Einstein - from Ulm to Princeton

Frank Steiner,
Department of Theoretical Physics, University of Ulm,
Albert-Einstein-Allee 11, D-89069 Ulm, Germany

Last year, the University of Ulm, the City of Ulm, and the German Physical Society celebrated the 125th birthday of Albert Einstein, who was born in Ulm on 14 March1879. Being fully aware of the multitude of events expected to happen at many places during the "World Year of Physics 2005", it was felt appropriate to commemorate Einstein at his birthplace already in 2004. This followed a long tradition in Ulm, where previously Einstein's 70th and 100th birthday had been celebrated in 1949 and 1979, respectively.

The celebration in Ulm consisted of a large number of events during a period of nine months. To bring Einstein's work, ideas and life to a broad audience, a series of a dozen of public lectures [1] were given by physicists and historians that met with great response. An "Albert-Einstein-Schülerwettbewerb" (competition for students at secondary schools) was organized, and a new "Einstein Opera" commissioned by the City of Ulm was performed at the Ulm Theatre. Furthermore, an "Einstein Exhibition" was installed which saw many visitors over several months.

On Einstein's birthday, 14 March 2004, the Mayor of the City of Ulm held a "Festakt" in Ulm's Einstein Hall in the presence of the President of the Federal Republic of Germany and the Prime Minister of Baden-Württemberg. In the evening of the same day, the opening ceremony of the Spring Meeting ("Frühjahrstagung") of the German Physical Society took place at the University of Ulm. The scientific and cultural highlights were the magnificent "Einstein Lecture" delivered by the Nobel Laureate, Chen Ning Yang [2], and the sensitive interpretation of the E minor Mozart Sonata (K304) by violinist and Einstein's great-grandson Paul Einstein. Let us cite from Yang's talk [2]: "Einstein was the greatest physicist of the 20th century, and with Newton the two greatest physicists of all times. His work is characterized by depth, scope, imagination, persistence and independence. Of the three great conceptual revolutions in fundamental physics in the 20th century, he was responsible for two, and had decisively shaped the third." The three revolutions referred to by Yang are of course special relativity (1905), general relativity (1915), and quantum theory (1900-1925).

Genius isn't always immediately recognized [3]

Albert Einstein's ancestors were of Jewish origin and had lived in southern Germany for centuries. His father Hermann served a merchant's apprenticeship in Stuttgart and arrived in the late 1860s in Ulm where several of his relatives had already settled. In 1870 he joined the feather-bedding firm of Israel and Levi. In 1876 Hermann Einstein married Pauline Koch.

Albert Einstein's younger sister Maria Winteler-Einstein (1881-1951), called Maja, wrote in 1924 about her brother [4]: "At his birth his mother was shocked at the sight of the back of his head, which was extremely large and angular, and she feared she had given birth to a deformed child. But the doctor reassured her, and after a few weeks the shape of the skull was normal... Otherwise,

▲ **Fig. 1:** Albert Einstein with his sister Maja, ca. 1885.

he developed slowly in childhood, and he had such difficulty with language that those around him feared he would never learn to speak... His early thoroughness in thinking was also reflected in a characteristic, if strange, habit. Every sentence he uttered, no matter how routine, he repeated to himself softly, moving his lips. This odd habit persisted until his seventh year."

In June 1880, the Einstein family moved to Munich. "Had Hermann remained in Ulm," wrote Maja [4], "his son Albert would also have been granted a more carefree youth." This remark does not allude to the fact that legend has it that Einstein was a "poor pupil", but rather refers to the economical situation of the family in Munich. After some success with an electrical firm which produced large-scale dynamos, arc lamps and telephone systems, the firm liquidated and the family moved without their son Albert to Milan in 1884 and a year later to Pavia.

Although later, Einstein commented only very negatively on his school days in Munich ("The teachers at primary school appeared to me as sergeants and the teachers at the Gymnasium as second lieutenants" [5]), he actually had been a good student. When at the age of 15, he abruptly left the Gymnasium in Munich without asking his parents and went to Milan, he got a certificate from a Gymnasium teacher, praising his "mathematical knowledge and abilities." (CP1, p.lxiv) Naturally, the parents were alarmed by his high-handed behaviour but he most adamantly declared that he would not return to Munich. However, he told his parents he would prepare himself for the entrance examination

to the Polytechnikum in Zurich. And in fact, in October 1895 he received an exceptional permission to take the examination even though he was two years under the regular admission age of eighteen. The examination consisted of two parts: one testing general knowledge, the other testing specialized scientific knowledge (arithmetic, algebra, geometry, physics and chemistry) (CP1, p.10). Although he passed the examination with the best outcome in the second part, he failed in the first, and therefore he was advised to attend the final year at a Swiss secondary school. Thus he entered in October 1895 the Cantonal School in Aarau.

In October 1896 he received in Aarau the Matura (graduation certificate) as the best of his class which enabled him to enter the Mathematical Section of the Polytechnikum at the age of 17 1/2. Here he met his first wife Mileva Mariç (1875-1948) who was the only female student in his section. She was born in Titel, a Serbian village near Novi Sad.

In his eighth semester, he wrote a Diploma Thesis on heat conduction and obtained in July 1900 at the age of 21 his Federal Diploma for Specialist Teachers of Mathematics and Physics. However, his hopes to get a position as an assistant at a university in Switzerland, Germany, Holland or Italy were not fulfilled, and thus he worked temporarily as a supply teacher in a private school. After his move to Bern in February 1902, he even put an advertisement in a local newspaper offering private lessons in mathematics and physics – first lesson free of charge! At last, in June 1902 he got a position as III.Class Technical Expert at the Swiss Patent Office in Bern and was promoted there in 1906 to become a II.Class Expert – after he had already published his revolutionary papers of 1905.

It was a big surprise, when in 1986 the love letters of Albert Einstein and Mileva Mariç written during the years 1897-1903 were discovered [6]. The letters show us the young man fallen in love and his relation to his first wife. They give us deep insight into his intellectual development during the years shortly before he published his epochal scientific papers that made him world-famous. Already in these letters we recognize a characteristic feature which he kept through all his life: absolute independence in scientific and political issues, be it with respect to people or institutions, the "suspicion against every kind of authority" [7]. Until the discovery of the love letters, the world did not know that in January 1902 Mileva had given birth, out of wedlock, to their first child, a daughter named Lieserl. The mystery surrounding Lieserl remains unsolved; probably she was put up for adoption. In January 1903, Einstein married Mileva who gave birth to two sons: Hans Albert (1904-1973) and Eduard (1910-1965).

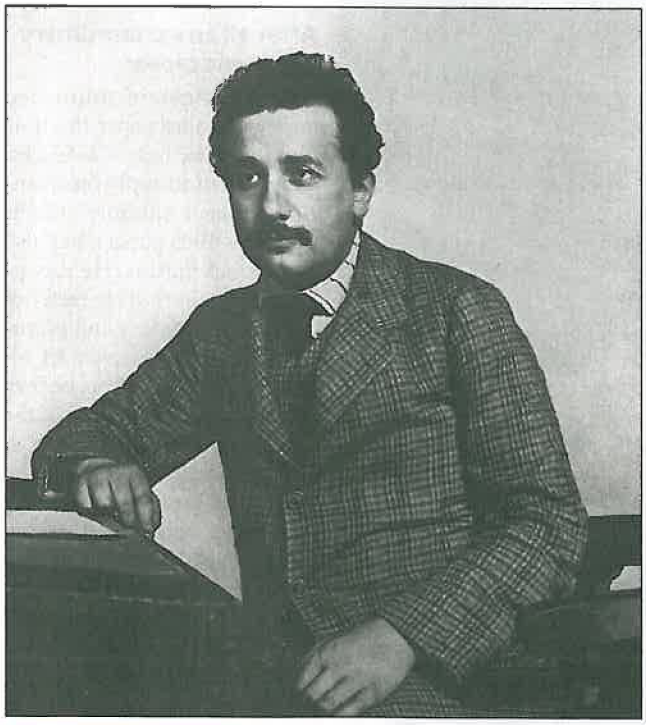
The annus mirabilis 1905

In 1905, Einstein's annus mirabilis or wonder year, the 26-year old patent clerk submitted five fundamental papers to the "Annalen der Physik" during the incredibly short period between 17 March and 27 September. For the first of these papers, and not for the Theory of Relativity, the Nobel Prize in Physics for 1921 was awarded to Einstein in 1922. In this paper, he developed a completely novel theory of light by introducing a new elementary particle, the light quantum or photon (c.f. Friedman's article, this issue). With the second and third paper, he became one of the most important advocates of the then still heavily disputed hypothesis on the existence of atoms. The fourth paper contains the foundation of the Theory of Special Relativity, and finally in the fifth and last paper of the annus mirabilis he derives his legendary formula $E=mc^2$.

In a letter to his friend Conrad Habicht (written on 18 or 25 May 1905), which is a typical example of his strong sense of humour, Einstein wrote: "So, what are you up to, you frozen whale, you smoked, dried, canned piece of soul, or whatever else I would like to hurl at your head, filled as I am with 70% anger and 30% pity! You have only the latter 30% to thank for my not having sent you a can full of minced onions and garlic after you so cravenly did not show up on Easter. But why have you still not sent me your dissertation? Don't you know that I am one of the 1 1/2 fellows who would read it with interest and pleasure, you wretched man? I promise you four papers in return, the first of which I might send you soon, since I will soon get the complementary reprints. The paper deals with radiation and the energy properties of light and is very revolutionary, as you will see if you send me your work first. The second paper is a determination of the true sizes of atoms from the diffusion and the viscosity of dilute solutions of neutral substances. The third proves that, on the assumption of the molecular theory of heat, bodies on the order of magnitude 1/1000 mm, suspended in liquids, must already perform an observable random motion that is produced by thermal motion; in fact, physiologists have observed <unexplained> motions of suspended small, inanimate, bodies, which motions they designate as 'Brownian molecular motion'. The fourth paper is only a rough draft at this point, and is an electrodynamics of moving bodies which employs a modification of the theory of space and time; the purely kinematic part of this paper will surely interest you." (CP(c)5, p.20)

It is remarkable that Einstein calls only his first paper, in which he explains the photoelectric effect, "revolutionary", and not the two papers on relativity. How revolutionary this paper really was, can be seen from an interesting document. It shows that even Max Planck, who had introduced the notion of quantum in 1900, criticized Einstein's light quantum hypothesis even still in 1913.

At the beginning of the year 1913 Fritz Haber had proposed that Einstein be brought to Berlin as a member of the Kaiser Wilhelm Institute of Physical Chemistry and Electrochemistry. By late spring, Max Planck and Walther Nernst had modified Haber's



▲ Fig. 2: Albert Einstein at the Patent Office in 1906.

proposal, combining the idea of Einstein's membership in the Prussian Academy of Sciences with the prospect of his directorship of a Kaiser Wilhelm Institute of Physics. (CP5, p.29) On 12 June 1913 Max Planck read aloud to the physical-mathematical class of the Academy a proposal for Einstein's membership in the Prussian Academy of Sciences which was signed by him, Nernst, Heinrich Rubens, and Emil Warburg. We read in this proposal: "In sum, it can be said that among the important problems, which are so abundant in modern physics, there is hardly one in which Einstein did not take a position in a remarkable manner. That he might sometimes have overshot the target in his speculations, as for example in his light quantum hypothesis, should not be counted against him too much. Because without taking a risk from time to time it is impossible, even in the most exact natural science, to introduce real innovations. At the moment he works intensively on a new theory of gravitation; with what success, only the future will tell." (CP(c)5, p.337)

After all an extraordinary academic career

In 1907 Einstein published another seminal paper, this time on the specific heat of solids. He was the first to apply the quantum concept not only to light (as in his 1905 paper), but also to normal matter. He recognized the universal character of the quantum theory and postulated that the energy of all vibrational phenomena, be they the oscillations of light or of the atoms in material bodies, has to be quantized. With this paper he established the quantum theory of solids with its far-reaching practical applications later on.

Einstein worked at the Patent Office until May 1909 when he accepted his first academic position as Associate Professor at the University of Zurich. Two months later, at the age of thirty, he was granted together with Marie Curie and others his first honorary doctorate in the physical sciences by the University of Geneva on the occasion of the University's 350th anniversary celebration. In 1910 Einstein moved to Prague where he accepted a Full Professorship at the German University. There he occasionally visited the salon of Bertha Fanta where he met Max Brod and Franz Kafka. In 1911 he was invited to attend the first Solvay Conference in Brussels and was given the honour of being the final speaker. The title of his talk was: "The Current Status of the Specific Heat Problem." At Brussels he met the leading physicists of the time, among them Marie Curie, Paul Langevin, Hendrik Antoon Lorentz, Henri Poincaré, Ernest Rutherford and the Berlin physicists, Max Planck and Walther Nernst. At Prague he obtained offers from the University of Utrecht and the ETH Zurich, and in 1912 he returned to Zurich to become a Full Professor at the ETH where he had studied several years before.

◀ Fig. 3: Albert Einstein in Princeton with Chen Yang's son Franklin Yang.

We have already cited from the proposal for Einstein's membership in the Prussian Academy of Sciences. In July 1913, Nernst and Planck visited Einstein in Zurich and offered him a well-paid position as a member of the Berlin Academy and director of the planned Kaiser Wilhelm Institute of Physics. Einstein accepted and moved in April 1914 to Berlin. He was now 34 years old and had an extraordinary position. In a letter to his first coworker Jakob Johann Laub he wrote: "On Easter I leave for Berlin as an Academy-man without any obligations, like a living mummy in a way. I am very happy about such a difficult career!" (CP(c)5, p.344)

From Einstein's correspondence we know now that he was attracted to Berlin not only by the famous physicists there and the excellent position, but also by his cousin Elsa Löwenthal-Einstein (1876-1936). Already from Prague he had written to her: "I can't even begin to tell you how fond I have become of you during these few days." (CP(c)5, p.291) And in July 1913 he wrote: "I rejoice at the thought that I will soon be coming to you. (...) Seeing you regularly will be the nicest thing that awaits me there!" (CP(c)5, p.343). Shortly after Mileva had joined Einstein in Berlin, it became clear that their marriage was ruined and Mileva returned with the two sons to Zurich. They got divorced in 1919, and a few months later Einstein married Elsa.

General relativity

Already in 1907, when most physicists still struggled with special relativity, Einstein sought a generalization. "So far we have applied the principle of relativity, i.e., the assumption that the physical laws are independent of the state of motion of the reference system, only to nonaccelerated systems. Is it conceivable that the principle of relativity also applies to systems that are accelerated relative to each other?" [8]

Between 1907 and 1915, Einstein wrote numerous papers attempting to generalize special relativity. For this purpose, he had first to find out that the required mathematics is Riemannian geometry and the absolute differential calculus developed between 1896 and 1900 by Elwin Bruno Christoffel, Gregorio Ricci, and Tullio Levi-Civita. Already in Prague he had realized that gravitational fields are equivalent to a curvature of space-time which can be described by a Riemannian metric. This idea led him in 1911 to the prediction that light waves should be bent near a heavy body like the sun.

In November 1915, which can be called "Einstein's wonder month", he gave four talks at the weekly plenary meetings of the Prussian Academy in Berlin. It is only at the last session on 25

November that he could present the complete gravitational field equations which form the basis of general relativity. "General relativity was a singularly profound creation of Einstein's. In originality and boldness I believe it has no equal in the history of physics." (C.N.Yang, [2]).

In Einstein's General Theory of Relativity space and time are no more rigid but rather become dynamical entities which are determined by matter. Already on November 15, when he did not yet have the correct equations, Einstein presented a crucial test of his new theory. "In the present work I find an important confirmation of this most radical relativity theory, showing that it explains qualitatively and quantitatively the secular rotation of the orbit of Mercury (...), which was discovered by Le Verrier and which amounts to 45 sec of arc per century. Furthermore, I show that the theory has as a consequence a curvature of light rays due to gravitational fields twice as strong as was indicated in my earlier investigation." [9] In al letter to his friend Paul Ehrenfest he wrote: "Imagine my delight at realizing that general covariance was feasible and at finding out that the equations yield Mercury's perihelion motion correctly. I was beside myself with joy and excitement for days." (CP(c)8, pp.177) "This discovery was, I believe, by far the strongest emotional experience in Einstein's scientific life, perhaps in all his life. Nature had spoken to him. He had to be right." (A.Pais, [10])

A few months later, Karl Schwarzschild found the exact solutions to Einstein's field equations for a spherically symmetric mass distribution. His by now famous solution provides the fundamental model of a black hole. Recently, it could be demonstrated using modern methods of infrared astronomy that there exists a massive black hole at the center of our Milky Way (e.g., H.Genzel in [1]).

In 1916 Einstein derived another fundamental prediction of his theory: the existence of gravitational waves. When more than 60 years later Russel A. Hulse and Joseph H. Taylor discovered a new type of pulsar, they used it for an indirect confirmation of the existence of gravitational waves. (For this work they received the Nobel Prize 1993).

At a solar eclipse in May 1919, two British expeditions confirmed Einstein's prediction of the bending of light. The results were presented in a memorable joint meeting of the Royal Society and the Royal Astronomical Society in London on 6 November 1919. The president of the Royal Society, Sir Joseph John Thomson, said in his summary: "This is the most important result obtained in connection with the theory of gravitation since Newton's day, and it is fitting that it should be announced at a meeting of the Society so closely connected to him."[11] The next day an article appeared in "The Times" (London) with the headlines "Revolution in science. New theory of the universe. Newtonian ideas overthrown." This was the birth of the Einstein legend (e.g., [10], pp. 306). Einstein himself accepted to write a guest article in "The Times" of November 28. "After the lamentable breach in the former international relations existing among men of science, it is with joy and gratefulness that I accept this opportunity of communication with English astronomers and physicists. It was in accordance with the high and proud tradition of English science that English scientific men should have given their time and labour (...) to test a theory that had been completed and published in the country of their enemies in the midst of the war." (CP(c)7, 213).

Cosmology and Einstein's "biggest blunder"

In February 1917, Einstein presented another epochal paper in which he applied his theory of gravitation to the Universe at large [12]. He introduced what we call today the Cosmological Principle that assumes that the large-scale structure of the Universe is homogeneous and isotropic, on average. With this paper he founded modern cosmology by constructing a model of the Universe fully compatible with observations at that time. He wrote to his friend Ehrenfest: "I have (...) again perpetrated something about gravitation theory which somehow exposes me to the danger of being confined in a madhouse." (CP(c)8A, 390).

The Einstein universe is closed. In describing the beings in it, Einstein wrote in his popular book: "The great charm resulting from this consideration lies in recognition of the fact that *the universe of these beings is finite and yet has no limits.*" [13] For reasons which were also metaphysical, Einstein wanted a static, eternal universe, i.e., without a Big Bang to use the modern term. He encountered, however, a problem because his field equations did not allow solutions unchangeable in time. As a way-out, he therefore modified his equations by adding an additional term containing a new fundamental constant, the so-called cosmological constant (in full agreement with general covariance). The Einstein universe possesses positive curvature, and its spatial shape is that of a three-dimensional hypersphere. Assuming that the universe is filled only with "dust" having constant density and zero pressure, he was able to calculate the "radius of the universe" which turned out be completely given in terms of the cosmological constant. When the observations by Vesto Melvin Slipher and Edwin Hubble clearly showed that the Universe is expanding, Einstein rejected the cosmological constant and remarked that its introduction "was the biggest blunder he ever made in his life". [14]

That Einstein did not realize that his field equations are not compatible with a static universe (with or without a cosmological constant), is one of his greatest "missed opportunities". Nevertheless, it may turn out in the future that his "biggest blunder" is actually one of his greatest achievements. Since a few years, it has been known that the Universe is filled with a mysterious, unknown energy, called dark energy, with negative pressure which is responsible for an accelerated expansion of the Universe at the present epoch. It turns out that all existing data are consistent with the assumption that the dark energy is identical with Einstein's cosmological constant!

During his Berlin time, Einstein made two important contributions to quantum theory. In 1917 he formulated a statistical theory for the interaction between photons and atoms which 40 years later was applied in the maser. In 1925 he predicted the Bose-Einstein condensation which 70 years later was achieved in dilute gases of alkali atoms by E.A.Cornell, W.Ketterle and C.E.Wiemann (Nobel Prize in 2001).

At Princeton, and the "obsession" with unified field theory

In 1932, Einstein received an offer to work at the newly founded Institute of Advanced Study in Princeton. At that time, he did not intend to leave Germany for good, but agreed to spend half of his time in Berlin and half in Princeton. In December 1932 he visited CALTECH. In January 1933, Hitler came to power, and on March 10 Einstein declared publicly his decision not to return to Germany. On March 28, he resigned from the Prussian Academy. After a stay in Belgium and England, Einstein arrived with his wife Elsa in New York on October 17. For his remaining 22 years he never went back to Europe again.

Einstein's work in Princeton is often considered as unimportant with the exception of his Einstein, Podolsky and Rosen paper [15] that in recent years has been recognized as a stimulating source of ideas. This is particularly so since "EPR-states", and,

in general, "entangled states" can now be realised experimentally. Furthermore, it is well known that the EPR-paper led Schrödinger to his famous paper on the "Schrödinger cat" [16].

In Princeton Einstein continued his work on a unified field theory which he had already started in Berlin. His efforts in this direction were not successful. His search for the basic principles of physics became an "obsession". "Assessing today Einstein's insistence on unified field theory, I would say, yes, it was an obsession. But what a grand obsession! It gave direction to later theoretical research, and its influence on fundamental physics will extend well into the 21st century." (C.N.Yang, [2])

During his whole life Einstein had two hobbies: sailing and music, but music had a particular emotional importance to him. He had played the violin since his sixth year. His preferred composers were Vivaldi, Bach, and Mozart. Paul Einstein wrote recently: "It's a fine line with Mozart between sensitivity and aggression, between line and colour. Besides, Mozart was a bit like Albert Einstein, a sharp-tongued intellectual, with powerful, outspoken ideas." (Letter to the author.)

On 18 April 1955 Einstein died of an aneurysm of the aorta at Princeton Hospital. ■

▲ Fig. 4: Paul Einstein in Ulm on 14 March 2004 in front of a picture of his great grandfather (showing Albert Einstein in Berlin in1921).

About the authors:

Frank Steiner is Professor of Physics and Head of the Department of Theoretical Physics at the University of Ulm. He was Professor of Physics at Hamburg from 1973 to 1995. His present work is on cosmology and quantum chaos. He is the author of the "Handbook of Feynman Path Integrals" (with C.Grosche; Springer, 1998).

References

[1] F.Steiner (Hrsg.), Albert Einstein - Genie, Visionär und Legende (Springer, Berlin, 2005, to be published).

[2] C.N.Yang, Einstein's Impact on Theoretical Physics in the 21st Century, Lecture delivered on 14.3.2004 at the University of Ulm; Association of Asia Pacific Physical Societies Bulletin 15 (2005) 4.

[3] S.Hawking, Albert Einstein, in: On the Shoulders of Giants. The Great Works of Physics and Astronomy (Running Press, Philadelphia/London 2002), p.1161.

[4] M.Winteler-Einstein, Albert Einstein – Biographical Sketch, CP(c)1, pp.xv-xxiii. – Here and in the following CP(c) denotes the companion volumes, vol.1-8, Princeton University Press 1987-2002 (containing the English translation of the original German documents), to "The Collected Papers of Albert Einstein",vol.1-9, Princeton University Press 1987-2004; the latter will be denoted by CP.

[5] A.Einstein, in: P.Frank, Einstein: sein Leben und seine Zeit (Vieweg, Braunschweig 1979), p.24.

[6] A.Einstein/M.Mariç, The Love Letters (Princeton University Press, 1992). - Their later correspondence covering the period until April 1920, has been published in CP5,8A,8B and 9.

[7] A.Einstein, Autobiographical Notes, in: P.A.Schilpp (ed.), Albert Einstein: Philosopher Scientist (Evanston,1949), 5.

[8] A.Einstein, Jahrbuch der Radioaktivität und Elektronik 4 (1907) 411. Transl. in CP(c)2, pp.252.

[9] A.Einstein, Erklärung der Perihelbewegung des Merkur aus der allgemeinen Relativitäts-theorie, Kgl.Preuß.Akad.d.Wissenschaften (Berlin) Sitzungsberichte (1915),831-839. Transl. in CP(c)6,112-116.

[10] A.Pais, "Subtle is the Lord...". The Science and the Life of Albert Einstein, Oxford University Press 1982, p.253.

[11] J.J.Thomson; Proc.Roy.Soc.96 A (1919)311.

[12] A.Einstein, Kosmologische Betrachtungen zur Allgemeinen Relativitätstheorie, Sitzungs-berichte Preuß.Akad.d.Wiss.(1917), 142.

[13] A.Einstein, Relativity. The Special and the General Theory (London, The Folio Society, 2004) (authorized translation by R.W.Lawson).

[14] A.Einstein, cited in: G.Gamow, My World Line (New York1970), p.150.

[15] A.Einstein, B.Podolsky, and N.Rosen, Can quantum-mechanical desription be considered complete?, Phys.Rev. 47 (1935)777.

[16] E.Schrödinger, Die gegenwärtige Situation in der Quantenmechanik, Naturwiss. 23 (1935), 807; ibid.823 and 844.