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Milestones in Physics (2)

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In December 1956 a memorable colloquium took place at the Rutherford Laboratory in England: speaker Abdus Salam, chairman Wolfgang Pauli, with the title "Two-component neutrino theory". As a young researcher I could attend this historic event since I was spending a year with professor Robert Frisch (nephew of Lise Meitner) at Cambridge in UK who had sent me to listen to Salam's talk. What was so memorable about this colloquium? At the end of Salam's speech Pauli got up and apologised publicly to Abdus for having strongly discouraged him to publish his theory. The reason for the change of Pauli's conviction was that some rumours had arrived from New York reporting that C. S. Wu had done an experiment proving the violation of parity conservation. Although nobody had seen any results, Wu was known as an extremely careful experimentalist and hence this rumour was taken seriously.

The author in his lab, about 1960.

For Pauli who was surrounded by an aura of a very critical thinker and who was always very sure of himself, this was certainly not an easy gesture. Pauli had been convinced that parity had to be conserved whereas Salam's theory implied that it was maximally broken. The argument to which Pauli adhered was an almost philosophical one: since nature "does not know" whether we observe it directly or through a mirror, mirror reflection invariance must hold and hence parity must be conserved (according to Noether's general argument that each invariance implies a conservation law). The German philosopher Immanuel Kant had already argued that we must consider this as "denknotwendig" (necessary thinking) if we want to explore nature. Similar arguments apply for other quantities e.g. for the electric charge. What we call 'positive' or 'negative' was a purely arbitrary historical decision and since nature 'does not know' anything about it, exchanging all positive charges in the universe by negative ones and vice versa, is an invariance and electric charge must be conserved. Thus it seemed that parity violation had shaken our fundaments of understanding nature. In 1956 the contacts between West and East just started to be open after the cold war and when the famous Russian physicist L. D. Landau heard about parity violation his reaction was similar to that of Pauli. "Space cannot be asymmetric" was his statement. It is not surprising that this discovery found at that time a similar interest in the media as the Higgs discovery today. The lesson we should learn from the discovery of parity violation is that we should not trust even in the most obvious general principles unless they are verified by experiments.

It was not immediately recognised that also the particle-antiparticle invariance C was violated. When this eventually was realised, some theorists found an excuse for the surprising P violation by consoling themselves that the combined operation of mirror reflection and charge conjugation CP is the proper operation to be conserved, but without a good reason for such an argument.

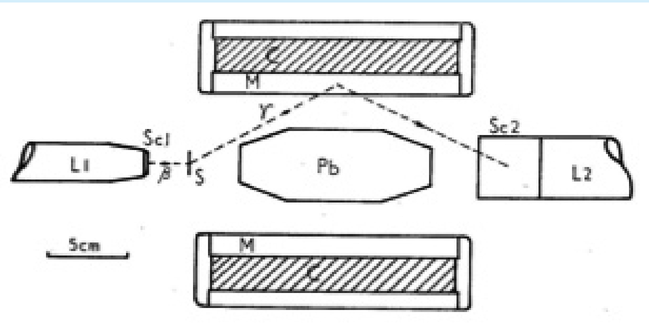
The colloquium where I had heard for the first time in my life about parity and its conservation, changed my direction of research. Back in the laboratory at Cambridge I studied during Christmas vacations the by now famous paper by Lee and Yang in which they proposed four experiments to check parity violation. One was the famous Wu experiment observing the asymmetric emission of beta-particles from polarised nuclei. A second experiment was the inverse, after the emission of a beta particle the remaining nucleus is polarised and if left in an excited state it emits a circularly polarised photon. Lee and Yang considered this experiment as unfeasible since they did not know of any way to measure circularly polarised photons. However, just before starting my visit at Cambridge I had done at my home university of Erlangen in Germany some experiments to measure the gamma-gamma circular polarisation correlations in nuclear decays using the photon scattering from polarised electrons in iron. So I knew how to do the 'unfeasible' experiment. I asked professor Frisch to allow me to perform it and immediately he promised to give me all the necessary support. In the machine shop I started to construct a cylindrical iron magnet to be used as a target of polarised electrons and Frisch managed to get me within a few days radioactive sources of ^{60}Co and ^{22}Na, the first decaying by electron emission (accompanied by antineutrino emission),

C. S. Wu and the author discussing helicities, about 1958.

the second a positron decay (with neutrino emission). In both cases I found within experimental errors a maximum violation of parity. At various occasions C. S. Wu mentioned later that this was the only experiment where it could be shown in the same apparatus that the helicities of neutrino and antineutrino are opposite and it was the first parity violation experiment in Europe. The publication had only one author who was technician, made the measurements, did the calculations for the size of the effect and wrote the paper within 5 weeks. What a beautiful time! Is this still thinkable today when experimental papers sometimes have several thousands of authors? The results were published in *Phil. Mag.* in February 1957 within several weeks (thanks to Otto Frisch who was editor) with those of the other 3 experiments proposed by Lee and Yang.

Parity

An experiment to observe parity violation must contain a helical quantity which changes sign under a mirror reflection. A helix is defined by a combination of a polar and an axial vector. In the famous Wu experiment ^{60}Co nuclei were oriented at low temperature (axial vector) and the momenta of beta particles (polar vector) observed in the direction of the nuclear orientation or opposite to it. The second experiment proposed by Lee and Yang is a reversal of the Wu experiment (see figure). One observes the direction of the emitted beta particle and after the beta decay the nuclei are oriented along this direction. If these nuclei emit a photon it becomes circularly polarised and its polarisation can be measured by Compton scattering from polarised electrons in iron. Since many nuclear beta decays are followed by a gamma, but only few nuclei can be oriented at low temperatures, this kind of experiment is adequate to study various problems. Thus it could be proved that the helicities for electron and positron emission are opposite and also the 100% polarisation of internal bremsstrahlung associated with K capture could be measured. For nuclear spectroscopy one can also obtain valuable information on the character of the beta transitions.



Measurement of circular polarisation of gamma rays in beta-gamma coincidence experiments, (H. Schopper, Phil.Mag.2, 710 (1957))
S: beta source, Sc1: scintillator to detect beta particle, Sc2: scintillator to detect gammas, M: magnet with coil C to Compton scatter gammas, Pb: lead absorber to stop direct gammas. Reversing the current in the coil C gives a change in the beta-gamma coincidence rate if the gammas are circularly polarised.

It is somewhat strange that the most obvious consequence of parity violation, the longitudinal polarisation of electrons was not mentioned in the famous paper by Lee and Yang. However, very soon it was predicted by several theorists and finally experimentally demonstrated.

The discovery of parity violation triggered a large number of subsequent experiments and put the theory of the weak interaction on a new basis.

After the first shock of maximal violation of parity and charge conjugation had been digested the next surprise came, the violation of the combined operation CP. In 1964 it was shown that in the decays of the neutral K-particles this operation was also violated, although not maximally like parity but only at the level of about $2x10^{-3}$. Because of the long known CPT theorem, based on very basic principles of field theory and claiming that CPT invariance should be conserved, the question arose whether time reversal invariance was also violated or whether the CPT theorem did not hold. Many experiments were performed to clarify these questions and at CERN even a storage ring, LEAR, and a dedicated experiment on discrete symmetries, CPLEAR, were constructed. So far it seems that T-reversal is violated whereas CPT invariance holds.

All this is now history. What surprises me is that the great shock which parity violation created about 50 years ago has more or less been forgotten, 'verdrängt'. The handedness of particles participating in the electroweak interaction are put into the theory 'by hand', without giving any theoretical arguments. On the other hand the Standard Model SM could easily accommodate P, C and CP violation in its formalism and make very precise predictions for the decays of particles containing heavy quarks.

In 2005 it was discovered that the neutrino masses are not vanishing, a supposition which formed the basis of the two-component neutrino model. With this most recent modification the Standard Model of particle physics seems to be in agreement with all experimental results, even the most recent ones at the LHC. Nevertheless the SM cannot be the final step since it leaves many fundamental questions unanswered. I am convinced the electroweak interaction has more surprises in store for us and a lot of fascinating work remains to be done.

References

For the historical development with many references see e.g. C. S. Wu and S. A. Moszkowski, *Beta decay*, Wiley&Sons 1966 and H. Schopper, *Weak interactions and nuclear beta decay*, North Holland 1966.
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