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POLARIZED He^3-ION BEAM*

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We report in this Letter the production of a positive-ion beam of polarized He^3. The intensity, ion-optical quality, and polarization of the beam make it suitable for injection into appropriate accelerators for use in nuclear scattering studies and nuclear structure research. A nuclear polarization of 0.05 in the beam has been directly measured by means of a nuclear double-scattering experiment, during which the beam intensity was 3 to 4 mA and the emittance approximately 1 cm rad $eV^{1/2}$.

An optical pumping technique[1] is used to produce the polarization. In this method, He^3 gas at typically 1 Torr is contained in a glass bulb and a weak electrodeless rf discharge is maintained in the gas. Metastable atoms in the 2^3S_1 ($F=\frac{3}{2}$ or $\frac{1}{2}$) state are produced in the discharge and may be polarized by means of optical pumping with circularly polarized (2^3P-2^3S) resonance radiation. This polarization is subsequently transferred to the much more numerous 1^1S_0 ($F=\frac{1}{2}$) ground-state atoms via spin-exchange collisions.[2] In the production of a polarized ion beam we make use of the fact that ions are also present in the discharge and may be extracted by standard rf ion-source techniques.[3]

The mechanism for production of ions in a helium rf discharge is not fully understood, so it is difficult to make any a priori assumptions about the polarization of new ions as they are formed in the discharge. Regardless of their initial polarization, however, one may reasonably expect that the ion polarization will come into equilibrium with the ground-state polarization prior to extraction; by virtue of the very large ($\simeq 10^{-15}$ cm^2) cross section for electron exchange in He^+-He collisions,[4] the average ion will make many (10 to 10^3) electron-exchange collisions as it drifts the several millimeters' distance to where it is extracted.

The experimental apparatus for producing the polarized He^3-ion beam and measuring its polarization is shown in Fig. 1. Resonance radiation from a bright He lamp is circularly polarized and shines on the glass optical pumping cell of about 100-cc volume in which a weak rf discharge is maintained. Because we must extract the He^3 ions from the cell an exit canal is provided. The extraction geometry, which

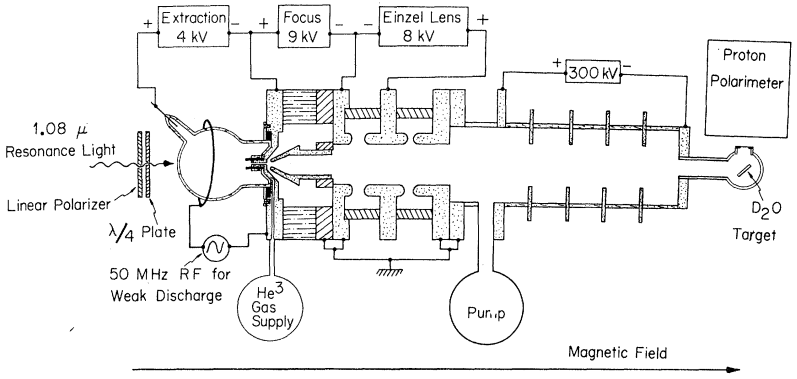

FIG. 1. Schematic view of apparatus used to produce a beam of polarized He^3 ions and to measure their polarization. A description of this figure is given in the text. The part of the drawing showing the optical pumping cell, the gap lens, and the einzel lens is approximately to scale.

has been the object of study by many authors,[5] is identical to that commercially available[6] with the exception that the exit canal is of smaller dimensions than usual (0.0135 in. diam by 0.080 in. long in the narrowest portion). The small exit-canal aperture is necessary to keep the He^3 pressure high enough and the mean time that a He^3 atom spends in the bulb long enough (in this case 0.4 Torr and 16 sec, respectively) so that an appreciable polarization by the optical pumping process is obtained. Fresh He^3 gas is supplied at a rate of about 5 cc STP per hour and is purified by passing it through a trap cooled to liquid-helium temperatures. Ions in the discharge are swept toward the exit canal by the extraction voltage and some pass through it to be accelerated. After the ions pass through the exit canal they are focused with conventional ion optics. Without an extensive search for optimum operating conditions we have obtained a beam described in the first paragraph.

The nuclear polarization in the ion beam was directly measured in the following way: The He^3 ions were accelerated to about 300 keV and were stopped in a frozen D_2O target. At these energies the reaction $He^3 + D^2 \rightarrow p + He^4 + 18.35$ MeV proceeds almost entirely through a $\frac{3}{2}^+$ resonance in the Li^5 system.[7] Assuming that s waves initiate the reaction, the polarization of the 15-MeV protons emitted from the reaction at 90° with respect to the He^3 polarization direction is given by the reaction

$$\vec{P}_p(90°) = -\tfrac{2}{3}\vec{P}_{He^3}.$$

The proton polarization was then measured by observing the asymmetry in scattering from He^4. A high-pressure He^4 polarimeter of a design similar to that of Lush, Griffith, and Imrie[8] with a calculated analyzing power of 0.6 was used. The He^3 ion polarization was thus taken to be 2.5 times the scattering asymmetry of 0.0227 ± 0.0033 observed in the proton polarimeter. By reversing the sense of circular polarization of the pumping light in the optical pumping process, the ion polarization may be reversed, allowing the effects of any instrumental asymmetries to be canceled out. The gas polarization in the optical pumping cell was measured by means of an optical technique[1,9] to be 0.05 ± 0.01, which, within experimental error, is the measured value of the ion polarization. This substantiates our expectation that ionization exchange collisions do, in fact, bring the ion polarization into equilibrium with the ground-state atom polarization before extraction. It also indicates that possible depolarizing collisions with the walls of the exit canal do not seriously degrade the beam polarization.

An ion source such as that described here is ideally suited for installation in an accelerator because of its simplicity. High-pumping-speed vacuum systems of the type found in conventional atomic-beam apparatus are not necessary because of the small gas load. Sophisticated cryogenic apparatus, which would be necessary for obtaining atomic beams of polarized He^3 by inhomogeneous magnetic field separation,[10] is not needed. The problem of ionizing the neutral polarized He^3 atoms is much simplified because they are ionized by an rf gas discharge in an almost closed glass bulb rather than in a crossed-beam configuration. The ion polarization, as mentioned above, is reversible with no effect on particle trajectories. The components are either commercially available or easy to build.

Further improvements in the polarized-beam intensity and polarization are very likely possible, but to optimize the parameters of the ion source it will be more efficient to use a beam accelerated to at least several MeV so that single-scattering determinations of the polarization are possible.

A more detailed report on the construction of this ion source is being prepared for publication.

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ISOTOPIC DISTRIBUTION OF SODIUM FRAGMENTS EMITTED IN HIGH-ENERGY NUCLEAR REACTIONS. IDENTIFICATION OF ^{27}Na AND POSSIBLE EXISTENCE OF HEAVIER Na ISOTOPES

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While the emission of light nuclei in high-energy nuclear reactions has been known for some time, it still appears desirable to have more experimental data to understand the reaction mechanism. It has recently become possible to use a mass spectrometer on line with an accelerator beam to measure yields for isotopes of alkali elements regardless of their half-life.[1] This information cannot be supplied by the conventional methods (emulsion, radiochemistry), and the particle identifying techniques seem to be limited at present to a region below the Na isotopes.

The purpose of this note is to report on an experiment on the Na isotopes which we have performed at the CERN proton synchrotron in an ejected beam of 10.5-GeV protons. Another experiment has been done simultaneously to study Rb and Cs fragments; it is reported in a separate paper.[2]

The experimental technique is described in detail elsewhere.[1] Nuclear recoils are stopped in heated graphite from where they quickly diffuse out. By surface ionization on a Re surface at about 1500°C, Na is selectively ionized.[3] Mass analysis of Na ions is then performed by a Nier-type arrangement (60° magnetic sector, 15-cm radius). An electron multiplier at the collector allows single-atom counting. Mass spectra are recorded by modulating ion-accelerating potentials synchronously with the address of a multiscaler memory. This allows repetitive accumulation with the result of improving statistics in the case of rare events.

The possibility of measuring cross sections of short-lived fragments relies critically on the rate of diffusion of Na in heated graphite which is shown in Fig. 1. The curve can be fitted mathematically by an expansion of the type $i(t)=\sum_n A_n \exp(-\lambda_n t)$. A least-squares fit was done with the aid of the Univac 1107 at Orsay. In a typical example 11, 39, and 50%, respectively, of the ^{24}Na atoms diffused out with "half-times" of 8, 46, and 141 msec.

There was a short pulse (2.1 μsec) of about 5×10^{11} protons every 11.5 sec. After each pulse, mass scanning and counting with the multiscaler were triggered and lasted between 60 and 200 msec. The operation was repeated 8 sec later to give a measure of the background.

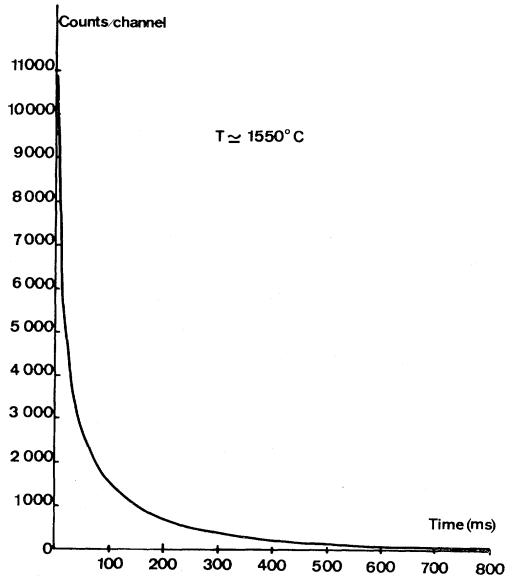

FIG. 1. Time dependence of ion current due to diffusion in the case of ^{24}Na in iridium-carbon target. Counting is performed during the first 60 to 200 msec after production and some 8 sec later to measure the background.