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8.12 On Universal Source for Polarized Heavy Ions

N.I.Zaika and A.V.Mokhnach

Institute for Nuclear Research of the Ukrainian Academy of Sciences, Kiev,USSR

An universal scheme of the polarized ion production is based on the method of the polarized electron attachment to an ion, as proposed firstly by Zavojsky [1] to obtain polarized hydrogen atoms. When the ion with the nonpaired polarized electron enters in a magnetic field the nucleus is partially polarized due to the hyperfine interaction, vector polarization for the polarized S-electron can reach value $P_z=1/(2s+1)$. Forming H-, Li-, Na-, K-like and other similar multiply-charged ions one can generate a wide range of the polarized ions [2]. For $3 \leq Z \leq 20$ region there are 14 isotopes of 11 elements with nonzero spin and with essential contents in natural mixture to be candidates for the production of the polarized multiply-charged ions using this method: $^{6,7}Li$, ^{9}Be, $^{10,11}B$, ^{14}N, ^{19}F, ^{23}Na, ^{27}Al, ^{31}P, $^{35,37}Cl$, ^{39}K. Ions similar H,Li,Na atoms have levels coincided with the state scheme of these atoms allowing for the Z^2 factor, for $l \geq 2$ Li- and Na-like ions have terms coincided with those of hydrogen-like systems with $Z=q$ [3]. Taking into account transition probability data for hydrogen-like system and l uniformity of population for the most probable population of states with large n to capture the electron by C^{6+} and O^{8+} ions in hydrogen [4] one can show that the ion ground state $1S_{1/2}$ is formed mainly through $nP \rightarrow 1S$ ($\sim 1/3$) and $2P \rightarrow 1S$ ($\sim 2/3$) transitions. Experimental data prove the theory conclusion on the maximum probability of the electron exchange for the nonsymmetric systems at $\Delta E \approx 0$ [5]. This condition is realized in multiply-charged ion-atom collisions when the capture takes place in the high lying states. One would expect the similar scheme for the ground state formation in the case of Li- and Na-like ions [2].

The captured electron depolarization owing to the spin-orbit coupling is estimated as in reference [6], it is less for strong fields H in the charge exchange region. If $H \lesssim 1$ T the expected polarization equals $(0.4 \div 0.6)/(2S+1)$. To avoid depolarization in fringe fields of the acceleration and transport systems the odd electron in nS state can be removed by the second charge exchange.

The heavy ion polarized source scheme based on this principle is showed in Fig.1. The beam from the polarized alkaline atom source (PAS) is aligned with the A^{q+} beam from the multiply-charged heavy ion source (HIS) in the first charge exchange region. Ions with the picked up polarized electron $A^{(q-1)+}$ are extracted by the separator S_1, accelerated by the electrostatic accelerator (EAC) and focused into the stripping carbon foil. The ion component A^{q+} is extracted by the second separator S_2.

High intensities of the initial heavy ion and high efficiency of charge exchange are necessary to achieve essential intensities of polarized heavy ions. For highly ionized heavy ions with energy up to tens of keV/A.M.U. cross sections for the electron pick up practically do not depend on ion energy and the structure of the residual electron shell and are of order 10^{-15} cm^2 [4,7].

The first charge exchange efficiency can be about $\varepsilon \simeq 0.1$ with the polarized atom density about $n \simeq 10^{14}$ cm^{-2}, it is available if one uses the modern dye-laser optical pumping [8].

The second charge exchange $A^{(q-1)+} \rightarrow A^{q+}$ efficiency depends on the energy of outgoing ions and is defined by the relation

$$E/A = e\ (V_s+V_a)q-V_a$$

V_s is close to V_a/q when stripping occurs in the carbon foil and the energy of ions $\vec{A}^{q+}$ injected into the main accelerator is small. Using this PHIS scheme for $^{13}C^{4+}$ the efficiency of $^{13}\vec{C}^{4+}$ transformation can reach a few percentage taking account intensity losses in the first and the second charge exchange regions if V_s and V_a would be 80 and 255 keV, respectively. Energy of polarized ions will be approximately 5 keV/A.M.U. for these conditions.

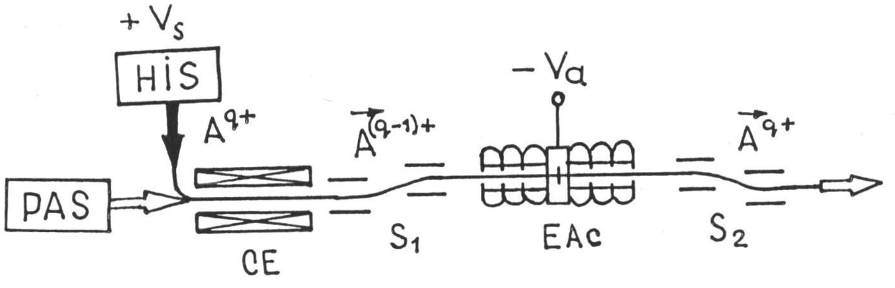

Fig. 1. Polarized heavy ion source (PHIS)

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