Search for Stable Elements Heavier than Uranium

Recent theoretical calculations suggest that element number 110 may live for millions of years. Researchers are looking for such a stable, superheavy element in platinum ores and cosmic rays and by heavy-ion bombardment of heavy nuclei.

Theory. Shell-model calculations have indicated that the next magic numbers of protons after $Z = 82$ (lead) are 114 and 126, and the next magic number of neutrons would be $N = 184$. Doubly magic isotopes with $A = 298$ and 310 might have lifetimes ranging from seconds to days.

A whole "island of stability" centered around ${}_{114}X^{298}$ might exist, according to some nuclear physicists, for example Wladyslaw J. Swiatecki and W. D. Myers of Lawrence Radiation Laboratory, Berkeley (*Nucl. Phys.* **81**, 1, 1966 and *Arkiv Fysik* **36**, 593, 1967). Now recent calculations by Sven Gösta Nilsson of Lund Institute of Technology, Lund, Sweden, Stanley G. Thompson and Chin Fu Tsang of Berkeley (reported in a recent issue of *Physics Letters*) with coworkers in Lund, and by Z. Szymanski and collaborators in Warsaw show that the doubly magic isotope ${}_{114}X^{298}$ should have a total half-life of years and isotope ${}_{110}X^{294}$ is likely to be even more stable.

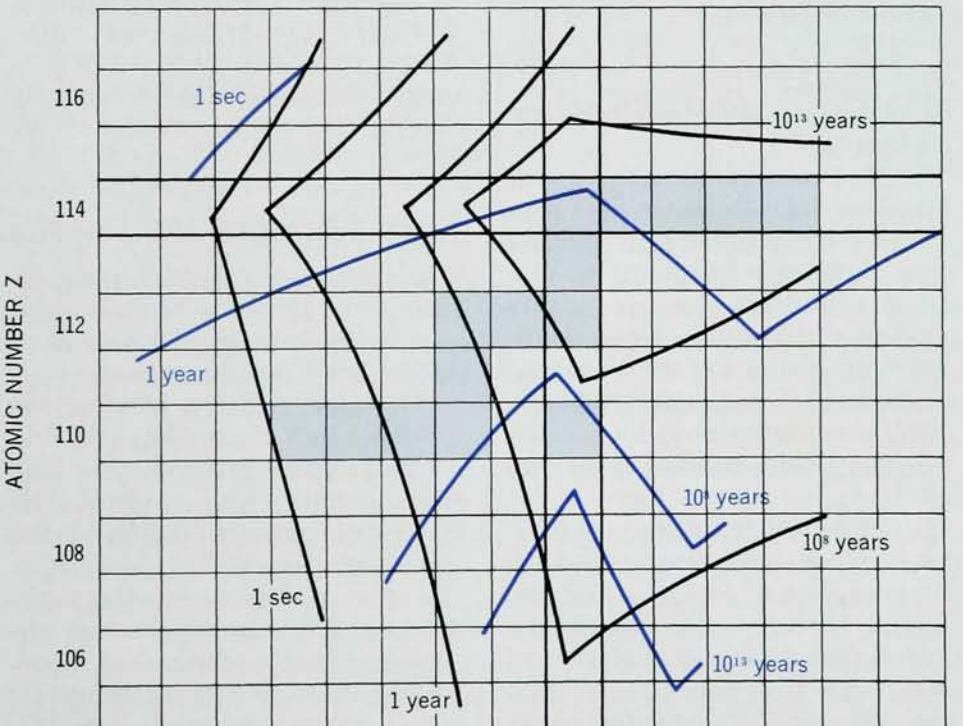
Nilsson and his collaborators calculated ground-state masses and potential energies of nuclei as a function of deformation. The calculation is based on a synthesis of two nuclear models, the liquid-drop model and the deformable shell model. The nucleus is allowed to elongate and develop a neck. Pairing effects are also included. Then the group calculated half-lives for alpha decay and spontaneous fission, and they tested for beta stability.

To check their calculation, the theorists applied it to the actinide region ($A \approx 242$). They obtained reasonably satisfactory values for fission half-lives and barrier heights. In particular, they found the barrier had a double hump, in agreement with recent experiments in the region $234 \lesssim A \lesssim 246$ (see page 64). The figure gives half-life contours for fission, alpha and beta decay. Although several $Z = 114$ isotopes appear to have fission half-lives greater than the age of the earth (5×10^9 years), alpha half-lives for the same nuclides are of the order of years and less.

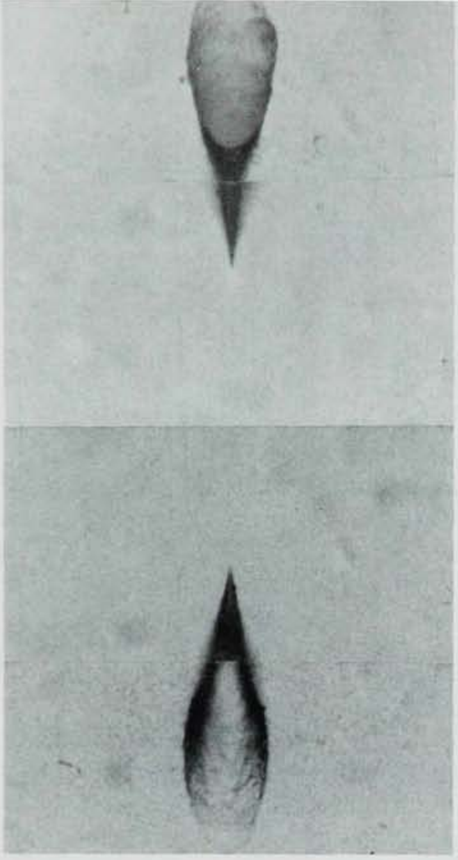
Nilsson and his coworkers applied a survival-of-the-fittest test with respect to fission, alpha and beta decay, and they find the best candidate to be ${}_{110}X^{294}$. Nilsson points out that its total half-life, estimated to be about 10^8 years, can be off by several powers of ten. Especially uncertain is the value for spontaneous-fission half-lives.

Search for superheavy. Several groups have searched for an element with Z near 114. Two Berkeley teams (one consisting of Thompson, Swiatecki, Harry Bowman, Raymond C. Gatti, Luciano G. Moretto and Richard C. Jared and the other consisting of Albert Ghiorso, Torbjorn Sikkeland and M. Nurmia) looked for the spontaneous fission of short-lived nuclei produced by the reaction $Cm^{248} + Ar^{40} \rightarrow {}_{114}X^{284} + 4n$. The search was unsuccessful, but the result was not unexpected, as the projectile did not have enough neutrons to produce a product with a neutron number near enough to the magic number 184. In the future, however, projectiles such as Ca^{48}, Ni^{64} and Ti^{50} might help.

Thompson and his collaborators looked for ${}_{110}X^{294}$ in platinum ores, as these elements are expected to be chemically similar. Assuming that the half-life was very long, they used x-ray fluorescence, mass spectrometry and activation with heavy ions and protons. Alternatively, assuming that the half-lives were shorter, they made low-background counts of neutrons, gammas and spontaneous fissions. They established an upper limit of 1 part in 10^{10} of platinum. The Thompson group is also looking in platinum ore



HALF-LIFE CONTOURS calculated from combination of liquid-drop model and deformable shell model. Black curves are contours of spontaneous fission half-lives. Colored curves are contours of alpha half-lives. Colored squares are beta-stable nuclei. Most stable nucleus appears to be ${}_{110}X^{294}$ with half-life of about 10^8 years.



SUPERHEAVY COSMIC-RAY trajectory is recorded in 1/4-mm-thick sheet of Lexan plastic that was etched in sodium-hydroxide solution, which attacks plastic more rapidly along path of heavily ionizing particle than elsewhere. This side view shows nucleus entering at base of one cone and leaving at other (*Phys. Rev. Letters* 21, 630, 1968). The four photos were taken by varying the focus of microscope.

for neutron-rich fission products coming from $_{110}X^{294}$.

P. H. Fowler of the University of Bristol and his collaborators have been scanning the skies at high altitudes with a detector consisting of iron sheets sandwiched between nuclear emulsions. They have reported evidence for elements up to uranium in cosmis rays (*Proc. Roy. Soc.* **A301**, 39, 1967) and more recently for one particle they believe may be heavier than uranium.

Using huge detector arrays of interleaved plastic track detectors and nuclear emulsions, groups at General Electric (Robert L. Fleischer, P. Buford Price and Glenn E. Nichols) and Washington University (George Blanford, Michael W. Friedlander, Joseph Klarmann, Robert M. Walker, John Wefel and William Wells) have found several nuclei about as heavy as those found by the Bristol team and have established that the nuclei were recorded at ceiling altitude (37 km) and were truly relativistic. Following three recent balloon flights with Fowler's group they have located the tracks of about 40 relativistic superheavy nuclei that they traced through the plastics and emulsions. All three groups are proceeding with the rigorous identification of these nuclei, some of which may be heavier than uranium. —GBL

Mind Your k's and q's to Simplify Solid-State Theory

Many solid-state theorists are enthused about a new quantum-mechanical representation recently developed by Joshua Zak of the Technion, Haifa (while at the Bitter National Magnet Laboratory, MIT). Zak's "*kq* representation" can be used to reproduce in an almost trivial way the many earlier and often complicated derivations of electron behavior in a periodic potential.

Although the uncertainty principle prevents treating particle coördinate x and momentum p together, in some situations precise information about either the coördinate or the momentum is irrelevant, Zak explains. In a solid where the potential is periodic, all the unit cells are identical; so all you need specify is the position of a particle within any such cell. He uses the well-known solid-state concept of quasi-momentum (reduced wave vector) defined so that exp $(-i\mathbf{k}\cdot\mathbf{t})$ is the eigenvalue of the operation of translation by the lattice vector $\mathbf{t}$ in ordinary space; p can equal k, $k + 2\pi/a$, $k + 2(2\pi/a)$, etc. Similarly he specifies the position by a quasi-coördinate q, which ranges only over the volume of a unit cell and is defined so that exp $(i\mathbf{K}\cdot\mathbf{q})$ is the eigenvalue of the operation of translation by the reciprocal lattice vector $\mathbf{K}$ in momentum space. k and q can be measured together, and they form the *kq* representation. Zak emphasizes that the uncertainty principle is not violated by the representation, since one only uses partial information about the coördinates.

Zak has applied his *kq* representation to the motion of electrons in solids in external fields. The derivation of the acceleration theorem for a Bloch electron in an electric field, $\hbar\dot{k} = -eE$ usually involves quite complicated expansions and integrations, Zak notes. But with his representation k is an independent variable in Schrödinger's equation, and the theorem follows at once from the simple quantum-mechanical rule that the time variation of k is given by the commutator of the Hamiltonian with k.

For a Bloch electron in a magnetic field, the main result of the effective Hamiltonian follows at once from Schrödinger's equation in the *kq* representation.

Zak is presently at Northwestern University.

New Insight Is Offered into the Fission Process

The existence of a double-humped fission barrier appears to be the explanation for the behavior of a wide range of heavy and superheavy nuclei.

This type of fission behavior was predicted by V. Strutinski[1] of the Kurchatov Institute (on leave at the Niels Bohr Institute), who calculated shell-energy corrections to the liquid-drop model as a function of deformation. These corrections modify the single-humped fission barier obtained previously with the uncorrected liquid-drop model to produce two humps (or more) separated by a well (figure 1). This well appears for rather large deformations ($\beta = 0.5$ to 0.6, where high values for β mean great deformation). The well allows formation of intermediate quasi-stationary states of the compound nucleus at these deformations.

The ground state, corresponding to the bottom of the second well, can explain the existence of spontaneously fissioning isomers, first observed by S. M. Polikanov and G. N. Flerov (Joint Institute for Nuclear Studies, Dubna) about seven years ago.

Saclay studies.[2] The excited states in the well can be responsible for certain structure effects found in some fission cross sections. The most spectacular of these effects is the intermediate structure in the cross section for subthreshold fission induced by resonance neutrons. Such structure was first observed and reported in 1966 by André Michaudon, Jacques Blons, A. Fubini and D. Paya at Saclay, in the fission cross section of Np^{237}; the 45-MeV electron linac served as a pulsed neutron source. Since at that time such intermediate structure was