Memorial Speech

Eduard Riecke

Editor's Note: An English translation of Eduard Riecke's work
"Gedächtnissrede. Wilhelm Weber (geb. 24. October 1804, gest. 23. Juni 1891)".[1]

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[1] [Rie92].

Contents

Chapter 1

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Eduard Riecke[2,3,4]

Wilhelm Weber (born October 24, 1804, died June 23, 1891).

Speech given at the public meeting of the *K. Gesellschaft der Wissenschaften* (Royal Society of Sciences) on December 5, 1891.

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[2] [Rie92].

[3] Translated by Mathias Hüfner, Email: mathias.huefner@t-online.de, homepage: `http://mugglebibliothek.de/`. Edited by A. K. T. Assis, `www.ifi.unicamp.br/~assis`

[4] The Notes by Mathias Hüfner are represented by [Note by MH:]; while the Notes by A. K. T. Assis are represented by [Note by AKTA:].

When we are gathered today to honor the memory of Wilhelm Weber, who was part of our society for six decades, we feel that with him, a time has come that will probably not appear a second time for our society and our university. Because of that name Weber, we think of the man who brought his younger comrade to Göttingen, of Gauss,[5] who was a true king, who cultivated the areas of mathematics, astronomy, and physics in such a way that even today the Kärrners were unable to clean up the stones he had broken. We think of Wöhler,[6] who first composed an animal substance from inorganic substances and cleared the way for the development of physiological chemistry. The light emanating from these names will still rest on our university in the most distant times. They place Göttingen in the first row of the locations in which the development of natural sciences began in our century. The privileged position we enjoyed has fallen victim to higher goals; but the thought of the past will remain alive and the contact with the ground on which we stand will steel us to the extent of the power given to us to work on the promotion of science. In this sense, I would like to speak of Wilhelm Weber, a man to whom the entire scientific world commanded the admiring veneration of everyone who approached him and a deep affection.

Wilhelm Weber was born in Wittenberg on October 24, 1804, the son of the local professor of theology, Michael Weber.[7] His childhood was the fifth among seven growing siblings. He saw his hometown in the hands of the French and experienced their siege by General von Bülow's Prussian army corps.[8] The bullets thrown into the city ignited a fire. His father's house was also robbed. The Weber family fled to the neighboring town of Schmiedeberg, and there, the thunder of the guns from the Battle of Leipzig reached the boy's ears. In 1815, the Wittenberg University was united with Halle, and the Weber family settled in the latter. Wilhelm Weber attended the orphanage's teaching facilities there, and later the university. Nothing is known about the influence of his teachers on his development. He mentions that only a few lectures were given in Halle, which would have been important to him. The case that in a theological house, three brothers devoting themselves to the study of natural sciences was probably a rare occurrence, and the question is how the scientific inclinations came into the house, in which the father was essentially devoted to theological and philological interests. First of all, the fact that the Weber family lived in Wittenberg in the house of a friend of theirs, Langguth,[9] a professor of natural science who was a friend of hers whose scientific collections had a certain fame at the time. In addition, a childhood friend of the owner Chladni, the discoverer of sound figures,[10] the first researcher of the meteoric masses that fell to the earth, lived in the same house in Wittenberg to the much-stimulated circle which, in particular, the lively and talented mother knew how to attract to the Weber house. We can probably assume that Chladni, who was also a welcome guest at the Weber house in Halle, first aroused the desire for physical experiments in his older brother Ernst Heinrich.[11] However, he recognized early on the unusual talent of his brother Wilhelm, who was ten years his junior, and, as Weber himself reported, was until he received his doctorate almost his only teacher in the field of natural sciences. Therefore, throughout his entire life, Wilhelm Weber felt for him not only the deep love of his brother, but also a

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[5] [Note by AKTA:] Carl Friedrich Gauss (1777-1855).

[6] [Note by AKTA:] Friedrich Wöhler (1800-1882) was a German chemist.

[7] [Note by AKTA:] Michael Weber (1754-1833).

[8] [Note by AKTA:] Friedrich Wilhelm Freiherr von Büllow was a Prussian general of the Napoleonic wars.

[9] [Note by AKTA:] Christian August Langguth (1754-1814) was a German physician and physicist.

[10] [Note by AKTA:] Ernst Chladni (1756-1827) was a German physicist and musician. He is specially known for the so-called Chladni figures or Chladni patterns, that is, the modes of vibration on a rigid surface.

[11] [Note by AKTA:] Ernst Heinrich Weber (1795-1878) was one of the founders of experimental physiology.

sense of piety that was directed towards the teacher and the almost fatherly friend. During Wilhelm's last years of study, the two brothers were engaged in experimental investigations, the results of which were published in the work "die Wellenlehre auf Experimente gegründet" (The Wave Theory Based on Experiments).[12] In 1826, Weber earned his doctorate with a dissertation "Ueber die Wirksamkeit der Zungen in den Orgelpfeifen" (on the effectiveness of reeds in organ pipes). The following year, he completed his habilitation in Halle with a paper "ueber die Gesetze der Schingungen zweier Körper, welche so mit einander verbunden sind, dass sie nur gleichzeitig und gleichmässig schwingen können" (on the laws of vibrations of two bodies which are so connected that they can only vibrate simultaneously and evenly). An extraordinary professorship in Halle was awarded to him in 1828. In the autumn of that year he set off on foot from Halle to attend the natural scientists' meeting in Berlin because the first salary, that the young professor had received, was enough, to cover the contribution for the widow's fund and otherwise the Weber family was used to restricting themselves because their fortune had been lost in the storms of the war. His stay in Berlin became crucial for Weber because there he attracted the attention of Gauss with a well-organized and well-delivered lecture on the compensation of organ pipes. When the full professorship of physics in Göttingen was finished due to the death of Tobias Mayer in 1830,[13] Gauss suggested him alongside Bohnenberger and Gerling to fill the chair,[14] by emphasizing in particular the greater genius in the work to be expected for the Kings Society of Sciences. That was an important moment in Weber's favor. In 1837, Wilhelm Weber was removed from office as one of the Göttingen Seven. Gauss and Alexander von Humboldt[15] tried to bring about his rehabilitation in Göttingen. However, the steps taken with this intention failed because Weber declared that he did not want to separate his fate in this matter from that of his comrades.

But Weber was not exiled, and the salary he received from the association founded to support the seven enabled him, who was always satisfied with little, to initially stay in Göttingen as a private citizen. However, he later refunded the transferred sums and handed them over to the Saxon Society of Sciences as a foundation for scientific purposes. What tied him to Göttingen was the desire to stay close to Gauss, and this led him to reject a professorship offered to him at the Polytechnic School in Dresden in 1841. But the following year, he was appointed to Leipzig in Fechner's place,[16] who had resigned from the professorship of physics due to severe suffering, and this time, he followed the call because he no longer wanted to be the only one, who accepted continued payment of his previous salary from the Leipzig club. He also found himself in Leipzig reunited with his brothers Ernst Heinrich and Eduard,[17] who were so closely associated with him, and in living with them, he found a substitute for his dealings with Gauss. But when the turn of the times brought the callback of the expelled professors to Göttingen, he did not hesitate to break the bonds that bound him in Leipzig and returned to the old chair.

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[12] [Note by AKTA:] [WW25].

[13] [Note by AKTA:] Johann Tobias Mayer (1752-1830) was a German physicist.

[14] [Note by AKTA:] Johann Gottlieb Friedrich von Bohnenberger (1765-1831) was a German astronomer, mathematician and phsicist. Christian Ludwig Gerling (1788-1864) was a German mathematician who studied under Gauss.

[15] [Note by AKTA and MH:] Alexander von Humboldt (1769-1859) was a German natural scientist and explorer, universal genius and cosmopolitan, scholar and patron.

[16] [Note by AKTA:] Gustav Fechner (1801-1887) was a German physicist, philosopher, and experimental psychologist.

[17] [Note by AKTA:] Eduard Friedrich Weber (1806-1871) was a German anatomist and physiologist.

Let us now try to get an idea of Wilhelm Weber's scientific achievements. We begin with the already-mentioned investigation into the wave movement. The reason for this was a coincidence: one day, one of the two brothers poured mercury to clean it through a paper funnel from one bottle to the other. He observed on the surface of the mercury in this second bottle highly regular but intricate figures that were created by the inflow of the mercury, and he recognized them as an effect of the same places where waves regularly cross each other. At the time when the Weber brothers began their investigations, wave theory had gained outstanding importance through the knowledge that the phenomena of light are based on wave movements in an elastic material, the ether, which permeates the entire space. A finely worked out theory of the waves traveling in such a medium had developed, which was in complete agreement with the phenomena of optics. In contrast to this, little was known about the waves that we create on the surface of a pond by throwing a stone into it, and the knowledge of the waves propagating in the air on which the sensations of sound and tones are based was incomplete in many respects. Filling in these gaps, the aim of the work undertaken by the Weber brothers was to give experimental research one lead over theory. The "Wellenlehre auf Experimente gegründet" (The Wave Theory Based on Experiments) will always remain one of the fundamental works of physical research, distinguished by a wealth of the finest and most peculiar observations from classical science. Simplicity of the experimental tools, the ingenious and exact methods of measurement, as well as the attractive presentation through which the reader is drawn into a lively interest in the work of the two researchers. We see the brothers at their wave trough like one the column of liquid sucked up in a glass tube allows the channel to fall back and thus creates the wave, while the other uses the watch to determine the speed of its progress, as they have the image of the wave drawn on a slate that is quickly dipped into the channel and uses the microscope to follow the paths in which the waves in the water suspended particles move back and forth, up and down. The authors have also collected with great care the facts which relate to the calming of the waves by a thin layer of oil spread on the surface of the water and, through their observations, have amplified them. In the interest of shipping, they call for a repetition of the experiments on a larger scale that Franklin had unsuccessfully undertaken to measure the surf of the sea.[18] They have significantly expanded our knowledge of the propagation of one liquid on the surface of another.

Through the perceptions made during the elaboration of the wave theory, Weber was led to a problem on which he wrote his dissertation, his habilitation thesis and a number of essays in the *Annalen der Physik*. The tone produced by a vibrating body, such as a violin string or an organ pipe, is under certain circumstances an extremely fine reagent to its physical properties. Strings are detuned by heating or cooling due to changed moisture conditions, and one can conclude from the changes in the tone the changes that have occurred in those external conditions. However, as often as you want to use the pitch in order to draw a conclusion about the nature of a body, you have to be able to compare the tone it produces with an absolutely unchangeable normal tone. But it is by no means easy to produce a body whose tone always remains at the same unchanging pitch. On closer examination, the tone of a tuning fork appears to be slightly lower if the fork is struck strongly, and slightly higher if it is struck lightly. Conversely, the tone of an organ pipe is higher if it is struck strongly and deeper if you blow on it weakly. Weber used this peculiar relationship to construct an instrument that produces the same tone when excited weakly and strongly. The same consists of the combination of a vibrating metal plate or tongue with an organ pipe; neither

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[18] [Note by AKTA:] Benjamin Franklin (1706-1790).

the tongue nor the organ pipe can do this. To carry out the oscillation that would be natural for each of them individually, one of the two bodies vibrating with each other must adapt its oscillations to those of the other so that both oscillate at the same time. Weber now sets things up so that the tone of the pipe is increased by the resonating plate by just as much as, conversely, the tone of the plate is deepened by the resonating column of air. The relationship remains even if the tongue and pipe are set into vibrations of greater width by blowing more strongly. The sound produced by such a "compensated pipe" retains its height regardless of the strength of the excitation.

If the Wellenlehre (wave theory) forms a monument to the intimate intellectual community that Wilhelm Weber shared with the older brother Ernst Heinrich, a similar relationship with the younger brother Eduard arose from the "Mechanik der menschlichen Gehwerkzeuge" (mechanics of the human walking apparatus),[19] in which the methods of physical research were applied to a physiological problem in an exemplary manner. The authors describe the appeal of the joint work in the preface with the following characteristic words.

> But even if we are convinced that the choice of our object does not require any defense, we do not want to hide the true reason that drove us to persistently pursue this object for a long time with combined forces. It was the joy that we found in a common activity, in an activity to which each of us brought our strengths and resources and which the other estimated and valued all the more highly because he lacked them. Humans are never more capable or more persistent in scientific research as with such mutual participation and stimulation that does not only take place after the work has been completed but throughout its entire course.

The mechanics of walking tools already belong to Weber's first Göttingen period, but his scientific activity in this period was determined by his close relationships with Gauss. Above all, it was the profit that he expected from this that made the Göttingen professorship so desirable to him. Gauss had devised a general theory of earth magnetism,[20] through which the secure ground was prepared for all work aimed at researching this enigmatic force. With Weber, he won a comrade in following the newly opened track, who knew how to take up the given suggestion and develop it further in an independent and significant way. Weber took an outstanding part in the establishment of the magnetic association, which brought together several observers scattered over a wide circle. Besides the collaboration with the magazine published by the association,[21] he planned work on the construction of instruments for measuring the magnetic forces in the development of new methods of observation. We also owe him an atlas of earth magnetism,[22] which shows the conclusions flowing from Gauss' general theory through a large number of magnetic maps.

We owe a device to the joint investigations of Gauss and Weber that was destined to make an epoch in the history of telegraphy. It consisted of a galvanic circuit between the observatory and the physical cabinet with wires in the air over the houses up to the St. John's Tower and so pulled down again. The entire wire length was $8000'$. At both ends, it was connected to multiplier wires, which were led around one-pound magnetic rods suspended according to Gauss's devices. The magnificent device, the practical implementation of which is thanks to Weber for galvanic investigations, also proved very directly the feasibility of an

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[19] [Note by AKTA:] [WW94] with English translation in [WW92].

[20] [Note by AKTA:] See [Gau39] with English translations in [Gau41a] and [GT14].

[21] [Note by AKTA:] [GW37], [GW38], [GW39], [GW40b], [GW41] and [GW43].

[22] [Note by AKTA:] [GW40a].

electromagnetic telegraph and convenient telegraphic communication for years, which was of great use for corresponding measurements at the observatory and the physical institute. Thanks to the device manufactured by Gauss and Weber, the problem of electrical telegraphy was solved for the first time safely and satisfactorily. The two researchers recognized without doubt that their invention contained the germ of a development that, as Gauss put it, almost frightened the imagination. But given the meager endowment of their institutes, they were content with it only to satisfy their special purposes. They left the further exploitation of the idea for world traffic to others, and so it was from Göttingen that Steinheil received the inspiration for the work through which he so greatly influenced the development of electrical telegraphy.[23] Naturally, the popular appreciation and the bright sound that Weber's name enjoys in wide circles are associated with the invention of the telegraph, as Weber was the only survivor of that memorable time. As much as we value the merit that lies in the first successful implementation of an idea that several outstanding physicists had tried in vain to realize, the invention of the telegraph is not Weber's most unique work. Rather, the information received from those times suggests that the original moving ideas are to be found on Gauss's side, while the credit for the practical implementation goes mainly to Weber.

When setting up the telegraph, Weber and Gauss made an ingenious application of the laws of magnetic induction which Faraday had recently discovered.[24] Weber's attention was thus turned to the discoveries of the great British researcher's direction and the witnesses of a sustained preoccupation with the new phenomena can be found in several treatises which he has written down in the "Resultaten aus den Beobachtungen des magnetischen Vereins" (results from the observations of the magnetic association).[25] Among the subjects with which they are concerned may be the use of the currents induced by the earth's magnetism for measurement. The earth inductor constructed for this purpose later became of fundamental importance for absolute resistance measurements. Weber also applied the principle of determining the elements of the earth's magnetism through galvanic observations to the measurement of the horizontal intensity. From the magnetic work, which had formed the main subject of his activity since his employment in Göttingen, Weber was unnoticed led to the field in which his genius was to develop in the freest and most original way, electrodynamics.

With his move to Leipzig began the series of treatises on elektrodynamische Maassbestimmungen (electrodynamic measurements), which are the main work of his life and a classic monument to him for all time.[26] Insofar as a theory is developed in these works which covers

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[23] [Note by AKTA:] Carl August von Steinheil (1801-1870) was a German physicist, inventor, engineer and astronomer. See [Pri83].

[24] [Note by AKTA:] Michael Faraday (1791-1867). Faraday's law of induction is from 1831, [Far32a] with German translation in [Far32b] and [Far89], and Portuguese translation in [Far11].

[25] [Note by AKTA:] See footnote 21.

[26] [Note by AKTA:] Weber wrote eight major Memoirs between 1846 and 1878 under the general title *Elektrodynamische Maassbestimmungen*, [Web46], [Web52b], [Web52a], [KW57], [Web64], [Web71], [Web78] and [Web94a]. The eighth Memoir was published only posthumously in his complete works. These 8 major Memoirs and other of his main works on electrodynamics have now been fully translated and commented into English in the 4 volumes of the book *Wilhelm Weber's Main Works on Electrodynamics Translated into English*. Volume 1: Gauss and Weber's Absolute System of Units, [Ass21b], Volume 2: Weber's Fundamental Force and the Unification of the Laws of Coulomb, Ampère and Faraday, [Ass21c], Volume 3: Measurement of Weber's Constant c, Diamagnetism, the Telegraph Equation and the Propagation of Electric Waves at Light Velocity, [Ass21d], and Volume 4: Conservation of Energy, Weber's Planetary Model of the Atom and the Unification of Electromagnetism and Gravitation, [Ass21e]. Included in these four volumes are also English translations of 5 papers by Gauss, translations of part of the correspondence between Gauss and Weber, 1 paper by Weber and Wöhler, 2 papers by Weber and Rudolf Kohlrausch (1809-1858), 1 paper by Fechner,

the entire area of electrical phenomena known at the time, they represent the completion of a great scientific development that goes back in its beginnings to Newton.[27] If we want to understand the meaning of Weber's electrodynamic theory in this context, we must first remind ourselves of the essential features of the earlier development.

Kepler had already conceived the notion that the planets were kept in their orbit by some force exerted by the sun.[28] He compared it to the attraction of a magnet to iron. He suspected that it diminished with distance, just like the effects of light. However, there was still a long way to go from such vague assumptions to Newton's theory of gravitation. First, a theory of motion and then a mathematical method had to be created to determine the resulting motion from the small changes that a given speed undergoes in a large number of successive time units. The creation of dynamics was the work of Galileo.[29] We owe the method of fluxions or differential calculus to Newton and Leibniz.[30] But then Newton achieved a big success. In a strict mathematical conclusion, he developed Kepler's laws from the assumption that the sun exerts a force on the planets that is inversely proportional to the square of the distance. He showed that this force is identical to the gravity that causes a stone to fall on the surface of the Earth. So Newton became the founder of the mechanics of the sky, which is still used today as the unrivaled model of mathematical physics. The same does not just reproduce the broad features of the phenomena, it rather follows the facts down to the finest details and every advance in observation is always just a new test for the perfection of the theory. The basis of Newton's theory, however, was formed by an assumption that was extremely strange to his contemporaries who were caught up in the Cartesian view,[31] which Newton himself seemed to consider to be little more than a mathematical fiction, but which his students soon turned into an unassailable dogma, the assumption of an immediate action at a distance between the bodies of the universe, as well as between the earth and the bodies on it, or finally [between] these latter themselves.

The question of the nature of the effects that we observe in the physical world, whether direct action at a distance or mediation through pressure and impact, is now closely related to a conflict of views on the nature of matter, which we trace through the history of physics back to Democritus and Aristotle.[32] One view assumes that matter constantly fills space, while the other view is that matter is composed of small particles, molecules and atoms, and imagine these separated from each other by empty spaces. One can see how much the idea of an immediate action at a distance had to come to the aid of atomism, and one will therefore not be surprised if the French physicists, in particular at the end of the last century and the beginning of this century, combined the atomistic view with the idea of action at a distance to gain a path into the area of molecular phenomena. Laplace[33] had already remarked that a ponderable body could be compared with a nebula, which offers the appearance of

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1 paper by Johann Christian Poggendorff (1796-1877), 1 paper by François Felix Tisserand (1845-1896), 2 papers by Carl Neumann (1832-1925), and 3 papers by Gustav Kirchhoff (1824-1887) related to Weber's electrodynamics.

[27] [Note by AKTA:] Isaac Newton (1687-1727).

[28] [Note by AKTA:] Johannes Kepler (1571-1630) was a German astronomer, mathematician, astrologer and natural philosopher.

[29] [Note by AKTA:] Galileo Galilei (1564-1642) was an Italian astronomer, physicist and engineer.

[30] [Note by AKTA:] Gottfried Wilhelm Leibniz (1646-1716) was a German mathematician, philosopher, scientist and diplomat.

[31] [Note by AKTA:] René Descartes was a French philosopher, scientist and mathematician.

[32] [Note by AKTA:] Democritus (c. 460 - c. 370 BC) was a Greek philosopher. Aristotle (384-322 BC) was a Greek philosopher and polymath.

[33] [Note by AKTA:] Pierre-Simon Laplace (1749-1827) was a French scientist and polymath.

a uniformly glowing disk in the night sky. Like a uniformly luminous disk consisting of an innumerable number of stars, between which wide spaces empty of stars extend, you can imagine ponderable bodies made up of molecules separated from each other by gaps, in comparison with which the dimensions of the molecules themselves disappear; and, just as the stars of a nebula attract each other with Newton's force, this would also be the case with the molecules of a body. But such an assumption is not suitable to explain the phenomena of elasticity or capillarity; rather, in the atoms of a body, Newton's attraction must be supplemented by other forces which have the property of only having a noticeable strength at very small distances, disappearing at larger distances. The introduction of these so-called molecular forces led to a theory that was in agreement with the phenomena of elasticity and capillarity, but which celebrated its greatest triumphs in the wave theory of light. The view that the ether has the properties of a solid, elastic body compared to the oscillations of light had already been developed by Fresnel to justify the possibility of transverse oscillations.[34] With such successes, the molecular theory had to become even more dominant in physics because, on the other hand, chemistry had also come to the assumption that bodies were made up of atoms or atom complexes, the molecules.

However, a question of fundamental importance was left open by the molecular theory or at least only touched superficially: the question of the stability of the assumed molecular systems. At the start, we compared such a system to a star cluster. But the fact that the similarity is not very extensive becomes clear when we look at our planetary system instead of a star cluster. As a result of the attractions that the planets exert on each other, their orbits continually deviate from Kepler's ellipses. However, the conditions of the system are such that the disruptions never add up to large amounts. The orbits actually traversed by the planets only carry out small oscillations around an unchanging position. The planetary system is stable as far as the orbits in which the individual bodies move are concerned. However, the systems' configuration is subject to the greatest changes as a result of these very movements. Similarly, the stability of a star cluster can only be that of movement. In contrast, molecular theory assumes that the individual molecules of a solid body are in stable equilibrium at certain points under the influence of mutually exerted forces and that the configuration of the system is completely determined and unchangeable as long as no external forces are acting on its body. It was noted that such an assumption only appears possible if the forces acting between the molecules contain both attractive and repulsive components. However, a real development of the stability conditions and a more precise formulation of the force law have not been attempted. For now, this assumption is only justified by the success with which it was introduced.

We can see how difficult it was for the idea of immediate action at a distance to gain more general significance despite the great success of Newton's theory of attraction from the fact that it was only around the year 1760 that action at a distance forces were introduced into the theory of static electricity and magnetism. But at the same time Euler,[35] an opponent of action at a distance, explained the electrical attractions and repulsions through changing pressure conditions in the air and developed a theory for the magnetic effects which is not too far removed from the views later developed by Faraday. Coulomb's measurements initially decided the alternative in favor of action at a distance.[36] To explain the electrical

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[34] [Note by AKTA:] Augustin-Jean Fresnel (1788-1827) was a French engineer and physicist.

[35] [Note by AKTA:] Leonhard Euler (1707-1783) was a Swiss mathematician, astronomer and physicist.

[36] [Note by AKTA:] Charles-Augustin de Coulomb (1736-1806). His main works on torsion, electricity and magnetism are now fully translated into Portuguese and English, [Ass22] and [AB23].

phenomena, he assumed the existence of two fluids corresponding to the electricity of glass and resin. Particles of the same fluid repel each other. Particles of different fluids attract each other with a force that, like gravity, is inversely proportional to the square of the distance. A corresponding assumption was then transferred to the theory of magnetism and was confirmed here by the measurements of Gauss.

At the beginning of our century, the field of magnetic and electrical phenomena experienced a tremendous expansion with the discovery of electromagnetism by Oersted,[37] the interaction of galvanic currents by Ampère,[38] and induction by Faraday. All of these phenomena are effects of electricity, which is in the state of galvanic current in wires. This means that the laws that Biot, Savart and Ampère established for the discovered effects have a substantially different character than the earlier laws of action at a distance.[39] In the electromagnetic interaction, Oersted determined the law of action of a very short straight piece of wire, which is the carrier of the galvanic current, on a magnetic pole. Ampère's law determines the interaction between two such pieces of wire. So, unlike Newton's or Coulomb's law, it is not about the interaction of point masses or centers of force, but about the interactions between points and line elements, and line elements among themselves. We call laws that relate to such effects elementary laws in contrast to Newton's point law. However, the fact that an element of a galvanic current cannot exist on its own is particularly noteworthy; it is only conceivable as part of a larger circle, of the closing arc of a galvanic voltaic cell[40] or a discharging Leyden jar. This remark leads to the question of whether it is not possible to reduce these elementary laws to simpler effects. But if one further sees the basis of the electrical phenomena in the existence of the electrical fluids, then there can be no doubt that the same particles, which in the state of rest attract or repel each other according to Coulomb's law, in the state of a galvanic flow must give rise to the effects discovered by Ampère. This creates the task that Ampère himself had already set: to investigate how the electrostatic action at a distance of the particles could be modified through movement in such a way that Ampère's law results as a result of the various effects. This task is what Weber solved in the First Treatise on electrodynamic measurements.[41] The fact that his intention from the outset was not just aimed at theoretical speculations but also directly at fundamental tasks of measuring physics can be seen from the following words with which the mathematical part of the investigation is introduced:[42]

> When one deals with the connection between electrostatic and electrodynamic phenomena, one need not only be guided by the general scientific interest in penetrating the relationships existing between the various parts of physics, but in doing so, we should also keep in mind a more specific purpose, which concerns the determination of the measurements of Volta-induction[43] from a more general basic law of the

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[37] [Note by AKTA:] Hans Christian Ørsted (1777-1851) was a Danish physicist and chemist.

[38] [Note by AKTA:] André-Marie Ampère (1775-1836) was a French physicist and mathematician. His main work on electrodynamics is from 1826, [Amp26]. Full Portuguese translation in [Cha09] and [AC11]. Partial English translations in [Amp65] and [Amp69]. Complete and commented English translations in [Amp12] and [AC15].

[39] [Note by AKTA:] Jean-Baptiste Biot (1774-1862) and Félix Savart (1791-1841) were French physicists, astronomers and mathematicians.

[40] [Note by AKTA:] In German: *einer galvanischen Säule*.

[41] [Note by AKTA:] [Web46] with partial French translation in [Web87] and a complete and commented English translation in [Web21c].

[42] [Note by AKTA:] See also [Web21c, p. 130].

[43] [Note by AKTA:] The expression utilized by Weber, *Voltainduktion*, had been first suggested by Faraday

> pure theory of electricity. But it is self-evident that the establishment of such measurements is intimately connected with the establishment of the laws to which the phenomena in question are subject, so that one cannot be separated from the other.

But if the general theory of electrical phenomena were to be founded on the foundation of Ampère's law, it seemed necessary first of all to subject this itself to a new test through exact measurements. Weber carried out this test with the electrodynamometer he designed, which has since become an important measuring device in electricity theory. If he stated that the observations were in perfect agreement with Ampère's law, if he regarded it as the precise expression for a very extensive class of facts, he overlooked a circumstance whose significance was only recognized later.

The object of observation is always only the effect of closed circuits. However, how the overall effect is distributed among the individual current elements is, to a certain extent, arbitrary, and this arbitrariness causes Ampère's law to appear as a possible, but not the only possible, expression of the electrodynamic interaction. By accepting the law, Weber introduced a somewhat hypothetical element into his theory. But he then brilliantly solved the task of uncovering the connection between the electrostatic and electrodynamic fundamental law through the law named after him, which determines the force acting between two electrical particles not only from their masses and their distance but also from their dependence on relative movement. With the establishment of this law, Weber had reached a point of view from which a uniform representation of electrical phenomena seemed possible. In the entire series of later treatises, he pursued his goal with great consistency and to an ever-increasing extent. He included the phenomena of magnetism in the circle of his views, and his last works also tried to connect gravitation and molecular effects with the law of electrical force. But true to the program set out from the beginning, his scientific activity was always twofold. Hand in hand with theoretical speculation came the electrical measurement determinations, which have become of fundamental importance for the practical and technical side of physics.

First and foremost, Weber's law had to apply to the phenomena of voltaic induction discovered by Faraday, to the creation of a current in a conductor wire when approaching an existing circuit, [and also] the creation of a current when the current strength in the neighboring circuit changes. In fact, in both cases, forces are exerted on the neutral electricity resting inside the conductors, which drive the positive particles in one direction and the negative particles in the opposite direction. These forces will therefore not attempt to displace the conductors themselves, as is the case with the effect discovered by Ampère. In fact, they only seek to move the electricity contained in the conductors, and we therefore call them electromotive. The application of Weber's law to the cases mentioned leads to elementary laws of voltaic induction, which are confirmed by observations of closed current and conductor circuits. The extension of the laws found to the phenomena of magnetic

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himself in paragraph 26 of his first paper on electromagnetic induction of 1831, [Far32a, § 26, page 267 of the *Great Books of the Western World*] with German translation in [Far32b] and Portuguese translation in [Far11, p. 159]:

> For the purpose of avoiding periphrasis, I propose to call this action of the current from the voltaic battery, *volta-electric induction.*

In this English translation of Riecke's biography we utilized the expressions *Volta-induction* and *voltaic induction* for this class of phenomena which is nowadays called Faraday's law of induction.

induction is made possible by the remark that the inducing effect of galvanic spirals is subject to the same law as that of a magnetic rod.

While in the First Treatise on Electrodynamic Measurements the interest concentrates primarily on the development of the general basic law, in the Second Treatise[44] the practical side of the task comes to the fore and from this point of view, it has just as fundamental significance, as the First for the development of the theory. Through the double interrelationship that exists between electricity and magnetism, through the peculiar distinction between electrostatic and electrodynamic phenomena, the number of quantities that form the object of observation and measurement is multiplied. The need therefore, becomes all the more urgent to have certain definitions for these quantities, a uniform system of measurements and convenient and precise methods of measurement. When founding his system of measurements, Weber started from an idea of great importance, which was first introduced into science by Gauss in his Treatise on the reduction of the intensity of the magnetic force to an absolute measure.[45] We want to imagine that an arbitrary agent is distributed in equal quantities between two identical ponderable bodies and that the result of this is a mechanical interaction, an attraction, repulsion, or rotation of the two bodies. The strength of the force exerted can be determined according to the general measure of mechanics, for example, by weighing. This can only depend on the spatial conditions and the number of agents. If the dependence on the lines and angles to be measured is known, a measure for the quantity of the agent in question results, namely one that only requires the establishment of the units of measurement for lines,[46] time periods, and masses. In this sense, Gauss taught how to determine the amount of magnetism contained in a steel rod in absolute terms. In the same sense, the amount of electricity imparted to two charged conductor balls can be calculated in absolute electrostatic measure from the repulsion between them. When the principle is applied to galvanic currents, however, the peculiar circumstance arises that the strength of a current can be judged just as well by its effect on a magnet as by its effect on a second current. There are therefore two different absolute measures for the strength of the galvanic current, and it makes sense to contrast these two with a third, which is particularly important because it establishes a direct relationship between the electrodynamic and electrostatic measurements. In accordance with the way in which we measure the strength of a river, is represented the unit of measurement of a galvanic current, in which the total amount of electricity flowing through the cross-section of the conductor wire in one second is equal to the electrostatic unit as produced by the repulsion of two charged conductors. Accordingly, one can also now set up three different measures for the electromotive forces. One can use the phenomena of magnet or voltaic induction for this purpose. But one can also be guided by the remark that the electromotive force of induction does not differ significantly from the

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[44] [Note by AKTA:] [Web52b] with English translation in [Web21d].

[45] [Note by AKTA:] Gauss' work on the intensity of the Earth's magnetic force reduced to absolute measure was announced at the Königlichen Societät der Wissenschaften zu Göttingen in December 1832, [Gau32] with English translations in [Gau33a], [Gau37a] and [Gau21a]. See also [Rei02, pp. 138-150].

The original paper in Latin was published only in 1841, although a preprint appeared already in 1833 in small edition, [Gau41b] and [Rei19]. Several translations have been published. There are two German versions, one by J. C. Poggendorff in 1833 and another one in 1894 translated by A. Kiel with notes by E. Dorn; a French version by Arago in 1834; two Russian versions, one by A. N. Drašusov of 1836 and another one by A. N. Krylov in 1952; an Italian version by P. Frisiani in 1837; an English extract was published in 1935, while a complete English translation by S. P. Johnson was published in 2003 and 2021; and a Portuguese version by A. K. T. Assis in 2003: [Gau33b], [Gau34], [Gau36], [Gau37b], [Gau94], [Gau35], [Gau52], [Gau75], [Gau03], [Gau21b], and [Ass03].

[46] [Note by AKTA:] That is, measurement of distances.

forces of electrostatics, which also seek to cause a separation of the electrical fluids, so that the electromotive force can be expressed just as well as the electrostatic force in terms of the general measure of mechanics. Finally, since the resistance of a conductor is equal to the ratio of the electromotive force to the strength of the galvanic current generated, the threefold possibility of determining the units also applies to this. Of particular interest is the relationship between the electromagnetic and electrodynamic measure on the one hand, and the electrostatic measure on the other, which is mediated by the so-called constant of Weber's law. According to this, the electrostatic repulsion of two similar particles is reduced by their movement and the constant mentioned indicates the relative speed at which the two particles no longer have any effect on each other. At the same time, however, it also provides the factor by which one must multiply an electromagnetically measured current intensity to express it in mechanical terms, i.e. in order to obtain the number of electrostatic units which the current carries through the cross-section of the conductor in one second. Weber carried out the experimental determination of his constants in collaboration with Robert Kohlrausch.[47] The ratio of the electromagnetic unit of current to the electrostatic was 3.111×10^{10} cm per sec., while according to the latest measurements, it is 3.012×10^{10} cm per sec. Both values can be considered equal at the speed of light. With the determination of Weber's constant, the electrical measurement system has reached its internal conclusion. The reason for this is that Weber has exerted a decisive influence on science to the greatest extent. In the present period of development, one will be inclined to look for the basis of his fame primarily in the works belonging to this subject. This is partly due to the ever-growing importance of electricity for technology and transport. Accurate measurements were not only a need of science but also of technology, and Weber had satisfied this need in advance. If the worker in an electrotechnical factory now operates with his amps, volts, and ohms in complete safety, then Weber deserves the first and foremost credit for this, and in this context, one should not hold back the regret that the Electrotechnical Congress in Paris suppressed the name Weber from the popular designation of electrical measurements.

Let us return back to Weber's work, which is important for the further development of his theory. Ampère had already shown that the assumption of special magnetic fluids is superfluous and that the phenomena of magnetism are completely explained if one considers each molecule under the assumption of a molecular constitution of iron surrounded by a ring-shaped galvanic current. In a non-magnetic piece of iron, these so-called Ampère molecular currents will have all possible orientations. In a magnetic field, they are rotated consistently by the electromagnetic action and then exert the same external effects which, according to the earlier view, were explained by the separation of magnetic fluids. Based on very attractive considerations, Weber also included in this theory the diamagnetic repulsions discovered by Faraday, which many bodies experience in the vicinity of a magnetic pole.[48] If the molecules of a body are surrounded by paths in which the electrical fluids move without electromotive force, i.e. without resistance, then induction currents must be able to occur

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[47] Although Riecke wrote "Robert Kohlrausch", the correct name is Rudolf Kohlrausch (1809-1858). This constant c would represent the uniform relative velocity at which Weber's force between the two particles would fall to zero. Weber's c (known throughout the 19th century as the *Weber constant*) is not the same as the modern $c = 2.998 \times 10^8$ m/s, but $\sqrt{2}$ times this last value (or, $c = 4.24 \times 10^8$ m/s). The *Weber constant*, c, was first measured by Weber and Kohlrausch in 1854-1856. They obtained $c = 4.39 \times 10^8$ m/s. See [Web55] with English translations at [Web21h]; [WK56] with English translations in [WK03] and [WK21], and Portuguese translation in [WK08]; and [KW57] with English translation in [KW21]. See also [Pog57] with English translation in [Pog21], and [Ass21a].

[48] [Note by AKTA:] [Web52a] with English translation in [Web21g].

in these paths. These must persist until they are destroyed by an opposing cause. But the currents that are induced by approaching a magnetic pole have such a direction that they produce a repulsion between the pole and the approaching body, which would be the same repulsion discovered by Faraday. With this theory, Weber believed that he had decided the alternative between the assumption of separable magnetic fluids and Ampère molecular currents in favor of the latter. However, all phenomena of diamagnetism can also be explained by the assumption that the air and the ether filling the so-called empty space are capable of magnetic polarization and to a higher degree than the so-called diamagnetic bodies. The existence of the Ampère molecular currents cannot therefore be claimed based on Weber's investigation. But we must not leave it without remembering that in it, for the first time, the magnetic excitation of bismuth in the interior of a galvanic spiral, the induction by the movement of a diamagnet, was not only demonstrated but also precisely measured and the ratio between the diamagnetic excitability of bismuth and the magnetic excitability of iron has been determined.

Weber's investigations, which we have reported above, are essentially related to the action at a distance effects of galvanic currents. The theory of the galvanic circuit, which Weber had already discussed in detail in his Treatise on resistance measurements, should be considered as an area of electrodynamics that, in many respects, allows a deeper insight into the nature of electrical phenomena. To address this problem, knowledge of the electromotive forces exerted on the fluid contained in a conductor is not sufficient. This also requires knowledge of the molecular resistances with which the movement of electricity has to contend with inside the conductor. Finally, the inert mass of the electricity put into flow must be given, if the movement is calculated according to the usual principles of mechanics. Kirchhoff was the first to give general equations for the movement of electricity in conductors,[49] assuming the general validity of Ohm's law.[50] To determine the laws of motion for conducting wires based on these equations, he introduced the assumption that every piece of such a wire that could still be considered straight was a million times longer than its thickness. It cannot be judged from the outset to what extent this requirement can be fulfilled in executable experiments and to what extent it is compatible with the general validity of Ohm's law. Only a little later than Kirchhoff, Weber submitted an investigation into the general laws of galvanic flow to the editor of the *Annalen für Physik und Chemie*. However, he withdrew it when he learned of the existence of Kirchhoff's work. Regardless of the general validity of Ohm's law, he then developed the equations of motion of electricity anew by starting from the general approach of mechanics and accordingly assigning to electricity a mass to be determined according to grams.[51] From the theoretical results of Weber's work, two are particularly interesting. He found that wave-like movements of electricity are possible in a linear conductor, similar to the progression of a wave in a tube filled with air. The propagation speed of waves could be expressed by the constant of Weber's law. It turned out that under certain conditions, it is equal to the speed of light. Weber was not inclined to attach any physical meaning to this result. Maxwell, however, based his theory of light on the relationship between Weber's constant and the speed of light when he found that the speed of propagation of electrical

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[49] [Note by AKTA:] Gustav Kirchhoff (1824-1887) was a German physicist. See [Kir49] with English translations in [Kir50] and [Kir21a], and French translation in [Kir54]; [Kir57a] with English translation in [Kir21c]; and [Kir57b] with English translation in [GA94] and [Kir21b].

[50] [Note by AKTA:] Georg Simon Ohm (1789-1854). Ohm's law is from 1826: [Ohm26a], [Ohm26c], [Ohm26d], [Ohm26b] and [Ohm27] with French translation in [Ohm60] and English translation in [Ohm66].

[51] [Note by AKTA:] [Web64] with English translation in [Web21b].

oscillations in the air corresponds to the speed of light.[52] A second comment relates to the inertia of electricity and the resulting deviations from Ohm's law. From the theory developed by Weber, it follows that the amplitude of fast electrical oscillations, which are excited in a closed conductor by a periodically changing force, depends on the inert mass of the electricity. The formulas reveal, at least in principle, the possibility of determining, by measuring the amplitude, the ratio in which the quantity of electricity contained in the unit length of the conductor wire stands to the square root of its inertial mass or the current strength to the square root of the kinetic energy of the current. The experimental part of the work, in which Robert Kohlrausch played a significant part, was interrupted right from the start by the latter's illness and death. Hertz[53] later found that the kinetic energy of the electricity in one cubic millimeter of a conductor through which the unity of electromagnetic current flows, i.e., 3×10^{10} electrostatic units (g.cm.sec.) in one second, must be smaller than the living force of one five hundredth milligram, which is moved at the speed of 1 millimeter pro sec.

Weber attempted to develop the theory of galvanic flow even more fully in the treatise "über die Bewegung der Elektricität in Körpern von molekularer Constitutuion" (on the movement of electricity in bodies of molecular constitution), published in the *Annalen der Physik und Chemie*.[54] In doing so, he replaced the dualistic idea recorded in his earlier work with a unitary one, assuming that the negative electrical particles adhere to the ponderable molecules, that the positive ones are in central motion around the molecules, whereby the Ampère rings then dissolve into systems of electrical satellites. Weber looks for the difference between conductors and insulators in the fact that in the former, the orbits of the positive particles extend into the spheres of attraction of the neighboring molecules, whereby a constant transition from one molecule to the other causes a constant change between central movement and flowing motion. If there is no external force, all directions in space will be equally represented in this flow movement. However, if an electromotive force acts on the conductor, the particles are deflected from the initial direction of movement, and the resulting joint displacement is the galvanic current. The electromotive force performs work, which finds its equivalent in the increased living force of positive electricity. Since, on the other hand, the current work is converted into heat according to Joule's law,[55] Weber comes to the conclusion that the heat energy of a body is nothing other than the kinetic energy of the positive electricity in central motion.

During the years in which Weber concentrated his efforts on electrodynamic measurements, the principle of conservation of energy founded by R. Mayer, Joule, and Helmholtz had achieved its central position in the field of exact natural sciences.[56] No law could be considered permissible that did not correspond to the requirements of the energy principle. Given the peculiar character of Weber's law, it seemed doubtful from the outset whether

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[52] [Note by AKTA:] James Clerk Maxwell (1831-1879 was a Scottish physicist.

[53] [Note by MH:] Heinrich Rudolf Hertz (1857-1894) was a German physicist. He confirmed Maxwell's equations by discovering electromagnetic waves propagating in space.

[54] [Note by AKTA:] [Web75].

[55] [Note by AKTA:] James Prescott Joule (1818-1889). See [Jou41b] and [Jou41a] with French translation in [Jou42]. See also [MS20] and [Mar22].

[56] [Note by AKTA:] The principle of the conservation of energy by taking into account thermal energy had been established by Julius Robert von Mayer (1814-1878) in 1842 and by James Prescott Joule in 1843, being also discussed by Hermann von Helmholtz (1821-1894), [May42] with English translation in [May62] and Portuguese translation in [May84]; [Jou43]; and [Hel47] with English translation in [Hel53] and [Hel66]. See also [Mar84].

it fulfilled that condition and whether the foundation of the entire theory was a legitimate one. Weber showed that the law of conservation of force applies to a system of particles that act on each other according to his law, i.e. that the sum of kinetic and potential energy is constant.[57] The difference compared to the usual form in which the potential-energy of a mechanical system appears is that in a system of electrical particles, it also depends on the relative speed. This now imposes a certain limitation on Weber's law. It turns out that its application to the movements of electrically charged bodies leads to worrying consequences if the density of the charge or the size of the bodies exceeds certain limits. A similar difficulty arises when one uses Weber's law to investigate the course of currents that have somehow been excited in a conducting body. Only for thin wires do the conclusions agree with the observed facts. In the case of bodies of larger dimensions, however, the equations of motion of electricity have, in addition to the integrals, which show a faster or slower disappearance of the excited movement, others that represent movements that increase to infinity. Helmholtz, who made these comments, has thus shown that Weber's law leads in certain cases to results that contradict the general views of mechanics. As long as these contradictions cannot be resolved, the law can only be attributed to the meaning of an interpolation formula. Within an area delimited by experience, it leads to correct results. But it cannot be applied beyond the same without coming into conflict with other facts of experience. After all, it will make a difference whether the conditions under which the law leads to contradictions are merely conceivable or whether they can also be realized experimentally. This point requires further clarification.

No matter how great weight one attaches to the concerns highlighted, the building erected by Weber always encompassed the entire area of the observed facts. With his preliminary works, he reached into the field of molecular phenomena and gave his creator a glimpse into the distant world of chemical affinities. One might therefore have expected that the breaches made in individual places in the walls would only serve as an incentive for redoubled work, and efforts would be made diligently to fill the gaps and strengthen the foundations. And if one was of the opinion that physical laws were ultimately nothing more than interpolation formulas that correspond to a given circle of facts, then one could expect that a formula that encompassed such an enormous circle could also be adapted through smaller additions to a somewhat enlarged circle. If this did not happen, if one left Weber's theory to build a new building on a new foundation, then there are other reasons for this, which are not directed against individual gaps in the theory, but against the entire foundation of the same. And we want to try to describe these as best as the short time allows in the following.

First, we have to mention a type of prejudice that relies on no less authority than that of Newton. Newton only described the gravity he introduced into science as a mathematical cause that one body acts on another through space. Without any mediation, it seemed absurd. But he left the question of whether the agent, which acts according to certain laws and creates gravity, is material or spiritual to his readers. Occasionally, he probably expressed the idea that the different tension of the aether filling space drives bodies from denser to less dense places and that gravity is based on this. He probably did not think much of such speculations and was satisfied that gravity exists and that the bodies of the sky and the sea tides move according to his laws.

Newton's vague suggestions gained firmer ground through Faraday, who, not accustomed to the formulaic language of mathematics, was looking for a clear means of being able to

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[57] [Web71] with English translations in [Web72] and [Web21f]; and [Web78] with English translation in [Web21e].

represent and understand the interactions of bodies in the areas of electricity and magnetism. Such a means presented itself to him in the lines of force, the system that we can so easily create with a magnet with the help of iron filings. If we look at such a chain connecting two friendly poles, we see that all its links are small magnets, which the opposite poles turn towards each other, which therefore attract each other and try to shorten the chain. If we imagine its ends soldered to the poles to which it connects, it will pull them towards each other, and the movement of the poles, which was otherwise seen as a consequence of their forces acting at a distance, now seems brought about by the tension of the chain. Faraday saw lines of force radiating out from an electrically charged body into the surrounding insulating space. Through processes of a hidden nature, a voltage was created along the lines of force, and this was the cause of the electrical phenomena observed. The wire in which a galvanic current moves is surrounded by ring lines of magnetic force and in these there is a voltage of the same kind as in that generated by a pole. The mutual disturbance of the voltages caused by two currents located next to each other in the same space is the cause of the apparent electrodynamic action at a distance. Faraday was also able to connect the facts of induction with the system of his lines of force by showing that an induced current always arises in a closed circuit when the number of lines of force passing through it changes. However, he found no clear mechanical picture of the relationship between the induced and the inducing circles. The theory developed by Faraday turned on its head the widespread and seemingly self-evident view that the conductors were the actual carriers of electrical forces and that the space surrounding them only played a passive role as long as it was impenetrable to the electrical fluids. According to him, the true cause of electrical effects lies in the insulators. The so-called conductors are incapable of conducting lines of electrical force and are only subject to the voltages of the insulator surrounding them. But this theory was much more than a clever game with possibilities and geometric lines because Faraday had shown that the insulators actually play an essential role in electrical phenomena and that a change in their electrical state really occurs along the lines of force. He had discovered that all bodies are capable of magnetic excitation, that there is actually a polarization of the surrounding space along the magnetic lines of force radiating from a pole. But if the dielectric and diamagnetic states assumed by Faraday have a real existence, then the attempt to consider them as the sole causes of the observed effects is also justified.

Mathematical physics, in particular the theory of potential, also led to views that contradicted the assumption of instantaneous action at a distance, but which were in contact with Faraday's theory in essential points. The safest and simplest means of representing the observed facts was increasingly considered not to be forces emanating from bodies, but rather to differential equations, which were satisfied by the quantities characteristic of the phenomena. But every differential equation can be understood as an instruction to calculate the state of any spatial element from that of a neighboring one. One can actually see from this the similarity of the mathematical concept with Faraday's idea of a dielectric or diamagnetic tension that progresses from element to element.

In mathematical physics, however, a development took place in another direction, moving away from the pursuit of atomistic theories and placing a new method of theoretical research in the foreground. Based on two general theorems of the principles of energy and entropy, it was possible to devise a theory of heat, which brought a wealth of new and surprising enlightenment. The peculiar advantage of this theory seemed to be that it was independent of any particular assumption about the nature of heat and that the change of ideas could not influence its unchanged and general validity. It made sense to apply the method thus provided in other areas and to connect the laws of phenomena not through special hypotheses about the nature of bodies but through those general principles. Thus, the principle of energy in the field of electricity made it possible to develop one from the other of the laws of the ponderomotive and electromotive actions of the galvanic current.

Faraday's ingenious intuition of a physical existence of the lines of force, as fruitful as it had been for his own discoveries, had to stand back against the theory of action at a distance as long as it had not found a mathematical formulation. This was given to it by Maxwell. The battle of the theories was now fought with equal weapons and it initially became apparent that their results as a whole agreed to a surprising extent. However, Maxwell soon made a major and momentous discovery based on his theory by showing that transverse electric and magnetic waves can propagate in an insulator and that their speed of propagation in air space is equal to the speed of light. On this, he based his electromagnetic theory of light, which was confirmed, although not completely, by a series of later observations. Although Helmholtz succeeded in deriving the formulas of Maxwell's theory of light from the laws of electric and magnetic actions at a distance, Maxwell's developments remained simpler and more direct. It was also shown here that Faraday's method is superior to the theory of actions at a distance, when it comes to describing phenomena using differential equations. Maxwell's theory was not only important because it combined the phenomena of light with those of electricity into a unified whole, it also opened a new path for the study of electricity itself. Because if light is based on electrical vibrations, then conversely, electrical vibrations must also have the properties of light. Rays of electrical force must spread through space according to the same laws as light rays. With this knowledge, the path was shown to decide between the theory of action at a distance and Faraday's view. Electrical oscillations occur when opposing electrical charges on two conductors balance each other out in the spark. According to the old theory, such a place is the origin of a double force and an immediate action at a distance, which requires no time to spread and which is to be regarded as the essential cause of the phenomena. In addition, there is a secondary effect as a result of the electrical and magnetic polarization of the surrounding air space, and this occurs at the speed of light from the spark gap. According to Maxwell's theory, the rays of electrical force that obey the laws of light are the only thing present. All effects produced by the spark gap are mediated by waves that travel through space at the speed of light. Now Hertz has shown through his work, which has developed so brilliantly from inconspicuous and painstaking beginnings, that from a spark gap effects spread at a finite speed, that their straight path is reflected and refracted through the intermediate media in the same way as the rays of light, and that the facts he observed, nowhere make it necessary to assume that, in addition to the mediated effects, there is also a direct action at a distance of the spark gap. In accordance with Newton's principle, that in order to explain phenomena one should not allow more causes than are true and are sufficient to explain those phenomena, in the field of electricity the assumption of instantaneous forces acting at a distance will be dropped and Maxwell's theory must be viewed as that which corresponds to the current point of view of our experience.

What is proven by the development described above against the basic views of Weber's electrodynamics, and what is put in its place? Weber's theory was based on two different pillars, the assumption of immediate action at a distance and the idea of the atomistic constitution of matter. Of these, the first pillar has proven to be insufficient and superfluous compared to the phenomena. But the second pillar is in no way shaken by Maxwell's theory; because the mechanism, on which the propagation of the electrical force is based, makes no special assumptions. One can just as easily think of waves in a medium that continuously fills space in terms of tensions and pressures between the neighboring volume elements of such a medium, [or] as a transfer from particle to particle in an atomistically constituted medium. In the latter case, the action at a distance is then reintroduced into the theory, with the change that it is no longer considered to be present for arbitrarily large distances, but only for molecular distances. The conviction that effects exist through pressure and tension may be more immediate. Although their assumption may be closer to our perception, we know nothing about how they come about, and even with them, the body ultimately acts where it is not, i.e., in the distance. In this sense, the confirmation of Maxwell's theory did not result in a decision being made against the assumption of action at a distance.

The theory of action at a distance has two centuries behind it. We will not expect that the new methods that are to take their place will appear to us in an equally sophisticated and uniform form. For the time being, the phenomena of gravity are separated from the other areas of physics by a deep gap, as long as it is not possible to explain Newton's attraction as an indirect effect caused by changes in the state of an ether-filling space. The attempts that have been made in this direction in recent times, from Riemann's metaphysical hydrodynamics to Isenkrahe's kinetic theory, do not have the character of a physical explanation.[58] They are based on a type of transcendental physics in that they attribute properties to the bodies that generate gravity that no physical body ever possesses. But even apart from this, we do not have a uniform method. Rather, an undeniable charm of current development lies in the diversity of perspectives from which attempts are made to bring connection and order into the realm of phenomena. The guiding ideas are not so separated from each other, that one excludes the other, but rather they can penetrate and complement each other in many ways, and we do not want to forget this relationship if in the following we separately highlight some points that are important in the recent developments of theoretical physics.

The first of these concerns the concept of energy, which has a fundamental meaning because it is the only thing that all areas of physics have in common. It therefore makes sense to place energy at the forefront of theory in each individual area and to connect the various areas with one another through the principle of conservation of energy. But people have gone even further by trying to view energy as a real substance and matter as the manifestation of energy. According to the different classes of physical facts, one has a mechanical, thermal, electromagnetic, and chemical form of energy. If it was previously considered a goal of science to reduce these different energies to a single form of mechanical or, more specifically, kinetic, the task of research is, on the other hand, limited to the investigation of the factors of energy in the individual areas, the paths, along which it moves and carries out its transformations. The demand made at the beginning to give the concept of energy a leading role in the development of theories has probably been fulfilled to a large extent. In its original form, Hamilton's principle of mechanics contains the difference between kinetic and potential energy.[59] In its further development, it reveals the possibility of replacing potential energy with the energy of hidden movements and of explaining action at a distance through movements in an intermediate medium. The mechanical theory of

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[58] [Note by AKTA and MH:] Bernhard Riemann (1826-1866) was a German mathematician and student of Gauss' non-Euclidean geometry, from which he developed his function theory of surfaces. He then became a temporary assistant to Wilhelm Eduard Weber. Caspar Isenkrahe (1844-1921) was a German mathematician, physicist and philosopher.

[59] [Note by AKTA:] William Rowan Hamilton (1805-1865) was an Irish mathematician, astronomer, and physicist.

heat made the most important contribution to the development of the concept of energy. The more recent presentations of the theory of electricity also take their starting point from this. In no area, however, does the principle of conservation of energy provide a sufficient foundation for the development of theory. Rather, other facts completely independent of the same are added to the observation everywhere. It must also be emphasized that the practical interest which for us is associated with the establishment of general theories is rarely satisfied by the mere knowledge of energy and its conversions, so the energy principle is also inadequate in this direction. The view that energy exists independent of bodies and that these are only the vessels in which the movements of energy take place is difficult to implement, especially in mechanics. Finally, science will not be satisfied with the existence of the different types of energy and the fact of their convertibility; rather, it will always pursue the question of whether this can not be explained by the internal agreement of the forms of energy. Similarly, light, heat, electricity, and magnetism were previously explained by the effects of as many imponderable bodies, whereas at present, we only have to assume the existence of a single one.

Insofar as energetics goes against the methods of molecular physics, it subordinates itself to those theories that make use of the idea of a continuous filling of space. Based on the diverse facts, they assign properties to the volume elements of a body, which can undergo a constant increase or decrease with the location; they try to find mathematical relationships between the quantities given in this way, which reflect the observed connections. The equations which are given to us by the theories of the continuum have the great advantage of being valid, independent of the ideas which we associate with the quantities contained in them. They provide us with a description of the phenomena that is as complete and as simple as possible. Now our task is not to describe the phenomena but to explain them, i.e. to devise moving systems, which are images of the unknown real processes, so that every relationship that takes place between the bodies has a similar kind in the model, of every change, that we can do with it, corresponds to a real process in the world of appearances. This requirement is not satisfied by the mathematical formulas of the continuum theories. We will continue to search for a clear interpretation of the same in order to provide a guide for further research. In agreement with this, Maxwell said in his dynamic theory of gases:[60]

> The properties of a body which is supposed to be a uniform continuum may be dogmatically asserted, but they cannot be explained mathematically.

In the introduction to the treatise on Faraday's lines of force, Maxwell contrasts the representations of phenomena through mathematical formulas and physical hypotheses in an eloquent manner.[61] He says that in the first case, one loses sight of the phenomena to be explained and that the pursuit of mathematical consequences does not open up any new insight into the connection of things. On the other hand, physical hypotheses only show us the phenomena in a mirror. The successful explanation of a limited circle blinds us to the facts and leads us to hasty conclusions. Maxwell, therefore, seeks to discover a method of inquiry that will give the mind at every step the support of a clear physical view, without luring it away from appearances into the pursuit of analytical subtleties, and without drawing it in favor of any preconceived opinion beyond the facts respectively. He satisfies these conditions by the method of mechanical analogies, on which he based his theory of

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[60] [Note by AKTA:] [Max67].

[61] [Note by AKTA:] [Max58] and [Max65].

electrodynamics. The hypothesis on which it is based is that two galvanic currents have a concatenation of the same kind as the mechanisms that we now call bicyclic systems. Under this assumption, the typical equations of the latter must also apply to two galvanic currents. In this way, Maxwell actually arrives at the laws for the electromotive and ponderomotive effects of electrodynamics.

The method of mechanical analogies is not opposed to molecular theories like energetics and continuum theories. The natural connection which we subordinate to the typical form of a cyclic system, can be caused by an action exerted by molecule on molecule, as by an agent that continuously fills the space. However, it cannot be assumed that we will soon be able to dispense with the ideas of molecular theory. Especially in chemisty, the phenomena of chemical equilibrium accessible to energetics form only a part of the ideas to be explained. The question of why the chemical elements come together in certain proportions to form solid bodies of a certain crystalline form, is no more connected to the laws of chemical equilibrium than the theory of elasticity is to the laws of melting and evaporation. In optics, wherever the phenomena of light are connected with the chemical constitution of bodies, we are led to the assumption of the smallest particles, independent of one another, whose nature is so absolutely unchangeable that they carry out exactly the same oscillations in the most remote star in the flame of a Bunsen burner.[62] If one wants to accept the kinetic theory of gases as just a mechanical analogy, it would have made it very likely that there are tiny particles in a gas that, in a certain sense, move independently of one another. Biology in the fields of botany and zoology is based entirely on the ideas of molecular theory. The theory of the continuum itself did not attempt to view molecules and atoms as superfluous in the phenomena mentioned. It only asserts that the idea of them is not the last to which we can reach, and in this sense, William Thomson exploited the theory of vortices in a frictionless fluid.[63] With this turn, continuum theory no longer regards bodies as uniformly filling space. It only imagines an ideal fluid behind the bodies, on whose forms of movement the phenomena of the physical world are based.

We had come to the conclusion that the assumption of instantaneous action at a distance, as made in Weber's law, was inadequate and superfluous, but that the idea of the molecular constitution of bodies was not affected by Maxwell's theory. From the previous comments, it follows that the further development of science will not change this. What were Weber's own views on the questions discussed? He believed that he could maintain the correctness of his law despite the objections raised. But he was clear from the beginning about the possibility that this law was not the ultimate cause of electrical phenomena. At the end of the First Treatise on electrodynamic measurements, he said:[64]

> It can be thought that the forces covered by the discovered fundamental law are partly also those forces which two electrical masses indirectly exert on each other and which therefore initially come from the intermediary medium and further must depend on all bodies that act on this medium. A question that has not yet been decided is whether knowledge of the intermediary medium would not be useful, even if not necessary, for determining the forces. The idea of the existence of such an intermediary medium can already be found in the idea of the electrically neutral fluid that is widespread everywhere. Even though this neutral fluid, apart from the conductors, has almost

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[62] [Note by AKTA:] Robert Bunsen (1811-1899) was a German chemist.

[63] [Note by AKTA:] William Thomson (1824-1907), or Lord Kelvin, was a British mathematician, physicist and engineer.

[64] [Note by AKTA:] See also [Web21c, p. 202].

> completely escaped the observations of physicists so far, there is now hope that it will be possible to gain more detailed information about this generally widespread fluid in several new ways. Perhaps in other bodies apart from the conductors, there are no currents but only vibrations, which will only be able to be observed more closely in the future. Furthermore, I only need to recall Faraday's recent discovery of the influence of electrical currents on light vibrations,[65] which makes it not unlikely that the ubiquitous electrical neutral medium is itself the ubiquitous ether that creates and propagates the light oscillations.

Weber was particularly concerned with molecular theoretical investigations in the last period of his scientific activity, initially attempting to penetrate into the relationships of molecular movements using his law. He found that two different types of motion are possible for two similar electric particles.[66] In the one, a mutual reflection of two approaching particles takes place; in the second, the particles form a persistent system in which their distance periodically increases from zero to a certain amount and then decreases again to zero. He connects the first movement with the kinetic theory of gases, the latter with the stability of chemical compounds. He also continued to pursue Mossotti and Zöllner's assumption that ponderable molecules should be viewed as compounds of positive and negative electrical atoms and that gravity could be explained by the predominance of electrical attraction over repulsions.[67] He dealt with the problem of explaining the phenomena of light through waves in an electrical ether, assuming that the movements of its atoms correspond to the assumptions of gas theory. As long as he was allowed to work, he pursued the goal that he described in 1875 with the words:[68]

> The true constitution of bodies and the true, albeit more complicated processes that depend on them, which can only be partially represented by simpler processes, will, regardless of all obstacles, always remain the subject and ultimate goal of research.

With this outlook, we would like to conclude our consideration of Weber's scientific work. But to us, Weber is more than just a famous researcher who gave science new goals and new directions. Here he was at the peak of his life, here he enjoyed the peace of his old age. We experienced the friendliness and goodness of his nature and admired the character of rare greatness and purity in his undemanding appearance. So, as a student and younger friend of the deceased, I can try to bring the image of his personality back to our memories. The hours in which I, as an older student, listened to his lecture on experimental physics will always be among the most beautiful in my memory. Some people may have missed the smooth flow of speech, and the charm of effective experiments, but how quickly one forgot the external features that might have been noticeable at the beginning because of the wonderful art with which he knew how to develop the connection between phenomena and to expand the knowledge step by step. His lectures had a stimulating effect far beyond the circle of physicists thanks to the fine and apt remarks with which he illuminated the spirit and methods of precise research. I was soon fortunate enough to be able to personally get closer to the man I admired as a teacher. Anyone, who has ever visited Weber, will

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[65] [Note by AKTA:] [Far46].

[66] [Note by AKTA:] That is, for two particles electrified with charges of the same sign.

[67] Ottaviano Fabrizio Mossotti (1791-1863) was an Italian physicist. Johann Karl Friedrich Zöllner (1834-1882) was a German astrophysicist. See [Web94b] with English translation in [Web21a].

[68] [Note by AKTA:] [Web75].

be familiar with the narrow room, the simple desk, will see him reading and working, his picture framed by the window through which the view fell onto the lawn and the towering trees of the garden. He will remember, not without emotion, the warm manner in which Weber greeted the visitor and the warm sympathy, he had for his concerns. It was a surprise of its own for the stranger when he came through the narrow, angled corridor between the houses on Jüdenstrasse to Wilhelm Weber's residence. In the middle of the city, separated from the noise and hustle and bustle of the day by few walls and yet peaceful and quiet, like the man who ended his great life in it. How pleased Weber was with the beautiful property, especially with the large, well-kept garden with its abundance of flowers and fruits and the secluded places that invited comfortable peace and quiet. How many a beautiful festival was celebrated there just a short time ago under his eyes, for he, who had retained the heart and faith of a child throughout his life, was full of joy when the garden echoed with the joy of a happy youth. When the older brother had retired from teaching, he and his family used to spend the summer in Göttingen in the Weber house, which had been enlarged for this purpose. A new life arose around the deceased. Although he was not married, he did not lack an attractive domesticity. When he returned to Göttingen, his niece Sophie Weber accompanied him, and from then on, with a short interruption, she ran his household and took care of his esteemed uncle. But more and more, the Göttingen house became the center of the family, and even that year, the children and grandchildren of his brother Ernst Heinrich gathered around the already suffering man. And just as this house was a place of quiet work and happy celebrations, it was also a place to which everyone was privileged to spend time, in it owed a variety of stimulation and support. Because Weber's interests were not limited to the circle of his science, he was a friend of philosophical reflection. He had an open sense of the beauty of poetry and knew and loved our classical music and also the things of this world. He followed the course of political events with wise judgment and patriotic spirit. When Weber comes before our inner eyes, we first think of his kindness and gentleness, his modesty in all the honors that fell to him in abundance without being asked for, and the amiable optimism that he maintained even when things did not go his way. But his kindness did not become weakness. Wherever he saw injustice, the man who was otherwise so calm could become violently angry.

He had a violent temper, it didn't matter to him whether it was a matter of big or small things and one might perhaps have smiled at the zeal with which he defended what he recognized as being right if it hadn't been the awe for the deep feeling for truth and right that was expressed in it. He showed how serious he was about this on November 18, 1837, when the new king repealed the basic law of the state and released the civil servants from the oath they had taken to the constitution. In the idea drawn up by Dahlmann, it was said:[69]

> The entire success of our effectiveness does not rest so surely on the scientific value of our teachings as on our integrity. As soon as we appear before the studying youth as men who play a careless game with their oaths, just as soon the blessing of our effectiveness will be gone.

Weber knew what was at stake for him when he signed these words; although he did not have the care of a family, the dismissal from office was hard enough for him, because through it, all the conditions of his existence were profoundly shaken. For the natural scientist, more

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[69] [Note by AKTA:] Friedrich Christoph Dahlmann (1785-1860) was a German historian and politician.

than for the representatives of the humanities, the possibility of successful work is tied to the possession of an academic chair, and the call to another university had to put an end to the intimate contact with Gauss and the joint work of the two researchers. But Weber clung to Gauss with a strong and deep feeling, which is expressed in the following words of a letter written after his dismissal:

> That I have had and will never have a higher wish in life than to always stay close to you, and you are certainly convinced that the dangers that now threaten the fulfillment of my wish are deeply shocking. If only I am not exiled, I will remain close to you and will know how to adjust myself without a cabinet.

But it was not only on a big occasion and with a big decision that Weber put his eyes on his own advantage behind what he considered his duty.

He demonstrated the same sense of duty towards the many small affairs which are connected with the position of professor and which so often disturb his circles at inopportune hours. Given his entire personality, Weber was not suitable to represent the university in a representative position. He also didn't like to show his personality in public. His influence on the affairs of the university and the share he took in them were therefore significant. He managed the deanship of the philosophical faculty three times; the reports on general affairs of the faculty or the needs of the institute he headed, which we have from his hand, are prepared with the same care as his scientific treatises and provide a wide range of instruction and inspiration.

Weber was a whole man, and whatever he did, he did it with all his strength and all his mind. He was pure and true and honest, and just as there was no falsity in himself, so he could not believe in any falseness in others. So his judgment could well be lacking, but the reason for the error was the inner goodness of his being. The work of his life, as it is handed down to posterity in his scientific treatises, unfolded with an admirable consistency from the beginning, without deviations, without regression, and with inner necessity. With the highest care in mathematical development, with the most unconditional reliability in the execution of the experiments, and with the most precise weighing of the secured ground, the broadest view of what can be achieved goes hand in hand. And he did not deceive Weber, because in all his work he did not seek his own, but, free from all selfishness and every touch of vanity, he placed himself in the service of the truth. When he became tired of working, he handed over one part of his official duties after another to younger hands, without complaint or bitterness. When the loss of his memory also made scientific work impossible, he laid down his pen, not without pain, but without the quiet peace of his soul ever being disturbed.

He had become lonelier over the years. His beloved brother went before him. The circle of friends, which used to gather every week for mutual instruction and informal exchange of ideas, had dissolved, and so it was more and more limited to the relationships that connected it with the nearby members of the family and with a few loyal ones friends from older times. So his mind gladly and often returned to days long past, and the present world appeared to him as if through a veil. What he experienced internally in those hours, when he seemed lost in dreams, is a secret that we remain in awe of. During the Pentecost days of that year, a change occurred in Weber's health, who had still retained admirable strength in his old age. Soon, one could no longer be mistaken that the denouement was coming. When, after misty days that forbade the enjoyment of the open air, the full sun shone again for the first time, he allowed himself to be led out into the garden, where he remained the whole day. After noon, he fell asleep sitting in the armchair. When the sun went down, his eyes opened clear and bright. He looked out into the distance, his gaze no longer directed at the things of this world, but up to a higher order that he had longed for a long time because he had grown tired of working in this world. Then he slumbered over into that long sleep, from which there is no awakening here, under the trees that he had once planted and which had been the witnesses of his blessed work for so long.

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