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T.O. Niinikoski, S. Penttilä and J.-M. Rieubland

CERN, Geneva, Switzerland

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T.O. Niinikoski, S. Penttilä and J.-M. Rieubland
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ABSTRACT

We have constructed a helium-cooled atomic source where the discharge tube is placed immediately above the helium bath. The advantages of our system are simplicity, very short length and therefore small losses of the atomic beam, and the possibility of cryopumping molecular hydrogen. Preliminary tests show the feasibility of these principles. Further work is aimed at geometrical and thermal improvements, and possibly the addition of a spin selection magnet near the cooling tube.

ATOMIC SOURCE

In the cold atomic sources the thermalization of the atoms emerging from the discharge tube is made by colliding them with the surface of a cold nozzle¹⁻³ or a separate He-cooled accommodator⁴⁻⁶. At LN₂ temperature, good dissociation degree has been maintained when the copper nozzle surface has been coated with H₃PO₄² or graphite³. At helium temperature the accommodator channel becomes coated with molecular hydrogen, which has a rather small adsorption energy (≈ 40 K) compared to that of most other solids. Although recombination on a H₂-coated wall at 4 K is faster than at higher temperatures, the cryopumping of H₂ will help to maintain good background pressure.

Figure 1a illustrates the configuration of our cold atomic hydrogen source, where the dissociator has been mounted in a small, continuous-flow, ⁴He refrigerator. The copper nozzle of the discharge tube is cooled by an enlarged copper heat-exchange surface in the pumped helium bath. The discharge tube and the RF cavity are cooled by cold helium vapour convection and flow through the cavity. Cooling of the discharge region was improved by forcing the flow of liquid helium through the helix coil. The diameter of the nozzle orifice is 0.6 mm.

The pyrex discharge tube (8 mm inside diameter) and the copper flange are sealed together by means of a short teflon shrink-tube. In some of the tests, teflon was also used for the discharge tube instead of pyrex.

Thermometers are fixed to the copper flange, nozzle, and cavity. The helium vapour temperature is measured after the cavity, the discharge pressure at the entrance to the cryostat. The flow to the dissociator is measured with a mass flowmeter. The cryostat is placed in a vacuum can, pumped by a turbomolecular pump of 270 l/s speed.

The helix-loaded cavity resonates at 96 MHz. A wide-band power amplifier of 100 W nominal power, driven by a variable frequency synthesizer, feeds the power to the cavity through a half-wavelength semi-rigid coaxial cable. The power is coupled-in with an ohmic contact to a low impedance point of the coil. A photodiode indicates the ignition of the discharge.

Fig. 1 a) The cold atomic hydrogen source. b) The improved source. A) Discharge tube; B) Cavity; C) Helix coil; D) Pumped helium bath; E) RF input; F) Teflon seal; G) Copper heat-exchange flange; H) Copper orifice; I) Skimmer; J) Collimator; K) Ionizer; L) Glass orifice; M) Indium seal; N) Thermalizer channel; P) Cryopump panels.

TEST RESULTS

The static loss to the ^4He bath without RF power and H_2 flow is about 2 W. When the discharge is operated, an additional heat load of 2-3 W appears in the helium bath. The temperature of the copper exchanger is 3 K, and the helium vapour temperature around the cavity is about 10 K.

Under typical operating conditions, the flow to the dissociator is somewhat below $2 \mu\text{mol/s}$ and the discharge pressure is 0.4 mbar; we estimate that the discharge works best at a density of 10^{17} cm^{-3} . The cryopumping on the cold surfaces, together with the turbomolecular pump, keep the pressure in the vacuum can at 10^{-7} mbar. The temperature of the atoms is probably below 20 K after the orifice, judging from the orifice temperature which must have been about 10 K because occasionally it was blocked by solid H_2 . It is not possible to control the nozzle and discharge-tube temperatures separately; they are determined by H_2 flow and RF power.

We are able to observe the beam with the quadrupole mass spectrometer, but accurate measurement of the dissociation degree was impossible without a chopper. At room temperature we determined the dissociation degree as 30% by switching the RF power on and off and observing the change in the mass-2 signal. When cooled with helium, the magnitude of the mass-1 beam signal with respect to the background indicates a somewhat lower dissociation degree; the reason for this may be bare Cu surfaces in the vicinity of the nozzle, too short mean free path in the discharge, or too low RF field near the orifice.

The discharge could always be started without an ignition spark. It is also possible to ignite the discharge when there is solid hydrogen on the wall of the discharge tube with no detectable gas pressure.

Sometimes the presence of the solid hydrogen in the dissociator causes a measurable change of the resonance frequency.

In the teflon tube the discharge is not stable, and light emission continues after closing the hydrogen flow. When the dissociator was disassembled, a brown deposit was found on the inner wall of the tube. The deposit might be sputtered teflon which has lost some fluorine.

The teflon shrink-seals of the discharge tube were not always helium leak-tight. In some cases leaks appeared only after applying the RF power.

The results and operating experience suggest an improved source, shown in Fig. 1b. Here the discharge tube and cavity are better separated from the thermalizer channel, so that their temperatures can be controlled individually. This will also reduce the heat load from the discharge to the helium bath. The copper nozzle must be either withdrawn from the RF field or replaced by a quartz orifice so that it can be placed in an area of high RF field. In the baffled thermalizer channel the warm atoms emerging from the orifice are cooled by having them collide with a surface coated with solid H₂.

To avoid scattering of atoms against hydrogen molecules, the temperature of the thermalizer must be held below 7 K, where the vapour pressure of solid hydrogen is 2×10^{-2} mbar. On the other hand, the solid hydrogen surface below 4 K would increase the surface recombination probability -- and therefore the beam loss to the wall of the channel -- because the surface adsorption time increases exponentially. By varying the length and the diameter of the channel, we may optimize the number of collisions so that we get the best cooling of the atoms without serious losses. The thermalizer might also consist of several parallel channels.

By adding cryopump panels for differential pumping, the atomic beam can be made cleaner and is better collimated. The panels are made by sintering a mixture of copper and charcoal powder onto copper plates.

We plan to couple a superconducting spin-state selection magnet to the thermalizer, the wall temperature of which, in this case, should be below 4 K. By using a superconducting solenoid it should be possible to match the magnetic field gradient with the temperature of the atomic beam.

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