Development of Polarized Radioactive Nuclear Beams I
— Polarization Analyzer Based on Beam-Foil Spectroscopy —

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We propose a method to produce spin-polarized radioactive nuclear beams for the spectroscopic studies of exotic nuclei. The nuclear polarization is produced in the following procedure, as in the polarized proton or ^{3}He ion-sources: (i) The spin polarization of the outermost electron of Rb atom is produced by the laser optical pumping. (ii) The radioactive nuclear beam passes through the Rb vapor and the nucleus picks up the polarized electron into its atomic state. (iii) The hyperfine interaction between the nucleus and the electron induces the nuclear polarization. The feasibility study of this method is in progress at the test bench in the East Experimental Hall. The layout of the test bench is shown in Fig. 1. The beam of stable nucleus at a few keV/amu is supplied from the compact ECR ion-source. The beam then goes through the Rb cell where high density Rb vapor is contained, and the beam ions pick up the spin polarized electron from Rb atoms, and finally the beam ions reach to the beam-foil spectroscopy system where the nuclear polarization is measured through the atomic transition.

The construction of the test bench will be completed soon. Some parts of the apparatus have been tested so far. Two major achievements to be mentioned are (i) the accomplishment of a highly precise polarimeter system for the beam-foil spectroscopy measurement, which is used to measure the polarization of stable nucleus and (ii) the success of the optical pumping of the Rb atoms. The former achievement is reported in the following. The latter one is described in the adjacent report.

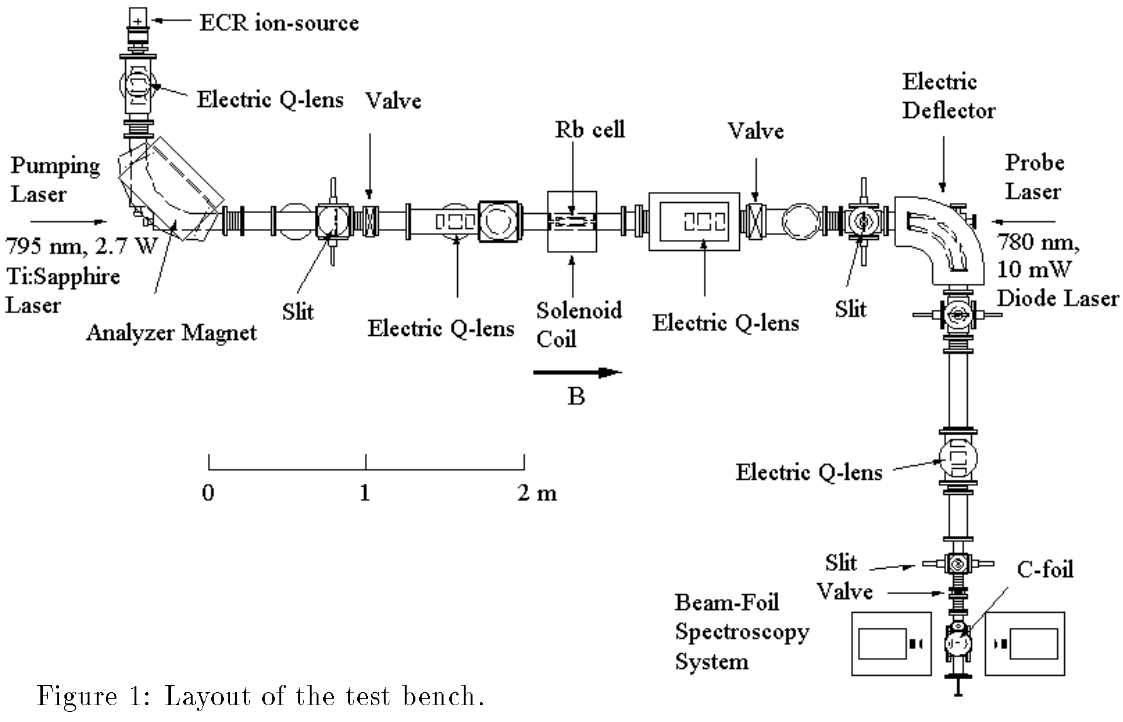

Figure 1: Layout of the test bench.

Prior to the completion of the test bench, the beam has been directly led into the beam-foil spectroscopy system in order to investigate the performance of the polarization analyzer in the beam-foil system. The principle of the analyzer is as follows: In the analyzer a thin carbon foil (1.5 μg/cm^2) is set on the beam axis and the beam passes through the foil. Before reaching to the foil the polarization is shared by the electrons and the nucleus. At the moment of interaction with the foil, the atomic polarization is completely destroyed due to the multiple atomic collisions, whereas the nuclear polarization remains the same. After passing through the foil, some of the atomic excited states are populated and then the hyperfine interaction induces atomic polarization from the nuclear polarization. The atomic polarization causes circular polarization of the de-excitation lights, i.e. fluorescence. The nuclear polarization therefore can be measured through the atomic transition. The fluorescence emitted in the direction of polarization, which is perpendicular to the beam axis, is focused by lenses to the polarimeter system consisting of a $\lambda/4$ plate, a linear polarizer, a monochromator and a photo-multiplier tube. We have installed two identical systems along the polarization axis in the both sides to the beam direction. This helps to large extent to eliminate spurious polarization such due to fluctuation of the beam intensity as well as the beam position.

In order to test the performance of the polarimeter, the tilted foil technique has been used: When the foil is tilted as shown in Fig. 2 atomic polarization is produced in the direction $\vec{n} \times \vec{v}$, where $\vec{n}$ and $\vec{v}$ denote the normal direction to the foil surface and the beam direction, respectively. The fluorescence is detected in the direction of polarization i.e., perpendicular to the surface of Fig. 2. Figure 3 shows the experimental results of the atomic polarization as a function of the tilt angle for the ^{1}P $\rightarrow ^1$D transition in N$^+$ ion (wavelength 399.5 nm) at the beam energy of 1.7 keV/amu. The foil was set 2 mm upstream the optical axis of the polarimeter. It is clearly shown that the polarization smoothly depends on the tilt angle as predicted by the "torque model". It is to be noted that at the tilt angle of 0 ° the polarization is consistent with 0. This means that the spurious asymmetry has been successfully cancelled out.

It should be pointed out that the beam energy in this experiment is the lowest in the tilted foil experiments so far. Polarization at such a low beam energy has been confirmed for the first time. In this measurement a remarkable amount of polarization has been conveniently obtained just by setting a tilted foil in the beam line. This method is possibly a versatile way to obtain a moderate amount of polarization for beams directly from ISOL.

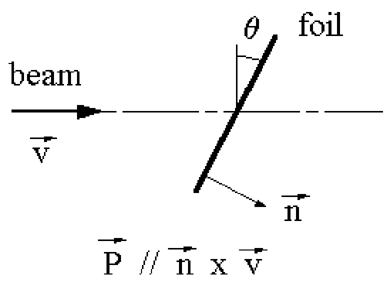

Figure 2: Polarization in the tilted-foil experiment.

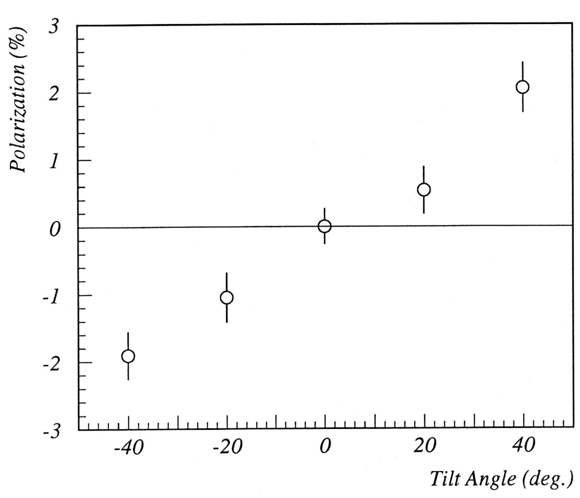

Figure 3: Atomic polarization as a function of the foil tilt angle.