search & discovery

Material in rare meteorites may pre-date solar system

The discovery of anomalously high proportions of oxygen 16 in certain rare meteorites has led to speculation that these meteorites may contain remnants of material with a separate nucleosynthetic history from the bulk of the solar system. This material appears to be present in meteoritic inclusions that have been analyzed[1] by Robert N. Clayton, Lawrence Grossman and Toshiko K. Mayeda, all geochemists at the University of Chicago, and may represent interstellar dust grains that somehow survived the formation of the solar system without being vaporized or homogenized.

If the inclusions are in fact the result of a single nucleosynthetic event, unlike all the other homogenized matter —terrestrial and lunar—so far studied, theorists would have a good chance to test their ideas on the origin of the elements and on solar-system formation.

Cut surface of Allende meteorite with numerous light and dark inclusions that show anomalously high proportion of O^{16}. These inclusions are composed of high-temperature silicates and oxides and may have condensed directly from the solar nebula prior to incorporation into the meteorite, according to Robert Clayton, Lawrence Grossman and Toshiko Mayeda (Chicago). The O^{16} component made up 1-2% of the mass of the inclusions.

The Chicago group was studying the anhydrous high-temperature phases that occur in the meteorites known as "C2" and "C3" carbonaceous chondrites. Their interest lay in studying the condensation chemistry—the temperatures at which various minerals condensed out of the solar nebula during the formation of the meteorite. About half their samples were from the Allende meteorite, which fell in Mexico in 1969, and about half from other C2 and C3 meteorites. In determining the O^{18}/O^{16} ratio, they came upon a surprise: Chemical fractionation (mass-related variations of a few percent in reaction rates for different isotopes) should lead to small variations in the O^{18}/O^{16} ratio. But the variations in O^{18} were too large, and too little of it was present, compared with other meteorites.

Over 25 years ago Harold Urey had noted that chemical isotope effects are almost linearly proportional to relative mass differences. The Chicago group reasoned, then, that for elements with three or more isotopes, isotope effects could be used to distinguish between

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Asymptotic freedom invoked to explain SLAC scaling

Recently many particle theorists have come out in favor of asymptotic freedom instead of academic freedom, at least in the high-energy regime. Some workers had been looking for a way to use field-theoretic ideas to explain the scaling behavior found in deep inelastic electron-proton scattering at SLAC. These experiments, which involve virtual photons, allow one to measure behavior at very small distances, a feature not available in normal high-energy proton-proton scattering.

Now David J. Gross and Frank Wilczek[1] (his graduate student) at Princeton and Hugh David Politzer[2] (a graduate student of Sidney Coleman's) at Harvard, have shown that there is a class of field theories that predict phenomena close to SLAC scaling. These are genuine Lagrangian field theories in which you could compute, in a way essentially independent of perturbation theory the small-distance behavior; then you find that the strength of the interaction goes to zero. The essential features of the work had been discovered a few months earlier by Gerard 't Hooft at the University of Utrecht, but he did not publish his results. In a rough sense, such asymptotically free theories are theories in which the interactions between fields go to zero as the spatial separation goes to zero.

One cause for all the excitement is that with asymptotically free theories it is actually possible to make some detailed calculations. Then, too, Coleman and Gross have shown[3] that nonabelian gauge fields are necessary for asymptotic freedom (necessary but not sufficient, because one can build models involving nonabelian gauge fields that are not asymptotically free). A much more restricted version of the same results was found by Anthony Zee (Princeton). Such nonabelian gauge fields have been used by Steven Weinberg (Harvard) and others in an attempt to unify the weak and electromagnetic interactions. Weinberg feels that asymptotic freedom allows one effectively to study a region where the strong interactions disappear so that one can "see through to the underlying field theory." It allows theorists to do calculations about processes at sufficiently high energies, just using simple Feynman diagrams that are valid despite the existence of strong interactions.

As Gross told us, "all the fog of the strong interactions suddenly goes away and you suddenly see the underlying dynamics. You can hope from there to extrapolate backwards from the region in which the interaction is weak, and therefore discernible, to the region where the really tough dynamical problems remain." We have not yet been able to explain the spectrum of hadrons with a dynamical theory, he said but "at least we have a starting point." Eventually, Weinberg feels, there is hope of unifying the strong, weak and electromagnetic interactions and testing this theory experimentally.

The method used by Gross and Wilczek and by Politzer to analyze the small-distance behavior of field theory is the renormalization group, an approach developed in the 1950's by Murray Gell-Mann and Francis Low and by E. C. G. Stuckelberg and André Peterman. Subsequently the importance of the renormalization group in strong interactions was emphasized by Kenneth Wilson (Cornell), who also applied this technique to critical phenomena (PHYSICS TODAY, March 1972, page 17) and by Kurt Symanzik (DESY) and Curtis Callan (Princeton). Gross, Wilczek and Politzer have actually evaluated the renormalization group parameters for a gauge field theory.

The renormalization group approach says that at high energies field theories behave as if there were an effective coupling that depends on energy. Using perturbation theory one finds that for any kind of scattering in second order the amplitude at high energies is proportional to the square of the charge but it has powers of log E, where E is energy. In fourth order one might get the fourth power of charge and powers of log E^2 and log E and so on. Summing all the logarithms one finds that effectively the whole series behaves as if it involved a single expansion parameter, which is the charge times some function of E, which one can call the effective charge. In quantum electrodynamics the effective charge increases with energy, at least for small energy and small charge, so that the electromagnetic interactions would get stronger for higher energies. But theorists have always thought there might be a field theory in which the effective charge decreased at higher energies. In addition, there had been the experimental observation at SLAC of the scaling predicted by J. D. Bjorken (SLAC); these experiments suggested that somehow strong interactions were becoming weak at very high energy.

As Gross explained to us, in an asymptotically free theory one can think of the coupling constant as going to zero as the momentum becomes larger; that is the theory is free—it has no interactions. In the free theory the behavior is pointlike, which gives one a way of understanding scaling, he said. Gross and Callan have shown[4] that for most field theories the only way one could explain the pointlike behavior seen at SLAC is if the theory is asymptotically free and the interaction turns off at large momentum. In this case one does not get scaling exactly; rather one obtains logarithmic deviations from scaling. Other theories, Gross told us, would yield a decrease with powers of momentum transfer.

Asymptotic freedom allows theorists to compute the actual behavior of the electroproduction structure function, $f(q^2, x)$ where q^2 is the four-momentum transfer squared and x is $q^2/2\nu$ and ν is the energy transferred to the hadrons in the lab system. This has been done by Gross and Wilczek[5] and by Howard Georgi (Harvard) and Politzer,[6] whose numerical results agree. They computed the moments of the structure functions, where the nth moment is

$$\int_0^1 x^n f(q^2,x)\, dx$$

Although they could not calculate the magnitude of the moments, they were able to find the q^2 dependence. Bjorken scaling would require the moments to be constant because the structure functions themselves are constant. Instead the two groups find the moments go as powers of $1/\log q^2$. In a typical theory the power is about $1/6$ for low moments and very slowly grows, becoming quite large for large moments.

Coleman points out that it is an open question whether SLAC is in the limiting region, asymptopia. "Some people say we are really seeing the Bjorken limit and the scaling that's observed is a reflection of things that are going on in that limit. And other people say what we're seeing at SLAC is some sort of low-energy epiphenomenon, and when we go to higher energy it will have absolutely nothing to do with an asymptotic limit." The approach to the asymptotic limit behaves as $1/\log q^2$, not as $1/q^2$.

Another calculation involving asymptotic freedom has been done by Zee[7] and by Thomas Appelquist (Harvard) and Georgi,[8] who calculated the total rate for electron–positron annihilation into hadrons at high energy. They showed that in an asymptotically free theory the rate is the same as the rate one would calculate if one ignored the strong interactions altogether. In addition they calculated the $1/\log q^2$ correction.

Gross and Weinberg have speculated that perhaps asymptotically free theories are singular enough at low momenta to explain why quarks are never observed. Gross explained to us that the charges might be totally shielded. The infrared singularities that make it difficult to discuss the low-energy behavior of an asymptotically free theory might also explain why quarks cannot be pulled out of hadrons. —GBL

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Two new bubble chambers may be last big ones

The world's largest bubble chamber, the 15-foot device at the National Accelerator Laboratory, was operated successfully at the end of September, and in October it ran with its 30-kG magnet at 86% of full field, using the 300-GeV repetition rate. Earlier this year the Big European Bubble Chamber (BEBC) began operating at CERN and is now being used for physics runs; it is a 3.70-meter device. These machines, together with the Argonne 12-foot chamber and the Brookhaven 7-foot chamber, may be the last generation of big bubble chambers to be built, according to Charles Peyrou, who heads the track-chambers division at CERN and Nicholas P. Samios of Brookhaven, who has many years of bubble-chamber experience.

The NAL chamber contains contributions from Argonne (superconducting magnet), SLAC (expansion system actuator), Brookhaven (vacuum vessel design) and CERN (optics, piston and seal). The 15-foot device is essentially a sphere with a nose, the sphere with a 12.5-foot diameter and the nose with a protrusion of 2.5 feet, which sticks out between the magnet coils; overall track length for charged particles is 15 feet. The volume of the liquid, which can be hydrogen, neon–hydrogen mixtures or deuterium, is 32 000 liters. Provision has been made for the installation of track-sensitive targets and for internal metal plates to help make gamma rays visible.

For photography the chamber has six 26-inch-diameter ports, each of which