Continuous density measurement of atomic hydrogen by means of a bolometer

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(Received 18 June 1990; accepted for publication 6 September 1990)

We developed a device which allows continuous measurement of the density of low-temperature stabilized atomic hydrogen by means of a bolometer. This density monitor was tested in a large open-storage cell during microwave-induced extraction of polarized atoms.

In a helium-film-covered storage cell, spin-polarized atomic hydrogen ($H\downarrow$) can be detected by bolometric measuring technique.[1] The method consists of inducing the recombination of H atoms on a He-bare bolometer surface. Under the assumption that each atom gives rise to an energy release of 2.24 eV, the number of atoms in the cell can then be calculated from the measured energy released to the bolometer.

This method is well developed and widely used because of its simplicity. However, the standard bolometer technique has two shortcomings: a density measurement results in the destruction of the sample and there is uncertainty in the fraction of collected recombination energy. In particular, this technique is not accurate in an "open" storage cell with magnetic confinement in at least one direction, because nonthermalized atoms and molecules can leave the cell. In this case, only a small fraction of the recombination energy would be deposited on the bolometer. In addition, this method cannot be used in the presence of microwave because the microwave radiation would directly heat the bolometer.

In this paper we describe a new method that overcomes these limitations. It was tested in the Michigan-MIT Ultracold Polarized Hydrogen Prototype Jet.[2]

The density monitor consists of a bolometer, which is enclosed in a small cell and mounted inside the storage cell. The hydrogen atoms can penetrate into the small cell of the monitor by passing through a small hole. The flow of atomic hydrogen entering the monitor cell was determined by measuring the heat released by hydrogen atoms recombining into molecules on the He-bare bolometer surface. The density of atomic hydrogen in the storage cell is then directly related to the flow Φ into the monitor cell by

$$\Phi = n/K, \tag{1}$$

where K is the flow impedance of the entrance hole, assuming that the pressure in the monitor cell is much smaller than in the storage cell.

In Fig. 1 the monitor design is shown schematically. The bolometer consisted of a small piece of a Speer resistor, which was glued with conductive epoxy CT-5047, from Emerson & Cuming, Inc., between two concentric 100-μm-thick copper cylinders 20 and 18 mm in length, and 7 and 5 mm in diameter, respectively. The total surface area of the bolometer was approximately 13 cm^2. This was about 70% of the total inside surface area of the enclosing volume. The Speer resistor had a resistivity of 240 Ω and a temperature sensitivity of about 0.1 Ω/mK at 1 K. The bolometer was thermally linked to the enclosing volume by two 140-μm-diam and 1-cm-long instrumentation wires, which were soldered to the copper cylinder. The bolometer was suspended with two 50-μm-thick nylon threads inside a 2.7-cm-long copper cell with a 1-cm-diam bore. This cell was then closed with two flanges. A 100-μm-thick copper foil which contained the entrance hole was soldered onto the front flange. Thus the size of the hole was much smaller than the wavelength of the microwave radiation to prevent penetration of the microwaves into the cell. The area of the hole was determined to be about 4×10^3 μm^2 with the help of a microscope. A 4-mm-diam copper tube extended from the rear flange to the outside of the storage cell. It was used to shield the electrical wires from microwave radiation. The inside temperature of the monitor was measured with a chip thermometer.[3] The effective volume of the monitor was 2.25 cm^3.

To determine the flow Φ of atomic hydrogen into the monitor we used the method developed by Berkhout *et al.*[4]: The bolometer was heated with a constant current to a temperature at which the He film was completely desorbed from the surface of the bolometer. When hydrogen atoms were

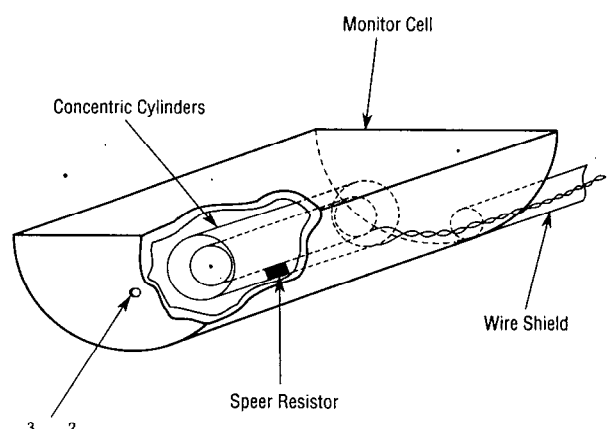

FIG. 1. Schematic drawing of the bolometric density monitor.

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 0034-6748/91/010251-02$02.00

flowing into the cell, the bolometer was additionally heated by the energy released by recombining atoms. The flow of hydrogen atoms was determined by measuring the reduction of the electric heating power that was necessary to keep the temperature of the bolometer constant. This method is especially well suited for the detection of relative changes of the flow. To measure the flow impedance of the entrance hole, the bolometer was coated with He film and the monitor cell was filled with atomic hydrogen until the density in the monitor and the storage cell were in equilibrium. Rapid recombination of the hydrogen inside the monitor was then triggered by burning the He film from the bolometer. The resulting heat pulse observed on the bolometer resistor was due to the recombination of all hydrogen atoms inside the monitor. With the known volume of the monitor an absolute value for the density could be determined. The measured pulse was later calibrated with an electric heat pulse.

The fraction of the recombination energy collected with the bolometer was estimated for both the flow and density measurements by comparing the response of the temperature of the whole monitor to electric heating with the response to recombination heating.

During the test of the density monitor hydrogen atoms were stored in the storage cell at temperatures below 0.3 K and in a magnetic field of 7.6 T. The effective volume of the storage cell was approximately 100 cm^3. Hydrogen atoms were ejected from the open-storage cell by flipping their electron spins using a 213-GHz microwave-driven transition. The storage cell was continuously filled with a constant flow of atomic hydrogen and we measured the densities of hydrogen atoms both with and without microwave-induced extraction. We found that the bolometer is not affected by the microwave radiation. The helium film was desorbed from the bolometer at a temperature of 1.3 ± 0.1 K at an ambient storage cell temperature of about 200 mK. To evaporate a 40-nm-thick He film an electric heat input of 55 μW was required. This results in an upper limit to the measurable flow of 1.5×10^{14} s^{-1}. Working at a higher temperature would increase this value at the cost of reduced sensitivity. The fraction of the recombination energy that was collected on the bolometer was estimated to be $80 \pm 20\%$.

Table I shows the results of the density measurements with and without microwave extraction. Φ is the measured flow of hydrogen atoms into the monitor and n is the measured equilibrium density inside the monitor. Equilibrium between inside and outside was typically reached after 100 s. Both flow and density measurements were corrected for incomplete collection of the recombination energy. The flow impedance, K, of the entrance hole was determined according to Eq. (1). Both values are in good agreement with each other and also with the value of 16 s/cm^3 calculated for an ideal 4×10^3 μm^2 aperture using the relation

$$K = 4/\bar{v}A, \tag{2}$$

where $\bar{v}$ is the average thermal velocity and A is the cross section of the aperture. Our test measurements showed that continuous microwave-driven extraction of hydrogen atoms lead to a decrease of the density in the storage cell by a factor of about 4.

TABLE I. Flow Φ of atomic hydrogen into the monitor and equilibrium density inside the monitor measured both with and without microwave extraction. K is the flow impedance of the entrance hole.

Φ (atoms s^{-1})	n (atoms cm^{-3})	K ($s\,cm^{-3}$)	Remarks
1.3×10^{14}	2.8×10^{15}	22	Without microwave extraction
3.6×10^{13}	6.3×10^{14}	17	With microwave extraction

We developed a density monitor, and used it successfully to measure the density of stored atomic hydrogen in a large "open"-storage cell. The method consists of the measurement of the leakage rate of hydrogen atoms through a small hole into a small enclosed volume, where the atoms are forced to recombine. This method can be improved by a dynamic feedback to determine the recombination energy continuously at constant temperature.

This work was supported by grants from the U.S. Department of Energy.

[1] I. F. Silvera and J. T. M. Walraven, Phys. Rev. Lett. **44**, 164 (1980).
[2] T. Roser, D. G. Crabb, W. A. Kaufman, R. S. Raymond, J. A. Stewart, and B. Vuaridel, in *Proceedings of the Topical Conference on Electronuclear Physics with Internal Targets*, 1989, edited by R. G. Arnold (World Scientific, Singapore, 1989), p. 183.
[3] Q. Li, C. H. Watson, R. G. Goodrich, D. G. Haase, and H. Lukefahr, Cryogenics **26**, 467 (1986).
[4] J. J. Berkhout, H. Höpfner, E. J. Wolters, and J. T. M. Walraven, Jpn. J. Appl. Phys. **26**, Supple. 26-3, 231 (1987).