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Feasibility of Nuclear Polarization of $^3He^{++}$ Ions by Electron-Transfer Processes

O. Karban, S. W. Oh,* and W. B. Powell
Department of Physics, University of Birmingham, England
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Preliminary results are reported of an experiment confirming the feasibility of a Lamb-shift source of polarized $^3He^{++}$ ions. Such a source is under construction and will be used for the axial injection of ions into a cyclotron.

The source to be briefly described is the outcome of various theoretical and practical studies made at Birmingham University since 1962 into the possibility of axially injecting a beam of polarized $^3He^{++}$ into a cyclotron. Consideration of the successful Lamb-shift sources for hydrogen ions[1] led to the idea[2] of a ^3He ion source based on the same principle. A beam of polarized $^3He^{++}$ ions can be achieved using the following sequence of processes: (a) the production of a beam of $^3He^+$ ions, containing a certain fraction of ions in the 2*S* metastable state; (b) the polarization of the electron spin state of the $^3He^+(2S)$ ions by electric-field quenching of unwanted components to the short-lived $^3He^+(2P_{1/2})$ state; (c) the partial transfer of electron polarization to nuclear polarization through hyperfine coupling; (d) the subsequent ionization of the $^3He^+(2S)$ ions to $^3He^{++}$ with discrimination against ionization of the unpolarized background beam of $^3He^+(1S)$.

The magnitude of nuclear polarization of the final $^3He^{++}$ beam depends mainly on the ratio of the electron capture cross sections σ_{21^*} and σ_{21} in process (a) and also on the ratio of the two electron-loss cross sections σ_{1^*2} and σ_{12} in process (d). Here 2 refers to the doubly ionized and 1 to the singly ionized atom, with 1* denoting the metastable state.

Since no experimental information was available on the above cross sections in the energy region considered (about 30 keV for the optimum cyclotron injection energy), an experiment was performed to establish the combined effect of processes (a) and (d). The experiment determined the fraction of the final $^3He^{++}$ beam resulting from electron loss by the $^3He^+(2S)$ component, and also the overall efficiency of both the electron-transfer processes.

A sketch of the experimental arrangement is shown in Fig. 1. Both electron-transfer processes took place in canal-shaped gas targets GT_1 and GT_2 operating at pressures low enough to avoid multiple collisions. The required

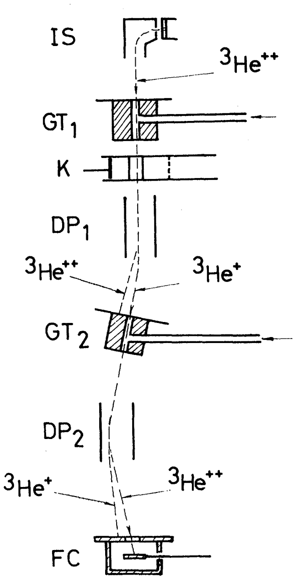

FIG. 1. Sketch of the experimental arrangement for investigation of electron-transfer processes with incident $^3He^{++}$ ions showing ion source (IS), gas targets (GT_1 and GT_2), electrostatic deflection plates (DP_1 and DP_2), microwave cavity (*K*), and Faraday cup (FC).

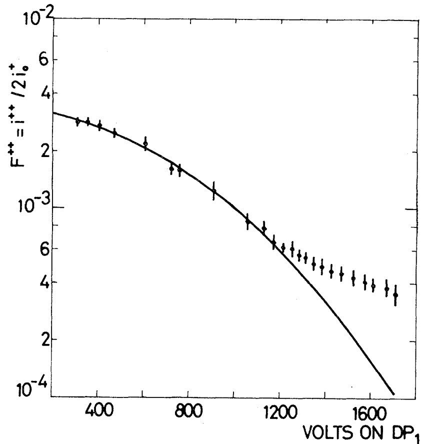

FIG. 2. Fractional yield of $^3He^{++}$ from the second gas target as a function of the quenching field for a 23-keV $^3He^{++}$ beam incident on the first gas target. Nitrogen gas was used in both targets.

charged components, selected by the electrostatic deflection plates DP_1 and DP_2, were measured in the Faraday cup FC. Several combinations of conventional gases were investigated for the energies in the range 16–35 keV. The initial $^3He^{++}$ beam was formed in a cyclotron-type ion source IS with a hooded arc.

Assuming preferential ionization in GT_2 of the (2S) component of the $^3He^+$ beam emerging from GT_1, the resulting $^3He^{++}$ beam at DP_2 should depend on the ratio $^3He^+(2S)/^3He^+(1S)$ after GT_1. Thus, the fraction of $^3He^{++}$ beam formed by electron loss from the metastable state can be determined by introducing a quenching device between the gas targets. A typical result using electrostatic quenching by the dc field in DP_1 is presented in Fig. 2, where the ratio $F^{++}=i^{++}/2i_0^+$ is plotted as a function of the voltage on DP_1 (i_0^+ represents the $^3He^+$ current with no gas in GT_2). As can be seen, the ratio F^{++} decreases by a factor of 7 as the quenching voltage increases from 300 to 1700 V. This indicates that the "background" due to the ground-state ionization does not exceed 15%. The solid line in Fig. 2 is a theoretical quenching rate for a pure $^3He^+(2S)$ beam normalized to low-field experimental points. As an independent and direct check on the above result rf quenching was also used. This has the advantage that no $^3He^+$ current measurement is required. The $^3He^+$ beam was passed through a klystron-fed cavity (K in Fig. 1) tuned to 14 GHz to induce transitions between the $2S_{1/2}$ and $2P_{1/2}$ states of $^3He^+$ ions. The ratio of the $^3He^{++}$ currents with the klystron off and on was between 5:1 and 6:1, which is in agreement with the value measured by the dc method. With the assumption of no significant loss of metastable beam except by process (b), the nuclear polarization of the injected $^3He^{++}$ beam should not be less than 35%. A detailed description of this experiment and of the polarized ^3He ion source which is now being constructed will be the subject of a further communication.

Individual cross sections of the processes involved are at present being investigated at the Queens University, Belfast. Preliminary data[3] indicate that the $^3He^+(2S)$ and $^3He^+(1S)$ ions are formed approximately in the ratio of 1:20. This value combined with the above results indicates that the electron loss from the metastable state is enhanced by a factor of about 100.

We are indebted to Professor Hasted of London University for encouraging us in the belief that the cross sections would be large enough to lead to a viable polarized ^3He source, and to Professor Gilbody for communicating his preliminary results. We are also grateful to Professor Burcham for his constant interest in this work and a critical discussion of the results.

*Present address: University of Manitoba, Winnipeg, Canada.

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