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POSSIBLE APPLICATION IN INTENSE POLARIZED SOURCES

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ABSTRACT

We briefly review the status of spin-polarized atomic hydrogen and discuss a possible way of extending the present limit of density. Pulse extraction of stabilized atoms by millimetre waves is proposed as a means of producing polarized atomic beams of uniform velocity and low divergence. It is speculated that these atoms could be used either as jet targets of a conventional type, or as a stored atomic beam target by injecting them into a storage ring intersecting with an accelerator beam. When used in a polarized ion source, the high density of the atomic beam could possibly also improve the ionizer efficiency.

INTRODUCTION

The anomalously low surface adsorption energy ϵ_a of atomic hydrogen on helium-coated walls ($\epsilon_a/k = 0.9$ K on ^4He ¹ and $\epsilon_a/k = 0.3$ K on ^3He - ^4He mixture²), together with electron spin alignment by magnetic selection, reduces the surface recombination speed and allows the gas phase density n_v to be increased by the magnetic compression. The surface density $n_s = n_v \lambda \exp(\epsilon_a/kT)$ [where $\lambda = (2\pi\hbar^2/mkT)^{1/2}$ is the thermal deBroglie wavelength] increases rapidly when T goes below ϵ_a/k , and approaches theoretically the saturation limit $n_{\text{sat}} = \epsilon_a/2V_{\text{int}}^S$, where V_{int}^S is the interaction potential of the 2-d gas of electron-spin-aligned atomic hydrogen ($\text{H}\downarrow$)³. In practice, recombination prevents the attainment of this saturation surface density which is presumably due to insufficient cooling of the superfluid film on the surface.

By going to a high trap-field (≥ 8 T), the thermal leak time constant $\tau = 4c_{\text{H}}c_{\text{M}}V_{\text{eff}}/K\bar{A}$ (where V_{eff} is the effective volume, K the Clausius flow conductance factor, $\bar{A}$ the filling tube cross-section, and c_{M} and c_{H} are the magnetic and He vapour compression ratios) becomes substantially longer ($\geq 10^3$ s) than the decay time constant due to recombination⁴ on the ^4He surface. The addition of ^3He on the ^4He film, in the absence of magnetic surface impurities⁵, increases the relaxation time $a \leftrightarrow b$ to about one hour (we label the magnetic states of H by a, b, c, and d from the lowest to the highest energy), which leads to a large enrichment of the pure b-state because of the higher recombination speed of the "mixed" a-state⁶. Densities of 10^{17} cm^{-3} have been reported^{6,7}.

CERN APPARATUS

Our apparatus is based on the use of the existing polarized target instrumentation: a horizontal dilution refrigerator having a maximum cooling power of $Q_{\text{max}} = 300 \text{ mW}$ at 0.5 K ⁸; a room tempera-

Fig. 1 Schematic drawing of the stabilization cell area of the CERN apparatus. The inset shows the possible modification for vacuum tube access to the cell opposite the load port.

ture bore, superconducting solenoid with 7 T peak field or 5 T shimmed homogeneous field in about 2 cm³ volume; and microwave equipment for ESR at 140 GHz. We are also completing our NMR equipment for 1 GHz operation. In the dilution refrigerator the cell holder enters the mixing chamber directly through a horizontal access tube of 5 cm minimum diameter; the evacuated cell holder plugs this tube with a rapid indium seal at the back of the still⁸. Inside the cell holder a circular waveguide, up to four semirigid coaxial cables, and a teflon tube provide transmission of microwaves, RF for NMR and hydrogen from a RT dissociator. The dissociator consists of a quartz discharge tube in a coaxial cavity tuned to the frequency of the 2.45 GHz magnetron tube. A three-way teflon valve allows us to tune the dissociator so that it is isolated from the teflon tube leading to the sample cell.

A schematic diagram of the present sample cell is shown in Fig. 1. The accommodator tube, 20 cm in length, has a large surface area; this can be further enlarged, both inside and outside, with sintered copper. The large area provides adequate removal of the surface recombination heat from the ⁴He film inside to the helium mixture in the mixing chamber. This recombination during the magnetic compression in the continuous cold accommodator tube will enrich the H₂ gas with b-state atoms before it enters the sample cell. We predict that this will lead to higher densities in the cell than has hitherto been the case.

The sample cell can be extended to the isolating vacuum of the dilution refrigerator, and further to a vacuum pipe outside the refrigerator. Atoms can thus be extracted by microwave pulses⁹ to an external beam line, or alternatively an external beam can be shot through the gaseous atomic hydrogen sample. The superfluid film which climbs towards higher temperature along the heat exchanger and the outer surfaces of the still will be evaporated and recondensed back to the continuous heat exchanger surface before reaching the mixing chamber; this technique has already been demonstrated in a smaller dilution refrigerator, even at a ³He circulation speed as low as 2 millimoles/s¹⁰, although involuntarily (due to a superleak).

The EPR absorption measurements, using a bolometer to detect the microwave intensity¹¹, will give the number densities N_a and N_b of the a-state and b-state. This will allow the measurement of their time

evolution and therefore the direct determination of their recombination coefficients and relaxation times. The microwaves can also be used for extracting one of the states from the cell, permitting measurements in "clean" a-state or b-state. The NMR absorption signal will measure the density difference $N_a - N_b$, and can be used for gas-phase nuclear polarization measurement when combined with the measurement of density using a pressure gauge. The measurement of the cell surface temperature, combined with the above, will make it possible to monitor the attainment of thermal equilibrium in the gas phase, the thermal conductivity of which might not be large at high density. The pressure, temperature, and density in the gas phase will give the equation of state, the anomalies of which could predict the Bose-Einstein condensation to the ground state.

POSSIBLE APPLICATIONS

The straightforward use of high-density b-state H as a polarized target might offer interesting possibilities with polarized γ beams; the pair formation due to heavier nuclei can be avoided if an open geometry target cell will be used, and the target and beam vacuum are connected. Both transverse and longitudinal polarizations can be envisaged, the former using a split-pair solenoid. Experiments with charged beams are possible at an energy that is high enough to extract the wanted secondary particles from the field. The reversal of the polarization in a high-density $H\downarrow$ target will not be possible, but one might consider the idea of the precessing target polarization. Another possibility would be the reversal of the stabilizing field or of the experimental geometry⁹.

At very high density a closed geometry cell might burst because of recombination. A simple calculation shows that adiabatic recombination of gaseous $H\downarrow$, at the same density as STP H_2 (0.1 g/l), results in 100 atm H_2 pressure. This is another reason why open geometry cells should be considered for magnetically confined $H\downarrow$ targets.

At "low" density, say below 10^{15} cm^{-3} , both a-state and b-state can be present under continuous loading. These densities might not be of interest in extracted beam experiments. The low density, however, might be useful in applications where one extracts atoms in c-state or d-state by driving the allowed transitions $a \rightarrow d$ or $b \rightarrow c$ by microwaves⁹. Low density is also required for two other reasons: firstly, because of the mean free path in the gas phase; secondly, because too high a surface density might lead to uncontrolled recombination under a saturating microwave pulse. The microwave extracted atoms could have, for example, a kinetic energy of 3.5 K (5 T field) and velocity spread corresponding to a temperature below 0.5 K. Because of the focusing properties of solenoid fields for the c-state or d-state atoms, the resulting beam would have a low divergence; it could be further focused by hexapole magnets. We speculate that such a pulsed beam from a continuously loaded stabilization cell could find applications as a polarized gas jet target¹², in intense polarized ion sources, or in atomic beam storage rings. Such a storage ring could possibly accumulate even higher densities of the c-state or d-state atoms and could be used equally as a gas jet target or in an ion source by colliding with an ionizing alkali beam. This would allow

the ionizing region to be separated from the low-temperature storage cell, without large losses in the atomic flux. Furthermore we note that the atomic storage ring, consisting of hexapole and quadrupole magnets for focusing and bending, could also use oscillating solenoid fields and drift tubes for bunching and accelerating the atoms.

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