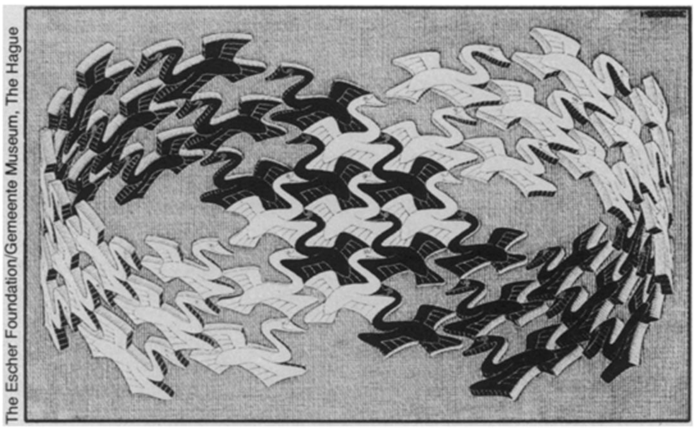
Weighed in the Balance and Found: Neutrino



The Escher Foundation/Gemeente Museum, The Hague

Is it one or the other or both? It vibrates back and forth. Swan oscillations of Maurits Escher.

It is a commonplace of textbooks and popular books in physics that the neutrino, in however many varieties it may exist, possesses no rest mass. When Enrico Fermi invented it — that seems the right verb to use — it needed that characteristic. It was invented to carry energy away from the radioactive beta decay of nuclei. To serve in every case it had to be able to carry any amount of energy from zero to whatever. If it had a rest mass, there would be an irreducible minimum of energy it could carry. Ergo: No rest mass for the neutrino.

Now they are beginning to say it has a rest mass. Frederick Reines of the University of California at Irvine said it loud and clear at the Washington meeting of the American Physical Society last week. A group at the Institute for Experimental Physics in Moscow is saying it, but they seem to be adducing little in the way of supporting evidence. There are murmurs that experiments in a number of other places are getting results that tend in that direction. Reines, Henry W. Sobel and Elaine Pasierb (all of U.C. Irvine) make a flat statement in a paper to be published in PHYSICAL REVIEW LETTERS: "We report evidence for neutrino instability...."

What everybody is talking about is not a direct measurement of the neutrino mass, but the detection of an activity that logically demands the existence of a rest mass for the neutrino. This is the "instability" in the sentence just quoted. More often, by Reines and everybody else, it is called "neutrino oscillation."

When Fermi thought up the existence of the neutrino, he needed only one kind. But in recent years it has become clear that as Fermi's neutrino is closely associated with the electron (in beta decay and everywhere else) so there are individual varieties of neutrino to go with the electron's close relatives, the muon and the tau lepton. (Muon neutrinos have been discovered; tau meutrinos as yet have not.) The general belief was that the different kinds of neutrino were separate particles, and always maintained their distinctions from one another. The present claim is based on the observation that they change back and forth from one sort to another — neutrino oscillations.

The experiment Reines was talking about was set up at the Savannah River Nuclear Reactor in South Carolina to look for neutral current weak interactions involving neutrinos and the particles of the atomic nucleus. It placed a detector full of heavy water at a point 11.2 meters from the reactor and recorded interactions between the flux of neutrinos from the reactor and the deuterium nuclei in the heavy water.

All interactions that neutrinos participate in are "weak." Of all the forces in physics only those generated by the weak interaction affect neutrinos. Weak interactions come in two varieties, charged current and neutral current. In a charged current interaction two colliding particles exchange a unit of electric charge and change identities. In the neutral current, no charge is exchanged and identitites are retained. The charged current has been around since weak interactions were first studied. The neutral current is a prediction of the unified field theories of the last few years. It was first found in collisions between neutrinos and electrons. This was an attempt — and the first reported successful one — to find it in interactions between neutrinos and atomic nuclei.

The neutral current interaction the experiment found was the type in which an electron neutrino strikes a deuterium nucleus, breaks the nucleus into its constituent proton and neutron and remains itself intact. The corresponding charged current reaction, which also occurred in the experiment, causes the proton to turn into a neutron and the neutrino into a positron so that the outcome of the collision is two neutrons and a positron. The finding of the neutral current with respect to electron neutrinos was reported in PHYSICAL REVIEW LETTERS (Vol. 43, p. 96) by Pasierb, H.S. Gurr, J. Lathrop, Reines and Sobel. The neutral current came out with the probability predicted by the most widely regarded of the modern theories, but the troubling aspect was that the experimental ratio of neutral current events to charged current events seemed wrong compared to the theoretically expected ratio.

Then, says Reines, speaking at the end of April, "Six weeks ago there occurred to us a powerful way to look at the data. If one analyzes the data in a special way, uncertainties melt away like snow on a warm day." Namely, the analysis took into consideration the selectivity of the charged current (it takes only electron neutrinos) and the indifference of the neutral current, which will accept all kinds. If there were somehow other varieties of neutrinos in the stream by the time it got to the heavy water tank (although it should be all or nearly all electron neutrinos coming out of the reactor) and fewer electron neutrinos, that would explain the "ratio of ratios." This is the quotient of the observed and expected ratios of the charged and neutral current processes. It should be one. It is in fact 0.43, and the conclusion from that number is that electron neutrinos (and by implication all other kinds) are unstable. "The universe is not the way we thought," says Reines. Electron neutrinos can change into muon neutrinos and back again. Such oscillation was predicted by a Japanese group, M. Nakagawa, H. Okonogi, S. Sakata, and A. Toyoda in 1963 and by Bruno Pontecorvo working in Moscow in 1968.

What oscillation has to do with a mass for the neutrino comes from the quantum mechanical principle that a particle is also a wave. Seen as a particle it appears to have a nitty gritty kind of individual definition, but seen as a wave it is more ambiguous. Any given wave can be regarded as the sum of certain other waves; new waves can be built by superposition of old waves. A whole branch of mathematics is devoted to this. No wave is really more basic than another.

Analysis of this experiment regards the wave that represents the neutrino as observed to be really a kind of beat wave, a superposition of two underlying waves (representing fundamental physical states that are never directly observed). These two fundamental waves proceed together, getting alternately in and out of phase with each other. The superposition, the beat wave, generated by this in-and-out-of-phase process, brings forth the observed neutrino wave. That manifests itself as either electron or muon neutrino according to the momentary relationship of the underlying waves. So what is ostensibly an electron neutrino when it comes out of the reactor can change itself to muon neutrino and back perhaps more than once on the way to the detector. (The tau neutrino, incidentally, does not seem to oscillate to an electron neutrino.)

There is a certain mass assocated with each of these underlying waves. There has to be. This is how the mass comes in. If it were not there, both waves would travel at the speed of light. They would be always in phase. There would be no interference, no oscillation in the superposition wave. There would in fact be no reason to talk of two underlying states, nor would there be

$$\bar{\nu}_e + d \nearrow n + n + e^+ \quad \text{c.c.}$$
$$\bar{\nu}_e + d \rightarrow n + p + \bar{\nu}_e \quad \text{n.c.}$$

Reines, Sobel, Pasierb

Mene, mene, tekel *neutrino. Its charged current interactions did not weigh enough in the balance.*

neutrino oscillations. So the mass must be there. The experiment can calculate the mass *difference* between the two underlying states, which Reines calls "neutrettos." It comes to about one electron-volt. The masses of the observed neutrinos remain to be determined.

The neutrino having been weighed in the balance and found not wanting, the hand seems to be writing on the wall at high speed. Reines read to a press conference a telegram he had received from David Schramm and Gary Steigman, astrophysicists at the University of Chicago, who after congratulating him on his result go on to point out that a mass of 25 electron-volts for the observed neutrinos would provide enough mass in the form of neutrino haloes around galaxies to close the universe. The universe would then apparently oscillate from big-bang explosion to big-bang explosion. Reines rather chuckles at the theological implications of that.

Less cosmically this result could "solve" the problem of the solar neutrinos, or to be more exact, turn it into a different problem. The nuclear processes in the sun are supposed to produce a certain flux of neutrinos. Observations have failed to measure that flux. Physicists have suggested that something is wrong with the sun. It may have "turned off." Reines now says the problem could be oscillating neutrinos deceiving the detectors. The sun may still be on after all.

A fundamental implication of the result, Reines says, is that the "flavors" or the characteristics of being an electron neutrino, a muon neutrino or a tau neutrino may not be distinct. Distinctness of flavors — these and others — and parallels among them are basic to the unified field theory schemes that are now trying to compose a comprehensive description of physics. Will a confusion of flavors make tutti fruiti of their work? One might paraphrase I. I. Rabi's famous remark about the muon: Consider the neutrino. Who ever ordered it to behave like that? □

Fest for Sakharov: Message to Moscow

The case of Andrei D. Sakharov has stirred up the American physics community to the same or perhaps even a higher degree than that of Aleksandr Solzhenitsyn stirred up the American literary establishment. It is hardly surprising that in these cases of persecution by totalitarian governments people respond most vigorously to the situation of a colleague. They can understand the prohibitions and impositions in terms of their own activities. So the literati identified with Solzhenitsyn, and the scientific establishment, particularly the physics establishment, is holding rallies for Sakharov.

Sometimes the hero turns out to be a little difficult to identify with. Solzhenitsyn is quite right wing (so the American left cannot justify itself in his person). He is a fervent Russian nationalist (sponsored by an American intelligentsia that tends to think nationalism rather than Marxism is the source of the trouble in Russia). Mirabile dictu, he is something of a clericalist (in one essay he seemed to suggest turning over the government of Russia to the Orthodox bishops). Finally, like many Russian intellectuals, he is grumpy. So we now begin to hear murmurs that Solzhenitsyn is not the writer he was reputed to be.

In Sakharov's case the bond between the man and his western supporters seems stronger than ever. It may be that the physicists will not be disillusioned because they seem to know Sakharov better than the literati knew Solzhenitsyn. International physics is a more communal and closely knit world than the literary elite, in spite of the Iron Curtain.

Attempts to detract from Sakharov's professional character have not come from disgruntled acolytes in the West. They all come from the Soviet press. The content of these remarks is that Sakharov, having lost his talent for physics, went into politics in order to stay in the public eye. American physicists reacted with outrage to these "slanders" and organized a session at last week's APS meeting to refute them.

Chaired by the president of the APS, Herman Feshbach of Massachusetts Institute of Technology, the session was meant to reaffirm belief in Sakharov as a physicist and as a human being and to drum up support for his cause. Adherents to a moratorium on scientific contacts with the Soviet Union were solicited as were signatures on a telegram of support addressed to Sakharov.

The purpose of all this activity was to demonstrate to the Soviet authorities that Sakharov is not forgotten by his colleagues in the West. Edward Lozansky of the University of Rochester, executive director of the Sakharov International Committee and himself an emigré from the Soviet Union, remarked that the Soviet authorities are evidently hoping that the furor will die down, and then they can proceed with harsher measures unnoticed. That must not be allowed to happen, Lozansky says: "Sakharov's welfare is our welfare."

That identification was the keynote of the proceedings. The two scientific papers, on thermonuclear fusion by Melvin B. Gottlieb of Princeton University and on particle physics by Sheldon Lee Glashow of Harvard University, were intended to review branches of physics in which Sakharov had made contributions and mention his work by the way. Perhaps Sakharov's most widely known contribution was the invention (with Igor Tamm) of the tokamak, the controlled fusion device that many physicists believe will be the foundation of a successful fusion reactor. A particle physics example is his prediction of the masses of the charm particles. His was one of two successful attempts at this very difficult accomplishment. In 1966, long before this year's grand unified theories made it mandatory, he speculated that the proton might be subject to radioactive decay and drew a cosmological conclusion from that that explains the observed imbalance between matter and antimatter in the universe.

He has not lost interest, the participants in this meeting assert. He continues to write scientific papers alongside his political statements. As recently as six months ago he managed to publish a paper, an accomplishment that Lozansky attributes to the intervention of Pyotr Kapitsa, possibly the most renowned of living Russian physicists. More recently two papers dated Jan. 22 were "lost" on the way to publication. He has since reconstructed the work in a single paper and sent it by the hand of his wife directly to the president of the Soviet Academy of Sciences (which publishes the scientific journals).

Tributes to Sakharov's personal qualities were also numerous. They gave the meeting an air of solemnity and moral intensity. Gottlieb quoted Lev A. Artsimovich, who led the development of tokamaks at the Kurchatov Institute in Moscow, as saying of Sakharov: "The man is a saint." That seemed to embarrass some people a little. Certainly he is a kind of martyr, and for the people in the hall that night, a living symbol. The whole affair is a testimony that no longer can a government interfere with a citizen's freedom and expect it to remain an internal matter. □