Title

COLLISIONAL PUMPING FOR THE PRODUCTION OF INTENSE SPIN-POLARIZED, NEUTRAL BEAMS: TARGET CONSIDERA-TIONS

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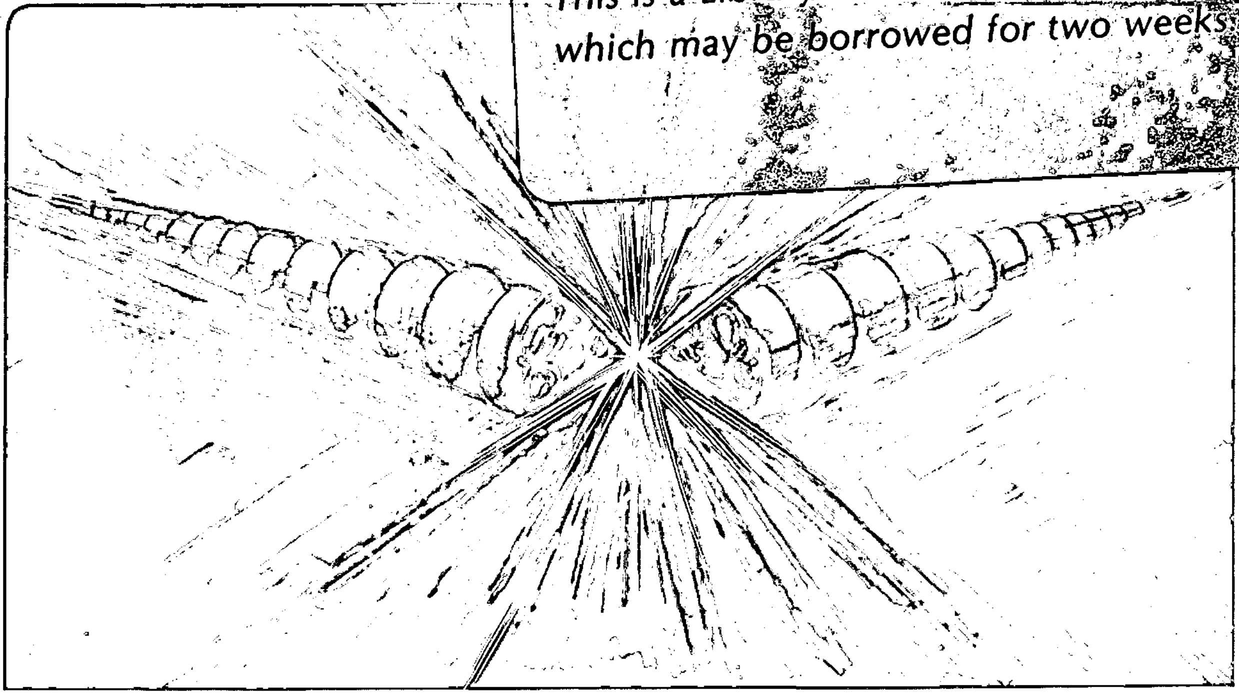

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We have recently proposed[1,2] a new method for the production of nuclear-spin-polarized ions and atoms. A fast beam of atoms is pumped to a single spin state by means of successive capture of a spin-polarized electron followed by the loss of an electron, in a highly electron-spin-polarized medium. This process, which we call collisional pumping, is characterized by the transfer of the electron spin to the nucleus through hyperfine interactions whenever the atom is in a neutral state. We anticipate that fast polarized beams of 1A or more can be produced, with possible applications to accelerators and fusion research.

This process can be accomplished by passage of a low-energy (~ 1 keV/u) H^+ (D^+,T^+) beam through a polarized alkali-metal-vapor target of about 10^{16} electron-spin-polarized atoms/cm^2. The only bound state of a negative hydrogen ion is a singlet state, which provides a selection mechanism by making electron attachment impossible when the projectile and target electrons have the same spin. In our electron-spin-polarized target (at low magnetic fields) this condition occurs 100% of the time only for atoms where the nucleus and its electron have acquired the same spin alignment as the target. Thus, for a sufficiently thick target, the beam which emerges is almost entirely neutral as well as completely electron- and nuclear-spin polarized for a 100% electron-spin-polarized alkali-vapor target. Another interesting feature of the emerging beam is that, because of the spin-dependency of electron attachment, it can be made negative in a second reverse-polarized alkali target more efficiently than non-polarized atoms in a non-polarized target.

At higher energies few negative ions are produced, and a charge-state-equilibrated beam consists primarily of atoms and positive ions. In this situation, a polarized alkali-vapor target is limited in its ability to polarize the beam because an atom formed by capture of a polarized electron has a high probability of being in an electronically excited state and the beam will lose part of its polarization when these states decay. For this reason, and also because it is a better neutralizer, an electron-spin-polarized H-atom target is more suitable than the alkali-vapor target. Electron capture into excited states is not eliminated, but it is reduced so that it only causes 5-10% depolarization of the beam. The positive-ion-neutral-atom cycle does not have a selection mechanism such as described in the low-energy situation (the beam continues to undergo charge-changing collisions even after becoming polarized). However the entire beam (ions and atoms) is pumped to almost the target polarization in a target of about ten times the charge-equilibrium thickness.

One of the thickest polarized sodium-vapor targets produced to date[3] is about 10^{13} atoms/cm^2. The polarization is limited by the balance between depolarization at the walls and the optical pumping rate. This target is in a strong magnetic field, so the nuclear spin is decoupled from the electron spin, and the valence electron on an alkali atom can become spin aligned by the atom's absorption (without re-emission) of a single circularly polarized photon. In a low magnetic field, where collisional pumping can operate, the hyperfine interaction reduces the average electron alignment until the nuclei are also aligned, thus more optical pumping is required to produce an electron-spin polarized target.

A useful target of 10^{16} polarized atoms/cm^2 will require hundreds of watts of cw laser power. The only commercially available tuneable lasers in this power range are pulsed. To test collisional pumping, we intend to acquire a long-pulse (500 μs) 10-kW tunable dye laser. The pulse length is sufficient to allow all of the radiative decays and hyperfine oscillations necessary for polarization to occur. To eliminate radiation trapping, we intend to employ a two-component target (perhaps Na-Cs) and will optically pump the minor (< 1%) component, which will polarize the other component through the very large (thermal) spin-exchange cross section of 10^{-14} cm^2. The spin-exchange time (tens of ns) is short enough for the target to come to a steady-state condition well within the laser pulse time of 500 μs. This spin-exchange mechanism can be used to produce a polarized alkali-vapor target for the polarization of low-energy beams, as described, or, with atomic hydrogen as the major target constituent, for the polarization of higher energy beams.[4]

The target we propose to make is for the purpose of determining the feasibility of, and the parameters for, such targets to be used on high-energy accelerators and for producing multi-ampere neutral beams for heating and fueling polarized fusion reactor plasmas. We expect to be able to specify the laser power required to produce and maintain various polarized targets and the polarization rate possible (to sustain multi-ampere beams), and to verify the collisional-pumping mechanism for the production of polarized ion and atom beams. Present neutral beam sources[5] routinely accelerate as much as 250 milliamperes/cm^2 of hydrogen ions. Similar intensities would provide tens of milliamperes of polarized positive or negative ions for accelerator applications, and ampere-size beams for fusion applications.

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