Reflections

Einstein's Life and Legacy

Introduction

Albert Einstein is the most luminous scientist of the past century, and ranks with Isaac Newton as one among the greatest physicists of all time. There is an enormous amount of material to choose from in talking about Einstein. He is without doubt also the most written about scientist of the past century, may be of all time. The Einstein Archives contain about 43,000 documents, and so far as I know the "Collected Papers of Albert Einstein" have only come upto 1917 with Volume 8 in English translation; another 32 volumes remain to be produced. In the face of all this, this account must be severely selective, and coherent as well.

Einstein's life was incredibly rich and intense in the intellectual sense. This will become clear as I go along. In any case let me begin by presenting in *Box* 1 a brief listing of a few important dates in his life, howsoever inadequate it may be.

He was scientifically active essentially from 1902 upto 1935 at the highest imaginable levels, thus for more than three decades.

The Miraculous Year

Now let us turn to technical matters. First, a brief mention of his creative outburst of 1905, whose centenary we are celebrating this year. There were four fundamental papers, and the doctoral thesis, all in the six months from March to September. The first paper on the light quantum concept and explanation of the photo electric effect was submitted to Annalen der Physik in March; the second on Brownian Motion in May; and the third setting out the Special Theory of Relativity in June. His doctoral thesis, just 18 pages long and titled "A new determination of molecular dimensions", was submitted on July 20th; and the mass-energy equivalence paper in September. Of these

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Box 1. Some Important Dates in Einstein's Life

14 March 1879	Born in Ulm, Germany, to Pauline Koch and Hermann Einstein.
1886-1895	Catholic primary School, then Luitpold Gymnasium, Munich.
1895	Year spent in Pavia, Italy.
1895-1896	Cantonal School, Aarau, Switzerland; gives up German citizenship.
1896-1900	Student at ETH, Zurich for Diploma to teach in high school.
1901	Gets Swiss Citizenship.
1902-1909	Temporary Technical expert 3rd class in Bern Patent office, permanent in 1904, 2nd class in 1906.
1903	Marries Mileva Maric.
1905	Annus Mirabilis; PhD from University of Zurich.
1909-1911	Enters academia, Associate Professor at University of Zurich.
1911-1912	Professor, University of Prague.
1912-1914	Professor, ETH, Zurich.
1914-1932	Professor, University of Berlin, no teaching duties, under Prussian Academy of Sciences.
1917	Director, Kaiser Wilhelm Institute, Berlin.
1919	Divorces Mileva, marries cousin Elsa Einstein Lowenthal.
1921	First trip to USA; Nobel Prize in Physics.
1933	Resigns from Prussian Academy, leaves Europe for USA.
1933-1955	Institute for Advanced Study, Princeton.
1940	Becomes US citizen (remains Swiss Citizen).
18 April 1955	Dies at Princeton at 76.

four papers, all but the first were within the framework of classical, ie., prequantum, physics. And his own assessment of them was expressed in a letter to Konrad Habicht on May 18th or 25th, 1905:

"... I promise you four papers in return, the first of which I might send you soon, since I will soon get the complimentary reprints. The paper deals with radiation and the energy properties of light and is very revolutionary, as you will see ...".

While his work on Special Relativity, leading to a new view of space and time, has caught the public imagination for decades, Einstein himself would say years later that it was no comparison at all to the struggles he faced with both quantum theory and General Relativity. He abstracted the light quantum concept from an incisive analysis of the high frequency or nonclassical Wien limit of Planck's radiation law, combining thermodynamic and probability arguments. His conclusion was expressed in these words (in modern notation):

"... monochromatic radiation of low density (within the range of validity of Wien's radiation formula) behaves thermodynamically as if it consisted of mutually independent energy quanta of magnitude $h\nu$."

He then applied this 'heuristic viewpoint' as he called it to explain Lenard's results on the photoelectric effect. As for his profound analysis of space and time and the physical meaning of Special Relativity, let me only quote from a later 1907 review to show you how he disposes of the ether hypothesis in such authoritative fashion:

"... electromagnetic forces appear here not as states of some substance, but rather as independently existing things that are similar to ponderable matter and share with it the feature of inertia'".

Later work – the Quantum Theory Track

Now I would like to convey to you some idea of the magnitude and grandeur of his later work. For this it is useful to follow two tracks – track one on quantum theory, track two on the relativity theories. Each will be brief. Following the light quantum paper of 1905, the major milestones on the quantum theory track are given in *Box* 2.

Box 2. Einstein's Work on the Quantum Theory.

1907	Application of quantum theory to the specific heat problem.
1909	Energy fluctuations of Planck radiation – wave and particle contributions – first recognition of wave particle duality for light.
1916	New derivation of Planck's Law using Bohr's idea of stationary states of atoms, spontaneous and stimulated emission and absorption of radiation by matter.
1924	Theory of the ideal quantum (Bose) gas, number or density fluctuations, wave particle duality for matter, prediction of Bose–Einstein condensation.
1927-1930	Debates with Bohr – attempts to show inconsistency of quantum mechanics.
1935	Einstein–Podolsky–Rosen paper claiming incompleteness of quantum mechanics.

Now to some comments. The light quantum idea, conceived in 1905, was not accepted by the physics community in general for a very long time. Some of the principal opponents were Planck, Millikan and Bohr – they all believed that on account of interference and diffraction phenomena, one had to retain the classical Maxwell description of light at all costs, and limit quantum effects to matter and its interaction with radiation. Indeed Planck said in 1909:

"I believe one should first try to move the whole difficulty of the quantum theory to the domain of the interaction between matter and radiation".

As an amusing interlude, it should be mentioned that in their recommendation of Einstein for membership in the Prussian Academy in 1913, Planck and others wrote:

"That he may sometimes have missed the target in his speculations, as, for example, in his hypothesis of light quanta, cannot really be held too much against him, for it is not possible to introduce really new ideas even in the most exact sciences without sometimes taking a risk".

But Einstein, while always stressing the provisional nature of his hypothesis, steadily refined it over the years. While in 1905 he referred to light quanta as "mutually independent" and that light energy

"... consists of a finite number of energy quanta that are localized in points in space, move without dividing, and can be absorbed or generated only as a whole",

in 1909 he referred to them as "independently moving point like quanta with energy $h\nu$." In all these statements the reference was to the Wien limit of Planck radiation. In his 1916 work for the first time he explicitly attributed a momentum as well as energy to light quanta. He then wrote in two letters to his friend Michele Besso:

"With that, (the existence of) light quanta is practically certain", and

"I do not doubt anymore the *reality* of radiation quanta, although I still stand quite alone in this conviction".

The final acceptance of the light quantum came as late as 1923, after the discovery of the Compton effect, and the name 'photon' was invented by the chemist G N Lewis in 1926.

But here is Einstein's own expression of his struggle for comprehension, from a letter to Besso as late as December 1951:

"All the fifty years of conscious brooding have brought me no closer to the answer to the question, 'What are light quanta?' Of course today every rascal thinks he knows the answer, but he is deluding himself".

Till the very end, Einstein never accepted the traditional interpretation of quantum mechanics, and the claim of its finality or completeness. He never gave up his belief in the existence of a reality independent of observation, and his rejection of indeterminism at the fundamental level. After Heisenberg, Dirac and Schrödinger had created quantum mechanics in the two years 1925-1927, at first Einstein tried to show that it was inconsistent. He constructed ingenious thought experiments which he felt would circumvent the Uncertainty Principles, but each time Bohr was able to point out the flaw in the argument. Then in 1935, along with Podolsky and Rosen, he presented an argument purporting to show that quantum mechanics was incomplete. The key idea was to involve the classically valid concepts of locality and realism, and demand that any complete theory contain them. However later developments have shown that their arguments are untenable. For all that, his advice and comments proved crucial for both Heisenberg and Schrödinger in working out their respective forms of quantum mechanics. When Heisenberg told Einstein that in setting up matrix mechanics he had taken inspiration from Special Relativity and its emphasis on observables, Einstein replied:

"... on principle, it is quite wrong to try founding a theory on observable magnitudes alone.... It is the theory which decides what we can observe".

And in Schrödinger's case what proved crucial were Einstein's comments on de Broglie's thesis of matter waves – "has lifted a corner of the great veil" – and the concept of wave particle duality for matter coming from the density fluctuation formula for the ideal quantum gas.

The Relativity Track

Turn now to track two: the major signposts on the long and tortuous road from Special Relativity in 1905 to the field equations for gravitation in November 1915 are given in *Box* 3.

Box 3. The Road from Special to General Relativity

1907	First statement of Equivalence Principle for constant gravitational fields; gravity bends light rays; gravitational redshift.
1911-1912	Speed of light varies in gravitational field; attempt to use local light speed as scalar gravitational field.
1912	Analysis of rotating coordinate system; recognition of non-Euclidean geometry of space-time with gravitation present; metric tensor as gravitational field.
1913-1915	Rejection of general covariance based on meta-argument: metric "should be" uniquely determined by sources and boundary conditions.
1915	Return to general covariance earlier given up "only with a heavy heart"; the final field equations of general relativity.

It would be completely out of place for me to attempt to discuss these events in any detail, nor am I qualified to do so. I can only offer some comments and quotations to convey the magnitude of what was achieved. One aspect of Einstein's greatness was his recognition that in reconciling Special Relativity and Newtonian gravity, he had to go beyond both of them. He was willing to give up his own Special Relativity in favour of a more encompassing theory. His unerring instinct based on the Equivalence Principle led him along. Students of General Relativity know how enchantingly beautiful that theory is, but it was the end result of a truly superhuman struggle. Einstein himself said:

"Compared with this problem, the original relativity is child's play".

Why did it take so many years to create General Relativity? Here in his own words are the reasons:

"... The postulate of relativity in its most general formulation ... makes the spacetime coordinates into physically meaningless parameters".

"... Why were a further seven years required for setting up the general theory of relativity? The principal reason is that one does not free oneself so easily from the conception that an immediate physical significance must be attributed to the coordinates".

After returning to the principle of general covariance, and his discovery of the final field equations for gravitation on 25 November 1915, Einstein wrote in a post card to Arnold Sommerfeld in February 1916:

"You will be convinced of the general theory of relativity when you have studied it. That is why I am not mentioning a word in its defense".

He is at his most eloquent in this passage from a 1933 lecture in Glasgow:

"The years of searching in the dark for a truth that one feels but cannot express, the intense desire and the alternations of confidence and misgiving until one breaks through to clarity and understanding are known only to him who has himself experienced them."

Today General Relativity is a wonderfully mature subject. Ninety years have passed since it left Einstein's hands to become everyone's possession. The relationship between Special Relativity and General Relativity is extraordinarily delicate and beautiful. Echoing Landau and Lifshitz – general relativity "represents probably the most beautiful of all existing physical theories". And, notwithstanding some ambiguities, each special relativistic theory passes over in a natural manner into one consistent with general relativity:

"Every physical theory compatible with special relativity can be aligned into the system of general relativity by means of the absolute differential calculus, without (general relativity) supplying any criterion for the acceptability of that theory".

Einstein's deepest insights came from the use of invariance or covariance principles on the one hand, and the study of statistical fluctuations and thermodynamic arguments on the other. He viewed Special Relativity as a restrictive principle, not as a specific physical model:

"The principle of relativity is a principle that narrows the possibilities; it is not a model, just as the second law of thermodynamics is not a model".

So far ahead

In ever so many instances he was far ahead of all others in his understanding of Nature.

Leaving aside General Relativity which was his own creation, we can cite several examples. In 1905, as we saw, he had 'teased out' the light quantum concept from the Wien limit of Planck's law; he then realised that in the context of the complete law these quanta could not be regarded as mutually independent but would influence one another in some way. He even posed this years later as a problem for Bose to look at. In Stachel's view, this was an early glimpse of quantum mechanical entanglement, brought out fully into the open in the 1935 EPR paper. Then already in 1909 he grasped wave particle duality for light:

"It is my opinion that the next phase in the development of theoretical physics will bring us a theory of light that can be interpreted as a kind of fusion of the wave and the emission theory".

After the work in 1916-17 on spontaneous and stimulated emission he saw very clearly that the Maxwell field had to be quantized:

"The properties of elementary processes ... make it seem almost inevitable to formulate a truly quantized theory of radiation".

This is to be particularly contrasted with the views of Planck and Bohr, mentioned earlier, that radiation should continue to be treated classically. The quantum theory of the Maxwell field was formulated ten years later, in 1927, by Paul Dirac. Again in that same body of work he glimpsed the role of chance in quantum phenomena but regarded it as a deficiency, for he said it is

"a weakness of the theory ... that it leaves time and direction of elementary processes to chance; nevertheless I have full confidence in the reliability of the way entered upon".

So much of later quantum mechanics sensed so early!

Language, God, Music ...

Let us now turn briefly from his science to other aspects. Einstein had a remarkable gift with language, and wrote with great eloquence. He showed wonderful clarity, independence and boldness in thought and expression, and greatly inspired many of his own and later generations. Here are his tributes to some whom he greatly respected. After a careful critique of the foundations and inadequacies of Newton's mechanics, in the Autobiographical Notes, he says:

"Enough of this. Newton, forgive me; you found the only way which, in your age, was just about possible for a man of highest thought and creative power. The concepts, which you created, are even today still guiding our thinking in physics, 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".

About Lorentz, without whose preparatory work Einstein said he could never have discovered Special Relativity, he wrote:

"He meant more to me personally than anybody else I have met in my life time".

And soon after his first meeting with Niels Bohr in 1920, he said in a letter:

"Not often in life has a human being caused me such joy by his mere presence as you did".

About his work, some other gifted writers had this to say:

Hermann Minkowski on Special Relativity in 1908: 'Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality'.

Hermann Weyl on General Relativity in 1918: 'Einstein's Theory of Relativity has advanced our ideas of the structure of the cosmos a step further. It is as if a wall which separated us from Truth has collapsed.'

Paul Dirac in 1979: 'The Einstein theory of gravitation has a character of excellence of its own. Anyone who appreciates the fundamental harmony connecting the way nature runs and general mathematical principles must feel that a theory with the beauty and elegance of Einstein's theory has to be substantially correct'.

And here is a comment in a lighter vein: when Chaim Weizmann and Einstein reached New York after a long ship journey from Europe in 1921, Weizmann told the waiting reporters:

"Einstein explained his theory to me every day, and on my arrival I was fully convinced that he understood it".

Quite early in life, at age 12, Einstein lost faith in formal religion. He studied Kantian philosophy in his later student years. Often in scientific matters he referred to God in what may be termed a playful manner:

"Subtle is the Lord, but malicious He is not".

And about quantum mechanics:

"The theory yields much, but it hardly brings us close to the secrets of the Old One. In any case, I am convinced He does not play dice".

As he once explained, the God he had in mind was the God of Spinoza: Nature.

An oft-quoted pithy sentence is:

"Science without religion is lame; religion without science is blind".

Deep though it is, there is an austere quality about it too. Probably inspired by it, Victor Weisskopf expressed the essence of the idea in more human terms:

"Human existence is based upon two pillars: compassion and knowledge. Compassion without knowledge is ineffective; knowledge without compassion is inhuman".

Music was a vital component of Einstein's life, having learnt to play the violin at a young age. The most memorable incident in this connection is his reaction to Yehudi Menuhin's debut in 1929, at age 13, with the Berlin Philharmonic, playing the Bach, Beethoven and Brahms concertos in one programme. Einstein was so moved that he took Menuhin in his arms and exclaimed: "Now I know that there is a God in heaven!"

Through his clarity, courage and beauty of imagination, Einstein continues to inspire those of us who have chosen to pursue science, physics in particular. We are fortunate to be relatively close to him in time – born 126 years ago, worked from 100 to 70 years ago, died just 50 years ago. Much closer to us than figures like Kepler, Galileo and Newton. We constantly wonder – how could one person have accomplished so much?

We physicists must consider ourselves fortunate – we are able to try and understand what he did. Just as someone who knows Sanskrit can savour Kalidasa, those at home with English can delight in Shakespeare, and those with some musical training can lose themselves in the classics. So for us with a physics training the highest achievements of human thought in science are accessible. Others too can admire him for his human qualities.

Einstein realised full well that others would go beyond his work, however great it is. He said:

"In my opinion there is *the* correct path and ... it is in our power to find it".

When he died, his intellectual heir Wolfgang Pauli declared:

"Einstein's life ended .... with a demand on us for synthesis".

How then to conclude this talk? I can think of no better way than to say of Einstein what he said about Gandhi in 1939:

"Generations to come, it may be, will scarce believe that such a one as this in flesh and blood walked upon this earth".

Suggested Reading

[1] **Albert Einstein: Philosopher - Scientist, *The Library of Living Philosophers*, Vol.VII, ed. P A Schilpp, Open Court, La Salle, Illinois, 1949.**

[2] **A Pais, 'Subtle is the Lord...' *The science and the Life of Albert Einstein*, Oxford University Press, 1982.**

[3] **J Stachel, *Einstein's Miraculous Year: Five Papers that Changed the Face of Physics*, Princeton University Press, 1998.**

[4] **J Stachel, *Einstein from 'B' to 'Z'*, Birkhauser, 2002.**

[5] **Vasant Natarajan, V Balakrishnan and N Mukunda, *Resonance*, Vol.10, No. 3, pp.35-56, 2005.**

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