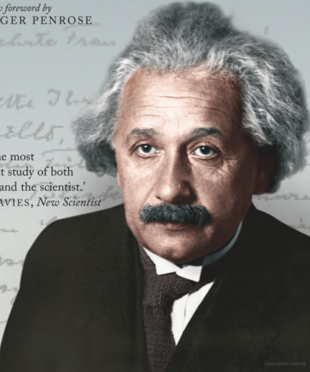
ABRAHAM PAIS

SUBTLE *is the* LORD

The science and the life of

ALBERT EINSTEIN

With a new foreword by
SIR ROGER PENROSE



'By far the most important study of both the man and the scientist.'
PAUL DAVIES, *New Scientist*

'Subtle is the Lord . . .'

The Science and the Life of Albert Einstein

ABRAHAM PAIS
Rockefeller University

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I

INTRODUCTORY

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1

Purpose and Plan

It must have been around 1950. I was accompanying Einstein on a walk from The Institute for Advanced Study to his home, when he suddenly stopped, turned to me, and asked me if I really believed that the moon exists only if I look at it. The nature of our conversation was not particularly metaphysical. Rather, we were discussing the quantum theory, in particular what is doable and knowable in the sense of physical observation. The twentieth century physicist does not, of course, claim to have the definitive answer to this question. He does know, however, that the answer given by his nineteenth century ancestors will no longer do. They were almost exactly right, to be sure, as far as conditions of everyday life are concerned, but their answer cannot be extrapolated to things moving nearly as fast as light, or to things that are as small as atoms, or—in some respects—to things that are as heavy as stars. We now know better than before that what man can do under the best of circumstances depends on a careful specification of what those circumstances are. That, in very broad terms, is the lesson of the theory of relativity, which Einstein created, and of quantum mechanics, which he eventually accepted as (in his words) the most successful theory of our period but which, he believed, was none the less only provisional in character.

We walked on and continued talking about the moon and the meaning of the expression *to exist* as it refers to inanimate objects. When we reached 112 Mercer Street, I wished him a pleasant lunch, then returned to the Institute. As had been the case on many earlier occasions, I had enjoyed the walk and felt better because of the discussion even though it had ended inconclusively. I was used to that by then, and as I walked back I wondered once again about the question, Why does this man, who contributed so incomparably much to the creation of modern physics, remain so attached to the nineteenth century view of causality?

To make that question more precise, it is necessary to understand Einstein's credo in regard not just to quantum physics but to all of physics. That much I believe I know, and will endeavor to explain in what follows. However, in order to answer the question, one needs to know not only his beliefs but also how they came to be adopted. My conversations with Einstein taught me little about that. The issue was not purposely shunned; it simply was never raised. Only many years after Einstein's death did I see the beginnings of an answer when I realized that, nearly a decade before the discovery of modern quantum mechanics, he had been the first to understand that the nineteenth century ideal of causality was about to become a grave issue in quantum physics. However, while I know more now about the evolution of his thinking than I did when I walked with him, I would not go so far as to say that I now understand why he chose to believe what he did believe. When Einstein was fifty years old, he wrote in the introduction to the biography by his son-in-law Rudolph Kayser, 'What has perhaps been overlooked is the irrational, the inconsistent, the droll, even the insane, which nature, inexhaustibly operative, implants in an individual, seemingly for her own amusement. But these things are singled out only in the crucible of one's own mind.' Perhaps this statement is too optimistic about the reach of self-knowledge. Certainly it is a warning, and a fair one, to any biographer not to overdo answering every question he may legitimately raise.

I should briefly explain how it happened that I went on that walk with Einstein and why we came to talk about the moon. I was born in 1918 in Amsterdam. In 1941 I received my PhD with Léon Rosenfeld in Utrecht. Some time thereafter I went into hiding in Amsterdam. Eventually I was caught and sent to the Gestapo prison there. Those who were not executed were released shortly before VE Day. Immediately after the war I applied for a postdoctoral fellowship at the Niels Bohr Institute in Copenhagen and at The Institute for Advanced Study in Princeton where I hoped to work with Pauli. I was accepted at both places and first went to Copenhagen for one year. Soon thereafter, I worked with Bohr for a period of several months. The following lines from my account of that experience are relevant to the present subject: 'I must admit that in the early stages of the collaboration I did not follow Bohr's line of thinking a good deal of the time and was in fact often quite bewildered. I failed to see the relevance of such remarks as that Schroedinger was completely shocked in 1927 when he was told of the probability interpretation of quantum mechanics or a reference to some objection by Einstein in 1928, which apparently had no bearing whatever on the subject at hand. But it did not take very long before the fog started to lift. I began to grasp not only the thread of Bohr's arguments but also their purpose. Just as in many sports a player goes through warming-up exercises before entering the arena, so Bohr would relive the struggles which it took before the content of quantum mechanics was understood and accepted. I can say that in Bohr's mind this struggle started all over every single day. This, I am convinced, was Bohr's inexhaustible source of identity. Einstein appeared forever as his leading spiritual partner—even after the latter's death he would argue with him as if Einstein were still alive' [P1].

In September 1946 I went to Princeton. The first thing I learned was that, in the meantime, Pauli had gone to Zürich. Bohr also came to Princeton that same month. Both of us attended the Princeton Bicentennial Meetings. I missed my first opportunity to catch a glimpse of Einstein as he walked next to President Truman in the academic parade. However, shortly thereafter, Bohr introduced me to Einstein, who greeted a rather awed young man in a very friendly way. The conversation on that occasion soon turned to the quantum theory. I listened as the two of them argued. I recall no details but remember distinctly my first impressions: they liked and respected each other. With a fair amount of passion, they were talking past each other. And, as had been the case with my first discussions with Bohr, I did not understand what Einstein was talking about.

Not long thereafter, I encountered Einstein in front of the Institute and told him that I had not followed his argument with Bohr and asked if I could come to his office some time for further enlightenment. He invited me to walk home with him. So began a series of discussions that continued until shortly before his death.* I would visit with him in his office or accompany him (often together with Kurt Gödel) on his lunchtime walk home. Less often I would visit him there. In all, I saw him about once every few weeks. We always spoke in German, the language best suited to grasp both the nuances of what he had in mind and the flavor of his personality. Only once did he visit my apartment. The occasion was a meeting of the Institute faculty for the purpose of drafting a statement of our position in the 1954 Oppenheimer affair.

Einstein's company was comfortable and comforting to those who knew him. Of course, he well knew that he was a legendary figure in the eyes of the world. He accepted this as a fact of life. There was nothing in his personality to promote his mythical stature; nor did he relish it. Privately he would express annoyance if he felt that his position was being misused. I recall the case of Professor X, who had been quoted by the newspapers as having found solutions to Einstein's generalized equations of gravitation. Einstein said to me, 'Der Mann ist ein Narr,' the man is a fool, and added that, in his opinion, X could calculate but could not think. X had visited Einstein to discuss this work, and Einstein, always courteous, had said to him that his, X's, results would be important if true. Einstein was chagrined to have been quoted in the papers without this last provision. He said that he would keep silent on the matter but would not receive X again. According to Einstein, the whole thing started because X, in his enthusiasm, had repeated Einstein's opinion to some colleagues who saw the value of it as publicity for their university.

To those physicists who could follow his scientific thought and who knew him personally, the legendary aspect was never in the foreground— yet it was never wholly absent. I remember an occasion in 1947 when I was giving a talk at the Institute about the newly discovered π and μ mesons. Einstein walked in just after I had begun. I remember being speechless for the brief moment necessary to overcome a sense of the unreal. I recall a similar moment during a symposium** held

*My stay at the Institute had lost much of its attraction because Pauli was no longer there. As I was contemplating returning to Europe, Robert Oppenheimer informed me that he had been approached for the directorship of the Institute. He asked me to join him in building up physics there. I accepted. A year later, I was appointed to a five-year membership and in 1950 to a professorship at the Institute, where I remained until 1963.

**The speakers were J. R. Oppenheimer, I. I. Rabi, E. P. Wigner, H. P. Robertson, S. M. Clemence, and H. Weyl.

in Princeton on March 19, 1949, on the occasion of Einstein's seventieth birthday. Most of us were in our seats when Einstein entered the hall. Again there was this brief hush before we stood to greet him.

Nor do I believe that such reactions were typical only of those who were much younger than he. There were a few occasions when Pauli and I were both with him. Pauli, not known for an excess of awe, was just slightly different in Einstein's company. One could perceive his sense of reverence. Bohr, too, was affected in a similar way, differences in scientific outlook notwithstanding.

Whenever I met Einstein, our conversations might range far and wide but invariably the discussion would turn to physics. Such discussions would touch only occasionally on matters of past history. We talked mainly about the present and the future. When relativity was the issue, he would often talk of his efforts to unify gravitation and electromagnetism and of his hopes for the next steps. His faith rarely wavered in the path he had chosen. Only once did he express a reservation to me when he said, in essence, 'I am not sure that differential geometry is the framework for further progress, but, if it is, then I believe I am on the right track.' (This remark must have been made some time during his last few years.)

The main topic of discussion, however, was quantum physics. Einstein never ceased to ponder the meaning of the quantum theory. Time and time again, the argument would turn to quantum mechanics and its interpretation. He was explicit in his opinion that the most commonly held views on this subject could not be the last word, but he also had more subtle ways of expressing his dissent. For example, he would never refer to a wave function as *die Wellenfunktion* but would always use mathematical terminology: *die Psifunktion*. I was never able to arouse much interest in him about the new particles which appeared on the scene in the late 1940s and especially in the early 1950s. It was apparent that he felt that the time was not ripe to worry about such things and that these particles would eventually appear as solutions to the equations of a unified theory. In some sense, he may well prove to be right.

The most interesting thing I learned from these conversations was how Einstein thought and, to some extent, who he was. Since I never became his co-worker, the discussions were not confined to any particular problem. Yet we talked physics, often touching on topics of a technical nature. We did not talk much about statistical physics, an area to which he had contributed so much but which no longer was the center of his interests. If the special and the general theory of relativity came up only occasionally, that was because at that time the main issues appeared to have been settled. Recall that the renewed surge of interest in general relativity began just after his death. However, I do remember him talking about Lorentz, the one father figure in his life; once we also talked about Poincaré. If we argued so often about the quantum theory, that was more his choice than mine. It had not taken long before I grasped the essence of the Einstein–Bohr dialogue: complementarity versus objective reality. It became clear to me from listening to them both that the advent of quantum mechanics in 1925 represented a far greater break with the past than had been the case with the coming of special relativity in 1905 or of general relativity in 1915. That had not been obvious to me earlier, as I belong to the generation which was exposed to 'ready-made' quantum mechanics. I came to understand how wrong I was in accepting a rather widespread belief that Einstein simply did not care anymore about the quantum theory. On the contrary, he wanted nothing more than to find a unified field theory which not only would join together gravitational and electromagnetic forces but also would provide the basis for a new interpretation of quantum phenomena. About relativity he spoke with detachment, about the quantum theory with passion. The quantum was his demon. I learned only much later that Einstein had once said to his friend Otto Stern, 'I have thought a hundred times as much about the quantum problems as I have about general relativity theory' [J1]. From my own experiences I can only add that this statement does not surprise me.

We talked of things other than physics: politics, the bomb, the Jewish destiny, and also of less weighty matters. One day I told Einstein a Jewish joke. Since he relished that, I began to save good ones I heard for a next occasion. As I told these stories, his face would change. Suddenly he would look much younger, almost like a naughty schoolboy. When the punch line came, he would let go with contented laughter, a memory I particularly cherish.

An unconcern with the past is a privilege of youth. In all the years I knew Einstein, I never read any of his papers, on the simple grounds that I already knew what to a physicist was memorable in them and did not need to know what had been superseded. Now it is obvious to me that I might have been able to ask him some very interesting questions had I been less blessed with ignorance. I might then have learned some interesting facts, but at a price. My discussions with Einstein never were historical interviews. They concerned live physics. I am glad it never was otherwise.

I did read Einstein's papers as the years went by, and my interest in him as an historical figure grew. Thus it came about that I learned to follow his science and his life from the end to the beginnings. I gradually became aware of the most difficult task in studying past science: to forget temporarily what came afterward. The study of his papers, discussions with others who knew him, access to the Einstein Archives, personal reminiscences—these are the ingredients which led to this book. Without disrespect or lack of gratitude, I have found the study of the scientific papers to be incomparably more important than anything else.

In the preface, I promised a tour through this book. The tour starts here. For ease I introduce the notation, to be used only in this and in the next chapter, of referring to, for example, Chapter 3 as (3) and to Chapter 5, Section (c), as (5c). To repeat, symbols such as [J1] indicate references to be found at the end of the chapter.

I shall begin by indicating how the personal biography is woven into the narrative. The early period, from Einstein's birth in 1879 to the beginning of his academic career as Privatdozent in Bern in February 1908, is discussed in (3), which contains a sketch of his childhood, his school years (contrary to popular belief he earned high marks in elementary as well as high school), his brief religious phase, his student days, his initial difficulties in finding a job, and most of the period he spent at the patent office in Bern, a period that witnesses the death of his father, his marriage to Mileva Marič, and the birth of his first son. In (10a) we follow him from the time he began as a Privatdozent in Bern to the end, in March 1911, of his associate professorship at the University of Zürich. In that period his second son was born. The next phase (11a) is his time as full professor in Prague (March 1911 to August 1912). In (12a) we follow him back to Zürich as a professor at the Federal Institute of Technology (ETH) (August 1912 to April 1914). The circumstances surrounding his move from Zürich to Berlin, his separation from Mileva and the two boys, and his reaction to the events of the First World War, are described in (14a). The story of the Berlin days is continued in (16) which ends with Einstein's permanent departure from Europe. This period includes years of illness, which did not noticeably affect his productivity; his divorce from Mileva and marriage to his cousin Elsa; and the death in his home in Berlin, of his mother (16a). Following this, (16b) and (16c) are devoted to the abrupt emergence in 1919 of Einstein (whose genius had already been fully recognized for some time by his scientific peers) as a charismatic world figure and to my views on the causes of this striking phenomenon. Next, (16d), devoted to Einstein's hectic years in Berlin in the 1920s, his early involvements with the Jewish destiny, his continued interest in pacifism, and his connection with the League of Nations, ends with his final departure from Germany in December 1932. The Belgian interlude and the early years in Princeton are described in (25b), the final years of his life in (26) to (28). The book ends with a detailed Einstein chronology (32).

Before starting on a similar tour of the scientific part, I interject a few remarks on Einstein and politics and on Einstein as a philosopher and humanist.

Whenever I think of Einstein and politics, I recall my encounter with him in the late evening of Sunday, April 11, 1954. That morning, a column by the Alsop brothers had appeared in the New York *Herald Tribune,* entitled 'Next McCarthy target: the leading physicists,' which began by stating that the junior senator from Wisconsin was getting ready to play his ace in the hole. I knew that the Oppenheimer case was about to break. That evening I was working in my office at the Institute when the phone rang and a Washington operator asked to speak to Dr Oppenheimer. I replied that Oppenheimer was out of town. (In fact, he was in Washington.) The operator asked for Dr Einstein. I told her that Einstein was not at the office and that his home number was unlisted. The operator told me next that her party wished to speak to me. The director of the Washington

Bureau of the Associated Press came on the line and told me that the Oppenheimer case would be all over the papers on Tuesday morning. He was eager for a statement by Einstein as soon as possible. I realized that pandemonium on Mercer Street the next morning might be avoided by a brief statement that evening and so said that I would talk it over with Einstein and would call back in any event. I drove to Mercer Street and rang the bell; Helen Dukas, Einstein's secretary, let me in. I apologized for appearing at such a late hour and said it would be good if I could talk briefly with the professor, who meanwhile had appeared at the top of the stairs dressed in his bathrobe and asked, 'Was ist los?' What is going on? He came down and so did his stepdaughter Margot. After I told him the reason for my call, Einstein burst out laughing. I was a bit taken aback and asked him what was so funny. He said that the problem was simple. All Oppenheimer needed to do, he said, was go to Washington, tell the officials that they were fools, and then go home. On further discussion, we decided that a brief statement was called for. We drew it up, and Einstein read it over the phone to the AP director in Washington. The next day Helen Dukas was preparing lunch when she saw cars in front of the house and cameras being unloaded. In her apron (she told me) she ran out of the house to warn Einstein, who was on his way home. When he arrived at the front door, he declined to talk to reporters.

Was Einstein's initial response correct? Of course it was, even though his suggestion would not and could not be followed. I remember once attending a seminar by Bertrand de Jouvenel in which he singled out the main characteristic of a political problem: it has no answer, only a compromise. Nothing was more alien to Einstein than to settle any issue by compromise, in his life or in his science. He often spoke out on political problems, always steering to their answer. Such statements have often been called naive.* In my view, Einstein was not only not naive but highly aware of the nature of man's sorrows and his follies. His utterances on political matters did not always address the immediately practicable, and I do not think that on the whole they were very influential. However, he knowingly and gladly paid the price of sanity.

As another comment on political matters, I should like to relate a story I was told in 1979 by Israel's President Navon. After the death of the then Israeli president, Weizman, in November 1952, Ben Gurion and his cabinet decided to offer the presidency to Einstein. Abba Eban was instructed to transmit the offer from Washington (27). Shortly thereafter, in a private conversation, Ben Gurion asked Navon (who at that time was his personal secretary), 'What are we going to do if he accepts?'

Einstein often lent his name to pacifist statements, doing so for the first time in 1914 (14a). In 1916 he gave an interview to the Berlin paper *Die Vossische Zeitung* about the work on Mach by his pacifist friend Friedrich Adler, then in jail

*Oppenheimer's description, 'There was always with him a wonderful purity at once childlike and profoundly stubborn' [O1] shows the writer's talent for almost understanding everything.

for having shot and killed Karl Stürgkh, the prime minister of Austria [E1]. After the death of Leo Arons, a physicist Einstein admired for his political courage but whom he did not know personally, he wrote an obituary in *Sozialistische Monatshefte* [E2]. After the assassination in 1922 of his acquaintance Walther Rathenau, foreign minister of the Weimar republic and a physicist by education, Einstein wrote of him in *Neue Rundschau:* 'It is no art to be an idealist if one lives in cloud-cuckoo land. He, however, was an idealist even though he lived on earth and knew its smell better than almost anyone else' [E3]. In 1923 Einstein became a cofounder of the Association of Friends of the New Russia. Together with Lorentz, Marie Curie, Henry Bergson, and others, he worked for a time as a member of the League of Nations' Committee for Intellectual Cooperation (16d). Among those he proposed or endorsed for the Nobel peace prize (31) were Masaryk; Herbert Runham Brown, honorary secretary of War Resisters International; Carl von Ossietzky, at the time in a German concentration camp; and the organization Youth Aliyah. He spoke out about the plight of the Jews and helped. Numerous are the affidavits he signed in order to bring Jews from Europe to the United States.

Pacifism and supranationalism were Einstein's two principal political ideals. In the 1920s he supported universal disarmament and a United Europe (16d). After the Second World War, he especially championed the concept of world government, and the peaceful—and only peaceful—uses of atomic energy (27). That pacifism and disarmament were out of place in the years 1933 to 1945 was both deeply regrettable and obvious to him (25b). In 1939 he sent his sensible letter to President Roosevelt on the military implications of nuclear fission. In 1943 he signed a contract with the U.S. Navy Bureau of Ordnance as occasional consultant (his fee was $25 per day).* Perhaps his most memorable contribution of that period is his saying, 'I am in the Navy, but I was not required to get a Navy haircut.' [B1]. He never forgave the Germans (27).**

Einstein's political orientation, which for simplicity may be called leftist, derived from his sense of justice, not from an approval of method or a sharing of philosophy. 'In Lenin I honor a man who devoted all his strength and sacrificed his person to the realization of social justice. I do not consider his method to be proper,' he wrote in 1929 [E4] and, shortly thereafter, 'Outside Russia, Lenin and Engels are of course not valued as scientific thinkers and no one might be interested to refute them as such. The same might also be the case in Russia, but there one cannot dare to say so' [E5]. Much documentation related to Einstein's interests in and involvements with political matters is found in the book *Einstein on Peace* [N1]).

Einstein was a lover of wisdom. But was he a philosopher? The answer to that

*The account of Einstein's consultancy given in [G1] is inaccurate.

**Einstein's cousin Lina Einstein died in Auschwitz. His cousin Bertha Dreyfus died in Theresienstadt.

question is no less a matter of taste than of fact. I would say that at his best he was not, but I would not argue strenuously against the opposite view. It is as certain that Einstein's interest in philosophy was genuine as it is that he did not consider himself a philosopher.

He studied philosophical writings throughout his life, beginning in his high school days, when he first read Kant (3). In 1943 Einstein, Gödel, Bertrand Russell, and Pauli gathered at Einstein's home to discuss philosophy of science about half a dozen times [R1]. 'Science without epistemology is—in so far as it is thinkable at all—primitive and muddled,' he wrote in his later years, warning at the same time of the dangers to the scientist of adhering too strongly to any one epistemological system. 'He [the scientist] must appear to the systematic epistemologist as a type of unscrupulous opportunist: he appears as *realist* in so far as he seeks to describe a world independent of the acts of perception; an *idealist* in so far as he looks upon the concepts and theories as the free inventions of the human spirit (not logically derivable from what is empirically given); as *positivist* in so far as he considers his concepts and theories justified *only* to the extent to which they furnish a logical representation of relations among sensory experiences. He may even appear as a *Platonist* or *Pythagorean* in so far as he considers the viewpoint of logical simplicity as an indispensable and effective tool of his research' [E6].

Elements of all these 'isms' are clearly discernible in Einstein's thinking. In the last thirty years of his life, he ceased to be an 'unscrupulous opportunist', however, when, much to his detriment, he became a philosopher by freezing himself into realism or, as he preferred to call it, objective reality. That part of his evolution will be described in detail in (25). There can be as little doubt that philosophy stretched his personality as that his philosophical knowledge played no direct role in his major creative efforts. Further remarks by Einstein on philosophical issues will be deferred until (16e), except for his comments on Newton.

The men whom Einstein at one time or another acknowledged as his precursors were Newton, Maxwell, Mach, Planck, and Lorentz. As he told me more than once, without Lorentz he would never have been able to make the discovery of special relativity. Of his veneration for Planck, I shall write in (18a); of the influence of Mach* in (15e); and of his views of Maxwell in (16e). I now turn to Newton but first digress briefly.

Einstein's deep emotional urge not to let anything interfere with his thinking dates back to his childhood and lends an unusual quality of detachment to his personal life. It was not that he was aloof or a loner, incapable of personal attachments. He was also capable of deep anger, as his attitude toward Germany during

*I should note that I do not quite share Isaiah Berlin's opinion [B2] that Mach was one of Einstein's philosophical mentors and that Einstein first accepted, then rejected Mach's phenomenalism. Einstein's great admiration for Mach came entirely from the reading of the latter's book on mechanics, in which the relativity of all motion is a guiding principle. On the other hand, Einstein considered Mach to be 'un déplorable philosophe' [E7], if only because to Mach the reality of atoms remained forever anathema.

and after the Nazi period attests. When he spoke or wrote of justice and liberty for others, called the Jews his brothers, or grieved for the heroes of the Warsaw ghetto, he did so as a man of feeling at least as much as a man of thought. That, having thus spoken and thus felt, he would want to return to the purity and safety of the world of ideas is not an entirely uncommon desire. Truly remarkable, however, was his gift to effect the return to that world without emotional effort. He had no need to push the everyday world away from him. He just stepped out of it whenever he wished. It is therefore not surprising either that (as he wrote shortly before his death) he twice failed rather disgracefully in marriage or that in his life there is an absence of figures with whom he identified—with the exception, perhaps, of Newton.

It seems to me that, when in midlife Einstein wrote of 'The wonderful events which the great Newton experienced in his young days. . . Nature to him was an open book. . . . In one person he combined the experimenter, the theorist, the mechanic, and, not least, the artist in exposition. . . . He stands before us strong, certain, and alone: his joy in creation and his minute precision are evident in every word and every figure . . .' [E8], he described his own ideals, the desire for fulfillment not just as a theorist but also as an experimental physicist. (In the second respect, he, of course, never matched Newton.) Earlier he had written that Newton 'deserves our deep veneration' for his achievements, and that Newton's own awareness of the weaknesses of his own theories 'has always excited my reverent admiration' [E9] (these weaknesses included the action of forces at a distance, which, Newton noted, was not to be taken as an ultimate explanation).

'Fortunate Newton, happy childhood of Science!' [E8]. When Einstein wrote these opening words in the introduction to a new printing of Newton's *Opticks,* he had especially in mind that Newton's famous dictum 'hypotheses non fingo,' I frame no hypotheses, expressed a scientific style of the past. Elsewhere Einstein was quite explicit on this issue:

> We now know that science cannot grow out of empiricism alone, that in the constructions of science we need to use free invention which only *a posteriori* can be confronted with experience as to its usefulness. This fact could elude earlier generations, to whom theoretical creation seemed to grow inductively out of empiricism without the creative influence of a free construction of concepts. The more primitive the status of science is the more readily can the scientist live under the illusion that he is a pure empiricist. In the nineteenth century, many still believed that Newton's fundamental rule 'hypotheses non fingo' should underlie all healthy natural science. [E10]

Einstein again expressed his view that the scientific method had moved on in words only he could have written:

> Newton, forgive me; you found the only way which in your age was just about possible for a man with the highest powers of thought and creativity. The concepts which you created are guiding our thinking in physics even today,

> although we now know that they will have to be replaced by others farther removed from the sphere of immediate experience, if we aim at a profounder understanding of relationships. [E11]

However, in one respect Einstein forever continued to side with Newton and to quote his authority. That was in the matter of causality. On the occasion of the bicentenary of Newton's death, Einstein wrote to the secretary of the Royal Society, 'All who share humbly in pondering over the secrets of physical events are with you in spirit, and join in the admiration and love that bind us to Newton', then went on to comment on the evolution of physics since Newton's day and concluded as follows:

> It is only in the quantum theory that Newton's differential method becomes inadequate, and indeed strict causality fails us. But the last word has not yet been said. May the spirit of Newton's method give us the power to restore unison between physical reality and the profoundest characteristic of Newton's teaching—strict causality. [E12]

What is strict Newtonian causality? As an example, if I give you the precise position *and* velocity of a particle at a given instant, and if you know all the forces acting on it, then you can predict from Newton's laws the precise position and velocity of that particle at a later time. Quantum theory implies, however, that I am unable to give you that information about position *and* velocity with ideal precision, even if I have the most perfect instrumentation at my disposal. That is the problem I discussed with Einstein in our conversation about the existence of the moon, a body so heavy that the limitations on the precision of information on position *and* velocity I can give you are so insignificant that, to all astronomical intents and purposes, you can neglect the indeterminacy in the information you obtained from me and continue to talk of the lunar orbit.

It is quite otherwise for things like atoms. In the hydrogen atom, the electron does not move in an orbit in the same sense as the moon moves around the earth, for, if it did, the hydrogen atom would be as flat as a little pancake whereas actually it is a little sphere. As a matter of principle, there is no way back to Newtonian causality. Of course, this recognition never diminished Newton's stature. Einstein's hope for a return to that old causality is an impossible dream. Of course, this opinion, held by modern physicists, has not prevented them from recognizing Einstein as by far the most important scientific figure of this century. His special relativity includes the completion of the work of Maxwell and Lorentz. His general relativity includes the completion of Newton's theory of gravitation and incorporates Mach's vision of the relativity of all motion. In all these respects, Einstein's oeuvre represents the crowning of the work of his precursors, adding to and revising the foundations of their theories. In this sense he is a transitional figure, perfecting the past and changing the stream of future events. At the same time he is a pioneer, as first Planck, then he, then Bohr founded a new physics without precursors—the quantum theory.

Einstein deserves to be given the same compliment he gave Newton: he, too, was an artist in exposition. His talent for the German language was second only to his gift for science. I refer not so much to his proclivity for composing charming little rhymes as to the quality of his prose. He was a master of nuances, which are hard to maintain in translation. The student of Einstein should read him in German. It is fitting that several of his important papers, such as his scientific credo in the *Journal of the Franklin Institute* of 1936, and his autobiographical sketch in the Schilpp book [E6], should appear side by side in the original German and in English translation. He wrote all his scientific papers in German, whether or not they eventually appeared in that language. Not only his mastery of language but also his perceptiveness of people is evident in his writings in memory of colleagues and friends: of Schwarzschild and Smoluchowski, of Marie Curie and Emmy Noether, of Michelson and Thomas Edison, of Lorentz, Nernst, Langevin, and Planck, of Walther Rathenau, and, most movingly, of Paul Ehrenfest. These portraits serve as the best foil for the opinion that Einstein was a naive man.

In languages other than German, he was less at ease.* On his first visit to Paris, in 1922, he lectured in French[K1]. He spoke in German, however, when addressing audiences on his first visits to England and the United States, but became fluent in English in later years.

Music was his love. He cared neither for twentieth century composers nor for many of the nineteenth century ones. He loved Schubert but was not attracted to the heavily dramatic parts of Beethoven. He was not particularly fond of Brahms and disliked Wagner. His favorite composers were earlier ones—Mozart, Bach, Vivaldi, Corelli, Scarlatti. I never heard him play the violin, but most of those who did attest to his musicality and the ease with which he sight-read scores. About his predilections in the visual arts, I quote from a letter by Margot Einstein to Meyer Schapiro:

> In visual art, he preferred, of course, the old masters. They seemed to him more 'convincing' (he used this word!) than the masters of our time. But sometimes he surprised me by looking at the *early* period of Picasso (1905, 1906). . . . Words like *cubism, abstract painting* . . . did not mean anything to him. . . . Giotto moved him deeply . . . also Fra Angelico . . . Piero della Francesca. . . . He loved the small Italian towns. . . . He loved cities like Florence, Siena (Sienese paintings), Pisa, Bologna, Padua and admired the architecture. . . . If it comes to Rembrandt, yes, he admired him and felt him deeply. [E13]**

*During the 1920s, Einstein once said to a young friend, 'I like neither new clothes nor new kinds of food. I would rather not learn new languages' [S1].

**I have no clear picture of Einstein's habits and preferences in regard to literature. I do not know how complete or representative is the following randomly ordered list of authors he liked: Heine, Anatole France, Balzac, Dostoyevski (*The Brothers Karamazov*), Musil, Dickens, Lagerlof, Tolstoi (folk stories), Kazantzakis, Brecht (*Galilei*), Broch (*The Death of Virgil*), Gandhi (autobiography), Gorki, Hersey (*A Bell for Adano*), van Loon (*Life and Times of Rembrandt*), Reik (*Listening with the Third Ear*).

As a conclusion to this introductory sketch of Einstein the man, I should like to elaborate the statement made in the Preface that Einstein was the freest man I have known. By that I mean that, more than anyone else I have encountered, he was the master of his own destiny. If he had a God it was the God of Spinoza. Einstein was not a revolutionary, as the overthrow of authority was never his prime motivation. He was not a rebel, since any authority but the one of reason seemed too ridiculous to him to waste effort fighting against (onc can hardly call his opposition to Nazism a rebellious attitude). He had the freedom to ask scientific questions, the genius to so often ask the right ones. He had no choice but to accept the answer. His deep sense of destiny led him farther than anyone before him. It was his faith in himself which made him persevere. Fame may on occasion have flattered him, but it never deflected him. He was fearless of time and, to an uncommon degree, fearless of death. I cannot find tragedy in his later attitude to the quantum theory or in his lack of success in finding a unified field theory, especially since some of the questions he asked remain a challenge to this day (2b)—and since I never read tragedy in his face. An occasional touch of sadness in him never engulfed his sense of humor.

I now turn to a tour of Einstein's science.

Einstein never cared much for teaching courses. No one was ever awarded a PhD degree working with him, but he was always fond of discussing physics problems, whether with colleagues his age or with people much younger. All his major papers are his own, yet in the course of his life he often collaborated with others. A survey of these collaborative efforts, involving more than thirty colleagues or assistants, is found in (29). From his student days until well into his forties, he would seek opportunities to do experiments. As a student he hoped to measure the drift of the aether through which (as he then believed) the earth was moving (6d). While at the patent office, he tinkered with a device to measure small voltage differences (3, 29). In Berlin he conducted experiments on rotation induced by magnetization (14b), measured the diameter of membrane capillaries (29), and was involved with patents for refrigerating devices and for a hearing aid (29). But, of course, theoretical physics was his main devotion.

There is no better way to begin this brief survey of his theoretical work than with a first look at what he did in 1905. In that year Einstein produced six papers:

1. The light-quantum and the photoelectric effect, completed March 17 (19c), (19e). This paper, which led to his Nobel prize in physics, was produced before he wrote his PhD thesis.
2. A new determination of molecular dimensions, completed April 30. This was his doctoral thesis, which was to become his paper most often quoted in modern literature (5c).

3. Brownian motion, received* May 11. This was a direct outgrowth of his thesis work (5d).
4. The first paper on special relativity, received* June 30.
5. The second paper on special relativity, containing the $E = mc^2$ relation, received* September 27.
6. A second paper on Brownian motion, received* December 19.

There is little if anything in his earlier published work that hints at this extraordinary creative outburst. By his own account, the first two papers he ever wrote, dating from 1901 and 1902 and dealing with the hypothesis of a universal law of force between molecules, were worthless (4a). Then followed three papers of mixed quality (4c, 4d) on the foundations of statistical mechanics. The last of these, written in 1904, contains a first reference to the quantum theory. None of these first five papers left much of a mark on physics, but I believe they were very important warming-up exercises in Einstein's own development. Then came a year of silence, followed by the outpouring of papers in 1905. I do not know what his trains of thought were during 1904. His personal life changed in two respects: his position at the patent office was converted from temporary to permanent status. And his first son was born. Whether these events helped to promote the emergence of Einstein's genius I cannot tell, though I believe that the arrival of the son may have been a profound experience. Nor do I know a general and complete characterization of what genius is, except that it is more than an extreme form of talent and that the criteria for genius are not objective. I note with relief that the case for Einstein as a genius will cause even less of an argument than the case for Picasso and much less of an argument than the case for Woody Allen, and I do hereby declare that—in my opinion—Einstein was a genius.

Einstein's work before 1905 as well as papers 2, 3, and 6 of that year resulted from his interest in two central early twentieth-century problems, the subjects of Part II of this book.

The first problem: molecular reality. How can one prove (or disprove) that atoms and molecules are real things? If they are real, then how can one determine their size and count their number? In (5a), there is an introductory sketch of the nineteenth century status of this question. During that period the chemist, member of the youngest branch of science, argued the question in one context, the physicist in another, and each paid little attention to what the other was saying. By about 1900 many, though not all, leading chemists and physicists believed that molecules were real. A few among the believers already knew that the atom did not deserve its name, which means 'uncuttable.' Roughly a decade later, the issue of molecular reality was settled beyond dispute, since in the intervening years the many methods for counting these hypothetical particles all gave the same result, to within small errors. The very diversity of these methods and the very sameness of the

*By the editors of *Annalen der Physik*.

answers gave the molecular picture the compelling strength of a unifying principle. Three of these methods are found in Einstein's work of 1905. In March he counted molecules in his light-quantum paper (19c). In April he made a count with the help of the flow properties of a solution of sugar molecules in water (5c). In May he gave a third count in the course of explaining the long-known phenomenon of Brownian motion of small clumps of matter suspended in solution (5d). The confluence of all these answers is the result of important late nineteenth-century developments in experimental physics. Einstein's March method could be worked out only because of a breakthrough in far-infrared spectroscopy (19a). The April and May methods were a consequence of the discovery by Dr Pfeffer of a method for making rigid membranes (5c). Einstein's later work (1911) on the blueness of the sky and on critical opalescence yielded still other counting methods (5e).

The second problem: the molecular basis of statistical physics. If atoms and molecules are real things, then how does one express such macroscopic concepts as pressure, temperature, and entropy in terms of the motion of these submicroscopic particles? The great masters of the nineteenth century—Maxwell, Boltzmann, Kelvin, van der Waals, and others—did not, of course, sit and wait for the molecular hypothesis to be proved before broaching problem number two. The most difficult of their tasks was the derivation of the second law of thermodynamics. What is the molecular basis for the property that the entropy of an isolated system strives toward a maximum as the system moves toward equilibrium? A survey of the contributions to this problem by Einstein's predecessors as well as by Einstein himself is presented in (4). In those early days, Einstein was not the only one to underestimate the mathematical care that this very complex problem rightfully deserves. When Einstein did this work, his knowledge of the fundamental contributions by Boltzmann was fragmentary, his ignorance of Gibbs' papers complete. This does not make any easier the task of ascertaining the merits of his contributions.

To Einstein, the second problem was of deeper interest than the first. As he said later, Brownian motion was important as a method for counting particles, but far more important because it enables us to demonstrate the reality of those motions we call heat, simply by looking into a microscope. On the whole, Einstein's work on the second law has proved to be of less lasting value than his investigations on the verification of the molecular hypothesis. Indeed, in 1911 he wrote that he would probably not have published his papers of 1903 and 1904 had he been aware of Gibbs' work.

Nevertheless, Einstein's preoccupation with the fundamental questions of statistical mechanics was extremely vital since it led to his most important contributions to the quantum theory. It is no accident that the term *Boltzmann's principle,* coined by Einstein, appears for the first time in his March 1905 paper on the light-quantum. In fact the light-quantum postulate itself grew out of a statistical argument concerning the equilibrium properties of radiation (19c). It should also be remembered that the main applications of his first work (1904) on energy fluctuations (4c) are in the quantum domain. His analysis of these fluctuations in blackbody radiation led him to become the first to state, in 1909, long before the discovery of quantum mechanics, that the theory of the future ought to be based on a dual description in terms of particles and waves (21a). Another link between statistical mechanics and the quantum theory was forged by his study of the Brownian motion of molecules in a bath of electromagnetic radiation. This investigation led him to the momentum properties of light-quanta (21c). His new derivation, in 1916, of Planck's blackbody radiation law also has a statistical basis (21b). In the course of this last work, he observed a lack of Newtonian causality in the process called spontaneous emission. His discomfort about causality originated from that discovery (21d).

Einstein's active involvement with statistical physics began in 1902 and lasted until 1925, when he made his last major contribution to physics: his treatment of the quantum statistics of molecules (23). Again and for the last time, he applied fluctuation phenomena with such mastery that they led him to the very threshold of wave mechanics (24b). The links between the contributions of Einstein, de Broglie, and Schroedinger, discussed in (24), make clear that wave mechanics has its roots in statistical mechanics—unlike matrix mechanics, where the connections between the work of Bohr, Heisenberg, and Dirac followed in the first instance from studies of the dynamics of atoms (18c).

Long periods of gestation are a marked characteristic in Einstein's scientific development. His preoccupation with quantum problems, which began shortly after Planck's discovery of the blackbody radiation law late in 1900, bore its first fruit in March 1905. Questions that lie at the root of the special theory of relativity dawned on him as early as 1895 (6d); the theory saw the light in June 1905. He began to think of general relativity in 1907 (9); that theory reached its first level of completion in November 1915 (14c). His interest in unified field theory dates back at least to 1918 (17a). He made the first of his own proposals for a theory of this kind in 1925 (17d). As far as the relativity theories are concerned, these gestation periods had a climactic ending. There was no more than about five weeks between his understanding of the correct interpretation of the measurement of time and the completion of his first special relativity paper (7a). Similarly, after years of trial and error, he did all the work on his ultimate formulation of general relativity in approximately two months (14c).

I focus next on special relativity. One version of its history could be very brief: in June, 1905, Einstein published a paper on the electrodynamics of moving bodies. It consists of ten sections. After the first five sections, the theory lies before us in finished form. The rest, to this day, consists of the application of the principles stated in those first five sections.

My actual account of that history is somewhat more elaborate. It begins with brief remarks on the nineteenth century concept of the aether (6a), that quaint, hypothetical medium which was introduced for the purpose of explaining the transmission of light waves and which was abolished by Einstein. The question has often been asked whether or not Einstein disposed of the aether because he was familiar with the Michelson–Morley experiment, which, with great accuracy, had demonstrated the absence of an anticipated drift of the aether as the earth moved through it without obstruction (6a). The answer is that Einstein undoubtedly knew of the Michelson–Morley result (6d) but that probably it played only an indirect role in the evolution of his thinking (7a). From 1907 on, Einstein often emphasized the fundamental importance of the work by Michelson and Morley, but continued to be remarkably reticent about any direct influence of that experiment on his own development. An understanding of that attitude lies beyond the edge of history. In (8) I shall dare to speculate on this subject.

Two major figures, Lorentz and Poincaré, take their place next to Einstein in the history of special relativity. Lorentz, founder of the theory of electrons, codiscoverer of the Lorentz contraction (as Poincaré named it), interpreter of the Zeeman effect, acknowledged by Einstein as his precursor, wrote down the Lorentz transformations (so named by Poincaré) in 1904. In 1905, Einstein, at that time aware only of Lorentz's writings up to 1895, rediscovered these transformations. In 1898, Poincaré, one of the greatest mathematicians of his day and a consummate mathematical physicist, had written that we have no direct intuition of the simultaneity of events occurring in two different places, a remark almost certainly known to Einstein before 1905 (6b). In 1905 Einstein and Poincaré stated independently and almost simultaneously (within a matter of weeks) the group properties of the Lorentz transformations and the addition theorem of velocities. Yet, both Lorentz and Poincaré missed discovering special relativity; they were too deeply steeped in considerations of dynamics. Only Einstein saw the crucial new point: the dynamic aether must be abandoned in favor of a new kinematics based on two new postulates (7). Only he saw that the Lorentz transformations, and hence the Lorentz–Fitzgerald contraction, can be derived from kinematic arguments. Lorentz acknowledged this and developed a firm grasp of special relativity, but even after 1905 never quite gave up either the aether or his reservations concerning the velocity of light as an ultimate velocity (8). In all his life (he died in 1912), Poincaré never understood the basis of special relativity (8).

Special relativity brought clarity to old physics and created new physics, in particular Einstein's derivation (also in 1905) of the relation $E = mc^2$ (7b). It was some years before the first main experimental confirmation of the new theory, the energy-mass-velocity relation for fast electrons, was achieved (7e). After 1905 Einstein paid only occasional attention to other implications (7d), mainly because from 1907 he was after bigger game: general relativity.

The history of the discovery of general relativity is more complicated. It is a tale of a tortuous path. No amount of simplification will enable me to match the minihistory of special relativity given earlier. In the quantum theory, Planck started before Einstein. In special relativity, Lorentz inspired him. In general relativity, he starts the long road alone. His progress is no longer marked by that light touch and deceptive ease so typical of all his work published in 1905. The first steps are made in 1907, as he discovers a simple version of the equivalence principle and understands that matter will bend light and that the spectral lines reaching us from the sun should show a tiny shift toward the red relative to the same spectral lines produced on earth (9). During the next three and a half years, his attention focuses on that crisis phenomenon, the quantum theory, rather than on the less urgent problems of relativity (10). His serious concentration on general relativity begins after his arrival in Prague in 1911, where he teaches himself a great deal with the help of a model theory. He gives a calculation of the bending of light by the sun. His result is imperfect, since at that time he still believes that space is flat (11). In the summer of 1912, at the time of his return to Zürich, he makes a fundamental discovery: space is not flat; the geometry of the world is not Euclidean. It is Riemannian. Ably helped by an old friend, the mathematician Marcel Grossmann, he establishes the first links between geometry and gravity. With his habitual optimism he believes he has solved the fifty-year-old problem (13) of finding a field theory of gravitation. Not until late in 1915 does he fully realize how flawed his theory actually is. At that very same time, Hilbert starts his important work on gravitation (14d). After a few months of extremely intense work, Einstein presents the final revised version of his theory on November 25, 1915 (14c).

One week earlier he had obtained two extraordinary results. Fulfilling an aspiration he had had since 1907, he found the correct explanation of the long-known precession of the perihelion of the planet Mercury. That was the high point in his scientific life. He was so excited that for three days he could not work. In addition he found that his earlier result on the bending of light was too small by a factor of 2. Einstein was canonized in 1919 when this second prediction also proved to be correct (16b).

After 1915 Einstein continued to examine problems in general relativity. He was the first to give a theory of gravitational waves (15d). He was also the founder of general relativistic cosmology, the modern theory of the universe at large (15e). Hubble's discovery that the universe is expanding was made in Einstein's lifetime. Radio galaxies, quasars, neutron stars, and, perhaps, black holes were found after his death. These post-Einsteinian observational developments in astronomy largely account for the great resurgence of interest in general relativity in more recent times. A sketchy account of the developments in general relativity after 1915 up to the present appears in (15).

I return to earlier days. After 1915 Einstein's activities in the domain of relativity became progressively less concerned with the applications of general relativity than with the search for generalization of that theory. During the early years following the discovery of general relativity, the aim of that search appeared to be highly plausible: according to general relativity the very existence of the gravitational field is inalienably woven into the geometry of the physical world. There was nothing equally compelling about the existence of the electromagnetic field, at that time the only field other than that of gravity known to exist (17a). Riemannian geometry does not geometrize electromagnetism. Should not one therefore try to invent a more general geometry in which electromagnetism would be just as fundamental as gravitation? If the special theory of relativity had unified electricity and magnetism and if the general theory had geometrized gravitation, should not one try next to unify and geometrize electromagnetism and gravity? After he experimentally unified electricity and magnetism, had not Michael Faraday tried to observe whether gravity could induce electric currents by letting pieces of metal drop from the top of the lecture room in the Royal Institution to a cushion on the floor? Had he not written, 'If the hope should prove well-founded, how great and mighty and sublime in its hitherto unchangeable character is the force I am trying to deal with, and how large may be the new domain of knowledge that may be opened to the mind of man'? And when his experiment showed no effect, had he not written, 'They do not shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists'? [W1] Thoughts and visions such as these led Einstein to his program for a unified field theory. Its purpose was neither to incorporate the unexplained nor to resolve any paradox. It was purely a quest for harmony.

On his road to general relativity, Einstein had found the nineteenth century geometry of Riemann waiting for him. In 1915 the more general geometries which he and others would soon be looking for did not yet exist. They had to be invented. It should be stressed that the unification program was not the only spur to the search for new geometries. In 1916, mathematicians, acknowledging the stimulus of general relativity, began the very same pursuit for their own reasons. Thus Einstein's work was the direct cause of the development of a new branch of mathematics, the theory of connections (17c).

During the 1920s and 1930s, it became evident that there exist forces other than those due to gravitation and electromagnetism. Einstein chose to ignore those new forces although they were not and are not any less fundamental than the two which have been known about longer. He continued the old search for a unification of gravitation and electromagnetism, following one path, failing, trying a new one. He would study worlds having more than the familiar four dimensions of space and time (17b) or new world geometries in four dimensions (17d). It was to no avail.

In recent years, the quest for the unification of all forces has become a central theme in physics (17e). The methods are new. There has been distinct progress (2b). But Einstein's dream, the joining of gravitation to other forces, has so far not been realized.

In concluding this tour, I return to Einstein's contributions to the quantum theory. I must add that, late in 1906, Einstein became the founder of the quantum theory of the solid state by giving the essentially correct explanation of the anomalous behavior of hard solids, such as diamond, for example, at low temperatures (20). It is also necessary to enlarge on the remark made previously concerning the statistical origins of the light-quantum hypothesis. Einstein's paper of March 1905 contains not one but two postulates. First, the light-quantum was conceived of as a parcel of energy as far as the properties of pure radiation (no coupling to matter) are concerned. Second, Einstein made the assumption—he called it the heuristic principle—that also in its coupling to matter (that is, in emission and absorption), light is created or annihilated in similar discrete parcels of energy (19c). That, I believe, was Einstein's one revolutionary contribution to physics (2). It upset all existing ideas about the interaction between light and matter. I shall describe in detail the various causes for the widespread disbelief in the heuristic principle (19f), a resistance which did not weaken after other contributions of Einstein were recognized as outstanding or even after the predictions for the photoelectric effect, made on the grounds of the heuristic principle, turned out to be highly successful (19e).

The light-quantum, a parcel of energy, slowly evolved into the photon, a parcel of energy and momentum (21), a fundamental particle with zero mass and unit spin. Never was a proposal for a new fundamental particle resisted more strongly than this one for the photon (18b). No one resisted the photon longer than Bohr (22). All resistance came to an end when experiments on the scattering of light by electrons (the Compton effect) proved that Einstein was right (21f, 22).

Quantum mechanics was born within a few months of the settling of the photon issue. In (25) I describe in detail Einstein's response to this new development. His initial belief that quantum mechanics contained logical inconsistencies (25a) did not last long. Thereafter, he became convinced that quantum mechanics is an incomplete description of nature (25c). Nevertheless, he acknowledged that the nonrelativistic version of quantum mechanics did constitute a major advance. His proposal of a Nobel prize for Schroedinger and Heisenberg is but one expression of that opinion (31).

However, Einstein never had a good word for the relativity version of quantum mechanics known as quantum field theory. Its successes did not impress him. Once, in 1912, he said of the quantum theory that the more successful it is, the sillier it looks (20). When speaking of successful physical theories, he would, in his later years, quote the example of the old gravitation theory (26). Had Newton not been successful for more than two centuries? And had his theory not turned out to be incomplete?

Einstein himself never gave up the search for a theory that would incorporate quantum phenomena but would nevertheless satisfy his craving for causality. His vision of a future interplay of relativity and quantum theory in a unified field theory is the subject of the last scientific chapter of this book (26), in which I return to the picture drawn in the preface.

Finally, I may be permitted to summarize my own views. Newtonian causality is gone for good. The synthesis of relativity and the quantum theory is incomplete (2). In the absence of this synthesis, any assessment of Einstein's vision must be part of open history.

The tour ends here. General comments on relativity and quantum theory come next, followed by a sketch of Einstein's early years. Then the physics begins.

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2
Relativity Theory and Quantum Theory

Einstein's life ended . . . with a demand on us for synthesis.
W. Pauli [P1]

2a. Orderly Transitions and Revolutionary Periods

In all the history of physics, there has never been a period of transition as abrupt, as unanticipated, and over as wide a front as the decade 1895 to 1905. In rapid succession the experimental discoveries of X-rays (1895), the Zeeman effect (1896), radioactivity (1896), the electron (1897), and the extension of infrared spectroscopy into the 3 μm to 60 μm region opened new vistas. The birth of quantum theory (1900) and relativity theory (1905) marked the beginning of an era in which the very foundations of physical theory were found to be in need of revision. Two men led the way toward the new theoretical concepts: Max Karl Ernst Ludwig Planck, professor at the University of Berlin, possessed—perhaps obsessed—by the search for the universal function of frequency and temperature, known to exist since 1859, when Gustav Robert Kirchhoff formulated his fundamental law of blackbody radiation (19a)*; and Albert Einstein, technical expert at the Swiss patent office in Bern, working in an isolation which deserves to be called splendid (3).

In many superficial ways, these two men were quite unlike each other. Their backgrounds, circumstances, temperaments, and scientific styles differed profoundly. Yet there were deep similarities. In the course of addressing Planck on the occasion of Planck's sixtieth birthday, Einstein said:

> The longing to behold . . . preestablished harmony** is the source of the inexhaustible persistence and patience with which we see Planck devoting himself to the most general problems of our science without letting himself be deflected by goals which are more profitable and easier to achieve. I have often heard that colleagues would like to attribute this attitude to exceptional will-power

*In this chapter, I use for the last time parenthetical notations when referring to a chapter or a section thereof. Thus, (19a) means Chapter 19, Section a.

**An expression of Leibniz's which Einstein considered particularly apt.

> and discipline; I believe entirely wrongly so. The emotional state which enables such achievements is similar to that of the religious person or the person in love; the daily pursuit does not originate from a design or program but from a direct need [E1].

This overriding urge for harmony directed Einstein's scientific life as much as it did Planck's. The two men admired each other greatly.

The main purpose of this chapter is to make some introductory comments on Einstein's attitude to the quantum and relativity theories. To this end, it will be helpful to recall a distinction which he liked to make between two kinds of physical theories [E2]. Most theories, he said, are constructive, they interpret complex phenomena in terms of relatively simple propositions. An example is the kinetic theory of gases, in which the mechanical, thermal, and diffusional properties of gases are reduced to molecular interactions and motions. 'The merit of constructive theories is their comprehensiveness, adaptability, and clarity.' Then there are the theories of principle, which use the analytic rather than the synthetic method: 'Their starting points are not hypothetical constituents but empirically observed general properties of phenomena.' An example is the impossibility of a perpetuum mobile in thermodynamics. '[The merit of] theories of principle [is] their logical perfection and the security of their foundation.' Then Einstein went on to say, 'The theory of relativity is a theory of principle.' These lines were written in 1919, when relativity had already become 'like a house with two separate stories': the special and the general theory. (Of course, the special theory by itself is a theory of principle as well.)

Thus, toward the end of the decade 1895–1905 a new theory of principle had emerged: special relativity. What was the status of quantum theory at that time? It was neither a theory of principle nor a constructive theory. In fact, it was not a theory at all. Planck's and Einstein's first results on blackbody radiation proved that there was something wrong with the foundations of classical physics, but old foundations were not at once replaced by new ones—as had been the case with the special theory of relativity from its very inception (7). Peter Debye recalled that, soon after its publication, Planck's work was discussed in Aachen, where Debye was then studying with Arnold Sommerfeld. Planck's law fitted the data well, 'but we did not know whether the quanta were something fundamentally new or not' [B1].

The discovery of the quantum theory in 1900 (19a) and of special relativity in 1905 (7) have in common that neither was celebrated by press releases, dancing in the streets, or immediate proclamations of the dawn of a new era. There all resemblance ends. The assimilation of special relativity was a relatively fast and easy process. It is true that great men like Hendrik Antoon Lorentz and Henri Poincaré had difficulty recognizing that this was a new theory of kinematic principle rather than a constructive dynamic theory (8) and that the theory caused the inevitable confusion in philosophical circles, as witness, for example, the little book on the subject by Henry Bergson written as late as 1922 [B2]. Nevertheless, senior men like Planck, as well as a new generation of theorists, readily recognized special relativity to be fully specified by the two principles stated by Einstein in his 1905 paper (7a). All the rest was application of these theoretical principles. When special relativity appeared, it was at once 'all there.' There never was an 'old' theory of relativity.

By contrast, the 'old' quantum theory, developed in the years from 1900 to 1925, progressed by unprincipled—but tasteful—invention and application of ad hoc rules rather than by a systematic investigation of the implications of a set of axioms. This is not to say that relativity developed in a 'better' or 'healthier' way than did quantum physics, but rather to stress the deep-seated differences between the evolution of the two. Nor should one underestimate the tremendous, highly concrete, and lasting contributions of the conquistadores, Einstein among them, who created the old quantum theory. The following four equations illustrate better than any long dissertation what they achieved:

$$\rho(\nu,T) = \frac{8\pi h\nu^3}{c^3}\frac{1}{\exp(h\nu/kT) - 1}, \tag{2.1}$$

Planck's formula for the spectral density ρ of blackbody radiation in thermal equilibrium as a function of frequency ν and temperature T (h = Planck's constant, k = Boltzmann's constant, c = velocity of light), the oldest equation in the quantum theory of radiation. It is remarkable that the old quantum theory would originate from the analysis of a problem as complex as blackbody radiation. From 1859 until 1926, this problem remained at the frontier of theoretical physics, first in thermodynamics, then in electromagnetism, then in the old quantum theory, and finally in quantum statistics;

$$E = h\nu - P, \tag{2.2}$$

Einstein's 1905 equation for the energy E of photoelectrons liberated from a metallic surface irradiated by light of frequency ν (19e), the oldest equation in the quantum theory of the interaction between radiation and matter;

$$c_\nu = 3R\left(\frac{h\nu}{kT}\right)^2 \frac{\exp(h\nu/kT)}{[\exp(h\nu/kT) - 1]^2}, \tag{2.3}$$

Einstein's 1906 equation for the specific heat c_ν of one gram-atom of an idealized crystalline solid, in which all lattice points vibrate harmonically with a unique frequency ν around their equilibrium positions (R is the gas constant) (20), the oldest equation in the quantum theory of the solid state; and

$$\text{Rydberg's constant} = \frac{2\pi^2 e^4 m}{h^3 c}, \tag{2.4}$$

the equation given in 1913 by Niels Bohr, the oldest equation in the quantum theory of atomic structure. Long before anyone knew what the principles of the quantum theory were, the successes of equations like these made it evident that such a theory had to exist. Every one of these successes was a slap in the face of hallowed classical concepts. New inner frontiers, unexpected contraventions of accepted knowledge, appeared in several places: the equipartition theorem of classical statistical mechanics could not be true in general (19b); electrons appeared to be revolving in closed orbits without emitting radiation.

The old quantum theory spans a twenty-five-year period of revolution in physics, a revolution in the sense that existing order kept being overthrown. Relativity theory, on the other hand, whether of the special or the general kind, never was revolutionary in that sense. Its coming was not disruptive, but instead marked an extension of order to new domains, moving the outer frontiers of knowledge still farther out.

This state of affairs is best illustrated by a simple example. According to special relativity, the physical sum $\sigma(v_1,v_2)$ of two velocities v_1 and v_2 with a common direction is given by

$$\sigma(v_1, v_2) = \frac{v_1 + v_2}{1 + \frac{v_1 v_2}{c^2}} \tag{2.5}$$

a result obtained independently by Poincaré and Einstein in 1905. This equation contains the limit law, $\sigma(v_1,c) = c$, as a case of extreme novelty. It also makes clear that for any velocities, however small, the classical answer, $\sigma(v_1,v_2) = v_1 + v_2$, is no longer rigorously true. But since c is of the order of one billion miles per hour, the equation also says that the classical answer can continue to be trusted for all velocities to which it was applied in early times. That is the correspondence principle of relativity, which is as old as relativity itself. The ancestors, from Galileo via Newton to Maxwell, could continue to rest in peace and glory.

It was quite otherwise with quantum theory. To be sure, after the discovery of the specific heat expression, it was at once evident that Eq. 2.3 yields the long-known Dulong–Petit value of 6 calories/mole (20a) at high temperature. Nor did it take long (only five years) before the connection between Planck's quantum formula (Eq. 2.1) and the classical 'Rayleigh–Einstein–Jeans limit' ($h\nu \ll kT$) was established (19b). These two results indicated that the classical statistical law of equipartition would survive in the correspondence limit of (loosely speaking) high temperature. But there was (and is) no correspondence limit for Eqs. 2.2 and 2.4. Before 1925, nothing was proved from first principles. Only after the discoveries of quantum mechanics, quantum statistics, and quantum field theory did Eqs. 2.1 to 2.4 acquire a theoretical foundation.

The main virtue of Eq. 2.5 is that it simultaneously answers two questions: where does the new begin? where does the old fit in? The presence of the new indicates a clear break with the past. The immediate recognizability of the old shows that this break is what I shall call an orderly transition. On the other hand, a revolution in science occurs if at first *only* the new presents itself. From that moment until the old fits in again (it is a rule, not a law, that this always happens in physics), we have a period of revolution. Thus the births of the relativities were orderly transitions, the days of the old quantum theory were a revolutionary period. I stress that this distinction is meant to apply to the historical process of discovery, not to the content of one or another physical theory. (I would not argue against calling the abandonment of the aether and the rejection of absolute simultaneity in 1905 and the rejection of Newton's absolute space in 1915 amazing, astounding, audacious, bold, brave . . . or revolutionary steps.)

No one appreciated the marked differences between the evolution of relativity and quantum theory earlier and better than Einstein, the only man who had been instrumental in creating both. Nor, of course, was anyone better qualified than he to pronounce on the structure of scientific revolutions. After all, he had been to the barricades. Let us see what he had to say about this subject.

Early in 1905 he wrote a letter to a friend in which he announced his forthcoming papers on the quantum theory and on special relativity. He called the first paper 'very revolutionary.' About the second one he only remarked that 'its kinematic part will interest you' [E3].

In a report of a lecture on relativity that Einstein gave in London on June 13, 1921, we read, 'He [Einstein] deprecated the idea that the new principle was revolutionary. It was, he told his audience, the direct outcome and, in a sense, the natural completion of the work of Faraday, Maxwell, and Lorentz. Moreover there was nothing specially, certainly nothing intentionally, philosophical about it. . . .' [N1].

In the fall of 1919, in the course of a discussion with a student, Einstein handed her a cable which had informed him that the bending of light by the sun was in agreement with his general relativistic prediction. The student asked what he would have said if there had been no confirmation. Einstein replied, 'Da könnt' mir halt der liebe Gott leid tun. Die Theorie stimmt doch.' Then I would have to pity the dear Lord. The theory is correct anyway [R1]. (This statement is not at variance with the fact that Einstein was actually quite excited when he first heard the news of the bending of light (16b).)

These three stories characterize Einstein's lifelong attitude to the relativity theories: they were orderly transitions in which, as he experienced it, he played the role of the instrument of the Lord, Who, he deeply believed, was subtle but not malicious.

Regarding Einstein's judgment of his own role in quantum physics, there is first of all his description of his 1905 paper 'On a heuristic point of view concerning the generation and transformation of light' as very revolutionary (19c). Next we have his own summary: 'What I found in the quantum domain are only occasional insights or fragments which were produced in the course of fruitless struggles with the grand problem. I am ashamed* to receive at this time such a great honor for this' [E4]. Those words he spoke on June 28, 1929, the day he received

*I have translated *Ich bin beschämt* as *I am ashamed* rather than as *I am embarrassed* because I believe that the first alternative more accurately reflects Einstein's mood.

the Planck medal from Planck's own hands. By then the revolutionary period of the old quantum theory—which coincided exactly with the years of Einstein's highest creativity!—had made way for nonrelativistic quantum mechanics (and the beginning of its relativistic extension), a theory which by 1929 was recognized by nearly everyone as a new theory of principle.

Einstein dissented. To him, who considered relativity theory no revolution at all, the quantum theory was still in a state of revolution and—as he saw it—remained so for the rest of his life; according to him the old did not yet fit in properly. That is the briefest characterization of Einstein's scientific philosophy. He was more deeply commited to orderly transition than to revolution. He could be radical but never was a rebel.

In the same speech in 1929, he also said, 'I admire to the highest degree the achievements of the younger generation of physicists which goes by the name quantum mechanics and believe in the deep level of truth of that theory; but I believe that the restriction to statistical laws will be a passing one.' The parting of ways had begun. Einstein had started his solitary search for a theory of principle that would maintain classical causality in an orderly way and from which quantum mechanics should be derivable as a constructive theory.

Far more fascinating to me than the substance of Einstein's critique of quantum mechanics—to be discussed in detail in (26)—is the question of motivation. What drove Einstein to this search which he himself called 'quite bizarre as seen from the outside' [E5]? Why would he continue 'to sing my solitary little old song' [E6] for the rest of his life? As I shall discuss in (27), the answer has to do with a grand design which Einstein conceived early, before the discovery of quantum mechanics, for a synthetic physical theory. It was to be a theory of particles and fields in which general relativity and quantum theory would be synthesized. This he failed to achieve.

So to date have we all.

The phenomena to be explained by a theory of principle have become enormously richer since the days when Einstein made the first beginnings with his program. Theoretical progress has been very impressive, but an all-embracing theory does not exist. The need for a new synthesis is felt more keenly as the phenomena grow more complex.

Therefore any assessment of Einstein's visions can be made only from a vantage point that is necessarily tentative. It may be useful to record ever so briefly what this vantage point appears to be to at least one physicist. This is done in the following 'time capsule,' which is dedicated to generations of physicists yet unborn.*

2b. A Time Capsule

When Einstein and others embarked on their programs of unification, three particles (in the modern sense) were known to exist, the electron, the proton, and the

*The following section is meant to provide a brief record without any attempt at further explanation or reference to literature. It can be skipped without loss of continuity.

photon, and there were two fundamental interactions, electromagnetism and gravitation. At present the number of particles runs into the hundreds. A further reduction to more fundamental units appears inevitable. It is now believed that there are at least four fundamental interactions. The unification of all four types of forces—gravitational, electromagnetic, weak, and strong—is an active topic of current exploration. It has not been achieved as yet.

Relativistic quantum field theories (in the sense of special relativity) are the principal tools for these explorations. Our confidence in the general field theoretical approach rests first and foremost on the tremendous success of quantum electrodynamics (QED). One number, the g factor of the electron, may illustrate both the current level of predictability of this theory and the level of experimental precision which has been reached:

$$\tfrac{1}{2}(g-2) = \begin{cases} 1\ 159\ 652\ 460\ (127)\ (75) \times 10^{-12} & \text{predicted by pure QED*} \\ 1\ 159\ 652\ 200\ (40) \times 10^{-12} & \text{observed} \end{cases}$$

It has nevertheless become evident that this branch of field theory will merge with the theory of other fields.

'If we could have presented Einstein with a synthesis of his general relativity and the quantum theory, then the discussion with him would have been considerably easier' [P1]. To date, this synthesis is beset with conceptual and technical difficulties. The existence of singularities associated with gravitational collapse is considered by some an indication for the incompleteness of the general relativistic equations. It is not known whether or not these singularities are smoothed out by quantum effects.

There is hope that gravitational waves will be observed in this century (15d).

The ultimate unification of weak and electromagnetic interactions has probably not yet been achieved, but a solid beach-head appears to have been established in terms of local non-Abelian gauge theories with spontaneous symmetry breakdown. As a result, it is now widely believed that weak interactions are mediated by massive vector mesons. Current expectations are that such mesons will be observed within the decade.

It is widely believed that strong interactions are also mediated by local non-Abelian gauge fields. Their symmetry is supposed to be unbroken so that the corresponding vector mesons are massless. The dynamics of these 'non-Abelian photons' are supposed to prohibit their creation as single free particles. The technical exploration of this theory is in its early stages.

Promising steps have been made toward grand unification, the union of weak, electromagnetic, and strong interactions in one compact, non-Abelian gauge

*In this prediction (which does not include small contributions from muons and hadrons), the best value of the fine-structure constant α has been used as an input: $\alpha^{-1} = 137.035\ 963\ (15)$. The principal source of uncertainty in the predicted value of $(g-2)$ stems from the experimental uncertainties of α, leading to the error (127). The error (75) is mainly due to uncertainties in the eighth order calculation [K1].

group. In most grand unified theories the proton is unstable. News about the proton's fate is eagerly awaited at this time.

Superunification, the union of all four forces, is the major goal. Some believe that it is near and that supergravity will provide the answer. Others are not so sure.

All modern work on unification may be said to represent a program of geometrization that resembles Einstein's earlier attempts, although the manifold subject to geometrization is larger than he anticipated and the quantum framework of the program would not have been to his liking.

In the search for the correct field theory, model theories have been examined which reveal quite novel possibilities for the existence of extended structures (solitons, instantons, monopoles). In the course of these investigations, topological methods have entered this area of physics. More generally, it has become clear in the past decade that quantum field theory is much richer in structure than was appreciated earlier. The renormalizability of non-Abelian gauge fields with spontaneous symmetry breakdown, asymptotic freedom, and supersymmetry are cases in point.

The proliferation of new particles has led to attempts at a somewhat simplifed underlying description. According to the current picture, the basic constituents of matter are: two classes of spin-½ particles, the leptons and the quarks; a variety of spin-1 gauge bosons, some massless, some massive; and (more tentatively) some fundamental spin-zero particles. The only gauge boson observed so far is the photon. To date, three kinds of charged leptons have been detected. The quarks are hypothetical constituents of the observed hadrons. To date, at least five species of quarks have been identified. The dynamics of the strong interactions are supposed to prohibit the creation of quarks as isolated, free particles. This prohibition, confinement, has not as yet been implemented theoretically in a convincing way. No criterion is known which enables one to state how many species of leptons and of quarks should exist.

Weak, electromagnetic, and strong interactions have distinct intrinsic symmetry properties, but this hierarchy of symmetries is not well understood theoretically. Perhaps the most puzzling are the small effects of noninvariance under space reflection and the even smaller effects of noninvariance under time reversal. It adds to the puzzlement that the latter phenomenon has been observed so far only in a single instance, namely, in the $K^\circ - \overline{K}^\circ$ system. (These phenomena were first observed after Einstein's death. I have often wondered what might have been his reactions to these discoveries, given his 'conviction that pure mathematical construction enables us to discover the concepts and the laws connecting them' [E7].)

It is not known why electric charge is quantized, but it is plausible that this will be easily explicable in the framework of a future gauge theory.

In summary, physicists today are hard at work to meet Einstein's demands for synthesis, using methods of which he probably would be critical. Since about 1970, there has been much more promise for progress than in the two or three decades before. Yet the theoretical structures now under investigation are not as simple and economical as one would wish. The evidence is overwhelming that the theory of particles and fields is still incomplete. Despite much progress, Einstein's earlier complaint remains valid to this day: 'The theories which have gradually been associated with what has been observed have led to an unbearable accumulation of independent assumptions' [E8]. At the same time, no experimental evidence or internal contradiction exists to indicate that the postulates of general relativity, of special relativity, or of quantum mechanics are in mutual conflict or in need of revision or refinement. We are therefore in no position to affirm or deny that these postulates will forever remain unmodified.

I conclude this time capsule with a comment by Einstein on the meaning of the occurrence of dimensionless constants (such as the fine-structure constant or the electron–proton mass ratio) in the laws of physics, a subject about which he knew nothing, we know nothing: 'In a sensible theory there are no [dimensionless] numbers whose values are determinable only empirically. I can, of course, not prove that . . . dimensionless constants in the laws of nature, which from a purely logical point of view can just as well have other values, should not exist. To me in my 'Gottvertrauen' [faith in God] this seems evident, but there might well be few who have the same opinion' [E9].

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3

Portrait of the Physicist as a Young Man

Apart . . . 4. Away from others in action or function; separately, independently, individually.

Oxford English Dictionary

It is not known whether Hermann Einstein became a partner in the featherbed enterprise of Israel and Levi before or after August 8, 1876. Certain it is that by then he, his mother, and all his brothers and sisters, had been living for some time in Ulm, in the kingdom of Württemberg. On that eighth of August, Hermann married Pauline Koch in the synagogue in Cannstatt. The young couple settled in Ulm, first on the Münsterplatz, then, at the turn of 1878–9, on the Bahnhofstrasse. On a sunny Friday in the following March their first child was born, a citizen of the new German empire, which Württemberg had joined in 1871. On the following day Hermann went to register the birth of his son. In translation the birth certificate reads, 'No. 224. Ulm, March 15, 1879. Today, the merchant Hermann Einstein, residing in Ulm, Bahnhofstrasse 135, of the Israelitic faith, personally known, appeared before the undersigned registrar, and stated that a child of the male sex, who has received the name Albert, was born in Ulm, in his residence, to his wife Pauline Einstein, née Koch, of the Israelitic faith, on March 14 of the year 1879, at 11:30 a.m. Read, confirmed, and signed: Hermann Einstein. The Registrar, Hartman.' In 1944 the house on the Bahnhofstrasse was destroyed during an air attack. The birth certificate can still be found in the Ulm archives.

Albert was the first of Hermann and Pauline's two children. On November 18, 1881, their daughter, Maria, was born. There may never have been a human being to whom Einstein felt closer than his sister Maja (as she was always called). The choice of nonancestral names for both children illustrates the assimilationist disposition in the Einstein family, a trend widespread among German Jews in the nineteenth century. Albert was named (if one may call it that) after his grandfather Abraham,* but it is not known how the name Maria was chosen. 'A liberal

*Helen Dukas, private communication.

spirit, nondogmatic in regard to religion, prevailed in the family. Both parents had themselves been raised that way. Religious matters and precepts were not discussed' [M1]. Albert's father was proud of the fact that Jewish rites were not practised in his home [R1].

Maja's biographical essay about her brother, completed in 1924, is the main source of family recollections about Albert's earliest years. It informs us of the mother's fright at the time of Albert's birth because of the unusually large and angular back of the baby's head (that uncommon shape of the skull was to be permanent); of a grandmother's first reaction upon seeing the newest member of the family: 'Viel zu dick! Viel zu dick!' (much too heavy!); and of early apprehensions that the child might be backward because of the unusually long time before it could speak [M2]. These fears were unfounded. According to one of Einstein's own earliest childhood memories, 'when he was between two and three, he formed the ambition to speak in whole sentences. He would try each sentence out on himself by saying it softly. Then, when it seemed all right, he would say it out loud' [S1]. He was very quiet as a young child, preferring to play by himself. But there was early passion, too. On occasion, he would throw a tantrum. 'At such moments his face would turn pale, the tip of his nose would become white, and he would lose control of himself' [M2]. On several such occasions, dear little Albert threw things at his sister. These tantrums ceased when he was about seven.

The relationship between the parents was an harmonious and very loving one, with the mother having the stronger personality. She was a talented pianist who brought music into the home so the children's musical education started early. Maja learned to play the piano. Albert took violin instruction from about the time he was six until he was thirteen. The violin was to become his beloved instrument, although playing remained a burdensome duty to him through most of these early years, in which he took lessons from Herr Schmied [R2]. He taught himself to play the piano a bit and grew especially fond of improvising on that instrument.

Hermann Einstein, an unruffled, kind-hearted, and rather passive man, loved by all acquaintances [R3], was fond of literature and in the evenings would read Schiller and Heine aloud to his family [R4]. (Throughout Albert's life, Heine remained one of his most beloved authors.) In his high school years, Hermann had shown evidence of mathematical talent, but his hopes for university study were not realized because the family could not afford it.

Hermann's venture into the featherbed business was not very successful. Shortly after Albert's birth, Hermann's enterprising and energetic younger brother Jakob, an engineer, proposed that together they start a small gas and water installation business in Munich. Hermann agreed to take care of the business end and also to invest a substantial part of his and Pauline's funds in the enterprise. In 1880 Hermann and his family moved to Munich, where they registered on June 21. The modest undertaking opened on October 11 and had a promising beginning, but Jakob had greater ambitions. A few years later, he proposed starting an electrotechnical factory to produce dynamos, arc lamps, and electrical measuring equipment for municipal electric power stations and lighting systems. He also suggested that the brothers jointly buy a house in Sendling, a suburb of Munich. These plans were realized in 1885 with financial support from the family, especially Pauline's father. The firm was officially registered on May 6, 1885.

Albert and Maja loved their new home on the Adelreiterstrasse with its large garden shaded by big trees. It appears that business also went well in the beginning. In a book entitled *Versorgung von Städten mit elektrischem Strom,* we find four pages devoted to the 'Elektrotechnische Fabrik J. Einstein und Co. in München' from which we learn that the brothers had supplied power stations in München-Schwabing as well as in Varèse and Susa in Italy [U1].

Thus Einstein spent his earliest years in a warm and stable milieu that was also stimulating. In his late sixties he singled out one particular experience from that period: 'I experienced a miracle . . . as a child of four or five when my father showed me a compass' [E1]. It excited the boy so much that 'he trembled and grew cold' [R5]. 'There had to be something behind objects that lay deeply hidden . . .the development of [our] world of thought is in a certain sense a flight away from the miraculous' [E1]. Such private experiences contributed far more to Einstein's growth than formal schooling.

At the age of five, he received his first instruction at home. This episode came to an abrupt end when Einstein had a tantrum and threw a chair at the woman who taught him. At about age six he entered public school, the Volksschule. He was a reliable, persistent, and slow-working pupil who solved his mathematical problems with self-assurance though not without computational errors. He did very well. In August 1886, Pauline wrote to her mother: 'Yesterday Albert received his grades, he was again number one, his report card was brilliant' [E1a]. But Albert remained a quiet child who did not care to play with his schoolmates. His private games demanded patience and tenacity. Building a house of cards was one of his favorites.

In October 1888 Albert moved from the Volksschule to the Luitpold Gymnasium, which was to be his school till he was fifteen. In all these years he earned either the highest or the next-highest mark in mathematics and in Latin [H1]. But on the whole, he disliked those school years; authoritarian teachers, servile students, rote learning—none of these agreed with him. Further, 'he had a natural antipathy for . . . gymnastics and sports. . . . He easily became dizzy and tired' [R6]. He felt isolated and made few friends at school.

There was no lack of extracurricular stimuli, however. Uncle Jakob would pose mathematical problems and after he had solved them 'the boy experienced a deep feeling of happiness' [M3]. From the time Albert was ten until he turned fifteen, Max Talmud, a regular visitor to the family home, contributed importantly to his education. Talmud, a medical student with little money, came for dinner at the Einstein's every Thursday night. He gave Einstein popular books on science to read and, later, the writings of Kant. The two would spend hours discussing science and philosophy.* 'In all these years I never saw him reading any light lit-

*After Talmud moved to the United States, he changed his name to Talmey. A book he wrote contains recollections of his early acquaintance with Einstein [T1].

erature. Nor did I ever see him in the company of schoolmates or other boys of his age,' Talmud recalled later [T2]. In those years, 'his only diversion was music, he already played Mozart and Beethoven sonatas, accompanied by his mother' [M4]. Einstein also continued to study mathematics on his own. At the age of twelve he experienced a second miracle: he was given a small book on Euclidean geometry [H2], which he later referred to as the holy geometry book. 'The clarity and certainty of its contents made an indescribable impression on me' [E1]. From age twelve to age sixteen, he studied differential and integral calculus by himself.

Bavarian law required that all children of school age receive religious education. At the Volksschule, only instruction in Catholicism was provided. Einstein was taught the elements of Judaism at home by a distant relative [M5]. When he went to the Luitpold Gymnasium, this instruction continued at school. As a result of this inculcation, Einstein went through an intense religious phase when he was about eleven years old. His feelings were of such ardor that he followed religious precepts in detail. For example, he ate no pork [M6]. Later, in his Berlin days, he told a close friend that during this period he had composed several songs in honor of God, which he sang enthusiastically to himself on his way to school [S2]. This interlude came to an abrupt end a year later as a result of his exposure to science. He did not become bar mitzvah. He never mastered Hebrew. When he was fifty, Einstein wrote to Oberlehrer Heinrich Friedmann, his religion teacher at the Gymnasium, 'I often read the Bible, but its original text has remained inaccessible to me' [E2].

There is another story of the Munich days that Einstein himself would occasionally tell with some glee. At the Gymnasium a teacher once said to him that he, the teacher, would be much happier if the boy were not in his class. Einstein replied that he had done nothing wrong. The teacher answered, 'Yes, that is true. But you sit there in the back row and smile, and that violates the feeling of respect which a teacher needs from his class' [S1, S2].

The preceding collection of stories about Einstein the young boy demonstrates the remarkable extent to which his most characteristic personal traits were native rather than acquired. The infant who at first was slow to speak, then becomes number one at school (the widespread belief that he was a poor pupil is unfounded) turned into the man whose every scientific triumph was preceded by a long period of quiet gestation. The boy who sat in the classroom and smiled became the old man who—as described in Chapter 1—laughed because he thought the authorities handling the Oppenheimer case were fools. In his later years, his pacifist convictions would lead him to speak out forcefully against arbitrary authority. However, in his personal and scientific conduct, he was not a rebel, one who resists authority, nor—except once*—a revolutionary, one who

*Einstein's one truly revolutionary contribution is his light-quantum paper of 1905. It is significant that he never believed that the physical meaning of the light-quantum hypothesis had been fully understood. These are matters to which I shall return in later chapters.

aims to overthrow authority. Rather, he was so free that any form of authority but the one of reason seemed irresistibly funny to him. On another issue, his brief religious ardor left no trace, just as in his later years he would often wax highly enthusiastic about a scientific idea, then drop it as of no consequence. About his religious phase, Einstein himself later wrote, 'It is clear to me that [this] lost religious paradise of youth was a first attempt to liberate myself from the "only-personal"' [E3], an urge that stayed with him all his life. In his sixties, he once commented that he had sold himself body and soul to science, being in flight from the 'I' and the 'we' to the 'it' [E4]. Yet he did not seek distance between himself and other people. The detachment lay within and enabled him to walk through life immersed in thought. What is so uncommon about this man is that at the same time he was neither out of touch with the world nor aloof.

Another and most important characteristic of Einstein is already evident in the child quietly at play by itself: his 'apartness.' We also see this in the greater importance of private experience than of formal schooling and will see it again in his student days, when self-study takes precedence over class attendance, and in his days at the patent office in Bern when he does his most creative work almost without personal contact with the physics community. It is also manifested in his relations to other human beings and to authority. Apartness was to serve him well in his single-handed and single-minded pursuits, most notably on his road from the special to the general theory of relativity. This quality is also strongly in evidence during the second half of his life, when he maintained a profoundly skeptical attitude toward quantum mechanics. Finally, apartness became a practical necessity to him, in order to protect his cherished privacy from a world hungry for legend and charisma.

Let us return to the Munich days. Hermann's business, successful initially, began to stagnate. Signor Garrone, the Italian representative, suggested moving the factory to Italy, where prospects appeared much better. Jakob was all for it; his enthusiasm carried Hermann along. In June 1894, the factory in Sendling was liquidated, the house sold, and the family moved to Milan. All except Albert, who was to stay behind to finish school. The new factory, 'Einstein and Garrone,' was established in Pavia. Some time in 1895, Hermann and his family moved from Milan to Pavia, where they settled at Via Foscolo 11 [S3].

Alone in Munich, Albert was depressed and nervous [M4]. He missed his family and disliked school. Since he was now sixteen years old, the prospect of military service began to weigh on him.* Without consulting his parents, he decided to join them in Italy. With the help of a certificate from his family doctor attesting to

*By law, a boy could leave Germany only before the age of seventeen without having to return for military service. Einstein's revulsion against military service started when, as a very young boy, he and his parents watched a military parade. The movements of men without any apparent will of their own frightened the boy. His parents had to promise him that he would never become a soldier [R4].

nervous disorders, he obtained a release from the Gymnasium and in the early spring of 1895 traveled to Pavia. He promised his parents, who were upset by his sudden arrival, that he would prepare himself by self-study for the admission examination at the ETH in Zürich and also informed them that he planned to give up his German citizenship [F1]. A new, freer life and independent work transformed the quiet boy into a communicative young man. The Italian landscape and the arts made a lasting impression on him [M7].

In October 1895 Einstein went to Zürich to take the ETH examination. He failed, although he did well in mathematics and the sciences.* Following a suggestion to obtain the Matura, the high school diploma that would entitle him to enroll at the ETH, he next went to the cantonal school in Aarau, in the German-speaking part of Switzerland, where he boarded with the Winteler family. For Jost Winteler, one of his teachers and a scholar in his own right, Einstein developed great respect, for Frau Winteler a deep affection. He got along well with their seven children and was treated as part of the family.

For the first time in his life he enjoyed school. Shortly before his death he wrote, 'This school has left an indelible impression on me because of its liberal spirit and the unaffected thoughtfulness of the teachers, who in no way relied on external authority' [E5]. The frontispiece photograph, taken in Aarau, shows Einstein as a confident-looking, if not cocky, young man without a trace of the timidity of the earlier years. A classmate later remembered his energetic and assured stride, the touch of mockery in his face, and his 'undaunted ways of expressing his personal opinion, whether it offended or not' [S4]. He may always have been sure of himself. Now it showed.

A brief essay by Einstein, entitled 'Mes Projets d'Avenir,' has survived from his Aarau schooldays (reproduced on pp. 42–43). Written in less-than-perfect French in about 1895, it conveys his sense of purpose. In translation, it reads

> My plans for the future
>
> A happy man is too content with the present to think much about the future. Young people, on the other hand, like to occupy themselves with bold plans. Furthermore, it is natural for a serious young man to gain as precise an idea as possible about his desired aims.
>
> If I were to have the good fortune to pass my examinations, I would go to [the ETH in] Zürich. I would stay there for four years in order to study mathematics and physics. I imagine myself becoming a teacher in those branches of the natural sciences, choosing the theoretical part of them.
>
> Here are the reasons which led me to this plan. Above all, it is [my] disposition for abstract and mathematical thought, [my] lack of imagination and practical ability. My desires have also inspired in me the same resolve. That is quite natural; one always likes to do the things for which one has ability. Then there is also a certain independence in the scientific profession which I like a great deal. [E5]

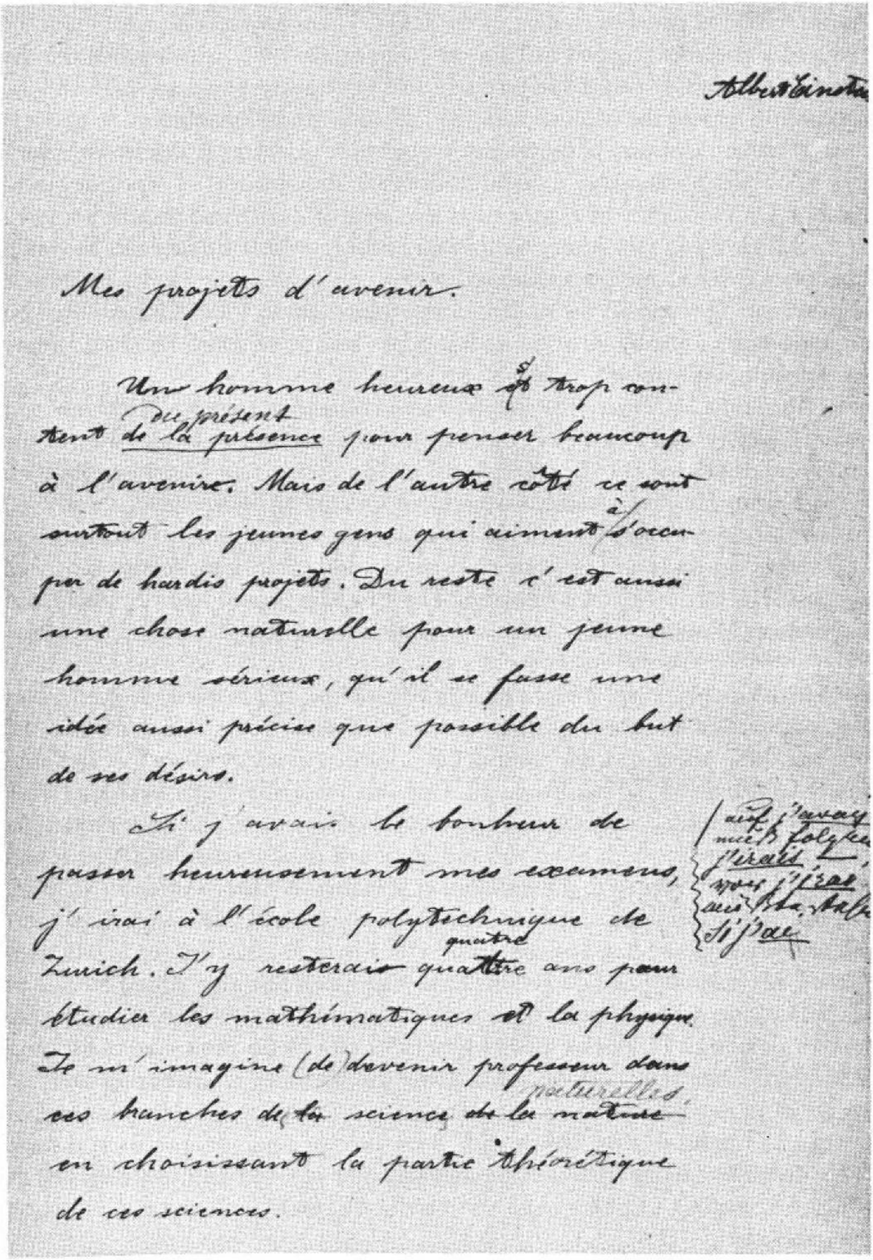
*He was examined in political and literary history, German, French, biology, mathematics, descriptive geometry, chemistry, physics, and drawing and also had to write an essay.

In 1896 Einstein's status changed from that of German high school pupil in Aarau to that of stateless student at the ETH. Upon payment of three mark, he received a document, issued in Ulm on January 28, 1896, which stated that he was no longer a German (more precisely, a Württemberger) citizen. In the fall he successfully passed the Matura with the following grades (maximum = 6): German 5, Italian 5, history 6, geography 4, algebra 6, geometry 6, descriptive geometry 6, physics 6, chemistry 5, natural history 5, drawing (art) 4, drawing (technical) 4. On October 29 he registered as a resident of Zürich and became a student at the ETH. Upon satisfactory completion of the four-year curriculum, he would qualify as a Fachlehrer, a specialized teacher, in mathematics and physics at a high school. Throughout his student years, from 1896 to 1900, Einstein lived on an allowance of one hundred Swiss francs per month, of which he saved twenty each month to pay for his Swiss naturalization papers.*

At this time, however, his family was in financial trouble. Hermann and Jakob's factory in Pavia failed and had to be liquidated in 1896. Most of the family funds poured into the enterprise were lost. Jakob found employment with a large firm. Hermann decided once more to start an independent factory, in Milan this time. Albert warned his father in vain against this new venture and also visited an uncle in Germany to urge him to refrain from further financial support. His advice was not followed. The Einsteins moved back to Milan and began anew. Two years later Hermann again had to give up. At that time, Albert wrote to Maja, 'The misfortune of my poor parents, who for so many years have not had a happy moment, weighs most heavily on me. It also hurts me deeply that I as a grown-up must be a passive witness . . . without being able to do even the smallest thing about it. I am nothing but a burden to my relatives. . . . It would surely be better if I did not live at all. Only the thought . . . that year after year I do not allow myself a pleasure, a diversion, keeps me going and must protect me often from despair' [M8]. This melancholy mood passed when his father found new work, again related to the installation of electrical power stations.

Einstein's student days did have their pleasant moments. He would allow himself an occasional evening at a concert or a theatre or at a Kaffeehaus to talk with friends. He spent happy hours with the distinguished historian Alfred Stern and his family, and with the family of Marcel Grossmann, a fellow student and friend. His acquaintance in Zürich with Michele Angelo Besso grew into a life-long friendship. Then and later he could savor the blessings of friendship and the beauty of music and literature. But, already as a young man, nothing could distract him from his destiny, which with poetic precision he put in focus at the age of eighteen: 'Strenuous labor and the contemplation of God's nature are the angels which, reconciling, fortifying, and yet mercilessly severe, will guide me through the tumult of life' [E6].

*In the *Tagesblatt der Stadt Zürich* of 1895, one finds the following typical advertisements: small furnished room SF 20/month; two daily hot meals in a boarding house SF 1.40/day without wine; a better room with board SF 70/month. (I thank Res Jost for finding this out for me.) Thus Einstein's allowance was modest but not meager.



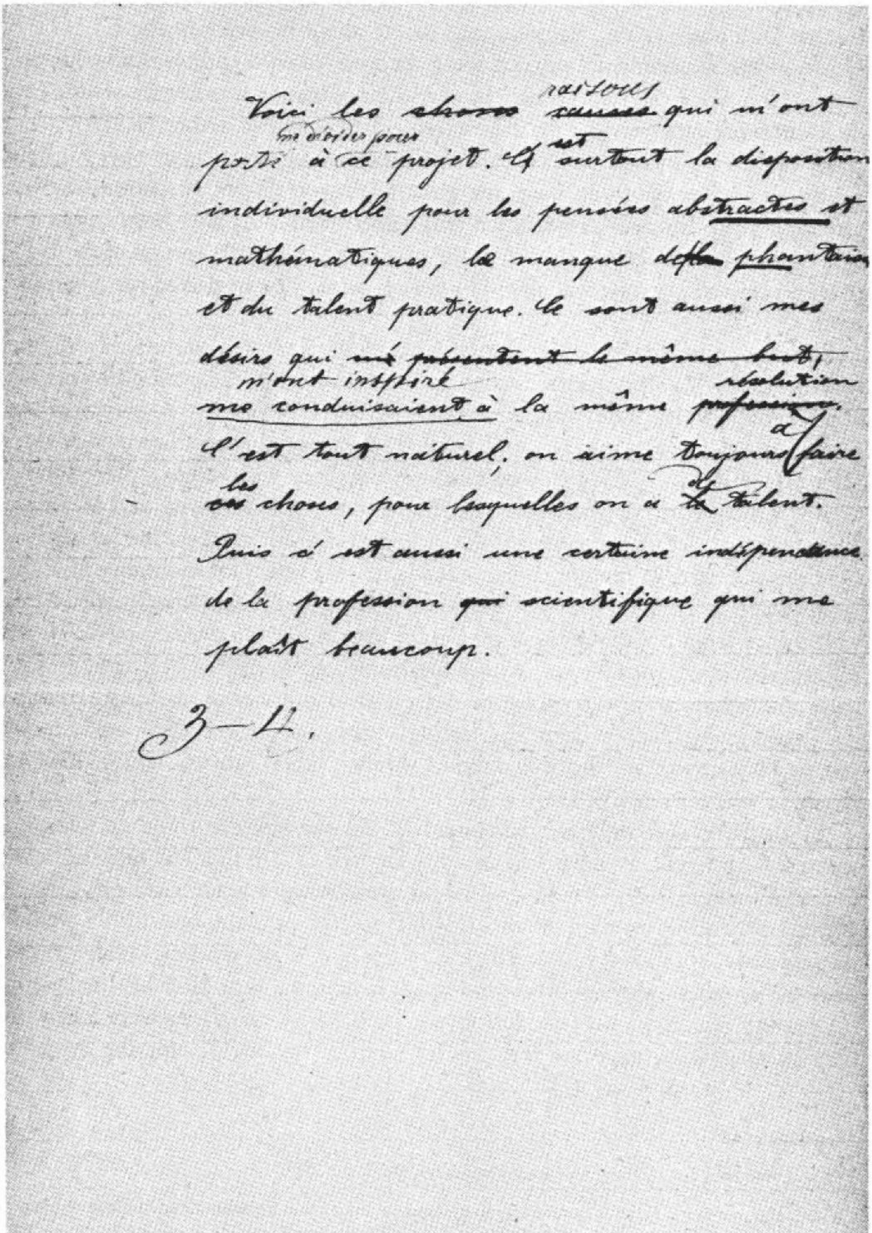
Albert Einstein

Mes projets d'avenir.

Un homme heureux est trop content de la présence pour penser beaucoup à l'avenire. Mais de l'autre côté ce sont surtout les jeunes gens qui aiment s'occuper de hardis projets. Du reste c'est aussi une chose naturelle pour un jeune homme sérieux, qu'il se fasse une idée aussi précise que possible du but de ses désirs.

Si j'avais le bonheur de passer heureusement mes examens, j'irai à l'école polytechnique de Zurich. J'y resterais quattre ans pour étudier les mathématiques et la physique. Je m'imagine (de) devenir professeur dans ces branches de la science de la nature en choisissant la partie théorétique de ces sciences.

Einstein's essay written in Aarau, for which he received the grade 3 to 4 (out of 6). Courtesy Staatsarchiv Kanton Aargau.



Voici les ~~choses~~ raisons ~~causes~~ qui m'ont
porté à ce projet. me décider pour C'est surtout la disposition
individuelle pour les pensées abstractes et
mathématiques, le manque de ~~la~~ phantaisie
et du talent pratique. Ce sont aussi mes
désirs qui ~~me présentent le même but,~~
m'ont inspiré
~~me conduisaient à~~ la même ~~profession~~ résolution.
C'est tout naturel, on aime toujours à faire
les ~~ces~~ choses, pour lesquelles on a du ~~le~~ talent.
Puis c'est aussi une certaine indépendance
de la profession ~~qui~~ scientifique qui me
plaît beaucoup.

3–4.

'Most of the time I worked in the physical laboratory, fascinated by the direct contact with observation,' Einstein later wrote about his years at the ETH [E7]. However, his experimental projects were not received with enthusiasm by his professor, Heinrich Friedrich Weber. In particular, Einstein was not allowed to conduct an experiment on the earth's movement against the aether [R8].* At one point Weber is supposed to have said to Einstein: 'You are a smart boy, Einstein, a very smart boy. But you have one great fault: you do not let yourself be told anything' [S5]. Einstein's fascination with experiment must have been dampened. It is recorded in the Protokollbuch of the mathematics-physics section of the ETH that he received a strong warning *(Verweis)* because he neglected his laboratory work.

Einstein, in turn, was not impressed with Weber's physics courses. He 'did not care much for [Weber's] introduction to theoretical physics because he was disappointed not to learn anything new about Maxwell theory. . . . As a typical representative of classical physics, [Weber] simply ignored everything which came after Helmholtz [S6]. He followed some other courses with intense interest, however.** On several later occasions, he singled out Adolf Hurwitz and Hermann Minkowski as excellent mathematics teachers [R9, E6].† But on the whole Einstein did not excel in regular course attendance. He relied far more on self-study. As a student he read the works of Kirchhoff, Hertz, and Helmholtz; learned Maxwell theory from the first edition of *Einführung in die Maxwellsche Theorie der Elektrizität* by August Föppl, which had come out in 1894 [F1]; read Mach's book on mechanics, 'a book which, with its critical attitudes toward basic concepts and basic laws, made a deep and lasting impression on me' [S8]; and studied papers by Lorentz and by Boltzmann.‡ Among other subjects which drew his attention was the work of Darwin [R9].

'In all there were only two examinations; for the rest one could do what one wanted . . . a freedom which I thoroughly enjoyed . . . up to a few months before the examination' [E9]. These few-month periods were made easy for Einstein because Marcel Grossmann made available his lecture notes, beautifully written, meticulously organized.§ Nevertheless, these times of working under orders imposed by others were an ordeal to him. It took him a year after his final examination to fully regain his taste for physics [E9]. His final grades were 5 each for theoretical physics, experimental physics, and astronomy; 5.5 for the theory of

*See Section 6d.

**For a complete list of Einstein's four-year curriculum, see [S7].

†It is of interest for Einstein's later work on general relativity that he also attended some of Geiser's lectures on differential geometry [K1, R10]. I discuss Geiser's influence in Section 12b.

‡I have not found any evidence for the correspondence between Boltzmann and Einstein referred to in [M9] and [S9].

§These lecture notes are now in the historical collection of the library in Zürich.

functions; 4.5 for an essay on heat conductivity (out of a maximum of 6). And so, in August 1900, Einstein became qualified as a Fachlehrer, together with three other students, who each immediately obtained positions as assistants at the ETH [S5]. A fifth student, Mileva Marič, did not pass.* Einstein himself was jobless.

It was a disappointment for him. He never quite forgave Weber for holding out an assistantship and then letting the matter drop.** In September he wrote to Hurwitz, asking if he could be considered for a vacant assistantship [E11]. A few days later, he wrote again, 'I note with great joy that there is a prospect of obtaining the position' [E12]. Nothing came of this, however. And so as the year ended, he was still without work.

However, there were some satisfactions. In December 1900 he finished his first scientific paper, dealing with intermolecular forces, and submitted it from Zürich to the *Annalen der Physik* [E13]. On February 21, 1901, he was granted the Swiss citizenship for which he had saved so long.† For the rest of his life, he remained a citizen of Switzerland, 'the most beautiful corner on earth I know' [S10].

Early in 1901 Einstein again tried to find a university position. 'I have been with my parents [in Milan] for three weeks to seek from here a position as an assistant at a university. I would have found one long ago if Weber had not played a dishonest game with me' [E14].‡ In March 1901 he sent a reprint of his first paper to Friedrich Wilhelm Ostwald in Leipzig, along with a letter in which he inquired 'whether you perhaps might have use for a mathematical physicist who is familiar with absolute measurements' [E15]. In April he wrote to Heike Kamerlingh Onnes asking for a position in Leiden [E16]. Perhaps he never received replies. Certainly his applications were unsuccessful. He was discouraged, as we know from a letter from his father to Ostwald§: 'My son is deeply unhappy with his current state of unemployment. Day by day the feeling grows in him that his career is off the track . . . the awareness weighs on him that he is a burden to us, people of small means' [E17]. Hermann asked Ostwald to at least send a few words of encouragement about his son's paper. Nine years later, Einstein and Ostwald would both be in Geneva to receive honorary doctorates. The year after that Ostwald would be the first to propose Einstein for the Nobel prize.¶

*Mileva made a second try in July 1901 and failed again.

**After Weber's death in 1912, Einstein wrote to a friend, in a way quite uncommon for him, 'Weber's death is good for the ETH' [E10].

†He had formally applied for citizenship on October 19, 1899. On January 10, 1900, his father made the required declaration that he had no objections to this application [F2]. On March 13, 1901, he was declared unfit for the army (Untauglich A) because of flat feet and varicose veins.

‡' . . . wenn Weber nicht ein falsches Spiel gegen mich spielte.'

§The letters from the Einsteins to Ostwald have been reproduced in [K2].

¶See Chapter 30.

Finally Einstein found a temporary job. Starting May 19, 1901, he became a substitute teacher for two months at a high school in Winterthur. He wrote to Winteler that he had never expected to derive such pleasure from teaching. 'After having taught for five or six hours in the morning, I am still quite fresh and work in the afternoon either in the library on my further education or at home on interesting problems. . . . I have given up the ambition to get to a university since I saw that also under the present circumstances I maintain the strength and desire to make scientific efforts' [E18].* To Grossmann he wrote, also from Winterthur, that he was at work on kinetic gas theory and that he was pondering the movement of matter relative to the aether [E19].

After Winterthur, another temporary position came his way. He was appointed for one year, to begin in September 1901, at a private school in Schaffhausen [F3]. Once again there was enough time for physics. Here is Einstein writing in December 1901: 'Since September 15, 1901, I am a teacher at a private school in Schaffhausen. During the first two months of my activities at that school, I wrote my doctoral dissertation on a topic in the kinetic theory of gases. A month ago I handed in this thesis at the University of Zürich'** [E20]. This work was not accepted as a thesis, however.† This setback was the last one in Einstein's career. It came at about the time that he left Schaffhausen for Bern, where he was to spend the most creative years of his life.

The first initiative for the move to Bern had already been taken some time in 1900, when Marcel Grossmann had spoken to his family about Einstein's employment difficulties. This led Marcel's father to recommend Einstein to Friedrich Haller, the director of the federal patent office in Bern. Einstein was deeply grateful for this recommendation.‡ There the matter rested until December 11, 1901, when a vacancy at the patent office was advertised in the *Schweizerisches Bundesblatt.* Einstein at once sent a letter of application [E20]. At some point he was interviewed by Haller. Perhaps he received some assurances of a position at that time. In any event, he resigned his job at Schaffhausen and settled in Bern in February 1902, before he had any appointment there. At first his means of support were a small allowance from his family and fees from tutoring in mathematics and physics. One of his students described him as follows: 'about five feet ten, broad-shouldered, slightly stooped, a pale brown skin, a sensuous mouth, black moustache, nose slightly aquiline, radiant brown eyes, a pleasant voice, speaking

*In this same letter, Einstein also reported that he had met one of the leading German physicists. I have been unable to find out who that was.

**At that time, the ETH did not yet grant the PhD degree.

†I have been unable to find a response from Zürich concerning Einstein's proposed thesis. This kinetic theory paper was later published [E21]. Earlier in the year, Einstein had contemplated submitting an extended version of his first paper, on intermolecular forces, as a PhD thesis [E14].

‡He expressed his gratitude in a letter to Marcel Grossmann dated April 14, 1901, [E14] (not 1902, as is stated in [S11]).

French correctly but with a light accent' [F4]. It was at this time that he met Maurice Solovine, 'der gute Solo,' who came to be tutored and became a friend for life. Einstein, Solovine, and another friend, Konrad Habicht, met regularly to discuss philosophy, physics, and literature, from Plato to Dickens. They solemnly constituted themselves as founders and sole members of the 'Akademie Olympia,' dined together, typically on sausage, cheese, fruit, and tea, and generally had a wonderful time.*

Meanwhile, Einstein's appointment by the Swiss federal council came through. As of June 16, 1902, he was technical expert third class at the patent office at an annual salary of SF 3500—on a trial basis.

Before settling in Bern, Einstein already had plans to marry a fellow student from the ETH with whom he had often discussed science in Zürich. She was Mileva Marič (or Marity), born in 1875 in Titel (South Hungary), of Greek Catholic background. Einstein's parents were strongly opposed to the marriage; 'perhaps they had wished to pursue other plans' [M10]. In 1902 there was temporary friction between Einstein and his mother, who neither then nor later liked Mileva [E23]. It was altogether a hard year for Pauline. Her husband's series of misfortunes had undermined his robust health. A brief and fatal heart disease felled him. Einstein came from Bern to Milan to be with his father, who on his death-bed finally consented to his son's marriage. When the end was near, Hermann asked everyone to leave so that he could die alone. It was a moment his son never recalled without feelings of guilt**. Hermann Einstein died on October 10, 1902, and was buried in Milan.

Albert and Mileva married on January 6, 1903. There was a small party that evening. Afterward, when the couple arrived at their lodgings, Einstein had to wake up the landlord. He had forgotten his keys [M10]. Much later, Einstein recalled the inner resistance with which he had entered the marriage [E24]. On May 14, 1904, their son Hans Albert was born, through whom the family line continues to this day.

Einstein did well at the patent office. He took his work seriously and often found it interesting. There was always enough time and energy left for his own physics. In 1903 and 1904 he published papers on the foundations of statistical mechanics. On September 16, 1904, his provisional appointment was made permanent. Further promotion, wrote Haller, 'should wait until he has fully mastered machine technology; he studied physics' [F5].

No one before or since has widened the horizons of physics in so short a time as Einstein did in 1905. His work of that year will of course be discussed at length

*In his late sixties, Einstein remembered the days 'when we ran our happy "Academy," which after all was less childish than those respectable ones which I got to know later from close in' [E22]. The best description of the Akademie is the one by Solovine, who records that the members also read Spinoza, Hume, Mach, Poincaré, Sophocles, Racine, and Cervantes [S12].

**Helen Dukas, private communication.

in later chapters.* Here I note only that in March he completed a paper which was to earn him the Nobel prize and that in April he finished an article which finally gained him the PhD degree from the University of Zürich [E25].

On April 1, 1906, Einstein was promoted to technical expert second class with a salary raise to SF 4500. He now knew enough technology and, writes Haller, 'belongs among the most esteemed experts at the office' [F6]. At the end of 1906, he finished a fundamental paper on specific heats. He also found time to write book reviews for the *Annalen der Physik* [K3]. At the end of 1907 Einstein made the first important strides toward the general theory of relativity (see Chapter 9).

Here the sketch of the young man's life ends. Einstein's days in Bern are not yet over, but a new phase is about to begin: his academic career (see further Section 10a).

At the end of his life, Einstein wrote that the greatest thing Marcel Grossman did for him was to recommend him to the patent office with the help of the elder Grossman [E26]. That no doubt is true. Einstein's funds may have been limited, his marriage may not have been perfect. But, for the man who preferred to think in apartness, the Bern days were the closest he would ever come to paradise on earth.

An Addendum on Einstein Biographies

In preparing this chapter, I have striven to rely as much as possible on original documents. The Einstein Archives in Princeton and Helen Dukas's guidance were, of course, of prime importance. I also derived great benefit from the *Wissenschaftschistorische Sammlung* of the ETH Library in Zürich, where Dr. B. Glaus gave me much help. In addition, I have made grateful use of the following biographies.

1. *Albert Einstein, Beitrag für sein Lebensbild* by Maja Einstein; in manuscript form. Completed in Florence on February 15, 1924. The original manuscript is in the hands of the Besso family; a copy is present in the Princeton Archives. Cited in the references to this chapter as M.
2. *Albert Einstein, a Biographical Portrait* by Anton Reiser, the pen name for Rudolf Kayser; A. and C. Boni, New York, 1930. Cited below as R. In 1931, Einstein wrote about this book: 'The book by Reiser is, in my opinion, the best biography which has been written about me. It comes from the pen of a man who knows me well personally' [E8]. (Kayser, a connoisseur of the German language, was for many years the chief editor of the influential *Neue Rundschau,* a Berlin monthly; he was also the author of numerous books and a teacher. In 1924 he married Einstein's stepdaughter Ilse.)

*For the doctoral thesis and Brownian motion, see Chapter 5. For special relativity, see Chapters 6 through 8. For the light-quantum hypothesis, see Chapter 19.

3. A. Einstein, Autobiographisches, in *Albert Einstein: Philosopher-Scientist* (P. Schilpp, Ed.); Tudor, New York, 1949. Cited below as E. The closest Einstein ever came to writing an autobiography. Indispensable.
4. C. Seelig, *Albert Einstein;* Europa Verlag, Zürich, 1960. Quoted below as Se. The material is based in part on an extensive correspondence between the author and A. Einstein, Margot Einstein, and Helen Dukas. This biography is a much-expanded version of an earlier book by C. Seelig, *Albert Einstein;* Europa Verlag, Zürich, 1954. (The English translation of this last book is not recommended.)
5. B. Hoffmann in collaboration with H. Dukas, *Albert Einstein, Creator and Rebel;* Viking, New York, 1972.
6. *Albert Einstein in Bern* by M. Flückiger; Paul Haupt Verlag, Bern, 1974. Cited below as F. Contains a number of reproductions of rare documents pertaining to Einstein's younger days. The text contains numerous inaccuracies.
7. Philipp Frank, *Albert Einstein, sein Leben und seine Zeit;* Vieweg, Braunschweig, 1979. This German version is superior to the English edition, *Einstein, His Life and Time,* Knopf, New York, 1947, since large parts of the German edition do not appear in the English one. The German edition also contains an introduction by Einstein in which he mentions that he encouraged Frank to write this book.
8. H. E. Specker, Ed. *Einstein und Ulm;* Kohlhammer, Stuttgart, 1979. Contains details about Einstein's ancestry, including a family tree.
9. C. Kirsten and H. J. Treder, Ed., *Albert Einstein in Berlin 1913–1933;* Akademie Verlag, Berlin, 1979. An annotated collection of documents from the archives of the Prussian Academy of Sciences. Splendid.

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E3. E, p. 4.
E4. A. Einstein, letter to Hermann Broch, September 2, 1945.
E5. ——, *Mes Projets d'Avenir;* the original is in the Staatsarchiv Kanton Aargau.
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E7. E, p. 14.
E8. A. Einstein, letter to E. F. Magnin, February 25, 1931.
E9. E, p. 16.
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E15. ——, letter to W. Ostwald, March 19, 1901.

E16. ——, letter to H. Kamerlingh Onnes, April 17, 1901.
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II

STATISTICAL PHYSICS

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