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STABILIZATION OF SPIN-POLARIZED ATOMIC HYDROGEN AT LOW TEMPERATURE

V.G.Luppov, M.Mertig[*], Yu.K.Pilipenko

A cryostat for stabilization of gaseous atomic hydrogen at low temperatures and in high magnetic fields was built up. Gas densities of ≈ 10^{13} atoms/cm^3, which remain stable for more than one hour, were achieved in the first experiments.

The investigation has been performed at the Laboratory of High Energies, JINR.

Стабилизация спин-поляризованного атомарного водорода при низкой температуре

Луппов В.Г., Мертиг М., Пилипенко Ю.К.

Создан криостат для стабилизации газообразного атомарного водорода при низких температурах в сильных магнитных полях. В первых экспериментах достигнута плотность ≈ 10^{13} атомов/см^3, которая остается стабильной более одного часа.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Due to the weak interaction and the light mass of a hydrogen atom, electron-spin-polarized atomic hydrogen remains a gas even at absolute zero temperature/1/. This property gives in principle the unique possibility of reaching a phase transition to a Bose-Einstein condensed state in a weakly interacting gas of bosons, i.e. the macroscopic population of the ground state at finite temperature. Many new interesting phenomena, for example, gaseous superfluidity, should be presented by this condensate, and this prospect has stimulated large experimental and theoretical activities in the field of stabilization of polarized atomic hydrogen/2/. However, maximum densities of ≈ 10^{18} cm^{-3}, reported to date, achieved in special compression experiments/2/ are at least one order of magnitude smaller than those required for the onset of Bose-Einstein condensation.

Hydrogen atoms interact via the singlet ($^1\Sigma_g^+$) or triplet ($^3\Sigma_u^+$) potential depending on the fact whether the electron spins are aligned antiparallel or parallel, respectively. Due to a large depth of ≈ 4.8 eV of the $^1\Sigma_g^+$ potential, unpolarized hydrogen atoms energetically

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[*] *Permanent address: Technische Universität Dresden, Sektion Physik, Mommsenstr. 13, 8027 Dresden, GDR*

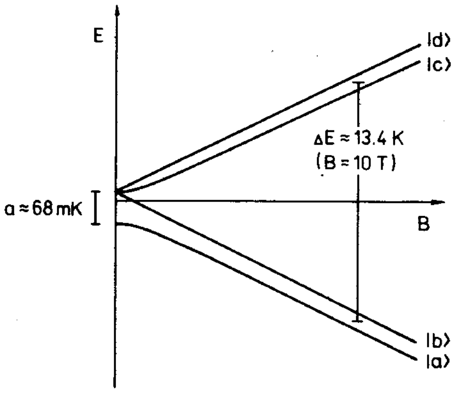

Fig. 1. Diagram of the energy levels of the hydrogen atom in the ground state in an external magnetic field.

prefer the state of the H_2-molecule. However, the interaction via the $^3\Sigma_u^+$ potential is practically repulsive. This suppresses molecular recombination of two atoms with parallel electron spins. Therefore, electron-spin-polarization is the main principle of high-density stabilization of atomic hydrogen.

Figure 1 shows the hyperfine diagram of the energy levels of a hydrogen atom in the ground state in an external magnetic field. The two lower ($|a>$ and $|b>$) and two upper ($|c>$ and $|d>$) levels are electron spin-down (H↓) and spin-up (H↑) states, respectively. In a field of 10 T the energy separation between different electron-spin states is ≈ 13.4 K. Therefore, at low temperatures ($T \lesssim 1$ K) and in high magnetic fields ($B \approx 10$ T) atomic hydrogen can be stabilized by separation of the H↑ and H↓ states and subsequent magnetic confinement of H↓ at the maximum of the field. Gas densities of $\approx 10^{16} \div 10^{17}$ cm^{-3} are achievable in this way/2/.

Proceeding from the experimental progress in this field, it has been suggested to use low temperature stabilized spin-polarized atomic hydrogen for creating high intensity polarized sources and targets to carry out investigations in high energy and nuclear physics /3/. To provide a high intensive polarized proton beam, a source applying low temperature atomic hydrogen stabilization technique is under design at JINR, Dubna. As the first stage, a cryostat for stabilization of spin-polarized atomic hydrogen was built /4/ (see Fig. 2). The atomic hydrogen produced in a 2.45 GHz dissociator cooled by liquid nitrogen flows through a teflon tube, which leads into a superconducting solenoid with a maximum field of 7 T and is cooled by contact with the walls of the tube. The H↑ and H↓ states are separated by the magnetic field gradient between the dissociator and the entrance of the stabilization cell (SC). H↑ atoms are repelled by the field, and H↓ ones are attracted and accelerated into the high field region, where the stabilization cell with a volume of ≈ 1.5 cm^3 is placed. The H↓ atoms are thermalized by wall collisions at the temperature of the

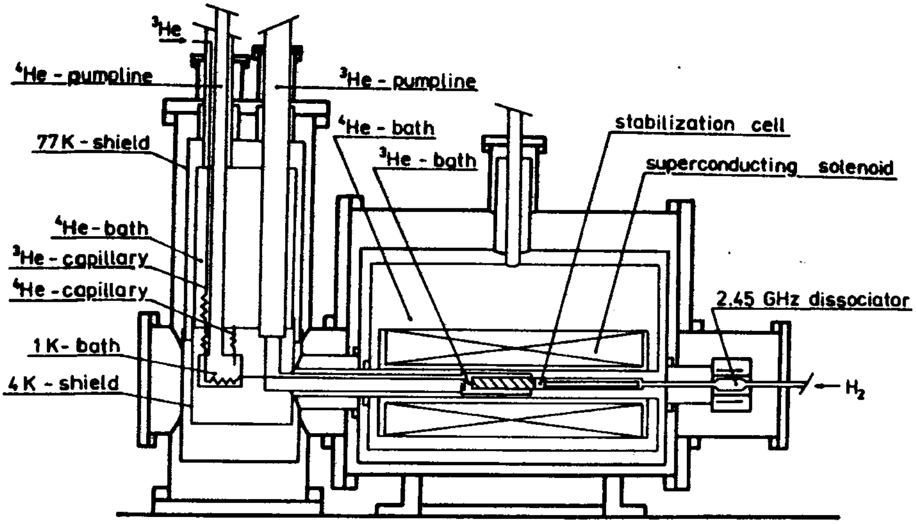

Fig. 2. Schematic diagram of the apparatus.

SC which is cooled by a horizontal, continuously working ^{3}He evaporation refrigerator with a minimum temperature of 350 mK and a cooling power of ≈ 20 mW at 500 mK. They are confined to the field centre by the magnetic field gradient. The walls of the SC are coated with a superfluid helium-4 film which spontaneously covers all available areas of the cell. The adsorption energy of H on the ^{4}He-surface is low ($\epsilon_a \approx 1$ K/5/) what allows a considerable decrease of the surface recombination of the H↓ in comparison to the uncoated surface of the cell. Moreover, for the same reason it is necessary to cover the low-temperature part of the hydrogen atom guide tube to the SC by a protective H_2 coating.

Gas densities of at least 10^{13} atoms/cm^3 have been achieved in our first experiments. This density is obtained by filling the SC with a flux of $\approx 10^{11}$ atoms/s over a period of ≈ 100 s. In a magnetic field of 7 Tesla and at a temperature of 0.44 K no decrease of the detected density was observed for more than one hour after turning off the dissociator. This indicates that the magnetic confinement in our SC works very well.

The presence of the H↓ in the cell is detected by means of a special carbon bolometer placed in the SC. The bolometer is thermally connected to the cell wall by fine wires with small heat conductivity. These wires are simultaneously used as current-voltage leads. The basic idea of atom hydrogen detection is to determine the number of atoms in the cell volume by measuring the heat release due to the recombina-

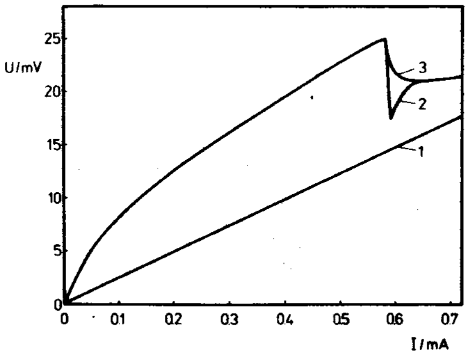

Fig. 3. Current-voltage curves of the detection bolometer under different conditions.

tion of atoms on the uncoated surface of the bolometer/6/. Typical, observed current-voltage curves of the bolometer under different conditions are shown in Fig. 3. Without a ^{4}He film coating, the bolometer, which possesses a negative resistance derivation versus temperature, is overheated even by the applied measuring current, and its resistance is small (Curve 1). When ^{4}He is condensed in the SC, the resistance of the bolometer covered with a superfluid helium film increases due to a more effective heat removal. In this case the current-voltage curve shows a peak when Ohmic heating evaporates the ^{4}He from the surface of the bolometer more rapidly than it can be replenished along the wires (Curve 3). When atomic hydrogen is present in the cell, it recombines on the He — free bolometer surface within a few milliseconds leading to detectable overheating of the bolometer (each atom gives rise to an energy release of 4.48/2 eV). Therefore, a sharp drop of the current-voltage curve is observed at the point of helium evaporation (Curve 2). Unfortunately, this detection method is a destructive one because the stabilized gas is destroyed by measuring the density. Therefore, Curve 3 is repeated in the recording immediately after the density detection.

We can calibrate recombination energy release by supplying an electric pulse of known energy to the bolometer and recording the caused resistance drop. However, when the atoms recombine to H_2, only a fraction of the recombination energy is delivered to the bolometer (the other part is delivered to the copper walls of the SC). Therefore, only a lower bound for the number of recombinations or the H↓ density can be determined in this way.

Moreover, the results of our first experiments show that at the present time a further increase of density is prevented by incomplete thermalization of the hydrogen atoms at low temperatures before entering the SC and, consequently, incomplete separation of the H↑ and H↓ states during filling the cell. Accordingly, we hope to increase the magnitude of density of the stored gas by its more effective cooling before entering the SC. Moreover, a capacitive pressure gauge is under test for density measurements without destruction of the stabilized hydrogen gas during detection.

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