Translation: Measurements of Becquerel rays

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Measurements of Becquerel rays. The Experimental Confirmation of the Lorentz-Einstein Theory.

By A. H. Bucherer (Bonn)

To the extent by which the theory of electricity occupies other areas of the phenomenal world, and in this way is becoming the foundation of the whole of physics, the desire for a consistent theory of the actual electrodynamic phenomena increases. It appeared for a long time, as if the Faraday-Maxwell-concept of the aether as the mediator of the electromagnetic processes, would serve as a sufficient and definite foundational hypothesis.

Now, by further developing the aether concept in an epistemological way, one suddenly arrived at a dualistic view of aether and matter. The aether was interpreted as something that exists separately from matter, and thus one was faced with the questions, as to whether the aether is moving along with matter, or whether it is at rest. It was recognized soon, that the hypothesis of the stationary aether is the simpler one, and Lorentz made it to the foundation of his older theory of electrons. In this theory, the aether occurs as "quasi-matter". Thus the aether must be included in a dynamic system, in order to maintain the validity of the third axiom of Newton. A uniformly moving charge \( A \) per se exerts another force upon a resting \( B \), as \( B \) upon \( A \). The great inner improbability of this assumption caused difficulties for the older theory; even more the inner contradiction consisting in the fact, that a reference system shall be defined by the aether, although it represents an infinitely extended homogeneous medium.

However, the demonstration was most disastrous, that no influence of annual motion of Earth through the aether could be found in the optical phenomena, which was contrary to the requirement of the theory. Although this theory was occasionally further elaborated mathematically, it was definitely clear for the physicists, that further progression can only be made on the basis of the principle of relativity. The requirement was to be made, that at uniform motion of two bodies \( A \) and \( B \) relative to each other, their interaction shall be independent from whether \( A \) or \( B \) are to be assumed as being at rest or in motion.

The path to such a theory was paved by Lorentz in the year 1904. He showed, that by a suitable transformation of time and coordinates, the influence of uniform motion upon the optics of moving systems in Maxwell's equations, is vanishing, and that all observations known up to then, are in agreement with the additional consequences of this new theory. The deformation which the body's are undergoing by their motion, is characteristic for this theory. All dimensions, which coincide with the direction of motion, are contracted in the ratio \( \sqrt{1 - \beta^2} \), where \( \beta \) means the ratio of the body's velocity to the speed of light. Then it was shown by Einstein, that one arrives at the exact same experimental consequences, when "local time" as introduced by Lorentz, is defined as time \( \text{per se} \), and at the same time the space coordinates in Maxwell's equations are so transformed, that they are in agreement with this definition of time. The relativity principle is clearly emphasized in Einstein's version. While in Lorentz's version, the deformation and the kinetic energy are still definitely localized, this localization becomes relative according to Einstein. Einstein and Planck alluded to the important consequences following from the relativity principle. I recall, that the equations of motion assume the classical from of the Lagrangian equations after some transformations; and that one, starting from the principle of least action, arrives at important conclusions concerning the entropy and temperature of moving bodies. Also the extension of the concept of mechanical mass (which is dependent on velocity and energy content, and which also has relative character) is highly remarkable, namely the law of the constancy of mass is now logically connected with the law of the conservation of energy. The law of the conservation of the center of gravity becomes widened, by extending it to radiating systems as well. This is because electromagnetic radiation is connected with an emanation of mass. That this theory will also be fundamentally important for astronomy, and that it is destined to achieve a particular agreement with the astronomical observation by extension of Newton's law, shall also be mentioned.

The concept of the aether experiences a remarkable transformation. Because when a pure translatory motion of the system doesn't influence the phenomena arising in it, then properties must ascribed to the aether as the mediator of these processes, which are incompatible with the previous concept of the aether. The previous dualistic view of aether and matter must be replaced by a monistic one.

Thus, the relativity principle presents itself as a far-reaching and surprisingly unifying principle.
This principle peremptorily requires a direct experimental test. – It was clear from the outset, that only such phenomena can be used as confirmations of the validity of the competing theories, where the bodies are moving with high velocities. For that, measurements of Becquerel rays are suitable, and W. Kaufmann undertook the difficult task, to conduct experiments in this direction. Kaufmann’s method is known to all of us, and also that Kaufmann drew the conclusion with certainty, that the relativity theory shall be considered as disproved by his experiments.

A situation of unique difficulty was created by this result.

Some physicists now further developed the relativity principle, with the expectation that more precise measurements nevertheless would eventually bring a decision, while others (including me) interpreted Kaufmann’s result as decisive. Since all other observations alluded to the existence of some kind of relativity principle which was still unknown, I thus developed a new relativity principle, which, however, only had the character of a calculation rule. Kaufmann’s measurements were compatible with this principle, and (as I was thinking at that time) it was only about the investigation of the deviation of electrons flying obliquely towards the magnetic field. Here, differences with respect to Maxwell’s theory should occur.

A clarification of the state of facts could only be achieved by new experiments, conducted with essentially increased precision. For that purpose, I created a new experimental arrangement, which I already described in the Physikalische Zeitschrift.[1] The method chosen, allowed for testing my relativity principle, i.e. an investigation of the deflection of electrons flying obliquely towards the field direction, as well as testing the Lorentz-Einstein relativity principle and the initial theory of Maxwell, thus the same question which formed the subject of Kaufmann’s investigation. Becquerel rays shall fly through a condenser field, and the electric force acting upon the electrons shall be compensated by superposition of a uniform magnetic field, which is parallel to the plates of the condenser. After leaving the condenser, the magnetic field alone acts upon the rays. The deflected electrons fall upon a photomicrograph film, so that the deflection can be measured. Since the force stemming from the magnetic field is proportional to the velocity of the electrons, then the compensation can only exist for a quite definite velocity, and only electrons of this velocity can traverse the condenser field undeflected, and therefore they can leave.

The details of the experimental arrangement are as follows: The condenser consists of two circular plates lying horizontally, whose diameter is ca. 8 cm and whose mutual distance amounts to ca. ¼ mm. As radiation source, a granule of radium salt in the form of a sphere (namely fluoride instead of the previously used bromide) is brought between the plates in the center of the condenser. Since the specific concentration of radium in fluoride is more than double as in bromide, the time of exposition becomes quite essentially diminished by using fluoride, which is of great importance in these experiments. The condenser is located in a cylindric tin consisting of brass, namely at half the height from the ground, so that its surfaces are located exactly perpendicular to the cylinder axis, which passes through the center of the condenser. The cylindric tin (which is very exactly formed) has an inner diameter of ca. 16 cm and an inner height of 8 cm. This tin can be airtightly sealed by sanded glass covers, so that it can be evacuated. The air pump employed was a Gaede pump, which worked excellently. By suitable drilling, the cables (being isolated from an accumulator battery) were inserted into the brass tube. The photographic plate is pressed by two springs against the interior wall of the tin. The latter can be inserted into the interior of the solenoid, whose rectangular cross-section is adapted to the dimensions of the tin. The solenoid is 103 cm long and has two windings of 103 turns each. The field strength achievable with the solenoid, was ca. 140 Gauss.

The purpose of my arrangement can be easily recognized. Since the directions of the rays are namely forming all possible angles \( \alpha \) with the direction of the magnetic force, then the force (occurring according to Maxwell’s theory) can assume all possible values. If the electrodynamic force and the electric one \( eF \) is compensated, it is

\[
\frac{u}{v} = \beta = \frac{F}{vH \sin \alpha}.
\]
By means of this arrangement, rays of a certain velocity find quite automatically the angle, at which the compensation occurs at a given field strength, and which allows them to leave the condenser. Thus electrons of all velocities and corresponding masses will hit upon the film, and thus produce a curve which allows to determine the mass as a function of velocity. Consequently, a single exposition suffices to test the various theories of the electron. The equations of motion of the electrons assume the following form:

\[
\begin{align*}
\frac{d}{dt} (m\dot{x}) &= 0 \\
\frac{d}{dt} (m\dot{y}) &= eH\dot{z} \\
\frac{d}{dt} (m\dot{z}) &= -eH\dot{y}
\end{align*}
\]

Here, \( e, m \) mean the specific charge and mass of the electron. The direction of increasing \( x \) is the direction of the magnetic field \( \mathbf{B} \). While the \( X \)- and \( Y \)-axes coincide with the plane of the condenser plates, \( z \) is perpendicular to this plane. Within the condenser, the direction of motion forms the angle \( \alpha \) with \( \mathbf{B} \). Due to the spiral motion in the pure magnetic field, however, the direction deviates from the initial one, so that the impact point \( P \) upon the film, lies in the direction \( \theta \) which somewhat deviates from \( \alpha \). If one integrates the preceding equations and if one sets \( \varphi = \frac{e}{m} H t \), then it follows:

\[
\begin{align*}
\dot{x} &= u \cos \alpha \\
\dot{y} &= u \sin \alpha \cos \varphi \\
\dot{z} &= -u \sin \alpha \sin \varphi.
\end{align*}
\]

If one furthermore sets \( OD = DP = \alpha \), and

\[ u = \frac{F}{H \sin \alpha}, \]

then one obtains by repeated integration:

\[
\begin{align*}
x &= a \cos \alpha + \frac{m}{e} \frac{F}{H^2} \varphi \cot \alpha \\
y &= a \sin \alpha + \frac{m}{e} \frac{F}{H^2} \sin \varphi \\
z &= \frac{m}{e} \frac{F}{H^2} (1 - \cos \varphi).
\end{align*}
\]

If one denotes the values of \( x, y, z \) and \( \varphi \) (present at the impact point of the electron) by index \( \Theta \), and if one furthermore sets

\[ \frac{F}{2aH^2} = K, \]

then one finds:
\[ \begin{align*}
(1) \quad \frac{z_0}{2a} &= \cos \Theta = \frac{1}{2} \cos \alpha + K_\sigma \phi_0 \cot \alpha \\
(2) \quad \frac{x_0}{2a} &= \sin \Theta = \frac{1}{2} \sin \alpha + K_\sigma \phi_0 \sin \phi_0 \\
(3) \quad \frac{z_0}{2a} &= K_\sigma \phi_0 (1 - \cos \phi_0) \\
\end{align*} \]

By insertion of (3) into (1) and (2) it follows:

\[ \begin{align*}
(1a) \quad \sin \Theta &= \frac{1}{2} \sin \alpha + \frac{z_0 \sin \phi_0}{2a (1 - \cos \phi_0)} \\
(2a) \quad \cos \Theta &= \frac{1}{2} \cos \alpha + \frac{z_0 \phi_0 \cot \alpha}{2a (1 - \cos \phi_0)} \\
\end{align*} \]

\( \alpha \) is given from these equations, and from that the velocity of the ray hitting at \( P \).

Since \( \theta \) slightly differs from \( \alpha \), one proceeds just so, as if the electron (which is hitting at \( P \)) would have moved with the previously calculated velocity at a circular path in a vertical plane, which passes through the radium granule and \( P \).

Now, the force acting in the magnetic field is:

\[ (4) \quad \frac{m u^2}{r} = e Hu \sin \alpha. \]

However, as it is shown by a simple calculation, it is:

\[ (5) \quad \frac{1}{r} = \frac{a^2}{2z} \left( 1 + \frac{z^2}{\alpha^2} \right) \]

Now if one considers, that according to Lorentz:

\[ (6) \quad \frac{e}{m} = \frac{e}{m_0} (1 - \beta^2)^{-\frac{1}{2}}, \]

then the relations (4), (5) and (6) give

\[ (7) \quad \frac{e}{m_0} = \frac{2zv}{a^2 \left( 1 + \frac{z^2}{\alpha^2} \right) H \sin \alpha} \tan \arcsin \beta \]

While according to Maxwell under employment of Abraham's formula, and when we set \( \tanh \delta = \beta \):

\[ (8) \quad \frac{e}{m_0} = \frac{2zv}{a^2 \left( 1 + \frac{z^2}{\alpha^2} \right) H \sin \alpha} \left\{ \frac{3}{4} \frac{2\delta - \tan h 2\delta}{\tan h 2\delta} \right\} \]

Obviously only that theory is valid, for which \( \frac{e}{m_0} \) is a real constant for any value of \( \beta \) within the observational errors.

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**The experiments.**

I omit at this place the experiments, which I have undertaken to test my relativity principle. The report shall suffice, that I refuted this theory by my experiments.

Therefore, it is still only about the question: whether the Lorentz-Einstein theory or Maxwell's theory.

In the investigation of this question, I was led by the following viewpoints:
1. It was desirable, to investigate a velocity range (being as large as possible) of rays, because only in this way, the sought velocity function can be determined with certainty. Rays that are too fast had to be excluded, because the percentage errors become too great due to their slight deflectability.

2. Since the specific charge assumes (at very slight velocities) the same value for all relevant theories, also rays being as slow as possible had to be investigated in order to determine \( \frac{e}{m_0} \).

It was indeed achieved by me, that rays of \( \frac{1}{4}\) of the speed of light are deflected and radiographically fixed. This is also of special importance, because the investigation remains confined to a single area. It was avoided to resort to comparisons with cathode-rays values. In my point of view, the previous measurements of cathode rays were namely made (with exception of Bestelmeyer's) under hardly controllable circumstances, by using an energy equation for the calculation of the velocity, which hardly accounts for the complicated energy changes in the vicinity of the cathode. The processes taking place at the cathode, are too little investigated, to serve as a foundation of the calculations. That also the Zeeman effect (at the current state of research) can give no information about the specific charge of the electron, can be seen from the deviating values, which have been given from the investigation of the spectra of various metals at strong and weak fields.

3. A main requirement was the precision of the measurement of the apparatus constants. I believe that I have gone so far in this respect, as it was allowed by the current physical technology. The apparatuses were made with great skill and understanding by the renowned firm M. Wolz in Bonn. In the following, I give a short overview concerning the most important auxiliary measurements.

I. The electric field.

The electric field of the condenser was given from the measurement of the potential difference of an accumulator battery of 320 elements, and the thickness of the quartz plates which determined the distance of the condenser plates. After every measurement, the potential difference was measured by the compensation method. The thickness measurement is based on the following arrangement: The arm balance of a fine balance was used as a lever, whose rotation axis was the knife edge; the other end of the lever rested upon an optical plane plate. On the arm balance, a vertically located mirror was mounted, in which a fine platinum wire was mirrored. A fine cathometer of Wolz was adjusted to the image, and if one moved the quartz plate (which was to be measured) between lever and optical plate, then the mirror image was displaced. The catheterometer was again adjusted and read. A simple calculation then gave the thickness of the plate of 0,25075 mm.

II. The magnetic field.

The solenoid field was so measured, that its magnetic effect upon a magnetic needle suspended in the interior at a quartz string, was compensated by a coil (being exactly measurable and wound on marble) which was moved over the solenoid. \( \mathbf{H} = 23,24 \mathbf{\theta} \) was given as the average field strength, while \( \mathbf{H} = 23,19 \mathbf{\theta} \) in the center of the solenoid, where \( \mathbf{\theta} \) was measured in Ampere. The current was provided by the urban center, and was regulated by means of a Siemens precision-Ampere-meter and a constant resistance. The constancy was so good in general, that one could be assured, that the solenoid current and thus the magnetic field remained constant up to one-thousandth.

The results.

Every single of the obtained curves allowed to determine the specific charge of the electron as a function of velocity, and thus to decide the question concerning the sought natural law. For the purpose of this report, however, I preferred to calculate (from a series of curves) the maxima \( Z_m \) of deflection, which were read by means of a cathometer. Thus one obtains results, which were achieved under manifold experimental conditions. One avoids the already given and somewhat complicated calculations, whose discussion would lead too far at this place. In the following table, I have put together the results. Regarding the first series, it is still to be noticed, that the small deviation of the value of \( \frac{e}{m_0} \) is probably explained by the difficulty of current regulation, which is required at so small rays. A look upon the both last columns shows, that the decision turns out in favor of the Lorentz-Einstein theory.
<table>
<thead>
<tr>
<th>Number of experiment</th>
<th>$\beta_m$</th>
<th>$H$ in Gauss</th>
<th>$Z_m$ in mm</th>
<th>$\frac{e}{m_0} \times 10^{-7}$ according to Lorentz</th>
<th>$\frac{e}{m_0} \times 10^{-7}$ according to Maxwell</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 u. 11</td>
<td>0.3178</td>
<td>104.54</td>
<td>16.37</td>
<td>1,695</td>
<td>1,676</td>
</tr>
<tr>
<td>8</td>
<td>0.3792</td>
<td>115.76</td>
<td>14.45</td>
<td>1,706</td>
<td>1,678</td>
</tr>
<tr>
<td>7</td>
<td>0.4286</td>
<td>127.35</td>
<td>13.5</td>
<td>1,706</td>
<td>1,670</td>
</tr>
<tr>
<td>13</td>
<td>0.5160</td>
<td>127.54</td>
<td>10.18</td>
<td>1,704</td>
<td>1,648</td>
</tr>
<tr>
<td>3</td>
<td>0.6879</td>
<td>127.54</td>
<td>6.23</td>
<td>1,705</td>
<td>1,578</td>
</tr>
</tbody>
</table>

It remains, to come back to the possibility of the inclusion of a certain correction at the values of deflection. My calculations are related to deflections, which the rays (being compensated within the condenser) experience in the pure magnetic field. However, besides those normal rays, also anomalous ones occur, namely rays that didn't experience a complete compensation of the acting forces withing the condenser, and therefore traverse the condenser in a curved path. They are making the radiographic curve somewhat less clear, and are possibly displacing somewhat the center-of-gravity line of the curve. I have calculated these extreme rays, and convinced myself that they didn't noticeably influence the results.

Finally I still want to shortly remark about the obvious constancy of the values of $\frac{e}{m_0}$; it is an advantage of the method used by me, that (as the calculation shows) small errors in the determination of the electric field strength are only slightly influencing this constancy, provided, that these slight errors are made evenly at all experiments. Thus when the value of $\frac{e}{m_0} = 1,705 \times 10^7$ contains a possible error, then the essential result of my experiment is not altered by that. This result is the confirmation of the relativity principle.

**Supplement.**

As a calculation shows, which was conducted only afterwards and which is based on a successful experiment, the action of the protection ring around the condenser is not without influence as I believed and also expressed at the beginning. Theoretically, this marginal action is just so, as if the radius of the condenser would be increased by a small amount – here 0.31 mm. If one applies this correction, than $\frac{e}{m_0} \times 10^{-7}$ becomes 1,730; 1,730; 1,729; 1,730 according to Lorentz for the experiments No. 8, 7, 13, 3 respectively.

(Received September 23, 1908.)

**Discussion.**

**Bestelmeyer:** I would like to ask the reader to provide the following dimensions. How large was the distance between the plates (reader: ¼ mm). How large was the diameter of the interior condenser (reader: 40 mm). How was the length of the path between the plates (4 cm) and outside of the plates? (4 cm), and how large was the deflection of the rays? (16 mm down to 6.23 mm). There, I would like to allude to a difficulty at the measurements. Electrons are moving rectilinear between the condenser plates, for which the electric and magnetic force is equal. However, besides the rays which are passing through rectilinearly in the condenser, also such ones are traversing which have a substantially greater and a substantially smaller velocity. For the dimensions that you have given now, those are (in my estimation) ca. ± 10 perc. which are passing through with different velocity, and when one determines now from the deflection of the value of $e/m$, then it is not sure as to whether it belongs to the rays of average velocity, or to the ones having a velocity which is 10 perc. higher or lower. Thus one must know the initial radiation distribution. If they are altogether of the same amount, then one can assume that the deflection also corresponds to the mean velocity.

**Bucherer:** I have taken pains to investigate this error strictly mathematically. For that purpose, I have solved a transcendental equation from that I measured the velocities and the radius of curvature. It is given, that these rays don't matter. This is different with Bestelmeyer's method. There, the slit is wider. When you look at the image, then you will see that the extra rays play no role at all. The image can only stem from the central rays, which are normally passing through, that is, which have no curvature. I want to write down here some numbers, which take this point into account; namely, z (i.e. the deflection experienced by the extra rays) corresponds to the following velocities:
$\beta_m = 0.516; \ z_m = 10.18 \text{ mm}$

$\beta = 0.47; \ z = 0.971 \text{ cm}$

$\beta = 0.588; \ z = 0.954 \text{ cm}$

For rays that are passing through rectilinearly, i.e. the normal rays, $z_m = 10.18 \text{ mm}$, and eventually for faster rays, the deflection is $0.954 \text{ cm}$. You see, that the deflection of these rays lies in the vicinity of the normal rays, so that (at most) a small widening can occur by that. The distance of the condenser plates is $\frac{1}{2} \text{ mm}$, this at most gives a width of up to $\frac{1}{4} \text{ mm}$; actually, the curve is not wider. *This clearly proves, that the extra rays play no role.*

**WHEN:** I would like to ask the reader, if he maybe has evidence, why the experiment of KAUFMANN has led to results which are different from his ones.

**BUCHERER:** I don't want to start a criticism of KAUFMANN's experiments, without expressly confirming, that I highly esteem the pioneering work of KAUFMANN. When I now pass to a criticism of KAUFMANN's experiments, then I want to allude at first to the difficulty in the measurement of such a small curve.

The velocities, which come into account, are 0.8 to 0.56 of the speed of light. I haven't taken into account the lower values of the deflection, since the percentage errors are too high at this place. In the area, which come into question for KAUFMANN, the curve is already very small as well. I precisely looked at the curve and discovered an asymmetry of 5 perc. at one portion, which is as much as the difference of the theories in this range of velocity. I alerted KAUFMANN to this fact, so he has measured again and has actually found the deviation of 5 perc. Another point is as follows: I have measured the resistance of the condenser; KAUFMANN assumes it to be infinitely great.

When the resistance of the condenser doesn't vanish, then an error is inserted by that, which I estimate to 1 perc. in KAUFMANN's experiment. I myself have found the following relations (a drawing is following, in which condenser, resistances, and the battery are indicated schematically). When the switched resistance doesn't vanish against that of the condenser, then the potential difference of the battery is evidently not relevant. This error alone amounts to 0.06 perc. at my experiments. (Numbers are given again.) You see, already there you get noticeable resistances. At KAUFMANN's experiments, the resistances already amounted several megohm. Also the voltage measurements of KAUFMANN are invalid in my view. Another error is possibly that one: At such exact measurements as they come in question here, the plate may not be so compressed, that the pressure occurs in the middle, but the pressure may only exerted upon the quartz plates, otherwise the pales will be easily bend. When one studies interference phenomena, one sees that when it is pressed from the middle, surely a dozen rings are leaving. Then, the difficulty of the magnetic field has to be mentioned. KAUFMANN uses a permanent magnet of 145 Gauss; he had an armature, which was removed and then the magnetism possibly changes with time. Also at this place, a source of error possibly enters.

**BESTELMEYER:** I don't believe, that the question concerning the sources of error mentioned by me, can be decided here. Thus I only want to say, that I'm not convinced that the mentioned sources of error actually play no role here. Here, it is about very precise measurements. When one considers the smaller dimensions of the apparatus, then the curves approximately show the same sharpness, as in my experiments. For the faster rays, the velocity function according to LORENTZ's theory, is ca. 1,24, according to ABRAHAM it is 1,19. The larger velocities correspond the smaller values of deflection. The smaller velocities correspond to the larger deflections. Even at great velocities, the difference between the theory of LORENTZ and that of ABRAHAM only amounts to a few tenths of a millimeter at the measurement; I believe, that the measurements can possibly be imprecise by that amount. Though I don't want to definitely assert this here, without a more detailed examination of the numbers.

**BUCHERER:** I'm responding to this: Here, the values of $z$ are of such kind, that one can assume without further ado, that the extra rays have no effect. Take an optical analogue. Imagine, that the condenser plates are sooty, then the extra rays will only come to deflection in small number through the condenser (drawing). They cannot exert an influence, this is totally excluded. Here, this influence lies only at rays having velocities between the speed of light and 0.95. This bundle was overlooked by BESTELMEYER at all. I have conducted measurements also with respect to this. Therefore, I have taken (at the results represented by me here) only the maxima of the curves, to avoid exactly this point, and the influence is vanishing at those maximi.

**MINKOWSKI** (Göttingen): I want to express my delight, that the experimental results speak in favor of LORENTZ's theory when compared with the one of the rigid electron. That one day this will be the case, could not be doubted at all from the theoretical standpoint. The rigid electron is in my view a monster when put together with MAXWELL's equations, whose innermost harmony is the relativity principle. When one approaches MAXWELL's equations on the basis of the idea of the rigid electron, then it just appears to me, as if one goes into a concert and one has plugged ones ears with cotton. One has to admire in the highest the courage and the force of the school of the rigid electron, which jumps over the widest mathematical hurdles with a fabulous approach, in the hope to fall upon experimental ground at the other side. Yet the rigid electron is not a working hypothesis, it is a working hindrance.
BUCHERER: The situation is mostly represented in a wrong way. It is actually not about the decision between Maxwell's and Lorentz's theory; indeed, Maxwell's theory is already superseded for a long time by the experiments of Michelson and Morley, as well as Trouton and Noble.

MINKOWSKI: Not Maxwell's and Lorentz's theories are the actual oppositions, but the rigid and the non-rigid electron, i.e. the Zeppelin- and the Parseval-electron. Historically, I want to add that the transformation, which play the main role in the relativity principle, were first mathematically discussed by Voigt in the year 1887. Already then, Voigt drew some consequences with their aid, in respect to the principle of Doppler.

VOIGT: Minkowski is reminiscent of an old paper of mine. There, it is about the applications of Doppler's principle, which occur in special parts, though not on the basis of the electromagnetic theory, but on the basis of the elastic theory of light. However, already then some of the same consequences were given, which were later gained from the electromagnetic theory.

1. 8, 430, 1907.


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