Martinus van Marum: A Dutch Scientist in a Revolutionary Time

by

L.M.L.F. Hosselet

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Preface.

This publication, dealing with the life and experiments of Martinus Van Marum, originates from lecture notes prepared, amongst other things, for the exhibition "The Dutch Republic in the days of John Adams", which was intended as a very special tribute by the Dutch Government to the United States on the occasion of the Bicentennial Celebrations in 1976. I had become involved with these activities due to the fact that, as a senior lecturer in the field of high voltage technology at Eindhoven University of Technology, I was asked to take charge of the installation of a full size replica of Van Marum's machine at the exhibitions in Philadelphia, New York, Chicago, and Raleigh, N.C., and to organize some correlative lectures. This replica had been built at my University under the supervision of the late H.J. de Weijer. It was transported to the United States for the occasion.

Martinus Van Marum lived in an era which was revolutionary in human thinking and behaviour, marked historically by "The Enlightenment", "The French Revolution" and "The Restoration". He was the last "general scientist" and in his behaviour one of the first, if not the first, who advocated for "applied science".

It is for this reason, that Prof.Dr.ir. P. Eijkhoff, strongly supported by several former colleagues of the Faculty of Electrical Engineering of the Eindhoven University of Technology, advised me to adapt these lecture notes into a paper.

That stimulation has resulted in this publication on the history of electricity, consisting of two separate parts. The first part deals with Van Marum and his work in relation to the era in which he lived, whereas the second part deals with his electrical experiments at the Teyler Institute in Haarlem.
I would like here to express my gratitude to Mr. I.V. Bruza, M.Sc., Librarian at the Eindhoven University of Technology, Faculty of Electrical Engineering, for the time spent on checking, formatting and supplementing the literature references.

I am also greatly indebted to my former colleague Mr. C. Huber, MSc., for meticulously rereading and correcting the manuscript, and for providing useful comments.

Finally I want to express my acknowledgement to Mrs. B.A. Cornelissen-Milner for her spontaneous assistance in correcting the Preface and Summary.

L.M.L.F. Hosselet

Achel (Belgium), Spring 1988
Summary:

Martinus Van Marum lived in a time, in which human thinking and social circumstances were greatly influenced by the ideals of the Enlightenment and the events in and around the French Revolution.

In this publication the author tries to give an impression of the life and work of Martinus Van Marum (1750-1837), Dutchman, and one of the last general scientists. A description is given of the social and scientific circumstances in which Van Marum was living at the start of his scientific career.

Van Marum succeeded in raising enough money to finance the building of the "large electrical machine", in fact the largest electrostatic generator ever made, constructed by John Cuthbertson, which still stands in the Teyler Museum in Haarlem today. He carried out many experiments which became famous in Europe. From his experiments he became convinced that Lavoisier's theory, which revolutionised the way in which the chemists of that period thought, was correct. Under the influence of the political troubles in Europe as a result of the French Revolution, finances for expensive experiments became more and more limited. That, and a certain lack of ideas for new electrical experiments, caused him to turn his attention to other branches of science. Being a general scientist this, for him, was no great problem.

Following Oerstedt's experiments with electromagnetism, Van Marum displayed a last burst of activity in the field of electricity. This resulted in a request to the Director of the Teyler Foundation to install a very large apparatus for electromagnetic experiments, which, however, never materialized.

He never succeeded to make the "great jump" in electricity, but even though he felt that many of his expectations had
not been fulfilled, he was, as the first of a new breed of scientists - the "applied scientists" - convinced that one day electricity would greatly benefit mankind, as he illustrated in his statement, "One step further on in this science may enable us to make it bring us great benefits".

Hosselet, L.M.L.F.
MARTINUS VAN MARUM: A Dutch scientist in a revolutionary time.
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Martinus Van Marum,
(1750 - 1837)
a Dutch scientist in a revolutionary time.
by

Introduction.
In 1987 two hundred years had elapsed since an interesting publication by the Dutch scientist Martinus Van Marum appeared in Volume IV of the "Transactions of the Second Teyler Society" [1]. To this publication, that was written in the French and Dutch languages, there was affixed a separate Dutch publication, entitled: "Outline of the Teaching of M. Lavoisier, concerning pure Atmospheric Air and the Union of its Fundamental Principle with Various Bodies" [2].

It is this publication, based on experiments of Van Marum with the large electrical machine of the Teyler Institute in Haarlem, The Netherlands, that gave the first clear exposition of Lavoisier's theory, as Lavoisier himself never produced more than a summary of his theory until 1789 [3]. With this publication Van Marum had a great share in the promotion and acceptance of Lavoisier's theory which he indicated as "the new chemistry".

I will try to give in two separate publications a description of the person of Martinus Van Marum. In the first, I will give a general description of Van Marum and his work against the background of the time in which he was living. The second will deal with his experiments with the large electrical machine at the Teyler Institute in Haarlem.
The life and times of Martinus Van Marum.

1. Who was Martinus Van Marum?
The father of Martinus, Petrus Van Marum, was born in Groningen, The Netherlands, where, in 1736, he obtained a degree as civil engineer and surveyor. He moved to Delft, where he married with Cornelia van Oud Heusden in 1744. Martinus Van Marum was born on March 20, 1750. From 1754 till 1764 his father was the owner of a Delft pottery "De Romein". After the sale of this pottery the family left Delft for Groningen.

December 31, 1764 Martinus was immatriculated at Groningen University, where he studied medicine and philosophical subjects: biology, physics, chemistry, geology and palaeontology. August 7, 1773 he obtained not only his doctor's degree in philosophy, but also the licence to add the characters "A.L.M." to his name. These characters are an abbreviation of "Artium Liberalium Magister" (Master of Liberal Arts), a degree that was a tradition of the old medieval universities, but was dropped in 1814 after the Restoration. August 21, 1773 he also obtained his doctor's degree in medicine.

In this context it is of interest to give an impression of the scientific climate at the time Van Marum was born. In the second half of the 18th century in England as well as in the Netherlands there was a widespread interest in science. In the Republic of the Seven United Provinces there were universities at Leiden (since 1575), Franeker (1585), Harderwijk (1600), Groningen (1614) and Utrecht (1636). In addition there were also "Illustrious Schools" in Deventer (1630) and in Amsterdam (1632) which gave practically the same instructions, although their degrees were not as prestigious as those of the universities.

At that time The Netherlands had a good name in the natural sciences, mathematics and medicine. Well known were the na-

The general interest in physics and the sciences resulted in the foundation of scientific societies. In 1662 the Royal Society of London was founded, followed by the Académie des Sciences in Paris (1666), the Akademie von Berlin (1700), the Academy of St. Petersburg, Russia (1725), the American Philosophical Society (1744) and the Academy of Philadelphia (1751).

Based on these models also scientific societies in The Netherlands were founded: in 1752 the "Hollandsche Maatschappij der Wetenschappen" (Dutch Society of the Sciences), with the motto "Deo et Patriae", was founded in Haarlem, followed in 1768 by the "Zeeuwsch Genootschap der Wetenschappen" (Zealand's Society of the Sciences) at Vlissingen (Flushing) and in 1769 by the "Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte" (Batavian Society of Experimental Philosophy) at Rotterdam.

Separate from the "Hollandsche Maatschappij der Wetenschappen" in 1778 another great scientific institute was founded in Haarlem, named "Teyler's Stichting" (the Teyler Foundation). This was in accordance with a testamentary stipulation of Pieter Teyler van der Hulst, an affluent silk manufacturer and merchant, who died at Haarlem in 1778.

The Teyler Foundation consisted of "Teyler's Godgeleerd Genootschap" (the Teyler Theological Society), a philanthropic department and "Teyler's Tweede Genootschap" (the Second Teyler Society) with the branches "Natural Sciences", "Poetry", "History", "the Art of Drawing" and "Numismatics". The Natural Sciences branch was subdivided into "Botany", "Zoology", "Mineralogy", and "Astronomy and Related Subjects".

In 1776 Van Marum settled down into practice as a physician in Haarlem. His choice for Haarlem was inspired by the fact
that Haarlem at that time was a large and highly intellectual centre.

At the annual meeting of May 21, 1776 van Marum was elected as a member of the "Hollandsche Maatschappij", and October 24, 1776 he was appointed as a lecturer in philosophy and mathematics. May 21, 1777 he was appointed director of the cabinet of natural curiosities belonging to the "Hollandsche Maatschappij der Wetenschappen". During the first three months this appointment was without any payment, from September on, however, at an annual salary of Dfl 300,--. In 1780 he was elected as a member of the Second Teyler Society.

February 11, 1781 Van Marum married Joanna Bosch, born June 16, 1739. She was the only daughter of Jan Bosch (1713-1780) and Catharine Blauuwduyf, who died already in 1760. Jan Bosch was the printer of the "Verhandelingen" (Proceedings) of the "Hollandsche Maatschappij".

As one may observe, Johanna was more than ten years the elder of Martinus. But this circumstance was compensated by the fact that Joanna brought with her more than Dfl 100,000 at a time when Van Marum possessed less than Dfl 8000.--. In this connection it should be remarked that both parents of Van Marum were still living and, just like in our days, nobody wanted to be undressed before his death.

The marriage of Van Marum and Joanna Bosch was very happy, though they were not blessed with children.

It also should be mentioned that Van Marum maintained contacts with almost all great men in the world of that time, among them Franklin, Goethe, Galvani, Volta, Lavoisier, and Cavendish. Joanna Bosch made copies of all letters that Van Marum wrote to scientists all over the world. From these letters, that are reprinted on p. 361/375 of Vol. 1 of [4], we now have the opportunity to get a good impression of Van Marum, his interests, his friends, and his correspondents.

As a result of his marriage Van Marum now was a rich man. So he could afford to make yearly international journeys.
through Europe with a scientific purpose. He kept diaries of these journeys, which were reprinted in 1970 [5]. These diaries are very interesting as well as amusing to read. The author made many critical remarks on a lot of subjects he came across during his journeys. These diaries provide a clear image of Van Marum as a person and of the time in which he lived.

He continued his large journeys through Europe till 1802 when, as a result of political troubles, it became difficult to travel. It should be noted that in 1802 he was a man of 52 years of age, and travelling in his days was not as simple and easy as in our days.

His shorter journeys to the Southern Netherlands, however, he continued till 1829. As a result of the Belgian Revolution, which started on July 21, 1830, it was impossible to go to Belgium. Nevertheless, though he was now a man of 80 years of age, he still travelled regularly in Holland, and he continued to travel from Haarlem to Amsterdam to visit the meetings of the Academy of Sciences at Amsterdam until shortly before his death, December 26, 1837. His wife had died before on February 27, 1821.

2. The start of Van Marum's scientific career.
In 1783 Van Marum became a corresponding member of the "Academie des Sciences" in Paris, and in 1784 he was appointed director of "Teyler's Physische en Naturalien Kabinet en Bibliotheek" (the Teyler Cabinet of Physical and Natural Curiosities and Library), a new department of the Second Teyler Society.

This museum had been built behind the house of the late Pieter Teyler van der Hulst and was practically complete in 1784. This museum is still in existence and open to visitors. The physical instruments were to be displayed and experiments to be carried out in the large oval room, where also the collection of natural curiosities was accommodated.

The library occupied the gallery on the first floor.
As the "Hollandsche Maatschappij" was more specialized in zoology, the two institutions decided to divide their interests: the "Hollandsche Maatschappij" concentrated on zoology, "the Teyler Second Society" on fossils.

The first very important instrument Van Marum ordered to be made was the very large electrical machine, made by John Cuthbertson (1742-1821) under the constant supervision of Van Marum himself. This machine has attracted the attention of every visitor of the Teyler Museum from 1784 up till now. Among the visitors were, of course, many scientists and physicists from the whole of Europe, but also the stadtholder Willem V, the king Louis Napoleon of Holland, the emperor Napoleon Bonaparte and, after the French time, Willem I, the king of the United Kingdom of Holland and Belgium.

Van Marum's experiments with this large electrical machine are described very conscientiously in three volumes of the Proceedings of the Second Teyler Society in the years 1785, 1787 and 1795.

From these proceedings one gets an impression of his intensive and systematic way of experimenting. Besides that he did not hesitate to ask the opinion of others and also requested them to suggest other experiments which could be done by him.

* A true and working copy of this large electrical machine (property of the Eindhoven University of Technology) has been exhibited in various places in The Netherlands. It was one of the highlights of the exposition that was offered by the Dutch Government to the people of the United States at the occasion of the celebration of the Bicentennial in 1976. The aim of this exposition, that visited successively Philadelphia, New York, Chicago and Raleigh, N.C., was to give an impression of the state of Art and Science in the Republic of the Seven United Provinces, now The Netherlands, at the time of the Declaration of Independence.
His fame in the field of electricity cannot be better expressed than by a quotation from his diary of his journey to Paris in 1785 [6], where he met Benjamin Franklin, the nes-tor of the authorities in electricity, who was ambassador of the United States in Paris at that time.

Franklin said to Van Marum: "that he was particularly pleased to learn, before his departure from Europe, of the new progress in the doctrine of electricity, and that he was convinced, that I had got very far in this field" [6, p.40]. Van Marum's subsequent scientific course was strongly influenced by this visit to Paris, not so much by his meeting with Franklin, but by a revolution in chemistry.

3. The meeting with Lavoisier in Paris.
During his stay in Paris Van Marum also had a meeting with Lavoisier. By weighing experiments Lavoisier showed that during combustion a component is added. This component was called by Lavoisier the "principe oxygène". This was in fact a revolutionary way of thinking in chemistry, as up till then the old "phlogiston theory" of Becher and Stahl was generally accepted. This theory said that by combustion of substances a component became separated. This component that was to be the principle of fire, was called phlogiston. The more phlogiston a substance contained, the better it would burn. The first treatise by Lavoisier appeared in 1773, followed by more in the years 1774-1780 [7, 8].

Up till then Van Marum had been an advocate of the phlogiston theory. There is a treatise from his hands for the Second Teyler Society, dated 1778 and printed in 1781, that deals with phlogisticated and dephlogisticated airs [9]. Another essay was composed in 1783 by Van Marum and a co-worker, Paets van Troostwyk, and printed in 1787 [10].

Also his first experiments with the large machine, published in 1785 in the Proceedings, were based on phlogiston.

But the visit to Paris in 1785 made Van Marum doubt about the phlogiston theory. Subsequently he was induced to exami-
ne the matter more accurately. After experiments with his large machine he became convinced of the correctness of the ideas of Lavoisier. So in 1787 he published in the Proceedings of the Second Teyler Society his famous "Schets der Leere van Mr. Lavoisier" (Outline of the Teaching of Mr. Lavoisier) [2]. This publication was the first clear exposition of this theory, as Lavoisier did not produce a summary of his own theory until 1789 [3].

In the years 1792-1794 Van Marum pushed this theory in his lectures. Besides that, in 1798 he simplified the chemical instruments to show the validity of the theory of Lavoisier. His struggle was hard: Priestley was the last great advocate of the phlogiston theory, right unto his death in 1805. On the other hand, the Germans were not so eager to accept the theory of the Frenchman Lavoisier, Becher (1625-1682) and Stahl (1666-1734) being Germans, they were the hardest to convince. This is stated by a friend of Van Marum, prof. Damen from Leyden: "If such persistent sticking to prejudice is patriotism, then Germans are great patriots" [11].

The fact that Priestley was a supporter of phlogiston is also the reason that not until April 19, 1798 Van Marum was accepted as a member of the "Royal Society of London", although already in 1790 he had gone to London with the hope of getting the long cherished election!

The guillotining of Lavoisier, May 8, 1794 during the Reign of Terror, made a deep impression on Van Marum. In the introduction of his series of chemical lectures he referred to this fact in November 1794: "However, in this very year, science has received a blow which is probably the most severe that could have been dealt to it. The death of Lavoisier, the great restorer of chemistry, a man whose services in the restoration of a science can perhaps be considered as equal to those of Newton, will rob us, to all appearance, of the outcome of a great number of experiments" [12].
4. Miscellaneous experiments carried out by Van Marum.

Apart from his electrostatical experiments, that will be described in the second part of this publication, Van Marum also worked in the field of "exploding wires". The large electrical machine, that under good atmospheric conditions could generate a maximum voltage of about 300 kV, could be connected to a great battery of Leyden jars, consisting of 225 jars with a total capacity of about 1.125 µF. So he disposed over an energy source of about 55 kJ, which he could discharge through conductive wires. These experiments, done with several materials, gave him indications for the design of good lightning conductors [13]. From these experiments he also came to guide-lines for the installation of lightning conductors. As he was not only a propagandist for, but also personally active with research on lightning conductors, he invented means for protecting windmills against lightning. In 1785 he also discovered with his large machine that ozone is formed in the electrical discharge [14]. This is reported in a letter by Van Marum to Cavendish [15].

He discovered that earthed conductors need a certain thickness to prevent corona phenomena to occur. As a physician he also used the machine to perform medical researches, e.g. the influence of the electric field on pulsation [16].

It may be mentioned that Van Marum preferably experimented on cold and freezy days in order to prevent the air moisture from interfering with his electrical experiments.

May 19, 1794 Van Marum was appointed secretary of the "Hollandsche Maatschappij der Wetenschappen" (Dutch Society of the Sciences). For the first five years, on account of the financially critical time, he fulfilled this task without any salary.

The discovery of the Voltaic Pile by Volta in 1800 brought the end of the electrostatical era. The new electricity was named galvanic electricity, in honour of Galvani. Van Marum, together with prof. Pfaff from Kiel, Germany, effected the proof that both kinds of electricity are the same.
With the political troubles in Europe in the last decade of the 18th century the financial situation degraded more and more. The time to make large and expensive experiments had passed. So Van Marum's interest went to geology. He arranged the mineralogical collections four times in accordance with several new theories. In 1796/1797 he gave lectures on general geology and especially on volcanoes, in 1797/1798 on fossils and palaeontology. This was not a completely new hobby of his, for formerly he also had been active in this field. In the period 1782-1790 he compiled a fossil collection for the Teyler Museum. At public auctions and during his journeys he bought the best fossils and minerals he could get. In 1784, for instance, he bought for 200 ducates, about Dfl 1000.-%, the head of the Mosasaurus from the St. Pietersberg at Maastricht, The Netherlands. In the years 1799/1800 and 1800/1801 he conducted studies of the original crust of the earth and the determination of the kinds of rock that compose the earth's crust.

In the meanwhile he also exhibited a broad interest in botany. In 1789 the dahlia came from Mexico to Madrid, and from there to the "Jardin des Plantes" in Paris. From Thouin, director of this garden, Van Marum received dahlias. "Plantlust" was his home outside Haarlem, where he used to stay from April to October. In 1810 he there had a collection of 3000 species of plants from all parts of the world: Africa, Asia, and America, and among them already 4 kinds of dahlias. During the winter months he lived in Haarlem.

That Van Marum was a medical doctor can be seen from his activities in the years 1793-1798, the period there was no money for large experiments. In 1793 he experimented on the rescuing of drowned persons by administering additional oxygen, by removing the water from the lungs and by giving hot baths to keep the temperature of the drowned person at a proper level.
In 1797 he invented a portable fire engine and in 1798 he conducted a study on ventilation and air conditioning especially on ships. In the field of public health he recommended planting trees and cleaning the streets to prevent pollution of the urban atmosphere. He also warned against burials in churches.

Van Marum also liquefied NH$_3$ at a pressure of 3 bar on a cold day. He did not, however, conclude from this fact that all gases could be liquefied under certain conditions.

His social responsibility is shown by an improvement, in 1800, of Papin's Digester, a kind of pressure cooker used to prepare soup for the poor of Haarlem. In 1814, after the Restoration of the reign of the House of Orange in the United Kingdom of Holland and Belgium, Van Marum became Knight of the Order of the "Nederlandsche Leeuw" (Dutch Lion). At that time Van Marum had been busy with his botanical studies.

5. Van Marum's later years.

After the publication "Rules about the Influence of Electrical Currents on Magnetism and Vice Versa" by Oerstedt in 1820, Van Marum occupies himself with electromagnetism. This results in a request of March 29, 1822 to the Director of the Teyler Foundation to acquire a very large apparatus for experiments on electromagnetism. It should be mentioned that he was already 72 years old and had lost his wife on February 27, 1821.

Since 1826 Van Marum worked vigorously to enlarge the Teyler Library.

During the years 1816 till 1829 he went to Belgium almost yearly. His best friend in Belgium was Parmentier, the burgomaster of Enghien and a well-known lover of plants. They exchanged plants for their collections. As a result of the Belgian Revolt he could not visit Belgium and lost all his contacts after 1830. Not until April 28, 1837 did he restore his correspondence with Parmentier.
It should be mentioned too, that in the years 1810-1836 Van Marum worked much for the Royal Institute of Science at Amsterdam in committees and as a lecturer, and he regularly attended its sessions. The distance between Haarlem and Amsterdam is about 30 km!

On December 26, 1837 he died in Haarlem, after an illness of only four days at an age of 87 years. This was just too soon for him to enjoy the pleasure of travelling by railway, as it started in The Netherlands in 1839 with the line from Haarlem to Amsterdam.

His wife, who to the very last had continued to copy the correspondence of her husband, had been buried in the "Nieuwe Kerk" at Haarlem. But as burials in churches were prohibited since 1825, he could not be entombed in the grave of his wife. So he was buried at the General Cemetery in Overveen, near Haarlem, on January 2, 1838. This cemetery was closed in 1917, and his tombstone was bought by the "Hollandsche Maatschappij der Wetenschappen" and placed in the garden wall of the "Maatschappij" , Spaarne 17 at Haarlem.

6. Van Marum's place in the history of electricity.

During his studies Van Marum had heard about the experiments on electricity of Benjamin Franklin. Franklin had showed that atmospheric discharges were of electrical origin. At the time of Franklin's death Van Marum was 40 years old. At that time, 1790, Galvani showed the frog experiment, a hard time for all frogs! Volta discovered the Voltaic Pile, which gave the experimenters a continuous source of current, a fact that, in 1820, enabled Oerstedt to discover the effect of a current on magnets and vice versa, and Ampère to formulate his laws of electromagnetic forces on conductors. Van Marum showed that galvanic electricity and electrostatic electricity are the same.

At the time of Van Marum's death, Faraday (1791-1867) was 46 years old. Maxwell, whose "Treatise on Electricity and Magnetism" appeared in 1866, was born in 1831.
It may be remarked here, that nowadays static electricity again is an important topic. Especially the widespread application of synthetic materials introduces new problems in our society. In the sugar- and paper-industry, as well as in sawing- and flower-mills, paint-spraying and coal mines many cases could be cited of explosions caused by electrical discharges as a result of static electricity.

I hope these notes give the reader an impression of the time and circumstances, in which Martinus Van Marum lived, of the difficulties he met, of the importance of his person in the development of our knowledge in many fields of science, and of the revolutionary time in which he lived and worked, revolutionary not only in a political sense, but also for the scope of science.

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The experiments of Martinus Van Marum using the large electrical machine at the Teyler Institute.
by

1. Introduction.
As a result of a testamentary disposition of Pieter Teyler van der Hulst, the "Teyler's Stichting" (the Teyler Foundation) was established at Haarlem, The Netherlands, in 1778. This Foundation consisted of a philantropical and a theological department.

For the other branches of science, among them physics, "Teyler's Tweede Genootschap" (the Second Teyler Society) was created. In 1784 this Second Society was extended by a new department, called "Teyler's Physische en Naturalien Cabinet en Bibliotheek (the Teyler Physical and Natural Cabinet and Library).

Martinus Van Marum, who had been director of the Natural Cabinet of the "Hollandsche Maatschappij der Wetenschappen" (the Dutch Society of the Sciences) since May 21, 1777 and who, in 1780, had been elected as a member of the Second Teyler Society, was appointed as director of the Teyler Physical and Natural Cabinet and Library.

The first very important instrument he caused to be made was the large electrical machine. This machine still exists and is standing in its original place in the Teyler Museum at Haarlem *.

The arguments Van Marum used to recommend to the Directors and Members of the Second Teyler Society to build this

* A true and working copy of this large electrical machine (property of Eindhoven University of Technology) has been on exhibit in various places in The Netherlands and in The United States.
machine were:
1) progress in "electrical science" was being made with the use of ever larger machines, "giving a more powerful electrical force";
2) his conviction was, that a still more powerful electrical force "would lead to new discoveries";
3) the costs of a larger electrical machine could not be provided by a physicist at his own expenses;
4) the fact, that "the machine needs more space than is generally available in any private house".

Cuthbertson, an English instrument maker living in Amsterdam since 1768, made the machine under the constant supervision of Van Marum. It is the largest of its kind ever constructed in the world.
The experiments that Van Marum carried out with this large electrical machine are described in the "Verhandelingen" (Transactions) of the Second Teyler Society of the years 1785, 1787 and 1795.
It is impossible to describe in a short article all experiments he made with this large electrical machine, as they occupy more than 240 pages in the Transactions. So only a short review of his experiments will be given to provide an impression of the broad field a scientist would cover in those times.

2. Construction and power of the machine.
In the "Transactions" of 1785 Van Marum describes the difficulties he met in the construction of the machine. Here he also notes that, "because of the well-known damp atmosphere in this country, the machine could not be used in the winter except during frost or drying winds". Therefore he always worked with open windows during winter [1]. The first experiments are only efforts to establish and to demonstrate in various ways "in how far the power of this machine surpasses that of others". As the glass he ordered
for his Leyden jars arrived too late, in these "Transactions" he only describes experiments with the conductor of the machine. But he expresses already his expectations to make new discoveries with the future large battery. So he also invites every physicist to communicate to him his ideas or views on further experiments. He promises to publish the results and, especially, to mention the name of whomsoever had suggested to him the idea for the experiment. And he stipulates: "As my way of thinking does not permit me to claim other peoples ideas as my own, I will describe without any reservation whatever I have been informed of and which has led to any discovery made by this machine" [2].

From the description of the electrical machine in these "Transactions" we learn that the machine has two glass discs, each with a diameter of 65" (165 cm) and placed at a distance of 7 1/2" (19 cm) from each other. These discs are rubbed at the top and at the bottom on both sides, so there are 8 cushions, each with a length of 15 1/2" (39,4 cm). For normal experiments two persons are necessary to turn the machine, for experiments of longer duration four men are needed at the crank. For this purpose a second crank is provided.

The experiments to show the great force of this machine are described in Chapter 2 of the First Part [3]. To get an impression of this force, we mention here that he obtained discharges with a length of normally 21" (53,3 cm), and under suitable atmospheric conditions even 24" (61 cm). From this we can conclude that he must have attained voltages of more than 350 kV.

By passing the electrical discharges over badly conducting surfaces, as e.g. wood, sprinkled with bronze dust, he could lengthen the discharges up to 6 feet (183 cm)! A sphere of 4 1/2" (11,4 cm), attached to the conductor even gave plume discharges with rays of 16" (40,6 cm).

Earthing the receiving conductor by a thin iron wire with
helical twists and a length of 207 ft (63 m), attached to the balustrade of the gallery in his laboratory, he observed that the whole wire was lit up by rays with lengths of 1" (2.5 cm) each time a discharge appeared between the first conductor and the receiving conductor [4]. In these experiments he also discovered that grounded wires have to be of a certain diameter to prevent corona discharges. In his opinion "the electrical matter was meeting too much resistance when passing through the wire itself" [5]. Up till then fusing of metals was only possible using Leyden jars. But the conductor of this machine had a power that was great enough to fuse metals totally without any Leyden jar! The presence of the electric field, as well as its momentary disappearance during the discharges of the machine was observed at hands and face at a distance of 8 ft (244 cm), at a distance of 2 ft (61 cm) even at the muscles of chest and arms. In the space between the conductors it was impossible to bear this influence [6]!

Really dangerous experiments were made with two circular discs with conducting surfaces and a diameter of 6 ft (183 cm). These discs were suspended in a parallel fashion at a mutual distance of 2 ft (61 cm) by means of silk cords attached to the ceiling. One of the discs was connected with the positive conductor of the machine, the other was charged negatively by induction by touching with one hand. In his other hand Van Marum held a copper sphere at a distance of 1" (2.5 cm) from the disc connected to the conductor. When turning the machine, a discharge passed after 2 or 3 seconds between the sphere and the disc, giving his body a terrible shock! Then he proceeded to find out the greatest distance between sphere and disc still to give a discharge. This distance he stated to be 1 1/2" (3.8 cm) [7].

From these experiments we learn, that he short-circuited a high voltage capacitor of about 40 pF, charged at a voltage of about 90 kV, with his own body! So a charge of 3.6 µC
passed his body, and, assuming a value of about 4500 Ω for the resistance of his body, this must have caused a peak current of 20 A.

This experiment was repeated for several distances between the discs. At a distance between the discs of 4' (122 cm) and a distance between the sphere and the disc of 1" (2.5 cm), he felt a strong shock up to his elbow (the capacity was now reduced to 20 pF), at 5' and 1/2" (13.3 pF and 15 kV) the shock became up to his wrist. At 12' (3.66 m) and a distance smaller than 1/4" (0.6 cm) the shock was only noticeable in his fingers.

His machine was so powerful, that a sharp steel point, held opposite to the end of the conductor became luminous up to a distance of 28' (8.53 m) from the conductor. The electrometer showed an indication even at the furthest possible distance from the conductor, at 40' (12.2 m). The balls moved no less than 1/2" (1.25 cm) from each other [8].

To obtain a powerful negative force at his machine, he removed the carvings of the table and replaced the carved cap by another one without any decoration and with edges and corners rounded as much as possible for experiments with negative polarity.

3. Experiments without Leyden jars battery.

In Chapter 1 of the Second Part one meets the physician Van Marum, as he researches the influence of positive and negative charge on the heart beat rate. On the metal covered top of an insulated table there was the possibility to place three persons: the person that was the subject of the experiment and two persons that could take the pulse of the subject to check the heart beat rate. This experiment was repeated on several persons with the metal table top either connected to the positively or to the negatively charged conductor of the machine. His conclusion was that the small differences he found should be "due to some fear on the part of the person concerned" [9].
Chapter 2 deals with the research on changes in several gases after passage of electric sparks.

Van Marum found, that after passage of sparks through oxygen during 15 minutes, the volume would have decreased by 5% and there would be a very strong smell of the air "that resembled the strong smell of electric matter". The same smell was found if he made this experiment in air during 30 minutes, the volume shrinking by almost 1 1/2 %. This was the first time that ozone was described scientifically [10].

He continues his experiments in several kinds of "air". In this relation it should be mentioned that in that time the several gases were indicated as a kind of air, e.g. "inflammable air" for carbon dioxide. These gases he prepared in chemical reactions, after which he led electrical discharges through the gas. From an eventually decrease of the volume he concluded that under the influence of the discharges chemical reactions took place [11].

Later he applied his results to prove the theory of Lavoisier and became a protagonist of the ideas of Lavoisier.

His experiments concerning the effect of lightning are described in chapter 3 [12].

Up to then one had thought that the chance for a sphere to be hit by lightning was greater than for a point, as the surface of a sphere is greater. So a sphere was expected to give a better protection against lightning. He showed by experiments that electrical discharges pass just as readily onto sharp points as onto spheres.

To demonstrate the fearful effect of lightning, he used the model of a house from which the windows were blown out and in which inflammable material ignited as soon as the top of the house was hit by an electric discharge from the machine. By connecting a metal bar on the top of the house with ground he showed the protective effect of lightning conductors.

With these experiments and demonstrations Van Marum encoura-
ged the more general use of lightning conductors. One should not forget that at that time it was very difficult to convince people of the desirability of the use of lightning conductors as, apart from supposed scientific objections, there were also theological objections against the use of lightning conductors [13].

4. The first capacitor battery.
The first capacitor battery is described in Chapter 1 of the Third Part. This battery consisted of 135 Leyden jars with a total coated surface of glass of 130 square feet (12,07 m²).

To show the force of this battery he split a cylinder of palmwood, 3" (7.6 cm) in diameter and with a length of 3" (7.6 cm) along its axis by a discharge. From mechanical experiments he knew that a force of 615 lbs (2735 N) was needed to split a palmwood cylinder of 1" (2.5 cm) diameter and a length of 1" (2.5 cm). So he calculated the force of his battery to be equal to a mechanical force of 5535 lbs (24610 N).

With this battery he also could totally fuse an iron wire with a diameter of 1/240" (0.105 mm) over a length of 25 ft (7.6 m).

The research on formation and destruction of magnetism by discharging his battery, as described in Chapter 2, was less successful. At that time some scientists had already come to the conclusion, that electricity had a great influence on magnetism, and that consequently there must be some similarity between the action of both electricity and magnetism. As the experiments up till then had not been convincing, and even contradicting, Van Marum repeated the former experiments with his battery. But his experiments also gave him such contradicting results, that he states "that the effect of an electric discharge is just the same as that of other causes which set up a certain vibration in the steel of magnets" [14]. His results offer no foundation for the theory.
that electric forces possess some or other influence on magnetic power or that there is some similarity between these two forces!

He also studied the reduction and oxidation of metals by electricity as he describes in Chapter 3 and 4.

Up till then the experiments on reduction had not been convincing. So he made experiments in this field with his colleague Paets van Troostwyk. They showed that a reduction of metals could be reached by electrical discharges. As electricity also could be used to oxidize metals he makes the remark that these results seem to be contradictory with his results on reduction of metals. "But it should be realized, that fire had also two opposite effects on the metals with respect to oxidation and reduction" [15].

5. Experiments with the large capacitor battery.

In 1787 the "First Sequel to the Experiments with Teyler's Electrical Machine" was published in Volume IV of the Transactions of the Second Teyler Society.

In part I he describes his experiments with the enlarged battery of 225 Leyden jars with a total surface of coated glass of 225 square feet (20.9 m²).

After a description of the construction of this battery he shows its great force with experiments. With one discharge of his battery he could now totally fuse 50 ft (15.2 m) of an iron wire with a diameter of 1/240" (0.105 mm), or split a palmwood cylinder, 4" (10 cm) high and 4" (10 cm) in diameter.

From this last experiment he calculated that the electric force of his battery should be equivalent with a mechanical force of more than 10040 lbs (44640 N)!

Experiments on fusing metals are described in Chapter 2 and 3. He took wires of several metals with a constant diameter of 1/38" (0.668 mm) and determined the maximum length that could be fused with equal charges of the battery. He found:
for lead 120" (3.05 m), for tin 120" (3.05 m), for iron 5" (12.5 cm), for gold 3 1/2" (8.9 cm) and for copper, brass and silver less than 1/4" (6 mm). He compared these values for fusability with the values of the melting temperatures, which indicate the fusability by fire. He concludes: "there is but little similarity between the fusability of metals by electric matter and by fire" [16].

He repeated these experiments for several thicknesses of wires but did not find any regularity between electric fusing and fusing by fire. Let us remark that Ohm's law was formulated only in 1826 and that Joule, born in 1818, formulated his discovery about the relation between heat and electricity in 1843!

From his experiments on fusing metals Van Marum deduced instructions for lightning conductors [17]:

1) For iron conductors the minimal diameter must be 1/2" (1.25 cm), for lead strips the cross-section must be no less than four times the cross-section of an iron wire.
2) If copper is applied as a conductor it is sufficient to have only half the diameter of an iron wire to run as little risk as the latter of being fused or broken by an electric discharge.
3) For protection of ships copper conductors are preferable as there will be less danger of fire, for iron wires become red hot when a strong discharge passes through them.

In Chapter 7 he describes experiments concerning lightning conductors that are too thin or consist of chains. From these he derives further instructions concerning lightning conductors [18]:

1) The conductors must be so thick that there is no danger of their being melted or made red hot by a lightning discharge.
2) A chain is not as good a lightning conductor as a continuous conductor or one that is composed of few parts. In the latter case special attention should be given to the connections of the several parts. They must be well soldered together.
3) The conductor should not be imbedded in masonry or woodwork, because this might be split or broken when the lightning strikes the conductor.

4) Copper is a better conductor than brass or iron.

Chapter 4 deals with new and further experiments on oxidation of metals by electrical discharges. In the Transactions one finds very detailed drawings of his observations. If one compares these results with present results one sees the accurateness of former researchers.

Chapter 5 deals with experiments on oxydating metals in various gases by electrical discharges. Here he already accepts the theory of Lavoisier. From experiments to oxydate lead and tin in nitrogen he states, in accordance with Lavoisier, that oxygen is necessary for the oxydation of metals.

Oxydating lead in pure oxygen he obtained a yellow powder where, in atmospheric air, he only got a blackish colour of the oxydation product. For other metals he found no more oxydation in oxygen than in atmospheric air. He only states that the red hot globules of iron acquire a very high degree of heat in oxygen.

At first he was surprised that oxydation of tin appeared in nitrogen-pentoxide, \( \text{N}_2\text{O}_5 \). But then he realised that Lavoisier had shown that salpetric acid partly consisted of oxygen that could oxydate the tin. It was a question of a greater affinity of oxygen for tin than for nitrogen. Later on he discovered that also iron and lead could be oxydated in salpetric air.

The Second Part of the First Sequel comprises experiments carried out near the conductor of the machine.

In Chapter 1 he describes the production of nitrogen-pentoxide, \( \text{N}_2\text{O}_5 \), in air by electrical discharges.

In Chapter 2 he describes an experiment with balloons to imitate atmospheric phenomena. Two balloons are filled with
air and then connected to opposite poles of the machine. As soon as the machine generated electricity the repelling forces between the molecules in the balloons caused the volume to increase, the specific weight of the air in the balloons to decrease and both balloons to rise. Due to the opposite charges the balloons attracted each other and came into contact, whereupon the charges were neutralized. As in this moment the volumes decreased again, both balloons fell down. He compared these movements with the movements of clouds [19].

The Appendix of this publication is very famous, as herein Van Marum gives a very detailed outline of the Theory of Lavoisier. He supports this theory with many experiments he made with his machine. For this purpose he also designed new chemical instruments to verify the theory of Lavoisier. He performed experiments not only by oxydating several metals, but also by showing that oxygen is necessary to build up acids as sulphuric acid, phosphoric acid and nitric acid. He states that this new theory also greatly clarifies the processes in plants and animal life and that one of the functions of inhalation is "to enable the animal body to lose in this way some of its carbon of which it appears to have too large a quantity" [20].

6. Experiments carried out in the period 1787-1795.
In 1795 his "Second Sequel to the Experiments with Teyler's Electrical Machine" is published in Volume XI of the "Transactions" of the Second Teyler Society.
In the preface he says that a great part of the experiments described were already performed in the years 1787/1790, but that he hoped to get more pregnant details. He also remarks, that many of the suggested experiments could also be done on smaller machines. He states:"As the use of our machine makes great demands on our skill, attention and time, I deemed it better to restrict it to only such experiments as cannot be performed so well with the ordinary machines" [21].
In this preface he also states that from experiments described in Chapter 3 of Part II it is shown, "that electric matter is not a simple substance of a particular kind, as many people have taken it to be, but that it is a complex substance, consisting of calorique, united with some other substance unknown till now" [22]. It was to take still more than 50 years before Joule stated the equivalence of electric and calorific heat.

Neither was he able to solve the problem of why electricity is generated by frictioning the glass. In his experiments to find "the cause of disturbance of the equilibrium of electric matter" by frictioning the glass only at one side, he found that both sides of the glass attracted electric matter. So the question was not solved as to what causes the electric matter to leave the cushions during the ordinary friction of glass and to accumulate on the surface of the glass to cause a disturbance of the equilibrium there.

And in his disappointment he speaks like a prophet, stating in his preface: "For a long time already I have been of the opinion, and I still hold this belief, that if we knew and understood better what causes the disturbance of electric equilibrium, we could probably also make better use of it ourselves. The general distribution of electric matter and its great quantity in all bodies found on the surface of the earth, give us good reasons to think that this matter is destined by the Creator to fulfil very essential designs in the economy of Nature" [23].

As a result of the experiments of Galvani on frogs and other animals, he states that he thinks that "in our bodies, as well as in those of animals, a slight disequilibrium of the electric matter is continually brought about, and that at the restoration of the equilibrium the nerves are stimulated for muscular movements" [24].

And further on one reads: "Until now the friction of bodies has been the most common means to bring about electric dis-
equilibrium, but if we could find out in what way it is produced, we might derive from this knowledge other still unknown means to effect it, and at the same time become able to make it more advantageous for our purposes (......). One single step further on in this science may enable us to make it bring us great benefits" [25] *. In this opinion he also refers to the fact, that formerly in other fields of physics the progress of science halted until a new discovery came. He then continues: "It seems to me that the theory of electricity is now in such a stationary period. At least I do not see for the present that there is any train of promising investigations which offers the prospect of interesting results" [26].

In the field of chemistry he states that he only devised a new apparatus to make the experiments on the decomposition of water easier and less costly.

From this preface one can deduce a certain hesitation about future discoveries, and by reading his "Second Sequel" one cannot suppress the impression that he thinks he has done everything possible with his instrumentary but sees for the moment no further way to reach a great success.

The first part of these Transactions deals only with improvements of the electrical machine, especially relating to the construction of the cushions and changes in the shape of the conductors.

In Chapter 1 of Part II he is again the physician and he describes further experiments to check the influence of the electric field on the heart rate, which confirms his former results. New is the research concerning the influence of the

* Here, as elsewhere, we recognize a distinctive feature of Van Marum's character: He is as much busy doing fundamental research as he is on the outlook for beneficial applications of his discoveries. He is an applied-science advocate, a very early scientific engineer !
electric field on "the invisible perspiration", since the general idea was that the effect of electric force was sweating. By weighing experiments with an accurate balance, he found, as checked by other physicians, that this was not the general case. Most persons began sweating as an effect of fear rather than that of electric force. These experiments conformed thoroughly his own conviction.

His love for botany is combined with his electrical interest in Chapter 2, where he describes experiments concerning "the irritability of the vessels of plants as the cause by which their sap ascends and circulates". In these experiments he tries to extend the theory of Galvani on contraction of blood vessels by electric impulses to the sap-vessels of plants. These vessels, he thought, must also possess a certain irritability to cause the ascending and circulation of the sap. In his opinion the results of the experiments he made in this field provided a great likelihood for his theory.

The experiments in Chapter 3, that demonstrate the presence of heat in electric matter, lead to a contradiction: from electric discharges and from experiments on fusing metals and so on it was clear that the electricity consisted partly of heat. But a conductor, having been charged with electricity showed no rise in temperature! So if heat was present in electric matter, it was not always to be expected in a free state. To examine this he made many convincing experiments to produce gases from solids or liquids, as it was already proven that solids or liquids could only be converted into a gas if heat was supplied. The results of the experiments concerning the decomposition of substances in electric discharges, as described in Chapter 4, did not encourage him to continue them, as he states at the end of this chapter.
In Chapter 6 he again describes experiments on lightning conductors. He shows that if the wires are too thin, corona will be seen. An important statement was that the extension of the corona was independent of the material used, only the diameter of the wire determined the extension of the corona at a given discharge.

In Chapter 7 he describes a lot of mixed experiments, e.g. the influence of electric discharges on the evaporation in plants, on the behaviour of weak plants (mimosa pudica), or on the growths of leaves of hedysarum gyrans, the influence of electricity on barometric pressure, on the evaporation of liquids under atmospheric pressure, on the specific weight of atmospheric air, and on the influence of pressure on the performance of the conductor of the machine.

He also gives an addition to Chapter 3, in which he describes the results of experiments with discharges through conductors of several materials. He states, that the heat development is greater in poor conductors than in good ones.

Part III deals with experiments with a battery of 550 square feet (51.1 m²) of coated glass. With this battery he could fuse 25" (63.5 cm) of an iron wire with a diameter of 1/40" (0.635 mm), with the former battery of 225 square feet (20.9 m²) only 10" (24.5 cm) of the same wire. Due to a new construction of the friction pads he could charge this battery fully with only 90 rotations of the electrical machine, with the old construction he needed 160 rotations to charge fully the 225 square feet (20.9 m²) battery.

The experiments on eels and rabbits to find the cause of their death as described in Chapter 2 show again the physician. From these experiments he deduces that people and animals are killed when the electric discharge passes through their heart and the large arteries coming from the heart "because it immediately destroys their irritability, and so
at the same time the circulation of the blood" [27].

Experiments concerning the effect of electrical discharges on trees, described in Chapter 3, show that the vegetative life of even the most luxuriant tree can soon be destroyed by a sufficiently powerful discharge.

Chapter 4 deals again with lightning conductors. A certain Mr. Patterson of Philadelphia was awarded a gold prize by the American Philosophical Society for an essay. Mr. Patterson proposed in this essay an improvement of the lightning conductor by applying a piece of plumbago, about 2" (5 cm) long and ending in a sharp point. As in the view of Mr. Patterson plumbago could not be fused at all, or only with great difficulties, this plumbago should protect the sharp point of the lightning conductor against fusing by placing this plumbago a little bit above the metal cylinder of the conductor. Van Marum showed in experiments, that the best plumbago is reduced to powder when a discharge of his battery passes through it. So he warns that plumbago cannot be used on conductors to serve this purpose.

In Chapter 7 he describes observations concerning large batteries and how to use them.

In 1770, Nairne in England, who used a battery of 50 square feet (4.6 m²), found that it was necessary to use a conductor with a length of 5 ft (1.52 m) when discharging the battery, to prevent the destruction of Leyden jars. For Van Marum's battery of 135 square feet (12.5 m²) this length proved to be sufficient, but for the 225 square feet (20.9 m²) battery he needed a greater length of the conductor. For the large battery of 550 square feet (51.1 m²) he needed a length of 18 ft (5.48 m) for the short circuiting of the battery. He employed a thick copper tube, 1" (2.5 cm) in diameter. But this length was not fully adequate to protect the glass of the jars, for one jar was thrice broken.
during the discharge of the battery. "However, this did not happen when, instead of the thick copper wire, I employed thin metal wires, animal bodies or other conductors, in which the electric current encountered more resistance than in the thick copper wire" [28]. Ohm's law as well as the self-inductance had not yet been defined.

A certain Mr. Brooks made the recommendation to place a layer of paper between the metal layer and the glass to protect the jars. Van Marum found, that now the charging of the battery took much more time, and in discharging the battery he observed that the power of the battery was much smaller. An iron wire, that was made red hot by the discharge of a jar, did not become red hot with the same "charge" after the jar was coated with paper. In our view it is quite simple to explain that the total capacity of the series capacitance of Leyden jar and paper layer is lower, so the stored energy in the jar would also be smaller than before. Also the paper acts, especially in humid conditions, as a resistance in series with a capacity, so he needed more time to charge the battery.

Further experiments placed him on a better trail, as he found that the effect of loss in capacity was less if the paper to coat the jar was thinner. He concludes: "But the difference between the flowing in these iron wires was so considerable that I was convinced by it that the force of our battery would be weakened too much when the coating was carried out in the way Mr. Brooks advised" [29].

In an Appendix he also gives the description of a simple electrical machine, presented in a letter to Jan Ingenhousz (1730-1799), and formerly published in the "Journal de Physique", June 1791, that has several advantages over the ordinary construction [30].

7. Conclusion.

In this article it has been tried to give a review of the
experiments Van Marum made with the large electrical machine of the Teyler Institute and of the problems he encountered in his work, on the one hand as a result of practical difficulties, on the other hand due to the general shortcomings of contemporary physical insight into the essence of electricity and the consequent lack of the possibilities for a theoretical approach.

Mention is made of his disappointment in not succeeding to make the "great jump" in the progress of science, and the conviction he had that one day mankind would be able "to make electricity more advantageous for our purposes".

We in our time have reached this point, but for Van Marum the further development of electricity had first to wait for Volta, who enabled a steady flow of current over a long time. Once a source of flowing electricity was created, experiments on electromagnetism could be realized by Oerstedt and several weeks later presented in a mathematical form by Ampere (1820). In 1828 Ohm's Law is published and in 1831 Faraday discovers electromagnetic induction. Though a universal theory is only formulated in 1866 by James Clark Maxwell in his "Treatise on Electricity", the great technical development in electricity was able to start already in 1831 "to make electricity more advantageous for our purposes".

With the political troubles in Europe at the end of the 18th century the financial situation degraded more and more. The time to make large and expensive experiments had passed. Van Marum, who died December 26, 1837 at the age of 87, from 1795 onward, focussed his interest on other fields of science, like geology, public health, mineralogy, palaeontology and botany. Up to his last days he held a large interest in science.

I will finish with the words, with which Van Marum closed his "Outline of the Theory of Lavoisier" and which are still and always valid for each new theory or development: "Therefore, however much light this theory sheds, it does on the other hand make us realize, how much remains to be explored."
Indeed, it is the fate of every Natural Scientist, that each newly discovered truth generally presents him with other unknown matters, of which he had not previously realized his ignorance" [31].

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