Put to the test

The proton has turned out to be a little smaller than the estimate of the best theory, says **S Ananthanarayanan**

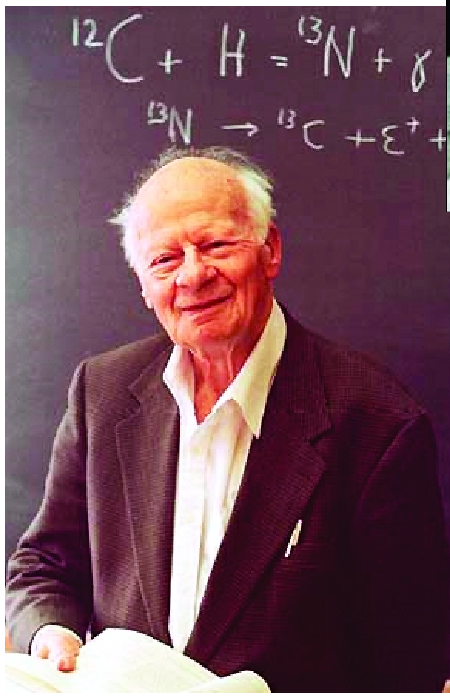
THE present theory of the interaction of matter and photons, which deals with all atomic and nuclear science, is able to estimate the value of physical constants with unprecedented accuracy. That the radius of the proton may be less than measured, and accepted so far, may raise questions of how good the theory is, despite its unequalled success.

The jewel of physics

This is how the maverick genius and Nobel laureate RP Feynman described *Quantum Electrodynamics (QED)*, which was developed to take care of inadequacies that had appeared in *quantum mechanics*. By the middle of the 20th century, quantum mechanics, which is the theory of how matter behaves at very small dimensions, had grown enormously successful. It arose to answer the crisis physics was in around the turn of the century — when classical physics found itself inadequate before things like radioactivity, X-Rays, the way atoms emitted light of specific colours or even the way the heat waves coming off a warm object were distributed.

Quantum mechanics found that everything fell into place if it were considered that energy did not flow in a continuous stream but in packets called *quanta*. The heat from a warm object had been seen as coming from vibrations within the object. In classical physics, all frequencies of vibration were allowed, and this implied that radiation from the object would be mostly in the highest frequencies, which was contrary to experience. But if it were taken that particles in the object exchanged packets of energy, then with energy proportionate to frequency, the number of particles at different frequencies would then get distributed, just like the speed of molecules in a gas — which is exactly what was observed.

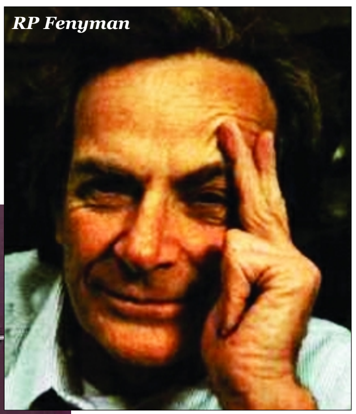
Atoms had been found to consist of a positively charged nucleus with electrons going around in orbit. Light was emitted when an electron dropped from a higher orbit to a lower one. Under quantum mechanics, the orbits, or energy levels of electron, are in steps of energy. The light emitted must hence be only of the colours that correspond to energy difference between permitted steps.



Emeritus Professor of Physics Hans A Bethe in his campus office on 19 December 1996. On the blackboard is his "Carbon Cycle" equation for nuclear energy generation in stars.

Quantum mechanics was soon formulated in elegant mathematics and even the theory of relativity had been built in. The mathematics could explain, with remarkable accuracy, not just the colours of atomic spectra but most of the observed features of atomic or nuclear behaviour.

But in 1947 a celebrated experiment revealed a feature called the *Lamb Shift*, of the internal structure of spectral lines of hydrogen that the existing theory could not account for. Attempts to deal with the problem led to infinite values appearing in the solutions, which did not made sense. But the same year, Hans Bethe proposed a mathematical device that did set the problem right, but the device had no theoretical or experimental basis. This device, called *renormalisation*, was later developed to be more general and the theory grew into the celebrated QED, a powerful way of computing that has set the course for further research.



RP Fenyman

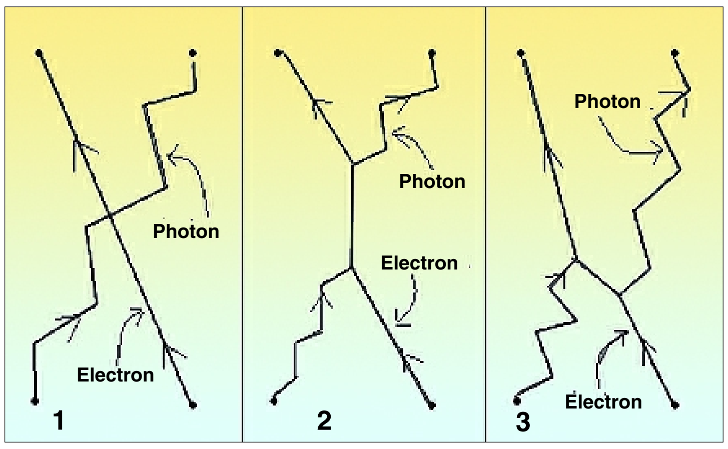
But for all its success and the Nobel prize for Feynman and Julian Schwinger in 1965, the former was not satisfied with the "ad hoc" method, and he likened it to a "shell game" and "hocus pocus".

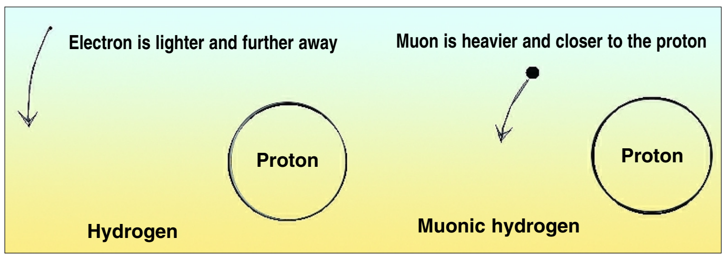
The success, incidentally, is that the theory is able to compute values that have been verified to an accuracy of 10 parts in a billion. The distance from Kolkata to Kanpur is 1,000 km. This amounts to a million metres or a billion millimeters. Accuracy, or 10 parts in a billion is 10 mm, or 1 cm in a distance of 100 km.

Confirmation of QED has become a major area of research and much effort in high-energy facilities, such as accelerators, is devoted to detecting discrepancies or lack of the same between theory and observation.

Feynman's formulation

Feynman's way of considering an interaction, say of an electron with a photon, is that there are different ways for the electron and photon to reach the end position. For instance, the photon and electron may just go to the final places without interacting, (Case 1 in the picture). Or else they could combine, move forward and separate (Case 2). Then again, the electron could emit a photon which goes to the destination, while the electron absorbs the first photon before reaching its own destination (Case 3).





Each of these possibilities has a probability and the probability of the end result is the sum of all probabilities. Feynman's method of QED was to list the ways a thing can happen and add the probabilities. It is a lot more complicated, in practice, but the method was feasible and powerful.

But the real problem was of a different kind. This is that every segment of a path could always be broken into segments, and each of these segments into more segments, ad infinitum. This difficulty, in fact, was the same as the infinite values that Bethe handled with renormalisation, and the same needs to be done with Feynman's solution. So this has been done, but Feynman himself was unconvinced and he called it a "dippy process".

Success questioned

One success of QED, then, is that it can explain the feature of the splitting of spectral lines, called the Lamb Shift. The Lamb Shift is a feature of the spectrum of hydrogen which consists of an electron orbiting a proton. The reason for the *shift* is that the electron is really not infinitely heavier than the electron and also that the proton is not really a point, as the ordinary theory assumes. In the process of explaining the shift, QED arrives at a value for the radius of the proton which is in agreement with the best experimental value available.

This best value, so far, has been through experiments with the usual hydrogen atom, where the proton is relatively far from the electron. But a more sensitive measurement of the proton is possible with a different experiment, where the electron is replaced by a *muon*, a particle with the same charge but about 207 times the mass of the electron. This atom behaves just like hydrogen, except that the muon is much closer to the proton than the electron in normal hydrogen. The electronic states and the fine structure of spectra are then easier to measure with precision.

In the current issue of *Nature*, an international group of scientists at the Paul Scherrer Institute in Switzerland reports precise measurements of the Lamb Shift that it carried out using muonic hydrogen. The result of the measurements gives a significantly lower value for the radius of the proton than the dimensions that have been accepted so far. If this, in fact, is the case, then the validity of QED becomes questionable or there is need to revise the values of other fundamental constants whose values appear in the computation.

The reason for the difference is yet to be explained. The proton size, in fact, is not measured but needs to be calculated using QED from the results of the experiments. In the many steps involved, there are all kinds of space for errors. The discrepancy may be better understood in future experiments, with hydrogen, muonium — which is an electron around — and antimuon in place of the proton and poitronium — an electron around a positron — the helium ion, which is an electron around two protons and two neutrons or anti-hydrogen, which is an anti-proton and an anti-electron.

But this approach, of high accuracy spectroscopy as carried out by the PSI group, may be the way to verify QED as opposed to the high-energy collisions in accelerators.

The writer can be contacted at simplescience@gmail.com

Genetic gaffe

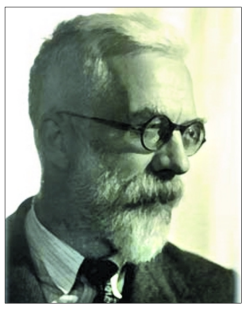
Tapan Kumar Maitra assesses the first 100 years of Gregor Johann Mendel criticism ~ a favourite with admirers and naysayers alike ~ and points out where the father of the modern theory of inheritance ~ and his detractors ~ went wrong

OVERWHELMING evidence gathered during this century has proven the correctness of Gregor Johann Mendel's conclusions. However, close scrutiny of Mendel's paper has led some to suggest that a) he failed to report the inheritance of traits that did not show independent assortment and b) he fabricated numbers. Both these claims are, on the surface, difficult to ignore — both have been countered effectively.

The first claim that Mendel failed to report crosses involving traits that did not show independent assortment arises from the observation that all seven traits that Mendel studied do show independent assortment and that the pea plant has precisely seven pairs of chromosomes. For Mendel to have chosen seven genes, one located on each of the seven chromosomes, by chance alone seems extremely unlikely. In fact, the probability would be 7/7 X 6/7 X 5/7 X 4/7 X 3/7 X 2/7 X 1/7 = 0.006

That is, Mendel had less than one chance in 100 of randomly picking seven traits on the seven different chromosomes. However, in 1977 L Douglas and E Novitski analysed Mendel's data in a different way. To understand their analysis, we need to know that two genes sufficiently far apart on the same chromosome appear to assort independently. Thus, Mendel's choice of characters showing independent assortment has to be viewed in light of the lengths of the chromosomes.

That is, Mendel could have chosen two genes on the same chromosome that would still show independent assortment. In fact, he did exactly that. For example, stem length and pod texture — wrinkled or smooth — are on the fourth chromosome pair in peas. Douglas and Novitski report that the probability of randomly choosing seven characteristics that appear to assort independently is actually between one in four and one in three. So it seems that Mendel did not have to manipulate his choice of characters in order to hide the failure of independent assortment. He had a one in three chance of naively choosing the seven characters that he did, thereby uncovering no deviation from independent assortment.



British statistician, RA Fisher suggested that Mendel's data was more hypothetical than experimental.

The second claim that Mendel fabricated data comes from careful analysis of Mendel's paper by RA Fisher, a brilliant English statistician and population geneticist. In a paper published in 1936, Fisher pointed out two problems in Mendel's work. First, all of Mendel's published data taken together fit their expected ratios better than chance alone would predict. Second, some of Mendel's data fit incorrect expected ratios. This second "error" on Mendel's part need a bit of explanation.

Mendel (left) believed that pea hybrids form germinal and pollen cells that correspond to all the constant forms resulting from the combination of traits united through fertilisation.

Mendel determined whether a dominant phenotype in the F_2 generation was a homozygote or a heterrozygote by self-fertilising it and examining 10 offspring. In an F_2 generation composed of 1AA:2Aa:1aa, he expected a 2:1 ratio of heterozygotes to homozygotes within the dominant phenotypic class. In fact, this ratio is not precisely correct because of the problem of misclassification of heterozygotes. It is probable that some heterozygotes will be classified as homozygotes because all their offspring will be of the dominant phenotype. The probability that one offspring from a Aa individual has the dominant phenotype is 3/4 or 0.75: the probability that 10 offspring will be of the dominant phenotype is $(0.75)^{10}$ or 0.056. Thus, Mendel misclassified heterozygotes as dominant homozygotes 5.6 per cent of the time. He should have expected a 1.89: 1.11 ratio instead of a 2:1 to demonstrate segregation. Mendel classified 600 plants this way in one cross and got a ratio of 201 homozygous to 399 heterozygous offspring.

This is an almost perfect fit to the presumed 2:1 ratio and thus a poorer fit to the real 1.89:1.11 ratio. This bias is consistent and repeated in Mendel's trihybrid analysis.

Fisher, believing in Mendel's basic honesty, suggested that the latter's data do not represent an experiment but more of a hypothetical demonstration. In 1971, F Welling published a more convincing case in Mendel's defense. Pointing out that the data of his rediscoverers are also suspect for the very same reason, Welling suggested that the problem lies with the process of pollen formation in plants, not with the experimenters.

In an Aa heterozygote, two "A" and two "a" cells develop from a pollen mother cell. These cells tend to stay together on anther. Thus, pollen cells do not fertilise in a strictly random fashion. A bee is more likely to take equal numbers of "A" and "a" pollen than chance alone would predict. The result is that the statistics Fisher used are not applicable. By using a different statistic, Welling showed that, in fact, Mendel need not have manipulated any numbers — nor would have his rediscoverers — in order to get data that fit the expected ratios well. By the same reasoning, very little misclassification of heterozygotes would have occurred.

More recently, Welling and others have made several additional points. First, for Mendel to be sure of 10 offspring, he probably examined more than 10 and thus probably kept his misclassification rate lower than 5.6 per cent. Second, despite the fact that Fisher was a brilliant statistician, several researchers have advanced compelling arguments to demonstrate that his statistical analyses were incorrect. In other words, for subtle statistical reasons, many of his analyses involved methods and conclusions that were false.

We must, therefore, conclude that there is no compelling evidence to suggest that Mendel, in any way, manipulated his data to demonstrate his rules. In fact, taking into account what is known about, it is only logical to believe that he didn't.

The writer is Associate Professor of Botany, Ananda Mohan College, Kolkata

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Stem cell 'pharmacies'

They'll be as common as chemist shops in 20 years time, writes **John von Radowitz**

ACCORDING to Professor David Warburton, one of the world's leading experts on stem cells and regenerative medicine, stem cell "pharmacies" that dispense tissue therapies could be as common as chemist shops in 20 years' time. He said the era of stem cell technology was only just beginning and in two decades he expected it to yield undreamed-of forms of personalised treatment for damaged body parts and organs.

David Warburton

Speaking on the eve of a major stem cell meeting in Nottingham, he said, "In about 20 years' time you'll get a diagnosis for a specific problem and be given stem cells to treat that problem."

Stem cells are "mother" cells that can be grown in the laboratory and used to make replacement tissue, such as brain neurons or insulin-producing pancreas cells. Those obtained from early stage embryos — Embryonic Stem Cells — have the ability to become virtually any kind of tissue in the human body.

The use of human embryos in research creates ethical concerns. However, recent developments have led to ways of "tweaking" the genes of ordinary cells to turn them into stem cells with ESC-like properties. Such research, combining genetics with regenerative medicine, has enormous potential, Professor Warburton believes. "It's a wonderful time to be working in medical research," he said. "Genomic research is going to apply stem cell research not only to a specific disease but to a specific person with a disease. You're going to have personalised regenerative medicine."

Based at the Saban Research Institute of the Children's Hospital in Los Angeles, Professor Warburton has pioneered research into the use of stem cells extracted from the amniotic fluid that surrounds a baby in the womb. He is currently is working towards clinical trials of kidney treatments using amniotic stem cells. "These cells go around the circulation, sniff out the damage and change the milieu inside the kidney," he said.

Scientists at his laboratory are also looking at reconstructing lungs using stem cells — a feat that has already been achieved in animals. Other developments that might soon produce benefits include experimental stem cell treatments for blood diseases and spinal cord injuries.

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