The Neutrino Flies as Fast as a Photon

In the 1930s the phenomenon of nuclear beta decay presented a mystery that threatened to overthrow one of the cherished laws of physics, the law of conservation of energy. In beta decay a neutron turns into a proton by emitting an electron. So much had been experimentally recorded thousands of times. But the energy didn't add up; energy was leaking out in some unseen way.

Considering the question, Enrico Fermi postulated the existence of an electrically neutral, massless particle to take away the energy. Using his native language, he named it neutrino, little neutral thing. Since the rules of special relativity require that a particle with no rest mass travel at the speed of light, it was assumed that neutrinos traveled that fast.

Now, 45 years after Fermi put the neutrino into physical theory, an experiment at the laboratory named for him, the Enrico Fermi National Accelerator Laboratory, indicates that the supposition that neutrinos travel at the speed of light is correct to within a fairly narrow margin of error. The report is in the April 12 PHYSICAL REVIEW LETTERS. The experiment was a collaboration of 14 physicists from Brookhaven National Laboratory, Purdue University, California Institute of Technology, Fermilab and Rockefeller University (Joshua Alspector et al.).

It may seem odd that it took 45 years to verify such a supposition, but the history of neutrinos is as elusive as the particles themselves. It was apparent from the very first that neutrinos must have little or no interaction with other matter because they were never detected in the beta-decay experiments. Nevertheless, physicists believed in them for lack of a better explanation of how the missing energy leaks away. It was not until 1956 that neutrinos were first detected.

Today we know that there are at least two kinds of neutrinos. When the second was discovered, the richness of the Italian language in diminutive suffixes led some physicists to suggest differentiating it with the name "neutretto," but that didn't go over. The two are now called electron neutrino and muon neutrino. We also know that in ordinary beta decay it is actually an antineutrino that is emitted. But all of this makes no difference to the current experiment because all four, the two neutrinos and the two antineutrinos that match them, should go at the same speed.

The course over which the neutrino speed was measured consisted of 1,800 feet of earth and steel in Fermilab's neutrino line. At one end of the line protons from the laboratory's big synchrotron struck a target to produce secondary particles, among them neutrinos. The purpose of the earth and steel was to screen out secondary particles that interact more readily with matter than neutrinos. At moderate energies only neutrinos could get through the shield; at high energies both neutrinos and muons could. At the other end was a 150-ton detector made of electronic counters and steel plates.

At high energies muons travel for all practical purposes at the speed of light. Since they have a small rest mass, they can never quite reach the speed of light (so long as special relativity is correct), but at Fermilab energies they get extremely close. The experiment compared the pattern of neutrinos arriving at the detector at different energies with that of muons at high energies. The patterns reproduced the timing of the pulses of protons that had created the muons and neutrinos, thus indicating that all the particles had traveled at the same speed. Since the high energy muons go at (very nearly) the speed of light, that means that all the neutrinos did, too.

The result is a support for the principle that massless particles go at the speed of light or that the neutrino is massless or both. The neutrinos at different energies all travel at the same speed. Under the assumptions of special relativity, that means a massless particle going at the speed of light.

The precision of the experiment is about five parts in 10,000. Further work will attempt to increase the precision. The error limit still allows the possibility that the neutrino has an extremely tiny rest mass, and that is important to some theorists. For example, the nuclear processes in the sun should produce a flow of neutrinos. Fifteen years of experiment have not recorded the expected amount. Some theorists have proposed that that is because the neutrinos decay into something else on the way from the sun to the earth. (In eight minutes flight time they have plenty of opportunity.) But they can do that only if they have some rest mass. Particles without rest mass must remain themselves. So it would be nice if experiment could narrow the possible limit of a neutrino rest mass below the amount required by this and other suggestions of decaying neutrinos. □

Complicating the law of gravity

One of the oldest and most important tenets of classical physics is the inverse-square law of gravitation, the principle that the gravitational force between two bodies is inversely proportional to the square of the distance between them. Isaac Newton deduced it by comparing the acceleration of the moon with the acceleration of a small body near the earth's surface and then strengthened it by pointing out that it made a plausible explanation for the planetary orbits that Johannes Kepler had worked out from observations.

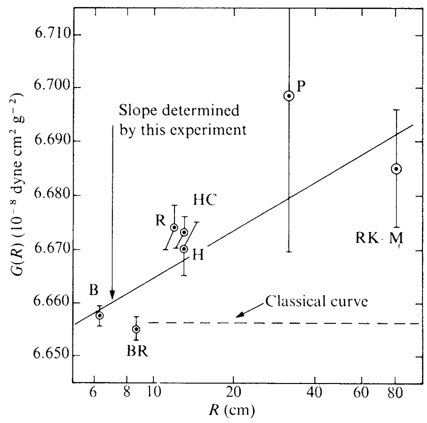
The inverse-square law makes the calculation of gravitational fields fairly simple and straightforward compared to other possible choices. It contributes to the unity of classical physics because the other great fundamental class of force in classical physics, electrostatics, shares the inverse-square character. Coulomb's law says that the electrostatic force between two charged bodies is inversely proportional to the square of the distance between them.

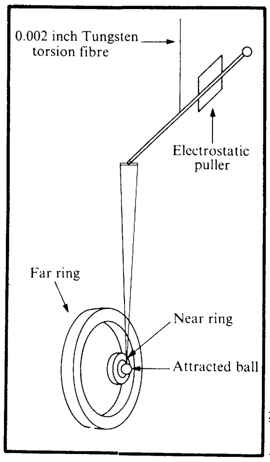
The latest news is that although electrostatics comes through with still flying colors, there appears to be a discrepancy in the inverse-square law for gravity at close, but still classical, distances, say tens of centimeters. The report, representing more than a year's work by Daniel R. Long of Eastern Washington State College in Cheney, Wash., and some of his students, appears in the April 1 NATURE.

Astronomers have verified the inverse-square law for planetary motions (more specifically those of Mercury) to high precision. Long does not contest this, but he points out that the distances involved in the case of Mercury are 11 orders of magnitude greater than the ones at which he worked. In view of the things that have been happening lately in physics, he says, it is not implausible that what is valid astronomically may fail in the laboratory.

There have been a number of laboratory measurements of gravitational force; everyone who has studied physics can probably remember the names of the most famous ones. Long contends that most of these experiments did not really test the accuracy of the inverse-square law itself. The few that did, he points out, all recorded seeming divergences. Long stresses that his work is consistent with past tests, saying that he has had a hard time convincing the scientific community of this.

What Long adds is evidence for a systematic trend in the deviation from the inverse-square law as the distance changes. He presents a graph that shows an apparent variation of Newton's universal gravitational constant, the constant of proportionality in the inverse-square law. The constant varies from slightly less than





Ring and ball variant of Cavendish balance (left) determined slope (above) for variation of universal gravitational constant at short, but classical distances.

Long/Nature

6.660 x 10^{-8} at 6 centimeters separation to slightly under 6.690 x 10^{-8} at 80 centimeters separation. (The unit of the constant is dynes times centimeters-squared per gram per gram.) The slope of the line, Long says, rests on 1,200 pages of calculations with 50 calculations per page.

Now, if the constant is not a constant, but a variable depending on the distance (at least at laboratory distances), then the law is no longer a simple inverse square relation but depends on the distance in a much more complicated way. What Long proposes in fact is to multiply the constant (that is, its usual generally accepted value) by a variable factor amounting to 1 plus 0.002 times the natural logarithm of the distance. That complicates the works.

The experiment itself compares the gravitational attraction between two rings of different sizes and compositions and a ball. The large ring contains 57,580.83 grams of brass and has an outside radius of 27.112 centimeters, an inside radius of 21.589 centimeters and a thickness of 7.633 centimeters. The small ring is made of 1,225.271 grams of pure tantalum; its outside radius is 4.5536 centimeters, its inside radius 2.7513 centimeters and its thickness 1.7765 centimeters. Rings were chosen for a convenient field configuration.

The ball to be attracted by these rings is 50 grams of tantalum. It is suspended from a counterbalanced rod. The rod in turn is suspended at its balance point by a tungsten wire. The gravitational forces on the hanging ball are measured by balancing them against an electrostatic force exerted on the opposite end of the rod. The large ring is placed farther from the ball than the small ring, and the quantity to be measured is the ratio of the difference between the torques exerted on the rod by the attractions of the two rings for the ball to the torque exerted by the attraction of the near one. The whole thing must be done in a vacuum and must be strictly shielded from vibrations and other disturbances.

In the same issue, NATURE carries a comment by one of the journal's anonymous scientist-correspondents. The commentator suggests that Long's result may be an indication of a small repulsive component to the law of gravity at these distances. Long says this may be the case, but the most important thing right now in his opinion is to get together the resources so that someone else can duplicate the experiment and see if the results are reproducible. Then one can see about alterations in the theory. □

Families and intellect: Scores to increase

If simplicity is beauty, then Robert B. Zajonc is to be congratulated for a beautiful piece of work. Last year he proposed an elegant, straightforward theory that helps explain individual differences in intelligence (SN: 2/8/75, p. 82). For this work he and Gregory B. Markus received the 1975 Socio-Psychological Prize of the American Association for the Advancement of Science. Now, with a growing body of data to support his work, Zajonc, a University of Michigan psychologist, uses his theory to explain the ongoing, 12-year decline in Scholastic Aptitude Test (SAT) scores. But a good theory does more than explain—it predicts. In the April 16 SCIENCE Zajonc predicts what might be a dramatic increase in SAT scores by 1980.

The theory, called the confluence model, relates intellectual growth to family configuration—family size and the age spacing of children. The basic idea of the model is that within the family, the intellectual growth of every member is dependent on that of all other members, and that the rate of this growth depends on the family configuration. This can be illustrated mathematically. Suppose the absolute intellectual levels of parents to be 30 arbitrary units each, and the intellectual level of their newborn child to be zero. The intellectual environment of the family at the birth of the first child, then, has an average value of 20 (30+30+0/3=20). If a second child is born when the intellectual level of the firstborn reaches four, the second born enters into an intellectual environment that has an average value of 16 (30+30+4+0/4=16). If a third child is born when the intellectual level of the first has reached seven and that of the second child is three, the family intellectual environment will be reduced to 14.

These figures suggest that intellectual environment should decline with birth order, but child spacing must also be considered. If the second child is not born until the first reached an intellectual age of 24, the newborn enters an environment of 21, which is even more favorable than the 20 entered by the first-born. Hence, says Zajonc, with large enough age gaps between children, the negative effects of birth order can be nulified or even reversed.

Zajonc admits that this sort of formulation is "obviously a simplification of what is an enormously complex process." The amount of time parents spend with their children as well as what they do during that time is important. A game of tag may not be as conducive to the development of intelligence as a game of chess. But even though the confluence model ignores much of the richness of the social processes that go into intellectual growth, it does help explain and predict differences in intellectual test performance. Zajonc cites several large-scale studies.

The average scores of nearly 800,000 candidates on the National Merit Scholarship Qualifications Test were examined as a function of family size and birth order. Scores declined with increasing family size and within each family they declined with birth order. Similar results come from other studies: 70,000 school children in Scotland, 100,000 in France and 400,000 in the Netherlands. Even though the results are from different tests, different age groups and different countries, they all indicate that intellectual level generally declines with family size. The rate o decline was not the same for all studies, but the confluence model can account for the differences by considering the birthrates and age spacing between children. As birthrate goes up, spacing declines and family intellectual environment declines.

Other evidence comes from twin studies. When twins are the first offspring, the family intellectual environment at birth is 15 (as opposed to 20 for a single child). This should and does show up on test results. The effect is heightened for triplets. For twins separated at birth (by the death of one or for some other reason), test scores are nearly the same as for nontwins.

Parental absence is another factor. A child born into a one-parent family enters an intellectual environment of 15. Test scores and studies of children of men in the service support this. Studies also show that remarriage by the remaining parent, if it occurs early enough in the child's life, results in improved intellectual performance. Only children present a special case because they don't score as high as would