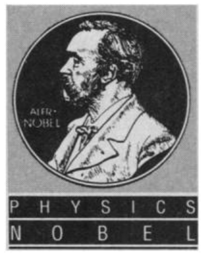
Physics Nobel Honors the Discovery of Quarks

The achievement, by a SLAC-MIT team, was a classic case of serendipity: a "routine" experiment that went one extra step...



FOR PROVING THAT PROTONS, neutrons, and other such elementary particles are made of even more fundamental building blocks known as quarks, the 1990 Nobel Prize in Physics goes to Jerome I. Friedman and Henry W. Kendell of the Massachusetts Institute of Technology, and to Richard E. Taylor of the Stanford Linear Accelerator Center (SLAC).

Other particle physicists hailed the choice wholeheartedly—especially at SLAC, where the three researchers did their prizewinning work in the late 1960s and early 1970s. "The only question in my mind is, Why did it take so long?" laughs laboratory director Burton Richter, himself the winner of a Nobel prize for his 1974 codiscovery of a subatomic particle known as the J/Psi.

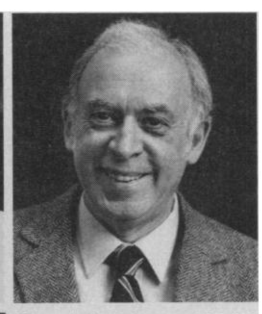
"It's one of the pivotal contributions to physics in this century," agrees SLAC alumnus Roy Schwitters, who now heads the Superconducting Super Collider laboratory in Texas.

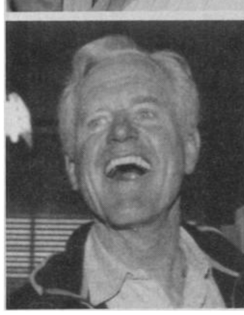
If Schwitters exaggerates, it's not by much. In announcing the award on 17 October, the Royal Swedish Academy of Sciences compared the SLAC-MIT experiment to the discovery of the atomic nucleus in the first decade of this century. In much the same way that Ernest Rutherford and others probed the interior of atoms by bombarding them with alpha particles from a radioactive isotope, Taylor, Friedman, and Kendall probed the interior of the atom's building blocks, protons and neutrons, by bombarding them with high-energy electrons coming out of SLAC's 3-kilometer-long linear accelerator. And just as the scattering of Rutherford's alpha particles revealed the existence of a very small, very dense kernel of matter at the center of the atom—the nucleus—the electron scattering in the SLAC-MIT experiment revealed that protons and neutrons are filled with hard little points: quarks.

"The SLAC-MIT experiment was really critical," says Richter, "because until then most of the world thought that the quark model was a nice, mathematical way to think about protons, but nothing more."

Indeed, when quarks were first proposed by Caltech theorists Murray Gell-Mann and George Zweig in 1964, they were really not much more than a classification scheme, a way of bringing some order to the myriad of previously unsuspected particles that physicists seemed to be turning up with every new accelerator. First, said Gell-Mann and Zweig, assume that there are three types of quarks—*up*, *down*, and *strange*—each of which, in turn, carries a certain set of "quantum numbers" such as electric charge. Then, to classify a real particle such as the proton, the neutron, or any of their relatives in the "baryon" family, assign quarks to each particle in groups of three. Thus, the proton will have the assignment *up-up-down*, a more exotic creature known as the Ω^- will have the assignment *strange-strange-strange*, and so on. Meanwhile, particles of another large family, the mesons, can be classified by assigning each one a quark and an antiquark; a π^+ meson is labeled *up-antidown*, and so forth.

Considered purely as a classification scheme the quark theory worked beautifully, correctly predicting the quantum numbers of every particle it was applicable to. But as a description of what was really going on inside these particles—well, no one had ever actually seen a quark, despite strenuous efforts to find one. And until somebody came up with direct evidence of quarks' existence, hard-nosed empiricists simply were not going to believe in them.





Quark hunters. *SLAC physicist Richard Taylor (top left) and his MIT colleagues Jerome Friedman (top right) and Henry Kendall (bottom left) didn't start looking for quarks—but they grabbed the chance when they had it.*

As it happens, Taylor, Friedman, and Kendall didn't start out looking for quarks at all. Quite the opposite, recalls SLAC's founding director Wolfgang Panofsky: their experiment was widely perceived as a worthy, but routine follow-up to the pioneering work of Stanford's Robert Hofstadter.

Working at the university's High Energy Physics Laboratory, the precursor to SLAC and the place where all three of the new laureates served their apprenticeships, Hofstadter had spent the 1950s bouncing electrons off target nuclei of elements ranging from hydrogen to lead. In the process, he had demonstrated that protons and neutrons are not tiny points at all, but fuzzy little blobs about 10^{-13} centimeters across—a result so striking that it won the Nobel Prize for 1961. But his very success meant that no one, not even Taylor, Friedman, and Kendall, expected their new experiment to show much more than higher resolution images of the same old fuzzballs.

On the other hand, the three young researchers had a few extras going for them. One was SLAC itself, a brand new accelerator whose 20-billion-electron-volt energy was a considerable step up from what was available at the older laboratory. Another was their own experimental setup, which for the time was a technological tour de force. Their plan was to direct SLAC's electron beam into a tank of either liquid hydrogen or liquid deuterium, where the electrons would scatter from the nuclei. Then they would use two huge detectors of their own design to measure the energy and angular deflection of the scattered electrons to fractions of a percent.

During their first experimental run, starting in early 1967, Taylor, Friedman, and Kendall confined their attention to the same kind of "elastic" scattering events studied by Hofstadter. That is, they looked only at events in which the electrons and nuclear protons bounced off each other like rubber balls, without breaking up. And not surprisingly, they got exactly the same result Hofstadter had: the soft, fuzzy protons were unable to scatter the electrons very far at all.

However, once they had gotten their bearings in familiar territory, the SLAC-MIT team struck out in an uncharted direction. At the suggestion of a young SLAC theorist named James Bjorken, they began to look at highly *in*elastic scattering, in which the electron blows the target proton to bits. Rather paradoxically, said Bjorken, this messy sounding interaction turns out to be the cleanest possible way to probe for hard, point-like structures in the proton. If such structures exist at all, he pointed out, they would make their presence known by deflecting some of the inelastically scattered electrons through a very wide angle. Their signature would be unmistakable.

And that, to the astonishment of everyone, was exactly what the SLAC-MIT team found. In effect, each wide-angle electron they saw was resolving Hofstadter's fuzzball into a mass of hard little granules. Indeed, by the time Taylor, Friedman, and Kendall had completed checking and cross-checking their experiments in the early 1970s, they had not only demonstrated that the granules inside the proton were in fact the long-sought quarks, but they had also demonstrated that the quarks themselves were embedded in a sea of electrically neutral "gluons" that held them together.

"It was a milestone in our understanding of matter," says Panofsky. At a stroke, the SLAC-MIT experiment ended decades of confusion and ambiguity about the fundamental structure of the particles and laid the groundwork for the unified theories of the strong, weak, and electromagnetic interactions that followed almost immediately.

And, Panofsky adds, the result was a testament to the three researchers themselves. "They didn't set out to look for point-like structures in the proton," he says. "It was a surprise—that they creatively took advantage of. They were experimentalists' experimentalists." ■ M. MITCHELL WALDROP

Three "Practical" Economists Share Nobel

The 1990 Nobel Prize in Economic Sciences was awarded last week to three Americans whose work explains how individuals and corporations make investment decisions. They are Harry Markowitz of the City University of New York, Merton Miller of the University of Chicago, and William Sharpe of Stanford University. Widely known not only to academics but to the professional economists on Wall Street, the three have done much to shape today's stock and bond markets. Mutual fund managers, for example, follow general principles for designing portfolios that were laid down by Markowitz and elaborated by Sharpe, and Miller's work guides many decisions on corporate financing.

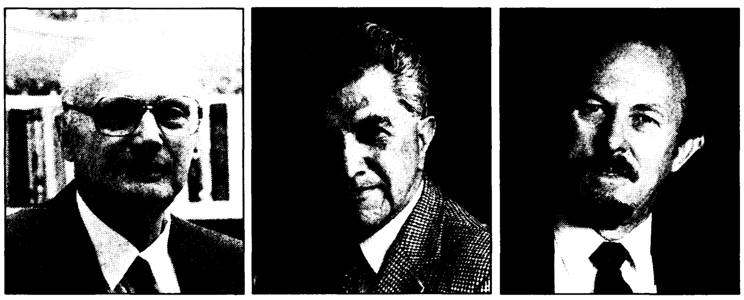
The prize signifies the acceptance of finance—which for many years was taught in business schools instead of economics departments—as an integral part of economic theory, says Franco Modigliani, a Massachusetts Institute of Technology economist and 1985 Nobel laureate. The three prizewinners were part of a group of researchers in the 1950s and 1960s who put finance on a rigorous theoretical footing. And, Modigliani adds, "This rigorous approach has really spun off many practical applications."

Modern portfolio design, for instance, can be traced back directly to Markowitz's work in the 1950s. In his theory of portfolio selection, developed in his 1955 Ph.D. dissertation at the University of Chicago, Markowitz worked out simple formulas to determine the best way to choose investments so that risks are minimized while potential rewards are maximized. A key insight of this work was the realization that the total risk of a portfolio of stocks and other assets depends not just on the risks of the individual investments but on the correlations between those risks. The risk of investing in an auto maker, for instance, can be somewhat balanced out by buying stock in an oil company, since a sharp rise in the price of oil may hurt the auto company's profits but should increase those of the oil corporation. Markowitz developed a mathematical model for evaluating the aggregate risk of a portfolio of investments.

Sharpe applied Markowitz's work to understand how markets such as the New York Stock Exchange determine the prices of securities. "For quite a while, economists thought that the stock market was a casino," Modigliani said, "so there was little interest in it." But Sharpe, along with several other economists in the mid-1960s, showed how an efficient market bases the prices of securities on their potential risks and their expected returns—an observation that seems obvious now but was not at the time.

In a surprising spin-off of this work, Sharpe showed that a speculative investment strategy and a cautious one should differ only with regard to how much each puts into risky investments, not what the risky investments are. A cautious investor might buy mainly government bonds with only a small percentage of his money going into the stock market, while a speculator might even go into debt to play the market. But the money each of them puts into the stock market is best invested in the same way: In the absence of special knowledge about how certain stocks will perform, the most efficient way to take risks is to put money in a highly diversified portfolio that follows the market. This reasoning underlies the existence of today's "market funds."

In the late 1950s and early 1960s, Miller, initially in collaboration with Modigliani, investigated another practical economic question: Should companies finance expansion by issuing more stock or by borrowing the money? That had been a central issue in finance, but Miller showed that it didn't make any difference—that a firm's market value and average cost of capital remained the same no matter whether it chose equity financing or borrowing. "That caused enormous commotion at the time," said George Stigler, an economist and Nobel laureate at the University of Chicago. But Miller was able to substantiate his result by putting together a database that tracked stock prices from the New York Stock Exchange from 1926 on. Different tax treatments of borrowing and equity financing modify their impacts on a company, however, and Miller has extended his original analysis to determine how varying tax policies affect a firm's capital asset structure. John Gould, dean of Chicago's Graduate School of Business, says that Miller's findings have "changed the way finance is taught in the United States and around the world." ■ ROBERT POOL



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Financial wizards. *Harry Markowitz, Merton Miller, and William Sharpe helped make financial economics a rigorous science.*