A Hydrogen Ion Beam Method of Molecular Density Measurement Inside a 4.2-K Beam Tube

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Abstract

In our first experiments on synchrotron radiation induced photodesorption in a 4.2-K beam tube, the molecular density was measured by room temperature ion gauges and RGAs outside the beam tube. The molecular density inside the 4.2-K beam tube was therefore unknown, since the mean molecular speed of photodesorbed molecules had not been measured. To determine the density inside the 4.2-K beam tube we have developed a direct method of measurement utilizing the neutralization of H^+ beams, which are proportional to gas density. The hydrogen ion beams (up to 20 keV, ~1 μA) are extracted from an rf ion source and guided into the cold beam tube by a bending magnet. The H^0 and H^- produced in the beam tube are magnetically separated from H^+ and detected with secondary electron multipliers (SEMs). Small superconducting dipole magnets located near the center of the beam tube allow a ~20-cm segment of the injected ion beam to be offset a few mm from the injection axis; detection of H^0 and H^- produced along this offset segment provides a localized density measurement. If necessary, detector background due to synchrotron radiation photons can be discriminated against by gating the detector on between the bursts of synchrotron radiation. The experimental setup and initial data will be presented.

1. INTRODUCTION

Photon-stimulated gas desorption can be a serious problem in achieving desirable vacuum inside a beam tube in the next generation of proton colliders — the 20-TeV Superconducting Super Collider (SSC), which was to be built in the USA [1], and the 7.7-TeV Large Hadron Collider, which is being planned for construction at CERN [2]. The proper design of the beam tube requires performing some special photodesorption experiments at LHe temperature. The main parameter that must be determined is the gas density inside the cold beam tube. The usual techniques of pressure measurement by vacuum gauges and residual gas analyzers (RGAs) installed in the warm part of the experimental setup do not give the cold density directly, since the mean molecular speed of the photodesorbed molecules is not known [3].

A direct method for measurement of the gas density using an H^+ ion beam injected into the cold tube is described in this article. This method uses charge exchange of the H^+ beam with the molecules of the desorbed gas, and it is based on the well-known cross section values for the following elementary processes:

$$H^+ + A = H^0 + A^+$$
$$H^+ + A = H^- + A^{++}$$

The amounts of H^0 and H^- are proportional to gas density. Cross sections in other gases (CO, CO_2, CH_4) are also known to some extent. The different energy dependence of the cross sections for these gases may allow measurement of the density of each gas species.

2. EXPERIMENTAL SETUP

The experiments have been performed on the synchrotron radiation beamline SSC1 of the VEPP-2M electron-positron storage ring at Budker Institute of Nuclear Physics in Russia. The schematic of this experiment is shown in Fig. 1. The details and parameters of the beamline and LHe cryostat are given in ref. [3,4]. The photon critical energy and intensity of the SSC1 beamline are the same as in the SSC (284 eV, ~10^{16} photons/m/s).

An rf ion source is used for generation of the H^+ ions. An rf generator with frequency 33 MHz provides the discharge plasma. All equipment was shielded from the rf power. The energy spread of the H^+ beam was minimized by filtering the rf from the beam extraction electrodes. A 10-keV, 100-μA ion beam is extracted through a 1-mm-diameter hole and focussed with a 6-7 kV einzel lense immediately outside the ion source. From the ion source the beam passes into a 90° magnet mass analyzer M1 (bending radius R = 8 cm, magnetic index n = 0.5). A collimator COL1 with a 1-mm -diameter hole is at the exit of M1. Measurement of the current to four split-plate electrodes in front of C1 is used for optimizing the focussing and steering of the beam. A similar collimator, COL2, is located at the entrance to the 127° bending magnet M2 (R = 8 cm, n = 0.5) which guides the beam along the axis of the cold beam tube.

The focussing system includes triplet (Q1-Q3) and doublet (Q4,Q5) magnetic quadrupole Panofsky lenses, two electrostatic einzel lenses (L1,L2), an electrostatic octopole corrector-stigmator (behind L1), and magnetic dipole correctors (C1-C6). The H^+ beam diameter is within 1-3mm at the detectors. A movable phosphor (LD1) is used for observation

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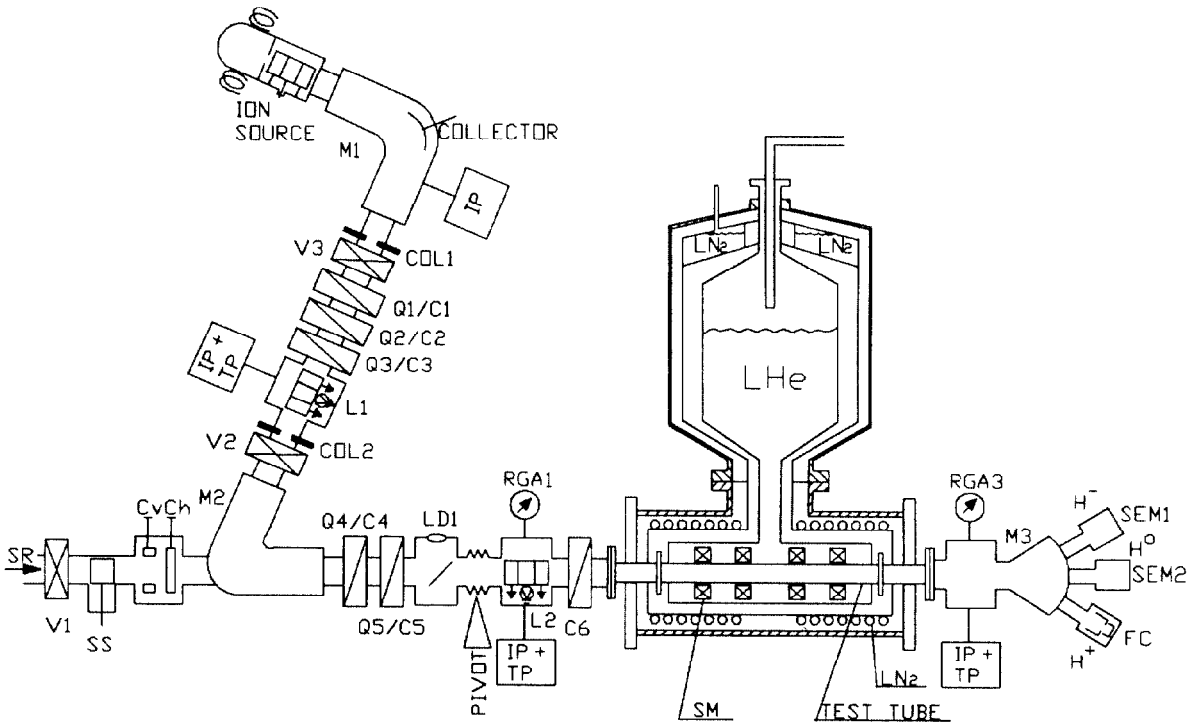

Figure 1. Setup for direct measurement of molecular density inside a 4.2-K beam tube by the ion beam method. L1,L2: einzel lenses; M1–M3: bending magnets; SM: superconducting magnets (4); C1–C6: correctors; Q1–Q5: quadrupoles; FC: Faraday cup; SEM1,SEM2: secondary electron multipliers; COL1, COL2: ion beam collimators; V1–V3: vacuum valves; SS: safety shutter; LD1: phosphor; IP+TP: combination ion and Ti sublimation pump; RGA1–RGA3: residual gas analyzers; Cv, Ch: SR vertical and horizontal collimators.

of the ion beam and synchrotron radiation (SR) position. The high-voltage power supplies for the ion source and electrostatic lenses are voltage-regulated with accuracy 10^{-4}. All power supplies for bending magnets, quadrupoles, and correctors are regulated with accuracy 10^{-4}.

In the cold beam tube the ion beam can be displaced from the tube axis by four superconducting bending magnets (SM1–SM4) installed in the middle of the beam tube. This allows measurement of the secondary particle beams created

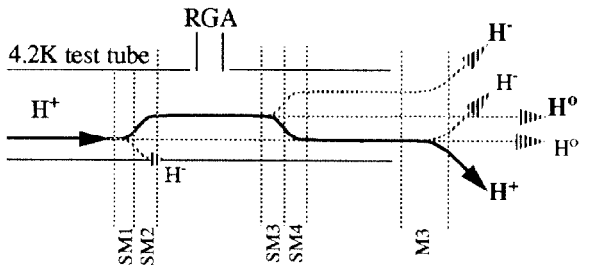

Figure 2. Illustration of secondary particle beam separation inside the beam tube. (the beams in bold font were used in the experiments)

on the 20-cm section of the beam tube (Figure 2). The secondary beams H^0 and H^- are separated at the detectors by the dipole magnet M3. The ~ 2μA H^+ beam is directed to a 25-mm -diameter Faraday cup with a 1-mm-diameter hole. A second Faraday cup is behind the 1-mm hole. Scanning the beam across this dual Faraday cup detector allows measurement of the spatial structure of the beam. Neutrals and negative ions are transported to the corresponding SEMs. The SEMs can be operated in both the current and counting modes. The counting mode is used to measure the absolute calibration of H^- and H^0 intensity. Every H^- or H^0 particle with energy ~10 keV produces an output pulse with an amplitude of order of 10^5–10^6 electrons. A pulse of this magnitude can be easily read by the data acquisition system.

To distinguish the beam charge exchange signals from SR -induced background the ion beam is intensity modulated with alternating voltages on the electrode-collector inside the M1 magnet or on the octopole corrector. The frequency of the modulation was 0.1–1 kHz.

The influence of ion-stimulated desorption due to scattered protons was eliminated by using the ion beam in a pulse mode (pulse width = 0.3–1 ms, pulse repetition time = 1.5 s). Observation of ion-stimulated desorption was used to check the ion beam alignment along the beam tube. The absence of ion-stimulated desorption was used as a criterion of good alignment.

Gas pressure was measured simultaneously with the ion beam by calibrated rf quadrupole RGAs at room temperature. An RGA was connected to the center of the beam tube and at each warm end.

A differential pumping system including three vacuum pumps IP1–IP3 and two collimators COL1 and COL2 provides the necessary pressure drop from $5 \cdot 10^{-6}$ Torr in the M1 magnet

vacuum chamber to $5 \cdot 10^{-10}$ Torr in the test tube. Opening and closing the valve V3 produced no measurable change in beam tube pressure at RGA1. The pressure in the ion source is about $1 \cdot 10^{-3}$ Torr.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In the first series of experiments we have simultaneously measured the amount of H^- by the ion beam technique and the H_2 pressure by RGA in the middle of the 4.2-K beam tube. These measurements were done both with SR photons on and off.

With the SR gated off the H_2 molecules inside the tube have temperature 4.2 K. Thus the H_2 density n_1 can be calculated by the following formula:

$$n_1 = n_{293} \frac{\bar{v}_{293}}{\bar{v}_{4.2}}, \qquad (1)$$

where n_{293} ($n=P/kT$) is the H_2 density at room temperature measured by RGA, and $\bar{v}_{293}$ and $\bar{v}_{4.2}$ are effective mean molecular speed for 293 K and 4.2 K respectively. At the same time the H^- intensity I^-_1 is:

$$I^-_1 = n_1 \cdot L \cdot \sigma \cdot I^+, \qquad (2)$$

where L is the path length where the negative ions have been created, σ is the cross section of the reaction, and I^+ is the intensity of H^+s.

In the presence of synchrotron radiation, the effective mean molecular speed $\bar{v}$ is unknown. The H_2 density in this case can be determined by the following expressions:

$$n_2 = n_1 \frac{\bar{v}_{293}}{\bar{v}_{4.2}} + \Delta n \frac{\bar{v}_{293}}{\bar{v}} \qquad (3)$$

and

$$I^-_2 = L \cdot \sigma \cdot I^+ \cdot (n_1 + \Delta n), \qquad (4)$$

where Δn is the density increase due to photodesorption. The combination of expressions 1–4 gives the following formula for the effective mean molecular speed of the photodesorbed molecules:

$$\bar{v} = \frac{(P_2 - P_1)}{P_1} \frac{I^-_1}{(I^-_2 - I^-_1)} \bar{v}_{4.2}, \qquad (5)$$

where P_2 is the H_2 pressure measured by the RGA with SR on and P_1 with the SR off.

It is necessary to mention that in this case we do not have to determine σ and L. We have only to keep creating the negative ions within the cold beam tube or keep the density in the warm ends of the tube much lower than inside the beam tube.

The typical results of the volume density measurements inside the 4.2-K beam tube are presented in Table 1.

Table 1
Results of volume density measurements.

	$I(H^-)$, nA	P_{H2}(RGA), Torr
photons on	360	$1.5 \cdot 10^{-8}$
photons off	235	$5.0 \cdot 10^{-9}$

The proton beam current $I(H^+)$ was about 0.5 μA for photons on and off.

By using this data and formula (5), the mean molecular speed $\bar{v}$ of desorbed molecules due to synchrotron radiation can be estimated. This speed is equal to $8 \cdot 10^4$ cm/s, which corresponds to 60 K. Using the value of H_2 molecular speed and RGA measurements, the density increase due to photodesorption can be calculated.

4. CONCLUSIONS

1. A special hydrogen ion experimental setup has been designed, built, and operated. This setup allows the direct determination of the molecular gas density inside a cryosorbing beam tube by measuring the intensity of charge exchange products H^- and H^0. The sensitivity of gas density measured by this setup is better than 10^8 1/cm^3.

2. The first results of the measurement of speed of H_2 molecules desorbed from the surface of a 4.2-K simple beam tube due to synchrotron radiation have been obtained. This speed is equal to $8 \cdot 10^4 \pm 1.5 \cdot 10^4$cm/s and corresponds to an effective temperature of 60 ± 20 K. Using this value of speed we can eliminate the uncertainty for gas density measurements in ref. [3].

3. Plans for work with this experimental setup include the measurements of molecular speed and density:
a) in beam tube liner configurations,
b) in beam tubes with different surface coverage of physisorbed H_2 molecules, and
c) for other gases (CO, CO_2) by variation of the energy of the proton beam.

5. REFERENCES

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