Nuclei That Interact Before Their Time

Nuclear physicists seek a six percent solution, an explanation why that proportion of atomic nuclei interact before they ought to. It may involve a new state of matter.

By DIETRICK E. THOMSEN

An event that happens before it is expected can be troubling or embarrassing in many cases. When an atomic nucleus traveling through some detecting material interacts with a nucleus of that material before it should, that event could be downright revolutionary in the view of physicists. Such an interaction-prone nucleus is called an anomalon. The existence of anomalons could mean that some nuclei come in weird and hard-to-explain shapes or that internally they are strange new states of matter—acting like bundles of quarks, for instance, instead of like collections of neutrons and protons. In the words of William C. McHarris of Michigan State University in East Lansing, they make people "think of science fiction."

Up to now what evidence of anomalons there was came from observations of detectors made of photographic emulsion. At the recent International Conference on Nucleus-Nucleus Collisions, held at MSU, Wolfgang Heinrich of the University of Siegen in West Germany reported evidence that they also appear in detectors made of stacks of plastic foil. This tends not only to support the existence of anomalons but also to indicate that their appearance does not depend on the nature of the detecting material—strengthening the belief that the phenomenon involves the moving nucleus more than the substance in which it is moving.

This is significant—if anomalons really do exist. Even physicists who are excited about anomalons admit that the statistics are poorer than they would like. Other physicists use those statistics to vehemently deny the existence of anomalons. The chance that the analysis is wrong and that anomalons really don't exist is estimated by Howel Pugh of the Lawrence Berkeley Laboratory in Berkeley, Calif., at one in 1,000; physicists would like less than one chance in a million of being wrong before they firmly decide something exists, he says. But anomalons are so revolutionary that a fuss is being made nevertheless.

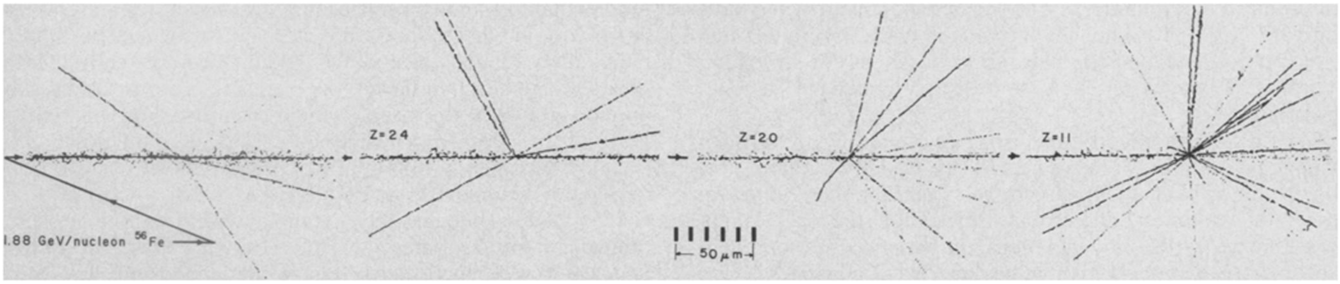
The history of anomalons began almost 30 years ago with just five or six observations of cosmic rays—not nearly enough to draw any conclusions. Pugh credits further progress to the persistence of one physicist, Barbara Judek of the Canadian National Research Council in Ottawa. A few years ago Judek came to Berkeley to irradiate emulsion detectors with the high-energy nuclei that LBL's Bevalac accelerator alone can provide. In late 1980, she and E. M. Friedlander, R. W. Gimpel, Harry H. Heckman and Y. J. Karant of LBL and E. Ganssauge of Philipps University in Marburg, West Germany, published evidence for the existence of anomalons that involved many more instances and much better statistics (PHYSICAL REVIEW LETTERS, Vol. 45, p. 1084). Since then, Pugh says, physicists from all over the world have been coming to the Bevalac to irradiate detectors and to analyze them for anomalons. Heinrich's group from West Germany irradiated their plastic foils there.

What is seen in the detectors is simple, but tantalizing: A nucleus enters the detector and interacts with something in it. The original projectile nucleus comes apart into several daughters. It is among the daughters that anomalons are found. Six percent of the time a daughter travels substantially less distance than on the average it ought to before it interacts in its turn. Furthermore, the phenomenon seems to be heritable. Anomalons are more likely to be found in the third generation among the daughters of anomalons than among the daughters of normals.

To go a shorter distance before interacting—to have a shorter mean free path as it is technically termed—means to have a greater cross section for interaction. Cross section means probability, but in this case it can be treated as a measure of the physical size of the nucleus. A nucleus that is bigger than others of its element is more likely to hit something than the others; or the internal construction of the anomalous nucleus may somehow be different from that of others so that it exerts stronger forces on its surroundings and so can interact with things farther from itself.

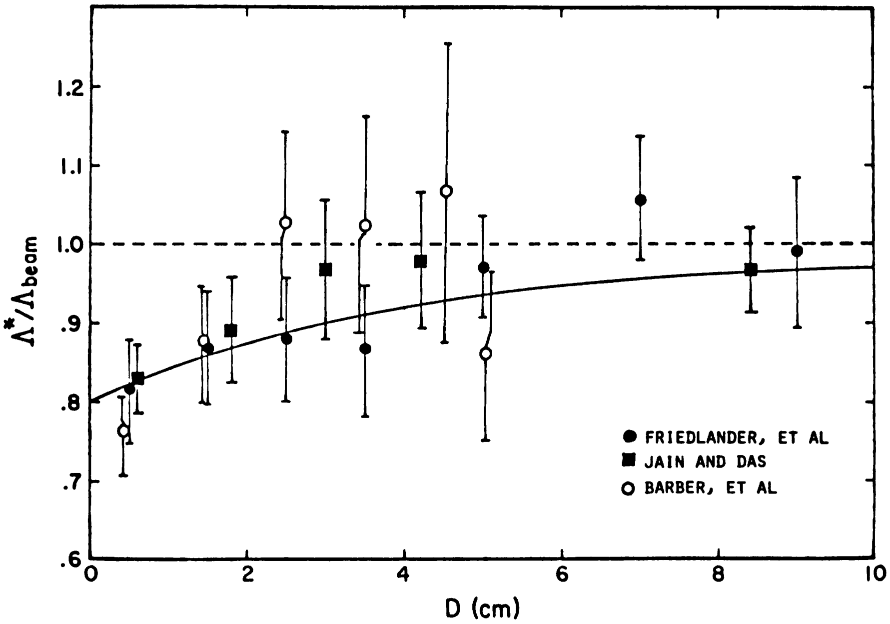
Attempts at theoretical explanation take off from both ideas. Probably the most popular is the one that attributes the anomaly to quarks and says that the anomalous nucleus is some kind of new state of quark matter. A nucleus usually behaves as if it were made up of neutrons and protons. Each neutron and proton is built of three quarks, and the quarks are held together by an extremely strong force, the so-called color force. Normally each neutron or proton is a "color singlet"—that is, neutral with respect to the color force so that the color force stays within it and does not reach outside it, and the world outside the nucleus sees neutrons and protons inside the nucleus, not quarks.

Suppose, however, as Helmut Satz of the University of Bielefeld in West Germany



A nucleus of iron-56 enters a detector and starts a chain of four fragmentations, becoming successively chromium, calcium, sodium and exiting as an alpha particle.

Illustrations: LBL



Expected mean free paths compared to experimental. The straight broken line at 1.0 is the expected value for normal nuclei. The solid curve is the expectation if 6 percent of the fragments are anomalons. (D is the distance from the point of emission of a given fragment.) Data of three experimental groups tend to be closer to the solid curve.

describes it, something happens in a high-energy collision between projectile and target nucleus, some kind of superheating perhaps, that destroys the integrity of individual protons and neutrons and produces a globule of matter that is a kind of plasma of quarks. (The term "plasma" usually refers to an ionized gas, but it is used here because such a conglomerate of quarks would have a similar structure and behavior.) If there is such a plasma and the anomalon is a fragment of it, it could exert color-force effects on the surroundings and so account for the increased probability of interaction. "If one had an indication of fractionally charged particles," says Satz, that would be a handle. Quarks are supposed to have electric charge in fractions of the charge of a proton. Fractional charge on an anomalon would be an indication of unbalanced quarks and so suggest that it was a fragment of such a quark plasma.

Other attempts at explanation try to increase the physical size of the anomalon by making it a "bubble nucleus," one blown up to be much thinner than its normal density, or by giving it an odd shape, a dumbbell or torus shape. Nuclei are normally quite densely packed and spherical in shape (a sphere being energetically the most efficient shape), and it will take some unusual mechanisms to erect or maintain these others. McHarris and John Rasmussen of LBL present one that depends on pi mesons.

The energies at which experiment is now operating (up to a billion or 2 billion electron-volts per neutron and proton) are really not enough, McHarris says, to cause the kind of quark rearrangements that would lead to a quark plasma. But they are "in the range to produce [pi mesons] in great quantity," he says. (Pi mesons have a virtual or latent existence in every nucleus, and addition of energy can bring them out into a real, independent existence.)

McHarris and Rasmussen propose that if an anomalon comes out of the collision that makes it with an abnormal number of neutrons for its size (not an implausible supposition under the circumstances) and if those neutrons are splashed outward, then the negative pi mesons created at the same time will be able to bind themselves to neutrons and groups of neutrons and erect and stabilize an extended halo of neutrons around the core of the anomalon. Thus the anomalon would be a kind of bubble nucleus, for which they coin the word "pineut," and have a larger size and a larger cross section for interaction.

As experiments continue, the scientists' first job is to assemble better statistics and so either convince the skeptics of the existence of anomalons or, by going the other way, end the excitement. Assuming the excitement continues, there are many things that need to be found out. As Piyare Jain of the State University of New York at Buffalo points out, experiment needs to discover whether the effect depends on the energy of the original projectile nucleus (there is some evidence that it does) and whether it depends on the charge (atomic number) of the fragment. It has been seen so far for fragments with fairly high atomic numbers, but not, so far, for helium nuclei (atomic number 2). And then one might look for evidence favoring specific theoretical suggestions — for example, fractional charge for the quark plasma, or gamma rays, which would be produced by the pi mesons in the Rasmussen-McHarris scheme. ☐