search & discovery

Kondo methods may work for quarks and gluons too

Methods developed for solving problems in statistical mechanics and in solving the Kondo problem are showing promise that they might explain how at the same time quark effects can be observed at high energies and appear to be infinitely bound when observed at low energies. Once again some beautiful work in one field may have an impact in another.

The story begins with the work of Jun Kondo (University of Tokyo), who in 1964 considered the problem of a magnetic impurity in a metal. He assumed the impurity had a spin, without worrying where the spin came from, introduced an exchange interaction between the spin and the conduction electrons, and then calculated the transitions and the cross section just one step beyond the Born approximation. Kondo found that if he went to the next order in perturbation theory, he got a logarithmic singularity at low temperature. This explained the long-standing puzzle of a resistance minimum in metals, but raised a problem of finding a theory that would not diverge at low temperature. The original Kondo formula for the Kondo temperature T_K, where the convergence of the Born series breaks down was:

$$T_K = E_F \exp(-1/\rho J)$$

where E_F is the Fermi energy, ρ is the density of states at the Fermi level and J is the exchange interaction.

Kenneth Wilson (Cornell) has pointed out[1] that the Kondo problem is more fascinating to theorists than is justified by its experimental significance. The reason, Wilson says, is that the theoretical models involving a single impurity coupled to a free electron band were simpler versions of the problem of ferromagnetism in metals.

The breakdown of the Born series at low temperatures indicated a strong effective coupling of the impurity to the conduction-band electrons, and this led theorists, including Y. Nagaoka (Kyoto University) in the mid-1960's to speculate that the impurity would form a singlet bound state with the electrons in the conduction band; thus there would be no local moment due to the impurity at zero temperature.

The big problem was to determine whether the shielding of the impurity at

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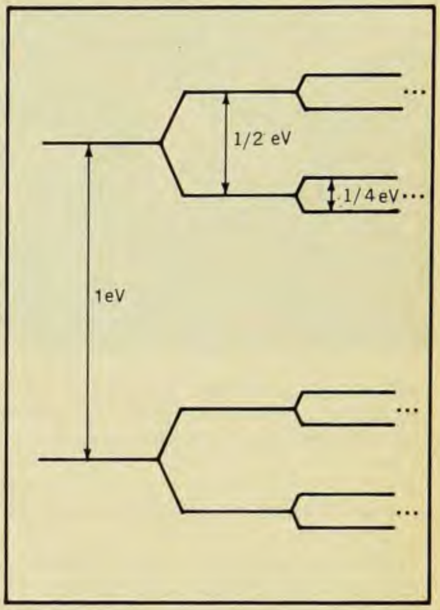

Wilson's recursion scheme develops multiple energy-scale structure for the many-electron states of the conduction band. He treats as unperturbed the energies of order 1 eV, then treats energies of order ½ eV as a perturbation on 1 eV, and so on.

Stabilization problem threatens future of Scyllac

Facing a deadline of September 1977, fusion physicists at Los Alamos are working hard to demonstrate that they can stabilize the plasma in Scyllac, one of the three major approaches in ERDA's magnetic confinement effort. Recently Robert Hirsch, ERDA's new assistant administrator for solar, geothermal and advanced energy systems said (PHYSICS TODAY, June, page 69) that a real question exists as to the future of Scyllac if present trends are not reversed. Meanwhile Los Alamos is studying alternative schemes for the laboratory to pursue if Scyllac work is terminated.

Scyllac is a high-density device in which a theta pinch is formed in an 8-meter diameter torus. Fred Ribe, director of Los Alamos magnetic-confinement efforts, told us that linear theta pinches have shown very good confinement and achieved high temperatures—5 kV, but that their confinement is limited by end losses. When theta pinches are produced in a toroidal geometry, the plasma tends to pop out in both the plane of the circle and perpendicular to the plane. To overcome this instability, the Los Alamos experimenters have been using feedback stabilization.

Last March, in view of Scyllac's instability problems, Hirsch (then head of ERDA's Division of Controlled Thermonuclear Research) and his successor, Edwin Kintner (who heads the newly named Division of Magnetic Fusion Energy), imposed an 18-month deadline on the Scyllac effort. The laboratory is to do a well-defined set of experiments aimed at improving the equilibrium so that it can be stabilized. At the end of that time either the Scyllac experiments will be stopped or Los Alamos will propose to ERDA that Scyllac be treated as a full major alternative in the magnetic confinement effort.

Scyllac experiments employ a compression field of 20 kG and an $l = 1$ magnetic field of about 2 kG (l is a parameter describing the geometry of the field, and an $l = 1$ field is a simple, corkscrew helix with a circular cross section). In addition an $l = 0$ field is applied. (This field, instead of being helical, has a circular cross section whose diameter varies periodically.) The $l = 0$ and $l = 1$ fields produce a plasma equilibrium that is unstable. To stabilize the plasma an $l = 2$ field of 50 G is applied (which produces an elliptical plasma cross section) in response to optical sensing of plasma position. This feedback-stabilization technique is supposed to push the plasma back in the equilibrium position. So far the experimenters have been able to stabilize the plasma in the direction perpendicular to the plane of the torus and to some extent in the plane of the torus.

Another toroidal theta-pinch experiment is ISAR T1, at the Max Planck Institute for Plasma Physics in Garching, Germany. Unlike Scyllac, ISAR T1 uses an $l = 2$ field with their $l = 1$ field to produce equilibrium. In addition ISAR T1 uses a helical discharge tube so that the

Scyllac compression coil. Image-converter cameras (foreground) take streak photos of plasma through slots in front and top of coil. Five optical feedback detector stations are shown. Bundles of white cables power compression coil from capacitor banks in rear (not shown).

plasma is forced immediately in a helical shape.

Last month, as part of the plan developed with ERDA, Los Alamos experimenters under Warren Quinn were scheduled to begin a series of experiments as a result of collaboration with Garching, in which Scyllac's toroidal discharge chamber will be replaced by a helical one, in the expectation that transient disturbances of equilibrium will be eliminated in the formation of the plasma. Also, in a second experiment, Scyllac will start using an $l = 2$ field to produce equilibrium, instead of the $l = 0$ component.

If the Scyllac feedback stabilization succeeds, Ribe hopes to build a Staged Scyllac. This device would cost $10 million of operating funds, would have a 25-meter diameter and would be capable of feedback stabilization or wall stabilization. In the latter approach, the plasma is supposed to stabilize itself by having the $l = 1$ field interact with the wall. This will only work, Ribe told us, with plasmas much fatter (more dough in the doughnut) than presently available with Scyllac or ISAR T1.

Alternatives. In case Scyllac does not succeed, Hirsch and Kintner have asked Los Alamos to strengthen other parts of its program and introduce new concepts other than toroidal theta pinches. An existing Los Alamos program, under Don Baker, on toroidal z pinches will be expanded. Next year it is planned to use $2 million out of operating funds for a new and larger device (expanded from 15 to 40 cm in minor diameter), ZT-P, which will use a reverse-field toroidal z pinch (in which one applies a toroidal magnetic field but causes it to reverse its sign as it goes from the center to the outside). Another program that will be strengthened is the attempt to use end stoppers on the linear theta pinch.

In response to Hirsch's request for an alternative concept to toroidal theta pinches, Los Alamos plans to start experiments with liners, starting next year with $600 000. In this approach one uses a cylindrical copper shell (say 1 mm thick and with a 10-cm diameter), putting a cold plasma and a magnetic field into the shell. Then the shell is imploded in 3 microseconds, boosting the magnetic field to a few megagauss and producing a very dense, hot plasma. Because plasma burn is rapid, Ribe says, one can avoid problems with stability and confinement. The approach is not new. Liner work is going on at Los Alamos, at the Naval Research Laboratory and earlier, was done at Frascati, Italy. In the Soviet Union the liner concept is now the number-two concept in their magnetic-confinement program, according to Ribe. Soviet liner work is going on at a branch of the Kurchatov Institute—at Krasnaya Pochra (near Moscow) and the Efremov Institute in Leningrad. —GBL

Intense neutron sources for fusion studies

Steady-state sources of intense neutrons are under way at two US laboratories. They would be used to study radiation damage produced in controlled-fusion reactors. If funds are appropriated for the Los Alamos Scientific Laboratory's $25.4-million Intense Neutron Source, it would be expected to produce fluxes of 2×10^{14} 14-MeV neutrons/cm^2-sec after it became operational near the end of fiscal 1980. Meanwhile, Rotating-Target Neutron Source II, under construction at the Lawrence Livermore Laboratory, may begin initial operation leading to a maximum 14-MeV-neutron flux of 1.5×10^{13} neutrons/cm^2-sec as early as March of 1978; total cost of the RTNS-II is estimated at $5 million.

Design parameters for sources. The INS would employ a 300-keV tritium beam impinging upon a supersonic jet of deuterium gas to put out 10^{15} high-energy neutrons every second. The high flux thus produced would approximate expected conditions inside fusion reactors of the magnetic-confinement type. An additional use for the source, according to INS group leader C. Robert Emigh, will be to evolve techniques of tritium handling in pumping, purification, containment and cleanup operations. Two accelerators and two buildings are anticipated by INS planners.

In Livermore's new source, which constitutes an improved version of the RTNS-I developed in 1967 for radiation-effects studies, a 400-keV beam of deuterons is to strike the inner surface of a rotating titanium-tritide target in the form of a section of a sphere. This target, 46 centimeters in diameter and spinning at the rate of 5000 rpm, would contain materials to be tested. The samples would be bombarded by so-called "fusion" neutrons, 4×10^{13} neutrons/sec being produced at a beam current of 150 mA. Advanced development efforts, a long-term project for RTNS-II workers, might eventually enable them to produce 10^{14} neutrons/sec at 400 mA, with a maximum flux of 4×10^{13} neutrons/cm^2-sec for samples 1 cm in diameter.

Target lifetime short. One disadvantage of Livermore's technique is that the targets themselves wear out relatively soon in use. As the deuteron beam heats the tritium, the neutron yield decreases; the rotation method extends the target's lifetime by preventing overheating due to beam-incidence concentration at any one point, and it is also possible to rock the target up and down so that the beam may strike over a range of target radii. Normally, however, the beam remains incident at a fixed radius until neutron output declines substantially, at which time the target is adjusted and a new band is used. The neutron output of the RTNS-I during its early years dropped by half in 50 hours; performance has greatly improved since, and the loss in yield is now only about 15% in 100 hours. The same 100-hour period is expected to result in similar changes in output for the RTNS-II.

Both the INS and the RTNS-II are designed to operate in the steady-state, or DC, mode in order to facilitate their use for long-term applications. Most accel-