news and views

Discovery of superheavy elements

from Peter Hodgson

THE super-heavy elements 116, 124 and 126 have now been detected in the mineral monazite from Madagascar by a group of nuclear physicists from the University of Florida at Tallahassee, Oak Ridge National Laboratory and the University of California at Davis.

Over the past few decades a series of elements heavier than uranium have been discovered, mainly by successive addition of neutrons. After plutonium and neptunium came elements such as fermium, einsteinium, mendelevium, nobelium and lawrencium. All are highly radioactive, and the heavier they are the shorter their half-lives.

It has been known for a long time that the stability of nuclei is connected with their shell structure, those with magic numbers of neutrons or protons (corresponding to complete shells) being particularly stable. Lead 208 is especially stable, consisting of 126 neutrons and 82 protons, both magic numbers. The results suggested that the nuclei with even higher magic numbers of neutrons and protons might also be more stable than surrounding nuclei. It was considered very doubtful whether they would actually be stable, but it was thought possible that they would have half-lives long enough for them to be detected and their properties established.

The ensuing search for the offshore islands of nuclear stability or near-stability in regions of the periodic table beyond the peninsula of the heavy elements captured the imagination of nuclear physicists. Many different methods have been discussed, and among the most promising of these is the hope that the super-heavy elements (as they came to be called) could be produced in collisions between heavy ions at energies high enough to overcome their mutual electrostatic repulsion. The difficulty is then to make them stick together, for there is so much energy in the system that they are very likely to fly apart again.

The possibility of such reactions was one of the strongest arguments put forward in support of the funding of heavy ion accelerators, and these are now operating or under construction in the USA, USSR, UK and other countries. At the same time there has been intense theoretical work devoted to the prediction of the properties of the super-heavy elements by extrapolation from the properties of the known nuclei. It is thus a great surprise that super-heavy nuclei have now been found to be stable and waiting to be found in a familiar mineral.

The presence of unusual elements in monazite was suggested by studies by Robert T. Gentry of the halos in mica caused by radioactive inclusions. Most of the halos could be identified as due to known radioactive nuclei, but a few could not. It proved possible to remove the inclusions from the mica and bombard them with 5.7 MeV protons from the Tallahassee Super FN Tandem. Examination of the resulting X-rays by T. A. Cahill, R. C. Flocchini, N. R. Fletcher, H. C. Kaufmann, L. R. Medsker and J. W. Nelson showed frequencies corresponding to the $L\beta_2$ transition in element 116 and the $L\alpha_1$ transitions in elements 124 and 126. These transitions were found only using the targets from inclusions showing the anomalous halos. These super-heavy elements are identified with 99% confidence, and in addition there is weak evidence for the elements 114, 125 and 127. The abundance of the super-heavy elements is about 10^{11} atoms per inclusion. Their chemistry is being studied by T. A. Carlson and B. Fricke. The alpha and beta activity of these elements is being studied by J. D. Fox and K. Kemper; the alpha particle energies are around 5 MeV.

These results have stimulated intense theoretical activity in a group consisting of J. Berelacqua, D. Stanley, P. J. Philpott, D. Robson, F. Petrovich and M. Golin. Using the single-particle shell model, it is possible to obtain the energies of the single-particle states as

eigen values of a one-body potential. The parameters of this potential can be fixed to give the energies of the known single-particle states in Pb, Sn and Ba. Using the known dependence of the one-body potential on A and on the nuclear asymmetry parameter $(N-Z)/A$ enables the energies of the single-particle states in heavier nuclei to be calculated. Calculations made some time ago indicated that $Z=114$ is likely to be the next nucleus of higher stability than its neighbours, so the experimental indications of $Z=116$ are somewhat puzzling. Calculations for $Z=126$ indicate that this also should be a stable nucleus, shown by the energy gaps between the filled and the next unfilled shells.

Calculations were also made for the nucleus $Z=164$ and this comes out to be particularly stable, with neutron and proton energy gaps of 2.9 and 2.4 MeV respectively. The energy of the alpha-particles from the decay of this nucleus was calculated to be 9.5 MeV, which corresponds very well with the unexplained 'giant haloes' found in monazite. This nucleus has not yet been detected by the X-ray method, so this at present remains an unconfirmed possibility. If confirmed, it could account for the anomalous lead isotopic ratios found in monazite.

The alpha-particle half-lives were calculated for a range of super-heavy nuclei, and were found to be sufficiently large for them to be found naturally for elements 114, 124, 125, 126 and 127, but not for 116 and 128. So 116 is a puzzle in this respect as well. The element 164 was on the borderline of half-lives acceptable for stability.

There is certainly much more experimental and theoretical work to be done to confirm these results, to determine the structure of these new nuclei, and to account for their properties experimentally. This is a major breakthrough which will stimulate many new researchers in the months to come. □