EINSTEIN: HIS IMPACT ON ACCELERATORS; HIS IMPACT ON THE WORLD *

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Abstract

The impact of the work of Albert Einstein on accelerator physics is described. Because of the limit of time, and also because the audience knows the details, the impact is described in broad strokes. Nevertheless, it is seen how his work has affected many different aspects of accelerator physics. In the second half of the talk, Albert Einstein's impact on the world will be discussed; namely his work on world peace (including his role as a pacifist, in the atomic bomb, and in arms control) and his efforts as a humanitarian (including his efforts on social justice, anti-racism, and civil rights).

Figure 1: "Everything that is really great and inspiring is created by the individual who can labor in freedom." "The state has become a modern idol whose suggestive power few men are able to escape."

INTRODUCTION

In this, the International Year of Physics, just 100 years after Albert Einstein's fabulous year of 1905, it is appropriate to recall Einstein's work. Most particularly, at the Free Electron Laser Meeting of this year, 2005, a talk was presented on Einstein's impact both on accelerator physics and upon the world. Obviously this could have been – even should have been – a very long talk, for his impact was beyond belief and would have taken a very long time to describe in any semblance of a fair description. Clearly, however, the Meeting had to proceed, and so this rather modest presentation was given.

Nevertheless, even in a brief talk some sense of Einstein's impact could be conveyed and it was, in this spirit, which the presentation was made. The first half was devoted to his impact on accelerators, a far larger impact than one might at first realize. The second half of the talk described his impact on the world of his concern with world peace and with various humanitarian causes.

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IMPACT ON ACCELERATORS

Proceeding with very broad stokes, as the practitioners of beam physics are well-aware of the details I shall only indicate the general areas where Einstein had a large impact. In short, I will name the areas, but give no details. I do give the dates, because I think it is very interesting how Einstein's work in the first and second decade of the last century didn't get applied to accelerators until very much later.

Special Relativity

Lev Landau complimented Gersh Budker with the nickname "engineer of relativity"

a. The first impact of relativity was on the Betatron (1940) [mv vs p]; i.e., the change of circulation frequency with energy limiting the top energy of a cyclotron. Nevertheless the 184" cyclotron was initiated (1941). The way to circumvent this limit was first appreciated by Thomas (1938), and then after WWII by McMillan (1945), and then, subsequently, with FFAG radial sector and spiral ridge cyclotrons (1954).
b. A second aspect of relativity was the need for complete relativistic dynamics, which came to the fore with the invention of synchrotrons (1953).
c. A third aspect of relativity was time dilation. This is of importance for decaying species (muons) (1969).

Brownian Motion

Einstein's thesis and six papers prior to 1905 were on fluctuation phenomena. Here he presented arguments that convinced the world of the reality of atoms. So, we can reasonably consider that all fluctuation phenomena go back to Einstein. Thus we note the following four phenomena:

Incoherent radiation (which is only due to the fluctuations in beam current) (1947)

a. Gas scattering and intra-beam scattering (1963)
b. Stochastic cooling (1972); Optical stochastic cooling (1993)
c. The limit on muon cooling (1981)

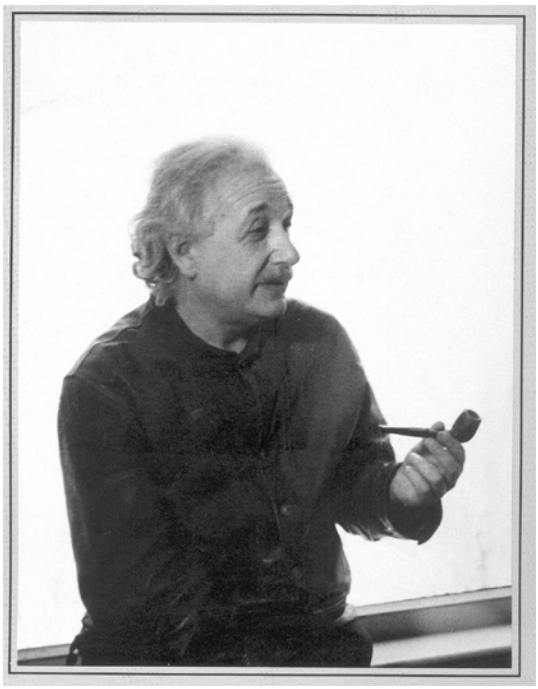

Figure 2: "It is a precarious undertaking to say anything reliable about aims and intentions."

Photo-Electric Effect

The realization that photons are "real"; that they carry energy and have momentum was one of Einstein's most important contributions. It was, in fact, the contribution mentioned in the Nobel Prize. The effect is everywhere in accelerator science:

a. Radiation effect on betatron and synchrotron motion (Radiation damping and ultimate emittance) (1955)
b. Laser cooling (1990)
c. Photo-cathodes (1995)
d. Many particle detectors….

A and B Coefficients

This work was not done in that wonderful year of 1905, but in 1916. Since the work is not as well-known to accelerator physicists, as is his earlier work, let me review Einstein's 1916 work:

Let N_a be the number of atoms in lower level a.
Let N_b be the number of atoms in upper level b.
Let $\omega_{ba} = (E_b - E_a)/\hbar$ be the transition frequency.
Let dN_{ab}/dt be the transition rate.
Let $\rho(\omega_{ba})$ = energy density of radiation per unit angular frequency range.

Then:
$dN_{ab}/dt = A N_b + B N_b \rho(\omega_{ba})$

and, as Einstein showed: $A = (\hbar \omega_{ba}^3 / \pi^2 c^3) B$

Thus there is a direct relation between spontaneous and stimulated emission. This is the very concept behind the laser and, hence, any use of lasers is based upon this work. I think of such things as in:

a. Laser alignment (1960s)
b. Laser cooling (1990)
c. Laser acceleration (1979)

The Madey Theorem (1971) says that the gain spectrum is the derivative of the spontaneous emission spectrum; i.e., there is a relation between stimulated and spontaneous emission. This is exactly an application of Einstein's work on A and B coefficients.

General Relativity

Perhaps the first application of general relativity to accelerators was by Larry Jones and I (1956), in response to an argument that storage rings would not work because of gravity pulling all the particles to the bottom of the vacuum chamber. We showed this was incorrect, but used general relativity so as to cloud the issue! More serious applications are:

a. John Bell and J. Leinaas analysis of the ultimate polarization in a storage ring (1983). An accelerated electron sees the vacuum photons as a gas at a temperature $T = \hbar a/2\pi kc$ (Hawking, Unruh Radiation), where k is Boltzman's constant, $\hbar$ is Planck's constant, and a is the acceleration. The electron is shaken up by these photons and that limits the polarization to less than 100%. This same result can be derived much more easily by a straightforward analysis, but that it was equivalent to Hawking Radiation was a most interesting observation.
b. Jie Wei's derivation of beam frame equations (1993), needed to do Molecular Dynamics numerical calculations of crystalline beams.
c. Some suggested experiments to use accelerated particles to study general relativity. (Nothing has come of these ideas.)(1990s)

IMPACT ON THE WORLD

Einstein's family life left much to be desired. He married Mileva Maric on Jan. 6, 1903 (although they had a child prior to that, which they gave up for adoption, and all records are lost). Perhaps, there are lots of little Einsteins running around. They had two sons; the first Hans Albert was born on May 14, 1904. They separated in 1914 (and he was pleased to have quiet and peace while working out general relativity). They were divorced in 1919 (and he agreed to give Mileva the Nobel Prize money when he won it: 30,000 kroner). He married cousin Elsa in 1919 (she had two daughters 20 and 18). Elsa died in 1936. (Remark made soon after, **"I have settled down splendidly here…."**)

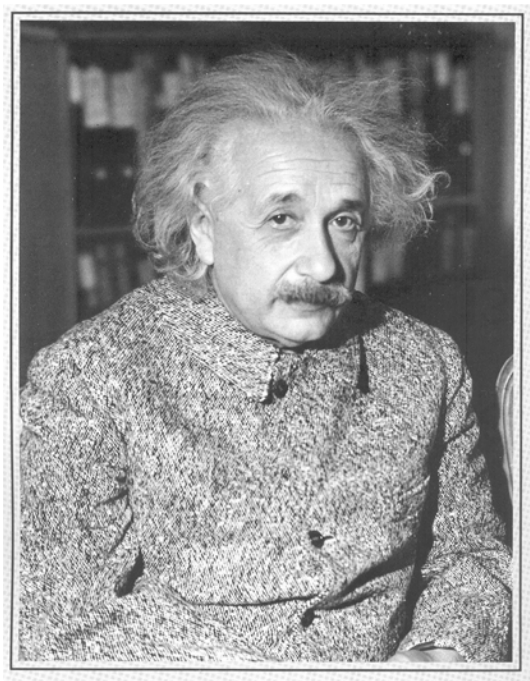

Figure 3: "All means prove but a blunt instrument, if they have not behind them a living spirit." "We must overcome the horrible obstacles of national frontiers." "My life is divided between equations and politics."

World Peace: Pacifist, Atomic Bomb, Arms Control

"I made one great mistake in my life - when I signed the letter to President Roosevelt recommending that atomic bombs be made…" (1954) (Note: Not referring to the cosmological constant.)

a. Einstein was politically active at a rather early time. He was a pacifist during WWI and signed the Manifesto of the 93 and Manifesto to Europeans (1914)
b. Pacifist during WWI. (His salary support, however, was from those who supported German militarization.) His pacifism caused him problems in Germany both during and after the war.
c. He developed the "two percent" solution to war (1930). (Refuse to fight; if only 2 % of the citizens objected that would flood the jails and prevent a war.)
d. His revulsion towards Nazism caused him to give up pacifism. (A pro-Nazi paper, in 1930, put 50,000 Marks on his head. Einstein replied, "I didn't know I was worth so much")
e. On Oct. 1940 he became a US citizen. He was delighted and offered to give up his cherished sailboat if that was required. In July, he had been denied clearance (He didn't know that in Oct.). Thus he was never was privy to the work at Los Alamos. (His FBI file was 1,800 pages long.) He worked on Naval problems during WWII.
f. However, through conversations with Otto Stern he knew, in general terms, what was going on at los Alamos, and in December 1944 he wrote a long letter to Niels Bohr advocating "internationalization of military power".
g. Einstein joined Szilard in urging President Roosevelt not to use the A-bomb on people, but his letter was found un-opened on Roosevelt's desk after Roosevelt's death.
h. In 1946 Einstein became the first chairman of The Emergency Committee of Atomic Scientists (Members such as Linus Pauling, Hans Bethe, Vicki Weiskopf.)
i. The Bertrand Russell-Albert Einstein Declaration (concern that nuclear weapons would be used in any world war and a call for the repudiation of war as a means of settling disputes) was initiated by Russell in Feb, 1955. Einstein worked on it through April 11 (He died on April 18) This Declaration was the start of Pugwash.

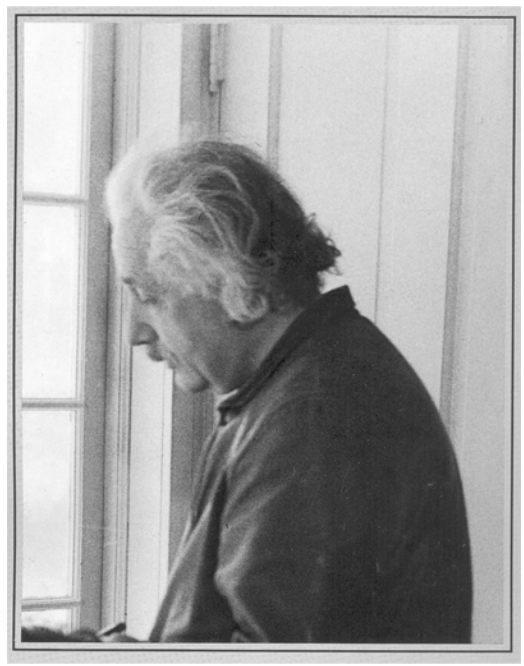

Figure 4: "One can organize to apply a discovery already made, but not to make one."

Humanitarian: Social Justice, Anti-Racism, Civil Rights

Einstein was well known for these qualities, and with good reason.

a. Even as early as 1922, he had visa problems getting into the USA, but he played the press very astutely and was granted a visa the very next day. (He was not naive at all.)
b. In 1953, an open letter, published in the New York Times: **"However, this refusal to testify must not be based on the Fifth Amendment, but on the assertion that it is shameful for a blameless citizen to submit to such an inquisition…"** The claim that it is wrong to obey the law, when it is a bad law, brought strong reaction against Einstein.

c. Published only after his death: **"I want to suggest that the practices of those ignoramuses who use their public positions of power to tyrannize professional intellectuals must not be accepted."**
d. In reaction to McCarthy, and the denial of clearance to J. Robert Openheimer, in 1954, **"If I were a young man again.... I would not try to become a scientist or a scholar or a teacher, I would rather choose to be a plumber or peddler, in the hope of finding that modest degree of independence still available under present circumstances."**

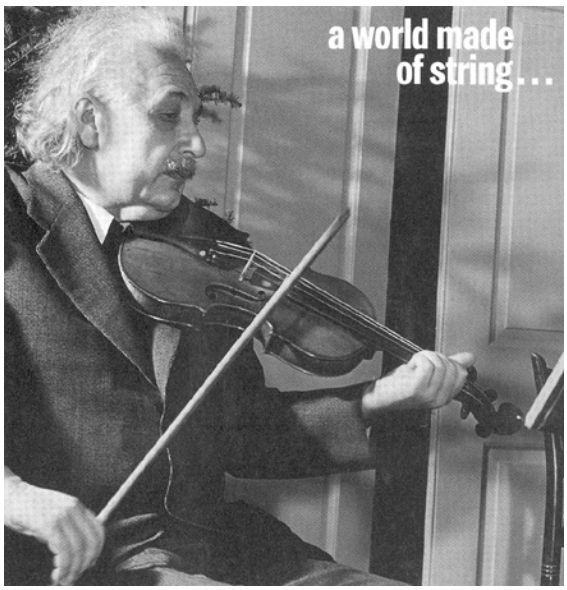

Figure 5: "A table, a chair, a bowl of fruit and a violin.... what else does a man need to be happy!"

Acknowledgement

The very fine pictures of Einstein and many of the quotes were collected by Swapan Chattopadhyay and first used by him at the Particle Accelerator Conference in May 2005.

REFERENCES

There are hundreds of books on Einstein. Just a few which have been used for this presentation, are:

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