Physics prize takes another tour de force

When a trio of scientists in the 1960s achieved one of the great quests of modern physics, none of their colleagues believed they were right. Calculations based on their theory—which united two fundamental forces of nature, the electromagnetic and weak forces—generated absurd answers.

Now a pair of Dutch researchers has won the 1999 Nobel Prize in Physics for finding a way to sidestep the absurdities, which led to tests and acceptance of the so-called electroweak theory.

Gerardus 't Hooft of the University of Utrecht in the Netherlands and Martinus J.G. Veltman, now retired from the University of Michigan in Ann Arbor, invented a calculation technique that made possible ultraprecise predictions of real-world quantities based on the electroweak theory. Their tool, known as dimensional regularization and first described in 1971, also applies to similar theories that describe other forces.

Armed with this new mathematical capability, physicists went on to construct the so-called standard model of particle physics, a sweeping theory that explains all known particles and their interactions with unprecedented success.

"This work ['t Hooft and Veltman] did together was the key that unlocked the standard model," says Helen R. Quinn of Stanford (Calif.) Linear Accelerator Center.

"It was a watershed. It was a very important development," says Sheldon L. Glashow of Harvard University, a codeveloper of the electroweak theory. He, the late Abdus Salam, and Steven Weinberg of the University of Texas at Austin won the 1979 physics Nobel for their work, which explains the behavior of the force responsible for nuclear decay.

Absurdities had also cropped up in the 1940s, when efforts to reconcile the theories of electromagnetism and quantum mechanics generated unacceptable, infinite values for properties such as charge and mass of the electron.

Richard P. Feynman, Julian Schwinger, and Sin-Itiro Tomonaga figured out a way to make the infinite values cancel out by means of a process called renormalization. In essence, the trio proposed that clouds of evanescent virtual particles obscure the properties of every real particle. They received the 1965 Nobel Prize in Physics for that achievement.

't Hooft and Veltman did much more than retrace those steps. The electroweak theory is a different, more complex beast. The fields it describes involve more elaborate symmetry than is present in electromagnetic fields. As a result, physicists have to worry about the order in which certain transformations of the fields take place.

The Dutch method annihilated infinities there, too. It made meaningful calculations possible as it extended the notion of particle clouds to the Z and W particles of electroweak theory.

Using this method, physicists have accurately estimated properties of elusive particles, such as the top quark, prior to discovery (SN: 7/1/95, p. 10). Such estimates enable scientists to predict the correct energy ranges for accelerator experiments.

Researchers still use the 18-year-old method to hone estimates for the final unfound particle of the standard model, the Higgs boson (SN: 6/19/99, p. 399). Physicists believe that it confers mass on other fundamental particles.

The method also helps physicists construct so-called grand unified theories, which attempt to unify the electroweak force with the strong force that binds particles within the nucleus. Attempts to unify gravity and quantum mechanics also generate infinite values, but taming them requires a leap beyond what 't Hooft and Veltman have done, physicists say.

That they should win the prize comes as no surprise to particle physicists. In discussions before the announcement, "those were the names we were all saying," says Quinn. Weinberg adds, "I've hoped for ['t Hooft and Veltman to win] this prize for some time." —*P. Weiss*

Chemistry Nobel spotlights fast reactions

For more than 10 years, Ahmed H. Zewail of the California Institute of Technology in Pasadena has been using extremely short laser pulses to track intimate details of chemical reactions. This week, the Royal Swedish Academy of Sciences awarded the 1999 Nobel Prize in Chemistry to Zewail for his groundbreaking investigations of atom movements during the birth and destruction of molecules.

When molecules undergo chemical reactions, their atoms shift so quickly that scientists require laser pulses lasting only a few femtoseconds (quadrillionths of a second) to obtain snapshots of the making and breaking of chemical bonds. Zewail and his coworkers developed laser techniques for observing such interactions and used them to investigate a variety of fundamental chemical processes.

In femtosecond spectroscopy, researchers initiate a reaction with a laser pulse that pumps more than enough energy into a gas of reactants to begin breaking bonds. They then send in a series of weaker laser pulses of different energies to detect the altered molecules.

Initially, Zewail and his team studied such elementary reactions as the dissociation of iodocyanide (ICN) into iodine (I) and cyanide (CN) and the interaction between hydrogen (H) and carbon dioxide (CO_2) to form carbon monoxide (CO) and hydroxyl (OH). In the hydrogen–carbon dioxide reaction, the chemists showed that a hydrogen atom temporarily joins with a carbon dioxide molecule to form a surprisingly long-lived, loose unit before it strips away an oxygen atom (SN: 12/12/87, p. 372).

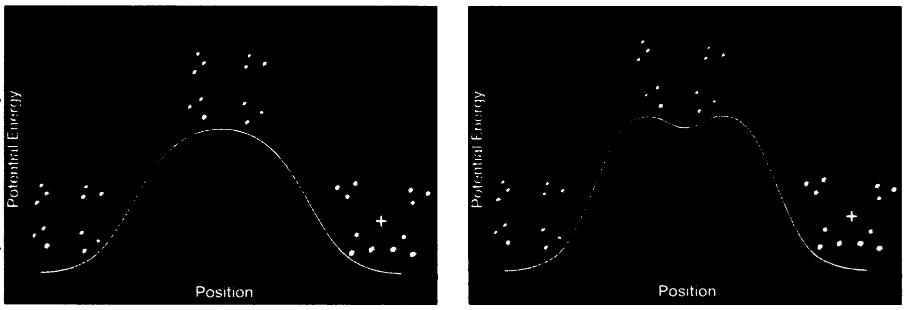
Zewail's group later used femtosecond laser pulses to observe atomic movements in iodine and other two-atom molecules, capturing in detail individual rotations and vibrations of the molecules (SN: 3/3/90, p. 135). Another study highlighted how solvent molecules exert an influence on bond breaking (SN: 7/31/93, p. 71).

Recently, Zewail has focused on biologically important chemical processes of large molecules, such as chlorophyll and retinal. He and his coworkers have demonstrated experimentally that light can convert a molecule from one structure to another with high efficiency because energy is quickly channeled to the appropriate place in the excited molecule.

"Zewail pioneered . . . femtosecond methods to investigate photochemical reactions," says Nicholas J. Turro of Columbia University. "His research involves brilliant technique development and experimental conception and execution."

Scientists are now using femtosecond spectroscopy to study how catalysts or molecular electronic components function and to probe what mechanisms underlie biological processes. —*I. Peterson*

Royal Swedish Academy of Sciences



Zewail's team used femtosecond spectroscopy to demonstrate that the splitting of a cyclobutane molecule into two ethylene molecules does not proceed via a single step, which would involve breaking two bonds simultaneously (left), but rather in two steps, with the formation of a short-lived intermediate product in which just one bond is broken (right).