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.

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.

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 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 difcan be set up in two while the third room receives a beam. A single-gap high-resolution magnetic spectrometer is on order and is expected to arrive in 1972. Roughly half of the machine time is expected to be utilized by university users.

Wegner and Alburger are proud of the tandem's gas-handling system, which was designed by the Brookhaven staff. Unlike typical large Van de Graaffs (which can take about a day to pump the gas out, evacuate the tank, let air in, make the repair, pump the air out, let the insulating gas back in the bank and compress) the double Emperors can each go from beam off to beam on in about four hours. Besides needing large compressors, vacuum pumps and air circulators, the system has an automatic temperature control (which keeps gas temperature controlled within a few degrees) to protect the innards of the accelerator from thermal shock.

The Brookhaven double-tandem project was started by Alburger in 1962 and met its scheduled completion date of July 1970 with two days to spare. Final cost of $12 million was within 1% of the original estimate. —GBL

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negative kaons were stopped. The experimenters not only obtained K-mesic x-ray spectra but also found in sulfur the natural line width and the strong-interaction energy shift as compared with the energy expected from a pure electromagnetic interaction.[4]

After the K meson is captured by the nucleus, Σ^- hyperons are produced by various strong processes. Because the Σ^- has only about 20-MeV energy it is quickly Coulomb captured in the same target as the K meson. The CERN experimenters observed x rays coming from sigmic atoms simultaneously (resolution time of 10^{-8} sec) with the kaonic x rays. Wiegand's experiment on kaonic spectra last year had shown a transition in potassium that could be attributed to a sigmic atom, but the CERN evidence is more complete, as they obtain a series of x-ray lines for three different elements.

As the Σ is heavier (1197 MeV) than a kaon (494 MeV), the strong interaction becomes important at higher orbits and should be able to probe the nuclear surface at nuclear densities only 10^{-3} of that at the center of the nucleus. At a given location the sigmas can determine what the ratio of neutrons to protons is.

To make antiprotonic atoms the experimenters used the same beam, tuning it differently. For each synchrotron burst 300 antiprotons were stopped in the target. Gamma spectra were collected by three lithium-doped germanium detectors (1% resolution) in coincidence with an antiproton trigger. Antiprotonic atoms with several different nuclei between phosphorus and thallium were produced.

Although these latest experiments on exotic atoms offer considerable new information, nuclear theorists have their work cut out for them interpreting the data properly.

In addition to the antiprotonic spectra, the CERN experimenters reported a new determination of the mass of the antiproton. Their value is 938.3 ± 0.5 MeV, making the mass of the antiproton and the proton equal within 0.5 MeV with a confidence of 68%.

Because the x-ray spectra of spin-1/2 particles consist of doublets, if one can observe the line splitting the magnetic moment of the Σ or antiproton can be determined. The CERN group has already seen a broadening of the $n = 10 \rightarrow n = 9$ transition that is consistent with an antiprotonic magnetic moment equal to that of the proton. It remains to be seen whether or not the experimental techniques can be improved sufficiently to obtain the magnetic moment of the Σ from a measurement of the fine-structure splitting. —GBL

References

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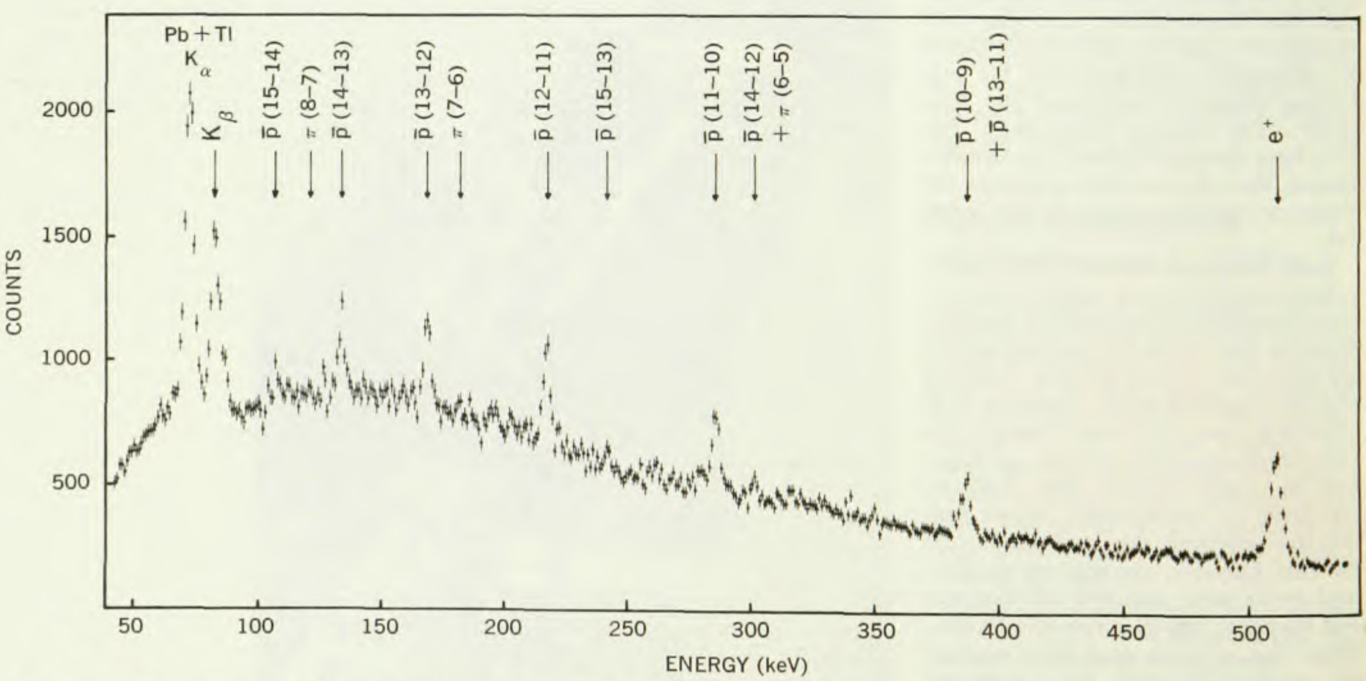

Antiprotonic x-ray spectrum of Tl^{81}. Peaks correspond to atomic transitions, disappear when antiproton is captured by nucleon.