DETERMINATIONS OF ELECTRODYNAMIC MEASURE:
particularly in respect to the connection of the Fundamental Laws of Electricity with the Law of Gravitation[1]

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1.

On deriving qualitative differences of bodies from quantitative ones, on the hypothesis that all ponderable molecules are connections of positive and negative electrical molecules

A distinction has been made between the *ponderable bodies* in space in solid, liquid, and gaseous aggregate states, and *imponderable bodies*, in particular *light material* (Lichtstoff), *heat material* (Wärmestoff), *two electrical* and *two magnetic* materials and, accordingly, all of physics has been categorized into the Mechanics of ponderable *solid*, *liquid*, and *gaseous* bodies, and the Theories of *Light*, of *Heat*, of *Electricity*, and of *Magnetism*.

In the course of the development of these theories, however, the theory of *magnetism* along with its extension into the theory of diamagnetism, has been entirely absorbed by the *theory of electricity*, so that the *assumption of two special*

EDITOR'S NOTE: The author's notes are represented by [N. A.], the notes by H. Weber, the editor of this fourth volume of Weber's *Werke*, are represented by [N. H. W.], while the notes of the editors of this English translation are represented by [N. E.].

[1] [N. E.] Translated into English from Wilhelm Weber, "Elektrodynamische Maassbestimmungen insbesondere über den Zusammenhang des elektrischen Grundgesetzes mit dem Gravitationsgesetze," *Wilhelm Weber's Werke*, Vol. IV: *Galvanismus und Electrodynamik*, part 2, edited by H. Weber (Berlin: Julius Springer Verlag, 1894) pp. 479-525.

Wilhelm Eduard Weber (1804-1891) wrote eight major Memoirs between 1846 and 1878, under the general title *Elektrodynamische Maassbestimmungen* (Determinations of Electrodynamic Measure). This eighth Memoir, thought to be written in the 1880s, was published posthumously in 1894.

magnetic materials has been discarded. Likewise, the differentiation of a *light ether* for light radiation from a *heat ether* for heat radiation, has also been dropped; *an ether*, however, for light and heat radiation remains, and a *heat material* as a conductor for heat in the interior of ponderable bodies, in particular metallic heat conductors.

It is interesting to pursue this present development of physical research further and indeed, one observes:

Firstly, that the *theory of magnetism* can only be absorbed by the theory of electricity under the *assumption* of *movable parts in the interior* of all magnetic and magnetizable bodies, i.e., *positive electrical molecules*, which form *molecular currents* around the *negatively* electrically charged ponderable molecules, in the interior of all magnetizable bodies.[2]

Secondly, by the further consideration, that the *theory of galvanism and of heat*, in order likewise to be absorbed by the theory of electricity, must also presuppose movable parts in the interior of all galvanic conductors and heat conductors; that, however, these need by no means be *different parts* which produce *in the interior of ponderable bodies*, *magnetism*, and *others* which produce the motion of *galvanism*, and still others, whose movements produce *heat*; rather that *the same parts*, according to the difference of their motions, can produce *magnetism*, *galvanism*, and *heat*, sometimes together, sometimes separately, and that these moving parts in the interior of ponderable bodies are *molecules of one electricity*, which ought to be called *positive electricity*.

Thirdly, it is to be considered, that the movements of these positive electrical molecules around the negatively electrically charged *ponderable molecules* of bodies, *either* form closed orbits, or spiral orbits differing only slightly from circular orbits with *periodically* increasing and attenuating diameter, *or* spiral-shaped orbits with continuously increasing diameter, whereby they ultimately pass over into a ballistic trajectory, thus effecting the transfer of this electrical molecule from *one ponderable molecule* to *another neighboring*

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[2] [N.E.] The signs of the charge are reversed in Weber's notation compared to modern usage. Thus the particle of positive charge, orbiting about a negatively charged central body, corresponds to the negatively charged electron of modern parlance. It should be noted that Weber is 30 to 40 years ahead of his time in proposing an electrical atom.

ponderable molecule, whereupon in part *heat conduction*, and in part *galvanic currents* in metallic conductors, are based.

Fourthly, and finally, it is furthermore to be considered, that by means of *magnetic or electrodynamic induction from the outside,* circular currents around the *ponderable molecules* of a body may be excited, or circular currents already in existence may be *enhanced*, *weakened*, or *changed in direction*.

It is self evident, that *all metallic heat- and electricity- conductors* belong to the class of ponderable bodies, around whose molecules *positive electrical molecules* move in circular orbits, albeit with increasing diameters, which make a transition into a ballistic trajectory and thus a transition from those *ponderable* molecules about which they revolve, to neighboring *ponderable molecules*; that, on the other hand, all transparent bodies, such as glass and crystals, belong to the class of *ponderable bodies* about whose molecules positive electrical molecules indeed move, but only in *tighter circles without transition into a ballistic trajectory* (which, therefore, are neither conductors of heat nor electricity), while the greater remaining part of the body consists of the space (like the space of the universe) between the *ponderable molecules,* with positive electrical molecules forming the light ether, and characterized by ballistic or wave motion.

As concerns the molecular currents formed by *electrical molecules* around *ponderable molecules*, it is evident, that an attractive force issuing from the ponderable molecules is required for the persistence of such circular currents, and the question is merely, where this attractive force comes from? Is a contrary electrical charge of the ponderable molecules necessary for it, or can each ponderable molecule found in each center exert this attractive force for itself alone? It turns out, that this force of attraction can be exerted by the *ponderable* molecules for themselves alone, without an additional electrical charge, and indeed upon a *positive* electrical molecule circling about it, as well as on a *negative* electrical molecule, presupposing that the following two assumptions, first clearly and definitively expressed by Zöllner,[3] are met:

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[3] [N. E.] J. C. F. Zöllner, "Über die Ableitung der Newton'schen Gravitation aus den statischen Wirkungen der Elektricität," in J. C. F. Zöllner, *Wissenschaftliche Abhandlungen*, Vol. 1 (L. Staackmann, Leipzig, 1878), pp. 417-495. See also F. Zöllner, *Erklärung der univesellen Gravitation aus den statischen Wirkungen der Elektricität und die allgemeine Bedeutung des Weber'schen Gesetzes, mit Beiträgen von Wilhelm Weber mit einem vollständigen Abdruck der Originalabhandlung*: *Sur les forces qui régissent la*

1. *That all ponderable molecules are mere connections of equal quantities of positive and negative electricity*, and that

2. *The force of attraction of equal quantities of different kinds of electricity is greater than the repulsive force of the same quantities of similarly charged electricity.*[4]

These two assumptions form the foundation for that *theory of ponderable bodies*, according to which the *law of gravitation* which is valid for all of these bodies, is yielded as a necessary consequence of the fundamental law of electricity.

It is easy to appreciate the great importance, which the confirmation of the above assumptions would have for all of physics, if one considers the extraordinary multiplicity of *qualitative differences* of ponderable bodies, all of which, accordingly, would have to be reducible to mere *quantitative* differences, which differences would have to be derivable from the fundamental law of electricity.

2.

The Derivation of the Law of Gravitation from the Fundamental Law of Electricity according to Zöllner

The derivation of the law of gravitation from the fundamental law of electrical action according to Zöllner, requires closer examination in order to be able to build further upon it.

According to Zöllner, it is assumed, that every *ponderable molecule* consists of one or more molecules of positive electricity and one or more molecules of negative electricity, where the first is denoted with $+e$ or $+ne$, the

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constitution intérieure des corps aperçu pour servir à la détermination de la cause et des lois de l'action moléculaire, par O. F. Mossotti (Leipzig, L. Staackmann, 1882), pp. 1-43.

[4] [N. E.] That is, the attractive force between the charges $+e$ and $-e$ is greater than the repulsive force between $+e$ and $+e$, and also greater than the repulsive force between $-e$ and $-e$.

latter with $-e$ or $-ne$. The numerical value of e (aside from the sign) serves to determine the *quantity of electricity* of a molecule, independent of the *kind of electricity*, which may be positive or negative, for e is made dependent merely upon the choice of the *unit of length* and of the *unit of force*, whereas ee denotes the *repulsive force* of a positive or negative electrical molecule $\pm e$ *on a molecule equal to it in the unit of distance*.

It is furthermore assumed, that the magnitude e, which is called *quantity of electricity*, and is distinguished from the *mass* ε of the molecule, is *equal for all electrical molecules*, and that, consequently, the ponderable molecule composed of $+e$ and $-e$ is always *neutral*, i.e., that it behaves the same with respect to a $+e$ as to a $-e$. The same holds as well for ponderable molecules composed of $+2e$ and $-2e$, or $+3e$ and $-3e$, etc.

From this equality of quantities of electricity, which, according to Zöllner, holds for *all simple electrical molecules*, whereupon the *neutrality* of *ponderable molecules* composed of an equal number of positive and negative electrical molecules is based, it does indeed follow, that there is an *equality of mass* of all *positive electrical* molecules among themselves, as well as of all *negative electrical* molecules among themselves, but it by no means follows, that *the masses of positive and negative molecules are the same*, rather the decision about the equality or inequality of their masses must remain for experiment to determine, be it by direct measurements of mass, or by an indirect route by investigating their connection with other measurable phenomena.It then results from the *fundamental law of electrical action*,[5] that the force which *two ponderable molecules* (where

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[5] [N. E.] What Weber calls the *fundamental law of electrical action* is the expression he introduced in 1846 for the force between the electrical charges e and e' separated by a distance r, i.e. $\frac{ee'}{r^2}\left(1-\frac{a^2}{16}\frac{dr^2}{dt^2}+\frac{a^2}{8}r\frac{d^2r}{dt^2}\right)$, (see W. Weber, "Determinations of electrodynamic measure: concerning a universal law of electrical action," *21st Century Science & Technology*, www.21stcenturysciencetech.com/Articles%202007/Weber_1846.pdf). In 1852, he replaced the constant $a^2/16$ by $1/c^2$ obtaining $\frac{ee'}{r^2}\left(1-\frac{1}{c^2}\frac{dr^2}{dt^2}+\frac{2}{c^2}r\frac{d^2r}{dt^2}\right)$, (see W. Weber, "Elektrodynamische Maassbestimmungen insbesondere Widerstands-messungen," reprinted in *Wilhelm Weber's Werke*, Vol. 3: *Galvanismus und Elektrodynamik*, part 1 (Berlin: Julius Springer, 1893), pp. 301-471 especially p. 366).

In Weber's formulation, the force between particles was thus dependent upon their *relative velocity* and *acceleration*. This constant c would represent the uniform each is composed of $+e$ and $-e$) exert upon each other, are the sum of four forces, which the two constituent parts $+e$ and $-e$ of *one ponderable molecule* exert, from an arbitrary distance r, in relative rest or motion, upon the two constituent parts $+e$ and $-e$ of the *other ponderable molecule*, namely, *firstly* the two *repulsive forces* of the *molecules of similar kind* contained in the ponderable molecules:

the *repulsive force* of $+e$ and $+e$

$$=\frac{ee}{r^2}\left(1-\frac{1}{c^2}\left(\frac{dr}{dt}\right)^2+\frac{2r}{c^2}\frac{d^2r}{dt^2}\right)$$

the *repulsive force* of $-e$ and $-e$

$$=\frac{ee}{r^2}\left(1-\frac{1}{c^2}\left(\frac{dr}{dt}\right)^2+\frac{2r}{c^2}\frac{d^2r}{dt^2}\right);$$

secondly, the *attractive forces* of the *dissimilar electrical molecules* contained in the same ponderable molecules, which, according to Zöllner's assumption, ought to be larger in a relationship of $1:1+\alpha$, namely,

the *attractive force* of $+e$ and $-e$

$$=-(1+\alpha)\frac{ee}{r^2}\left(1-\frac{1}{c^2}\left(\frac{dr}{dt}\right)^2+\frac{2r}{c^2}\frac{d^2r}{dt^2}\right),$$

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relative velocity at which the force between particles would fall to zero. Weber's c (known throughout the 19th century as the *Weber constant)* is not the same as the modern $c=2.998\times10^8 m/s$, but $\sqrt{2}$ times this last value (or, $c=4.24\times10^8 m/s$). The *Weber constant,* c, which is also the ratio between electrodynamic and electrostatic units of charge, was first measured by Weber and Kohlrausch in 1855-1856. They obtained $c=4.39\times10^8 m/s$. An English translation of one of their papers: W. Weber and R. Kohlrausch, "On the amount of electricity which flows through the cross-section of the circuit in galvanic currents," can be found in *Volta and the History of Electricity*, F. Bevilacqua and E. A. Giannetto, eds. (Milano: Università degli Studi di Pavia and Editore Ulrico Hoepli, 2003), pp. 287-297; available at http://www.ifi.unicamp.br/~assis.

the *attractive force* of $-e$ and $+e$

$$=-(1+\alpha)\frac{ee}{r^2}\left(1-\frac{1}{c^2}\left(\frac{dr}{dt}\right)^2+\frac{2r}{c^2}\frac{d^2r}{dt^2}\right).$$

This yields *a negative value of the repulsive force* (i.e., an attractive force) of *two ponderable molecules*, each of which consists of one $+e$ and one $-e$, i.e., the value

$$-2\alpha\frac{ee}{r^2}\left(1-\frac{1}{c^2}\left(\frac{dr}{dt}\right)^2+\frac{2r}{c^2}\frac{d^2r}{dt^2}\right),$$

where the unknown value of α can be determined by the consideration, that the above force, of which α is a factor, is set equal to the known *gravitational force* of the two ponderable molecules upon each other.

In this it has been assumed, that the two *electrical molecules* which belong to a *ponderable molecule* always remain at a negligibly small distance from each other.

If V is the *potential* of the two ponderable molecules, and consequently their repulsive force is

$$\frac{dV}{dr}=-2\alpha\frac{ee}{r^2}\left(1-\frac{1}{c^2}\left(\frac{dr}{dt}\right)^2+\frac{2r}{c^2}\frac{d^2r}{dt^2}\right),$$

then that *potential* is

$$V=-2\alpha\frac{ee}{r}\left(1-\frac{1}{c^2}\frac{dr^2}{dt^2}\right).$$

If now the mass of $+e$ is represented by ε, the mass of $-e$ is represented by $a\varepsilon$, then the acceleration of *one* ponderable molecule in the direction r, turns out to be $=1/\varepsilon\cdot[dV/dr]$, that of the *other* in the opposite direction is $=1/a\varepsilon\cdot[dV/dr]$; consequently, the relative acceleration of the first molecule with respect to the other is

$$\frac{d^2r}{dt^2}=\frac{1+a}{a\varepsilon}\cdot\frac{dV}{dr}.$$

Multiplying this equation by $2dr$, one obtains the following differential equation:

$$2\frac{dr}{dt}\cdot\frac{d^2r}{dt}=2\frac{1+a}{a\varepsilon}dV,$$

and by integration from $r=r_0$ to $r=r$, if r_0 represents that value of r, for which $[dr/dt]=0$,

$$\frac{dr^2}{dt^2}=\left(1+\frac{1}{a}\right)\cdot\frac{4\alpha ee}{\varepsilon}\left[\frac{1}{r}\left(1-\frac{1}{c^2}\frac{dr^2}{dt^2}\right)-\frac{1}{r_0}\right],$$

or, when $dr^2/dt^2=c^2u^2$ and the constant

$$\frac{4(1+a)}{a\varepsilon}\cdot\alpha ee=c^2\rho,$$

is established, then

$$u^2=\rho\left[\frac{1}{r}\left(1-u^2\right)-\frac{1}{r_0}\right],$$

the same equation which was found in the 7th Memoir, "Determinations of Electrodynamic Measure," p. 668,[6, 7] for two dissimilar electrical molecules e and e', only that here, where the issue is the reciprocal effect of *ponderable* molecules,

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[6] [N. H. W.] *Wilhelm Weber's Werke*, Vol. IV, p. 385.

[7] [N. E.] W. Weber, "Elektrodynamische Maassbestimmungen insbesondere über die Energie der Wechselwirkung, " *Abhandlungen der Königl.* Sächs. *Gesellschaft der Wissenschaften, mathematischphysik Klasse*, Vol. 11, Leipzig 1878, pp. 641-696; reprinted at *Wilhelm Weber's Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 361-412.

the factor 2α is added to the value of ρ and $-e$ and $a\varepsilon$ are applied for e' and ε'.[8]

This thus yields, for the reciprocal effect of two molecules at relative rest, consisting of *equal amounts* of positive and negative electricity, the same law as for two molecules subjected to the law of gravitation for all distances in comparison to which ρ is negligible; but for *molecular distances*, for which this is not the case, there are divergences from the Newtonian Law, which, were they

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[8] [N. A.] From the above equation, where the velocity u is expressed in parts of the velocity c known from the electrical basic law, i.e., from

$$u^2 = \rho\left(\left[\frac{1}{r}\right](1-u^2) - \frac{1}{r_0}\right),$$

one obtains

$$u = \pm\sqrt{\left[\frac{\rho}{r_0}\right]\cdot\left[\frac{(r_0-r)}{(r+\rho)}\right]},$$

i.e., for each distance r, two opposite equal values of u, one *positive* for the case of mutual separation of the molecules, and one *negative* for the case of mutual approach. If one considers here $r_0 - r = s$ as the *space of fall* downwards from the point of rest, in that one conceives the one ponderable molecule as like the mass of the Earth concentrated in one point, the other molecule conceived as represented by the falling stone, and u as the velocity of fall v of the stone expressed in parts of c , i.e., $cu = v$, this yields

$$\frac{v^2}{s} = \frac{\rho c^2}{[r_0(r_0+\rho)]},$$

i.e., the *Galilean law of falling bodies*, where the *constant*

$$\frac{\rho c^2}{[r_0(r_0+\rho)]}$$

has the significance of the constant usually denoted by $2g$ in the Galilean law of falling bodies.

corroborated, would serve as the best proof, that the ponderable molecules *really* do consist of *equal amounts* of positive and negative electricity.

Such *molecular distances* come into special consideration in the case of *ponderable gas molecules* according to the *dynamic gas theory*. Maxwell ("On the Dynamical Theory of Gases," *Philos. Transact.*, Vol. 157, Part I, page 49 ff.)[9] has already found, that the law of reflection and dispersion for the ballistic motion of the gas molecules in their encounter, necessarily assumed to explain the behavior of gases according to this theory (but which can not be founded upon the Newtonian law of gravitation), could be based upon an assumption conceived particularly for the purposes of this explanation, of a repulsive force proportional to the 5th power of the distance of the molecules, an assumption, however, which would otherwise be in no way justifiable. – Any such arbitrary assumption may now be entirely avoided, if all ponderable molecules, consequently also all gas molecules, are connections of *equal amounts of positive and negative electricity*, since the law of gravitation holds for such molecules only at greater distances, but, for molecular distances, the *law of reflection and dispersion* is similarly yielded, as for two *similar electrical* molecules in ballistic motion, which encounter one another according to the theory developed in the 7th Memoir, "Determinations of Electrodynamic Measures."[10]

An issue of special consideration in this reciprocal effect of *two ponderable molecules* consisting of equal amounts of positive and negative electricity, is that *equal forces* are exerted by the one molecule upon *both constituent parts of the other*, both upon the positive as well as the negative, and these are *forces of attraction*, the sum of which yields the *gravitational force* exerted by the one molecule upon the other.

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[9] [N. E.] J. C. Maxwell, "On the Dynamical Theory of Gases," *Philosophical Transactions*, Vol. 157, pp. 49-88 (1867); reprinted in W. D. Niven (editor), *The Scientific Papers of James Clerk Maxwell*, Vol. 2 (Cambridge University Press, Cambridge, 1890), pp. 26-78. For a discussion of all quotations of Maxwell made by Weber, see A. K. T. Assis and K. H. Wiederkehr, "Weber quoting Maxwell," *Mitteilungen der Gauss-Gesellschaft*, Vol. 40, pp. 53-74 (2003). Available in PDF format at: http://www.ifi.unicamp.br/~assis/.

[10] [N. H. W.] *Wilhelm Weber's Werke*, Vol. IV. p. 389.

By virtue of the here postulated force of attraction exerted by every *ponderable* molecule, not merely upon another *equal* molecule, but upon each of its two *constituent parts*, all of those ponderable molecules which had *first* met up with *positive electrical* molecules, would have bound them as *positive electrical satellites*, and, on the other hand, other *entirely identical* ponderable molecules, which had first met up with *negative electrical molecules*, would have bound them as *negative electrical satellites*; and, therefore, *all ponderable molecules* would fall into three classes, which can be distinguished as *positive ponderable, negative ponderable*, and *neutral*, of which the latter would be such ponderable molecules, which had not yet drawn satellites to themselves.

If all of these satellites remained bound with the ponderable molecules in the same way, they would have to be considered as belonging to them, and therefore *their mass would be the mass of the ponderable molecules* to which they belonged, and the mutual *gravitational force of the molecular pair* exerted by the satellites of *two* ponderable molecules, as well as that exerted by each of the two satellites upon that one of the two ponderable molecules to which it itself does not belong, would be either added or subtracted, depending upon the difference of the sign.

3.

On the inadequacy of direct attempts to decide the question, whether in the case of equal amounts of electricity, the attractive force of two unequal electrical molecules would really be larger than the repulsive force of two similar electrical molecules.

Metal conductors may be taken, for example two hollow spheres of copper, which are charged with equal amounts of positive or negative electricity, and the repulsive or attractive force exerted by two of these, respectively, at equal distances, can be measured with great accuracy. Were the precision of this measurement in no way limited, it is apparent, that it would have to be determinable thereby, whether, given equally strong charges, the *attractive force of dissimilarly charged conductors* were larger than the *repulsive force of similarly charged conductors*, or not.

The most precise instruments and experiments, which have been carried out to the purpose of similar measures, have been described in the 4th Memoir of

Determinations of Electrodynamic Measures[11,12] and the question is thus posed, whether, with the same instruments, measurements may be carried out to decide the above question.

With such a torsion balance as described in that place, the *repulsive forces* of *two similarly electrically* charged spheres, as well as the *attractive force* of two *dissimilarly charged* electrical spheres, could indeed be measured; it is, however, easily seen, that in the latter case, when the one sphere is positively charged, the other negatively, the *equality of the strength* of the two charges, could only be measured by completely discharging the two spheres in a condition of contact with one another. In order, therefore, to be certain of the *equal strength of the charge* immediately prior to the discharge, which is the essential point here, one can only bring two *entirely identical torsion-balances* into action simultaneously, by charging the *revolvable sphere* of the one torsion-balance *positively*, and the other *negatively*. But for each revolvable sphere of the torsion balance, there is a completely identical *fixed sphere*, which is in contact with the revolvable sphere when it is charged, which is the guarantee for the equality of the charge of both spheres of each pair. Now, the strength of the charge of the *positively* charged pair may be different from that of the *negatively* charged; this difference is precisely determinable, however, by measurement of their *force of repulsion*. If these repulsive forces of the positively charged [pair] are found to be the same as those of the negatively charged, it follows that *the absolute values of that positive and this negative charge are equal*.

These two *fixed spheres* are now, however, to be firmly bound to each other by a *well-insulating rod of shellac*, and let this rod of shellac be equipped with a pivot at its mid-point, about which it may be so rotated, that after a half rotation both fixed spheres have exchanged their positions, so that the distances of the two fixed spheres from the revolvable spheres of the two torsion-balances have remained unchanged.

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[11] [N. H. W.] Wilhelm Weber's *Werke*, Vol. III, p. 670.

[12] [N. E.] R. Kohlrausch and W. Weber, “Elektrodynamische Maassbestimmungen insbesondere Zurückfuhrung der Stromintensitäts-Messungen auf mechanisches Maass, ” *Abhandlungen der Königl.* Sächs. *Gesellschaft der Wissenschaften, mathematischphysische Klasse*, Vol. 3, Leipzig 1857, pp. 221-290; reprinted in *W. Weber’s Werke*, Vol. 3, H. Weber (editor), (Springer, Berlin, 1893), pp. 609-676.

If one denotes the equal charges of the revolvable sphere and the fixed sphere of the *first torsion-balance* with $+e$, and their distance from each other with r, and the same magnitudes for the *second torsion-balance* with $-e'$ and r', then *prior to the exchange of the fixed spheres* one obtains the two *repulsive forces* f and f', measured with the two revolvable scales, equal to ee/r^2 and $e'e'/r^2$; *after the exchange of the fixed spheres*, however, the measured *attractive forces* g and g' equal to $-(1+\alpha)\cdot ee'/r^2$ and $-(1+\alpha)e'e/r'^2$, from which the ratio of the product of the two *measured forces of repulsion* to the two *measured forces of attraction*, yields $ff' : gg' = 1 : (1+\alpha)^2$, where α can be determined by the measured magnitudes $ff'gg'$, i.e., $\alpha = \sqrt{gg'/ff'} - 1$.

But even with the greatest perfection of the *torsion-balances* produced for these measurements and with highest precision in the conduct of all measurements, it will not be possible to demonstrate with certainty, for equal charges, a difference in the magnitude of the *force of repulsion of similar electrical charges*, because this difference is much too small.[13]

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[13] [N. A.] Should it turn out, that out of all of the measurements conducted with the most perfect *torsion-balances*, the value of α is far too small to allow a secure determination from such observations, the question would still remain, whether it might be possible, on the basis of *other phenomena and observations*, to determine the magnitude of α, for example on the basis of the so manifold, most interesting phenomena and observations provided by Crookes' *light mills*.

One does not yet know exactly the difference which would be necessary between the front and back sides of the vanes of these light mills, so that the mills might be set into rotational motion by means of beams of light. Without a difference, however slight, between the two sides of the vanes, be it in their constitution or form (convex or concave), no rotation occurs.

It were, for example, possible, that, in the Crookes' light mills, the *necessary difference* between the front and back sides of each vane, is based on an *electrical difference*, for example, that the front side were more *positively electrical*, the back side *negatively electrical*, and that the beam of light would produce the rotation, in that it had the effect of a positively charged conductor, which *repulsed* the *positive* electrical *front side* of one vane turned toward it, and would *attract* the *negative* electrical *back side* of the other vane turned toward it.

Were this the case, it is evident, that one would only need to combine a second pair with the first pair of vanes, which would rotate with the latter about the same vertical axis. If, now, the second pair stood at right angles above the first, but turned toward the opposing side of the beam of light, then, given perfect symmetry, no rotation would occur, if the *force of attraction of dissimilar* electrical charges, given *equal strengths of*

If, however, in the future, it turns out, even with the measurements conducted with the most perfect instruments, that the value of α is much too small to allow of a secure determination, there would remain still one other factor contained in the fundamental law of electrical action, which could be used for the purpose of testing and confirming the Zöllner derivation of the law of gravitation from the electrical law, namely, the factor

$$\left(1-\left[\frac{1}{c^2}\right]\left[\frac{dr^2}{dt^2}\right]+\left[\frac{2r}{c^2}\right]\left[\frac{d^2r}{dt^2}\right]\right),$$

for which the proof would be of great interest, that its influence upon the movement of some heavenly bodies, although very small, were yet measurable.

C. Seegers first dealt with this in the essay *De motu perturbationibusque planetarum secundum legem electrodynamicam WEBERIANAM solem ambientium. Scripsit C. Seegers, Gott. 1864*, following which Prof. Scheibner in Leipzig found eight years later, that, while maintaining the numerical value of c for the Weber Constant, at best the difference that could be observed in the movement of mercury was a secular variation of the perihelion of 6.73 arc-seconds. – Finally, Tisserand, on 30 September 1872, provided an essay to the French Academy: “Sur le mouvement des planetes autour du Soleil d'après la loi electrodynamique de Weber.” *Compt. rend.* 1872, Sept. 30,[14] where he finds the value 6.28 for the secular variation of the perihelion for the case of Mercury, and the value of 1.32 seconds for Venus. As small as these corrections might be, it is

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charge, were equal to the repulsive force of similar electrical charges; but there would be a rotation, if the force of attraction of *dissimilar electrical charges*, given equal strengths of charge, were larger than the force of repulsion of *similar electrical charges*.

With the extraordinary precision and sensitivity, of which the light mills are capable, one may hope to be able to observe the *rotational effect* of this, however slight, preponderance of that force of attraction, and from that be able to determine the magnitude of α.

[14] [N. E.] M. F. Tisserand, “Sur le mouvement des planètes autour du Soleil, d’après la loi électrodynamique de Weber, ” *Comptes Rendues de l’Academie des Sciences de Paris*, Vol. 75, pp. 760-673 (1872). See also M. F. Tisserand, *Traité de Mécanique Céleste* (Gauthier-Villars, Paris, 1895), Vol. 4, Chap. XXVIII : “Vitesse de Propagation de l’Attraction, ” Section 225 : “Loi d’attraction conforme à la loi électrodynamique de Weber” ; and Section 226 : “Intégration rigoureuse des équations (8) ” ; pp. 499-503.

evident that it is possible to confirm or refute them with more precise observations.

For comparison with the Newtonian Law: the *law of gravitation derived by Zöllner from the fundamental law of electrical action*, two identical *ponderable molecules*, each of which consists of a $+e$ and a $-e$ (where each would exert the unit of force upon the molecule identical to it, at relative rest, at a given unit of distance), would exert a *force of attraction* upon each other at any arbitrary relative velocity and acceleration of

$$=2\alpha\frac{ee}{r^2}\left(1-\frac{1}{c^2}\left(\frac{dr}{dt}\right)^2+\frac{2r}{c^2}\frac{d^2r}{dt^2}\right).$$

While according to the *Newtonian law, two equal ponderable molecules of mass* m, expressed in parts of that mass which exerts the unit of accelerating force at the given unit of distance, would exert a *force of attraction*

$$=\frac{mm}{r^2},$$

to which one can add, that if n denotes the *number* of ponderable molecules constituted each of one $+e$ and one $-e$, contained in the *same unit of mass* according to which m is expressed, $2\alpha nnee/r^2 = mm/r^2$, thus

$$n=\frac{m}{e}\sqrt{\frac{1}{2\alpha}}.$$

4.

Electrical filling of space, particularly concerning the existence of an ether consisting of similar electrical molecules – light ether – in all spaces not occupied by ponderable bodies. – Manifold of ponderable bodies.

The assumption of the existence of a dispersed *imponderable ether* consisting of similar electrical molecules, in all spaces not occupied by *ponderable bodies*, depends, as already remarked in the foregoing Section, essentially upon the assumption, that all *ponderable molecules* are constituted of positive and negative electrical molecules, and indeed in *equal amounts*. From that, it would follow that, if negative electrical molecules existed at all in the world, but not in amounts equal to the positive [molecules], *the surplus of positive electrical molecules* (apart from the possibly existent *satellite* ponderable molecules, mentioned at the conclusion of the first Section, which, however, may be formed by *both kinds* of electrical molecules, without there being any reason for a greater number of one kind) would necessarily be dispersed in all spaces or intervals not occupied by ponderable bodies, and indeed, in consequence of the mutual repulsions, reflections and dispersions in all of their encounters, in *nearly uniform proliferation*.

But if now each *ponderable* molecule contains *equal amounts of positive and negative* electricity, which can be denoted with $+e$ and $-e$, the *equality of the amounts* by no means entails the *equality of the masses*, which must be distinguished from them, and thus the mass of the *amounts* of $+e$ may be denoted as ε, the mass of the *amounts* of $-e$ with $a\varepsilon$.

But even if the two *equal amounts* of two dissimilar electrical molecules $+e$ and $-e$ can combine into a ponderable molecule, there will be no combination *into a point*, rather, as close to one another as the two molecules may come, they will still always remain separated from one another, in that they rotate around one another; the two, which together have the mass of $(1+a)\varepsilon$, will, however, always remain in a very small space, which does not change under conditions of unchanged angular velocity, so that a certain *density* $d=[(1+a)/v]\cdot\varepsilon$ can be ascribed to such a *ponderable molecule*.

Were now such a combination *of all negative electrical* molecules with *positive electrical* molecules to have occurred, then all of the thus generated *ponderable* molecules, taken together, would occupy a certain *space*, and the entire remaining space would be empty, were not one of the two electricities, which can be taken as *positive*, existent in considerable surplus. In the case of such a *surplus*, however, all of the remaining space would be filled by an extant electricity of mutually *repelling* molecules, everywhere present in uniform distribution.

Let all of these electrical molecules uniformly filling the empty space be denoted as *imponderable ether*, while all of the *pair-wise combined* molecules, reduced into a closed space, form the world of *ponderable* bodies, accordingly, therefore, since *mass* is an attribute of all molecules, *ponderable masses* and *imponderable masses* must be distinguished from one another.

The *law of gravitation* has been called the *law of indifferent mass attraction*, which, according to the forgoing, would not be correct. For if positive electrical molecules also exist, which are not combined with negative electrical molecules into *ponderable* molecules, and thus do not belong to the world of *ponderable bodies*, which do, however, possess *mass*, then the Newtonian *law of gravitation* does not hold *for the masses of these latter molecules*, but an entirely different law, i.e., the *basic law of reciprocal electrical action*, according to which the action is not always that of attraction, but just as often that of repulsion, and the validity of the law of gravitation must be limited to the masses of those *pair-wise combined* positive and negative electrical molecules, called *ponderable molecules*. Those *positive electrical molecules*, which exist distinct from negative electrical molecules, and which fill, in uniform distribution, the empty space of the ponderable bodies, form the so-called *ether* – light ether.

If the *law of gravitation* holds neither for positive electrical molecules as such, nor for the negative as such, but for all *ponderable molecules* formed by combination of these two kinds of molecules, it is evident, since all characteristics of *combined* molecules must be based upon the characteristics of *non-combined* molecules, that the law of gravitation for all ponderable molecules must be based, in general, upon the law of electrical reciprocal action, as already demonstrated in Section 2.

But were all ponderable bodies really only combinations of positive and negative electrical molecules, the issue would be, given the essentially identical constitution of all ponderable bodies, how to explain the *infinite multiplicity and difference* of these ponderable bodies. The *reason for all of these differentiations* could only be found in different *numbers*, *spatial arrangements* and *kinetic energy* of the electrical molecules of both type combined in smaller groups, which need not be subjected to changes by external influences. The influence of the *number* and *arrangement*, as long as these were to remain unchanged, would be easier to observe and determine than the influence of different *kinetic energies* of the molecules acting upon one another in a group, whose laws have been impossible to completely develop out of the known basic laws, even under the limitation of only three molecules.

5.

Classification of material-molecules according to their composition and differentiation.

If there are two kinds of *simple* material particles, viz., simple *positive electrical* and simple *negative electrical*, then it is possible that, by combination of a plurality of electrical particles of either type with one another or of particles of one type with those of the other type, many kinds of different *composite* molecules can be formed, and indeed, *indissoluble molecules*.

Let the initial assumption be, that all positive and negative electrical particles possess the same *amounts* e and the same *mass* ε, so that the force is ee with which two similar particles at rest at a given unit of distance, repel each other, and ee/ε is the velocity which this force would impart to each of the two particles in a given unit of time.

Such a composite *indissoluble molecule* is formed of *two simple positive electrical* or *negative electrical* particles, which are at a smaller distance from one another than their critical distance ρ; for these attract one another with a force which would become *infinitely* large, given a distance growing up to ρ, from which it is evident, that no finite external force would be capable of pulling them apart to a distance of ρ, and thus also not beyond ρ. Both particles must therefore always remain within distances smaller than ρ.

Many more forms of such composite *indissoluble* molecules can exist, because, if a simple, for example positive electrical particle came together with more than one other such particle in a space so close, that the distances of these from one another were all smaller than ρ, so that *all of these particles together would form just one such indissoluble molecule*, as is the case for two. If of that plurality, for example of *three* particles, *a*, *b*, *c*, two of them, *a* and *b*, were to approach the distance ρ, where their mutual *force of attraction* would become infinitely large, it would only be possible for the third particle, *c*, to annul this force of attraction's becoming infinitely great, if this third particle were upon the opposite side at the same distance, thus at a distance $= 2\rho$ from *a*, which would be contrary to the assumption.

Under the same assumption for *negative electrical* particles as that just made for *positive electrical* particles, just as many cases of indissoluble molecules could exist, composed of simple *negative* electrical particles, as cases of indissoluble molecules composed of simple *positive electrical* molecules.

Additionally, not only two or three, but a far larger number of *similar electrical particles* could be together in such a small space, without the distance of any particle from another being greater than or equal to ρ, so that all of these particles together, also form an *indissoluble molecule which remains together for ever*. And finally, it should be noted that these particles enclosed in a small space of a molecule, have as little need to be at rest as the particles originally dispersed in larger spaces, but they can have the most manifold movements, partly *together*, in close connection with one another in space, partly *against* one another within the small space in which they are, without thereby ceasing to form an *indissoluble group* or a single *composite molecule*. Each such composite molecule forms an enclosed world for itself, and according to the difference of the number of simple electrical particles which it contains, and their mutual movements, such a composite molecule can exert quite diverse effects upon all other molecules lying outside of it, according to which *very diverse characteristics* may obtain for that molecule. If one further considers, that the *number* of simple electrical particles which can be combined in this way, although not unlimited, can yet be very large, it is conceivable, that such eternally unchangeable, partly positive, partly negative electrical particles or molecules can recombine themselves to quite *different ponderable bodies*, for example of very different density or hardness, etc., for each *group* consisting of a larger number of *similar electrical particles*, *partly positive, partly negative*, of which each occupies only a spherical space of diameter ρ, must obviously attract each other and combine with a *force much larger* than a simple positive electrical molecule with a simple negative electrical molecule.

For all such *indissoluble molecules* composed of more than two similar electrical particles, three cases can be distinguished, *firstly* the case where all of these molecules lie so close to one another, that, under effects from a distance, they can be considered as united at one point; *secondly*, the case where two molecules rotate around one another; and *thirdly*, the case where a larger number of molecules move in different orbits about each other in the space they occupy. Different characteristics of the molecules may be based upon these differences.

This yields the following classification of material molecules, first of the *indissoluble electrical* molecules, then of the *ponderable* molecules. The *positive* *or negative particles* contained in a molecule, are denoted by their number and + or – value sign, and that these together form an *indissoluble molecule* is indicated by enclosure in brackets.

1. Simple electrical molecules:
    - *positive electrical* molecule $(+1)$
    - *negative electrical* molecule (-1)
2. Composite indissoluble electrical molecules
    - of *positive electrical*:
        - of two $(+2)$,
        - of three $(+3)$,
        - of four $(+4)$,
        - of five $(+5)$,
        - of six $(+6)$, etc.
    - of *negative electrical*:
        - of two (-2),
        - of three (-3),
        - of four (-4),
        - of five (-5),

of six (-6), etc.[15]

3. *Ponderable* molecules, composed of the same number of *positive and negative electrical* molecules, which may be arranged graphically as follows.

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[15] [N. A.] Molecules $(+n)$ and $(-n)$, where n were a larger number, as a consequence of their larger reciprocal force of attraction, will seldom appear singly, but mostly only in composites $\begin{bmatrix} +n \\ -n \end{bmatrix}$, i.e., as *ponderable molecules*.

$$\begin{bmatrix}+1\\-1\end{bmatrix}$$

$$\begin{bmatrix}-2\\+1\\+1\end{bmatrix}\begin{bmatrix}+2\\-2\end{bmatrix}\begin{bmatrix}+2\\-1\\-1\end{bmatrix}\begin{bmatrix}+1\\+1\\-1\\-1\end{bmatrix}$$

$$\begin{bmatrix}-2\\-1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-3\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-3\\+2\\+1\end{bmatrix}\begin{bmatrix}+3\\-3\end{bmatrix}\begin{bmatrix}+3\\-2\\-1\end{bmatrix}\begin{bmatrix}+3\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+2\\+1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+1\\+1\\+1\\-1\\-1\\-1\end{bmatrix}$$

$$\begin{bmatrix}-2\\-1\\-1\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-2\\-2\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-3\\-1\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-4\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-4\\+2\\+1\\+1\end{bmatrix}\begin{bmatrix}-4\\+2\\+2\end{bmatrix}\begin{bmatrix}-4\\+3\\+1\end{bmatrix}\begin{bmatrix}+4\\-4\end{bmatrix}\begin{bmatrix}+4\\-3\\-1\end{bmatrix}\begin{bmatrix}+4\\-2\\-2\end{bmatrix}\begin{bmatrix}+4\\-2\\-1\\-1\end{bmatrix}\begin{bmatrix}+4\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+3\\+1\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+2\\+2\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+2\\+1\\+1\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+1\\+1\\+1\\+1\\-1\\-1\\-1\\-1\end{bmatrix}$$

$$\begin{bmatrix}-2\\-1\\-1\\-1\\+1\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-2\\-2\\-1\\+1\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-3\\-1\\-1\\+1\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-3\\-2\\+1\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-4\\-1\\+1\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-5\\+1\\+1\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-5\\+2\\+1\\+1\\+1\end{bmatrix}\begin{bmatrix}-5\\+2\\+2\\+1\end{bmatrix}\begin{bmatrix}-5\\+3\\+1\\+1\end{bmatrix}\begin{bmatrix}-5\\+3\\+2\end{bmatrix}\begin{bmatrix}-5\\+4\\+1\end{bmatrix}\begin{bmatrix}+5\\-5\end{bmatrix}\begin{bmatrix}+5\\-4\\-1\end{bmatrix}\begin{bmatrix}+5\\-3\\-2\end{bmatrix}\begin{bmatrix}+5\\-3\\-1\\-1\end{bmatrix}\begin{bmatrix}+5\\-2\\-2\\-1\end{bmatrix}\begin{bmatrix}+5\\-2\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+5\\-1\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+4\\+1\\-1\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+3\\+2\\-1\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+3\\+1\\+1\\-1\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+2\\+2\\+1\\-1\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+2\\+1\\+1\\+1\\-1\\-1\\-1\\-1\\-1\end{bmatrix}\begin{bmatrix}+1\\+1\\+1\\+1\\+1\\-1\\-1\\-1\\-1\\-1\end{bmatrix}$$

etc. etc.

Here, each of the numbers enclosed in the same brackets refers to a number of like electrical particles moving about each other, whose distance from one another remains smaller than ρ. These indissoluble particles move together in *one* orbit, and a particular orbit corresponds to each number. The orbits of dissimilar electrical particles are held together by mutual attraction. The molecules comprised in each number are, accordingly, indissoluble and likewise also all of the molecules of the *second* of the *three classes enumerated above*, also those, which are composites of many simple molecules, because they are similar and their distances from one another are $< \rho$.

In all molecules of the *third class*, on the other hand, those listed as *positive electrical* under + are *possibly* always dissoluble from the *negative electrical* listed under –, even if no force sufficient to cause their dissolution exists. In reality, no such dissolution, whereby a ponderable body were broken up into its imponderable constituent parts, has been observed. But since the dissolution of ponderable bodies into ponderable constituent parts is often observed, by continued dissolution, however, one finally arrives at ponderable bodies which have not been further dissoluble, one has indeed called these latter ponderable bodies *elemental bodies*, whereby however the *possibility* of their dissolution into positive and negative electrical molecules is not excluded.

Those ponderable molecules will be the most difficult to break down, where many *similar electrical* particles are at distances from one another smaller than ρ, thus all molecules denoted as $\begin{bmatrix} +n \\ -n \end{bmatrix}$, where n is a larger number. Ponderable molecules $\begin{bmatrix} +n \\ -n \end{bmatrix}$ with large number values n will accordingly behave as *ponderable elementary bodies*, while on the other hand ponderable molecules where n is a small number, for example 1, will be most easily dissoluble into *electrical elements*.

If one now takes the weight of the ponderable molecule $\begin{bmatrix} +1 \\ -1 \end{bmatrix}$ as the unity of atomic weight, n would be the atomic weight of the molecule $\begin{bmatrix} +n \\ -n \end{bmatrix}$. The smallest ponderable molecule known to us is that of hydrogen, and is usually given the value = 1. Accordingly, the atomic weights of the other previously not dissoluble ponderable bodies and the composition out of positive and negative electrical elementary particles, would be as follows:

	Atomic weight	Electrical composition
Hydrogen	1	$\begin{pmatrix}+1\\-1\end{pmatrix}$
Carbon	12	$\begin{pmatrix}+12\\-12\end{pmatrix}$
Lithium	13	$\begin{pmatrix}+13\\-13\end{pmatrix}$
Beryllium	14	$\begin{pmatrix}+14\\-14\end{pmatrix}$
Nitrogen	14	$\begin{pmatrix}+14\\-14\end{pmatrix}$
Oxygen	16	$\begin{pmatrix}+16\\-16\end{pmatrix}$
Fluorine	19	$\begin{pmatrix}+19\\-19\end{pmatrix}$
Bromine	20	$\begin{pmatrix}+20\\-20\end{pmatrix}$
Boron	22	$\begin{pmatrix}+22\\-22\end{pmatrix}$
Magnesium	25	$\begin{pmatrix}+25\\-25\end{pmatrix}$
Aluminum	27	$\begin{pmatrix}+27\\-27\end{pmatrix}$
etc.	etc.	etc.

The case where two entirely different ponderable molecules have the same atomic weight, occurs five times, and there is even one case where three such bodies have the same atomic weight, i.e.,

1. Beryllium and Nitrogen $\begin{pmatrix}+14\\-14\end{pmatrix}$

2. Cobalt and Nickel $\begin{pmatrix}+59\\-59\end{pmatrix}$

3. Rhodium and Ruthenium $\begin{pmatrix} +104 \\ -104 \end{pmatrix}$

4. Thorium and Uranium $\begin{pmatrix} +119 \\ -119 \end{pmatrix}$

5. Barium and Vanadium $\begin{pmatrix} +137 \\ -137 \end{pmatrix}$

and finally Gold, Platinum, and Iridium, all $\begin{pmatrix} +197 \\ -197 \end{pmatrix}$.

In what does the difference of such ponderable elementary bodies of the same atomic weight consist? This difference could, according to this hypothesis, only consist in the difference of the orbits and velocities, in and with which the united *positive electrical* particles of a ponderable molecule, whose distances from one another are smaller than ρ, move, and of the orbits and the velocities in and with which the united *negative electrical* particles of the same ponderable molecules, whose distances from one another are smaller than ρ, move. The more rapidly these orbits are traversed, the greater the molecule's resistance will be to the penetration of other particles, and thus the greater the hardness it will possess.

As far as the divergence of some atomic weights from the multiple of the atomic weight of hydrogen is concerned, they may, at least in part, be due to *satellites* of some ponderable molecules, whose existence seems to be bound to certain relationships, which shall be more closely examined.

A *ponderable* composite molecule of $+e$ and $-e$ (where for e also a plurality of similar electrical molecules can be posited) exerts two forces upon a *positive electrical* molecule $+e'$, i.e., one *repulsive force* from $+e$ upon $+e'$

$$= +\left(\frac{ee'}{r^2}\right) \cdot \left(1 - \left[\frac{1}{c^2}\right]\left[\frac{dr^2}{dt^2}\right] + \left[\frac{2r}{c^2}\right]\left[\frac{d^2r}{dt^2}\right]\right)$$

and one *attractive force* from $-e$ upon $+e'$

$$= -(1+\alpha)\left(\frac{ee'}{r^2}\right)\left(1 - \left[\frac{1}{c^2}\right]\left[\frac{dr^2}{dt^2} + \left[\frac{2r}{c^2}\right]\left[\frac{d^2r}{dt^2}\right]\right]\right),$$

thus, in sum, one *attractive force*

$$= -\alpha\frac{ee'}{r^2}\left(1 - \frac{1}{c^2}\frac{dr^2}{dt^2} + \frac{2r}{c^2}\frac{d^2r}{dt^2}\right).$$

By means of this *force of attraction* exerted by a *ponderable molecule* on the *positive electrical molecule*, the latter can be continuously maintained in a *rotational motion* around the *ponderable molecule*.

The same *ponderable molecule* consisting of $+e$ and $-e$ also exerts two forces upon a *negative electrical* molecule $-e'$, i.e., a *force of attraction*

$$= -(1+\alpha)\left(\frac{ee'}{r^2}\right)\left(1 - \left[\frac{1}{c^2}\right]\left[\frac{dr^2}{dt^2} + \left[\frac{2r}{c^2}\right]\left[\frac{d^2r}{dt^2}\right]\right]\right)$$

and a *force of repulsion*

$$= +\left(\frac{ee'}{r^2}\right)\left(1 - \left[\frac{1}{c^2}\right]\left[\frac{dr^2}{dt^2}\right] + \left[\frac{2r}{c^2}\right]\left[\frac{d^2r}{dt^2}\right]\right),$$

thus, in sum, also a *force of attraction*, and indeed of the *same magnitude* as the *force of attraction* exerted upon $+e'$, where this the *negative electrical* molecule can also be maintained in a *rotational movement around the ponderable molecule*.

In this way, most *ponderable molecules* will have obtained, over the course of time, either a *positive electrical* or a *negative electrical* molecule as a satellite, and accordingly the ponderable molecules would fall in *three classes*, i.e., into the class accompanied by *positive satellites*, into the class of those accompanied by *negative electrical satellites*, and into the class of those remaining *without satellites*.

If now *composites of ponderable molecules out of electrical particles* could occur up to the number of five positive particles with five negative particles, this would accordingly yield, according to the above scheme, 53 ponderable basic materials, from which the possibility of $53 \cdot 54/2 = 1431$ *binary composite ponderable bodies* would result.

If one further considers the extraordinary multiplicity which can occur in each of these *ponderable* molecules in relationship to the orbits and the *vis vivas* of particular electrical particles, out of which they are composed, there is the possibility of *infinitely many different kinds of such molecules*.

6.

Electricity in metallic conductors.

In the discussion "On Galvanometry" in Vol. 10 of the *Abhandlungen der Königl. Gesellschaft der Wissenschaften zu Goettingen* (1862)[16, 17], Section 33 deals with "the transformation of work of the electrical current into heat." It is there said: The work of the electrical current is related to the movement of electrical fluids, and according to the mechanical theory of heat, *heat* is also connected to the movement of a body, which, however, one usually distinguishes from the electrical fluids, and calls *heat material*, without however, determining this difference more closely. A closer examination of the way in which *work of the electrical current* is transformed into *heat*, would accordingly seem to require, that either the identity of heat-material with the electrical fluid is demonstrated, or, if this is not the case, that the movements of the electrical fluid would have to be pursued up to the point, here the transition of the movements from *electrical fluid* to *heat-material* occurs. In the latter case, however, the coexistence of many substances in the smallest parts of the space of the conductor would have to be assumed, i.e., the *ponderable conductor substance* along with *both electrical fluids*, and also the so-called *heat-material*. To avoid such an accumulation of material in the same space, one therefore initially attempted

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[16] [N. H. W.] Wilhelm Weber's *Werke*, Vol. IV, p. 17.

[17] [N. E.] W. Weber, "Zur Galvanometrie, " *Abhandlungen der Königl. Gesellschaft der Wissenschaften zu Göttingen, mathematische Klasse*, Vol. 10, Göttingen 1862, pp. 3-96; reprinted in W. Weber's *Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 17-96.

to eliminate the *ponderable conductor substance* to the extent possible [by assuming] that, for example, the copper, instead of being *uniformly* distributed *throughout the entire space*, is in *particular spatially separate* points, i.e, it is assumed that the so-called *ponderable molecules* are concentrated, and by further assuming the surface of each such molecule to be firmly connected to a layer of negative electrical molecules on its surface, and also that *positive electrical molecules* flow around it, which, in the case of a galvanic current, move successively from *one ponderable molecule to another*.

Whatever the forces upon which the *work* depends, generated by the exit of one such *positive electrical* molecule out of the sphere of attraction of a *negatively charged* ponderable molecule, an *opposite and equal work* will always be performed by the same electrical molecule *upon entrance* into the sphere of attraction of the next, also *negatively charged* ponderable molecule, so that these *two magnitudes of work* always compensate each other. Once, however, the electrical molecule is separated from *one* ponderable molecule, it will pass through the spatial interval α until the *next* ponderable molecule, driven by the electromotive force f, and thus perform the work $f\alpha$. The sum of all of these work-magnitudes $\sum f\alpha$ forms the electrical work in the conductor. Every electrical molecule, therefore, enters, upon transition *from one ponderable molecule to another*, with a *vis viva increased by* $f\alpha$ into the area of the latter, in comparison to the *vis viva* with which it exited from the area of the previous [molecule], whereby therefore the value of the *vis viva* in the total closed circuit must be increased by an equivalent amount with the total *electrical work*. An *increase of the vis viva equivalent to this electrical work* in all parts of the closed conductor taken together, however, is now, according to the *mechanical theory of heat*, also the *heat* produced by the current, and the question is only, whether it is itself identical to it, or whether that *vis viva* belonging to the electrical fluids must first be transferred to another medium (to the so-called *heat-material*), in order to appear as *heat*.

It has been demonstrated above, that there is no reason to assume such a transfer, that, however, with the omission of this transposition, every reason for assuming a particular *heat-material* or a *heat medium* also falls away, because it would be represented by *electricity*.

But now, if this representation of a so-called heat-material by electricity is to be complete, the laws of *heat conduction, of heat radiation*, and of *heat absorption*, as well as the dependent law of *temperature equalization* in ponderable bodies, must be derivable from the laws of movement of *electricity* in ponderable bodies and in empty space.

In the essay "On the Movement of Electricity in Bodies of Molecular Constitution" in *Poggendorff's Annalen*, 1875, Vol. 156,[18, 19] the attempt was actually made to trace all phenomena of *heat*, as well as of *magnetism* and *galvanism* to movements of *electricity* in these bodies.

Statics and dynamics of ponderable bodies are distinguished, depending upon whether one considers them in a state of rest or in movement; but in speaking of the state of rest in these bodies in statics, one has by no means characterized a state of rest of *all* parts encompassed within the bounds of these bodies, but only of those *ponderable* parts encompassed within these bounds. Without this restriction, it would never be possible to speak of the state of rest of a ponderable body, because other parts are contained in each such body in addition to its ponderable parts, which never come to rest.

Firstly, as we have seen, precise research into the observed *electrical* phenomena in *ponderable* bodies, has led to the result, that there are movable parts, i.e. *electricity particles*, in all of these bodies, whose dislocation and movement on the surface and in the interior of these bodies, is the reason for all phenomena of *electrical charge* and *galvanic currents*, as well as all *electrodynamical effects* as a whole.

Likewise, precise research of the *magnetic* phenomena in ponderable bodies, has led to the result, that in the interior of all of these bodies movable parts exist, which one had attempted to distinguish for a long time under the name of *magnetic fluids* from the first, i.e., from the *electrical*. Of this

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[18] [N. H. W.] Wilhelm Weber's *Werke*, Vol. IV, p. 312.

[19] [N. E.] W. Weber, "Ueber die Bewegung der Elektricität in Körpern von molekularer Konstitution," *Annalen der Physik und Chemie*, Vol. 156, pp. 1-61, reprinted in W. Weber's *Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 312-357.

magnetic fluid it was claimed, that it could be differently distributed in the interior of the body, depending upon different conditions, but that under persistent conditions it would come to rest and equilibrium. The reason for magnetic phenomena was sought in the *distribution* of these magnetic fluids, without requiring their continuous movement. But further research showed, that magnetic fluids at rest, however they were distributed, could not be the explanation for *all magnetic* (paramagnetic and diamagnetic) phenomena; that, however, *all* of these phenomena could be explained on the basis of the existence of *continuously moved* parts in the interior of ponderable bodies, and indeed, movement of the same parts, whose movements are the reason for all galvanic phenomena, viz., *electrical parts*.

Thirdly, there is the further point, that research into the *temperature* ascribable to each ponderable body, showed, that, in the interior of all of these bodies, movable parts exist, and that the reason for the observed temperature-phenomena, i.e., of *heat*, was to be sought in the movement of these parts. The suspected *identity* of these parts with the *electrical* [parts] has also been confirmed by facts, particularly by the *actual equality of vis viva produced by electromotive forces in the electrical and heat conductors, with that of the heat produced by current*.

In particular, in the investigations of heat production by the galvanic current in a conductor, it has been shown, that the *mechanical equivalent of the produced heat* in time-elements dt is equal to the product of dt into the current intensity i and into the electromotive force e, where for e the product of i may also be posited into the conductor-resistance w, thus $eidt = wi^2dt =$ the *mechanical equivalent of the heat produced*.

But now, $eidt$ is the product of the force acting upon the electricity flowing in the unit-length of the conductor into the distance traveled by this force in the time dt in the direction of this force, i.e., the work performed *by the moved electricity* contained in the unit length of the conductor in the time dt, which is the same as the *heat* produced in the unit length of the conductor in the time dt. Consequently, this *heat* is the same as the *work performed by the moved electricity*, and the *heat-material itself is identical to the moved electricity* in the conductor.

We limit ourselves here to considerations of the behavior of *electricity, galvanism, and heat* in *metallic conductors*, and leave to one side, whether their behavior in *moist conductors*, for example in diluted acids, would be the same or different; to distinguish the two cases, it may be noted, that the current in the first case, i.e., in *metallic conductors*, is formed merely by the electrical fluids, without any participation of ponderable molecules, while in the latter (i.e., in *moist conductors*), *ponderable materials*, such as hydrogen and oxygen, take part in the movement.

A clear insight into this relationship of the electrical fluids to the ponderable molecules in *metallic conductors during galvanic currents* requires, however, previous better knowledge of the behavior of the electrical fluids in *metallic conductors without galvanic current*. If there is no galvanic current in a metallic conductor, the electricity within it is by no means in a state of rest, rather it is in movement, and, accordingly, there exists a *vis viva* in metallic conductors, which is denoted with the name *heat*. Clear insight into the behavior of electrical fluids in metallic conductors, however, requires, therefore, a separation and precise distinction of *those movements* of the electricity present in metallic conductors, which are merely the reason for *heat phenomena*, from those, which form the *galvanic current* in metallic conductors.

As far, *firstly*, as the movement of the extant electricity in metallic conductors is concerned, which contain the reason for *heat phenomena*, we distinguish two parts in the space in this conductor, namely, that occupied by *ponderable molecules*, and that not occupied by ponderable molecules, so-called empty spaces in-between. In the latter there are *positive electrical molecules* which move, while all *negative electrical molecules* exist partly as persistent constituent parts of *ponderable molecules*, and partly as *charges* assumed to be temporarily bound to them.

The movements of the *positive electrical molecules* in the empty space surrounding a *ponderable metal molecule*, are not, however, limited to this space, rather such a molecule can pass from the environment of each *ponderable* molecule into the environment of a neighboring *ponderable* molecule; but this transition must take place from all ponderable molecules (if there is no galvanic current) indifferently in all directions, albeit not simultaneously, but successively. In bodies where that were not the case, there would be, as is easily seen, no *reciprocal heat radiation*, upon which, as is known, the law of *heat conduction* rests, i.e., the law of the *transfer* of the *vis viva* of heat from one ponderable molecule to the surrounding [molecules], which is the characteristic quality of *metallic conductors*. By *metallic conductors*, such bodies are understood, around whose *ponderable negative electrically charged molecules*, positive electrical molecules rotate, and are thrown out in all directions without differentiation.

All of these movements of electrical molecules in empty space between the ponderable *metallic molecules* follow laws, which are derivable from the *fundamental law of electrical action*. This derivation has already been provided in the cited essay in Poggendorff's Annalen, 1875, Vol. 156, Art. VI,[20, 21] "On the movement of electricity in conductors," pp. 39 ff.[22]

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[20] [N. H. W.] Wilhelm Weber's *Werke*, Vol. IV, page 339.

[21] [N. E.] W. Weber, "Ueber die Bewegung der Elektricität in Körpern von molekularer Konstitution, " *Annalen der Physik und Chemie*, Vol. 156, pp. 1-61, reprinted in W. Weber's *Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 312-357.

[22] [N. A.] This derivation was based upon consideration of the movement of two *dissimilar electrical* molecules, of which the *one* (negative electrical) is bound to a *ponderable* molecule, while *the other* (positive electrical) can move around it freely, and upon the resulting differences in the *molecular material constitution*.

Let us limit ourselves here to such systems which consist of pairs of molecules, of which the one $(-e)$ is *negative electrical* and bound to a ponderable molecule, the other $(+e)$ is *positive electrical* and moves around the first; in the 6th Memoir on "Determinations of Electrodynamic Measure" (*Abh. d. Kgl. Sächs. Ges. d. Wiss,* Leipzig 1871, Art. 11, p. 32) [N. H. W.: Wilhelm Weber's *Werke*, Vol. IV, p. 273] [N. E: W. Weber, "Elektrodynamische Maassbestimmungen insbesondere über das Princip der Erhaltung der Energie, " *Abhandlungen der Königl. Sächs. Gesellschaft der Wissenschaften, mathematischphysische Klasse*, Vol. 10, Leipzig 1871, pp. 1-61; reprinted in W. Weber's *Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 247-199; English translation in W. Weber, "Electrodynamic measurements – Sixth memoir, relating specially to the principle of the conservation of energy, " *Philosophical Magazine*, Vol. 43, pp. 1-20 and 119-149 (1872); see especially p. 125 of the English translation], the following equation was found for this:

$$\frac{u^2}{c^2} = \frac{r - r_0}{r - \rho}\left(\frac{\rho}{r_0} + \frac{r + r_0}{r} \cdot \frac{\alpha_0^2}{c^2}\right),$$

From the equation cited below *in the footnote* for a *dissimilar electrical molecular pair*, which is derived from the *fundamental law of electrical action*, it follows, as cited there, that for $u = 0$, either $r = r_0$ or $r = [n/(1-n)]r_0$.

From that the further result is, that such molecular pairs fall into two classes, i.e., into molecular pairs whose rotation around one another is *persistent*, and into such, whose rotation around each other *is not persistent*. Whether a molecular pair belongs to the one or other of these classes, depends upon its value for $n = -r_0\alpha_0^2/\rho c^2$, where r_0 denotes the smallest value of r, for which the relative velocity of the two molecules $u = 0$, and α_0 is the angular velocity of the electrical molecule around the ponderable [molecule] at distance r_0.

Persistence of the rotation of the electrical particle around the ponderable molecule occurs, when the value denoted by n lies between 1/2 and 1; *it does not occur*, on the other hand, if the value denoted by n lies between 0 and 1/2.

Since we consider here only pairs of dissimilar electrical molecules which can rotate around each other, where ρ always has a *negative* value, it follows, that n must always have a *positive* value. If this value is larger than 1, then $r_0 = -n\rho \cdot [c^2/\alpha_0^2]$ is the only value for r for which $u = 0$. If this value, on the other hand, is smaller than 1, but larger than 1/2, then, in addition to the value $r_0 = -n\rho \cdot [c^2/\alpha_0^2]$, there is another value for r, for which $u = 0$, i.e., that value for which $n([r_0/r]+1) = 1$, where the value $[n/(1+n)] \cdot r_0 = r^0$, from which it follows, that, if n is smaller than 1, but larger than 1/2, the distance

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where ρ, r_0, and α_0 are given constants, r is the distance of the two molecules from each other, and u is their relative velocity. If one substitutes $\alpha_0^2/c^2 = -n\rho/r_0$, one obtains

$$\frac{\rho - r}{\rho} \cdot \frac{u^2}{c^2} = \left(\frac{r}{r_0} - 1\right)\left[n\left(\frac{r_0}{r} + 1\right) - 1\right],$$

from which it follows, that for $u = 0$, either $r = r_0$ or $r = [n/(1-n)]r_0$.

of the two molecules from one another will alternately grow and recede, from r_0 to r^0 and then from r^0 to r_0, etc., whereby a *continuous rotation* of the two molecules around each other is given.

This *persistent rotation* of the two molecules around each other, if n is smaller than 1, but larger than 1/2, is now contrasted to the rotation of the molecules around each other, when n is smaller than 1/2, but greater than 0, where there is only a single value of $r = r_0$, for which $u = 0$, of which r would continuously grow *into infinity*, were it not prevented from doing so by external effects.

This growth of r (or the reduction of the curvature of the molecular orbit) is accelerated greatly upon approach, in a ballistic trajectory transition, of the *positive electrical molecule* toward a neighboring *ponderable* molecule, where the molecular orbit initially makes a transition into a straight-line ballistic trajectory, and then, with continued approach to the next *ponderable* molecule, finally enters again into a circular orbit around the latter molecule.

As a consequence of the different directions of the ballistic trajectories, through which the transition of this *positive electrical* molecule from one *ponderable* molecule to the *ponderable* neighbor molecules is mediated, a distribution of the same occurs to all *ponderable* neighbor molecules, just as, in reverse, the *positive electrical* molecules thrown out by all ponderable neighbor molecules reach the first *ponderable* molecule.

This ballistic trajectory of positive electrical molecules from each ponderable [molecule] to all ponderable neighbor molecules and the reverse, from all of these latter to the first, is denoted as *reciprocal radiation*. Fourier has shown, that the laws of *heat conduction* result from such *reciprocal radiation* between all *ponderable molecules* of a heat conductor, whereby the phenomena of distribution and movement of electricity are closely connected to the phenomena of distribution and movement of heat.

This is the basis, *firstly*, for the assumption, that *metals* are bodies, whose *negatively* charged *ponderable molecules* are surrounded by a flow of *positive electrical molecules*, which, however, do not find themselves in a *persistent rotation* around these, but rather in a *rotation, which transposes* *into a ballistic trajectory*, whereby these *positive electrical molecules* are dispersed in all directions. For these *positive electrical molecules*, that is to say, only the above cited value of n in metallic conductors smaller than 1/2 and larger than 0 is to be assumed.

This is, *secondly*, the basis for the assumption, that *solid ponderable bodies*, which distinguish themselves from metals in that they are *not conductors or electricity and heat*, for example, glass or crystals, are bodies, whose *ponderable molecules* indeed also have a *negative electrical* charge and are surrounded by a flow of *positive electrical particles*, but which find themselves in a *persistent* rotation around those *ponderable molecules*, [and] thus do not transpose into ballistic trajectories, since, that is, for them the above cited value n is larger than 1/2 but smaller than 1.

In place of the propagation of electricity and heat in *metallic conductors* through ballistic trajectories, in *glass-like and crystalline* bodies a propagation occurs through a *wave movement* of the *ether or light-medium* present in them, which is formed by the positive electrical molecules existing between the ponderable molecules.

Now the *laws of galvanic currents in metallic conductors* must be derived from the general *fundamental law of electrical action* according to the above determinations. Such a derivation has already been provided in the cited essay, "On the movement of electricity in bodies of molecular constitution" (*Poggendorff's Annalen*, 1875, Vol. 156, Art. VI),[23, 24] which shall be further elaborated here.

To this purpose, a *molecular constitution of metallic conductors* is assumed, i.e., a system of *ponderable* and *negative electrically* charged molecules, separated from each other by intervening spaces and in a stable equilibrium. This *stable equilibrium* of the *ponderable molecular system* forming the *metallic conductor*, is said to result in the way specified by Mossotti, 1. from the mutual *repulsion* of these ponderable molecules as a

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[23] [N. H. W.] Wilhelm Weber's *Werke*, Vol. IV, p. 339.

[24] [N. E.] W. Weber, “Ueber die Bewegung der Elektricität in Körpern von molekularer Konstitution, ” *Annalen der Physik und Chemie*, Vol. 156, pp. 1-61, reprinted in W. Weber's *Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 312-357.

consequence of their similar, i.e., *negative electrical charges*, while their mutual attraction, through gravitation, disappears; 2. from the mutual *repulsion* of all *positive electrical molecules* rotating around the ponderable molecules; 3. from the mutual *attraction of those ponderable molecules* with their negative electrical charges and *these positive electrical molecules* which fill the spaces in between. Mossotti attempted to prove the *possiblity* of such a ponderable molecular system in stable equilibrium in his essay: Sur les forces qui regissent la constitution intérieuse des corps, aperçu pour servir à la détermination de la cause et des lois d l'action moléculaire. Turin 1836.[25]

To this purpose, Mossotti assumes, that there are *ponderable molecules* at certain distances from one another in the space of a ponderable body, the which reciprocally repulse each other, – just as the above considered *negatively charged ponderable molecules of a metallic conductor* – and that their intervening spaces are filled by an *elastic fluid*, whose atoms also mutually repulse each other, but are attracted by the *ponderable* molecules, all of which also holds for the above *positive electrical* [molecules], which fill the intervening spaces of a metallic conductor, transposed into the ballistic trajectory, insofar as these also repulse each other, but are attracted by the *negatively* electrically charged *ponderable* molecules.

Mossotti then proves, that, given a certain relationship of the repulsive and attractive forces, those *ponderable molecules*, at *greater distances from one another*, behave just as if they alone existed, and attracted each other according to the law of gravitation; on the other hand, at *smaller* so-called *molecular distances*, they behave as if they were alone in space, and maintained each other in a *stable equilibrium* by the combined effect of the forces of attraction and repulsion.

The analogy of our case with that considered by Mossotti seems to lead to the same conclusion, i.e., to the possibility of the occurrence of a

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[25] [N. E.] Reprinted in: F. Zöllner, *Erklärung der univesellen Gravitation aus den statischen Wirkungen der Elektricität und die allgemeine Bedeutung des Weber'schen Gesetzes, mit Beiträgen von Wilhelm Weber mit einem vollständigen Abdruck der Originalabhandlung*: *Sur les forces qui régissent la constitution intérieure des corps aperçu pour servir à la détermination de la cause et des lois de l'action moléculaire*, par O. F. Mossotti (Leipzig, L. Staackmann, 1882), pp. 1-43.

stable equilibrium also of our *ponderable molecular system*, which forms *metallic conductors*.

It would accordingly also be true of *metallic conductors*, that two of their *ponderable molecules* at greater distances from one another, would behave as if they alone existed in space, and would attract each other by the law of gravitation, but at smaller so-called *molecular distances*, they would behave as if they alone formed a molecular system in *stable equilibrium*.

7.

Theory of the galvanic resistance of metallic conductors.

(See *Poggendorff's Annalen*, Vol. 156, pp. 49-55.)[26, 27]

Instead of the assumption of Mossotti on the interior constitution of solid bodies, mentioned in the previous Section, for the purpose of simplification of the consideration of *galvanic resistance of metallic conductors*, the assumption is made here of a *solid bonding* of the *negative electrical molecules* of the metallic conductor, separated from each other by intervening spaces, and represented by *fixed lines*, which do not hinder the movements of *positive electrical molecules* around all particular ponderable molecules and their transition into ballistic trajectories.

The really very *solid cohesion* of the ponderable molecules of *metallic conductors* is probably due to the reason, that each *positive electrical* molecule in its circular orbit, encompasses not only the one *negative electrical* molecule of the *one* ponderable neighboring molecule, but also the *other negative electrical* molecule of the *other* ponderable neighboring molecule. The same holds for the circular orbit of every *negative electrical* molecule and two positive electrical neighboring molecules.

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[26] [N. H. W.] Wilhelm Weber's *Werke*, Vol. IV., p. 348-353.

[27] [N. E.] W. Weber, “Ueber die Bewegung der Elektricität in Körpern von molekularer Konstitution, ” *Annalen der Physik und Chemie*, Vol. 156, pp. 1-61, reprinted in W. Weber's *Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 312-357.

Let us assume, that one such negative electrically charged *ponderable molecule* of a metallic conductor is at point *A*, Fig. 1, around which *imponderable positive electrical molecules* move, as described above. Were there *no electromotive force*, then, according to the hypothesis, the *positive electrical* molecules, having made the transition to ballistic trajectory, would move, seen from the position *A*, in all directions indifferently, indicated in the figure by six cardinal directions, i.e., by the radians *Aa*, *Ab*, *Ac*, *Ad*, to which are added in thought the two radians *Ae* and *Af* perpendicular to the plane of the figure upwards and downwards.[28] The velocity of these ballistic motions would be assumed to be identical in all of these directions, and *each such orbit* would extend into the area of the next ponderable molecule, whose mean length would be $= r'$ and taken to be along the *length of the conductor element*.

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[28] [N. H. W.] In the above figure, drawn by Weber himself, the directions *Ae* and *Af* are drawn laterally.

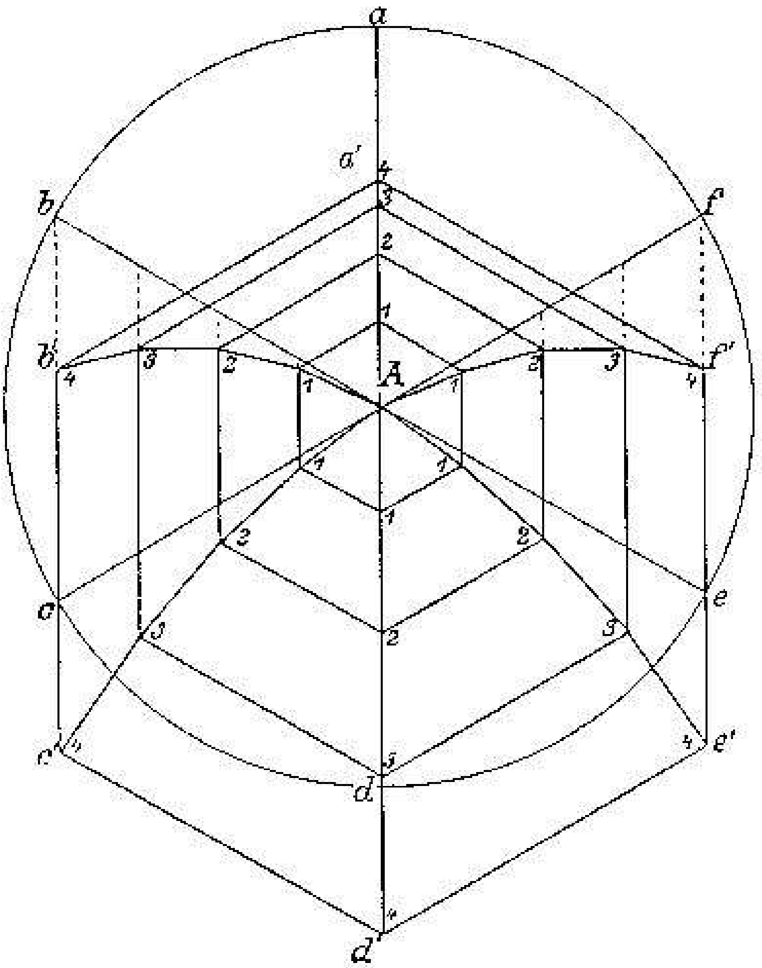

Fig. 1.

But if now an *electromotive force* acts upon all of these *positive electrical* molecules moving in different directions in ballistic motion, for example, Fig. 1 in the vertical direction from top to bottom, then all of these molecules will be deflected from their straight-line ballistic orbit, in a way similar to [the trajectory] of a thrown stone by the force of gravitation, and must [then] describe curved orbits, which are represented in the Figure beneath the straight-line ballistic orbits, i.e., Ab' beneath Ab, Ad' beneath Ad, where Ae' and Af' are to be conceived as beneath Af.

As far as the resulting movement of current is concerned, it is evident, that the initial *ballistic motions* contribute nothing to that *movement of* *current* without the additional movement of the *electromotive force*, because they occur symmetrically in all directions, so that one may, therefore, completely abstract from those ballistic motions in determining the latter [current movement]. For the current movements of the molecules thrown out, only the orbits $aa' = bb' = cc' = dd' = ee' = ff' = r'$ remain.

One can also conceive of all of the *ponderable molecules*, which are thrown out from *A*, contained in the same *conductor element* = *r'*, as united in the same way with the ejected *positive electrical molecules* for the purpose of determining the current, and likewise all of the *ponderable molecules* contained in the *following conductor element* = *r'* in *A'*, and so forth, where $AA' = A'A''... = r'$, denoted as the *mean distance of two ponderable* molecules, between which *immediately reciprocal radiation* occurs. *r'* is accordingly the mean path distance, which the positive electrical molecules ejected by the ponderable molecules must travel, until they reach into the area of the next ponderable molecule, around which they once again rotate.

If one denotes the amount of positive electricity with *E*, which is ejected or radiated by a ponderable molecule in a unit of time, and *n* is the number of such molecules contained in the *unit of length* of a *closed* conductor, then *r'* is the mean path length which each particle of the amount of electricity *E* travels from the site of the *radiating* molecule to the site of the *absorbing* molecule in the conductor *l*, consequently, *nr'E* is the limit-value of the *current intensity* for growing *electromotive force*, expressed according to *mechanical measure*, and the *strength of a galvanic current*, which is generated in one such closed conductor by a *weaker electromotive force*, will be equal to only a *fraction of nr'E.*

In order now to determine this fraction, let the *ballistic velocity* of the positive electrical molecules which issue from a *ponderable* molecule in *A*, Fig. 2, be denoted as α, *AB* would be the direction in which such a molecule moves, and ξ is the path traveled with this velocity in time *t*, $\xi = \alpha t$. If, however, a constant electromotive force $= e^0$ acts upon this molecule, according to mechanical measure in the direction parallel to *AC*, which describes the angle ψ with *AB*, then this molecule would, through this force alone, travel in time *t* a growing path η proportional with t^2 or ξ^2. Accordingly,

$$\eta = a\xi^2,$$

$$x = \xi \sin\psi,$$

$$y = \xi \cos\psi + \eta = x \operatorname{cotg}\psi + \frac{a}{\sin\psi^2} x^2,$$

$$r^2 = x^2 + y^2,$$

which yields

$$y = \operatorname{cotg}\psi \cdot \sqrt{r^2 - y^2} + \frac{a}{\sin\psi^2} \cdot \left(r^2 - y\right).$$

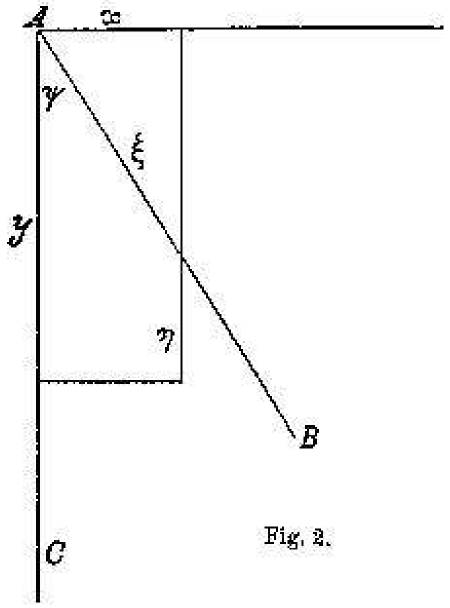

Fig. 2.

On this hypothesis, this ballistic motion reaches its end, when the molecule ejected from *A* travels the path r' and thus arrives in the area of the *next ponderable molecule of the metallic conductor*.

If one denotes with y' the value for $r = r'$, one obtains the equation:

$$y' = \cot g\psi \cdot \sqrt{r'^2 - y'^2} + \frac{a}{\sin\psi^2} \cdot \left(r'^2 - y'^2\right),$$

from which the result, that, for growing values of the *electromotive force* a, y' approaches a *limiting value*, i.e., the value r'.

Let E denote the amount of positive electricity radiated by the *ponderable molecule* in A in the unit of time, and n the number of *ponderable molecules* contained in the unit length of the conductor, where $nr'E$ is the amount of positive electricity, which would pass through, in the given *limit case*, the cross-section of the conductor in the unit-time, and would be the maximum of the current strength for electromotive force growing into infinity, according to *mechanical measure*. The *current intensity* would, accordingly, not always grow proportionally with the *electromotive* force, but it would approach the limiting value $nr'E$ as the electromotive force grew into infinity.

If, however, the *electromotive force* or the magnitude a proportional to it, is very small, in which case $r'\cos\psi$ is an approximate value of y', which can be applied in the *last member multiplied with a* of the above cited equation, i.e.,

$$y' = \cot g\psi\sqrt{r'^2 - y'^2} + \frac{a}{\sin\psi^2}\left(r'^2 - y'^2\right),$$

can be substituted for y', then one obtains the equation

$$y' = \cot g\psi\sqrt{r'^2 - y'^2} + ar'^2,$$

or

$$\left(y' - ar'^2\right)^2 \sin\psi^2 = \left(r'^2 - y'^2\right)\cos\psi^2.$$

If $y'^2\cos\psi^2 - a^2 r'^4 \sin\psi^2 = y'^2\cos\psi^2 - a^2 r'^4 \sin\psi^2$ is added, then one obtains

$$y'^2 - 2y'ar'^2 \sin\psi^2 = r'^2 \cos\psi^2 - a^2 r'^4 \sin\psi^2 ,$$

or

$$y' - ar'^2 \sin\psi^2 = \pm r' \cos\psi .$$

Accordingly, one obtains *in the mean* for each two molecules, which are ejected from A in the directions determined by the two angles ψ and $\pi - \psi$,

$$y' = ar'^2 \sin\psi^2 .$$

The mean value of the paths of all molecules ejected from *A*, in the direction of the electromotive force acting upon it, is accordingly

$$\frac{1}{2\pi} \int_0^{\pi/2} 2\pi\, y' \sin\psi\, d\psi = ar'^2 \int_0^{\pi/2} \sin\psi^3 d\psi = \frac{2}{3} ar'^2 .$$

Were this value = *r'*, then the *current intensity* would be equal to the previously considered *limit value*, i.e., = *nr'E*, according to mechanical measure; but the *real current intensity*, at small values of *a*, as assumed here, is only a small fraction, i.e., $\frac{2}{3} ar'$, according to which, therefore, the *real current intensity according to mechanical measure* is obtained, i.e.,

$$i^0 = \frac{2}{3} ar' \cdot nr' E \cdot \left[\sqrt{\frac{MR^3}{T^4}} \right],$$

if the posited *measure of the mass, length and time* are denoted with *M*, *R*, and *T*. In this equation, only *a* requires to be more precisely determined, and this is achieved in the following way. The *electromotive force, according to mechanical measure*, acting upon each *electrostatic unit* of the electricity issuing from *A*, is denoted as e^0. If the mass of the electrostatic unit is posited $= [1/\sigma] M$, then the accelerating force $= \sigma\, e^0$ and the path traveled in time *t* as a consequence of this acceleration from *A*

$$\eta = \frac{1}{2}\sigma e^0 t^2 = a\xi^2 = a \cdot \alpha^2 t^2 ;$$

consequently

$$a = \frac{1}{2}\frac{\sigma e^0}{\alpha^2} .$$

According to mechanical measure, the *current intensity* is accordingly[29]

$$i^0 = \frac{1}{3}\frac{\sigma e^0 r'}{\alpha^2} \cdot nr'E\left[\sqrt{\frac{MR^3}{T^4}}\right].$$

Following this determination of the *current intensity* i^0 *according to mechanical measure*, the *electromotive force according to mechanical measure* still remains to be determined, which acts upon the entire closed circuit, whose length is denoted with *l*, and every length of which contains *n* ponderable molecules, of which each is identical to the molecule *A*, which ejects *E* positive electrical units each second, and e^0, as indicated, denotes the *electromotive force according to mechanical measure* acting upon each *electrostatic* unit (whose mass $= [1/\sigma]M$).

nlE is, accordingly, the number of *electrostatic units* existing in the entire circuit, which are in ballistic motion. The *electromotive force* e^0 acts upon each unit of electricity, but not one second long, in which this particle, on account of its already extant ballistic-velocity, would travel the path α, but only during the fraction r'/α of a second, i.e., during the time in which the same would travel the path *r'* with the velocity α.

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[29] [N. A.] This value of i^0 is the same given in *Poggendorff's Annalen*, Vol. 156, p. 53 [N. H. W.: *Wilhelm Weber's Werke*, Vol. IV, p. 352][N. E: W. Weber, "Über die Bewegung der Elektricität in Körpern von molekularer Konstitution, " Annalen der Physik und Chemie, Vol. 156, pp. 1-61, reprinted in *W. Weber's Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 312-357.], but where the limit-value cited here as *nr'E* is denoted as $n\varepsilon\sigma$. The then following determination of the electromotive force $e^0 = \gamma/\sigma\left[\sqrt{MR^{-1}T^{-2}}\right]$, on the other hand, requires the here following correction, i.e., $e^0 = 2\alpha^2 a/\sigma\left[\sqrt{MR^{-1}T^{-2}}\right]$.

This yields the electromotive force for the entire circuit according to mechanical measure $= nlEe^0$, but which does not act *continuously* upon the totality of ejected particles of all *nl* ponderable molecules of the closed circuit simultaneously at any given moment, but only for r'/α seconds, which however, repeats itself at each following ejection, i.e., *E*-times each second, which is equivalent in its effect to the *electromotive force for the entire circuit according to mechanical mass* being

$$E^0 = nlE \cdot \frac{r'}{\alpha} e^0 .$$

The quotient of this *electromotive force*, divided by the *current intensity according to mechanical measure* $i^0 = \frac{1}{3}\left[\sigma e^0 r'/\alpha^2\right] \cdot nr'E$, then yields the *resistance of the circuit according to mechanical measure*:

$$w^0 = nlE \cdot \frac{r'}{\alpha} \cdot \frac{e^0}{\frac{1}{3}\frac{\sigma e^0 r'}{\alpha^2} \cdot nr'E},$$

$$w^0 = \frac{3\alpha l}{\sigma r'},$$

where r'/α denotes the time *tT* in the unit-measure of time *T*, which each ejected particle needs in order to travel its orbit *r'*. Moreover, *l* is the expression for the length, according to the length-metric *L*, of the entire closed circuit = *lL*. Finally, $3/\sigma$ is a pure number, i.e., σ the pure number relationship of the mass of the electrostatic unit to the mass of one milligram. According to established measures, one obtains therefore the *resistance of the circuit according to mechanical measure*

$$w^0 = \frac{3}{\sigma} \cdot \frac{\alpha l}{r'} \left[\frac{R}{T}\right],$$

i.e., the resistance of a circuit according to mechanical measure is *directly proportional length l of the circuit* and *inversely proportional* to the time r'/α in which an electrical molecule ejected by a ponderable molecule with a ballistic-velocity of α travels the mean length r' of the orbit until the next ponderable molecule, where the citation in *Poggendorff's Annalen*, Vol. 156, p. 54, is to be accordingly corrected.[30, 31]

8.

Some problems still to be solved according to the basic law of electrical effect in connection with the hypothesis of the composition of ponderable molecules out of positive and negative molecules.

All *persistent aggregate states* of electrical and positive molecules must be capable of derivation from the *fundamental law of electrical action*, on the hypothesis that ponderable molecules are connections of positive and negative electrical molecules, which then must yield the *mechanics of all bodies in such an aggregate state*.

Accordingly,

1. the *mechanics of expandable fluids* (gases),

2. the *mechanics of non-expandable fluids*, and

3. the *mechanics of solid elastic bodies* are to be explained.

In the explanation of the mechanics of bodies in the *first of the three cited aggregate states*, i.e., of the *gases*, the hypothesis would be that these consist of *ponderable nuclei*, which exist in larger spaces from one another, each accompanied by a positive electrical *satellite*. In *each gaseous form*, *all of the nuclei* would be hypothesized to be *identical*, but different from those of every other gaseous form; the *satellites*, on the other hand, would be the same for *all gaseous forms*, i.e., all of them identical positive electrical molecules. Two molecules of any gas with its satellites would, therefore, attract each other on account of the *force of gravitation of their nuclei*, but on

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[30] [N. H. W.] Wilhelm Weber's *Werke*, Vol. IV, p. 352.

[31] [N. E.]: W. Weber, “Über die Bewegung der Elektricität in Körpern von molekularer Konstitution, ” *Annalen der Physik und Chemie*, Vol. 156, pp. 1-61, reprinted in W. Weber's *Werke*, Vol. 4, edited by H. Weber (Springer, Berlin, 1894), pp. 312-357.

account of the *electrical repulsive force of their satellites*, they would repulse each other, and indeed, at *equal distances of the gas molecules*, there would be equal *repulsive forces of the satellites for all forms of gas*, *but different attractive forces of the nuclei for different forms of gas*. Furthermore, for each two gas molecules, there would be additionally a mutual force of attraction of the core of the one molecule and of the satellite of the other, which is the same for all molecule-pairs, but in relationship to the previously mentioned forces of repulsion, these are very small.

The thus occurring equality of the forces of repulsion of the gas molecules at equal distances for all gases, is of great importance for the mechanics of expandable fluids (gases) and deserves closer examination in the future.

For the explanation of the *mechanics of bodies in the second of the three cited aggregate states*, i.e., that of the *non-expandable fluids*, the hypothesis would be, that these consist of *ponderable molecules without satellites* which, on account of the reciprocal *force of gravitation* exerted upon each other, would rotate around each other.

Finally, for the explanation of the *mechanics* of bodies in the third of the three cited aggregates states, i.e., of solid elastic bodies, the difference between *electrical* conductors and *non-conductors* ought to be the first point to consider, a difference which must fundamentally be based on the interior constitution of these bodies, as is evident from the Sections 6 and 7, dealing with *metallic conductors*.

A well-founded explanation, of the connection of the fundamental electrical law with the law of gravitation of ponderable bodies requires, first of all, an explanation based on the fundamental electrical law of the *three aggregate states*, i.e., of the *solid, liquid* and *gaseous* states and their dependence upon heat, since the entire world of ponderable bodies is to be resolvable according to this connection into positive and negative molecules, according to which, therefore, not only the *law of gravitation* of ponderable bodies, but also all of their *aggregate states* must be derivable, where the chief issue would be the *explanation of heat* and its influence upon the *aggregate state*.

Differentiations are made between the *solid, liquid* and *gaseous* aggregate states of ponderable bodies, and among the *solid bodies*, between *metals and transparent solids*, where the *first* are characterized by conduction of galvanic currents, and the *latter* by propagation of light.

As for the bodies of the first, i.e., solid aggregate state, the consideration of the associated metals and their *electrical conduction capacities closely connected to their capacity for heat conduction*, has led to the hypothesis of *molecular* constitution, according to which positive electrical molecules rotate in these bodies around the individual ponderable molecules with continuously changing radii, each for so long, until it is transposed into a ballistic motion, and is thereby led out of the sphere of action of *one ponderable molecule into that of another*. The *heat conduction* of metals is based on the reciprocal *radiation* of ponderable molecules and the *galvanic conduction capacity* of metals. Since, however, the positive electrical molecules rotating around the ponderable molecules are not in a stable equilibrium, no wave-movement can occur in them, and therefore no propagation of light.

Moreover, as for the *solid aggregate states*, the consideration of *transparent solids* with their *propagation of light* and their *electrical insulating* [effect], leads to the *solid aggregate states* as explained by Mossotti, according to which molecules at certain distances from each other are in stable equilibrium, which equilibrium comes into being through the *repulsive forces* of these molecules themselves, also through *the repulsive forces* of molecules of a (positive electrical) fluid contained in the intervening spaces, and finally through the *forces of attraction* between the ponderable and the (positive electrical) molecules.

The normal equilibrium state of the electrical fluid filling the intervening spaces is likewise the light-ether, through which light is propagated, for which, on account of its molecular constitution, three axes of elasticity obtain. A further consequence of the normal stable equilibrium state is [an explanation of] why no conduction of heat and electricity occurs in transparent solids by means of reciprocal radiation, but as a consequence of the disruption of the equilibrium, there are wave movements, i.e., light propagation in the imponderable medium filling the intervening spaces of the ponderable molecules, viz., the *light-ether*.

9.

Continuation.

In addition to the *mechanics of bodies according to the difference of their aggregate states*, on the same hypothesis as in the foregoing Section, the dependency of *all chemical properties of bodies* upon their molecular constitution must be derivable from the *fundamental law of electrical action*, for example, *all chemical properties of hydrogen, oxygen* and of *water*.

It would be assumed, for example, that each molecule of *oxygen* is composed of 160 positive electrical [simple molecules], and just as many negative electrical *simple* molecules (whose distances from one another, the totality of positive as well as the totality of negative, are smaller than the critical distance ρ), where, in the gaseous aggregate state, one positive electrical molecule also exists as a *satellite*, that furthermore each molecule of *hydrogen* is composed of 10 simple positive electrical [molecules], and just as many simple negative molecules, where likewise, in the gaseous aggregate state, there is one additional positive electrical molecule as a *satellite*; and, finally, likewise, that a molecule of *nitrogen* consists of 140 positive electrical and just as many negative electrical molecules, where in the gaseous state there is one additional positive electrical molecule as a *satellite*.

At the same pressure (with which these differently composed molecules occupy the same space, so that the densities would behave as the numbers of the simple electrical molecule-pairs which they contain, apart from their *satellites*, i.e., 160:10:140 = 16:1:14), whereby the numbers of molecules of these gases is the same in the same volume, the equal pressure would result merely from the reciprocal effect of the *satellites*, whose distances from one another would be the same under the same pressure. To be precise, this pressure resulting from the reciprocal effect of the satellites, would have to be added to a correction resulting from the mutual gravitation of the ponderable gas molecules and from the reciprocal effect of each gas molecule with the satellite of the neighboring gas molecule, but this can be considered to be vanishingly small.

Upon combination of hydrogen and oxygen to form water, the positive electrical *satellites* of the ponderable oxygen and hydrogen molecules would escape; but these ponderable molecules would themselves be set into rotation around each other, whereby water would be formed; if, on the other hand, no escape of the positive electrical satellites occurred, the same combination would form *steam*.

The *vis viva*, which each molecule of ponderable oxygen and hydrogen possesses by virtue of their rotation around each other, is the *latent heat of the water*; if this is withdrawn from the water, these ponderable molecules no longer form *water*, but *ice*. The molecules which rotated around each other in water, arrange themselves in ice in a sequence as a consequence of the firm connection of the *positive electrical* molecule of the one ponderable molecule with the *negative electrical* molecule of a ponderable neighboring molecule, etc.

All ponderable bodies, through which light- and heat radiation go, consist of isolated *ponderable molecules*, whose intervening spaces are filled by an imponderable *light- or heat-ether*. There is no reason not to assume, that this *light-* or *heat- ether* is formed by positive electrical molecules, which also fill empty space (of the universe -- Weltenraum), even if the enclosed ether in those intervening spaces of ponderable molecules, undergoes a modification of its aggregate state as a result of the later.

All *vires vivae* are products of masses into the squares of their velocities, and resolve into those of which we can observe the masses as well as their velocities, from the observation of which we obtain immediately neither knowledge of the masses nor of the velocities whose products they are. The *vires vivae* of the latter kind are called *light* and *heat*, because all perceptions of light and heat are the effects of *vires vivae*, from which we obtain immediately neither knowledge of the masses nor of the velocities, whose products they are.

At distances from each other smaller than ρ, identical electrical molecules can have diverse movements, without surpassing the distance ρ, and these movements can also exert a multiplicity of effects on the outside, so that these identical electrically composed molecules acquire heat, which is sometimes transferred to them from the outside, sometimes transferred from them to the outside.

10.

On diverse movements in the ponderable-body molecules formed of positive and negative electrical molecules, and on the heat characteristics dependent upon them.

If there really exists in the world only electrical molecules, which, by their connections, form all ponderable molecules, and, unconnected, form the imponderable media – which is usually denoted by the name of electrical charges, or as light- and heat-ether – it is evident, that all laws of equilibrium and of movement, as well as all phenomena of light and heat, of those ponderable bodies as well also of these imponderable media, must be derivable from the fundamental law of electrical action, if the position and the motion of all electrical molecules, from which those ponderable bodies and these imponderable media are formed, were given at any time.

Even if no general solution to this problem can be hoped for or expected, the possibility would yet exist, given the infinite multiplicity of ponderable bodies, to guess the composition of *one or some* of these bodies, as well as their mutual position and motion at a certain time, and from the then resulting development to compare their laws of equilibrium and motion, as well as their light and heat phenomena, with observed phenomena of these bodies and then to test the laws. By means of particular fortunate experiments, a breakthrough would be made to be able to decisively test and firmly establish, or to refute, the hypothesis made here.

It would represent progress in that direction, for example, if it were possible to demonstrate the existence of a positive electrical imponderable medium in space from the indeed extant surplus of positive electricity in the world as a whole, and to derive the laws of the wave movement of such a medium from the fundamental law of electrical action, and to demonstrate the agreement of that law with the laws of propagation of light and the radiation of heat in space.

It would also represent progress in this direction, if it were possible to consider bodies in the *gaseous* aggregate state as consisting of ponderable molecules bound with positive electrical molecules as satellites, so that the ponderable molecules for diverse gases would be different, but their electrical satellites would be the same for all forms of gas, and if it were possible to derive all laws of equilibrium and of movement, including the propagation of light and heat in all gases, from the fundamental law of electrical action. Without some such decisive results, there is no reason to expect a firm foundation for the theory of the electrical composition of ponderable molecules. In particular, there seems to be no sufficient reason for the great differences of chemical relationships between different kinds of ponderable molecules.

The chief issue would be the difference of the ponderable molecules, on which the difference of the specific weight of gases under equal pressures, would depend. A differentiation would be made in each gas molecule, apart from the satellites which are the same for all, between a positive electrical and a negative electrical molecule, in which the former can be either simple or itself composed of many, and the latter *either separably or inseparably* constituted, which is probably the reason for a multiplicity of differences among gases.

The additional consideration would be, that the movements of electrical molecules around each other, which form the *ponderable nuclei* of gas molecules, would be dependent upon external influences according to the laws of induction, and thus variable, but after removal of these influences, would be re-constitutible, so that they, apart from such transient changes, form the persistent differences of the gases.

11.

Ice, water, steam.

In ice, water, and steam, on the hypothesis, that ponderable molecules are connections of positive and negative electrical molecules, the interesting case occurs, where merely through heat, i.e., merely the differences of the movement of the molecules, such fundamental differences as the aggregate states of ice, water, and steam are produced.

The first point to be considered, is that a force of mutual repulsion must be attributed to the ponderable molecules of steam, which does not obtain for the ponderable molecules of ice and water. This mutual force of repulsion, however, can hold for these ponderable molecules only as a consequence of similar (positive) electrical satellites accompanying them, which the ponderable molecules of water must have obtained upon being transformed into steam. It would also result from this, that steam would have to behave toward the water out of which it emerged, *electrically positive*, which seems actually to be confirmed by the electrical effects of the represented electrical machines [Elektrisirmaschinen] with steam boilers. It becomes therefore unnecessary for the explanation of the efficacy of these steam-electric machines [Dampf-Elektrisirmaschinen] to have recourse to a *friction of the steam* on the walls of the exhaust pipes.

The[32] ponderable molecules [ponderable nuclei] of gases and steam exert no repulsive force upon each other, from which it follows, that the cause of the expansive force of gases and steam cannot lie in their ponderable molecules. Every ponderable molecule, thus also every ponderable gas or steam molecule, attracts, however, a *positive electrical* molecule, which can thus only remain in the sphere of efficacy of a ponderable molecule if it rotates around it with a certain velocity, and thus forms a *satellite* of the ponderable molecule. The ponderable molecules of gases and steam, when they are accompanied by one such formed *satellite* of such molecules formed from imponderable positively electrically charged molecules, exert by means of their satellite, *repulsive forces* upon each other, which are far greater than the *attractive forces* exerted by the ponderable molecules upon each other. The expansive forces of all gases and steam come from these repulsive forces of such satellites. And, at equal pressure and temperature, the specific weights of the gas and steam are nearly proportional to the weights of their ponderable molecules, because the weight of the satellites in comparison to the weight of the ponderable molecules, is small.

When *water* is transformed *into ice* by withdrawal of heat, i.e., by slowing down the rotation of the positive and negative electrical molecules around one another, the reason for the *formation of a thread* must result, where, when the rotation is *slowed*, the effects of the positive electrical and negative electrical poles which every ponderable molecule possesses, is greater than with *rapid rotation*. As a consequence of this stronger effect of

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[32] [N. H. W.] The following paragraph, the "expansive forces of gases and steam," is at the end of the original essay, but inserted here because of its connection to the discussion.

the electrical poles under conditions of slowed rotation, two neighboring molecules will close upon one another in rows with their dissimilar poles, where they are connected like parts of a thread.

But where do such satellites in water come from, if the water evaporates upon being subjected to heat?

11a.

The melting point of ice and the boiling point of water.

Even if every ponderable molecule is composed of one positive and one negative electrical molecule, there may occur great differences both of the positive as well as the negative electrical molecules in different ponderable molecules, depending upon whether the electrical molecules are simple or a multiplicity, but if the latter, then, according to Section 5, they must be *inseparable*, i.e., they may consist of an arbitrary number of similar electrical molecules, of which, however, none of them are at a distance from one another $> \rho$. Accordingly, a ponderable molecule can be formed from an n-fold, but inseparable positive electrical molecule and an n-fold also inseparable negative molecule, which are held together by their reciprocal force of attraction by rotating around one another. Such molecules are called *ponderable elemental bodies*, or *chemical atoms*, whose *weight* is proportional to the number n.

These must include all previously discovered chemical atoms. If, for example, *hydrogen* were a body consisting of *ponderable elementary particles*, and indeed that one for which $n = 1$, it would easily be shown, that the *ponderable elemental body* for which $n = 12$, would have to be *carbon*, that for which $n = 14$, *nitrogen*, that for which $n = 16$, *oxygen*, etc., up to gold, for which $n = 197$, and *silver*, for which n would have to be 216. There would thus result a large number of ponderable elementary materials, which can not yet be dissolved into other ponderable elemental materials, but [exist] possibly in positive electrical and negative electrical molecules, and indeed in n simple *similar* and inseparable composite electrical molecules, where n denotes a whole number, which would indeed have no *weight*, but a *mass*, which might not always be considered negligibly small.

The question now posed, however, is, in what does the change actually consist, which occurs with *ice at the melting point*, and also in what does the change consist, which occurs with *water at the boiling point*.

The fundamental point is, that heat flows into the body without changing its temperature. The heat flowing in, increases the *vis viva* in the body; the ponderable particles, however, do not participate in this increase of the *vis viva*; that increase of the *vis viva* must, therefore, occur in the similar electrical particles existing between the ponderable particles and independent of them.

In *metallic conductors*, it is assumed, that the positive electrical particles are in a circular movement around the ponderable molecules, by which they are attracted, and that this circular motion would be accelerated by the influx of heat, and propagated ballistically from the environment of the one ponderable molecule to the other.

In *moist conductors*, especially in water, the same assumption is made, with the difference, that the *accelerated* circular motion of positive electrical particles around each ponderable molecule, under the influx of heat, does not transpose into a ballistic motion, and thus *in no way* propagates from the environment of one ponderable molecule to that of another, but rather persists with the first molecule, but by means of increased centrifugal forces, the firm bond of this and the neighboring *ice-molecule*, according to Mossotti, would loosen, whereby the transformation of ice into water is effected.

The ponderable water molecules, with their *satellites* formed from positive electrical molecules, repel each other like molecules of air, and as a consequence would spread out in a wider space, were not a certain *external pressure* exerted upon them. But if this *external pressure* remain constant, while the centrifugal forces of the satellites continuously grow due to the continued influx of heat, the *external pressure* is overcome, and the water, transformed into steam, expands itself like air.

11b.

Crystal formation of solid bodies.

All ponderable molecules with their satellites exert collisional-, directional- or rotational-forces upon each other, which are of particular importance for the formation of crystals.

The great multiplicity and differences of these crystals are probably due chiefly, however, to the differences of those ponderable molecules themselves, i.e., in the differences of the *number* of positive and negative electrical molecules from which they are formed. Ponderable molecules formed of one positive and negative electrical molecule, are quite different from those formed of 10 or from 100 positive and negative electrical molecules.

Let it be assumed that all the positive as well as all the negative electrical molecules which form a ponderable molecule, are contained in the space of a sphere of a diameter $<\rho$, so that the distance between any two is always smaller than ρ. The number of similar electrical molecules which can be contained in one such space, depends, accordingly, obviously on the relationship of their diameters to ρ. If this relationship is a very small fraction, the number of identical electrical molecules in one such space can be very large, from which the possibility is evident, that this number may be greater than 10 or 100.

In addition to this difference in the *number*, both of positive as well as negative electrical molecules, from which the ponderable molecules are formed, there is also the multiplicity of different orbits and velocities of all of these molecules in their orbits, which they may travel in the spherical space constrained to the diameter of ρ, which of course must have a great influence upon the reciprocal effects of the ponderable molecules to which they belong, and upon the crystal formation which depends upon them. For an electrical molecule rotating in a circle around a ponderable molecule, represents, in its effect upon similar molecules, a magnet, and this effect, even if it disappears at measurable distances, can be very large at molecular distances, quite in agreement with chemical forces, for which it can be substituted here, since constraint within molecular distances is characteristic for all chemical forces.

12.

The light-ether is a static medium formed from positive electrical molecules.

Positive electrical molecules may be at rest, when they are enclosed in a space of *fixed boundary* and are so distributed, that each molecule, thus surrounded by other molecules, lies at the center of many molecule-pairs, so that, therefore, both molecules of each pair exist symmetrically at equal distances at opposite sides.

Were such a molecule slightly shifted in any direction, for example, from North to South, and thereby [moved] closer to the molecules on the southside, and more distant from the molecules on the northside, it would be driven back from South to North, from which it is evident, that such a shift would be in *stable equilibrium*.

That same which holds for molecules in a space of *fixed boundary*, also holds for countless molecules filling an unbounded space in the same way, and each disruption of the equilibrium position of these molecules would, as one can easily see, be propagated by wave motion.

In space, however, only light and heat waves are propagated, if, therefore, only positive electrical molecules can be distributed in this manner in space, then it seems that these positive electrical molecules would have to form the *light-ether* in space.

The velocity with which light waves are propagated in such an electrical medium, depends, at any given molecular mass, upon the magnitude of the force which acts in a given displacement upon the displaced molecule. This force is greater, the greater the number of molecules in the unit of volume.

Each such wave, even if it issued from one single point, spreads out to a surface, and the direction of oscillation of the individual molecules in this surface can be either perpendicular to the surface (longitudinal waves) or coincide with the surface (transversal waves). Since the length of all light waves is very short, but must still extend over a large number of molecular layers, the result is that the number of molecules must be very large even in small volumes, from which a very small space-content of molecules must be concluded, if, that is, only *action at a distance* is supposed to occur between molecules of light-ether, among which the dimensions of the bodies acting upon one another are negligible with respect to their distances.

The known great velocity of the propagation of light waves proves furthermore, that the mean distance of molecules in the light-ether can only be slightly larger than ρ, where, that is, the smallest change of this distance is connected with a very large change of the forces of repulsion, because this repulsive force becomes infinitely large for the distance ρ.

With the resulting very large number of molecules even in a very small segment of space, the further result, out of the totality of the very small mass of all of these molecules, is that the mass of *each particular* positive electrical molecule *is very small to a much higher degree*.

NOTE [by the editor of Vol. 4 of Wilhelm Weber's Werke, Heinrich Weber]: In addition to the Sections presented here, the original manuscript of Wilhelm Weber also included four other Sections, with the following titles:

1. The theory of the repulsion and distribution of electrical beams is not applicable for the foundation of a theory of dynamic media.

2. The theory of the light-ether in space as a static medium.

3. On the wave-theory of so-called dynamic media.

4. Laws of repulsion and distribution of gas molecules in ballistic trajectories according to the dynamic theory of gases upon their collision, on the hypothesis, that gas molecules are compounds of positive and negative electrical molecules.

which were located between Sections 4 and 5. Wilhelm Weber, however, later edited these Sections out of the discussion, for which reason they are not published here. It may be noted, however, that the entire estate [posthumous works] has been given to the Königlichen Bibliotek zu Göttingen (Royal Library of Göttingen), so that access to these Sections is still possible.

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Translated by George Gregory (1998), edited by 21st Century Science & Technology Editor Laurence Hecht and Prof. A. K. T. Assis of the State University of Campinas, Brazil (homepage: http://www.ifi.unicamp.br/~assis/).

This is the last of Weber's eight major memoirs. The first and sixth have been translated into English, namely: W. Weber, "Determinations of Electrodynamic Measure: Concerning a Universal Law of Electrical Action," available at www.21stcenturysciencetech.com/Articles%202007/Weber_1846.pdf, *and W. Weber, "Electrodynamic measurements – Sixth memoir, relating specially to the principle of the conservation of energy,"* Philosophical Magazine*, Vol. 43, pp. 1-20 and 119-149 (1872).*