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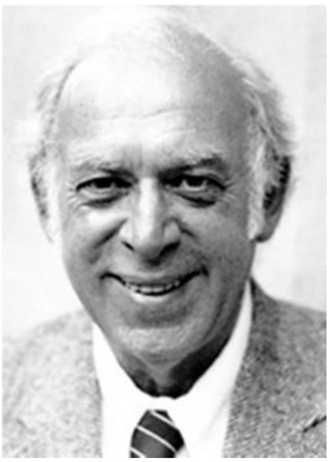
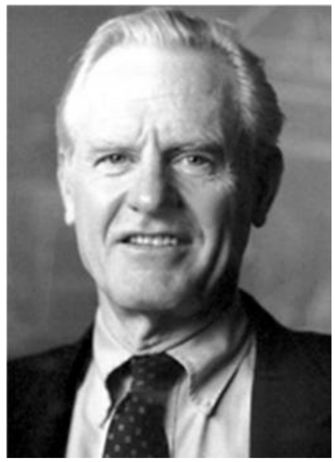
Nobel Prize in Physics 1990


Jerome I. Friedman | Henry W. Kendall | Richard E. Taylor

The Nobel Prize in Physics 1990 was awarded jointly to Jerome I. Friedman, Henry W. Kendall and Richard E. Taylor *"for their pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutrons, which have been of essential importance for the development of the quark model in particle physics"*.

Information about winners:

Jerome I. Friedman and **Henry W. Kendall**

both of the Massachusetts Institute of Technology, Cambridge, MA, USA,

Richard E. Taylor

Stanford University, Stanford, CA, USA,

RESEARCH INFORMATION:

A breakthrough in our understanding of the structure of matter

Professors **Jerome I. Friedman** and **Henry W. Kendall**, both of the Massachusetts Institute of Technology (MIT), and **Richard E. Taylor**, of the Stanford Linear Accelerator Center (SLAC), share this year's Nobel Prize in Physics. The value of the prize is 4 million Swedish crowns. The three prizewinners were key persons in a research team which in a series of investigations found clear signs that there exists an inner structure in the protons

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and neutrons of the atomic nucleus. What has become known as the "SLAC-MIT experiment" paved the way for further investigations of the innermost structures of matter. Ever since the beginning of this century, researchers have studied the inner structure of atoms. Our knowledge has increased successively, among other ways through the discovery (around 1910-1930) of the nucleus of the atom and its nucleons. During the 1950s there arrived on the scene a large number of what were termed hadrons, whose properties resembled those of nucleons. To reduce these to order, the concept of quarks was introduced, at the beginning of the 1960s. Yet it was impossible to see any traces of quarks in nature until the SLAG-MIT experiment itself.

The discovery was made when protons and neutrons were illuminated with beams from a giant "electron microscope" - a two-mile-long accelerator at SLAC in California, USA. The inner structure was interpreted to mean that **quarks** form the fundamental building blocks of protons and neutrons. The electrically neutral "glue" binding the quarks together is called **gluons**. All matter on earth, including our human bodies, consists to more than 99% of quarks with associated gluons. The little that remains is electrons.

Background information

The prizewinners' contributions

The work now rewarded was carried out at the end of the 1960s and the beginning of the 1970s by a group of researchers from MIT and SLAC. The work was a continuation of earlier investigations in which, using the electron as a probe, the structure of nucleons (protons and neutrons) was studied. Unlike in earlier investigations, electron beams of record-high energies were now available. These beams were supplied by a two-mile-long linear accelerator at SLAC, which afforded a "microscope" of higher resolution than earlier. No new phenomenon was expected: the experiment was fairly generally regarded as routine. Electron scattering against nucleons, but at lower electron energies, had been performed over two decades, and it was thought that enough was known about the structure of nucleons - a view that proved to be entirely false.

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The essence of the SLAG-MIT experiments was to observe how a beam of electrons at high velocities (energy from 4 GeV to 21 GeV) is affected when it is led through a target consisting either of liquid hydrogen or of deuterium. The scattered electrons were recorded using two large magnetic spectrometers. One of these was used for observing electrons scattered at 6 and 10 degrees, and the other for greater scattering angles (18, 26 and 34 degrees). As well as the scattering angle, the energy of the electrons was measured with the spectrometers.

Collaboration between SLAC and MIT started at the beginning of 1967, with the study of so called elastic scattering against protons (the process e + p - > e + p, in which the electron bounces against the proton as if they were both rubber balls). Similar experiments at lower electron energies had shown that the nucleons behaved like "soft" structures which were only able to scatter the electrons at small angles. The new results from elastic scattering confirmed the earlier measurements. The probability of obtaining a large scattering angle was found to be very small. Following this conventional initial phase, it was decided to have a look also at what was termed inelastic electron scattering, e + p -> e + X, where X is not necessarily a proton. Such processes were known from experiments at lower energies, and nothing fundamentally new was to be expected. However, the researchers found to their amazement that the probability of deep inelastic scattering - where the incident electron loses a large part of its original energy and emerges at a large angle in relation to the original direction - was considerably greater than expected. At first they believed the result was incorrect or misinterpreted. One suspected source of error was so-called radiation corrections - the incident or departing electron could radiate away part of its energy in the form of light, which they had not observed, and which could therefore, they thought, have caused them to misinterpret what had happened. But after careful work on the part of the research group it gradually became clear that an inner nucleonic structure, termed hard scattering centres, had been observed. Here was a repetition, although at a deeper level, of one of the most dramatic events in the history of physics, the discovery of the nucleus of the atom.

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History

At the beginning of our century Hans Geiger and Ernest Marsden performed a series of experiments in which they measured the scattering of alpha particles passing through a thin metal foil. Geiger and Marsden (1909) found to their surprise that some of the alpha particles were scattered at very large angles, such as 90°, to their original direction. The head in Manchester, where Geiger and Marsden were working, was Ernest Rutherford, one of the most eminent physicists of the time and winner of the 1908 Nobel Prize in Chemistry. Rutherford undertook a systematic theoretical investigation of Geiger's and Marsden's results and those of similar experiments with beta particles (as electrons were called at the time). In these, the no-less-amazing phenomenon had been discovered that a small fraction of the incident electrons boomeranged back after impact. Rutherford showed in a classic paper (1911) that the observations made did not agree with the current picture of the atom - a soft, jelly-like sphere in which the positive and negative charges were diffusely distributed. Such a soft target could at most produce a small deflection of the incident particles. He also found that the probability of many small deflections adding to achieve a large deflection was vanishingly small. After careful comparison of the data with theoretical expectations he concluded that *"considering the evidence as a whole, it seems simplest to suppose that the atom contains a central charge distributed through a very small volume, and that the large single deflections are due to the central charge as a whole, and not to its constituents"*. Thus the concept of atomic nucleus was born.

Knowledge of the structure of the nucleus of the atom increased considerably when James Chadwick discovered the neutron in 1932. In the same year, Werner Heisenberg realised that atomic nuclei consist of protons and neutrons. Chadwick was rewarded with the 1935 Nobel Prize in Physics for the discovery of the neutron and Heisenberg received the 1932 Physics Prize for "the creation of quantum mechanics". The realization that the proton and the neutron were building blocks of atomic nuclei represented a giant step forwards in the systematisation of the design of matter. Proton, neutron and electron became the three fundamental building blocks of nature. But as early as 1933-1934 it was suspected that the proton and the neutron were more complicated particles than the electron. The nucleons exhibited unexpectedly large magnetic fields ("anomalous magnetic moments") which could be interpreted in such a way that they contained electric currents. The magnetic properties of the nucleons were first measured by Otto Stern and co-workers. Stern was rewarded with the 1943 Nobel Prize in Physics for "the molecular ray method and his discovery of the magnetic moment of the proton. "

During the 1950s, the structure of nucleons was systematically investigated using electron scattering. A series of interesting phenomena were observed, among them that electrons with energies up to 1 GeV saw nucleons as soft "spheres", implying that electron scattering at large angles was very improbable. Measurements were taken of how charge and magnetism are distributed inside the nucleons. Robert Hofstadter played a leading role in these investigations and was rewarded with a 1961 Nobel Prize in Physics for his "pioneering studies of electron scattering in atomic nuclei and for his thereby achieved discoveries concerning the structure of the nucleons".

During the 1950s and 1960s the special position of the proton and the neutron as nature's building blocks was questioned. A large number of particles, termed hadrons, were being discovered at this time, and showed similarities to the nucleons. It became a matter of urgency to bring new order to physics so as to understand how hadrons should be classified. After many attempts, the riddle of the hadrons was successfully solved, mainly through the work of Murry Gell-Mann (Nobel Prize in Physics, 1969). The various hadrons were found to be related and to behave as members of a kind of family ("representations of a symmetry-group"). This abstract mathematical description became appreciably easier and more comprehensible when three building blocks were introduced, quarks. Now all the hadrons then known could be built up of these three quarks and their antiparticles. Since this involves great conceptual simplification, the quark concept was immediately taken seriously. Quarks were sought both in nature, e.g. in sea water, meteorites and cosmic rays, and in experiments using high-energy accelerators. But no quarks were to be found. After a time the most popular explanation of the absence of

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quarks was that they were only "mathematical quantities" included in the equations of physics.

The first traces of quarks

The SLAG-MIT experiments became the contemporary counterpart of Geiger's and Marsden's experiment. At that time, the scattering of alpha particles at large angles was explained by the existence of a "hard grain" the atomic nucleus - in the middle of the atom. In the modern version, Rutherford's role was assumed chiefly by the theoreticians James D. Bjorken and the late Richard P. Feynman (who received a Nobel Prize in Physics in 1965). This time, the scattering of electrons at large angles was explained by the existence of "hard grains" - quarks - in the nucleons. But the results could not be fully explained using quarks alone. The experiments indicated that there were also electrically neutral components in the nucleons, and there was great eagerness to discover their nature as well. Development was rapid and the neutral components of the nucleons were soon interpreted as gluons, the intermediaries of the strong force. This introduced a new era in the history of physics.

For more details please visit:

http://www.nobelprize.org/nobel_prizes/physics/laureates/1990/press.html