search & discovery

Antiproton found going 'round in strange circles

To the list of particles that have been Coulomb captured by a nucleus, add antiprotons and sigma minus particles. Gerhard Backenstoss and his collaborators from CERN, Karlsruhe and Heidelberg have observed x rays from atomic transitions of antiprotons bound in the Coulomb field of a thallium nucleus.[1] Similarly they observed x rays from atomic transitions of Σ^- particles orbiting sulfur, chlorine and zinc nuclei.[2] Only very high values of angular momentum are observed; at lower levels the orbit is within the nucleus and the Σ^- or antiproton is captured by a nucleon. The level at which transitions disappear is very sensitive to the arrangement of nuclear matter. As the particle works its way down to the nucleus its orbit becomes circular; so interaction with the nuclear surface is favored. The other exotic atoms previously observed contain pions, muons, and most recently, kaons.

Making an hadronic atom—pionic, kaonic, antiprotonic, sigmic—is a surprising experimental feat. The lifetime before the particle interacts with nuclear matter would be very short. However the atomic transitions can be observed while the particle approaches the nucleus. As soon as it reaches the low density nuclear atmosphere the absorption takes place in 10^{-16}–10^{-19} sec leading to a reduced x-ray intensity and a broadening of the x-ray lines.

As surprising as these new exotic atoms may be, are they anything more than an impressive juggling demonstration? The answer is, "Yes," for both nuclear and high-energy physicists. Besides gaining new knowledge of the distribution of nuclear matter within the nucleus, one can perhaps measure the magnetic moment of the Σ, a value predicted by symmetry schemes such as SU-3.

Muonic atoms have been the most extensively studied. Because muons interact only electromagnetically with the nucleus, such atoms have revealed details of nuclear charge distribution, the distribution of electric quadrupole moments and magnetic dipole moments across the nucleus. Pionic atoms, on the other hand, give different information. The pion interacts strongly with both neutrons and protons; so one can, for example, study x-ray transitions in O^{16} and O^{18}, finding the effect of two additional neutrons. Also, the pion essentially sees only pairs of nucleons; so one can learn something about short-range correlations in nuclear matter and the high-momentum components in nuclei.

Last year Clyde Wiegand[3] reported production of kaonic atoms throughout the periodic table with the Berkeley Bevatron. Unlike the pion, kaons can be absorbed on a single nucleon and are expected to be more sensitive to the extreme periphery of the nuclear surface.

The Berkeley studies were limited by the intensity of the kaon beam. So a special kaon beam was built at the CERN 28-GeV proton synchrotron. Protons struck a target, producing pions and kaons; a partially separated beam of negative kaons struck the sample intended to be transformed into exotic atoms. For each accelerator burst 1000

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Magic even–even nuclei show phase transition

In possibly the first mother–son scientific collaboration, Gertrude Scharff-Goldhaber (Brookhaven) and Alfred S. Goldhaber (Stony Brook) have suggested that in singly or doubly magic even–even nuclei there is a change in the nucleus resembling a first-order phase transition, such as occurs when a superconductor goes normal.[1] This change or rearrangement occurs between the 0+ ground state and a band of excited states 2+, 4+, 6+, and so on. The remarkable point, in the authors' view, is not the existence of this phase transition, but rather that all other even–even nuclei exhibit a single phase in which the ground state is part of a quasi-rotational band.

The idea of a nuclear phase transition is an outgrowth of the "variable moment of inertia" model developed last year for even–even nuclei by Mrs Goldhaber, M. A. J. Mariscotti and Brian Buck[2] (PHYSICS TODAY, March 1969, page 61). They were able to predict level spacings in ground-state bands, which are level sequences that have values of spin and parity of 2+, 4+, 6+, . . . The energy-level formula

$$E = \frac{C}{2}(I - I_0)^2 + \frac{J(J+1)}{2I}$$

worked for both rotational and vibrational bands. (I is nuclear moment of inertia, C and I_0 are adjustable parameters.) To fix $I(J)$, they introduced an equilibrium condition requiring that for each angular-momentum state J, the energy is a minimum. The model implies

Alfred Goldhaber and his mother Gertrude Scharff-Goldhaber suggest that in singly or doubly magic even-even nuclei the nucleus has a first-order phase transition.

that I increases in a regular manner with increasing J.

Last year's work considered only positive values of I_0, which correspond to the ground-state moment of inertia. It was found that I_0 increases smoothly as the number of neutrons and protons beyond closed shells increases, reaching a maximum just midway between shells. C, the stiffness parameter, is largest for the most stable nuclei of a given atomic number. With increasing Z, as the difference between neutron and proton number increases, C becomes smaller and in at least one nucleus, Fm^{254}, which can fission spontaneously, C appears to be negative.

Now Goldhaber and Goldhaber have extended the model to negative values of I_0, permitting description of nuclei with only two or four nucleons beyond a closed shell. As in the earlier work, they group nuclei according to the ratio of the energy of the 4^+ level (E_4) to the energy of the 2^+ level (E_2). The extension applies to the range $2.23 \geqq E_4/E_2 \geqq 1.82$.

The authors assert that there is a natural physical interpretation of the model when I_0 becomes negative. Now the ground-state moment of inertia is zero; that is, the ground-state shape is spherical. The larger the negative value of I_0, the more firmly the shell structure resists departure from spherical symmetry, becoming more rigid.

At $E_4/E_2 = 1.82$, the nucleus reaches a state of complete rigidity. As E_4/E_2 decreases still further, which happens for singly or doubly magic nuclei, the nucleus becomes brittle; that is, the ground state is so symmetrical that to reach the 2^+ state, the nuclear matter has to be rearranged; for example, an alpha particle can be promoted from the core to a higher orbit.

Such a change from the ground state to a higher J resembles a first-order phase transition, such as the transition from superconducting to normal. The magnetic field corresponds to J, and the temperature to the number of nucleon pairs beyond a closed shell. The "critical temperature" is reached at $E_4/E_2 = 1.82$.

At $E_4/E_2 = 2.23$, the function $I_{J=0}(I_0)$ has a discontinuous first derivative. The Goldhabers compare this situation to that of a Curie point, below which an increasing internal magnetic field (so-called "Weiss field") acts, analogous to the increasing rigidity found for nuclei.

(The Goldhabers note that it is possible to consider nuclear phase transitions as examples of many-body behavior in a remarkably small number of bodies, 100 or 200 nucleons. Many-body theory has been applied to the theory of nuclear matter, by Keith Brueckner, Hans Bethe and others, assuming an infinite number of nucleons and then calculating the average binding energy per nucleon in the nucleus. To make the theory more realistic one then tries to include the effect of the nuclear surface.)

The Goldhabers hope that their analysis will help in the effort to build a true microscopic theory of nuclei. —GBL

References

1. G. Scharff-Goldhaber, A. S. Goldhaber, Phys. Rev. Lett. 24, 1349 (1970).
2. M. A. J. Mariscotti, G. Scharff-Goldhaber, B. Buck, Phys. Rev. 178, 1864 (1969).

Element 105: Flerov reiterates Dubna priority claim

The priority dispute over who first made element 105 continues. Georgi N. Flerov, director of the laboratory of nuclear reactions at Dubna, has pointed out to PHYSICS TODAY that results of his new experiment on element 105 appeared in February in a Dubna publication. He noted that his publication preceded both the announcement made by Albert Ghiorso and his collaborators and a statement issued by the AEC on 28 April that the Lawrence Radiation Laboratory group had discovered element 105 and was naming it "hahnium." Ghiorso had told a press conference at the April APS meeting that he believed Flerov's first experiment on element 105 (PHYSICS TODAY, December 1967, page 61) was wrong but not necessarily the second experiment. He remarked that because the Soviet group did not propose a name they apparently did not feel their evidence was very strong.

Commenting on Ghiorso's statement, Flerov said, "Up to the time of the American authors first publication we had already studied all the types of decay of the new element and determined its chemical properties . . . we are fully confident in the authenticity of our data, and for proving the discovery of the new element we shall take advantage of scientific arguments. Therefore, stating that we were not sure of our results since we had not named the new element right away should be considered as the personal opinion of Ghiorso . . . Naturally, there is no accounting for tastes. But unfortunately, there are examples in the history of synthesizing new elements when haste in the announcement of a discovery and naming a new element has led to a situation when a little after the sensation only the name was left, but the nature of it was radically revised (recall even the history of element 102)."

In the 1967 Dubna experiment, Flerov and his collaborators had bombarded Am^{243} with Ne^{22} and observed two alpha emitters (with half lives between 0.1 sec and 3 sec) with alpha energies of about 9.4 and 9.7 MeV. The data suggested formation of ${}_{105}X^{260}$ and ${}_{105}X^{261}$.

The Berkeley experiment, done by Ghiorso, Matti Nurmia, Kari and Pirkko Eskola and James Harris, also used alpha-decay chains to infer the formation of element 105 (PHYSICS TODAY, July, page 58). They bombarded Cf^{249} with N^{15} and found an alpha emitter with 1.6-sec half life and 9.1-MeV decay energy. This alpha group preceded a subsequent alpha decay which they identified as belonging to ${}_{103}X^{256}$, thus providing quite strong evidence that the 1.6-sec activity belonged to 105.

Because LRL and Dubna have long been the only two labs that had the targets and beams to make new heavy elements there has been a continuing set of priority disputes between the two groups. In the past both groups had used a sequence of alpha-decay energy and lifetime measurements to infer production of new elements. But the new Dubna experiment studies instead the spontaneous-fission decay properties.

Flerov bombards Am^{243} with Ne^{22} and observes a spontaneously fissioning isotope with a halflife of 1.8 ± 0.6 sec. The yield corresponds to a formation cross section of $(5.0 \pm 1.5) \times 10^{-34}$ cm^2.

By comparing the angular distribution of recoil atoms with typical curves for compound-nucleus reactions and *multinucleon transfer reactions*, he concludes that the spontaneously fissioning isotope was formed by a compound nucleus. Then Flerov shows that the cross section for formation as a function of excitation energy of the compound system is characteristic of a reaction in which four neutrons are emitted, rather than say three neutrons and a proton or five neutrons. He then concludes that he has formed element 105 in the compound state, that only four neutrons are emitted, and that the mass is 261.

At the present time there is no conflict (except for priority) in that Flerov claims he found ${}_{105}X^{261}$ and Ghiorso that he found ${}_{105}X^{260}$. —GBL

Expand exploration of earth and ocean in 1970's

As an extension of the geodetic satellite program, an Earth and ocean program should be established over the next decade, says a NASA panel, headed by William Kaula (UCLA). In its report, *Solid-Earth and Ocean Physics*, the group outlined a program that would cost \$10 million in the first few years, about \$50 million in the middle of the decade and possibly double that figure. Goals would include:

- Identify the driving forces that account for motions, earthquakes and variations of the gravitational field.
- Study general ocean circulation at all depths.