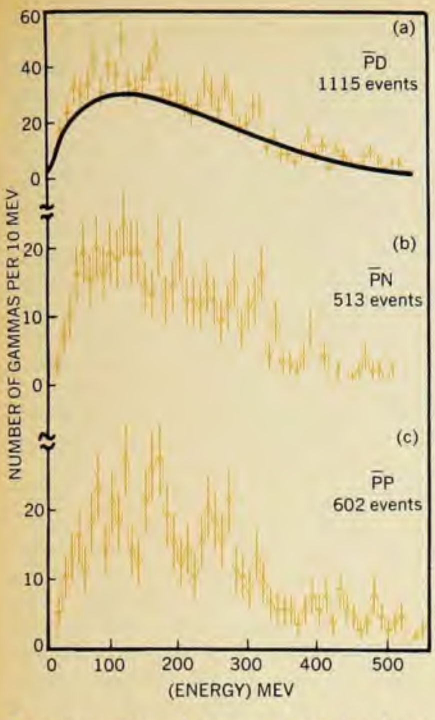

Energy spectra of gamma rays in all $\bar{p}d$ events (a) compared with the background (curve) expected if all gammas result from π^0 decays and if the π^0's have the same energy spectrum as $\pi^{\pm}$. Significant fluctuations do not correlate as well with annihilations on the neutron (b) as with those on the proton (c). From T. E. Kalogeropoulos et al, reference 2.

Anna Vayaki of Demokritos and Lee Gray, Jaya Roy, and George Tzanakos of Syracuse, under the direction of Theodore E. Kalogeropoulos of both Demokritos and Syracuse. They used the 30-inch deuterium bubble chamber at Brookhaven National Laboratory.

The Syracuse–Athens team measured all charged tracks associated with the pionic annihilation

$$\bar{p} + d \longrightarrow \text{pions} + \text{nucleon}$$

where the final state might consist of any number of pions from 1 to 7. In such annihilations, charge independence predicts that the total number of charged pions should equal twice the number of neutral (unseen) pions. It follows that the charged pions should have 2/3 of the available energy. In a study of about 3000 events the Syracuse–Athens team found that the total energy of the charged pions, after correction for events with invisible kaons, was 1169 ± 10 MeV, less than 2/3 the total available energy (1862 ± 2 MeV) by 72 ± 10 MeV. The experimenters calculated the contribution to this energy from gammas resulting from electromagnetic decays of the η and ω particles, which violate isotopic spin invariance, but found that this contribution totalled only 14 ± 3 MeV and cannot account for the observed effect.

In order to investigate the source of this excess energy further, Kalogeropoulos, together with Vayaki, Grammatikakis, Takis Tsilimigras and Simopoulou of Demokritos, studied the gamma-ray energy spectrum from the same bubble-chamber film. Their analysis revealed that an excess of about 0.73 gamma rays per event had been emitted above those normally associated with the neutral π^0.

There is evidence from the gamma-ray spectra, especially that from the $\bar{p}$ p annihilation (see figure) that these gammas are emitted when the nucleon–antinucleon system goes from a higher to a lower state prior to annihilation. However, an exact determination requires better measurement of the gamma-ray energy than can be made in deuterium bubble chambers. A Brookhaven–Syracuse collaboration is planning to repeat the experiments with a large sodium-iodide crystal detector, which will yield an order of magnitude more gammas. A counter experiment now in progress at Brookhaven to look for the charge independence violations in $\bar{p}p$ annihilations has so far yielded negative results; however these results may only mean that the resonances cannot be produced as effectively in $\bar{p}p$ as in $\bar{p}d$ systems because the total energy is above that required to produce the resonance and the $\bar{p}p$ system has no spectator nucleon to carry off some of the excess energy.

The current experiment is not the first to give evidence for the existence of nucleon–antinucleon bound states: Kalogeropoulos has called attention to the evidence in several review papers[4] and has participated in some of the relevant experiments. Among some of the experimental indications that he feels support the existence of bound states in the $\bar{N}N$ system at low energy are:

- the presence of unusually high angular momentum waves at rest and at low energies; this contradicts earlier beliefs of S-wave capture dominance for such annihilation.
- the lack of final-state interactions between the spectator nucleon and the annihilation products; this implied to Kalogeropoulos that a resonance was produced and lived long enough to be separated from the spectator nucleon before it decayed.
- the dependence of the reaction $\bar{p}d \to \pi^-\pi^0 p$ at rest on the momentum of the spectator proton; this suggested that the annihilation is very sensitive to energy and may go through a resonance.
- a peak in the momentum spectrum of the spectator proton in $\bar{p}d$ events with an even number of pions but no peak for an odd number of pions.
- two bumps observed in $\bar{p}p$ and $\bar{p}d$ annihilations measured in recent high statistics experiments.

In addition to the experimental indications, Iosif S. Shapiro and other theorists at the Institute for Theoretical and Experimental Physics have done calculations that predict resonant states in $\bar{N}N$.[5] —BGL

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A pulsar that doesn't slow down fast enough

A pulsar that is slowing down much less rapidly than any other known pulsar may have some interesting implications for current theories of pulsar formation and perhaps even for theories of expansion of the universe. David Richards, John Rankin and Gustave Zeissig studied the pulsar, JP 1953, as one of 13 in a continuing program of precise pulse timing[1] at the Arecibo Observatory in Puerto Rico. A surprising result of the study, they comment in *Nature*, is that for JP 1953, dP/dt, the change in its 0.4 sec period with time, is only about 0.003 ± 0.007 × 10^{-15} seconds per second. The previously known smallest value for any pulsar had been 0.15 × 10^{-15}, and a typical value exceeds 10^{-15}.

When the "age" of this pulsar is calculated, a puzzling situation arises: JP 1953 is apparently older than the universe. But, as Frank Drake (Cornell University, Ithaca) explains, this so-called "age" is not necessarily the past lifetime of the pulsar, and what we may be observing is a pulsar that was born spinning more slowly than other pulsars so far observed. Drake suggests that this pulsar may be a neutron star with a very low magnetic field, which he considers to be strange because no intermediate cases have been observed, or it may even be a white dwarf, which has a much larger moment of inertia than a neutron star.

A sufficiently low pulsar spindown rate could be a test of certain theories of expansion of the universe: This possibility has been pointed out by several astrophysicists, among them Charles Counselman and Irwin Shapiro (both of the Massachusetts Institute of Technology)[2] and Malvin Ruderman (Columbia University, New York), who connected the idea with this pulsar. As Ruderman described the situation to us, in some theories that involve time-dependent fundamental constants, a spinning neutron star would be expected to slow down even if the usual slowing down from electrodynamic torque were negligible. In those theories, for example, in which G, the universal gravitational constant, decreases, neutron star radii grow with time. The increasing moment of inertia of pulsars would then cause them to slow down. If no other spin-change mechanism is significant, the upper limit for the rate of decrease of G derived from JP 1953 is seven parts in 10^{10} per year; this value is nearly as good as that obtained from radar pulse measurements by Shapiro (less than one part in 10^{10} per year, Shapiro tells us) and may be improved by improved pulsar spindown observations. If the value of $G/\dot{G}$ is eventually found to be greater than 12×10^9 years (the age of the universe calculated from the latest value of the Hubble constant), those theories that account for expansion of the universe in terms of the weakening of the gravitational force may have to be ruled out. —MSR

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Laser-induced fusion

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show that shorter-wavelength lasers are required for fusion reactor applications because of other factors involved.

In a typical theoretical scheme of a fuel pellet, the hollow sphere of frozen DT is surrounded by a layer of low-Z material (see figure). The high-Z material is called a "pusher" or "tamper" and serves to confine the fuel and increase the burn efficiency, to shield the fuel from hot electrons and x rays that could preheat it (thus reducing the final compression) and to avoid the need for a tailored laser pulse. The layer of low-Z material is the "ablator;" it is blown away by laser heating to generate implosion pressures. If laser light is applied to the high-Z tamper, the heat is radiated away as thermal x rays. According to Morse, most researchers use numerical simulation models, including coupled thermonuclear burn, hydrodynamics and thermal conduction, to play games with this basic design, changing the thickness here and the composition there to see the effects of these changes on the net yield and behavior of the pellet. The Los Alamos workers used such a numerical model to study the effects of the anomalously low thermal conductivity of electrons that had been measured in their experiments.

Researchers at Livermore are dubious about the effectiveness of the pusher-type fuel pellets; once the pusher layer is thick enough to withstand the fluid instabilities, the gain of the pellet drops below the level required for fusion reactors. They feel the pusher-type fuel pellets may be valuable only in hybrid reactors, in which the thermonuclear neutrons initiate fission in a surrounding blanket. Such reactors may use long-wavelength lasers. For fusion reactors, the Livermore team proposes a hollow fuel pellet that does not have a pusher. It consists of frozen DT surrounded by an ablator layer of neon and then, after a space, by frozen hydrogen. The intermediate-Z layer of neon, in combination with short-wavelength lasers, enables the laser energy to be absorbed by classical inverse bremsstrahlung without generating superthermal electrons. The confinement function of the tamper is obviated by pulse shaping so that the pellet is driven to high enough compressions to burn efficiently without a tamper. The outer shell of hydrogen is exploded by a low-energy laser prepulse to form a low-density plasma cloud that helps provide a symmetric distribution of the energy to the pellet during the main pulse. The growth of fluid instabilities is controlled by making the DT shell relatively thick—about 20% of the radius—and by using a laser pulse shape consisting of an optimal sequence of five implosive steps.

A second basic variety of pellet is one composed of a series of shells of pusher material, separated by spaces or low-density material. Each successive inner shell has smaller mass. Thus, when the outer one implodes and pushes the inner ones in turn, the innermost and lightest implodes with by far the highest velocity, just as if one were hitting a row of successively smaller balls. This velocity multiplication is achieved at the expense of efficiency.

On the experimental side, the conference included reports of continued experiments and some new experimental designs. Many observers were impressed with the thoroughness of the series of experiments at KMS Fusion, Inc. This company has continued to produce yields of up to 10^7 neutrons (see PHYSICS TODAY, August 1974, page 17) and is investigating correlations of neutron yield with volume compression of the fuel pellets and other factors. All data still indicate, they feel, that the neutrons are thermonuclear, although yields of 10^9 or 10^{10} are required for a statistically significant test.

KMS Fusion, a private corporation, will be working more closely with the government-sponsored laboratories at Los Alamos and Livermore, according to a recent contract between KMS Fusion and the Energy Research and Development Agency. Among other things, the arrangement will give researchers at Los Alamos and Livermore a chance to check their computer codes used for laser fusion calculations against data from the KMS experimental system. In this way the program is similar to buying time on a reactor. It will complement the existing experimental programs at the ERDA labs.

Researchers from Los Alamos have developed a one-beam target[1] that had previously been classified because it is an asymmetric target. Most schemes for fusion power plants have envisioned a number of lasers spaced symmetrically around a spherical target, but a single laser would obviously simplify such designs. In the Los Alamos target, a spherical fuel pellet capped with plastic rests on a plastic disk. A laser prepulse expands the plastic of both cap and disk into a pancake-shaped cloud around the target. When the main laser pulse comes, the plastic, which has a high thermal conductivity because of its low atomic number, carries the laser energy uniformly to all sides of the spherical target. The Los Alamos group has obtained compressions of about 100 with such single-beam targets.

Recently, a group from Livermore has imploded a much more sophisticated target with a single laser beam to produce yields of around 10^4 DT neutrons and volume compressions of 100. Nuckolls presented these results to a conference sponsored by the Center for Theoretical Studies of the University of Miami on 20 January.

The fuel pellets used at this stage by experimenters such as those at Los Alamos, Livermore, the Naval Research Laboratory and the University of Rochester are hollow glass spheres (40 to 60 microns in diameter and about one micron thick) that are filled with DT gas at pressures of tens of atmospheres. (A notable exception is the Lebedev Institute in the USSR, which uses solid CD_2 pellets.) These so-called "microballoons" are relatively easy to produce and allow experimenters to view volume compressions with x-ray pinhole cameras (or, at Livermore, with an x-ray microscope). Such simplified targets are suitable for the early stages of experiments, which have achieved DT densities of 1 to 10 gm/cm^3, far from the DT densities of 1000 gm/cm^3 that are required to initiate a thermonuclear burn with sufficiently high gain to run a fusion power plant. However, comments Nuckolls, even these experiments have achieved Lawson numbers and temperatures comparable to those of the most advanced magnetic confinement experiments and also confirm the laser fusion computer models. —BGL

Reference

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