Einstein's Pathway to the Special Theory of Relativity

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By

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This book is dedicated in memory of the late Professor Mara Beller,
my PhD supervisor


GaLinaWeinstein

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INTRODUCTION

The history of the special theory of relativity abounds in many biographies and historical studies. The topic of Einstein's pathway to the special theory of relativity, however, is still as much a question for debate as it was thirty or forty years ago. It is a question of fundamental significance in the history of modern physics and its discussion raises fundamental issues in the understanding of Einstein's creativity.

This book is divided into four chapters. An appendix complements the main text of the book, and presents the history behind the sources mentioned in the text. The appendix allows the main text of the book to place greater emphasis on the historical profound relationships and principles, and on Einstein's path to the relativity theory.

The first chapter (A) presents a critical biography of Einstein from childhood until 1908 – the year that Einstein left the Patent Office.

The biography is based on primary sources. Einstein was apparently not attracted to biographies. He preferred a representation of events or relations in which the personal remains in the background. I have sought to write a biography according to these guidelines, but I do discuss a few family stories in order to clarify certain historically important topics.

I start with Einstein's childhood and schooldays: Albert Einstein and the family members seem to have exaggerated the story of Albert who developed slowly, learned to talk late and whose parents thought he was abnormal. These and other stories were adopted by biographers as if they had really happened in the way that Albert and his sister told them. Hence, biographers were inspired by such stories to create a mythical public image of Albert Einstein.

As a child, Albert had had a tendency toward temper tantrums. A young and impudent rebel with an impulsive and upright nature, he rebelled against authority and refused to learn by rote. He could not easily bring himself to study what did not interest him at school, especially humanistic subjects. Consequently his sister told the story that his Greek professor, to whom he once submitted an especially poor paper, went so far in his anger as to have declared that nothing would ever become of him.

Albert would study subjects in advance when it came to the sciences and during the long summer vacation he independently worked his way through the entire Gymnasium syllabus. He also taught himself natural science, geometry and philosophy by reading books obtained from a poor Jewish medical student of Polish nationality, Max Talmud, and from his uncle, Jakob Einstein.

I then describe Einstein's student days at the Zurich Polytechnic: he skipped classes, did not attend all the required lectures, and before sitting for an examination he studied instead from the notebooks of his good friend in class, Marcel Grossmann.

Einstein the free-thinker had little respect for the two major professors at the Polytechnic – Heinrich Friedrich Weber and Jean Pernet – who eventually turned on him. His beloved science lost some of its appeal to him because Weber's lectures did not include James Clerk Maxwell's electromagnetic theory. He also seldom showed up to Pernet's practical physics course. Through his forthrightness and distrust of authority he alienated his professors, especially Weber, who apparently conceived a particular dislike of him. At the Zurich Polytechnic Einstein could not easily bring himself to study what did not interest him. Most of his time he spent on his own, studying Maxwell's theory and learning at first hand from the works of the great pioneers in science and philosophy: Ludwig Boltzmann, Hermann von Helmholtz, Gustav Kirchhoff, Heinrich Hertz and Ernst Mach.

Einstein eventually finished first in his class in the intermediate exams, followed by his note-taker, Grossmann. It might be better, however, not to copy Einstein's recipe for studying in college: after obtaining his diploma, when he sought a university position, he was constantly turned down.

Rescue finally came from Grossmann, and thanks to him and Grossmann's father Einstein obtained a post in the Patent Office. There are strong reasons to believe that it was Einstein's rare mastery of Maxwell's electromagnetic theory that ultimately prompted the Director of the Patent Office to offer him a job. And it was there, in the Patent Office that Einstein hatched his most wonderful ideas and there that he spent his *Happy Bern Years*. Those wonderful ideas led to his *miraculous year* works of 1905.

Einstein had no expertise in academic matters and he was outside the academic world; nor did he meet influential professors or attend academic meetings. Rather, he discussed his ideas with his close friends and colleagues from the Patent Office.

In 1907, however, he finally got his foot in the academic doorway: Einstein became a *privatdozent* and gave lectures at the University of Bern.[1] His first students consisted of his two close friends and another colleague from the Patent Office.

I end my biographical survey with the mathematician, Hermann Minkowski, Einstein's former mathematics professor at the Zurich Polytechnic. During his studies at the Polytechnic Einstein had skipped Minkowski's classes.

In 1904 Max Born arrived for the first time in Göttingen. Many years later Born wrote his recollections of the period. In the summer of 1905 Minkowski and David Hilbert gave an advanced seminar on mathematical physics, relating to electrodynamical theory. Minkowski told Born later that it had come to him as a great shock when Einstein published his paper demonstrating the equivalence of the different local times of observers moving relative to each other. Minkowski had reached the same conclusions independently but had not published them because he wished first to work out the mathematical structure in all its splendor. He never made a priority claim and always gave Einstein his full share in the great discovery. Indeed, in his famous talk "Space and Time", Minkowski wrote that the credit for first recognizing clearly that the time of one electron is just as good as that of another, i.e., that t and t' are to be treated the same, should be given to Einstein.

The second chapter (B) provides a detailed account of *fin de siècle* physics.

The science of optics underwent drastic changes from the seventeenth to the nineteenth century. Until the beginning of the nineteenth century two rival theories of light were dominant among scientists: the corpuscular or emission theory of light, according to which light is composed of tiny corpuscles; and the wave theory of light, according to which light is just wave-like disturbances in a medium. Isaac Newton's name was linked with the idea underlying the first theory, although Newton himself did not express a strict adherence to any of the alternatives; while Christian Huygens tended to be associated with the idea underlying the second theory. There were several optical phenomena still requiring explanation, and the adherents of each of the two rival outlooks sought to provide such explanations and, in so doing, to bolster their own position.

A major turning point in this ambiguous state of affairs was made at the beginning of the nineteenth century by Thomas Young, Dominique François Arago, Augustin-Jean Fresnel and by the discovery of interference and polarization phenomena. Fresnel and Young proposed independently that one should assume that space was filled with an all-pervading subtle substance called *The Luminiferous Ether*. The consideration of such ether helped scientists to contradict the possibility of action-at-a-distance interaction between electrified bodies. Neither the idea of an ether nor the desire to contradict action-at-a-distance interactions were new. For example, Newton had thought of it in connection with gravitation in his attempt to find a way to avoid action-at-a-distance, and through this to derive a physical explanation for the law of gravitational attraction. Fresnel's ether was supposed to be physically elastic in order to explain the rapid transverse motion of light waves. Many problems arose from these attempts to ascribe mechanical properties to the ether, so that the waves propagating in it would possess all the properties of light.

During the nineteenth century analysis of an important astronomical phenomenon led to another type of difficulty that preoccupied scientists in the field of the optics of moving bodies: the phenomenon of stellar aberration. The phenomenon of aberration of starlight was discovered by James Bradley in 1728, as a result of his efforts to detect in certain stars an annual parallax – the change in the observed location of stars as a result of the change in the annual position of the Earth, stars that had passed near the zenith directly above the plane of the Earth’s orbit were the most amenable to accurate measurement of this effect.

Explaining stellar aberration was a major problem in nineteenth century physics. As interest in the wave theory of light gradually grew, the phenomenon of aberration demanded an explanation within the framework of wave theory. By 1818, in a letter to Arago, Fresnel explained that in the wave theory of light the velocity at which the waves propagate is independent of the motion of the body from which they emanate, an explanation that ran counter to the Newtonian theorem of the addition of velocities. In addition, it assumed that velocity was constant with reference to the ether. Fresnel postulated that in order to explain aberration within the framework of the new emerging wave theory of light, one was obliged to assume an ether wind or drift, penetrating freely through the pores of the Earth, as suggested originally by Thomas Young. Fresnel expanded Young's proposal to what has come to be known as the *immobile ether hypothesis*.

In addition to offering an explanation for the aberration, Fresnel's ether theory could shed light on the absolute motion of the Earth in the ether. If there was immobile ether it further raised the problem of why no optical experiment made on Earth had demonstrated, or could be expected to demonstrate, the motion of the Earth through the ether – whatever the optical phenomenon used to detect this motion. Newtonian classical mechanics was incapable of explaining this in a satisfactory manner. If the ether is immobile with respect to the sun, then the Earth should move with the same velocity of 30 kms/sec with respect to the ether as it moves with respect to the sun. Therefore, the velocity of the Earth relative to the immobile ether must be at least 30 kms/sec. According to Young and Fresnel's supposition, relating to an ether wind passing freely through the Earth, there must thus be a stream of the ether, an ether wind, flowing through our laboratories and attaining velocities of at least as great as 30 kms/sec. Accordingly, one should be able to measure the actual velocity of this supposed stream of ether relative to the laboratory; and from that measurement, infer the velocity of the Earth through the ether.

This possibility precipitated the ether drift experiments conducted for the express purpose of measuring the velocity of the Earth relative to the ether. First order terrestrial ether drift experiments investigated effects of the Earth’s motion proportional to v/c (the aberration constant), where v is the speed of the Earth through the ether and c the speed of light. They proved incapable of revealing the Earth’s motion with respect to the immobile ether and thus all the experiments that were aimed at ascertaining this gave negative results.

Fresnel tried to supply an explanation through two such experiments: Arago's experiment and that proposed by Roger Joseph Boscovich (carried out much later by Sir George Biddell Airy), whose outcome was that the motion of the planet Earth could not affect the laws of refraction. By viewing the stars with a telescope filled with water, it was hoped to disclose the Earth's motion with respect to the immobile ether. But the experiment provided negative results. Fresnel explained this result by suggesting that most of the ether is immobile, while the ether in transparent bodies, like water and glass, is slightly dragged along. Guided by this partial ether drag hypothesis he derived a formula for the speed of light in a moving medium known as *Fresnel's formula*, which included a dragging coefficient.

Despite the success of Fresnel's formula, however, his interpretation in terms of partial ether drag remained problematic, and many authors embracing the former explicitly distanced themselves from the latter. There was, of course, a simple, alternative explanation for these experimental results, in which there would seem to be no need for the peculiar partial dragging effect in transparent matter. If all ether inside matter were fully dragged along by it, the ether at the surface of the Earth would be at rest with respect to the Earth, which would explain automatically why no ether drift was ever detected. The concept of dragged along ether was much more natural than that of immobile ether. In 1845 George Gabriel Stokes developed a model in which the Earth drags along the ether. Stellar aberration continued to provide the strongest argument against such a model, and much of Stokes' efforts went into attempts to show that aberration could be accounted for on the basis of a dragged along and on the basis of an immobile ether.

In 1851 Armand Hippolyte Fizeau performed measurements of the speed of light in moving water. Fizeau's water tube experiment found that it was possible to measure the actual velocity by the interference method, and in so doing confirmed Fresnel's formula. This formula was found to represent the velocity accurately both for water and for other transparent media. In 1886, Albert Abraham Michelson, together with Edward Williams Morley, repeated the Fizeau experiment with improved accuracy. The experiment confirmed Fresnel's prediction. Michelson and Morley concluded that Fresnel had to be right and Stokes wrong.

In 1881 Michelson performed a second order ether drift experiment aimed at measuring the ratio v/c to second order. The means by which this experiment endeavoured to discover the Earth's motion with respect to the ether was mainly through the use of optical instruments (*interferometers*). It returned a negative result. However, the celebrated Michelson-Morley experiment of 1887 gave the same negative result of Michelson's first attempt in 1881, with reduced experimental error. Now both Fresnel's and Stokes' hypotheses appeared to be untenable.

Meanwhile, in 1886 Hendrik Antoon Lorentz argued that all experiments could be accounted for on the basis of a theory somewhere in between Fresnel's and Stokes', a theory that contains Fresnel's coefficient and in which all moving matter partially drags along the ether.

Two major theories were offered for extending Maxwell's electromagnetic theory to moving bodies: Heinrich Rudolf Hertz's 1890 macroscopic electrodynamics of moving bodies, and Lorentz's 1892 microscopic electron theory. Hertz's theory was contradicted by Fizeau's 1851 water tube experiment because it assumed a complete drag of the ether along with the bodies in motion. On the other hand, it was obviously compatible with the negative results of ether drift experiments.

Lorentz's theory explained all that Maxwell's theory had already explained and left intact the intimate connection between optics and electricity discovered by Maxwell. Lorentz started from the hypothesis that electrical charges are carried by material particles called the electrons and the electrons composing ponderable matter move in immobile ether. The study of the interactions between the immobile ether and the electrons in motion accounted for the observed phenomena: Aberration and Fizeau's 1851 experimental result both received a satisfactory explanation within Lorentz's theory. He was able to derive the Fresnel coefficient from his theory, reinterpreting it as due to an interaction between ether and matter that required no ether drag whatsoever. In 1895, Lorentz produced a more general derivation of the Fresnel coefficient with the help of an auxiliary quantity called *local time*. Formally, this derivation is very close to the derivation of the dragging coefficient in special relativity, based on the relativistic addition theorem for velocities.

However, all the experiments seeking to demonstrate the Earth's motion with respect to the ether contradicted Lorentz's fundamental hypothesis of immobile ether and moving electrons, in that they failed to reveal the preferred state of rest of the ether. For the purpose of reconciling the hypothesis of immobile ether with the negative results of the Michelson-Morley experiment, Lorentz proposed (in 1892) the contraction hypothesis (which had already been suggested by George Francis FitzGerald in 1889).

Lorentz included the contraction and other *compensations* within later versions of his 1892 theory, his 1895, 1899 and 1904 theories of the electron. In these later versions, Lorentz formulated a *theorem of corresponding states*. According to this new theorem, there existed mathematical transformations that preserved the elementary electromagnetic equations of Lorentz's electron theory almost in their original form. These transformations required a linear rescaling of time with the distance coordinate x so that the time coordinate t is replaced by the *local time*; and, for later, more exact, higher order versions of the theorem, lengths were contracted by the factor $\sqrt{1-({}^{v}/_{c})^2}$. By means of these transformations, Lorentz explained the impossibility of detecting the Earth's motion by electromagnetic and optical means; or, in other terms, the motion of the Earth through the ether had (almost) no observable effect on electromagnetic and optical processes.

Before 1905 Einstein had tried to discuss Fizeau's experiment as originally discussed by Lorentz. At that time he was still under the impression that the ordinary Newtonian law of addition of velocities was unproblematic. In 1907 Max Laue showed that the Fresnel dragging coefficient would follow from a straightforward application of the relativistic addition theorem of velocities. Indeed this derivation was mathematically equivalent to Lorentz's derivation of 1895. From 1907 onwards Einstein adopted Laue's derivation.

When Robert Shankland asked Einstein how he had learned of the Michelson-Morley 1887 ether drift experiment, Einstein told him that he had become aware of it through the writings of Lorentz, but it had come to his attention only after 1905. Otherwise, he said, he would have mentioned it in his paper. He continued to say that the experimental results that had influenced him most were those of stellar aberration and Fizeau's water tube experiment. They were enough, said Einstein. Indeed, the famous Michelson-Morley experiment is not mentioned in the 1905 relativity paper. Curiously, however, Einstein did not mention Fizeau's experimental result either, and this is puzzling in light of the importance of the experiment in Einstein's pathway to his theory. This topic is discussed in chapter D.

The third chapter (C) discusses Einstein’s path to special relativity and Henri Poincaré's contributions to the principle of relativity.

There is a major problem still basically unsolved: the vast amount of evidence and sporadic pieces of primary material do not shed too much light on the overall course of Einstein's thinking between 1901 and 1904, because he published nothing on the subject of optics or electrodynamics of moving bodies (relativity) between 1901 and 1904. Apparently, therefore, neither correspondence nor any other source can be said to assist in creating a coherent story of Einstein's path to the special theory of relativity between 1901 and 1904, for there are unfortunately no relevant new letters from this period. In chapter C I confront this problem and present my story of Einstein's path to relativity between 1895 and 1905.

In 1894-1895 Einstein wrote an essay that he sent to his uncle, Cäser Koch. At the time he believed in the ether theory, but did not show any knowledge of Maxwell's electromagnetic theory. In 1895, at the age of sixteen, Einstein was also familiar with the principle of relativity in mechanics. A year later, in 1895-1896, while in Aarau, Einstein conceived of a thought experiment: the chasing of a light beam thought experiment. In 1899 Einstein studied Maxwell's electromagnetic theory. Around 1898-1900 he invented the magnet and conductor thought experiment (asymmetries in Lorentz's theory regarding the explanation of Michael Faraday's induction).

Between 1899 and 1901 Einstein was occupied with the contradiction between the Galilean principle of relativity and the constancy of the velocity of light in Maxwell's theory. He was also interested in ether drift and appears to have designed at least two experiments: the first in 1899 and the second, two years later. In 1901 Einstein still accepted the Galilean kinematics of space and time, in which the Galilean principle of relativity holds true.

Between 1901 and 1903 Einstein was working on two topics: the quantum of light problem and the electrodynamics of moving bodies. The two topics seemingly could, however, be said to depend on one another; they were interwoven. For the telling here, I first unravel them (in chapters C and D), and follow each in turn. Subsequently, I consider the part that Einstein's work on the quantum of light and on relativity played on his path to special relativity.

We should remember that between 1901 and 1903, Einstein was still sitting in the Patent Office. One can imagine him trying to hide from his boss, writing notes on small sheets of paper and, according to reports, seeing to it that the small sheets of paper on which he was writing would vanish into his desk-drawer as soon as he heard footsteps approaching behind his door.

Einstein nonetheless said that he had enjoyed considerable freedom in the *worldly cloister*, where during 1901-1903, he was perhaps *ruminating* (i.e., pondering) his best ideas, *brooding* upon the Maxwell-Hertz equations for empty space. He tried to solve the conflict between the Galilean principle of relativity and the constancy of the velocity of light. He dropped the ether hypothesis and replaced Lorentz's theory with emission theory. Einstein seems to have engaged with emission theory for an extra year, from 1903-1904 until almost spring-summer 1904, apparently, remote as possible from Lorentz's theory.

Einstein discussed Fizeau's experiment using emission theory but then demonstrated why emission theories could not hold true. Towards spring-summer 1904 he dropped emission theory and returned to Lorentz's theory. He tried to discuss Fizeau's experiment in Lorentz's theory, by now firmly believing that Lorentz's theory was correct. The invariance of the velocity of light however contradicted the addition rule of velocities used in mechanics. Einstein realized the difficulty in seeking to resolve this, and spent almost a year in vain trying to modify Lorentz's idea in the hope of solving the problem. In spring 1905 he found the final solution: the *step*, which solved his dilemma.

An additional topic discussed in Chapter C is Henri Poincaré's Dynamics of the Electron and ideas in regard to the principle of relativity. I begin with Poincaré's biography followed by his possible influence on Einstein. I first present a brief biographical sketch of Poincaré, which does not in any way reflect Poincaré's rich personality and immense activity in science. It is interesting to note that, as opposed to the plethora of biographies and secondary papers studying the life and scientific contributions of Albert Einstein, one finds far fewer biographies and secondary sources that discuss Poincaré's life and work.

From 1920 on Einstein became a myth and a world famous figure, whereas during his lifetime Poincaré was not a cultural icon. Despite Poincaré's brilliance in mathematics, he was to remain an internationally famous mathematician mainly within the professional circle of scientists. He published more papers than Einstein, performed research in many more branches of physics and mathematics, received more prizes on his studies and was a member of more academies world-wide. Despite this tremendous yield, Poincaré did not win a Nobel Prize.

During Poincaré's travels to Europe, Africa and America, his companions noticed his broad knowledge on everything from statistics to the history and curious customs and habits of the local people. He taught almost every subject in science, possessing such an encyclopedic knowledge that he was able to engage with the outstanding questions of the time in the different branches of physics and mathematics. Indeed he altered the thinking in entire fields of science, such as non-Euclidean geometry, Arithmetic, celestial mechanics, thermodynamics and kinetic theory, optics, electrodynamics, Maxwell's theory and other topics at the forefront of *fin de siècle* physical science.

Prior to 1905 Poincaré had stressed the importance of the method of clocks and their synchronisation but, unlike Einstein, issues of magnet and conductor or chasing a light beam and overtaking it, were not a matter of great concern for him. In 1905 he elaborated upon Lorentz's 1904 electron theory in two papers entitled "On the Dynamics of the Electron". In May 1905 Poincaré sent three letters to Lorentz at the same time that Einstein wrote his famous May 1905 letter to Conrad Habicht, promising him four works, of which the fourth one was only a rough draft at that point. In the May 1905 letters to Lorentz Poincaré presented the basic equations of his 1905 Dynamics of the Electron. Hence, in May 1905, Poincaré and Einstein both had drafts of papers relating to the principle of relativity. Poincaré's draft led to a space-time mathematical theory of groups at the basis of which stood the postulate of relativity, and Einstein's draft led to a kinematical theory of relativity.

Poincaré did not renounce the ether theory. He wrote a new law of addition of velocities but did not abandon the tacit assumptions made about the nature of time, simultaneity and space measurements implicit in Newtonian kinematics. Although before 1905 he questioned absolute time and absolute simultaneity, he did not make tacit new kinematic assumptions about space and time. He also did not require reciprocity of appearances and, therefore, did not discover relativity of simultaneity: those are the main hallmarks of Einstein's special theory of relativity. Nevertheless, as shown by other writers, Poincaré's theory influenced later scientists, especially Hermann Minkowski.

Einstein was the first to explore the *inertial* mass-energy equivalence. In 1905 he showed that a change in energy is associated with a change in *inertial* mass, equal to the change in energy divided by c^2.

In 1900 Poincaré considered a device that could create and emit electromagnetic waves. The device would emit energy in all directions, as a result of which it would recoil. No motion of any other material body would compensate for the recoil at that moment. Poincaré found that as a result of the recoil of the oscillator, in the moving system, the oscillator generating the electromagnetic energy would suffer an *apparent complementary force*.

In addition, in order to demonstrate the non-violation of the theorem of the motion of the centre of gravity, Poincaré needed an arbitrary convention, the *fictitious fluid*. Einstein had demonstrated that if the inertial mass E/c^2 is associated with the energy E, and assuming the inseparability of the theorem of the conservation of mass and that of energy, then – at least as a first approximation – the theorem of the conservation of the motion of the centre of gravity would also be valid for all systems in which electromagnetic processes take place.

Prior to 1905 (and also afterwards) Poincaré had not explored the inertial mass-energy equivalence. In 1908 Einstein wrote the German physicist Johannes Stark that he was a little surprised to see that Stark had not acknowledged his priority regarding the relationship between inertial mass and energy.

Present-day relativistic kinematics follows the general pattern established by Einstein in 1905. Therefore, much effort has been invested in determining whether Poincaré had in fact preceded the main features of Einstein's 1905 relativistic kinematics. The history of Poincaré's contributions is usually understood in terms of *Poincaré was just a step away* from Einstein's 1905 special relativity. Poincaré, however, created a space-time mathematical theory of groups, at the basis of which stood the postulate of relativity, to which I also briefly refer from the philosophical point of view.

Poincaré's philosophy of conventionalism sprang from his research into geometry during a period (the end of the 1880s) when non-Euclidean geometries were constantly considered a matter of possibility. Poincaré developed two kinds of conventionalism: conventionalism applicable to geometry and conventionalism for the principles of physics. Both sprang from his mathematical group theory. He adopted the notion of Lie groups, developed by the Norwegian mathematician Marius Sophus Lie, and demonstrated that all geometries could be generated from Lie groups, arriving thereby at the conclusion that they are all logically equivalent.

Poincaré began to think of conventionalist ideas as a result of the development of non-Euclidean geometry in the nineteenth century. The non-Euclidean geometries arose as a logical alternative to Euclidean geometry. However, they were not considered as geometries that could represent bodies in the real world, unlike Euclidean geometry. Poincaré agreed with this contention and it underlined his philosophy of conventionalism, which complied with the basic thesis of his mathematical group theory.

The final chapter (D) engages with Einstein's methodology and presents a critical analysis of his relativity theory.

The status and meaning of the special theory of relativity is still as much a question for debate as it was a hundred years ago. This chapter discusses the various methodological problems in special relativity that occupied scholars when Einstein's relativity theory was first introduced.

Fairly soon after Einstein had formulated his relativity theory, his friend Paul Ehrenfest reasoned that the theory was simply a reformulation of Lorentz's electrodynamic theory. Einstein's response to his friend was that the theory of relativity is a theory of principle; and he explained that, beyond kinematics, the 1905 heuristic relativity principle could offer new connections between non-kinematical concepts.

Indeed when Einstein appreciated that the results of the Dayton Clarence Miller ether drift experiments might be confirmed, he declared that relativity theory could not be maintained, since the experiments would then prove that, relative to the coordinate systems of the appropriate state of motion (the Earth), the velocity of light in a vacuum would depend upon the direction of motion. With this, the principle of the constancy of the velocity of light, which forms one of the two foundation pillars on which the theory is based, would be refuted. He was prepared to give his relativity theory up completely in the case of irrefutable contrary empirical evidence since special relativity is a heuristic system of two principles; it is not a constructive theory like the ether-based electron theory, then one cannot modify principles without giving up the whole theory. However, a theory of principle has a solid theoretical basis, and therefore there is little chance that experiments like that of Miller's (and also like that of Walter Kaufmann's discussed in Chapter D) would turn out to be right.

Another topic discussed in this chapter is Einstein's methodology. Einstein himself seems to have made different statements regarding the process that results in a new idea, ranging from discovering the principle of relativity to the theory of relativity as an invention.

Einstein desired to invent, and he compared the inventive science to music ("Thinking for its own sake, as in music"), and music was also an inspiration for his scientific inventions. Einstein characterized the process of his creativity using the words: *free creations of the human mind*. Those are theoretical scientific ideas and musical sonatas, both enhancing one another.

For Einstein, the process of thinking consists of two stages. The first stage is primary non-verbal in nature. Words or the language, as they are written or spoken, do not seem to play any role in his mechanism or thought. The psychical entities which seem to serve as elements in thought are clear images. Many of the crucial thought experiments Einstein later reports confirm the existence of this first stage of the thinking process (for instance, the chasing a light beam and the magnet and conductor thought experiments).

At a secondary stage, it was necessary for him to transform the results of the primary process into forms communicable to others. The need to put ideas into communicable form led Einstein to search throughout his early life for people to act as *sounding boards* for his ideas.

At the age of four or five, young Albert experienced a wonder. His father Hermann showed him a compass. This experience, so recounts Einstein himself in his *Autobiographical Notes*, changed his life. His thinking went on for the most part without use of signs (words), and he *wondered* quite spontaneously about this experience. The significance of a wonder for Einstein was that Einstein had the ability to keep the child alive in the man. Towards the end of his life Einstein mused that he was brought to the formulation of relativity theory in good part because he kept asking himself questions concerning space and time that only children wonder about. For Einstein a wonder was an apparent conflict between a phenomenon and our established conceptual framework.

Einstein's 1905 relativity paper became famous as the one in which he inferred odd and curious effects. One immediate consequence of this was that of discussions of the misunderstandings and paradoxes in the theory.

Einstein wrote in his 1905 relativity paper that the theory developed here was based on the kinematics of the rigid body. It was shown that a rigid body cannot exist in the special theory of relativity. In addition, it was claimed that special relativity assumes a connection between synchronisation and contraction; a connection that was challenged.

It should be keep in mind that a discussion of these topics requires additional philosophical reinforcement (which is beyond the scope of this book); and, therefore, the discussion of these topics in this book is restricted.

Reformulations of the elements of the relativity theory that appear to render the theory applicable to similar phenomena were also suggested: distant simultaneity can be defined with respect to a given frame of reference without any reference to synchronised clocks; and a theory of relativity without light was posited.

In 1905 Einstein presented the *Clock Paradox* and in 1911 Paul Langevin expanded Einstein's findings to human observers, as the *Twin Paradox*. I explain the difference between Einstein and Langevin. Einstein did not present the so-called Twin Paradox, but later continued to speak about the clock paradox.

Einstein might not have been interested in the question of what happens to the observers themselves, possibly because he dealt with measurement procedures, clocks and measuring rods. Einstein's observers were measuring time with these clocks and measuring rods and he might not have been interested in studying the so-called biology of the observers themselves, as to whether they were getting older, younger or had undergone any other changes. Such changes appeared to be beyond the scope of his *principle of relativity*, or kinematics. The processes and changes occurring among the observers seemed to be more appropriate for philosophical rather than scientific discussions. To the later writers, who criticized Einstein's clock paradox, such as the anti-Semites who blamed the theory of relativity as an anti-German science, he quickly replied with witty retorts.

In 1907 Einstein discussed with Wilhelm Wien the occurrence of superluminal velocities in dispersive and absorptive media. He tried to present to Wien an expression for the group velocity in dispersive media based on his 1905 addition theorem for relative velocities, which he claimed to be valid for absorptive media, and to demonstrate the impossibility of superluminal velocities. However, he recognized that his expression required an amendment and correction. Having failed to convince Wien, he was finally confused, lacking a correct expression for the group velocity in dispersive media. However, he wrote to Wien that it was beyond doubt that the electromagnetic theory of dispersion could never yield superluminal velocity for the propagation of an optical signal.

We should recall that Einstein was occupied among others, with the microstructure of radiation (light quantum paper). In 1905 the well-known physicist Max Planck was coeditor of the *Annalen der Physik*, and he accepted Einstein's paper on light quanta for publication, even though he disliked the idea of *light quanta*. Einstein's relativity paper was received by the *Annalen der Physik* at the end of June 1905 and Planck was the first scientist to take note of Einstein's relativity theory and to report favorably on it. In his 1905 relativity paper Einstein used a seemingly conventional notion, *light complex*, and did not refer to his novel quanta of light heuristic with respect to the principle of relativity. He chose the language *light complex* for which no clear definition could be given. With hindsight, however, in 1905 Einstein had made exactly the right choice not to mix concepts from his quantum paper with those from his relativity paper. He focused on finding the solution to his relativity problem, whose far-reaching ramifications Planck had already sensed.

Before ending with Dayton Clarence Miller's experiments I discuss Einstein's 1905 relativity theory of the motion of an electron. He obtained expressions for the longitudinal and transverse masses of the electron using the principle of relativity and that of the constancy of the velocity of light. It was quite natural and presumably expected that Einstein's expression for the mass of the electron would seem to resemble that of Lorentz. And indeed, I have already remarked that Einstein's above solution appeared to Ehrenfest to be very similar to Lorentz's one: both clearly suggested a deformed electron. Einstein commented on Ehrenfest's paper and characterized his work as a theory of principle and reasoned that, beyond kinematics, the 1905 heuristic relativity principle could offer new connections between non-kinematical concepts.

Walter Kaufmann concluded that his own measuring procedures were not compatible with the hypothesis posited by Lorentz (Lorentz's electron) and Einstein. However, unlike Ehrenfest, he gave the first clear account of the basic theoretical difference between Lorentz's and Einstein's views.

Finally, Alfred Bucherer conducted experiments that confirmed Lorentz's and Einstein's models, while Max Born analyzed the problem of a rigid body and demonstrated the existence of a limited class of rigid motions, concluding that the main result was a confirmation of Lorentz's formula.

The final topic is that of Miller's ether drift experiments. The negative result of the Michelson-Morley experiment stimulated many repetitions of this experiment during the next fifty years, especially in light of the implications of Einstein's special theory of relativity. Every trial of this experiment yielded a null result within the accuracy of the observations. Then in the 1920s, the history of relativity took some interesting turns.

A repetition of the experiment, performed by Miller, appeared to be perplexing, as he had observed very small fringe displacements. There was great excitement amongst experimentalists and the scientific community; and even Einstein declared that, if these results would be substantiated, he would give up his special theory of relativity, and with it also his general theory of relativity! Einstein nonetheless announced that there was practically no likelihood of Miller being right, and upon hearing the rumor about Miller's experiments for the first time, Einstein produced one of his classical *aperçus*: "The Lord God is Subtle, but malicious he is not".

A.

From Einstein's Childhood to Patent Office

1 Einstein's Parents and Sister Maja

Albert was born on the morning of March 14, 1879, at 11:30 a.m, in the city of Ulm, at the former *Bahnhofstraße* 135B, which vanished in 1945 (Birth Certificate, *CPAE* 1, Doc. 1). It is quite symbolic that Einstein was born in a street named "Station Street", as if he was born into his thought experiments of stations and trains. The house in Ulm where he was born no longer stands. World War II reduced it to rubble. A street in Ulm has since been named *Einsteinstraße*.[2]

Ulm is a Swabian town on the Danube, in the state of Württemberg, in southern Germany. In the correction to Seelig's biography it was noted that the word *Swabian* should not be taken literally, because in Switzerland the Germans were all called *Swabians*. Einstein's childhood was spent in Munich, the capital of Bavaria, but Einstein was especially *Swabian* because he had a *Swabian* sense of humour. There is a particularly *Swabian* good-natured humour, curiously like English humour, and a *Swabian* taste for practical jokes (EA 39-084; Vallentin 1954, 6).[3]

On his birth certificate Einstein is recorded as born to the merchant Hermann Einstein and his wife Pauline née Koch, both of the Israelite religion. Helen Dukas told Abraham Pais that Einstein's name was supposed to be Abraham, for his paternal grandfather, Abraham Rupert Einstein, but his parents found the name too Jewish and adopted only the initial A, naming him Albert instead (Pais 1982, 35; Calaprice 2005, 352).

Hermann Einstein was a native of the small town of Buchau on the Federsee and Pauline Koch of Kannstatt on the Neckar. He was a merchant who possessed a particular inclination for technical matters. He ran an electrical business and enjoyed solving technical problems and the mathematics taught in the lower forms of the German secondary schools. Music meant little to him as a distant and not very necessary pleasure. He did not concern himself with politics but he loved literature and, in the lamp-lit evenings, he read Schiller and Heine (Talmey 1932a, 160, 1932b, 68; Reiser 1930, 26).

Albert Einstein was thus quite the opposite of his father, except for his love of mathematics. Empires and rising mighty powers disgusted him and his concern with politics was as a pacifist and humanist. Furthermore, he showed no inclination for commercial and business matters.

Hermann Einstein had several brothers and sisters. Jakob Einstein, a younger brother, was the only brother to acquire an higher education, attending the *Polytechnische Schule* (polytechnic school) in Stuttgart from 1867 to 1869. He served as an engineer in the army during the Franco-Prussian War and in 1876 he moved to Munich and started a gas-fitting and plumbing firm (*CPAE* 1, l-li, notes 7-9).

In contrast to Albert's father, his mother Pauline Koch, was in many respects more serious and did not always see the world through his optimistic eyes. She enjoyed her life, loved people and her household and possessed a genuine and hearty humour (of the *Swabian* kind). Of little Albert, she often prophesied that "some day he will be a great professor" (Reiser 1930, 27).

Einstein's mother had a brother, Cäser Koch, Einstein's uncle. He lived in Stuttgart and often visited Einstein's family. In January 1885 Uncle Koch returned to Germany from Russia, where some of his family were living. With him he brought a model steam engine as a present for Albert purchased during a visit to Munich that year. Shortly afterwards Uncle Koch married and moved to Antwerp – where the young Albert was subsequently taken on a conducted tour. The uncle was a grain merchant, hardly close to science and physics, but nevertheless it was to Cäser that Einstein was to send, as a boy of sixteen, his first essay on physics.

Regarding religion, the family never attended the local synagogue, nor did they keep a kosher home. Hermann saw in Jewish customs and traditions "an ancient superstition". There is one story that sounds more like a family legend or, better, an Einstein anecdote, than a reality. The family had one particularly hard-bitten agnostic uncle, whom Einstein used as a peg for an old Jewish joke. He would always describe with relish how he had surprised him one day in full formal dress preparing to go to the synagogue. The uncle had responded to the nephew's astonishment at seeming him there with the warning: "Ah, but you never know". Thus, writes Ronald Clark in his biography, Einstein was nourished on a family tradition that had broken with authority; one that dissented, sought independence and deliberately did not tow the line (Clark 1971, 8-9).[4]

The story perfectly suits both Einstein's *Swabian* sense of humour and the legend of Einstein the atheist. Einstein later, in Zurich of 1909, displayed an atheistic approach to religious issues (Seelig, 1954, 133, 1956a, 113). Though he would identify with great passion and care with his tribe, the Jewish people, and endeavoured to assist the Jews and the Jewish people on every occasion, he himself was not religious.

On November 18, 1881, a daughter was born to Hermann and Pauline. She was named Maria (Miriam), but throughout her life she was called Maja. In 1924, in her *Biographical Sketch* (after Einstein had become world famous), Maja recounts a family story: when the two-and-a-half-year-old Albert was told of the arrival of his little sister, with whom he could play, he must have imagined a kind of toy, for at the sight of his new sister he asked, with great disappointment, "Yes, but where are its wheels?" ["Ja, aber wo hat es den seine Rädchen?"] (Winteler-Einstein 1924b, 1vii, 1924c, xviii).

The famed psychoanalyst Erik Erikson explained his interpretation of the story (Erikson 1979, 152):

> "Now, as to the little wheels, the German word for it is *Rädchen*, or in Swabian, *Rädele*, which rhymes with that for little girl (*Mädchen*, or *Mädele*). Is it not possible that a play with rhymes began early in this thoughtful child, even as it continued throughout his life as an humorous need at the oddest moments 'ein Gedichte zu mache' – to make a little poem or 'ditty'? More, one might consider a special preoccupation with 'the way things rhyme' to be an important trend throughout Albert's development".

Maja recounted that Albert as a child would play by himself for hours. As a boy he "developed slowly in childhood, and he had difficulty with language that those around him feared he would never learn to speak. But this fear also proved unfounded" (Winteler-Einstein 1924b xlviii-lxvi; 1924c, xviii). In 1930 Einstein's son-in-law, Anton Reiser (Rudolf Kayser), recounted the same story, "Slowly, and only after much difficulty, he learned to talk. His parents thought he was abnormal. The hired governess called the still, backward, slow-speaking Albert, 'Pater Langweil' (Father Bore)" (Reiser 1930, 27).[5]