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Puzzle of two-pion production: Is the pion a point charge?

The pion is acting more like a point charge than most particle physicists had expected. The behavior shows up in electron–positron collision experiments performed during the first six or seven months of operation of the Adone storage ring in Frascati, Italy.

It appears that the pion is acting like the atom that bounced too many alpha particles back at Ernest Rutherford to be explained by the Thomson model, thus indicating that the atom had a hard core, the nucleus. Rutherford's cross sections were far too big for a diffuse structure, and so are those found at Frascati. The cross section for multihadron (more than two) production is surprisingly high, suggesting that the instantaneous charge distribution of the pion corresponds to pointlike constituents, giving strong support for a parton picture of the pion structure.

The cross section for producing a π^+–π^- pair is very high, too, high enough to indicate that the pion may be behaving as a pointlike structureless particle like the electron or muon, but the data are still being interpreted.

Preliminary results were reported in September at the "Rochester" high-energy conference in Kiev and then at an informal conference in Frascati by four groups, designated by Frascati as the "μ–π group" (whose spokesmen were Marcello Conversi and Mario Grilli), "$\gamma\gamma$ group" (G. Salvini), "boson group" (V. Silvestrini), and the "Bologna–CERN–Frascati group" (Antonino Zichichi). The energy of each beam ranged from 0.75 to 1.1 GeV, or 1.5 to 2.2 GeV in the center-of-mass system.

Despite the surprises for some cross sections, quantum-electrodynamics predictions for cross sections were borne out in preliminary results from electron–positron elastic scattering and muon pair production.

Two-pion production. Both the μ–π and Bologna–CERN–Frascati groups reported on production of collinear pion pairs. Because the experimenters only use those events in which the pions come off 180 deg apart, they exclude events in which additional particles are produced. Zichichi told PHYSICS TODAY that accurate calibrations must be made

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In Adone storage ring at Frascati electrons and positrons collide, each with 1.1 GeV.

Low-temperature physics runs both hot and cold

The domain of the low-temperature physicist now extends down as low as microdegrees Kelvin and, on the high side, up to the rather startling temperature of 10^8 K. Valid claims to these two extreme regions of temperature were staked out by two papers presented at the recent 12th International Conference on Low Temperature Physics at Kyoto. In the first, P. M. Berglund, G. J. Ehnholm, R. G. Gylling, O. V. Lounasmaa and R. P. Søvik (Helsinki University of Technology) reported the successful operation of a large cryostat that has reached temperatures as low as 500 microdeg K. The system, which combines dilution refrigeration with the relatively new technique of nuclear adiabatic demagnetization, promises to open the way for physicists to study the properties of matter at temperatures an order of magnitude lower than has previously been possible.

A report on low-temperature phenomena at 10^8 K was made by David Pines (University of Illinois) who gave a general survey of the states of matter within neutron stars. Although the ambient temperature in such stars is believed to be around 10^8 K, because of the tremendously high pressure within these superdense stars the relative temperature is such that matter exists in states that would correspond on earth to temperatures in the millidegree region. Thus the free neutrons that make up most of the core of a neutron star are believed to be in a superfluid state.

Nuclear cooling. Although the potential of nuclear demagnetization for reaching temperatures much lower than is possible with electronic cooling has been recognized since the 1930's, the technique has become practical only with the advent recently of dilution refrigeration and high-field superconducting magnets. Representing the farthest advance in nuclear cooling to date, the cryostat built and operated by Berglund's group features an enormous dilution refrigerator that serves as the precooling stage for the nuclear stage. This refrigerator, considerably larger than those now operating in the US, is capable of absorbing the heat of magnetization from the nuclear stage at the rate of 10 erg/sec at 15 millideg K. The rate of He^3 circulation in the refrigerator is 200 micromole/sec.

In the nuclear stage the latest word in superconducting magnets produces an average field of 45 kG over the 12-mole copper specimen. The magnet is 20 cm long with 7-cm inner diameter and is wound with filamentary Nb–Ti wire, which is guaranteed to operate free of flux jumps. The copper specimen is in the form of 0.05-mm wire, which makes thermal contact with a precooling stage through eight sintered copper blocks having a total surface area of $8 m^2$. In reaching the record equilibrium temperature of 0.52 millideg K the Finnish group was able to keep the nuclear stage below 1 millideg K for over six hours. Although other experimentalists have cooled nuclear-spin systems (in isolation from the lattice) to even lower temperatures, this is the lowest lattice and conduction-electron temperature yet to be achieved.

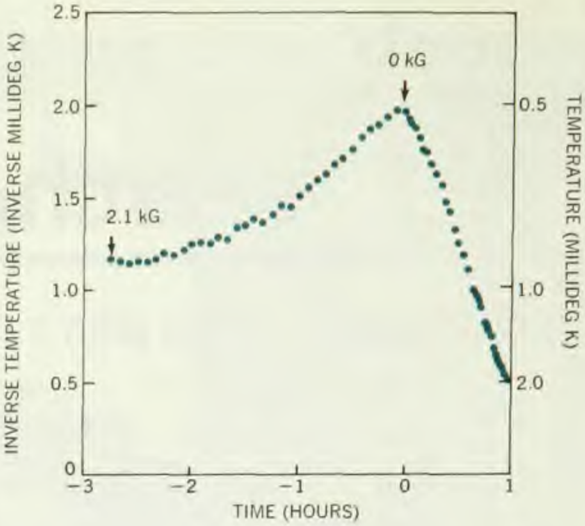
The obvious first use of this new kind of facility, group-member Robert Gylling told PHYSICS TODAY, is to redo at 200 microdeg K the experiments on the properties of He^3 carried out by several US groups in the millideg-K range.

But first, the group would like to improve the system to the point where it operates at 200–300 microdeg K for 15 hours. To do this a more powerful magnet (80 kG) will be needed as well as a better understanding of an anomalously large heat capacity that unexpectedly appeared in the nuclear stage during the test runs.

According to the values achieved for the initial and final magnetic fields the Finnish group had expected to reach a final temperature of 190 microdeg K, but additional unexplained heat capacity in the nuclear stage limited the temperature to 520 microdeg K. Suspected origins of the excess capacity are nuclear quadrupole levels in either the copper or an indium coating or impurities within the copper.

Neutron stars. The most significant information yet to be gleaned from pulsar signals about the state of matter in the interior of neutron stars has come from the two "speedups" that have been observed in the Vela and Crab pulsars. The best explanation of these abrupt increases in rotational frequency is that they are due to "starquakes"—sudden contractions of the solid crust of the neutron star.

In both cases, a portion of this frequency jump has been observed to decay exponentially (in a matter of days for the Crab pulsar and years for the Vela pulsar), in agreement with theoretical predictions made by Pines, Gordon Baym, Christopher Pethick, and Malvin Ruderman early last fall. If, as these theorists propose, the relaxation process is caused by the frictional braking effect of the liquid core on the solid crust (as the angular velocities of the two regions adjust to the same value), then the fact that this process occurs over a time scale of months or years is very good evidence, according to Pines, that both the neutrons and protons in the core are in superfluid states. Otherwise coupling of the core (predominantly neutrons) with the crust would occur through electromagnetic or nuclear interactions within extremely short periods of time (10^{-11}–10^{-17} sec).



Temperature of 520 microdeg K is reached in nuclear demagnetization to zero field. Between the times −3 hours to 0 hour the field is swept linearly from 2.1 kG to 0. Subsequent warming up is, on a $1/T$ scale, linear with time and much slower than expected.

If the protons and neutrons are superfluid then the only process through which the increased angular velocity of the crust can be communicated to the neutrons of the stellar interior is through the interaction of electrons with the magnetic moments of the normal neutrons in the cores of the vortex lines parallel to the star's rotational axis (these vortices provide the moment of inertia for the rotating mass of superfluid neutrons). This extremely weak coupling between crust and core is able to yield the macroscopic times observed.

Future observations of how often speedups occur, Pines expects, will test Ruderman's starquake explanation for these events. The solid crust of the star is formed when the star is spinning comparatively fast; as the star slows, its rotation and centrifugal forces on the crust decrease, and gravity will pull it toward a less oblate shape and so stress it. When stresses in the crust reach a critical value, the crust cracks (a starquake), some stress is relieved, and the oblateness of the crust is reduced. The process then commences anew. (These readjustments are astonishingly small in physical magnitude—the quake observed in the Vela pulsar was equivalent to the average shrinkage of the crust of 1 cm, while the smaller Crab speedup corresponded to a crustal shrinkage of 1/20mm.) Pines and Baym have developed a simple model of starquakes that relates the buildup and release of strain energy to the stellar structure and allows one to predict when the next quake will occur from the size of the last quake.

According to their estimate, if the starquake explanation is correct, the Vela pulsar must be a quite light neutron star ($M \lesssim 0.1 M_{\odot}$) which, in view of the comparatively large magnitude of its last quake, may not be expected to quake again for some 300–500 years. The same model predicts that the slightly heavier and faster spinning Crab pulsar should quake again within the next year or so. Such rapid buildup of strain energy at first seemed unreasonable unless the crust of the Crab pulsar was much thicker than had been estimated. The crust boundary is determined by the density at which the nuclei within it, which are increasingly neutron rich as one goes to higher and higher matter densities (further into the star), break into their constituent protons and neutrons. Pines reported that Baym, Pethick and Hans Bethe have very recently made some improved nuclear-physics calculations that indicate that the crust may extend to twice the density previously estimated, so that stars the size of the Vela and Crab pulsars ($M \lesssim 0.15\ M_{\odot}$) possess very substantial crusts; indeed Vela may be a nearly solid star. For such stars, quakes of the magnitude observed for the Crab could occur once a year.

For Pines, one of the most fascinating aspects of working on the theory of neutron stars is that it touches on almost every branch of physics, from general relativity to fundamental-particle theory to plasma theory to solid state. As he told the conference, the neutron star is the interfield problem par excellence. For the condensed-matter theorist, he mentioned a number of problems of interest both to the beginning graduate student and the seasoned theorist, problems which for the liquid core ranged from consideration of differential rotation and turbulence in the inhomogeneous neutron superfluid to studies of relaxation processes in p-state superfluids and of Alfvén and other slow macroscopic modes in the coupled neutron–proton system. In the crust, one can look at band-theoretical aspects of neutron motion, the interaction of the crustal superfluid neutrons with nuclei found there (which could give rise to vortex pinning) and microscopic calculations of various crust parameters. —HLD