Nuclear Science: X-ray Evidence for Superheavy Elements

Last month, a team of scientists announced that it had evidence for the existence of superheavy elements with atomic numbers of (in order of decreasing confidence) 126, 116, 124, and 127. The investigators from the Oak Ridge National Laboratory (ORNL), Florida State University (FSU), and the University of California at Davis (UCD) could not determine the masses of the heavy atoms, which were found in naturally occurring mica formations, from their data, however.

The superheavy elements in themselves are not surprising to physicists, who have long predicted their existence. Although elements with atomic numbers much greater than 100 are highly unstable, numerous calculations have indicated the possibility of long-lived nuclei with from 110 to 114 protons and 184 neutrons. These predictions have, in fact, stimulated intense searches for superheavy species in recent years, both in nature and in accelerators. Until now, no convincing evidence had been found.

If their findings are confirmed by subsequent experiments (one scientist said he would bet \$10 but not \$1000 they would be), a frantic race can be expected between nuclear physicists around the world to explore this so-called island of stability of superheavy nuclei (*1*). And because the new elements have atomic numbers larger than expected, nuclear physicists will have to revise existing theories of nuclear structure and nuclear synthesis.

The investigators detected the elements by bombarding small monazite inclusions in a mineral known as biotite, with a 30-micrometer-wide proton beam from the Florida State tandem Van de Graaff accelerator. Agreement between the energies of the x-rays emitted from the monazite with values of x-ray energies that were previously predicted for superheavy elements by Thomas Carlson and his associates, who are also researchers at Oak Ridge, led the ORNL-FSU-UCD team to conclude that the heavy atoms were present.

Inasmuch as the putative superheavy elements were present in very small amounts (less than 100 picograms), the x-ray signals were weak, resulting in less than optimum signal-to-noise ratios. This, combined with the observation of only one x-ray line for each of the species (or, in one case, two weak lines), led the group to emphasize that it is only claiming evidence for, not the discovery of, superheavy elements.

This attitude also characterizes those observers who have seen the data. Says Francis Perey, one of a group of several Oak Ridge scientists who reviewed the ORNL-FSU-UCD group's results before they were made public, "The peaks are there, but the statistics are not quite good enough to be completely convincing as to their identification."

Monazites are minerals containing the rare earths cerium and lanthanum and the actinides uranium and thorium. They occur widely throughout the world, in such places as Brazil, South Africa, and India. The particular specimens used in the x-ray investigation originated in the Malagasy Republic and were given to Robert Gentry of ORNL several years ago.

Gentry was interested in explaining the origin of giant halos that occur around some thorium-rich monazite inclusions in biotites. Halos are discolored regions caused by radiation damage to the material surrounding an inclusion when the radioactive elements therein decay by emitting alpha particles. Halos traced to uranium and thorium decay have been characterized by Gentry and others. The size of a halo increases with the energy of the alpha particle emitted, but the giant halos (with radii from 50 to 100 micrometers) were too large to be explained by alpha decay of any known element (*2*).

Mystery of the Giant Halos

After exhausting other explanations for the giant halos (some were shown to have a chemical origin), Gentry turned to investigating the possible existence of new sources of radioactivity, such as superheavy elements. The use of an ion microprobe mass analyzer (an instrument in which a narrow scanning beam of oxygen ions sputters ions from the surface of a sample into a mass spectrometer) provided evidence for high mass particles in the inclusions, but could not exclude the possibility that they were molecular ions, such as oxides. The use of a scanning electron microscope beam to excite x-rays from elements in the inclusion was also unsuccessful because a high background radiation obscured signals coming from anything present in very small concentrations.

Then, last fall, Gentry queried Thomas Cahill and Robert Flocchini of UCD about an x-ray technique that they and their associates at Davis had been using to monitor air pollutants. It is one of the ironies of life that these researchers were stimulated to develop the ion-induced x-ray method for analysis of such environmental contaminants when support for the Crocker Nuclear Laboratory accelerator at UCD was terminated 6 years ago, and the laboratory was left to pay its own way.

After conferring with Gentry, the UCD researchers decided that a hunt for superheavy elements would be feasible with the UCD technique. Exciting x-rays with ions from an accelerator reduces the background considerably at high x-ray energies. Moreover, there would be a window in the monazite for the L x-rays (those emitted when electrons fill vacancies in the L shell of an atom) expected from superheavy elements. The window occurs between 21 kev, the highest energy of the L x-rays emitted by uranium and thorium, and 30 kev, the lowest energy of the K x-rays emitted by lanthanum and cerium. The theory for L x-rays is also more accurate than that for the higher energy K x-rays because L shell electrons tend to avoid the nucleus.

In order to ensure that the x-rays came only from the monazite inclusion and that enough x-rays were counted to obtain a statistically significant result, the researchers had to focus the ion beam on the inclusions, which have diameters of 50 to 100 micrometers, for long periods of time (an hour), a never-before-achieved accomplishment in itself. The UCD accelerator was not up to this task. As it happened, however, Cahill was going to FSU on sabbatical, and the tandem Van de Graaff there was, if not ideal, the best machine available anywhere. Thus, Cahill joined with Neil Fletcher, Henry Kaufman, Larry Medsker, and William Nelson at FSU to perform the x-ray experiments.

If confirmed, the identification of superheavy elements will have a profound effect on nuclear physics. It may also serve to raise the sagging spirits of U.S. nuclear physicists, who have been suffering the indignities of funding cuts in recent years. And, if the x-ray evidence holds up, the two most successful laboratories in producing elements with high atomic numbers, the University of California's Lawrence Berkeley Laboratory (LBL) and the Joint Institute for Nuclear Research in Dubna, U.S.S.R., have been scooped. As soon as more material becomes available, according to Albert Ghiorso of LBL, these laboratories and others will engage in a race to explore the properties of these superheavy elements and to create new ones by bombarding the monazite in accelerators.

Finding superheavy elements in monazites, which were formed early in the earth's history, raises at least two questions for nuclear scientists. Calculations based on a synthesis of the liquid drop and shell models of the nucleus had indicated that element 126, for example, would decay by alpha emission with half-lives from a few nanoseconds to about a thousand years, depending on the number of neutrons, according to J. Rayford Nix of the Los Alamos Scientific Laboratory in New Mexico. But the geologic age of the earth is 4.5×10^9 years.

The short half-lives expected are due to the large electrostatic repulsion between protons which overcomes the attractive nuclear forces and makes spontaneous fission of nuclei more and more likely as their atomic numbers rise above 100. The probability of radioactive decay by emission of alpha particles also increases as coulomb forces become stronger. The shell model of the nucleus, whereby the protons and neutrons are arrayed in shells somewhat like atomic electrons, provides a way to circumvent these instabilities under certain circumstances.

When the proton and neutron shells are filled, a barrier to fission large enough to permit lengthy nuclear lifetimes occurs. The "magic number" for which this closed shell condition would hold was thought to be 114 protons and 184 neutrons. But all calculations of nuclear lifetimes are based on extrapolations of models known to fit much lower mass nuclei. Thus, calculating the stability of superheavies is a tricky business.

By making only small changes in the parameters used in a model such as Nix's, theoreticians can effect changes in nuclear lifetimes of several orders of magnitude, according to Fred Petrovich at FSU. Looked at from this point of view, the new superheavy elements provide a guidepost for assigning values to parameters which were heretofore selected on the basis of incomplete information.

A second problem for theoreticians has to do with whether the putative superheavy elements were created by the processes of nucleogenesis in stars. The most important of these for heavy elements is the r-process in supernovas, which involves a sequence of multiple capture of neutrons to increase the nuclear mass followed by emission of electrons to increase the atomic number. Calculations based on the liquid drop model of the nucleus had led theorists to believe that spontaneous fission would interrupt this process before superheavy elements could be formed, according to Nix. Moreover, the details of the giant halos are such that it is possible that they were caused by alpha decay of even heavier elements than those apparently now residing in the monazite inclusions, say the experimenters, and thus would be much harder to produce.

For now, the most important thing, all agree, is to verify the existence of superheavy elements. The ORNL-FSU-UCD team is now working to improve their data by correcting the tendency of the Van de Graaff beam to wander away from the inclusion. But, if further x-ray evidence proves inconclusive, a number of scientists who are waiting in the wings with other physical and chemical tests involving separation, concentration, or nuclear bombardment of superheavy elements would be only too happy to have a crack at the new elements.

—ARTHUR L. ROBINSON

References

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Hormone Receptors: New Clues to the Cause of Diabetes

Diabetes is commonly thought of as a disease in which the pancreas produces insufficient quantities of the hormone insulin. For about 10 percent of American diabetics, who suffer from the juvenile-onset form of the disease, that is, in fact, the case. But for the vast majority, who suffer from maturity-onset diabetes, the pancreas produces normal quantities of insulin—and, in many cases, quantities that are well above normal. The problem is, rather, a reduced sensitivity of fat and muscle cells to the effects of insulin, a phenomenon commonly referred to as insulin resistance.

The cause of this insensitivity is still unknown. But a significant increase in understanding of the fundamental defect of diabetes has evolved in the past 3 years. The principal catalyst for this progress was the identification of specific sites on cellular membranes where insulin and glucagon interact with the cell to regulate glucose metabolism. Identification of these receptors has provided a major new tool for study of the basic causes of diabetes. This tool has so far made possible the discovery that binding of both insulin and glucagon to many types of cells is much lower than normal in both diabetics and insulin-resistant obese individuals. It has also shown that insulin binding can be returned toward normal by regulation of the diet and by certain drugs. Some evidence further suggests that screening for reduced insulin binding can identify individuals who are likely to develop diabetes.

Direct studies of the insulin-receptor interaction with the use of radioactively labeled insulin were first attempted in 1949 by William C. Stadie of the University of Pennsylvania, but severe technical difficulties were encountered. The problems included the extremely small amount of hormone that binds to the receptor, uncertainty about whether the labeled hormone was biologically active, and complications resulting from nonspecific binding. The problems were largely resolved by 1969, when two groups of investigators independently solved the problems and made the first clear identification of hormone receptors. Ira H. Pastan of the National Cancer Institute, Jesse Roth of the National Institute of Arthritis, Metabolism, and Digestive Diseases (NIAMDD), and Robert J. Lefkowitz, now at the Duke University School of Medicine, identified the receptor for adrenocorticotropic hormone (ACTH). And S.-Y. Lin and Theodore L. Goodfriend of the University of Wisconsin identified the receptor for angiotensin.

The techniques developed by these investigators have proved applicable to all the polypeptide hormones, each of which has a receptor in the cell mem-