Celebrating the Neutrino

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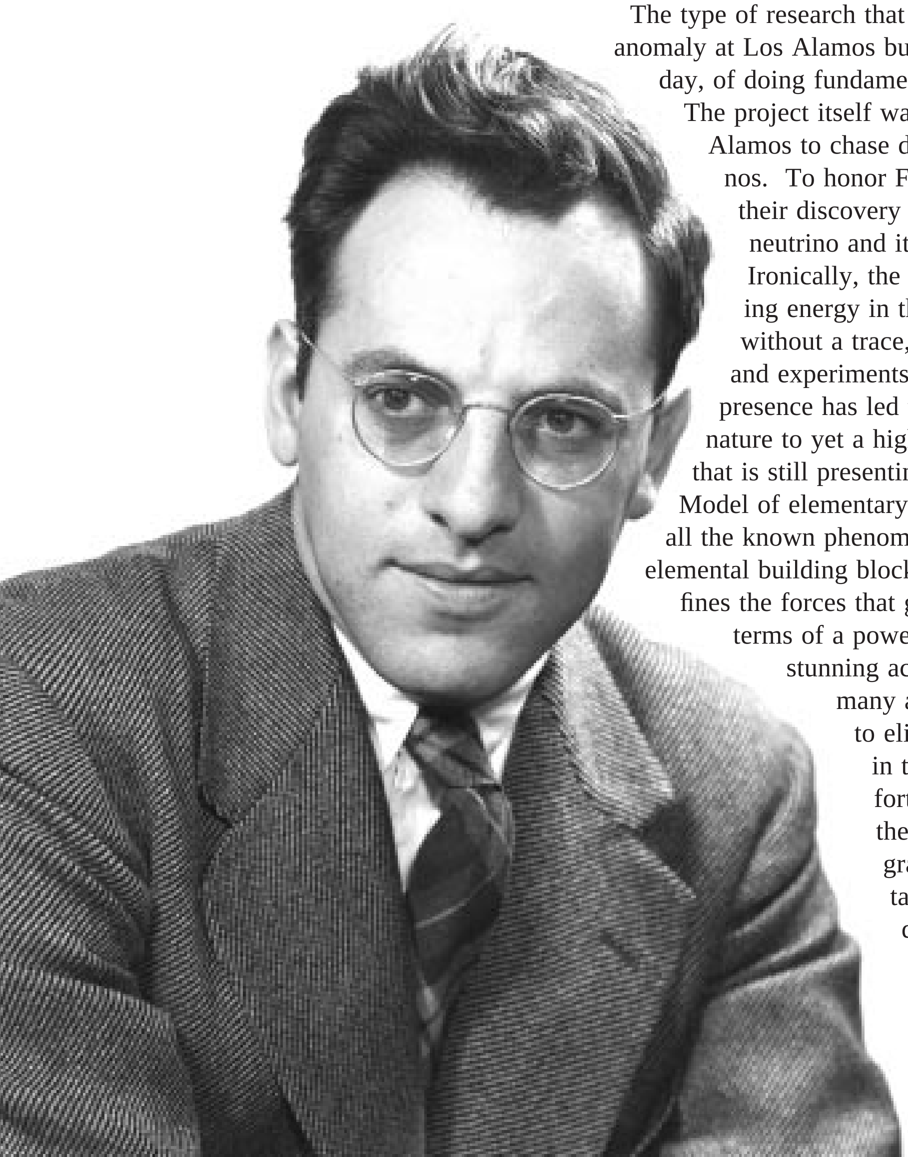
In 1995, Fred Reines was awarded the Nobel Prize in Physics for the detection of the neutrino, the most elusive and intriguing nature's fundamental building blocks. Its existence had been deduced as early as 1930, and it was more or less taken for granted, although never seen directly, for the next twenty-five years. Then in a series of two bold experiments carried out between 1953 and 1956, Fred Reines and Clyde Cowan, Jr. led a team of talented scientists and technicians at Los Alamos in making the first definitive measurement of an event induced by a free neutrino, thus proving that this theoretical construct did indeed exist. Now, forty years later, the Nobel Committee has chosen to recognize this outstanding achievement. Not only is this a great honor for Fred personally, but also for Los Alamos National Laboratory as this is the first time Laboratory-sponsored work has been awarded the Nobel Prize. The Laboratory is extremely proud of Fred for bringing that honor to this institution. Very sadly, Clyde Cowan, Jr. was not alive to share the award with Fred, but his equal contribution is recognized by all, and in that knowledge, portraits of both men are being hung beside some of the other great scientists who have graced this institution.

The type of research that Reines and Cowan took on in the 1950s is not an anomaly at Los Alamos but rather part of the Los Alamos tradition, held to this day, of doing fundamental science side-by-side with mission-oriented work. The project itself was the first in a series of extraordinary efforts at Los Alamos to chase down and uncover the properties of the elusive neutrinos. To honor Fred and Clyde and their colleagues and to celebrate their discovery and the work it inspired, this issue is devoted to the neutrino and its remaining mysteries.



Ironically, the neutrino, which was invented to carry away the missing energy in the radioactive decay of certain nuclei and disappear without a trace, has maintained a persistent presence in the thoughts and experiments of particle physicists. Time after time its ghostly presence has led to some new puzzle that pushes the understanding of nature to yet a higher level. Even today, the neutrino is the one particle that is still presenting mysteries that cannot be explained by the Standard Model of elementary particle physics. That mathematical model describes all the known phenomenology of the elementary particles in terms of the elemental building blocks of matter known as quarks and leptons. It also defines the forces that govern the interactions among the constituents in terms of a powerful principle known as gauge symmetry. Although a stunning achievement in both form and economy, the model has many arbitrary features, and many physicists have attempted to eliminate those by creating an even more unified picture in the form of grand unified theories. Despite those efforts the Standard Model has remained unchanged over the last decade. None of the predictions of the beautiful grand unified theories have been confirmed experimentally. Instead the only hint of physics beyond the Standard Model comes from the neutrino. And it comes from the hint that neutrinos may not be massless after all.

Although neutrinos have managed to keep the attention of physicists for over six decades, ever since 1930 when Wolfgang Pauli first proposed that they exist, they have not become a household word. That's because these tiny bits of nothingness or almost nothingness, participate in only one of the four fundamental forces in nature, namely the weak force, and that force does not manifest itself in our everyday lives. In fact, the weak force may seem to be superfluous at first because the other three appear to do the major work of creating order in the universe. Gravity holds us to earth and keeps the planets in their orbits, electromagnetism holds the atoms together and governs the chemistry of the elements, and the strong force holds nuclei together and governs the processes of nuclear fusion and fission that release energy, power the stars, and produce heavy elements from light ones. But wait! There we must stop because the making of the elements involves not only fusion of two nuclei into a heavier one through the strong force, but also the slower and quite permanent decay of one element into another through the most common process governed by the weak force—nuclear beta decay. In a typical beta decay reaction, the weak force turns a neutron into a proton and simultaneously creates an electron and the infamous neutrino. If the neutron is bound in a nucleus, the proton remains bound, but the newly created electron and neutrino leave the nucleus, carrying the energy released by the reaction. Beta decay and its various inversions and variations played a big role in the first few minutes following the Big Bang, when neutrons and protons were free, and they interacted through the weak force as well as the strong to create the primordial abundances of helium and some of the light elements. It is similarly involved in the synthesis of the helium in the center of stars and is therefore crucial to the thermonuclear processes that keep the sun shining for us by day and the stars twinkling in the heavens by night. Whether in the interior of stars or in the envelopes of supernovae, the weak force works to make all the elements we know on Earth. The weak force is the force of transmutation. Without it, the elements and therefore us, would never have come to be.

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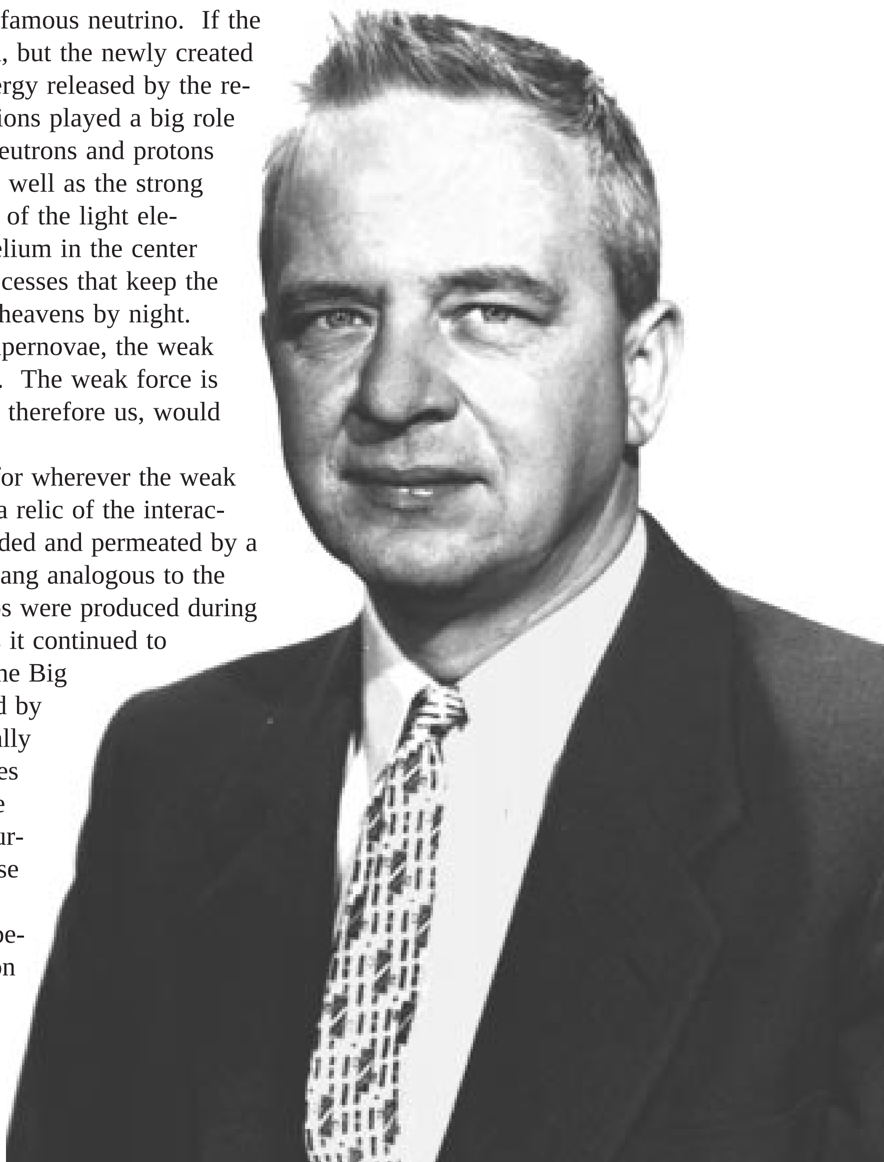
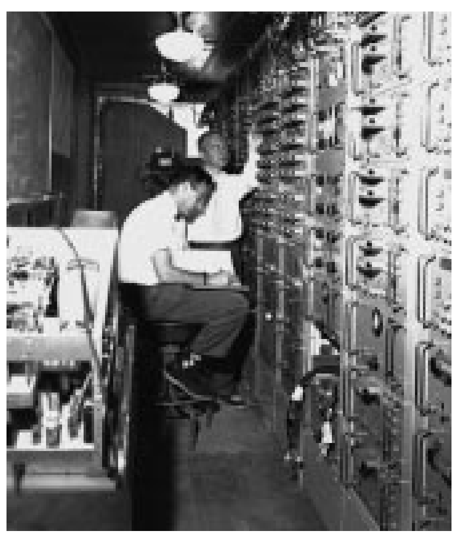


And so the neutrino's importance becomes apparent, for wherever the weak force plays a role, we usually find the neutrino either as a relic of the interaction or as a major participant. Even now we are surrounded and permeated by a thermal background of neutrinos, a remnant of the Big Bang analogous to the well-known 3-degree black body radiation. The neutrinos were produced during primordial nucleosynthesis and decoupled from matter as it continued to expand and cool during the first few minutes following the Big Bang. In addition to this thermal sea, neutrinos produced by thermonuclear processes at the center of sun are continually making the journey to Earth, streaming through our bodies and everything they meet, and continuing out through the solar system and past our galaxy in an almost endless journey to the far reaches of the universe. Once created, these elusive particles have a very small chance of interacting with matter, and so their presence is mostly silent. But because they interact so little, they also preserve information about the conditions present when they were created.



The first two articles have the theme of the experimental challenge then and now—THEN is a review of Reines/Cowan experiments that proved the existence of the neutrino, and NOW is a state-of the-art neutrino experiment on a question that has occupied scientists since the neutrino's existence was first postulated: Do neutrinos have mass? Preliminary results of the Los Alamos experiment suggest that the answer is yes. If this result holds up, it would mean that neutrinos make up a significant fraction of the mass of the universe. It would also mean that Los Alamos scientists have once again performed an historic experiment in the field of neutrino physics.

Juxtaposing the two experiments highlights their similarities, among them the fact that the same neutrino-induced reaction is the signal in both cases, liquid scintillation detectors are used in both, and the primary challenge is to see a small signal amidst a large background of unwanted events. But the differences are just as striking. The sensitivity required, for example, has increased by many orders of magnitude (VERN: HOW MANY?). The size of the detector has increased by WHAT? and the data acquisition system and ability to discriminate one event from another has become a high art. Accompanying these two pieces is a sidebar outlining the ongoing commitment of the Laboratory's administration and scientists to this particularly challenging, almost impossible field of uncovering the secrets of the neutrino. ■

Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold-shoulder steel and sounding brass,
Insult the stallion in his stall,
And, scorning barriers of class,
Infiltrate you and me! Like tall
And painless guillotines, they fall
Down through our heads into the grass.
At night, they enter at Nepal
And pierce the lover and his lass
From underneath the bed—you call
*It wonderful; I call it crass**

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