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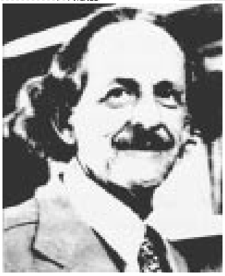

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The 1988 Nobel Prize in Physics: Melvin Schwartz, Leon Lederman, Jack Steinberger, and the Story of Two Neutrinos

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The 1988 Nobel Prize in physics was awarded to Melvin Schwartz, Leon Lederman, and Jack Steinberger for their discovery (1962) of the muon neutrino, as well as for their development of the method used in the discovery. The experiment is described, and biographical data on the laureates are presented. The citation record of the paper reporting their prizewinning work indicates that its greatest impact was felt within one year of publication.

In ancient Greece philosophers postulated that the ultimate, indivisible element of matter was the atom. There was little refinement in that theory for more than 2,000 years. At the turn of this century, the electron was discovered (1897); later, atomic nuclei (1911). A new view of the basic constituents emerged in the 1920s and 1930s with the discovery of nuclear components: neutrons and protons.[1] Since that time, scientists have redefined many times over the ultimate, indivisible particles of matter. The post-1945 period has seen the number of identified subatomic particles grow from approximately 12 in 1950 (including electrons, protons, neutrons, neutrinos, and photons) to more than 100 today,[2] as powerful machines (called particle accelerators) were developed for smashing bits of matter together and studying the scattered by-products. This modern "nuclear particle era" began in the late 1950s. The 1988 Nobel Prize in physics was awarded for pioneering work performed during the first years of this era by Leon Lederman, who was, until recently, at the Fermi National Accelerator Laboratory (Fermilab), Batavia, Illinois, and who is now a professor at the University of Chicago, Illinois; Melvin Schwartz, now president of Digital Pathways, Inc., Mountain View, California; and Jack Steinberger, now senior physicist at the European Center for Nuclear Research (CERN), Geneva, Switzerland. The prizewinning experiment, which discovered a new type of subatomic particle while using a new research technique, was performed while all three were at Columbia University, New York.

According to the awards committee, the prizewinners

> opened entirely new opportunities for research into the innermost structure and dynamics of matter. Two great obstacles to further progress in research into weak forces—one of nature's four basic forces—were removed by the prizewinning work. One of the obstacles was that there was previously no method for the experimental study of weak forces at high energies. The other was theoretically more fundamental, and was overcome by the three researchers' discovery that there are at least two kinds of neutrino.... The view, now accepted, of the paired grouping of elementary particles has its roots in the prizewinners' discovery.[3]

The neutrino, which figures so prominently in the Nobel laureates' work, is the "ghost" of particle physics. A neutrino has no identifiable mass, no electrical charge, no measurable size, and travels at the speed of light. Neutrinos are among the most abundant particles in the universe. One of their sources is the interiors of stars, where it is believed they are generated in the nuclear plasma. Neutrinos were first proposed and discussed in the 1930s, while direct evidence of neutrinos was discovered in 1956.[4] These particles are difficult to detect and can pass through astronomical thicknesses of


Leon Lederman (left) *and Melvin Schwartz* (right). *Jack Steinberger's photograph was not available.*

matter without colliding with any other particle. Even near misses are quite rare. You may be amazed to know that trillions of neutrinos are passing harmlessly through your body every second as you read this sentence.

Background

The idea of a high-energy neutrino experiment was first considered in late 1959. The Columbia University Physics Department had a tradition of a coffee hour at which the latest problems in the world of physics came under intense discussion. At one of those meetings there was a discussion of the possibilities for investigating weak interactions at high energies. A number of experiments were considered and rejected as infeasible. As the meeting broke up, there was some sense of frustration about what could be done to disentangle the high-energy weak interactions from the rest of what takes place when energetic particles are allowed to collide with targets.[5] According to Schwartz, "That night, lying in bed, it came to me. It was incredibly simple. All one had to do was use neutrinos." He was just 27 at the time.[6] Soon after, planning for the experiment began in earnest.

The experiment to learn more about weak interactions used new technologies—a spark chamber (recently invented at the time) and a newly completed alternating gradient synchrotron (AGS), a type of particle accelerator, at the Brookhaven National Laboratory on Long Island, New York.

By September 1961 Lederman, Schwartz, and Steinberger had set up their equipment next to the synchrotron, using an internal beryllium target for the accelerated protons to smash into. The collisions gave rise to pions, most of which left the accelerator. About 10 percent of these pions decayed, giving rise to neutrinos.[7] To detect neutrinos, and not other unwanted particles from the accelerator, a filter was set up outside the accelerator and forward of the beryllium. Armor plating from a scrapped warship was used, a wall of steel 13.5 meters thick. Neutrinos would zip right through, although virtually all other particles would be stopped dead. Behind the steel wall, the detector—the spark chamber—was set up. This detector had to contain enough material to make a few of the neutrinos react. The spark chamber consisted of 90 aluminum plates (which in total weighed 10 tons), the target for the neutrinos. Sandwiched between the aluminum plates were layers of neon gas. If any of the neutrinos interacted in the aluminum plates to produce charged particles, the particles would ionize the gas, knock-

Table 1: Papers authored by J. Steinberger, L. Lederman, and M. Schwartz and cited in the *SCI*® from 1945 to 1988. The papers are arranged in descending order, according to number of citations. A = total number of citations. B = bibliographic citation. Research fronts to which the paper is core are listed in parentheses after the bibliographic citation.

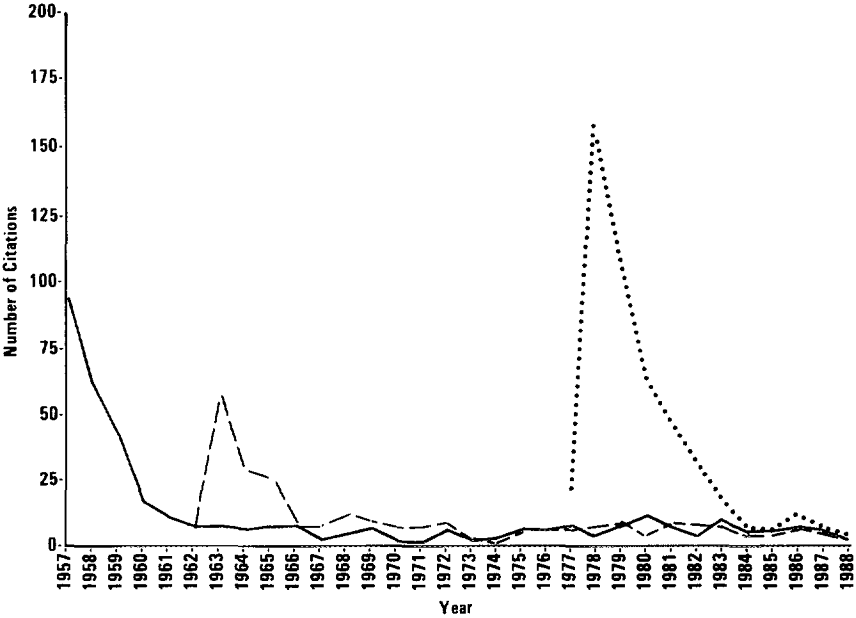
A	B
506	**Herb S W, Hom D C, Lederman L M, Sens J C, Snyder H D, Yoh J K, Appel J A, Brown B C, Brown C N, Innes W R, Ueno K, Yamanouchi T, Ito A S, Jöstlein H, Kaplan D M & Kephart R D.** Observation of a dimuon resonance at 9.5 GeV in 400-GeV proton-nucleus collisions. *Phys. Rev. Lett.* 39:252-5, 1977. (78-1253, 79-0261, 80-0019, 81-0183, 82-0661, 83-0922)
362	**Garwin R L, Lederman L M & Weinrich M.** Observations of the failure of conservation of parity and charge conjugation in meson decays: the magnetic moment of the free muon. *Phys. Rev.* 105:1415-7, 1957.
262	**Innes W R, Appel J A, Brown B C, Brown C N, Ueno K, Yamanouchi T, Herb S W, Hom D C, Lederman L M, Sens J C, Snyder H D, Yoh J K, Fisk R J, Ito A S, Jöstlein H, Kaplan D M & Kephart R D.** Observation of structure in the (upsilon) region. *Phys. Rev. Lett.* 39:1240-2, 1977. (78-1253, 79-0261, 80-0019, 81-0183, 82-0661)
251	**Steinberger J.** On the use of subtraction fields and the lifetimes of some types of meson decay. *Phys. Rev.* 76:1180-6, 1949.
236	**Danby G, Gaillard J M, Goulianos K, Lederman L M, Mistry N, Schwartz M & Steinberger J.** Observation of high-energy neutrino reactions and the existence of two kinds of neutrinos. *Phys. Rev. Lett.* 9:36-44, 1962.
197	**De Groot J G H, Hansl T, Holder M, Knobloch J, May J, Paar H P, Palazzi P, Para A, Ranjard F, Schlatter D, Steinberger J, Suter H, von Rüden W, Wahl H, Whitaker S, Williams E G H, Eisele F, Kleinknecht K, Lierl H, Spahn G, Willutzki H J, Dorth W, Dydak F, Geweniger C, Hepp V, Tittel K, Wotschack J, Bloch P, Devaux B, Loucatos S, Maillard J, Merlo J P, Peyaud B, Rander J, Savoy-Navarro A, Turlay R & Navarria F L.** Inclusive interactions of high-energy neutrinos and antineutrinos in iron. *Z. Phys. C—Par. Field.* 1:143-62, 1979.
124	**Christenson J H, Hicks G S, Lederman L M, Limon P J, Pope B G & Zavattini E.** Observation of massive muon pairs in hadron collisions. *Phys. Rev. Lett.* 25:1523-6, 1970.
119	**Hansl T, Holder M, Knobloch J, May J, Paar H P, Palazzi P, Ranjard F, Schlatter D, Steinberger J, Suter H, von Rüden W, Wahl H, Whitaker S, Williams E G H, Eisele F, Kleinknecht K, Lierl H, Spahn G, Willutzki H J, Dorth W, Dydak F, Geweniger C, Hepp V, Tittel K, Wotschack J, Bloch P, Devaux B, Loucatos S, Maillard J, Peyaud B, Rander J, Savoy-Navarro A, Turlay R & Navarria F L.** Results of a beam dump experiment at the CERN SPS neutrino facility. *Phys. Lett. B* 74:139-42, 1978.
119	**Kaplan D M, Fisk R J, Ito A S, Jöstlein H, Appel J A, Brown B C, Brown C N, Innes W R, Kephart R D, Ueno K, Yamanouchi T, Herb S W, Hom D C, Lederman L M, Sens J C, Snyder H D & Yoh J K.** Study of the high-mass dimuon continuum in 400-GeV proton-nucleus collisions. *Phys. Rev. Lett.* 40:435-8, 1978. (79-0121, 80-0164)

ing electrons from atoms. Then, under the influence of an electric field, the gas would break down and spark where ionized, revealing the passage of the newly created particles (hence the term "spark chamber").

A further filtering factor (besides concrete and lead bricks) was the amount of time (two microseconds, or 2×10^{-6} seconds) during which the beam was hitting the target spark chamber. This "time gate" was installed to minimize the number of events due to cosmic-ray background radiation (neutrinos from solar activity). The very short time "window" meant that any detected events that occurred outside of the window could then be excluded as not due to accelerator-induced, high-energy radiation.[5] The neutrino-beam technique, first used by these laureates, is now a mainstay at particle accelerators around the world.

In eight months of episodic running, the estimated 10^{14} neutrinos that passed through the 10-ton spark chamber yielded only 56 recorded events that looked like neutrino collisions. But almost all of the 56 events showed the collision producing a muon (similar in characteristics to an electron, but 200 times heavier) rather than an electron. Far fewer electrons had been produced than one would expect if all neutrinos were alike—of only one kind. Thus, this discovery was the first demonstration of the doublet pairing of leptons (electrons and neutrinos). The electron had its own private neutrino, and with Lederman, Schwartz, and Steinberger's discovery, so did the muon. The experiment was successfully completed in June 1962. A year later the Brookhaven accelerator result was confirmed at CERN.[8]

Figure 1: **Year-by-year cites to papers authored by 1988 Nobel Prize winners in physics.** Dotted line=Herb S W et al. *Phys. Rev. Lett.* 39:252-5, 1977. Solid line=Garwin R L et al. *Phys. Rev.* 105:1415-7, 1957. Dashed line=Danby G et al. *Phys. Rev. Lett.* 9:36-44, 1962.



"Observation of high-energy neutrino reactions and the existence of two kinds of neutrinos," the paper that reported the Nobelists' discovery of the muon neutrino, appeared in the September 1962 issue of *Physical Review Letters*.[9] According to data from the *Science Citation Index®*, the paper gathered five citations in its first year. In 1963, the year the group's findings were verified at CERN, the full impact of the discovery was felt: nearly 60 explicit citations. As we have observed in dozens of citation studies, significant findings in particle physics produce nearly instantaneous citation recognition. Table 1 is a list of the laureates' most-cited works. Figure 1 depicts the citation record of the 1962 *Physical Review Letters* paper from time of publication until Lederman, Schwartz, and Steinberger won the Nobel Prize in physics. Also charted in Figure 1 are the citation records of the two most-cited papers in Table 1.

Today, the two neutrinos form part of the "Standard Model" of the fundamental nature of matter. Although still incomplete, the model posits that there are two basic kinds of building block particles: the quarks and the leptons. All leptons have a corresponding member among the quarks (the so-called "doublet" nature of particles). The quarks feel the strong nuclear force and form the basis of particles such as the protons and neutrons of atomic nuclei. The leptons include three charged particles: the electron, the heavier muon, and the still heavier tau particle. There are also three neutral leptons—three neutrinos, one associated with each of the charged leptons.[10] Table 2 outlines the specific particles and forces presently known to make up all matter.[11,12]

Biographical Data on the Laureates

Lederman, Schwartz, and Steinberger were all physics professors at Columbia. At the time of the initiation of the prizewinning experiment, Schwartz was in his late twenties; Lederman and Steinberger were in their late thirties. As can be seen from Table 1, the paper describing their Nobel Prize-winning efforts has over 230 references to it to date. The apparently small number of citations— usually uncharacteristic of an important physics paper—is essentially an exam-

Table 2: The Standard Model of elementary particle physics, which consists of two sets of fundamental particles (fermions) and four forces (bosons) that govern interactions between particles.[11,12]

FERMIONS		BOSONS
QUARKS	LEPTONS	PHOTONS (carry electromagnetic force)
UP	ELECTRON	GRAVITONS (carry gravitational force)
DOWN	ELECTRON NEUTRINO	
CHARM	MUON	GLUONS (carry strong nuclear force)
STRANGE	MUON NEUTRINO	
TOP	TAU PARTICLE	INTERMEDIATE VECTORS (carry weak nuclear force)
BOTTOM	TAU NEUTRINO	

ple of obliteration by incorporation. The laureates' discovery and method were rapidly absorbed into the literature and superseded by other works.

Jack Steinberger

Steinberger, who was born May 25, 1921, in Bad Kissingen, Germany, has been described as one of the most gifted experimentalists in high-energy physics.[6] He emigrated to the US in 1934, ending up in Chicago. He majored in chemical engineering at the Illinois Institute of Technology, Chicago. Following his enlistment in the Army in 1942, Steinberger worked at the Massachusetts Institute of Technology radiation laboratory, Cambridge, where his serious interest in physics began. In 1948 he received his PhD in physics at the University of Chicago. He was professor of physics at Columbia from 1950 to 1971. Steinberger, during his tenure at Columbia, had been co-Nobelist Schwartz's thesis adviser. They had been doing bubble-chamber experiments together for years at the Brookhaven Cosmotron, a predecessor of the AGS that was used in the Nobel Prize-winning work. Since 1968 Steinberger has been at CERN.[3,6,8] Through 1988 Steinberger has had over 1,400 cumulative citations to papers either authored or coauthored by him.

Melvin Schwartz

Schwartz was born November 2, 1932, in the Bronx, New York. He attended the Bronx High School of Science. Schwartz did all of his university work at Columbia, earning a doctorate in physics in 1958. After serving on the Columbia physics faculty from 1958 until 1966, he moved on to Stanford University, California, where he remained until 1979. Since then he has been president of Digital Pathways, Inc., which produces data communications systems that secure computers from tampering by outsiders.[3,6] Of the three laureates, Schwartz has the least number of cumulative citations to his papers (through 1988, almost 500). This is no doubt due in part to the fact that Schwartz is pursuing entrepreneurial interests and is no longer in academe, where publishing papers is an integral part of communicating science.

Schwartz may have been deprived of an earlier opportunity of winning the Nobel Prize.[13] In the early 1970s, while working at the Stanford Linear Accelerator Center (SLAC), Schwartz may have been on his way to finding indirect evidence of the existence of the Z particles (which theorists say may unify the electromagnetic and weak forces of nature). Using a similar equipment setup as in the discovery of the muon neutrino, he detected, besides muon neutrinos, five unusual events with no muons. However, apparently due to the reluctance of SLAC management to authorize continued use of the accelerator and the rejection three times by the National Science Foundation of Schwartz's request for funding, the experiment went no further. It is believed that Schwartz had found evidence for the so-called "neutral currents," a weak interaction involving the Z particle. The Z particle was first detected at CERN in 1983. Carlo Rubbia and Simon van der Meer, who led the effort to discover the Z, shared the Nobel Prize in physics in 1984, as we discussed in a previous essay.[14]

Leon Lederman

Lederman was born into a Russian immigrant family on July 15, 1922, in New York

Table 3: Selected list of 1988 *SCI*® research fronts on elementary particles and forces. A = number of core papers. B = number of citing papers.

Number	Name	A	B
88-0440	Weak and hypoweak interactions	37	430
88-0445	Energy and symmetry of states in light nuclei	21	299
88-1221	CERN collider and the Standard Model	4	37
88-1230	The quark structure of matter	11	133
88-1723	Low-energy nuclear electron capture and determining neutrino mass	3	21
88-2496	Flavor and the structure of hadrons and nuclei	10	51
88-2695	Low-multiplicity collisions at the CERN ISR	2	14
88-2852	Cosmology and particle physics	13	153
88-3244	Proton-proton scattering	8	59
88-4004	Aspects of the chiral quark model	6	110
88-4077	Quark plasma oscillations	2	39
88-4715	Review of particle properties	7	106
88-4720	Supersymmetry and the unification of fundamental interactions	3	45
88-5595	Cosmic ray neutrinos in the atmosphere	2	10
88-6950	Strangeness in dense matter	2	24
88-7263	Theory of heavy fermion systems	3	30
88-7481	Neutrino mass and left-right symmetry	2	49

City. He grew up in the Bronx, just 10 blocks from where co-Nobelist Schwartz lived. Following his secondary schooling at James Monroe High School in New York, Lederman graduated with a degree in chemistry from the City College of New York in 1943. Although he majored in chemistry, he got more enjoyment out of physics courses. He went on to study physics on a scholarship at Columbia, receiving his doctorate in 1951. Lederman was director of Columbia's Nevis Laboratory from 1962 to 1979, when he became director of Fermilab. Just recently retired from his directorship, Lederman now teaches as the Frank L. Sulzberger Professor of Physics at the University of Chicago. Lederman was instrumental in convincing Schwartz that the AGS at Brookhaven National Laboratory was powerful enough to conduct the neutrino experiment, despite Schwartz's initial misgivings. Happily, Lederman's hunch was correct. He is an outspoken proponent of the Super-conducting Super Collider (SSC).[3,6,8]

Of the laureates Lederman has the most cumulative citations to his papers—over 2,800. Indeed, the most-cited work in Table 1, entitled "Observation of a dimuon resonance at 9.5 GeV in 400-GeV proton-nucleus collisions," was coauthored by Lederman. Nearly all of the most-cited papers in Table 1 relate to the use of accelerators in the discovery and observation of nuclear particles.

Neutrino Physics Today

High-energy physicists have a continuing interest in neutrinos, as these particles are believed to hold the key to solving fundamental questions in physics and early universe cosmology. This interest is confirmed by ISI® research-front data. Three 1988 fronts are explicitly tied in with neutrinos: #88-1723, "Low-energy nuclear electron capture and determining neutrino mass"; #88-5595, "Cosmic ray neutrinos in the atmosphere"; and #88-7481, "Neutrino mass and left-right symmetry." Table 3 is a selected list of 1988 research fronts that deal with particle physics activity.

Neutrinos figure prominently in the attempt to complete the Standard Model of elementary particles. Although the tau particle has been discovered, there has been no direct evidence yet in hand for a tau neutrino (which there should be, according to the "doublet" nature of these particles—indeed, a corresponding hypothetical "top" quark is still being sought at both the CERN and Fermilab accelerators).[15]

The search for other types of neutrinos besides electron neutrinos and muon neutrinos has implications for astrophysicists and their big bang theory of how the universe was created. The theory works extremely well at present with just the known particles accounted for and with the notion that the neutrino has no mass; however, if further types (termed generations) of neutrinos are found, then the big bang theory, as now formulated, would be in serious trouble. If neutrinos have a nonzero mass, they would constitute a significant fraction of the total mass of the universe. This would have a major impact on the issue of whether the universe will continue to expand forever or whether it will in fact eventually recompress. If neutrinos have mass, they would add to the gravitational attraction, and they would tend to slow up the universe's expansion and eventually turn it around.[16]

A related issue, perhaps of more practical immediacy to laypersons, is the ongoing puzzlement by physicists over the discrepancy between the number of neutrinos observed coming from our sun, which is much lower than the number predicted to be generated according to the most up-to-date theories. Neutrinos are created in nuclear reactions that are directly sensitive to the sun's temperature, and the numbers recorded that reach the earth are less than one-third of the number predicted by theory.[17] If a practical way can be found to show that neutrinos do have mass, the discrepancy may be explained. The understanding of how the sun shines, with a corresponding lack of neutrinos being emitted from the process, will help scientists determine accurately the energy-generating processes in the core of our star, as well as its health.

In the past decade, seven other physicists have been awarded Nobel Prizes (in 1979, 1980, and 1984) for their discoveries about the fundamental particles of matter. This reflects the importance that world science places on this field. As efforts to learn more about the constituents of the atomic nucleus have increased, larger and more powerful particle accelerators have been built. The proposed Texas-based SSC would be, if built, the largest and the most expensive accelerator ever.[18] The promise of making the Standard Model of elementary particles more complete indeed has allure, but can we afford the cost of increasing our knowledge of fundamental particles?

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REFERENCES

1. Subatomic particles. *Encyclopaedia Britannica.* Chicago, IL: Encyclopaedia Britannica, 1985. Vol. 28. p. 249-63.
2. **Lederman L M.** The upsilon particle. *Sci. Amer.* 239:72-80, October 1978.
3. **Royal Swedish Academy of Sciences.** Press release. 19 October 1988. 4 p.
4. Neutrino. *Encyclopaedia Britannica.* Chicago, IL: Encyclopaedia Britannica, 1985. Vol. 8. p. 625.
5. **Schwartz M.** The first high-energy neutrino experiment. *Science* 243:1445-9, 17 March 1989.
6. Winners of Nobel Prizes for unlocking secrets in physics and chemistry. *New York Times* 20 October 1988. p. B13.
7. **Schwartz M.** Personal communication. 10 July 1989.
8. **Schwarzschild B.** Physics Nobel Prize to Lederman, Schwartz and Steinberger. *Phys. Today* 42:17-20, January 1989.
9. **Danby G, Gaillard J M, Goulianos K, Lederman L M, Mistry N, Schwartz M & Steinberger J.** Observation of high-energy neutrino reactions and the existence of two kinds of neutrinos. *Phys. Rev. Lett.* 9:36-44, 1962.
10. **Sutton C, Anderson I & Joyce C.** When particle physics was still fun. *New Sci.* 120:30, 29 October 1988.
11. **Mistry N B, Poling R A & Thorndike E H.** Particles with naked beauty. *Sci. Amer.* 249:106-15, July 1983.
12. The Standard Model. *Supercurrents* 3:14-5, March 1988.
13. The man who rebelled against big physics.... *New Sci.* 120:31, 29 October 1988.
14. **Garfield E.** The 1984 Nobel Prize in physics goes to Carlo Rubbia and Simon van der Meer; R. Bruce Merrifield is awarded the chemistry prize. *Essays of an information scientist: ghostwriting and other essays.* Philadelphia: ISI Press, 1986. Vol. 8. p. 432-43.
15. **Lederman L M.** Observations in particle physics from two neutrinos to the Standard Model. *Science* 244:664-72, 12 May 1989.
16. **Lederman L M.** Personal communication. 10 July 1989.
17. **Finkbeiner A.** What's going on inside the sun? *Science 85* 6:30, 1985.
18. **Mervis J.** SSC faces uphill battle for funds. *THE SCIENTIST* 3(10):2-3, 15 May 1989.