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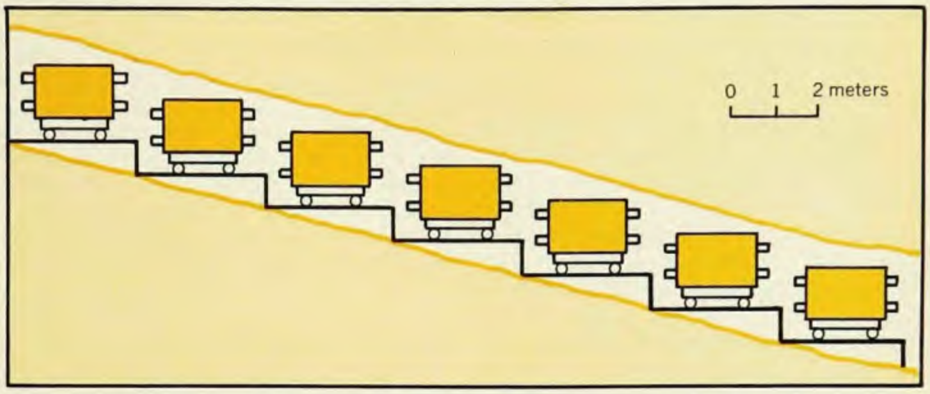
Antineutrino pulses could signal birth of neutron star

A bouncing baby neutron star emitting burps of antineutrinos may have been detected shortly after its birth in the collapse of an ordinary star. That is one explanation being offered for a curious event detected by a University of Pennsylvania–University of Texas–University of Torino collaboration, whose results were reported by Kenneth Lande at the Fourth International Conference on Neutrino Physics held in Downingtown, Pa. at the end of April.

On 4 January an array of Cerenkov counters deep within a gold mine registered four pulse sequences in a row, each lasting about a microsecond and separated by about a millisecond each. One popular way of envisioning the gravitational collapse of a star to a neutron star is that the neutron star would bounce many times, with roughly a 1-millisecond period.



Antineutrino detectors. Seven water Cerenkov counters are arranged in a tunnel 4850 feet below surface in the Homestake Gold Mine in Lead, S.D. On 4 Jan. the counters detected four antineutrino burps lasting 1 microsecond. Each burp was separated by 1 millisecond.

Detection. The group, consisting of Lande, George Bozoki, William Frati and C. K. Lee (Penn), Ervin Fenyves (University of Texas at Dallas) and Oscar Saavedra (University of Torino), had set up their apparatus in the Homestake Gold Mine in Lead, South Dakota next to the Brookhaven solar-neutrino experiment, the one that has been finding such an embarrassing (to theorists) shortage of solar neutrinos. The mine is 4850 feet deep. The group placed seven water Cerenkov counters in a row with an electronic readout arrangement that recorded the time distribution of pulses in each counter and the photomultiplier pattern and total pulse height associated with each pulse. The apparatus was to look for the reaction $\bar{\nu} + p \rightarrow n + e^{+}$.

Each Cerenkov counter is a 2-m^3 cylinder (in fact a 500-gallon fuel-oil tank), 1.78 m long by 1.22 m in diameter, which is filled with deionized water. A coincidence circuit gives an output pulse whenever five or more of the eight photomultipliers viewing the counter give coincident signals. If two or more counter pulses occur within 0.1 sec or if there is a single large-amplitude pulse, a magnetic tape recording is made of the time distribution of the pulses in each counter, the summed photomultiplier pulse amplitude associated with each pulse and the photomultiplier pattern involved in the coincidence.

A second apparatus has been set up in the Mont Blanc tunnel 5000 miles away from Homestake, but unfortunately it was not operating on 4 January.

The event on 4 January involved 24

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Two-photon absorption yields Doppler-free spectroscopy

In one of those events so typical of research, three groups have independently and almost simultaneously demonstrated two-photon absorption in sodium vapor without blurring from Doppler broadening. The technique appears to open up a new way of achieving high-resolution spectroscopy with tunable lasers. And it can be applied, for example, to induce photochemical reactions selectively, to separate isotopes, or to provide more precise values for the Rydberg constant and Lamb shifts.

The theory of two-photon transitions actually started with Maria Goeppert-Mayer's thesis in 1929. But experimental observations in the visible region have only become possible over the last ten or twelve years, once strong laser sources became available.

In 1970 L. S. Vasilenko, V. P. Chebotaev and A. V. Shishaev (Institute of Semiconductors in Novosibirsk) pointed out the possibility of using two-photon transitions for high-resolution spectroscopy without Doppler broadening. The paper did not apparently generate much interest at the time. Last year Bernard Cagnac, Gilbert Grynberg and Francois Biraben of l'Ecole Normale Superieure calculated that the technique should be feasible even with rather small laser powers. And in the US a visit by V. S. Letokhov (Institute of Spectroscopy, Moscow) to Cambridge and to Stanford, in which he discussed the original Soviet paper, seems to have stimulated groups at Harvard and Stanford to attempt the experiment. Two other recent papers, by D. E. Roberts and Edward N. Fortson (University of Washington) and by Paul L. Kelley and Helge Kildal (MIT Lincoln Lab) and Howard Schlossberg (Air Force Cambridge Research Labs), have discussed some applications of Doppler-free two-photon absorption processes. Meanwhile the group at l'École Normale Superieure was attempting the experiment they had discussed.

Recently *Phys. Rev. Letters* carried the announcement that the French group[2] had succeeded, and in an adjacent paper, that a Harvard team,[3] Marc D. Levenson and Nicolaas Bloembergen, had also succeeded. Still more recently a Stanford group, Theodore M. Hansch, Kenneth Harmode of collision in operation at any one time. If the Doubler were built, protons could be injected at their full energy; if not, the proton storage rings would operate initially up to the highest energy provided by the main ring and the lab might subsequently tackle the problem of accelerating stored beams. —*Barbara G. Levi*

Antineutrino pulses

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pulses within 3 msec in six of the Homestake detectors. There were four groups of pulses, each about 1 microsec wide. The first and second groups were separated by 640 microsec, the second and third by 968 microsec and the third and fourth by 928 microsec. The first group consisted of nine pulses spread over six counters, the second group involved six pulses and the third group eight pulses. The fourth burst filled the readout buffer; so the experimenters don't know what happened next. From their detector thresholds and pulse-height data, the observers estimate that if the pulses are due to antineutrinos, the energy of the antineutrinos (or positrons, whose energy differs from that of the antineutrino by 1 MeV) is between 20 and 100 MeV.

No one actually knew about the 4 January event until some time later, when a Homestake engineer, as was his weekly custom, removed the tape from the apparatus and mailed it to Penn. By that time, if the source were a bouncing neutron star it would have stopped bouncing. But it was not too late to check instruments that were running at the time.

Raymond Davis of Brookhaven swept his Cl^{37} tank in the Homestake mine to see if there were more events than would be expected from background. Davis did not see any excess counts. The Brookhaven apparatus is sensitive to neutrinos, not antineutrinos, with sensitivity comparable to the Penn–Texas–Torino apparatus. The latter device presumably saw 24 antineutrino captures. If the source produced equal numbers of neutrinos and antineutrinos Davis would have expected 70–90 atoms of Ar^{37} to be produced. Instead he saw fewer than 21 events, corrected to 4 January, which was consistent with the normal sensitivity of the detection system.

In fact, some theorists do not expect a collapsing star to emit neutrinos and antineutrinos of the same energy. Because of the large ratio of neutrons to protons in the collapsed star, Lande told us, one might expect that the neutrinos would be absorbed, make electrons, and then be reborn with less energy. The antineutrinos, however, would find the star relatively transparent and so would suffer no appreciable energy degradation in their transit of the star. Thus the collapsed star is likely to emit neutrinos with considerably less energy than antineutrinos, he said. Since the efficiency of the neutrino and antineutrino detectors each has a strong energy dependence, Lande argues, the effect of the diminished energy of the emitted neutrinos relative to that of the antineutrinos is to make neutrino detection more difficult.

At the moment there are no other underground antineutrino experiments running. Several years ago Frederick Reines (University of California, Irvine) and his collaborators had one in a South African gold mine, as did M. G. K. Menon (Tata Institute, Bombay), Arnold Wolfendale (Durham University, UK) and their collaborators in the Kolar gold mine in India; both of these are now dismantled. Neither experiment was sensitive to a train of pulses. In 1965 Ya. B. Zeldovich (Institute for Applied Mathematics in Moscow) and O. Kh. Guseinov had published a paper predicting that most of the 10^{54} ergs of gravitational potential energy emitted by a collapsing massive star would be radiated in 10^{-2} sec. Responding to this paper, G. T. Zatsepin and A. A. Chudakov are installing a 100-m^3 detector (100 tons) in a salt mine in Artemovsk, the Ukraine.

The usual scenario for a neutron star formed in a supernova explosion is that it will oscillate because it is formed very suddenly, and its period is expected to be about 1 millisecond. Some theorists would expect that while the neutron star is oscillating, it emits copious amounts of high-energy antineutrinos and not neutrinos. One theorist feels it is most likely that the Penn–Texas–Torino group was seeing the birth of a neutron star in the center of our galaxy. He thinks it is the center rather than the edge because a supernova was not observed visually, and that the event was within our galaxy because it would be much harder to observe one outside our galaxy. (The source would have to be 1000 times more intense to be seen coming from outside our galaxy.)

How often would one expect to observe the birth of a neutron star? From existing data on the occurrence of supernovas in galaxies like ours, one should expect one supernova in 30 years. Lande notes that if that were true, "You should get very young people to do experiments like this." But in fact the experiment had only been running since October. So the observers were either very lucky, or the events are much more frequent (or they have another cause). Another possibility is that some collapsing stars may not have any visible output. From the number of pulsars in our galaxy, one also estimates that a stellar collapse happens once every 30 years. But the consideration that encouraged the Penn–Texas–Torino group to try, was that by considering how many stars in our galaxy are capable of undergoing gravitational collapse, they estimated one or less collapses per year.

Sources of error. Davis told us that he cannot conceive of any kind of cosmic-ray event that could cause the kind of time structure reported. "But what to make of it, no one knows." Reines would like to learn of some other event in coincidence with the event, such as the response of a giant air-shower detector, or a Weber pulse. The Los Alamos Vela satellite system, which last year had detected many short bursts of cosmic gamma radiation, showed no response at the time of the 4 January event.

Reines suggests that the Penn–Texas–Torino workers may not have sufficiently isolated their tanks from electronic noise, and he feels that an oscilloscope display rather than a digital recording would have been more informative on this score. However, he admits, "The delays are such that it can't be anything but a first-rate discovery or electronic burbling."

In analyzing their sources of error the Penn–Texas–Torino group believe they have ruled out an electronic instrumentation effect. They obtained normal records of pulses 30 sec before and 9 sec after the event. There was no evidence of a power failure. When the power was deliberately momentarily turned off, the clock bin contained crazy numbers.

The experimenters made one silly but fortunate mistake, Lande told us. During their calibration run, four of the amplifiers in one tank were turned down to a low gain. That tank did not respond to the peculiar event of 4 January, although it responded perfectly well to the larger pulses produced by cosmic-ray muons. In the future the experimenters intend to operate a dummy tank to provide a similar check.

They observe about 300 two-fold coincidences per day and about four three-fold coincidences. On this basis, they would expect a 24-fold accidental correlation once in 10^{40} sec. As far as an extensive cosmic-ray shower being the cause, the experimenters figure that the probability of having three showers separated by 1 millisec each is one in 10^{26} sec.

The photomultiplier pulse heights recorded for the event showed that the charged particles had insufficient range to traverse more than one counter. They figure the probability they were seeing cosmic-ray muons is one in 10^{30} sec. —GBL □