Einstein's Pathway to the Special Theory of Relativity (2nd Edition)

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By

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“Great spirits have always encountered opposition from mediocre minds. The mediocre mind is incapable of understanding the man who refuses to bow blindly to conventional prejudices and chooses instead to express his opinions courageously and honestly”.

Albert Einstein, March 19, 1940.

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PREFACE TO THE SECOND EDITION

My primary goal in writing this second edition of *Einstein's Pathway to the Special Theory of Relativity*, is the following:

Firstly, I have updated and made corrections and minor revisions in many places in the text. I have also simplified explanations.

Secondly, I have added a chapter (Chapter D) on Einstein's route to the General Theory of Relativity (1905 – 1918) that will complement the text in my book, *General Relativity Conflict and Rivalries*, in which I focus on the work of Albert Einstein and his interaction with and response to many eminent and not-so-eminent scientists (1905 – 1945). In *General Relativity Conflict and Rivalries* I demonstrate that the ongoing discussions between Einstein and other scientists have all contributed to the edifice of general relativity and relativistic cosmology. In this edition of *Einstein's Pathway to the Special Theory of Relativity*, I centralize on Einstein's *own creativity*, *invention and inner struggles* on his route to general relativity, rather than on his interactions with other scientists.

In light of the burst of conferences that have taken place and publications that have appeared during 2015 (the centenary celebrations of Einstein's General Relativity) over the short time since my book, *General Relativity Conflict and Rivalries* has been out, I have also decided to update and correct the text of this book. I have added, in particular, a chapter that complements the above mentioned book and on which I have worked very hard, in order to make it a harmonious overview of Einstein's Odyssey to General Relativity.

Thirdly, I have added new sections to the chapters devoted to Einstein's biography, to his pathway to the special theory of relativity, and to the chapter devoted to Einstein's and Poincaré's creativity. I have significantly expanded these chapters in order to include new findings on Einstein's special relativity and have expanded the discussion on Einstein's biography and creativity in order to make a comparison between the discoveries of special and general relativity.

Fourthly, Einstein said that the real goal of his research had always been the simplification of theoretical physics (Dukas and Hoffmann 1979, 12, 122). My goal in this book is the simplification of the history of physics and I believe that this new edition fulfills this goal. I have tried to present the new material in the same simple style as the text dealing with Einstein's path to special relativity, namely with minimum mathematical formulas. Einstein also thought that a scientist should not attempt to popularize his theories. It is the duty of a scientist to remain obscure (Douglas Vibert 1956, 99-100). I thus have attempted to make Chapter D as intriguing as possible to readers with strong physics and historiography backgrounds. With this objective in mind, the explanations in Sections 3-7 of Chapter D are, understandably, less general. The mathematical background needed to read these sections corresponds to the level of a college student graduating in science.

Lastly, I wish to thank Prof. John Stachel from the Center for Einstein Studies in Boston University for sitting with me for so many hours discussing Einstein's special and general relativity and its history. Almost every day, John arrived with notes on my draft manuscripts and directed me to books in his Einstein collection, and gave me copies of his papers on Einstein, which I read with great interest.

Last, but not least, many thanks to CSP for supporting this project, and especially to Amanda Millar, Courtney Blades and Sophie Edminson for their patience and kind help in completing the present book and my first and second books, *Einstein’s Pathway to the Special Theory of Relativity first edition*, CSP, 2015 and *General Relativity Conflict and Rivalries: Einstein's Polemics with Physicists*, CSP, 2015.

INTRODUCTION

This book is divided into six chapters. While each chapter can be read separately, the book was written with the intention that the chapters be read sequentially.

In this edition I discuss two parallel topics: The story of Einstein's discovery of special relativity and general relativity.

The first subject in this edition is Einstein's path to the special theory of relativity, beginning from 1895 and until September 1905, Einstein's second relativity paper. 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. The second topic is Einstein's odyssey to the general theory of relativity. "Odyssey to General Relativity" is John Stachel's memorable phraseology. This phraseology represents Einstein's own struggles on his route to discovering the general theory of relativity.

While the two topics are to some extent separated by the chapters and sections of the book, I believe that it is important to note that they intermingle in my historical analysis of *Einstein's revolution*.

The First Chapter (A): A Critical Biography of Albert Einstein

Chapter A presents a critical biography of Einstein from childhood until 1914 – the year that Einstein left Zurich. 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, Joseph Degenhart, 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.

Between 1902 and 1909, Einstein was 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 1902-1905, he was perhaps *ruminating* (i.e. pondering) his best ideas, *brooding* upon the electrodynamics of moving bodies.

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.

In 1909 Einstein was appointed professor and teacher of theoretical physics at Zurich University by the Governmental Council of the Canton of Zurich, for the period of six years. He handed his resignation notice, effective October 1909, to the Director of the Patent Office. His doctorate student later recalled Einstein's informal teaching approach. Einstein entered classes (during 1909-1911) in his shabby clothes with trousers too short and an iron watch chain.

In March 1911, Einstein left his comfortable position at the University of Zurich and moved to the German University of Prague, Karl-Ferdinand

University. This position offered Einstein, for the first time in his life, a full professorship with significant research time.

Hardly six months after Einstein's departure from Zurich, and his friend and eternal lifesaver, Marcel Grossmann, whose father helped Einstein obtain the position in the Patent Office, asked Einstein whether he would be interested in a post at the Swiss Federal Polytechnic School. Einstein had been a student at this school, which he used to call the "Poly", the Zurich Polytechnic. He was happy to exchange Prague for Zurich and in August 1912, he returned as a full professor to the institute that he cherished. However, Einstein did not stay long in Zurich. In the spring of 1914 he moved to Berlin and became a member of the Royal Prussian Academy of Science.

The Second Chapter (B): *Fin de Siècle* Physics

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 endeavored 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 so that the time coordinate 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.

The Third Chapter (C): Einstein's Path to Special Relativity

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 tried to solve the conflict between the Galilean principle of relativity and the constancy of the velocity of light. 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, 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.

Between 1901 and 1903 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. He then suddenly arrived at a breakthrough: he found a simple relationship between the magnitude of the quanta of matter and the wavelengths of radiation.

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.

Curiously, Einstein did not mention Fizeau's experimental result in the relativity paper. This is puzzling in light of the importance of the experiment in Einstein's pathway to his theory. Einstein presented in the kinematical part the new relativistic addition law for velocities, but he did not derive Fizeau's experimental result from this law. Apparently, Einstein did not recognize that the result of the Fizeau experiment could be obtained using this law. He did not derive stellar aberration in a similar manner either. In Section §7 of the 1905 relativity paper Einstein derived the latter result from the same transformation equations of the wave normal that gave the Doppler effect without mentioning the relativistic addition law for velocities. In 1907 Max Laue obtained Fizeau's result from Einstein's relativistic addition law for velocities. Einstein was still so much under the spell of Lorentz's interpretation that in 1905 he did not derive Fizeau's result or aberration by using his new addition theorem for velocities; he thought he needed Maxwell's equations for this derivation. In order to derive Fizeau's result from the transformation of the wave he probably needed a complicated calculation. In later papers he followed a different path and derived aberration and Fizeau's result by means of the relativistic addition law of velocities – following 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. I have already remarked that Einstein did not mention Fizeau's experimental result either.

Michelson's experimental result is usually *cited* as a preliminary problem that demanded the abandoning of the ether and, which finally *led* to

Einstein's solution. According to this scenario, which usually appears in textbooks, it appears obvious that Einstein must have based himself on Michelson's experimental result on his pathway to special relativity; and if he did not explicitly use this experimental result, at least he knew for sure about the famous experiment prior to publication of the relativity paper. Indeed, in 1949, Robert Millikan claimed that, in the case of relativity the prime experimental builder had been Michelson's experiment on ether drift.

Michelson and Morley's experiment became more and more famous at that time. The Michelson experiment, and then the Michelson and Morley experiment demonstrated even more precisely, that the supposed motion of the earth through the ether did not produce any perceptible effect on the measuring instruments up to the second-order in (v/c).

Stachel and Gerald Holton summarized evidence from the period 1899-1902 and concluded that, although ideas about ether drift experiments formed an important component of Einstein's thinking about the complex of problems that ultimately led him to develop the special theory of relativity, the Michelson-Morley experiment did not play a significant role. Einstein was almost certainly aware in a general way of the existence of the Michelson-Morley experiment from late 1899 on, but it is not mentioned at all in his surviving letters from this period.

The difference between the context of discovery, in which the Michelson and Morley experiment played a negligible role, and the context of justification, in which it did play a major role is a good example of how many enduring myths have grown up about the revolution of special relativity. After 1905 Einstein wrote expositions of special relativity. In most of them he mentioned the Michelson-Morley experiment. From this we can infer that it is important to distinguish between the historical road that led to the development of the theory of relativity (the context of discovery of the theory), and the logical structure of the theory (the context of justification). After dealing with Einstein's path to the theory of relativity, I discuss the logical structure of the theory and analyze Einstein's relativity paper.

The special theory of relativity rests on two principles, an auxiliary definition is introduced in the kinematical part of the relativity paper, and different interpretations of space and time measuring procedures are brought. A few intuitive thought experiments are brought in order to explain to the reader in everyday language the proposed methods and the few central results of the kinematical part. The kinematical part presents the theory.

In fact, Einstein did not consider the kinematical part as a theory, he rather called it the "relativity principle"; he regarded the kinematical part and his relativity kinematics as a system of relativity with the aid of which he unified electricity and magnetism into one electromagnetic field. Einstein was the first to show that they are unified and he brought the two together in the form of the electromagnetic field. He obtained equations of transformation for the electric and magnetic fields, and solved a few problems in the optics and electrodynamics of moving bodies in a constructive way.

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 synchronization and contraction; a connection that was challenged.

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 synchronized 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.

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 Kaufmann'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. In 1907, Einstein's friend, Paul Ehrenfest, wrote a note in which he posed a query. Ehrenfest's query dealt with the structure of the electron. Einstein's above solution appeared to Ehrenfest to be very similar to Lorentz's one: both clearly suggested a deformed electron. Ehrenfest thought that Einstein's deformed electron could have been obtained from the good old theory of Lorentz, if we only used the method of deduction. If this was so, Ehrenfest understood that Einstein's theory was nothing but a reformulation of the electrodynamics of Lorentz. Einstein answered Ehrenfest's query by saying that the theory of the motion of an electron was obtained as follows: One postulates the Maxwell equations for vacuum for spacetime coordinate systems. By applying the Lorentz transformation derived by means of the system of relativity, one finds the transformation equations for electric and magnetic fields. Using the latter, and applying the Lorentz transformation, one arrives at the law for the acceleration of an electron moving at arbitrary speed from the law for the acceleration of a slowly moving electron, which is assumed or obtained from experience. This topic is further discussed in Chapter E.

Walter Kaufmann concluded that his own measuring procedures were not compatible with the hypothesis posited by Lorentz (Lorentz's electron) and Einstein. Kaufmann repeatedly confirmed Max Abraham's theory of electrons. However, unlike Ehrenfest, he gave the first clear account of the basic theoretical difference between Lorentz's and Einstein's views. Einstein reasoned that the probability that Abraham's theory was correct was rather small, because his basic assumptions concerning the dimensions of the moving electron were not suggested and justified by a theoretical system that encompass larger complexes of phenomena.

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.

It should be kept 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.

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.