AAGE BOHR

HUUS

BOEGGILD

MOELLER

nations. For example, mainland Chinese have been among the physicists there. They have had a density of two per year for the past three years. The last delegates have just left and so far no replacements have been designated. The institute has also been the source of several joint Soviet-American papers.

1921 STAFF was, from left, standing, J. C. Jacobsen, S. Rosseland (Norway), Georg Hevesy (Hungary), H. M. Hansen, Niels Bohr; sitting, J. Franck (Germany), H. A. Kramers (Netherlands), B. Schultz, secretary.

We lunched there recently with Aage Bohr, son of Niels and the present director, sharing smørrebrød in the institute lunchroom. The atmosphere was informal and easy; visitors from Sweden and Poland joined us along with Torben Huus of the Van de Graaff group. Bohr, Huus and Jørgen Bøggild (high energy) form the three-man council that governs the organization.

The present institute has a permanent staff of 40 to 50 (depending on how you count), about 50 visiting scientists from about 18 nations and about 100 graduate students of the University of Copenhagen (of which it is a part).

Activities. Most visitors come with funds provided by their own countries. Some have scholarships from the International Atomic Energy Agency, the United Nations Scientific and Cultural Organization (UNESCO) and the North Atlantic Treaty Organization. Some are financed by the institute itself; for example, the Ford Foundation has provided $150 000 to be used for visitors in the next five years.

Another prominent bit of stimulus is from NORDITA (Nordic Institute for Theoretical Atomic Physics), the Danish, Finnish, Icelandic, Norwegian, Swedish organization, which supports four staff members and 10–15 visitors at the Bohr Institute each year. Two of the NORDITA staffers are Ben R. Mottelson, who is widely known among nuclear physicists as a colorful and stimulating person and who is now at work with Bohr on a book about nuclear structure, and Leon Rosenfeld (editor of the North-Holland journal *Nuclear Physics*).

About two-thirds of the institute activity goes to nuclear structure study and uses the institute Van de Graaff, its often rebuilt cyclotron, its tandem accelerator located near the Danish atomic energy laboratory at Risø and an Aldermaston (England) Van-de-Graaff – spectrometer combination. Other concerns are high energy (with work at CERN), general relativity (under Christian Møller) and many-body theory. Solid-state is not included because it is part of the program of another university department that combines work in chemistry, physics and mathematics. Bengt Strømgren, recently returned from the Institute for Advanced Study and now holding a chair in astrophysics at Copenhagen University, is joining the activities.

History. Niels Bohr became a Copenhagen professor in 1916 and, with the help of the Carlsberg Foundation (which still contributes), many individual Danes and the Danish government, founded the institute. Its first building was completed in 1921. For years the organization was a meeting place, and a list of visitors who have spent significant periods of study there includes such great names as Lise Meitner, Léon Brillouin, Werner Heisenberg, Georg Hevesy, Edward Teller, Homi Bhabha, Bruno Rossi, H. A. Kramers (Niels Bohr's first assistant in Copenhagen), Felix Bloch, Paul Dirac, Nevill Mott, R. Bruce Lindsay, Harold Urey, Lev Landau. The original building is now one of ten; the population is about 30 times the eight persons (including secretary) who posed for a picture in 1921.

Amid the distractions of easy communication and rapidly moving persons, it is not easy to maintain the old atmosphere when everyone around learned to talk Danish in his work. But many alumni return frequently, and the residents make a desperate effort to defend the old customs. One hopes that they will always be successful. —RHE

High Isobaric Spin States Are Found in Light Nuclei

Nuclear physicists are enthusiastically exploiting their new ability to observe states whose isobaric spins are higher by one or two units than the ground state in light nuclei. During the past few years experimenters have located the lower $T = 3/2$ (where low-lying states are $1/2$) and $T = 2$ (where low lying states are 0) states in most of the light nuclei. Since excited states are

spread widely in energy in the light nuclei, high T states occur at high energy, and to produce them one needs an electrostatic accelerator (4–20 MeV) or an intermediate-energy cyclotron (about 50 MeV) with good energy resolution.

Isobaric spin multiplets have interested nuclear physicists ever since charge independence of nuclear forces was proposed. A multiplet with total isobaric spin T has $2T + 1$ members; the members of the multiplet are characterized by a z component of isobaric spin T_z [where $T_z = (N - Z)/2$] that ranges from $-T$ to $+T$ in integral steps. Until recently one only knew about two or at most three members of the same multiplet. Now with higher T states one can reach all the members of an isobaric quadruplet ($T = 3/2$) or even a quintuplet ($T = 2$).

The isobaric-multiplet mass equation suggested by Eugene Wigner (and demonstrated several years ago by Sam Treiman and Steven Weinberg) says that the mass of any member of an isobaric multiplet can be expressed as $A+BT_z+CT_z^2$ (the constants are different for each multiplet). With triplets one can merely determine A, B and C. But, as Denys Wilkinson and Gerald Garvey have stressed, with quadruplets and quintuplets the equation is overdetermined and thus can be checked. This has been done with high precision for the lowest mass-9 quadruplet by Charles Barnes and his collaborators at California Institute of Technology. The deviations found were of order α, the fine structure constant, as would be expected from the next terms in a perturbation expansion.

The Cal Tech results are consistent with the belief that the interrelations between nucleons in the $T = 3/2$ states of Li^9, Be^9, B^9 and C^9 are independent of whether the nucleons are protons or neutrons, and that therefore these states of the four nuclei are essentially identical from the nuclear point of view.

Several other quadruplets have been checked with less precision by Joseph Cerny and his collaborators at the University of California, Berkeley, and found to agree well with the mass formula.

Conservation of isobaric spin requires that isobaric spin remain constant in a reaction that involves only strongly interacting particles. This selection rule is not 100% obeyed, however, because the Coulomb field causes a weak mixing of the different isobaric spin states. So one can look at forbidden reactions, which are not "allowed" but nonetheless occur.

Allowed reactions. To observe high T states in allowed reactions one needs high energy (from the beam or the energy released by the reaction) and good beam quality. The states are several MeV into the continuum, so they are sitting on a very messy background of broad, overlapping continuum states. But since they are relatively narrow and have simple configurations, if one chooses the right reaction they can be made to stick out like needles above the background.

At Berkeley, Cerny, Garvey, Richard Pehl and others have used the 88-inch cyclotron and the reactions p,t and p,He^3 to reach $T = 3/2$ and $T = 2$ states in a large number of nuclei, starting with $T = 1/2$ and $T = 1$ target nuclei. Garvey and Benjamin Bayman had observed that essentially the reaction removes two nucleons from the target nucleus.

Instead of "double pick-up" reactions, Charles Barnes, Eric Adelberger, David Hensley, Arthur MacDonald and Patrick Nettles at Cal Tech have used the "double-stripping" reactions He^3,n and He^3,p on $T = 1/2$ and $T = 1$ target nuclei to reach the higher isobaric spin states. To a large extent the two methods of identifying higher isobaric spin states are in excellent agreement.

Forbidden reactions. To find high T states in forbidden reactions one needs the fine energy control and small energy spread associated with an electrostatic accelerator. Because the state is so narrow, however, one can learn a lot about isobaric spin purity since the interference of the state with the background of wider states will be dynamically simple. The resonances are so sharp, in fact (some as narrow as 100 eV), that they are ideal as calibration points at high excitation energies. (C^{12} + p, for example, has a resonance at 14.231 MeV, and one can use it to calibrate magnetic analyzers.)

Georges Temmer and his collabora-

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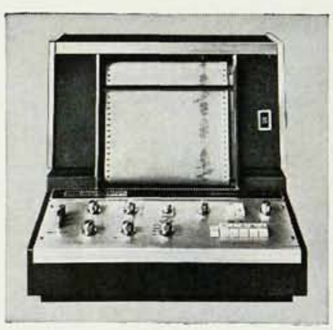

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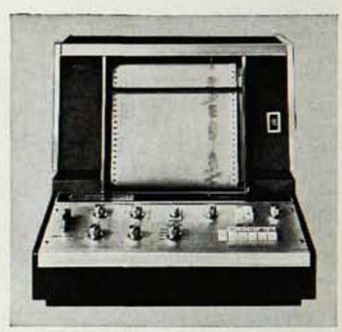

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tors at Rutgers University, as well as other groups at Yale University, Stanford University, Zürich University and Cal Tech, have observed a number of the high T states in "twice-forbidden" reactions; these are reactions in which both formation and decay of the high T state are forbidden by the isobaric spin selection rule $\Delta T = 0$. An example of such a reaction would be $O^{16} + p \rightarrow F^{17}$ $(T = 3/2) \rightarrow N^{13} + \alpha$. In both initial and final nuclear configurations the combined isobaric spin is 1/2. In spite of the severe hindrance produced by the near-conservation of isobaric spin, the high T states have been seen in this way in many nuclei because there are no "wide-open channels" (isobaric-spin allowed decays) to broaden the states.

The isobaric spin selection rule for gamma decay is $\Delta T = 0$ or ± 1; hence a gamma transition from a $T = 3/2$ state to a low lying $T = 1/2$ state is allowed. So a reaction like $Mg^{24} + p \rightarrow Al^{25}(T = 3/2) \rightarrow Al^{25} + \gamma$ is once forbidden (in the formation but not the decay). This reaction has been studied by David Youngblood, George Morrison and Ralph Segel at Argonne National Laboratory. The Al^{25} decays by positron emission to Mg^{25}, and they infer from the positron emission that the proton was captured. The Argonne group and Stanley Hanna, Frank Dietrich, Martin Suffert and A. V. Nero at Stanford University have studied this type of process by observing the capture gamma rays directly.

With a $T = 2$ state in a $T_z = 0$ nucleus one has the opportunity to search for a $\Delta T = 2$ gamma transition. The gamma-decay spectra of the lowest $T = 2$ state in both Mg^{24} and Ne^{20} have recently been examined carefully by Hanna, F. Riess, W. J. O'Connell, D. W. Heikkinen and H. M. Kuan, who formed the state by the once-forbidden combinations $Na^{23} + p$ and $F^{19} + p$. At the resonance corresponding to the lowest $T = 2$ state, the Stanford group found a strong gamma-ray cascade through a $T = 1$ state at lower excitation, and thence to the $T = 0$ ground state. They found no evidence for a $\Delta T = 2$ gamma transition, in agreement with the predictions of quantum electrodynamics. —GBL □