**“QED and the Men Who Made It: Dyson, Feynman, Schwinger and Tomonaga.”,** by Silvan S. Schweber, (Princeton University Press, USA), 1994, pp xvii + 732, Price $ 39.50pb. [ISBN 0-691-03327-7]

Quantum Electrodynamics, QED is widely recognised as the “Jewel of Physics”, a name given to it by the celebrated Richard Feynman, who called it our “proudest possession”. This epithet, is not only because the predictions of the theory have been found to be correct to an amazing degree of accuracy but also because the theory has served as the benchmark against all the other theories of elementary interactions are compared.

But like all other successful theories in physics, it did not develop a priori; nor was it the work of one single individual who sat down to work out the theory one day. Instead, it was the culmination of several decades of work by some of the finest human intellects of this century. And of course, with it come many anecdotes and a whole narrative.

What is QED? One of the finest descriptions of what the theory is and its import comes from Freeman Dyson, one of the key actors in the development of QED. Dyson calls it “..the theory which brought order and harmony into the vast middle ground of physics”, the middle ground excluding gravity and nuclear forces, but including the laws of atomic structure, solid state physics, lasers, optical spectroscopy and all of electronics. He goes on to add that “QED unifies all these diverse phenomena into a small number of principles of great generality and elegance, weaving together special relativity and quantum mechanics into a seamless fabric”.

By 1927, quantum mechanics was well established as the theory which correctly explained phenomenon within its realm of validity. This realm was governed by a fundamental constant of nature, Planck’s constant *h.* Any system whose characteristic mass (*m*), length (*l*) and time (*t*) were such that $ml^2 / t$ was of order *h* and $l / t$ was much smaller than *c*, the velocity of light, could be satisfactorily explained by the quantum mechanics of Heisenberg, Schrodinger and Dirac. What remained, however was the problem of “fitting of the theory with relativity ideas”, to paraphrase Dirac’s famous assertion. This was to preoccupy theoretical physicists for many years to come.

The first step towards this integration was in the form of Hole theory of Dirac. This was revolutionary because it entailed the creation and annihilation of matter as an intrinsic feature. Thus vacuum became a physical medium in which electron-positron pairs are being constantly created and annihilated. The development of relativistic quantum mechanics in the 1930’s can be seen as developing from two viewpoints. One was that of Dirac which took particles as fundamental entities while the other was the view which saw particles as quanta of fields which are fundamental. The quantum theory of fields, which was developed by de Broglie, Schrodinger, Jordan, Pauli and Heisenberg, was much richer in its potential than the particle approach, though both were essentially equivalent The field theoretic approach was further bolstered by Fermi’s theory of Beta decay and Yukawa’s theory of nuclear forces, both of which suggested that the domain of applicability of field theory possibly included weak and strong nuclear forces. Nevertheless, the hole theory, though beset with problems of ambiguity when it came to multi-electron systems was also fairly successful. In fact, most of the predictions of QED during this period came from hole-theoretic calculations. These included bremsstrahlung, Compton Effect and cross sections for electron-positron pair production and annihilation.

The successes of both these approaches were short-lived ; it was soon realised by the “founding fathers” that there were overwhelming difficulties when one did higher order calculations with the theory. The problem was of divergences or infinities in the calculation of certain physical quantities. These difficulties were sought to be overcome by various proposals which included the $\lambda$ limiting procedure of Wentzel, the C-meson field of Sakata, the procedure of redefining the charge current operator in the vacuum polarization so as to absorb the divergence and the redefinition of mass and charge parameter to remove the infinities. All these ideas however were unsatisfactory and thus the situation in the 1930’s and early forties was one of pessimism. The difficulties seemed insurmountable and this was an impediment to progress in the field and gave rise to an overall sense of gloom in the community.

The successful handling of the infinities came in the period 1945-50 principally due to the work of Kramers, Schwinger, Dyson, Feynman, Bethe and Tomonaga. Each of these individuals contributed significantly to the solution of the problems and placed the theory on a firm footing. Schwinger and Tomonaga developed a field theoretic formalism which identified and eliminated the divergences in a fully consistent, relativistic and gauge invariant fashion. This was essentially done by absorbing the divergent contributions into a redefinition of mass and charge parameters of the theory, an idea first suggested by Kramers. The formalism was elegant, self consistent and most importantly made predictions regarding phenomenon like Lamb shift, magnetic moment of the electron etc.

For instance, Bethe in 1947 explained the principal part of the Lamb Shift to be around 1040 MHz using Kramer's renormalization ideas; however Schwinger, Tomonaga and Feynman obtained better results in QED through refined valued of $\delta m / m$ , or equivalently slightly different values of self energy as obtained by Schwinger, Wiesskopf and Feynman. These differences are reflected in values of the Lamb Shift computed.

Good deal of pages are devoted to the multifaceted achievements of two stalwarts of QED, viz. Schwinger and Feynman. The former being a rigorous field theorist and the latter renowned for his populist and pedestrian approach. Feynman is well known for his diagrams which have become synonymous with calculations in field theory. Schwinger, on the other hand worked with obscure and abstruse mathematics as evidenced in his three monumental papers, QED I-III. Schweber points out extensively the criticism of Wentzel and Pauli (pp 345-352) but that does not belittle Schwinger's contribution to the development of QED.

Feynman, true to his idiosyncratic personality, followed a totally different approach. His method was more akin to Dirac where particles were taken as fundamental and phenomenon understood in terms of the space-time trajectories of these particles. This unconventional approach, resulted in an extremely efficient computational scheme which is all prevalent in the field ever since. It was left to Dyson to show that Feynman's approach could be derived from that of Schwinger and Tomonaga and the mass and charge renormalization (redefinition) removed infinities from the theory to all orders of perturbation theory. The scheme of removing divergences, called renormalization theory has played a central role in particle physics since then. The success of quantum electrodynamics together with the rules for renormalization was stupendous. It yielded values for quantities like the hyperfine structure of hydrogen or the magnetic moment of the electron which was in an unprecedented agreement with the experimental results. As an example of this unprecedented precision, Schweber mentions ( pp 206) that best measured value of electron's g-factor by Delmet et. al. as $g/2 = 1.001\ 159\ 652\ 193\ (4)$ agrees closely with QED which gives a value of 1. 001 159 652 459 (135).

Silvan S. Schweber, a distinguished physicist and the author of an excellent text book on relativistic quantum field theory, has donned the robes of a historian of science. And he has chosen to delve into one of the most exciting and intellectually fruitful period of science in this century. The book can essentially be divided into two parts. The first part deals with the development of the theory itself starting with the birth of quantum field theory. The various streams of the theory are described very clearly. The history of the ideas, the seminal conferences held at Shelter Island, Pocono and Oldstone, the various conflicting positions taken by the principal actors and interesting personal asides make wonderful reading.

What is remarkable about Schweber's work is that even though it is a work on history of science, he has steered clear of casting his book into any of the accepted moulds. It is easy, as he himself admits in the preface, to think of the history of QED fitting into both the Kuhnian mould or that of Lakatos. The Kuhnian notion of paradigm as a set of shared values (shared by a set of core workers) which determine the shape of the discipline, is easily substantiated by many examples from the history of QED. The whole program of renormalization could easily constitute a Kuhnian revolution. Afterall, ever since the success of renormalization in QED, it has been the cornerstone against which all contending theories of particle physics are measured. In fact, the "final" acceptance of the currently accepted gauge theories of strong and electroweak interactions, the so called Standard Model, was finally accepted only after t'Hooft proved their renormalizability in the early seventies. Likewise, the Lakatosian notion of competing modes of knowledge are evidently the particle and the field theoretic approach. But it is to Schweber's credit that he has stayed clear of these preconceived straightjackets. He is, as he says, interested in telling the story. And he certainly has done a wonderful job of it. Especially in the second part of the book.

The second part of the book deals with "The Men who made it". Here the author describes the life and work of the principal actors in the play, viz. Freeman Dyson, Richard Feynman, Julian Schwinger and Sin-itiro Tomonaga. Devoting a full chapter to each of these remarkable men, Schweber weaves an excellent story of how they carried out their work. Based on innumerable interviews with the scientists and their collaborators as well as many primary sources, he tells a wonderful tale of how real science is done. The specific character traits of the men and how these got reflected in their style of work, the post war milieu in particle physics, personal details of the scientists, it all adds up to a heady mix of an immensely readable account.

The book is a masterpiece. With many notes (thankfully assembled at the end), an extensive bibliography, and an eye for detail, Schweber has produced a narrative which will remain unmatched for some time to come. The only quibble one may have is on some occasions, he has gone in to too much, seemingly irrelevant details.

Silvan S. Schweber has spent the last 20 years researching for this book. And it shows in the thoroughness with which he has explored the subject. For a long time, history of science was a domain almost exclusively meant for the social scientists. Schweber has shown that not only can a practising scientist do an excellent job of it, but in some cases may even be better equipped to do history of science since s/he is acquainted with the inner dynamics of the working of the field. It is now upto other eminent scientists to take up the challenge from where Schweber has left it.

(1850 words)