PROPOSAL FOR THE STUDY OF K-MESIC ATOMS

by
G. Backenstoss and H. Daniel
CERN - Heidelberg - Karlsruhe
(proposal received 15 June 1967)

Measurements of the electric dipole transitions in K-mesic atoms provide a tool for the investigation of the interaction between the K meson and the nucleus at zero momentum, as well as for the study of the properties of the nucleus, particularly its surface. Furthermore, an exact measurement of a suitably high K-mesic X-ray transition will yield an independent determination of the K⁻ mass with an accuracy improved by a factor of 2.

The knowledge obtained from studies on K⁻-mesic atoms should be considered together with the information obtained from μ⁻- and π-mesic atoms. Muonic atoms have given very detailed information about the electric charge distribution of the nuclei. Pionic atoms show in addition effects which result in a shift of the energy levels of the mesic atom and a broadening of its level due to the strong pion-nucleus interaction. Furthermore, the magnitudes of these effects depend on the nucleon distribution and on the correlation of the nucleons in the nucleus. The levels of K-mesic atoms would depend on the K-meson-nucleus interaction on the nucleon distribution, especially at the nuclear surface, but not on the nucleon correlations, provided multi-nucleon K⁻ interaction is neglected. It should be possible at a later stage to decide whether the K⁻ meson has been captured by a proton or
by a neutron by observing the (Am^3) or the (Am^-) capture products as described in a recent proposal by Burhop et al.

As a first step we propose to measure the K-mesic X-ray transitions in a representative number of elements. The following transitions may be observable according to the calculations of Eisenberg and Kessler¹):

\[
\begin{align*}
3d-2p & \quad \text{for } 3 \leq Z \leq 7 \quad \text{with energies (keV)} \quad 15 < E < 80 \\
4f-3d & \quad " \quad 5 \leq Z \leq 15 \quad " \quad 15 < E < 135 \\
5g-4f & \quad " \quad 8 \leq Z \leq 30 \quad " \quad 20 < E < 250 \\
6h-5g & \quad " \quad 11 \leq Z \leq 50 \quad " \quad 20 < E < 400 \\
7i-6h & \quad " \quad 15 \leq Z \leq 80 \quad " \quad 20 < E < 600 .
\end{align*}
\]

At the upper limit of the indicated Z region the yields may be expected to be as low as 10%, and a considerable broadening of the lower level of the transition may occur. While the yields and level broadenings depend strongly on the exact knowledge of the K-nucleus potential, it should be remarked that always suitable Z values can be found at which yields and widths can be observed.

For the determination of the K^- mass, a high X-ray transition has to be selected for which the influence of the strong interaction shift can be neglected or be safely derived from lower transitions, and for which the finite size effect and vacuum polarization are small and calculable. With a method similar to that which we used for measuring the ^16O - ^18O isotope shift in muonic atoms, an accuracy of about 25 eV should be possible, yielding an error in the K^- mass of at least 1: 6000 = 0.017%, whereas the presently accepted K^- mass has an error of 0.035%. Therefore, the method provides a completely independent measurement of the K^- mass which will improve the accuracy of the measurement by at least a factor of 2.

The feasibility of the detection of K-mesic X-rays has recently been shown by the Berkeley group²) stopping ~ 25 K^-/pulse, i.e. 5/sec. However, the transition energies of real interest are the ones with relatively low yields and observable broadening. Therefore, we feel that in view of our earlier experience and the possibility of producing
a more intense $K^-$ beam at CERN, the field of K-mesic X-rays should be very rewarding at CERN.

It is further conceivable that also X-rays originating from $\Sigma^-$ atoms can be observed. The captured $K^-\Sigma$ mesons produce $\Sigma^-$ hyperons in 10-20\% of the cases. Their range in all practically usable target materials is sufficiently short, so that the majority of the $\Sigma^-$ stop in the target before they decay, thus having a good chance to be captured by a target atom. A high-yield $\Sigma^-$ X-ray, therefore, should not be more difficult to observe than a low-yield $K^-$ X-ray.

The experimental problems involved in measuring energies, yields, and line widths of K-mesic X-ray transitions are very similar to those we are at present experiencing with the detection of these effects in pionic atoms. Even the energy region of interest is very much the same in both cases. Therefore, the presently used techniques with Li-drifted Ge detectors would be applied where only the efficiency of the system has to be improved by increasing the area of the detector, which can be done by using several detectors. Such an improvement is already in progress for the pionic experiment. Only for the smallest energies indicated, i.e. for the smallest $Z$ values, the Ge detectors must be replaced by Si detectors. However these transitions are not of particular interest.

The geometry of the experimental layout has to be designed such that the $K^-\Sigma$ mesons are stopped in a relatively thin target, since the X-rays to be observed have rather low energy and, therefore, self-absorption of the X-rays in the target is important. However, a momentum bite of $\pm$ 2\% of an incident $K^-$ beam of 300 MeV/c seems to be tolerable provided the beam profile does not exceed 2 cm in at least one dimension. Then the target would be long in beam direction to cover the width of the $K^-$ range with a cross-section adapted to the beam profile, the detectors viewing the target from the broad side.

The purity requirements for the $K^-$ beam are not at all severe; one can discriminate against pions in the beam by two means. Firstly, a Čerenkov counter will be used in the beam telescope to reject the pions,
putting it in anticoincidence with the $K^-$-defining beam telescope. Secondly, the range of pions having the same momentum as the $K$ mesons is sufficiently larger than the range of the $K$ mesons, so that the $K$ mesons can be separated from the pions. However, the number of pions which can be tolerated in the beam is not so much a question of the rejection ratio for which we could easily obtain about $1:10^5$, but it is determined by the loading of the solid-state detectors, which results in a loss of resolution of the detectors and depends on the kind of background produced in the detectors by the pions passing through the target. However, it would seem safe to accept $10^2 - 10^3$ as may pions as $K$ mesons in the incident beam.

To estimate the PS time needed, we are in the position to use very representative measurements obtained with $\pi$ mesons from a 20 g H$_2$O target producing the 2p-1s transition in $^{16}$O which has a low yield of only about 2% and an energy of 160 keV. With the present set-up, about 70 events/h could be observed for 1000 $\pi^-$/sec stopped in the target. An increase of the counting efficiency by at least a factor of 2 is foreseen. Assuming that 10,000 X-ray quanta must be recorded in order to obtain a very good determination of the position and width of a broad line with a yield of 10%, about one day of PS time would be required provided 1000 $K^-$/pulse are stopped. This time is needed for the most interesting low-yield transitions, whereas the accumulation of other transitions should be correspondingly quicker.

Under the assumption that 1000 $K^-$/pulse could be stopped, the measurement of $K^-$ X-ray transitions in about 12 elements would require eight days of PS time. Four days are needed for the determination of the $K^-$ mass. For setting up the experiment, and for background and shielding tests, some parasitic time will be needed.

The proposed experiment will be carried out by the present CERN-Heidelberg-Karlsruhe group (C. Backenstoss, S. Charalambous, H. Daniel, H. Koch, M. Kroll, G. Poolz, H. Schmitt and L. Tauscher).