Hans Albrecht Bethe (1906–2005): Personal glimpses

Hans Albrecht Bethe, the last link among the founding fathers of physics of the last century, passed away on 6 March 2005 at the age of 98, although his active interest in physics almost till the end, had generated a yearning among his numerous students and admirers to see him alive for another two years, so as to complete his own century. Bethe had been an institution by himself, a coveted name that he had earned by impacting a whole spectrum of physics, from atomic processes responsible for the properties of matter, to nuclear forces governing the structure of atomic nuclei, within a 75-year time span ranging from the mid-thirties to the last decade of the twentieth century. No less was his concern for the social responsibility of science, a subject on which he had written numerous articles in influential journals. Whichever sector of physics he had set his eyes on, Bethe invariably left an indelible mark of his masterly grasp with deep insight born out of his twin characteristics of simplicity and thoroughness, be it in solid state physics (Bethe ansatz), or nuclear physics (Bethe's Second Principle Theory), or even quantum field theory (Bethe–Salpeter Equation; BSE). His fantastic powers of fast yet accurate calculation (in the days long before the computer revolution) had made him a legend of his time, thanks to his single-handed success in determining the energy production in the sun and the stars by a correct choice of a sequence of nuclear reactions resulting in the fusion of four hydrogen atoms into one helium atom, through four steps of the 'carbon cycle', leaving the original carbon to come out unscathed in the end. [The story of how Bethe achieved this feat while travelling in a train is vividly described by George Gamow in his book *Birth and Death of the Sun*]. His Nobel Prize (in 1967) for this great discovery, was a culmination of a sequence of most prestigious recognitions – the Presidential Medal of Merit in 1946; Max Planck Medal in 1955, and the Fermi Award in 1961.

Some of Bethe's early works have become household words in physics textbooks. The Bethe–Weitzacker mass formula is a classic example of physical insight, inasmuch as each term in the formula represents a distinct physical effect. [It is another matter that this formula has since undergone some quantum corrections a la Hugenholtz–Van Hove theorem, one in which an Indian physicist, L. Satpathy has made significant contribution]. Another household word is the Bethe–Heitler formula for Bremsstrahlung, whose agreement with data then available provided one of the earliest experimental support for the then nascent structure of quantum electrodynamics (QED). This formula also proved crucial for Homi Bhabha's theory of cascade showers, representing the soft component of cosmic rays. Bethe was equally dexterous in applying classical mathematical methods to (i) the calculation of electron densities in crystals; (ii) the order–disorder states in alloys (the Bethe ansatz); (iii) the ionization processes in shock waves, to name only a few. No wonder he headed the group of theoreticians for the Manhatten Project in Los Alamos, since his deep and versatile knowledge of physics had few equals.

At the next higher level of sophistication, there has been rich evidence of Bethe's transparent approach, all bearing the unmistakable marks of a 'yin–yang' Tao of simplicity with thoroughness. Some examples are his famous papers on (i) Lamb shift in QED, (ii) BSE in the strong interaction sector of quantum field theory (QFT), and (iii) effective range theory, and Bethe–Brueckner theory in nuclear physics. On the Lamb shift, it took Bethe (who had just returned from the Solvay Congress on the theme of renormalization) only two pages of the *Physical Review* (1947) to bring the theory (QED) to within less than a megacycle of the experimental value, using a simplified approach to the physical concept of the electromagnetic self-energy of the electron in the Coulomb field of a hydrogen-like atom (in which he did not forget to subtract the self-energy of a 'free' electron), while it took at least two volumes of the same journal to fill the remaining gap, using elaborate techniques of renormalization based on Tomonaga–Schwinger-Feynman–Dyson theory. The same degree of clarity was evidenced in the Bethe–Salpeter monograph in the *Handbuch der Physik* on the 'Quantum mechanics of one- and two-electron problems', which has become a classic of all times. BSE, which was derived by these two authors from diagrammatic considerations, using no more than simple quantum concepts, encompasses the most complex features of quantum field theory (as was derived by Gell-Mann and Low around the same time by more orthodox methods of QFT). Although not an exact equation, the BSE, together with its more formal QFT counterpart in the Dyson–Schwinger Equation, are the two most widely used equations in non-perturbative applications of strong interaction dynamics.

In the nuclear physics sector, Bethe demonstrated the power of simplicity through his success in extracting the 'cream' of low-energy effective range theory, viz. the scattering length a and effective range r_0, by using a simple yet transparent approach, in contrast to the elaborate variational theory of Walter Kohn on the same problem. And as a remarkable example of thoroughness without losing simplicity, in a single paper in the *Physical Review* (1956) Bethe effectively subsumed at least a dozen papers written earlier by Keith Brueckner, who had pioneered the field through a many-body formulation of nuclear structure. Bethe's feat was not entirely free of charge, for Dale Corson, the then Chairman of Physics at Cornell, had extracted his price for having paid US$ 1000 to the *Physical Review*, in the form of a seminar from Hans Bethe on the subject! [This was learnt by the author from the late Pasha Kabir.]

It was only after Bethe's paper that the Bethe–Brueckner microscopic theory of the nuclear many-body problem came of age, and became one of the most fashionable topics in nuclear physics which paved the way for many young minds to work on. This was despite the then tentative nature of the nucleon–nucleon interaction at a time which had provoked a Churchillian remark from the nuclear physicist Marvin Goldberger that 'in no other field has so much effort been spent towards so little effect'. As if to counteract the dampening effect of this statement from a leading nuclear physicist of the day, Bethe invoked his celebrated Second Principle Theory, which hypothesized the nucleon–nucleon interaction as 'given', much like the Coulombic electron–electron force, albeit with the difference that the understanding of the latter is at a much deeper level of theory. Indeed the entire edifice of nuclear physics has been based on the Second Principle Theory which has since undergone a metamorphosis with the advent of the quark model, for with the elementary particle status now vesting with quarks and gluons, the same Second Principle Theory is effecttively in the latter's court, since the infrared sector of QCD still remains unsolved.

As one of his Indian students in the early fifties (in the company of M. K. Sundaresan and Pasha Kabir), I had a rare opportunity to come into his direct contact and get a first-hand view of the human side of Bethe the physicist. I first came to Cornell on a cold November morning in 1952, on a three-year central states scholarship (Govt. of India) to work with Freeman Dyson (who had kindly consented to take me under his guidance). Dyson was a Professor of Physics at Cornell, while Bethe was the central figure at the Newman Laboratory of Nuclear Studies, whose Director was Robert Wilson. The subject of meson–nucleon resonances was 'hot' in those days. Especially the '33' resonance, first observed by the H. L. Anderson's team at the Chicago accelerator, attracted a good deal of attention from Dyson, who had just formulated the three-dimensional Tamm–Dancoff theory of meson–nucleon interaction as the right language of strong interaction dynamics. This had Bethe's immediate approval (despite his own involvement with the four-dimensional BSE!), and the entire Cornell team under the two giants soon unravelled the mystery of the '33' resonance! For a young worker (like me), it was indeed exciting to see this happening before his very eyes. There was little doubt that Cornell with its vibrant atmosphere, was the right place for a young aspirant to try his luck with physics. But it was a big disappointment to learn that Dyson was soon going to Princeton as a permanent member of the Institute of Advanced Study! However, the disappointment proved short-lived, due entirely to Bethe's grace, as he readily consented to take me over under his tutelege almost for the asking! Not only that; the tuition fees for a Ph D were very high at Cornell, which the Indian Embassy was unwilling to give. Bethe immediately came to my rescue by offering a research assistantship (over and above the scholarship) to cover the tuition charges! [This was a day of great relief for a young student of 23, some 10,000 miles away from home.] And Bethe gave me little work as a research assistant, leaving me entirely free to concentrate on the courses. I was equally lucky with Dyson's continuing interest in my work on the Tamm–Dancoff theory to which he had initiated me, whenever I needed his help by correspondence.

The atmosphere in the laboratory was most informal and pleasant, in tune with Bethe's balmy presence. To quote one example of this informal atmosphere, almost the entire physics faculty (Dyson included) attended a course given by Bethe on relativistic quantum mechanics in the fall of 1952, using as a background Dyson's famous lecture series on the same subject given a year earlier. Later in the spring of 1953, when Dyson visited Cornell to give a colloquium on the 'Overhauser effect', Bethe introduced him with the words: 'Professor Dyson left Cornell to work on the problems of quantum field theory in the Institute's quiet atmosphere, and therefore he is going to report today on the solid state'! The junior faculty at the time included among others Ed Salpeter (now a Distinguished Professor Emeritus of Physics at Cornell), Sam Schweber (now the official biographer of Bethe), Norman Austern (a pioneer in the theory of deuteron stripping, now deceased), and Marc Ross (a versatile particle physicist later turned economist), all of whom were extremely friendly and easily accessible to graduate students like us for our sundry needs, including occasional trips to the local ice-cream bars. It was during this period that Bethe wrote his famous book *Mesons and Fields*, with Schweber as his chief collaborator. This gave us an opportunity to peep into the anatomy of the famous book, which was taking shape before our eyes. Ross (before turning economist) was later to collaborate with me on the problem of strong decays of hadron resonances.

Stan Cohen, a graduate student of Bethe's, undertook an interesting task of making a plaster mould of Hans Bethe's bust. It sold like hot cakes at one dollar a piece. I grabbed one, and have since treasured this unusual piece.

Many years later, in 1969, when Bethe expressed a desire to visit Delhi and Agra in connection with his round-the-world tour with his family, we grabbed the opportunity and got the University of Delhi to confer on him a D Sc h.c. It was a memorable event for the university on 18 December 1969, after which Bethe also gave a lecture on the physics of the smallest and the largest. His famous 'pinhead' analogy still has a familiar ring, namely the size of the nucleus bears roughly the same ratio to the atomic size as does the size of a pin-head to that of the room (the familiar Lecture Theatre No. 2), where he was lecturing; and the atomic size bears almost the same ratio to the size of the pin-head! And despite his heavy schedule, Bethe did find time to visit us, and enjoyed immensely a discussion with an outstanding teacher of mathematics of his times (the late Jatindranath Mitra).

Bethe's human qualities extended well beyond physics to political and diplomatic levels. His friendly and unassuming personality coupled with an intensely practical yet liberal outlook, had made him ideally suited to his job as the head of the theory group at the Los Alamos project. On the other hand, the Hiroshima disaster created a strong feeling of social responsibility in Bethe and his Los Alamos colleagues, leading them to write and lecture on the nuclear threat, so as to increase public awareness.

At a more personal level, I had a pleasant taste of Bethe's liberal thoughts in the face of the well-known American government tilt towards Pakistan *vis-à-vis* India. The first occasion was the victory of Indira Gandhi in the General Elections of March 1971, when I received an unexpected message of good wishes from Bethe on her victory. His apparently soft corner for Indira Gandhi showed up once again towards the end of 1971 after the Indian victory in the Indo-Pakistan war, when I received a telephonic message of congratulations from him! On being told that that the Nixon government had menacingly poised the US navy at India's doors, his reassuring voice still rings in my ears: 'do not worry about it'!

Even during the last days of his life, when he was living in the Kendal of Ithaca retirement community (near Cornell University), Bethe did not forget his love for physics. His three lectures in quantum theory, meant for his neighbours at Kendal, as late as in 1999 (when he was 93), hold great appeal for experts and non-experts alike. He was an unusual creation of nature, whose gentle flash was a rare phenomenon that is unlikely to be repeated.

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