

# 1

## Albert Einstein's 'First' Paper\*

In 1894 or 1895, the young Albert Einstein wrote an essay on 'The Investigation of the State of Aether in Magnetic Fields.' He sent the essay, most probably his 'first' scientific work, with a letter to his uncle Cäsar Koch. Both items are presented in this article with some comments on the origins of Einstein's ideas on Special Relativity.

Albert Einstein always maintained that the trend of thinking that ultimately led to his work '*Zur Elektrodynamik bewegter Körper*' ('On the Electrodynamics of Moving Bodies')<sup>1</sup> had already begun when he was an adolescent young man. In conversations and interviews at various times, several people sought to find out from Einstein himself about his intellectual and scientific development in order to fix the chronology of the conception, gestation and birth of the Special Theory of Relativity. We know very little about Einstein as a boy and young scholar other than what he has himself mentioned in scattered writings or told his biographers and interviewers.

Gerald Holton, in his article 'Influences on Einstein's Early Work in Relativity Theory,' reported on his search in documents, diaries, notebooks, correspondence, and unpublished manuscripts in the Einstein archives at Princeton and other source materials for any indications relating to Einstein's 1905 paper on relativity,

---

\*During the summer semester in June 1970, I gave a series of lectures at the International Solvay Institutes of the *Université libre de Bruxelles* on the historical development of the quantum and relativity theories. One of my auditors was a young man, Jean Ferrard, whom Professor Jean Pelseener introduced me to as the grandson of Madame Suzanne Koch-Gottschalk, the daughter of Cäsar Koch and thus Einstein's cousin. Monsieur Ferrard arranged my meeting with Madame Suzanne Koch-Gottschalk, during which she told me that she had a box of papers in which there might be some Einstein documents and if I would help her in sorting them out. I was very excited by this opportunity, and went through the papers in the box; contained in it were Einstein's essay, discussed here, and the covering letter to his uncle. I told Madame Suzanne Gottschalk about the importance of these documents, and asked her permission to publish them, which she readily granted. I wrote this article and made copies of the Einstein documents I had found in the Gottschalk family box and personally gave them to Miss Helen Dukas in Princeton in May 1970; she and Otto Nathan, executor of the Einstein Estate, gave me permission to publish my article. After completing this essay, I sent a preprint of it to Freeman Dyson (as I did of all my papers for his comments); he replied to me at once, and said among other things: 'This paper is like the discovery of Linear B by Michael Ventris, and shows how humble are the origins of modern science. It is an important find; publish it immediately! Freeman.' It was published in *Physikalische Blätter* **27**, 385 (1971) and as Report No. CPT-82; AEC-31, January 8, 1971, of the Center for Particle Theory, The University of Texas at Austin. I have included this essay in this volume because of its historical interest.

"Über die Untersuchung  
des Aetherzustandes im magnetischen Felde.

Die folgenden Zeilen sind der erste be-  
stimmte Ausdruck meines einfachsten Gedankens  
über das hereinweg. Ganz. Das Personen  
Ganze drehen ist ersichtlich im einen Aether  
zusammen, der sich wie ein Programm als  
sein eine Abhandlung enthält. Abil ist mir  
aber vollständig im Weltweit fester, im Sinne  
in der Tiefe einwirkend zu sein, als es das  
kleine Kugelmännchen gestattet, so sollte ich, mir diesen  
Kugelmännchen nicht als Unvollständigkeit und gut zu sein. Wäre  
der Kugelmännchen das unvollständige Leben im Kugelmännchen  
gestaltet unvollständig, und dann ist über diese Zeilen  
abzugeben.

The introduction to Einstein's essay on 'The Investigation of the State of Aether in Magnetic Fields,' which he wrote at the age of 15 or 16 and sent to his uncle Cäsar Koch with a covering letter.

concluding that 'there is no contemporaneous draft or manuscript from which one might learn something of the genesis of the paper.'<sup>2</sup> Holton surveyed various books and authors that probably might have influenced the young Einstein ever since he came to the Aargau Cantonal School in Aarau in 1895,<sup>3</sup> and looked for some remarks or evidence that might have started Einstein's thinking on relativity. In these and the two notebooks of lecture notes which Einstein kept at Zurich during the period 1897 to 1900, Holton drew a blank. After a thorough and intensive search Holton decided that August Föppl's successful book '*Einführung in die Maxwellsche Theorie der Elektrizität*' ('Introduction to Maxwell's Theory of Electricity'), first published in 1894,<sup>4</sup> had a decisive influence on Einstein, that Föppl was the 'almost forgotten teacher.' Föppl, as Holton noted, was called in 1894 to the Technische Hochschule at Munich, where the young Einstein was then living. The suggestion is enticing that Einstein became familiar with Föppl's book shortly after it was published, learned from it the fundamentals of the electromagnetic theory of Maxwell and Hertz, was influenced by it in his formative years, and was probably inspired

by it to work on the theory of relativity. The headings like 'The Electrodynamics of Moving Conductors,' 'Electromagnetic Force Induced by Movement,' and 'Relative and Absolute Motion in Space' which occur in Föppl's book are indeed suggestive of an influence on Einstein. We should, however, remember that these topics were frequent enough in the scientific literature of the 1890's and the early 1900's, as the electrodynamics of moving bodies was one of the central problems of physics. Notation is often indicative of influence, and Einstein used Hertz' notation in his 1905 paper on relativity, not the Heaviside notation used by Föppl, indicating that Hertz' direct influence on Einstein might have been greater than it is generally assumed.<sup>4a</sup>

I have recently found a 'paper' (an essay) which the young Albert Einstein wrote in 1894 or 1895.<sup>5</sup> He sent the essay entitled '*Über die Untersuchung des Aetherzustandes im magnetischen Felde*' ('Concerning the Investigation of the State of Aether in Magnetic Fields') with a covering letter to his maternal uncle, Cäsar Koch, who was living in Antwerp, Belgium, at that time.<sup>6\*</sup>

The letter to Cäsar Koch and the essay were assigned the date of '1894 or 1895' by Einstein himself in 1950.<sup>7</sup> It is quite evident from the letter that he wrote the essay (during the year he spent in Milan) before he went to Zurich for the entrance examination of the 'Polytechnic' [E.T.H., *Eidgenössische Technische Hochschule*, Zurich — the Swiss Federal Institute of Technology].<sup>8</sup> The essay therefore pre-dates all source materials to which references have been made in connection with the origins of the theory of relativity. Before presenting Einstein's letter and essay, let us review some of the autobiographical and interview comments which are on record; all of them dwell upon Einstein's recollection of the vague beginnings of the 'relativity problem' going back to his Aarau days.

Thus the psychologist Max Wertheimer recalled 'those wonderful days,' beginning in 1916, when he questioned Einstein for hours on end alone in his study, and heard from him the story of the 'dramatic developments which culminated in the theory of relativity.' Wertheimer probed Einstein for the 'concrete events in his thought,' and Einstein described to him the genesis of each equation in great and specific detail.<sup>9</sup>

By the time the conversations with Max Wertheimer took place, Einstein had already completed the main edifice of his theory of gravitation and the general theory of relativity,<sup>10</sup> and he could take a long look back and reminisce about a glorious intellectual adventure. As Wertheimer recalls, 'The problem started when Einstein was sixteen years old, a pupil in the Gymnasium (Aarau, Kantonschule). He was not an especially good student, unless he did productive work on his own account. This he did in physics and mathematics, and consequently he knew more about those subjects than his classmates. It was then that the great problem really started to trouble him. He was intensely concerned with it for seven years; from the

---

\*I presented photocopies of these documents to Miss Helen Dukas in May 1970 for the Einstein Archives in Princeton. I am grateful to Miss Dukas and the Executor of the Estate of Albert Einstein, Dr. Otto Nathan, for permission to publish these items.

moment however that he came to question the customary concept of time, it took him only five weeks to write his paper on relativity. . . .<sup>11</sup>

On 4 February 1950, in the first of several visits that he made to Einstein in Princeton during the period 1950–1954, R.S. Shankland asked Einstein how long he had worked on the Special Theory of Relativity before 1905. Einstein told him that he had started on the problem at the age of 16, already as a student when he could devote only part of his time to it, and worked on it for ten years. He made many fruitless attempts to develop a theory consistent with the experimental facts, but they had to be abandoned, ‘until it came to me that time was suspect!’<sup>12</sup>

Einstein, in his conversation with Shankland, commented at length on the nature of mental processes, and emphasized that our minds do not seem to move step by step to the solution of a problem; rather, they take a devious route. ‘It is only at the last that order seems at all possible in a problem,’ said Einstein.<sup>13</sup> Of a later interview on 24 October 1952, Shankland reports, ‘I asked Professor Einstein about the three famous 1905 papers [*Annalen der Physik*, 17, 132, 549, 891 (1905)] and how they all appeared to come at once. He told me that the work on special relativity “had been his life for over seven years and that this was the main thing.” However, he quickly added that the photoelectric effect paper was also the result of five years pondering and attempts to explain Planck’s quantum in more specific terms. He gave me the distinct impression that the work on Brownian motion was a much easier job. “A simple way to explain this came to me, and I sent it off.”<sup>14</sup>

So again it was relativity, the problem of the electrodynamics of moving bodies, that went farthest back in his memory. Not only did Einstein have curiosity about the workings of nature, he had also acquired some knowledge of the essentials of physics and mathematics quite early in school. His remarks indicate that, even as a boy of sixteen, he had recognized the intellectual challenge of some fundamental problems of physics.<sup>15</sup>

Excitement about natural phenomena had come to Einstein early. At the age of 4 or 5, he had received a compass from his father to play with. The sense of wonder, of a ‘secret power behind the movement of the needle,’ which he experienced as a child remained a deep and lasting memory with him.<sup>16</sup> The various business crises of his father, which affected the fortunes of the family, did not destroy the atmosphere of free thought, experience, and sense of mystery about nature in which Einstein grew up. In 1889, at the age of 10 Albert Einstein entered the *Luitpold Gymnasium* in Munich. His work at the *Gymnasium* was a mechanical routine; but still, at the age of 12, he experienced the excitement and beauty of geometry when he came across an old textbook on Euclidean plane geometry at the school.

Of his boyhood studies, Einstein recalled in his autobiographical notes: ‘At the age of 12–16 I familiarized myself with the elements of mathematics together with the principles of differential and integral calculus. In doing so I had the good fortune of hitting up books which were not too particular in their logical rigour, but which made up for this by permitting the main thoughts to stand out clearly and synoptically. This occupation was, on the whole, truly fascinating; climaxes were

reached whose impression could easily compete with that of elementary geometry — the basic idea of analytical geometry, the infinite series, the concepts of differential and integral. I also had the good fortune to know the essential results and methods of the entire field of the natural sciences in an excellent popular exposition, which limited itself almost throughout to qualitative aspects ([Aaron] Bernstein's *People's Books on Natural Science*, a work of 5 or 6 volumes), a work which I read with breathless attention. I had also already studied some theoretical physics when, at the age of 17, I entered the Polytechnic Institute of Zürich as a student of mathematics and physics.<sup>17</sup> Einstein also recalled that 'at the age of 13 I read with enthusiasm Ludwig Büchner's *Force and Matter*, a book which I later found to be rather childish in its ingenuous realism.'<sup>18</sup>

On account of business difficulties his father left Munich in 1894 for Milan, but Einstein stayed on in a pension to complete his studies at school. He found the mechanical routine of his academic life at the *Gymnasium* intolerable, and a few months later he joined his parents in Milan. He had left the unpleasant rigors and discipline of the German *gymnasium*, but had also left the school in Munich without a diploma. Einstein was fifteen years old.

Einstein spent a year with his parents in Milan, and during this time thought about pursuing higher education in theoretical physics. Having no diploma from the *Gymnasium*, he thought of gaining admission to the Swiss Federal Institute of Technology in Zurich by taking the entrance examination. Later on, he recalled:

'As a sixteen-year-old I came to Zurich from Italy in 1895, after I had spent one year without school and teachers in Milan with my parents. My aim was to gain admission to the Polytechnic, but it was not clear to me how I should attain this, I was a self-willed but modest young man, who had obtained his fragmentary knowledge of the relevant fundamentals [mainly] by self-study. Avid for deeper understanding, but not very gifted in being receptive, studies did not appear to me to be an easy task. I appeared for the entrance examination of the engineering department with a deep-seated feeling of insecurity. Even though the examiners were patient and understanding, the examination painfully revealed to me the gaps in my earlier training. I thought it was only right that I failed. It was a comfort, however, that the physicist H.F. Weber informed me that I could attend his lectures if I stayed in Zurich. The director, Professor Albin Herzog, however, recommended me to the Cantonal School in Aarau, from where after one year's study I was graduated. On account of its liberal spirit and genuine sincerity, and teachers who did not lean on external authority of any kind, this school has left on me an unforgettable impression. Compared to the six years of schooling in an authoritatively run German *gymnasium* I became intensely aware of how much education leading to independent activity and individual responsibility is to be preferred to the education which relies on drill, external authority, and ambition. Real democracy is not an empty illusion.

'During this year in Aarau came to me the question: If one follows a light beam with the speed of light, then one would obtain a time-independent wave field. However, such a thing does not exist! This was the first childish thought-experiment which had

*something to do with the Special Theory of Relativity.* Invention is not the result of logical thinking, even though the final result has to be formulated in a logical manner.<sup>19</sup> (My italics.)

Einstein tried to imagine what he would observe if he were to travel through space with the same velocity as a beam of light. According to the usual idea of relative motion, it would seem that the beam of light would then appear as a spatially oscillating static electromagnetic field. But such a concept was unknown to physics and at variance with Maxwell's theory. Einstein began to suspect that the laws of physics, including those concerning the propagation of light, must remain the same for all observers however fast they move relative to one another.<sup>20</sup>

When Wertheimer asked Einstein if already at that time he had some idea of the invariance of the velocity of light for all observers in uniform motion, Einstein replied, 'No, it was just a curiosity. That the velocity of light could differ depending on the movement of the observer was somehow characterized by doubt. Later developments increased that doubt.'<sup>21</sup>

Says Wertheimer: 'Light did not seem to answer when one put such questions. Also light, just as mechanical processes, seemed to know nothing of a state of absolute movement or of absolute rest. This was interesting, exciting.

'Light was to Einstein something very fundamental. At the time of his studies at the *Gymnasium* [Aarau], the aether was no longer being thought of as something mechanical, but as "the mere carrier of electrical phenomena." '

Einstein's essay on the state of the aether in magnetic fields, presented in the following, refers to his familiarity with the experiments, and deals rather vaguely with the connection between the aether and electromagnetic phenomena. In his essay, presented here, Einstein proposed a method for detecting elastic deformations of the aether by sending light rays into the vicinity of the current-carrying wire. In his essay, Einstein raised the following main questions: (i) How does a magnetic field, which is generated when a current is turned on, affect the surrounding aether? (ii) How does this magnetic field, in turn, affect the current itself? Einstein believed in the existence of an aether at that time, and regarded it as an elastic medium; he wondered in particular how 'the three components of elasticity act on the velocity of the aether wave' which is generated when the current is turned on. His main conclusion was that 'Above all, it ought to be [experimentally] shown that there exists a passive resistance to the electric current's ability for generating a magnetic field; [this resistance] is proportional to the length of the wire and independent of the cross section and the material of the conductor.' Thus the young Einstein independently discovered the qualitative properties of self-induction, and it seems clear that Einstein was not yet familiar with the earlier work on this phenomenon, though at that time he knew that light is an electromagnetic phenomenon but was not yet familiar with Maxwell's theory.<sup>21a</sup>

The problems he thought about at Aarau clearly occurred to him after writing this essay. It is quite possible that sometime during his stay in Munich, Milan, Aarau or Zurich (that is, during the period 1894–1900), or even perhaps in Berne

during 1900–1905, Föppl's book<sup>4</sup> (to which Holton<sup>2</sup> attaches great importance as a possible influence on Einstein's early work on relativity theory) fell into Einstein's hands. It is important to emphasize, however, that Einstein does mention 'the wonderful experiments of Hertz' in his essay, and he continued to mention Hertz among his 'unforgotten' teachers like Helmholtz, Maxwell, Boltzmann, and Lorentz.<sup>22</sup> Whatever the real influences might have been on the genesis of Einstein's 1905 paper,<sup>23</sup> the following bits of "Einsteiniana" are the earliest available record of Einstein's intellectual adventure from his own hand, and they have therefore some historical interest.

**Letter to Cäsar Koch\***

*1894 or 1895. A. Einstein. (Date recalled in 1950.)*

My dear Uncle:

I am really very happy that you are still interested in the little things I am doing and working on, even though we could not see each other for a long time and I am such a terribly lazy correspondent. I always hesitated to send you this [attached] note; because it deals with a very special topic, and besides it is still rather naive and imperfect, as is to be expected from a young fellow like myself. I shall not be offended at all if you don't read the stuff; but you must recognize it at least as a modest attempt to overcome the laziness in writing which I have inherited from both of my dear parents. . . .

As you probably already know, I am now expected to go to the Polytechnic in Zurich. However, it presents serious difficulties because I ought to be at least two years older for that. We shall write to you in the next letter what happens in this matter.

Warm greetings to dear aunt and your lovely children,

from your  
Albert

---

\*Einstein's maternal uncle; sometimes in letters and addresses the name has been spelled with the French accent as 'César.' (My translation of the letter.)



## Concerning the Investigation of the State of Aether in Magnetic Fields\*

The following lines are the first modest expression of some simple thoughts on this difficult subject. With much hesitation I am compressing them into an essay which looks more like a program than a paper. Since I completely lacked the materials to penetrate the subject more deeply than was permitted by reflection alone, I ask that this circumstance should not be ascribed to me as superficiality. I hope the indulgence of the interested reader will correspond to the humble feelings with which I offer him these lines.

When the electric current comes into being, it immediately sets the surrounding aether in some kind of instantaneous motion, the nature of which has still not been exactly determined. In spite of the continuation of the cause of this motion, namely the electric current, the motion ceases, but the aether remains in a potential state and produces a magnetic field. That the magnetic field is a potential state [of the aether] is shown by the [existence of a] permanent magnet, since the principle of conservation of energy excludes the possibility of a state of motion in this case. The motion of the aether, which is caused by an electric current, will continue until the acting [electro-] motive forces are compensated by the equivalent passive forces which arise from the deformation caused by the motion of the aether itself.

The marvellous experiments of Hertz have most ingeniously illuminated the dynamic nature of these phenomena — the propagation in space, as well as the qualitative identity of these motions with light and heat. I believe that for the understanding of electromagnetic phenomena it is important also to undertake a comprehensive experimental investigation of the potential states of the aether in magnetic fields of all kinds — or, in other words, to measure the elastic deformations and the acting deforming forces.

Every elastic change of the aether at any (free) point in a given direction should be determinable from the change which the velocity of an aether wave undergoes at this point in that direction. The velocity of a wave is proportional to the square root of the elastic forces which cause [its] propagation, and inversely proportional to the mass of the aether moved by these forces. However, since the changes of density caused by the elastic deformations are generally insignificant, they may probably be neglected in this case also. It could therefore be said with good approximation: The square root of the ratio of the change of velocity of propagation (wavelength) is equal to the ratio of the change of the elastic force.

I dare not decide as to which type of aether waves, whether light or electrodynamic, and which method of measuring the wavelength is most appropriate for studying the magnetic field; in principle, after all, this makes no difference.

If a change of wavelength in the magnetic field can be detected at all in any given direction, then the question can be experimentally decided whether only the component of the elastic state in the direction of the propagation of the wave influences

---

\*My translation of Einstein's essay.

the velocity of propagation, or the components perpendicular to it also do; since it is known *a priori* that in a uniform magnetic field, whether it is cylindrical or pyramidal in form, the elastic states at a point perpendicular to the direction of the lines of force are completely homogeneous, but different in the direction of the lines of force. Therefore if one lets waves propagate that are polarized perpendicularly to the direction of the lines of force, then the direction of the plane of oscillation would be important for the velocity of propagation — that is if the component of the elastic force perpendicular to the propagation of a wave at all influences the velocity of propagation. However, this probably might not be the case, although the phenomenon of double diffraction seems to indicate this.

Thus after the question has been answered as to how the three components of elasticity affect the velocity of an aether wave, one can proceed to the study of the magnetic field. In order to understand properly the state of the aether in it [the magnetic field], three cases ought to be distinguished:

1. The lines of force come together at the North pole in the shape of a pyramid.
2. The lines of force come together at the South pole in the shape of a pyramid.
3. The lines of force are parallel.

In these cases the velocity of propagation of a wave in the direction of the lines of force and perpendicular to them has to be examined. There is no doubt that the elastic deformations as well as the cause of their origin will be determined [by these experiments], provided sufficiently accurate instruments to measure the wavelength can be constructed.

The most interesting, but also the most difficult, task would be the direct experimental study of the magnetic field which arises around an electric current, because the investigation of the elastic state of the aether in this case would allow us to obtain a glimpse of the mysterious nature of the electric current. This analogy also permits us to draw definite conclusions concerning the state of the aether in the magnetic field which surrounds the electric current, provided of course the experiments mentioned above yield any result.

I believe that the quantitative researches on the absolute magnitudes of the density and the elastic force of the aether can only begin if qualitative results exist that are connected with established ideas. Let me add one more thing. If the wavelength does not turn out to be proportional to  $\sqrt{A+k}$  [*sic*], then the reason (for that) has to be looked for in the change of density of the moving aether caused by the elastic deformations; here  $A$  is the elastic aether force, *a priori* a constant which we have to determine empirically, and  $k$  the (variable) strength of the magnetic field which, of course, is proportional to the elastic forces in question that are produced.

Above all it must be demonstrated that there exists a passive resistance to the electric current for the production of the magnetic field, that is proportional to the length of the path of the current and independent of the cross section and the material of the conductor.

## Notes and References

1. A. Einstein, *Annalen der Physik*, Ser. 4, **17**, pp. 891–921, 1905.
2. Gerald Holton, 'Influences of Einstein's Early Work in Relativity Theory,' *The American Scholar*, **37**, No. 1, pp. 59–79, Winter, 1967–68.
3. Albert Einstein was a pupil in the third and fourth classes of the Aargau Cantonal School in Aarau from October 1895 to early fall of 1896. In October 1896 Einstein enrolled at the E.T.H., Zurich, to study for a *Fachlehrer* (specialist teacher) diploma in mathematical physics, and was graduated in August 1900. (See Carl Seelig, *Albert Einstein*, Staples Press, London, 1956.) In his article (*ibid.*, p. 63) Holton remarks: 'As Besso wrote (in his notes of August 1946 for Strickelberg's article on Einstein in Switzerland), Einstein came to the Aarau Kanton-School in 1896. . . .' There is a slight confusion of dates in this. Both Seelig and Einstein are correct about the dates.
4. August Föppl, *Einführung in die Maxwell'sche Theorie der Elektrizität*, Druck und Verlag von B.G. Teubner, 1894.
- 4a. Heinrich Hertz' *Untersuchungen über die Elektrischen Kraft* was published in 1892; the first English edition of his *Electric Waves* was published in 1894 (McMillan and Co. Ltd.). Hertz died in 1894. Paul Drude's book *Physik des Aethers* was also published in 1894 (Verlag von Ferdinand Enke, Stuttgart, 1894).

Einstein's essay, presented in this article, clearly indicates that his interest in electromagnetism was aroused by the 'marvellous' experiments of Heinrich Hertz. These experiments, since Faraday's early work, were the most important in the field of electromagnetism and were justly so celebrated at the time. Faraday had discovered the law of electromagnetic induction in 1834, and it was this law that guided Einstein in his work on Special Relativity. Einstein built his theory on experimental facts. He starts his 1905 paper by pointing out that the law of induction contains an asymmetry which is artificial, and does not correspond to facts. Empirical observation shows that the current induced depends only on the relative motion of the conducting wire and the magnet, while the usual theory explains the effect in quite different terms according to whether the wire is at rest and the magnet moving or vice versa. At the time of Einstein's writing the law of induction was about 70 years old, and 'everybody had known all along that the effect depended on relative motion, but nobody had taken offence at the theory not accounting for this circumstance.' (See Max Born, *Physics and Relativity*, in *Physics in My Generation*, Springer Verlag New York, 1969.)

5. I am grateful to Madame Suzanne Koch-Gottschalk and Jean Ferrard for allowing me to examine the letters and papers relating to Einstein in the possession of their family. Madame Gottschalk has very kindly allowed me to publish the translation of Einstein's essay and to report on my findings for scientific purposes.
6. Cäsar and Jakob Koch were the two brothers of Einstein's mother Pauline. Jakob lived in Zurich and his name occurs several times in the Einstein-Besso correspondence. Cäsar Koch seems to have been Einstein's favorite relative. In one of the letters to Cäsar, Einstein remarks: '... *Bist Du mir doch immer der Liebste in der Familie gewesen.*' After his marriage to Mathilde Lévy at Basle in 1888, Cäsar went to Buenos Aires; following a sojourn there and return to Basle, he settled in Antwerp, Belgium, around 1891, and moved to Brussels after the First World War. He was a merchant of commodities. Cäsar Koch was very fond of Albert Einstein and encouraged him in his boyhood studies. Einstein visited the Koch family when he attended the first Solvay conference in Brussels in 1911. In the 1920's when Einstein used to visit Ehrenfest in Leiden and gave lectures there, or en route to Paris from Berlin, he always visited his uncle Cäsar. These personal contacts were continued when Einstein attended the fifth and sixth Solvay conferences in Brussels, in 1927 and 1930 respectively, and during

the months he spent as a refugee from Germany at Le Coq sur Mer near Ostende before his final departure from Europe to the United States. Later on, affectionate correspondence between Einstein, his wife Elsa, his sister Maja, and the Koch family was maintained.

I am grateful to Madame Suzanne Gottschalk, daughter of Cäsar Koch, for conversations about Einstein and her family, and for showing me numerous letters and photographs.

7. I have not been able to discover the identity of the person who showed Einstein these documents in 1950. Neither the owners of the documents nor Miss Helen Dukas, Einstein's former secretary, have any recollection of who this person was, nor could they offer any reasonable guess about his identity.
8. The choice of the E.T.H. in Zurich for Einstein's higher studies was made by his father Hermann and uncle Jakob Einstein. The two brothers at one time had founded a small engineering factory for making dynamos, measuring instruments and arc lamps, and Einstein's initial plan was to study engineering in Zurich.
9. Max Wertheimer, *Productive Thinking*, edited by Michael Wertheimer, Enlarged Edition 1959, Harper & Row Publishers, New York and Evanston, p. 213.
10. In 1905 Einstein continued the theme of his relativity paper by discussing the dependence of the inertia of a body on its energy (*Annalen der Physik*, ser. 4, vol. 18, pp. 639–641). In 1907 Einstein wrote on the possibility of a new test of the principle of relativity (*Annalen der Physik*, ser. 4, vol. 23, pp. 197–198), the inertia of energy as a consequence of the relativity principle (*Annalen der Physik*, ser. 4, vol. 23, pp. 371–384), and 'Relativitätsprinzip und die aus demselben gezogenen Folgerungen' (*Jahrbuch der Radioaktivität*, vol. 4, pp. 411–462, and vol. 5, pp. 98–99). In the last paper he explicitly stated the equivalence of inertial and gravitational mass, and gave the famous equation for mass in terms of energy. Einstein returned to the ideas of this paper in 1911 when he wrote on the influence of gravity on light (*Annalen der Physik*, ser. 4, vol. 35, pp. 898–908). The theme of relativity and gravitation was taken up in 1912, with papers on the velocity of light in a gravitational field (*Annalen der Physik*, ser. 4, vol. 38, pp. 355–369), the theory of a static gravitational field (*Annalen der Physik*, ser. 4, vol. 38, pp. 443–458), and replies to remarks of M. Abraham in short notes (*Annalen der Physik*, ser. 4, vol. 8, pp. 1059–1064; vol. 39, p. 704). A major summing up of the ideas expressed in these papers and approaches to the general theory of relativity and gravitation were made with Marcel Grossmann in 'Entwurf einer Verallgemeinerten Relativitätstheorie und eine Theorie der Gravitation' (*Zeitschrift für Mathematik und Physik*, vol. 62, pp. 225–261). Einstein presented a lecture on the physical foundations of the new theory of gravitation in an address to the *Naturforschende Gesellschaft*, Zurich, 9 September 1913 (*Vierteljahrsschrift*, vol. 58, pp. 284–290), and continued the theme two weeks later in a lecture at the 85th *Versammlung Deutscher Naturforscher* in Vienna on 21 September 1913. In 1914, Einstein wrote on the formal foundations of general relativity theory (*Sitzungsberichte der Preussischen Akademie der Wissenschaften*, part 2, pp. 1030–1085, 1914), gave several lectures on the problem of gravitation and relativity, and published a paper with M. Grossmann on the general covariance properties of the field equations of the theory of gravitation (*Zeitschrift für Mathematik und Physik*, vol. 63, pp. 215–225). Einstein continued to write on general relativity during the year 1915, and published new ideas on the application of the theory of astronomy; he also explained the perihelion motion of mercury on the basis of the general theory. Then in 1916 his great paper on the complete general theory of relativity was published: 'Grundlage der allgemeinen Relativitäts-theorie' (*Annalen der Physik*, ser. 4, vol. 49, pp. 769–822). In an important sense this was the culmination

of the intellectual adventure on which Einstein had started since the time he wrote to his uncle Cäsar Koch in 1894 or 1895.

11. Max Wertheimer, *ibid.*, p. 214.
12. R.S. Shankland, 'Conversations with Albert Einstein,' *American Journal of Physics*, vol. 31, pp. 47–57, 1963, p. 48.
13. R.S. Shankland, *ibid.*, p. 48.
14. R.S. Shankland, *ibid.*, p. 56.
15. Apart from questions concerning light and the electrodynamics of moving bodies, Einstein went to Aarau 'with the [then much debated] questions concerning the palpability [*Greifbarkeit*] of ether and of atoms' in mind. (For the quotation from Besso in this remark, see Holton, *ibid.*, p. 63.)
16. Autobiographical notes by Albert Einstein in *Albert Einstein, Philosopher–Scientist*, edited by Paul Arthur Schilpp (originally in Library of Living Philosophers, 1949), Harper Torchbooks Science Library, New York, 1959, p. 9.
17. Autobiographical notes by Albert Einstein, *ibid.*, p. 15.
18. Carl Seelig, *Albert Einstein*, Staples Press, London, 1956, p. 12.
19. Albert Einstein, *Autobiographische Skizze*; perhaps one of the last writings of Einstein (written in March 1955), was published in Fall 1955 in '*Schweizerische Hochschulzeitung*,' *Festnummer 1855–1955*, on the occasion of the centennial jubilee of the E.T.H. in Zurich. In this autobiographical sketch, Einstein recalled some touching memories of his life in Switzerland. This sketch was included in *Helle Zeit — Dunkle Zeit, In Memoriam Albert Einstein*, edited by Carl Seelig, Europa Verlag, Zurich, 1956, pp. 9–17. See pp. 9–10 for the quotation.
20. *Einstein: The Man and His Achievement*, a series of broadcasts on the BBC Third Programme, edited by G.J. Whitrow, BBC, London, 1967.
21. Max Wertheimer, *ibid.*, p. 215.
- 21a. A. Pais, *Subtle is the Lord*, Oxford University Press, 1982, p. 131.
22. Louis Kollross, 'Albert Einstein en Suisse—Souvenirs,' in '*Funfzig Jahre Relativitätstheorie*' (Bern, 11–16 July 1955), *Helvetica Physica Acta, Supplementum IV*, 1956, see pp. 274–275; also published as '*Erinnerungen eines Kommilitonen*' in '*Helle Zeit — Dunkle Zeit*,' *ibid.*, see p. 22.
23. In an undated letter, probably sometime after 6 March 1905, Einstein wrote to his friend Conrad Habicht in Schiers; 'But why have you not yet sent me your thesis? Don't you know, you wretch, that I should be one of the few fellows who would read it with interest and pleasure? I can promise you in return four works, the first of which I shall soon be able to send you as I am getting some free copies. It deals with the radiation and energy characteristics of light and is very revolutionary, as you will see if you send me your work in advance. The second study is a determination of the true atomic dimensions from the diffusion and inner friction of diluted liquid solutions of neutral matter. The third proves that on the premise of the molecular theory of induction, particles of the size 1/1000 mm., when suspended in liquid, must execute a perceptible irregular movement which is generated by the movement of heat. Movements of small, lifeless, suspended particles have in fact been examined by physiologists and these movements have been called by them "the Brownian movement." *The fourth study is still a mere concept: the electrodynamics of moving bodies by the use of a modification of the theory of space and time. The purely cinematic part of this work will undoubtedly interest you.*' (My italics.)

The fourth study, to which Einstein refers, was his paper on the Special Theory of Relativity. It was completed in Berne in June 1905, and received by the editor of *Annalen der Physik* on 30 June 1905. It is indeed quite remarkable that even at this late

date (sometime after 6 March 1905), Einstein refers to his study as 'still a mere concept.' This concept, however, had now been growing within him for almost ten years. On March 11, 1952, Albert Einstein wrote to Carl Seelig: 'Between the conception of the idea of this special relativity theory and the completion of the corresponding publication, there elapsed five or six weeks. But [he added rather cryptically] it would be hardly correct to consider this as a birthdate, because earlier the arguments and building blocks were being prepared over a period of years, although without bringing about the fundamental decision.' (See Ref. 2, p. 60.) Michele Besso, Einstein's friend and colleague at the Patent Office in Berne, was party to the 'fundamental decision,' the final progress of Einstein's conception, and its publication. In concluding his paper, Einstein wrote, 'I wish to say that in working at the problem dealt with here, I have had the loyal assistance of my friend and colleague M. Besso, and I am indebted to him for several valuable suggestions.'

1894 oder 95. A. Einstein. (Datum 1950 nachgeholt.)

Mein lieber Onkel!

Es freut mich wirklich sehr, dass Du Dich für mein bischen Thun und Treiben noch interessierst, trotzdem wir uns so lange nicht sehen durften und ich so grässlich fauler Briefschreiber bin. Und doch zögerte ich immer, Dir dieses Schreiben hier zu schicken. Denn es behandelt ein ein [sic] sehr speziales Thema, und ist ausserdem, wie es sich für so einen jungen Kerl wie mich von selbst versteht, noch ziemlich naiv und unvollkommen. Wenn Du das Zeug gar nicht liest, nehme ich Dirs durchaus nicht übel; Du musst es aber doch zum mindesten als einen schüchternen Versuch anerkennen, die von meinen beiden lieben Eltern geerbte Schreibfaulheit zu bekämpfen - - -

Wie Du schon wissen wirst soll ich jetzt auf das Polytechnikum nach Zürich kommen. Die Sache stösst aber auf bedeutende Schwierigkeiten, da ich dazu eigentlich zwei Jahre mindestens älter sein sollte. Im nächsten Brief schreiben wir Dir, was aus der Sache wird.

Innige Grüsse der lieben Tante und Deinen herzigen Kinderchen

von Deinem  
Albert

## Über die Untersuchung des Aetherzustandes im magnetischen Felde

Nachfolgende Zeilen sind der erste bescheidene Ausdruck einiger einfacher Gedanken über dies schwierige Thema. Mit schwerem Herzen dränge ich dieselben in einen Aufsatz zusammen, der eher wie ein Programm als wie eine Abhandlung aussieht. Weil es mir aber vollständig an Material fehlte, um tiefer in die Sache eindringen zu können, als es das blosser Nachdenken gestattete, so bitte ich, mir diesen Umstand nicht als Oberflächlichkeit auszulegen. Möge die Nachsicht des geneigten Lesers den bescheidenen Gefühlen entsprechen, mit denen ich ihm diese Zeilen übergebe.

Der elektrische Strom setzt bei seinem Entstehen den umliegenden Äther in irgend eine, bisher ihrem Wesen nach noch nicht sicher bestimmte, momentane Bewegung. Trotz Fortdauer der Ursache dieser Bewegung, nämlich des elektrischen Stroms, hört die Bewegung auf, der Äther verbleibt in einem potentiellen Zustande und bildet ein magnetisches Feld. Dass das magnetische Feld ein potentieller Zustand sei, beweist der permanente Magnet, da das Gesetz von der Erhaltung der Energie hier die Möglichkeit eines Bewegungszustandes ausschliesst. Die Bewegung des Äthers, welche durch einen elektrischen Strom bewirkt wird, wird so lange dauern, bis die wirkenden motorischen Kräfte durch äquivalente passive Kräfte kompensiert werden, welche von der durch die Bewegung des Äthers selbst erzeugten Deformationen herrühren.

Die wunderbaren Versuche von Hertz haben die dynamische Natur dieser Erscheinungen, die Fortpflanzung im Raume, sowie die qualitative Identität dieser Bewegungen mit Licht und Wärme aufs genialste beleuchtet. Ich glaube nun, dass es für die Erkenntnis der elektromagnetischen Erscheinungen von Wichtigkeit wäre, auch die potentiellen Zustände des Äthers in magnetischen Feldern aller Art einer umfassenden experimentellen Betrachtung zu unterziehen, oder mit anderen Worten, die elastischen Deformationen und die wirkenden deformierenden Kräfte zu messen.

Jede elastische Veränderung des Äthers an irgend einem (freien) Punkte in einer Richtung muss sich konstatieren lassen aus der Veränderung, welche die Geschwindigkeit einer Ätherwelle an diesem Punkte in dieser Richtung erleidet. Die Geschwindigkeit einer Welle ist proportional der Quadratwurzel der elastischen Kräfte, welche zur Fortpflanzung dienen, und umgekehrt proportional der von diesen Kräften zu bewegenden Äthermassen. Da jedoch die durch die elastischen Deformationen hervorgerufenen Veränderungen der Dichte meist nur unbedeutend sind, so wird man sie auch in diesem Falle wahrscheinlich vernachlässigen dürfen. Man wird also mit grosser Annäherung sagen können: Die Quadratwurzel aus dem Verhältnis der Veränderung der Fortpflanzungsgeschwindigkeit (Wellenlänge) ist gleich dem Verhältnis der Veränderung der elastischen Kraft.

Was für eine Art von Ätherwellen, ob Licht oder elektrodynamische, und was für eine Methode der Messung der Wellenlänge für die Untersuchung des magnetischen Feldes am geeignetsten sei, wage ich nicht zu entscheiden; im Prinzip ist es ja schliesslich gleich.



Zunächst kann, wenn überhaupt eine Veränderung der Wellenlänge im magnetischen Feld in irgendeiner Richtung sich konstatieren lässt, experimentell die Frage gelöst werden, ob nur die Komponente des elastischen Zustandes in der Richtung der Fortpflanzung der Welle oder auch die dazu senkrechten Komponenten eine Wirkung auf die Fortpflanzungsgeschwindigkeit ausüben, da a priori klar ist, dass in einem regelmässigen magnetischen Feld, sei es zylinder- oder pyramidenförmig, die elastischen Zustände an einem Punkt senkrecht zur Richtung der Kraftlinien vollständig homogen sind und anders in der Richtung der Kraftlinien. Lässt man daher senkrecht zur Richtung der Kraftlinien polarisierte Wellen durchdringen, so wäre für die Fortpflanzungsgeschwindigkeit die Richtung der Schwingungsebene von Bedeutung — wenn die zur Fortpflanzung einer Welle senkrechte Komponente der elastischen Kraft wirklich auf die Geschwindigkeit der Fortpflanzung einen Einfluss ausübt. Dies dürfte jedoch wahrscheinlich nicht der Fall sein, trotzdem das Phänomen der Doppelbrechung darauf hinzuweisen scheint.

Nachdem so die Frage entschieden wäre, wie die drei Komponenten der Elastizität auf die Geschwindigkeit einer Ätherwelle einwirken, kann zur Untersuchung des magnetischen Feldes geschritten werden. Um den Zustand des Äthers in demselben recht begreifen zu können dürften drei Fälle unterschieden werden:

1. Kraftlinien, die sich pyramidenartig am Nordpol vereinigen.
2. Kraftlinien, die sich pyramidenartig am Südpol vereinigen.
3. Parallele Kraftlinien.

In diesen Fällen ist die Fortpflanzungsgeschwindigkeit einer Welle in der Richtung der Kraftlinien und senkrecht dazu zu untersuchen. Unzweifelhaft müssen sich so die elastischen Deformationen samt ihrer Entstehungsursache ergeben, wenn es nur gelingt, genügend genaue Instrumente zur Messung der Wellenlänge zu bauen.

Der interessanteste, aber auch subtilste Fall wäre die direkte experimentelle Untersuchung des magnetischen Feldes, welches um einen elektrischen Strom herum entsteht, denn die Erforschung des elastischen Zustandes des Äthers in diesem Falle erlaubten [sic] uns, einen Blick zu werfen in das geheimnisvolle Wesen des elektrischen Stromes. Die Analogie erlaubt uns aber auch sichere Schlüsse über den Ätherzustand im magnetischen Felde, das den elektrischen Strom umgibt, wenn nur die vorher angeführten Untersuchungen zu einem Ziele führen.

Die quantitativen Forschungen über die absoluten Grössen der Dichte und elastischen Kraft des Äthers können, wie ich glaube, erst beginnen, wenn qualitative Resultate existieren, die mit sicheren Vorstellungen verbunden sind; nur eins glaube ich noch sagen zu müssen. Sollte sich die Wellenlänge nicht proportional erweisen  $\sqrt{A + k}$ , wobei  $A$  die elastischen Ätherkräfte a priori, also für uns eine empirisch zu findende Konstante,  $k$  die (variable) Stärke des magnetischen Feldes bedeutet, die natürlich den erzeugten in Betracht kommenden elastischen Kräften proportional ist, so wäre der Grund hierfür in der durch die elastische Deformationen erzeugten Veränderung der Dichte des bewegten Äthers zu suchen.

Vor allem aber muss sich zeigen lassen, dass es für den elektrischen Strom zur Bildung des magnetischen Feldes einen passiven Widerstand gibt, der proportional ist der Länge der Strombahn und unabhängig vom Querschnitt und Material des Leiters.