Alexander Hellemans

Nobel Prize 99

For the third time the Royal Swedish Academy of Sciences has awarded the Nobel prize for physics to researchers working in the field of electroweak theory. Gerardus 't Hooft, a professor at the University of Utrecht and Martinus Veltman, Professor Emeritus at the University of Michigan at Ann Arbor, received the prize for "elucidating the quantum structure of electroweak interactions in physics."

Together with quantum electrodynamics, electroweak theory is the foundation of the standard model, the general theory of particles and their interactions that has been developed over the last thirty years. The first time the prize honoured work in electroweak theory was in 1979 when Sheldon Glashow, Abdus Salam, and Steven Weinberg received it for the unification of the electromagnetic force with the weak force, the force responsible for the beta decay of atomic nuclei. The theory predicted three new exchange particles, very massive virtual particles that transmit the weak force: the W^+, W^-, and the Z^0. In 1984, Carlo Rubbia and Simon van der Meer shared the Nobel prize for the discovery of these particles at CERN, Europe's particle physics laboratory near Geneva, in 1983.

The electroweak theory, when first formulated in the sixties, was afflicted by a difficulty: the theory resisted all attempts at renormalization, that is, it could not be coerced into a form that would make it usable for precise predictions of properties of particles and interactions. Unlike quantum electrodynamics, which by then was renormalizable, the theory only allowed approximate calculations. For example, it allowed you to make calculations for the scattering between two particles by only looking at the exchange of a single force-carrying particle, and by ignoring higher-order interactions. However, in 1969, 't Hooft, then a young doctoral student, joined Veltman who was a professor at Utrecht and together they tackled what others thought was an insurmountable problem: the renormalization of the electroweak theory.

The main obstacle was that electroweak theory is based on a symmetry that isn't Abelian, explains 't Hooft. In a non-abelian symmetry, the result of two consecutive transformations depends on their order. One way of visualizing this is as follows: imagine you would take one step forwards and one step sideways, in a non-abelian world you would end up in a different place than if you had first taken a step sideways and then the step forwards. "The physical phenomena had to remain invariant under these transformations, and this implicated a more complex set of formulae," says 't Hooft. A second difficulty was caused by the higher-order corrections—corrections that have to be taken into consideration because in reality the interaction between two particles consists of the exchange of a virtual particle, but also of a series of higher order interactions, such as the exchange of additional virtual particles between the initial exchange particle and the interacting particles, and other virtual particles that can briefly come into existence. Here the problem was that these corrections assumed infinite values and the theory required renormalization.

Besides complex mathematics, 't Hooft and Veltman had to find the right equations that describe the interactions between particles on a small scale. "Our problem consisted of building a model that, as well on a small scale as at large distances, had the correct structure," says 't Hooft, who adds that for larger scales results from experiments were available to test the models. "There were many difficulties, and we had to find the right conditions for being able to say 'this is a good model.'" The path towards formulating a good model was not straightforward however, remembers 't Hooft. "In the early days there were all kinds of alternative ideas, and for a long time we thought that our efforts would not work out if we were to incorporate Z and W particles in our models."

By 1972 the two physicists had hammered out a working approach. Meanwhile, experiments had become much more precise. To get agreement between theory and experiment the calculation methods from 't Hooft and Veltman were essential. "The theory now allows you to make precise and systematic predictions," says Karel Gaemers, a particle physicist at the University of Amsterdam. As a result, the maximum for the mass of the top quark could be predicted years before it was discovered at the Fermi National Laboratory near Chicago in 1995.

"Veltman and 't Hooft were always very interested in confronting the standard model with experiments," says Gaemers. "Look at the impact of their work—for example, the research program of the Large Electron Positron Collider (LEP) at CERN has been inspired for a large part by their theoretical work in the sixties and the seventies. Now that the LEP program is almost completed, you see it is a convincing confirmation of the predictions of the standard model," says Gaemers, adding that the Higgs-boson, a particle also predicted by the Standard Model that would convey mass to the W and Z particles, still has to be found.

Therefore, the prize did not come as a surprise, "many colleagues in the high-energy physics community hoped they would receive it," says Gaemers. And indeed, the physics community itself was less patient. Both were recipients of several prizes: in 1993 Veltman won the High-Energy Physics Prize of the European Physical Society for "his work on massive Yang-Mills" and in July this year the EPS awarded 't Hooft the High Energy Physics Prize "for his pioneering contributions to the renormalization of non-abelian gauge theories."

Gerardus 't Hooft receiving this year's High Energy Physics Prize of the European Physical Society