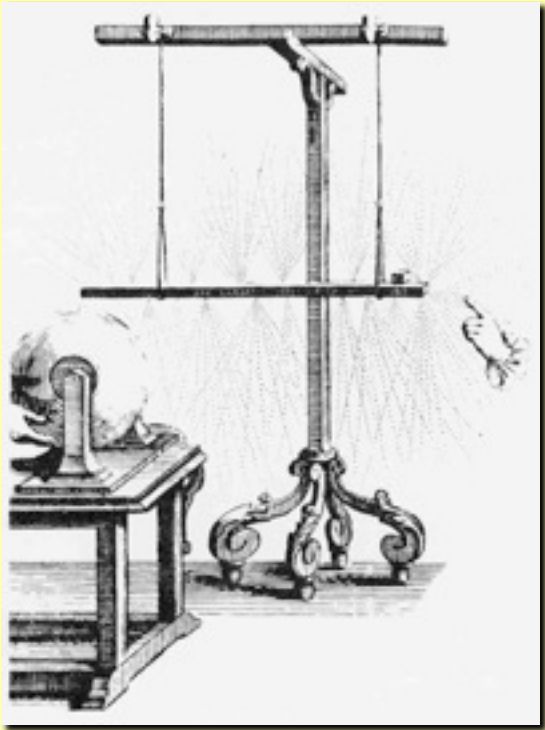
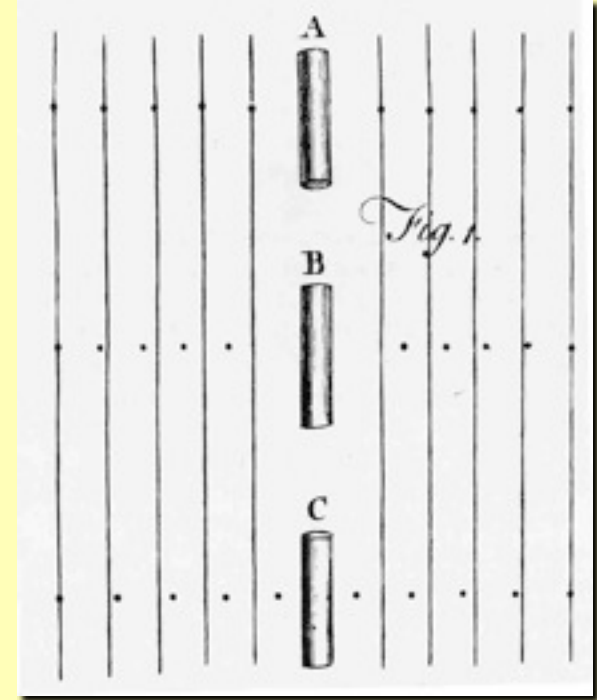
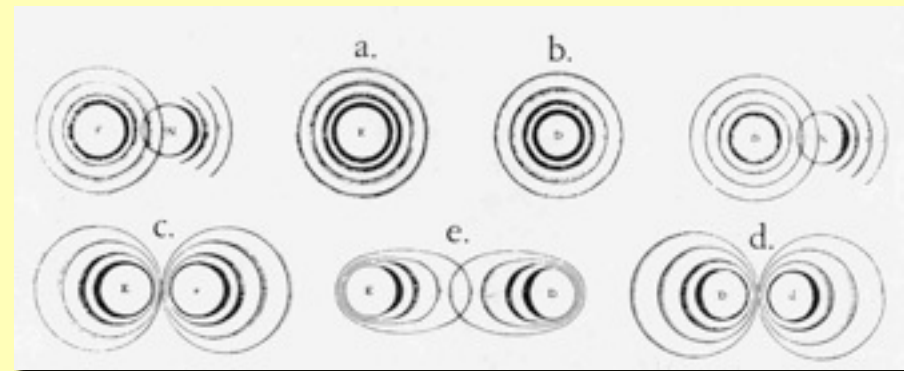


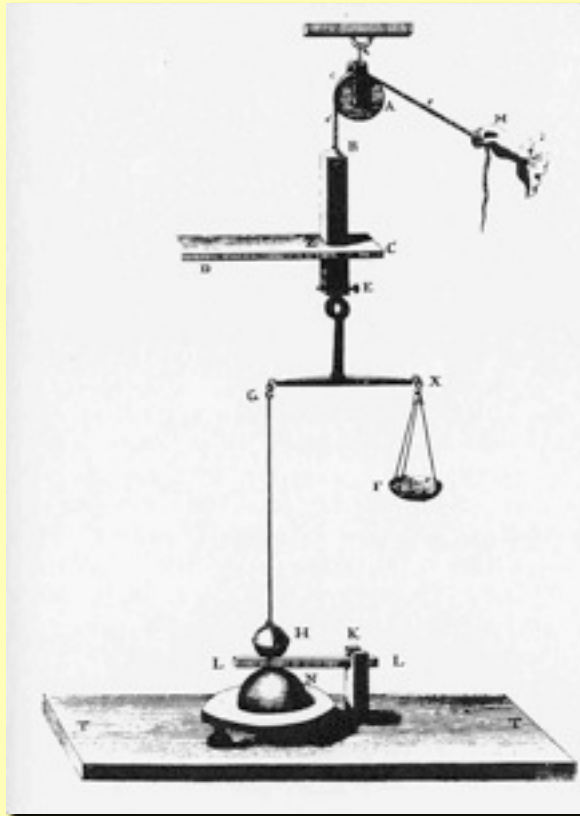
Illustration of the theory of effluent flow (Nollet 1750)



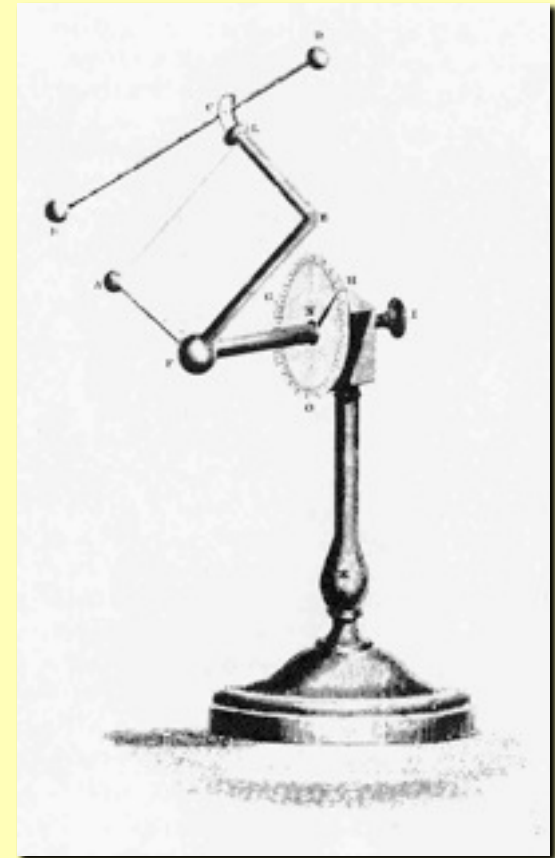
Electric field
John Canton (1766)



Electric field
Giambattista Beccaria (1772)



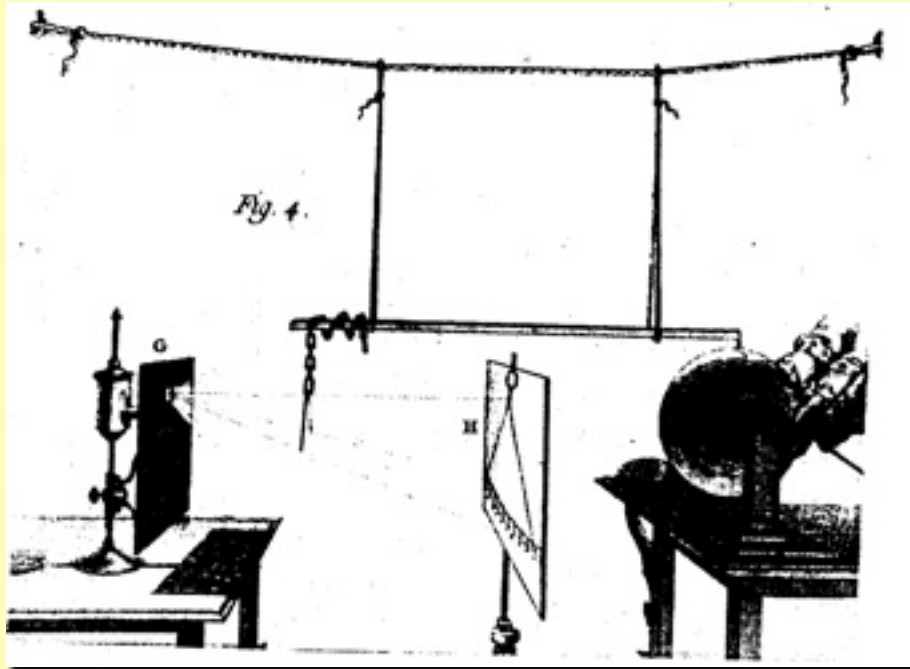
Musschenbroek's apparatus
for measurements of the
magnetic force (1754)



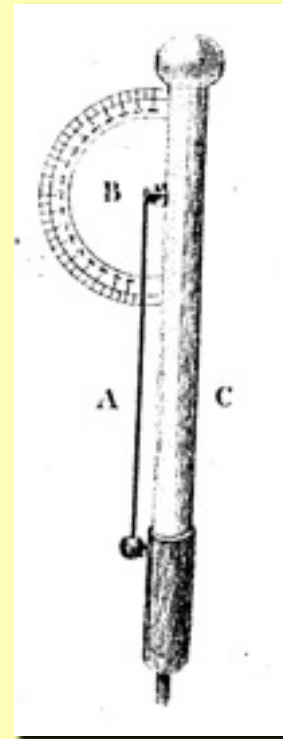
John Robison's apparatus
for measurements of the
electric force (1769)

First electroscopes with a scale

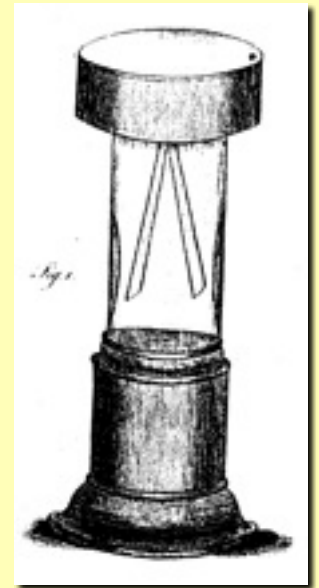
(electrometers)



Nollet (1747)



Henley (1772)



Bennet (1786)

Attempts to quantify electricity

What does the angular separation α of electrometer leaves measure?
What is its connection with measures of efficiency of electrostatic machines?

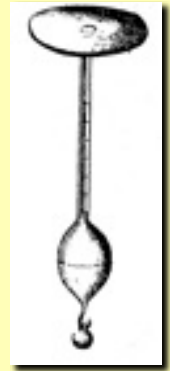
- the length of the longest electric spark,
- the area of glass rubbed per turn of the machine's wheel,
- the length of the standard wire fused by discharge of a Leyden jar or battery charged by a machine,
- the number n of turns of machine's wheel needed to charge various objects to the same angle α

It was found, that angle α is a measure of a 'height' of electricity, or 'tension' T , and n is a measure of charge Q

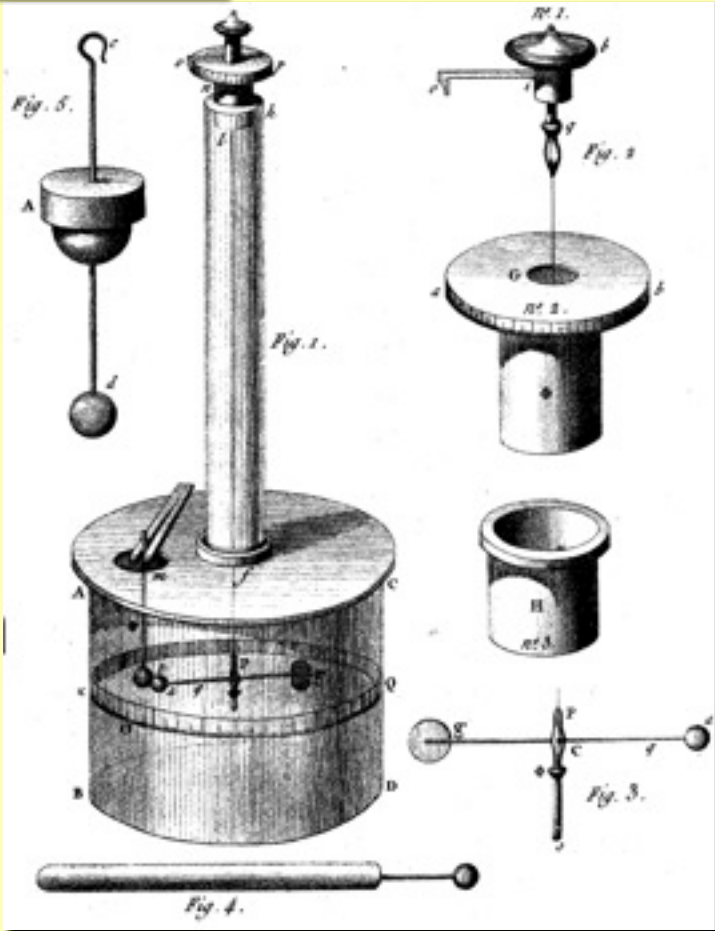
→ $Q = C T$ (Volta's law)



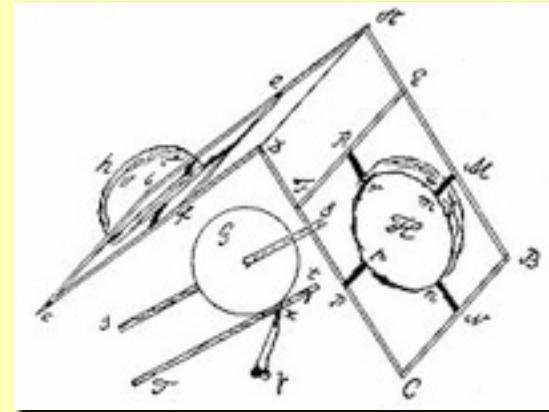
Charles-Augustin Coulomb
(1736-1806)



Daniel Bernoulli
(1760)



Coulomb's torsion balance (1785)



Henry Cavendish
(1772)

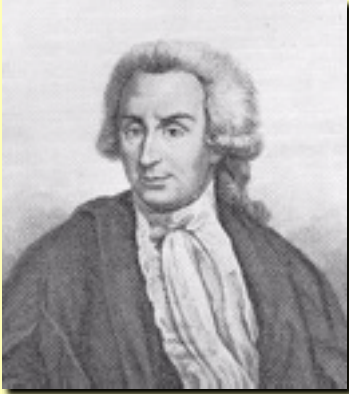
Coulomb's results were initially accepted only in France, where Poisson (1811) used them to build the first mathematical theory of electrostatics.

Scientists in other countries argued that Coulomb's results are unfounded because they were obtained with the use of a torsion balance whose properties were little known.

Alessandro Volta and Christian Oersted were among those who expressed disbelief in the $1/r^2$ law. Some scientists published results which they interpreted as evidence that the force of interaction between electric charges is of the form $1/r$.

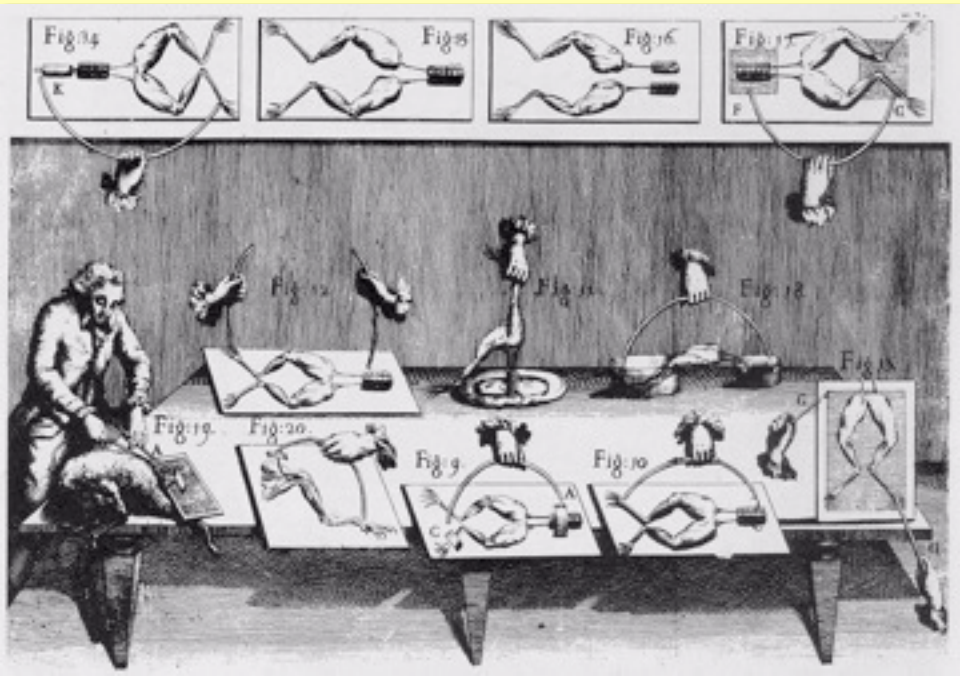
As late as 1836 William Harris argued in the *Philosophical Transactions* that his experimental results prove falsity of the Coulomb's law.

Animal electricity



Luigi Galvani (1737-1798)

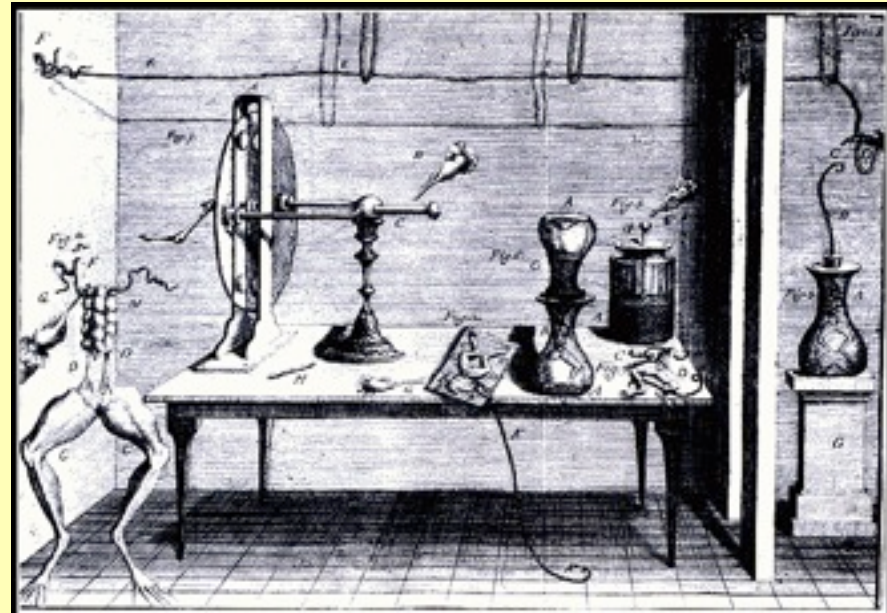
De viribus electricitatis in motu musculari
(1791)



"I think that it is certain that there is in animal bodies a kind of electricity which, following Bertholon and others, I shall name 'animal electricity'..."

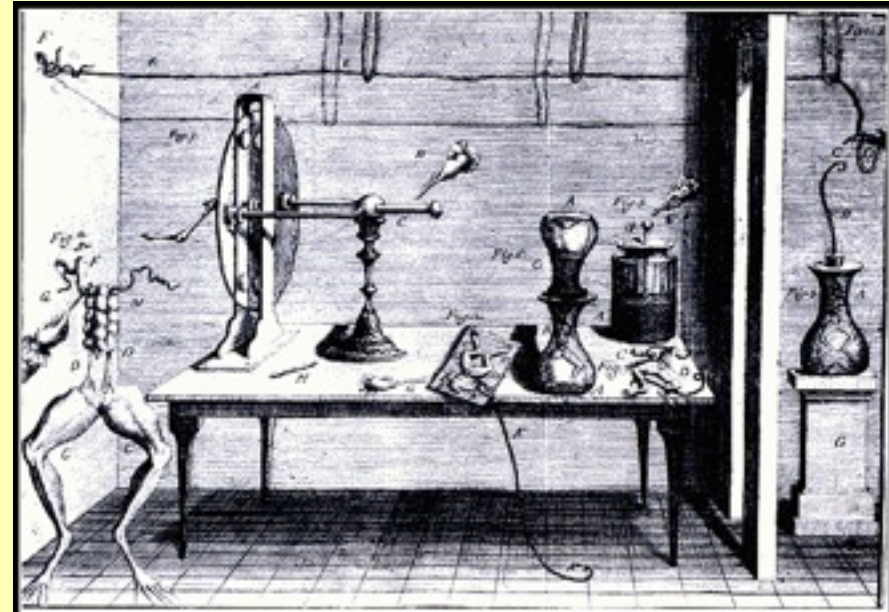
"The discovery was made in this way. I had dissected and prepared a frog and while I was attending to something else, I laid it on a table on which stood an electrical machine at some distance from its conductor and separated from it by a considerable space. Now when one of the persons who were present touched accidentally and lightly the inner crural nerves *DD* of the frog with the point of a scalpel all the muscles of the legs seemed to contract again and again as if they were affected by powerful cramps. Another one who was there, who was helping us in electrical researches, thought that he had noticed that the action was excited when a spark was discharged from the conductor of the machine."

Galvani, *De viribus electricitatis...*(1791)



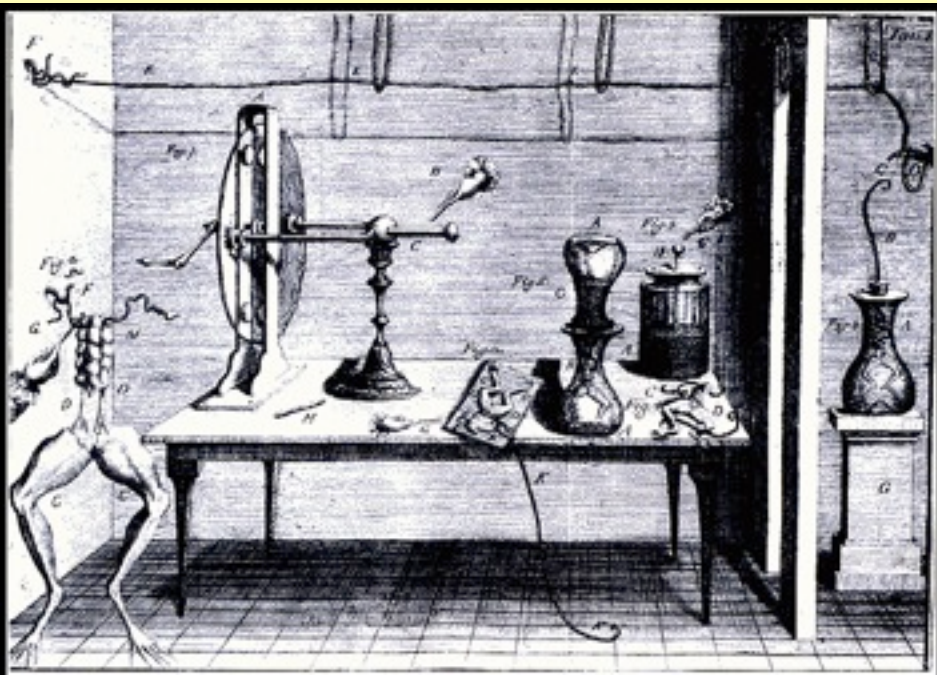
"Being astonished by this new phenomenon he called my attention to it, who at that time had something else in mind and was deep in thought. Whereupon I was inflamed with an incredible zeal and eagerness to test the same and to bring to light what was concealed in it. I therefore myself touched one or the other nerve with the point of the knife and at the same time one of those present drew a spark..."

Galvani, *De viribus electricitatis...*(1791)



"With the thought that these motions might arise from the contact with the point of the knife, which perhaps caused the excited condition, rather than by the spark, I touched the same nerves again in the same way in other frogs with the point of the knife, and indeed with greater pressure, yet so that no one during this time drew off a spark. Now no motions could be detected. I therefore came to the conclusion that perhaps to

excite the phenomenon there were needed both the contact of a body and the electric spark."



Galvani, *De viribus electricitatis...*(1791)

Franz Anton Mesmer – animal magnetism



PRÉCIS
HISTORIQUE
DES FAITS RELATIFS
AU
MAGNÉTISME-ANIMAL

JUSQUES EN AVRIL 1781.

Par M. MESMER, Docteur en Médecine de la Faculté de Vienne.

— — — — —
OUVRAGE TRADUIT DE L'ALLEMAND.
— — — — —



A LONDRES.

M. DCC. LXXXI.



PRÉCIS HISTORIQUE
DES FAITS RELATIFS
AU
MAGNÉTISME-ANIMAL.



Il y a quatorze ans que j'annonçai, pour la première fois, au Monde l'existence du MAGNÉTISME-ANIMAL.

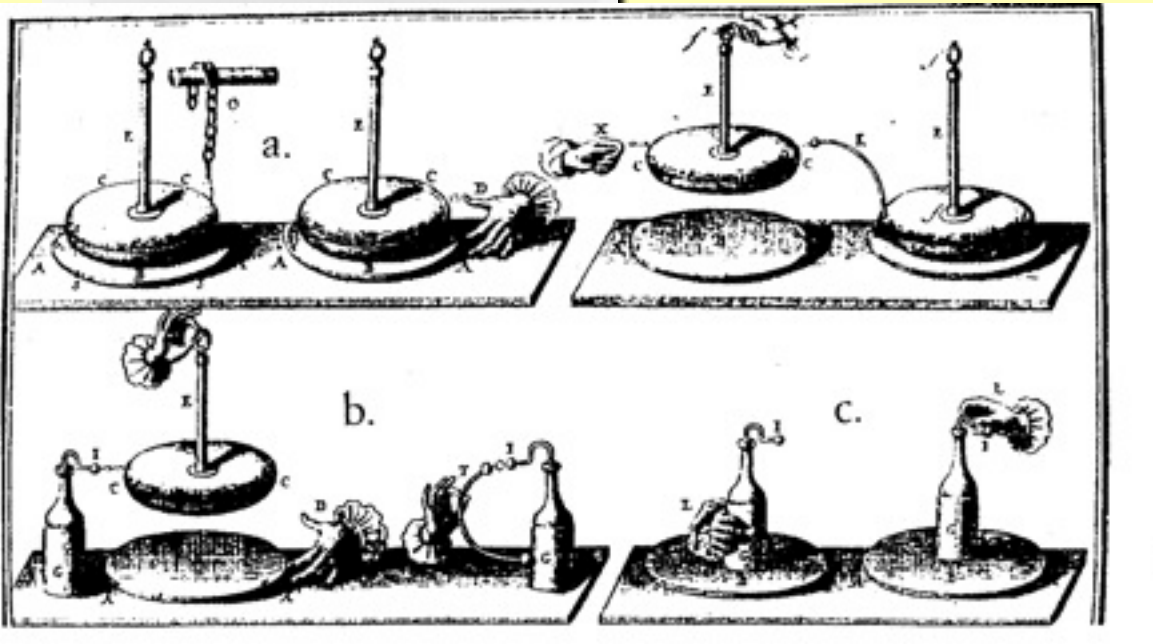
Lorsqu'en 1766 je donnai ma Dissertation de l'influence des Planètes sur le corps humain, j'appuyois ma théorie sur des principes reçus dans les sciences, & sur des exemples généralement connus; mais les inductions particulières que je tirois des uns & des autres n'étoient pas soutenues d'expériences immédiatement applicables à la question, il en résulteroit moins une doctrine à recevoir qu'un système à examiner.

Depuis que par la confiance de mes travaux & l'exactitude de mes observations, j'ai établi l'évidence de mes principes sur des preuves sans cesse renais-

A



Alessandro Volta (1745-1827)



Electrophore (1775)

”What is your opinion about the alleged animal electricity? Since quite some time I am convinced that the true source of this action is in the metals which are in touch with humid bodies or the water itself. Electric fluid in humid bodies is pushed by these metals in varying degree... more by zinc, and less by silver. When a good continuous conductor is provided, the fluid is put into circulation. If the frog leg nerves form any part of this conducting circuit... the muscles are induced to vibrate...”

Alessandro Volta, Letter to Antonio Maria Vassalli, *Giornale Fisico-medico* (1794)

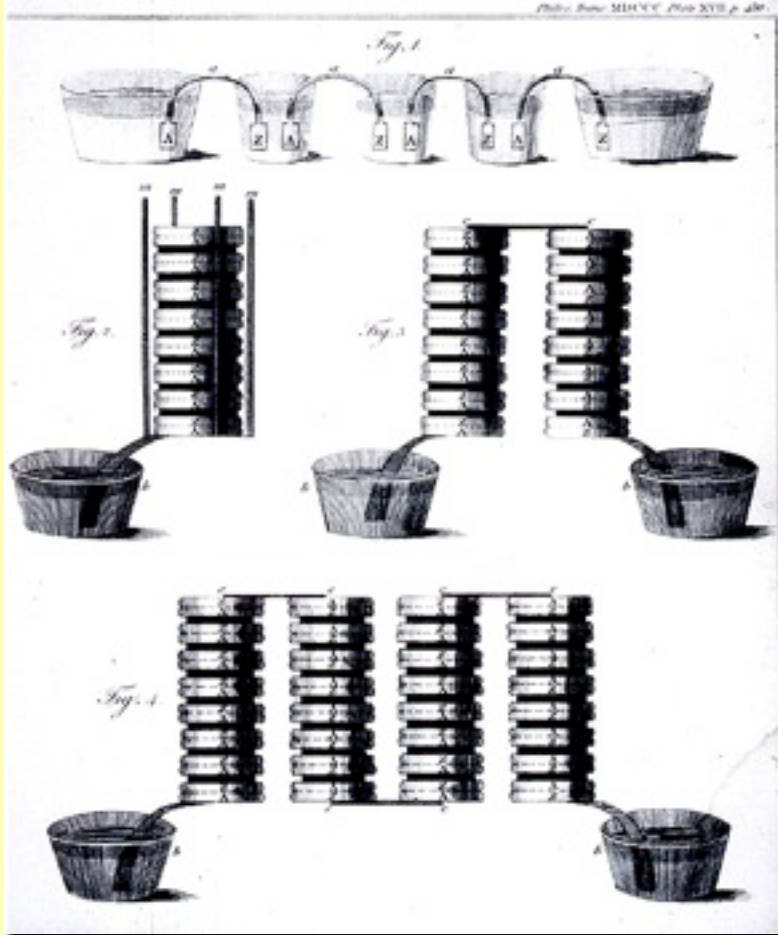
"If instead of muscles the conducting circuit includes nerves of taste or vision, a corresponding sensation of taste or light is induced; these sensations or movements are the more intense the more distant are the two metals in the following order: zinc, tinfoil, ordinary tin, lead, iron, brass and bronze of various composition, copper, platinum, gold, silver, quicksilver, graphite... It is quite obvious that everything here depends on the metals and their difference because the experiment will be successful only if the two metals are dissimilar. It would be equally justified to call it metallic electricity instead of animal electricity..."

Alessandro Volta, *Giornale Fisico-medico* (1794)

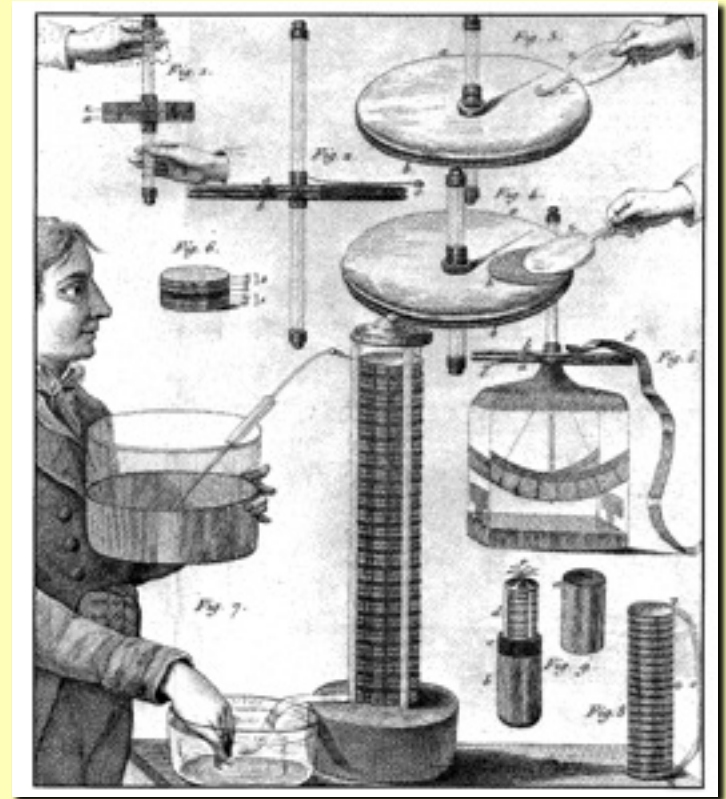
Alessandro Volta (1745-1827)



First electric battery



Volta's pile (1800)



Experiments with
the Volta's pile (1803)

Alessandro Volta, Letter to Sir Joseph Banks, 20 March 1800 (*Phil. Trans.* 1800)

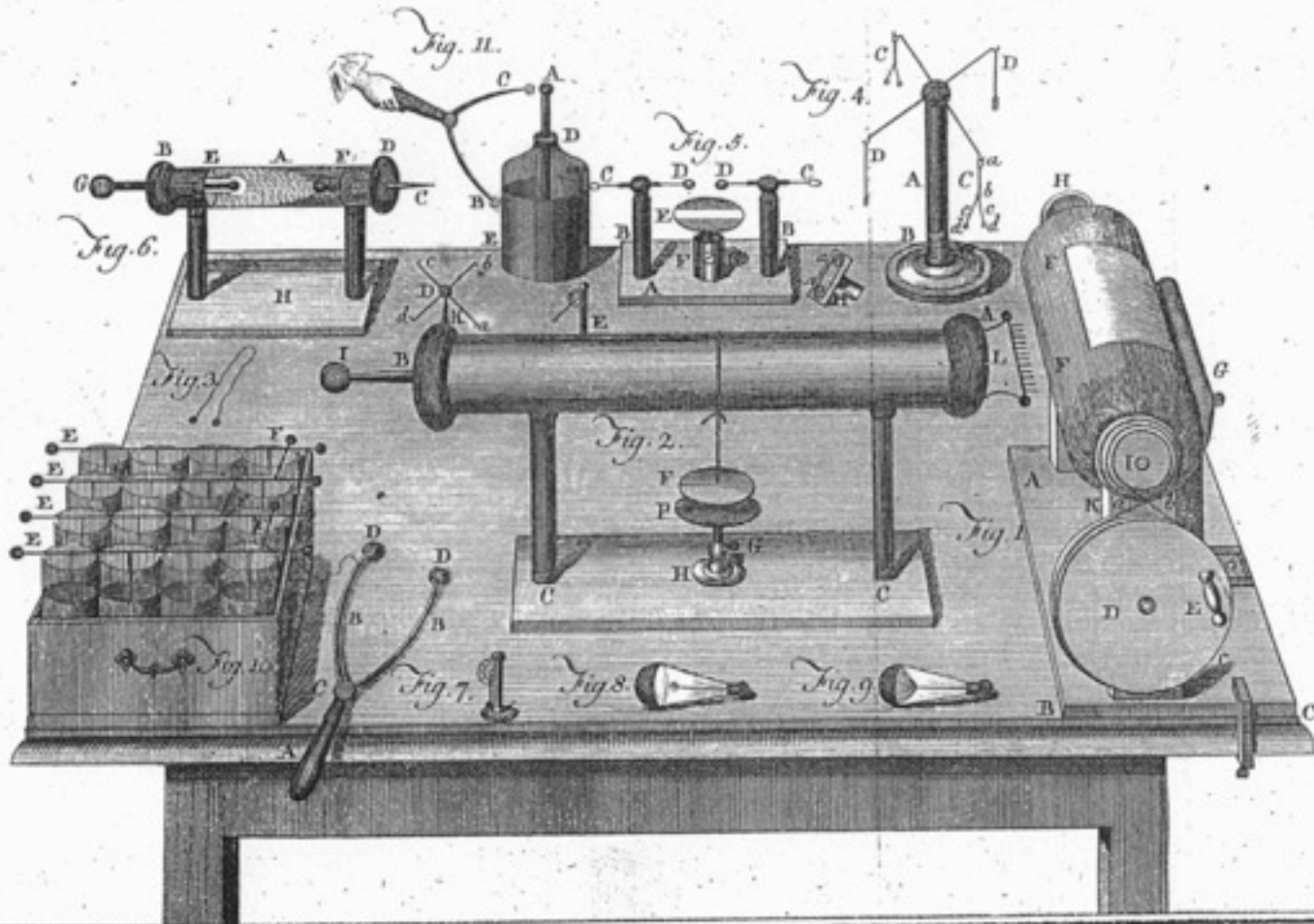
”After a long silence, which I do not attempt to excuse, I have the pleasure of communicating to you, Sir, and through you to the Royal Society, some striking results to which I have come in carrying out my experiments on electricity excited by the simple mutual contact of metals of different sorts, and even by the contact of other conductors, also different among themselves, whether liquids or containing some liquid, to which property they owe their conducting power. The most important of these results, which includes practically all the others, is the construction of an apparatus which, in the effects which it produces, that is, in the disturbances which it produces in the arms etc., resembles Leyden Jars, or better still electric batteries feebly charged, which act unceasingly or so that their charge after each discharge reestablishes itself;”

Alessandro Volta, Letter to Sir Joseph Banks, 20 March 1800 (*Phil. Trans.* 1800)

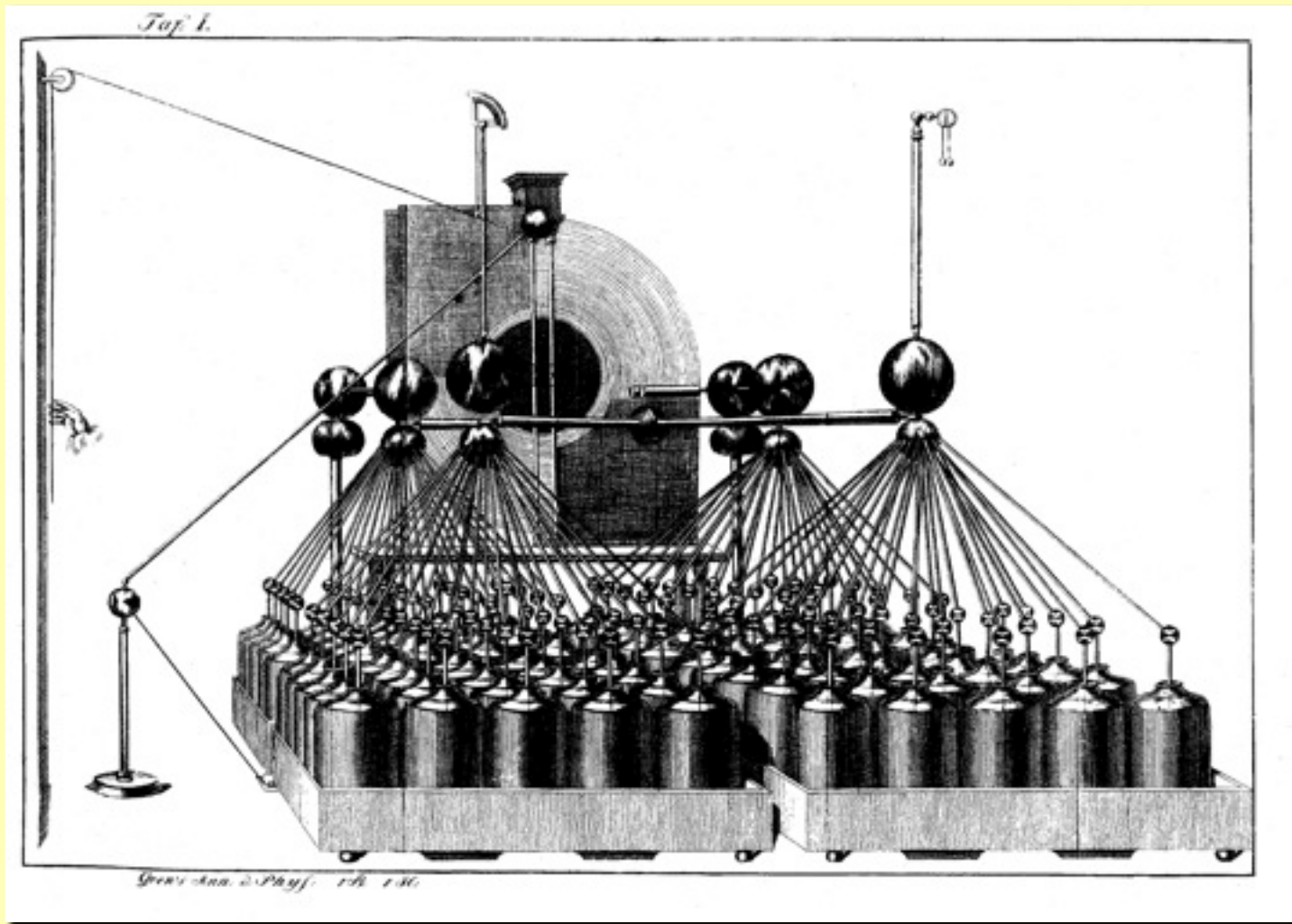
”which in a word provides an unlimited charge or imposes a perpetual action or impulsion on the electric fluid; but which otherwise is essentially different from these, both because of this continued action which is its property and because, instead of being made, as are the ordinary Jars and electric batteries, of one or more insulating plates in thin layers of those bodies which are thought to be the only electric bodies, coated with conductors or bodies called non-electrics, this new apparatus is formed altogether of several of these latter bodies, chosen even among the best conductors and therefore the most remote, according to what has always been believed, from the electric nature. Yes! the apparatus of which I speak, and which will doubtless astonish you, is only an assemblage of a number of good conductors of different sorts arranged in a certain way...”

”I provided myself with several dozen small round plates or discs of copper, of brass, or better of silver, an inch in diameter more or less (for example, coins) and an equal number of plates of tin, or which is much better, of zinc, approximately of the same shape and size... I further provided a sufficiently large number of discs of cardboard, of leather, or of some other spongy matter which can take up and retain much water, or the liquid with which they must be well soaked if the experiment is to succeed. These pieces, which I will call the moistened discs, I make a little smaller than the metallic discs or plates, so that when placed between them in the way that I shall soon describe, they do not protrude.”

"I place horizontally on a table or base one of the metallic plates, for example, one of the silver ones, and on this first plate I place a second plate of zinc; on this second plate I lay one of the moistened discs; then another plate of silver, followed immediately by another of zinc, on which I place again a moistened disc. I thus continue in the same way coupling a plate of silver with one of zinc, always in the same sense, that is to say, always silver below and zinc above or *vice versa*, according as I began, and inserting between these couples a moistened disc; I continue, I say, to form from several of these steps a column as high as can hold itself up without falling..."



Instruments for experiments with electricity (Cavallo, 1797)



Giant electrostatic machine of Van Marum (1799)

Reform of weights and measures



Determination of a unit length (foot)

The situation with measures in Europe was chaotic because there was multitude of different measures of weight and length

8. Proportions of the Long Measures of several Nations to the English Foot.

				Thoufandth Parts.	Inches.					Thoufandth Parts.	Inches.
English	-	-	foot	1000	12'000	Amsterdant	-	-	ell	2269	27'228
Paris	-	-	foot	1065 $\frac{1}{2}$	12'792	Antwerp	-	-	ell	2273	27'276
Rynland, or Leyden	-	-	foot	1033	12'396	Rynland, or Leyden	-	-	ell	2260	27'120
Amsterdam	-	-	foot	942	11'304	Frankiort	-	-	ell	1826	21'912
Brill	-	-	foot	1103	13'236	Hamburgh	-	-	ell	1905	22'860
Antwerp	-	-	foot	946	11'352	Leipfic	-	-	ell	2260	27'120
Dort	-	-	foot	1184	14'208	Lubeck	-	-	ell	1908	22'896
Lorrain	-	-	foot	958	11'496	Noremburgh	-	-	ell	2227	26'724
Mechlin	-	-	foot	919	11'028	Bavaria	-	-	ell	954	11'448
Middleburgh	-	-	foot	991	11'892	Vienna	-	-	ell	1053	12'636
Straßburgh	-	-	foot	920	11'040	Bononia	-	-	ell	2147	25'764
Bremen	-	-	foot	964	11'568	Dantzic	-	-	ell	1903	22'836
Cologne	-	-	foot	954	11'448	Florence	-	Brace or ell	1913	22'956	
Frankfort ad Mœnum	-	-	foot	948	11'376	Spanifh, or Caftile	-	palm	751	9'012	
Spanifh	-	-	foot	1001	12'012	Spanifh	-	vare	3004	36'040	
Toledo	-	-	foot	899	10'788	Lifbon	-	vare	2750	33'000	
Roman	-	-	foot	967	11'604	Gibraltar	-	vare	2760	33'120	
On the monument of Ceftius Statilius	}	-	foot	972	11'664	Toledo	-	vare	2685	32'220	
Bononia		-	foot	1204	14'448	Naples	-	palm	861	10'332	
Mantua	-	-	foot	1569	18'838		-	brace	2100	25'200	
Venice	-	-	foot	1162	13'944		-	canna	6880	82'560	
Dantzic	-	-	foot	944	11'328	Genoa	-	palm	830	9'960	
Copenhagen	-	-	foot	965	11'580	Milan	-	calamus	6544	78'528	
Prague	-	-	foot	1026	12'312	Parma	-	cubit	1866	22'392	
Riga	-	-	foot	1831	21'972	China	-	cubit	1016	12'192	
Turin	-	-	foot	1062	12'744	Cairo	-	cubit	1824	21'888	
The Greek	-	-	foot	1007	12'084	Old Babylonian	-	cubit	1520	18'240	
Old Roman	-	-	foot	970	11'640	Old Greek	-	cubit	1511	18'132	
Lyons	-	-	ell	3967	47'604	Old Roman	-	cubit	1458	17'496	
Bologna	-	-	ell	2076	24'912	Turkifh	-	pike	2200	26'400	
						Persian	-	arafh	3197	38'364	

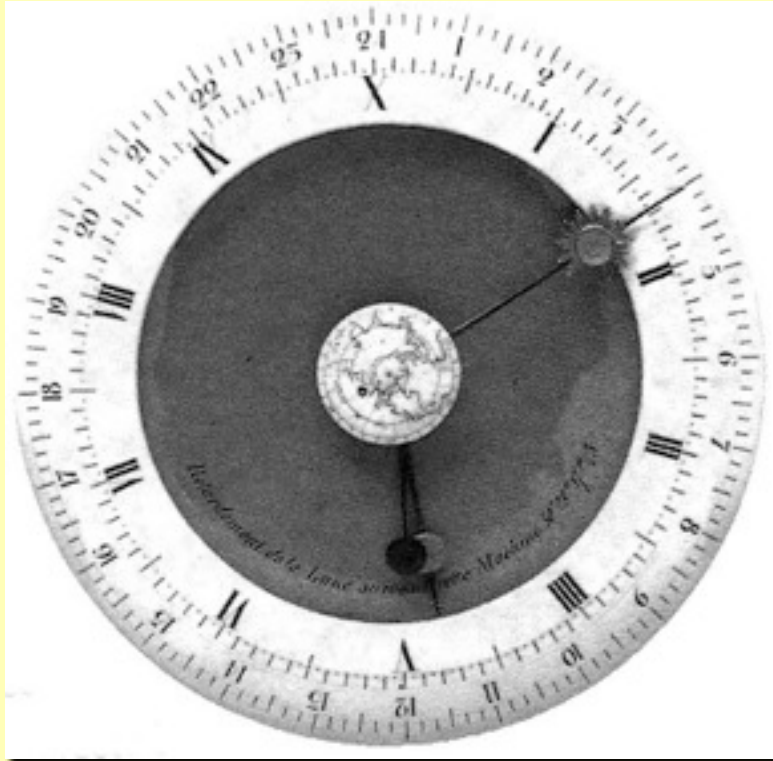
On May 8, 1790, the National Assembly of France decreed that a new system of weights and measures must be based on a suitable choice of **physical constants**, so that the new units could be adopted by all nations

mètre – one ten-millionth of the length of a quarter of the earth meridian

gramme – weight of water corresponding to the new unit of length

The new measures were approved as legal in December 1799, but their introduction in France met with strong resistance and was very slow.

Other countries accepted new measures with reluctance



Proposed decimalization of angular measures and time was not successful, and was soon abandoned as well as the new 'revolutionary calendar'

