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Status Report on the Internal Gas-Jet Target for the Heavy-Ion Storage Ring CRYRING

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Abstract

A supersonic gas-jet target for investigations of the detailed collision dynamics in fast ion-atom collisions by means of recoil-ion-momentum spectroscopy has been constructed for insertion into the heavy-ion storage ring CRYRING, situated at the Manne Siegbahn Laboratory, Stockholm University. The aim is to create a target with a density of 10^{12} cm^{-3} and a temperature of less than 10 mK (for the case of a He target) without seriously affecting the excellent vacuum conditions of CRYRING. The gas target will become a part of the storage ring, and hence fast beams of protons, highly-charged ions, and molecular ions will be available as projectiles. Here we present test results for parts of the system. These all indicate that the design criteria will be fulfilled.

1. Introduction

An internal gas-jet target, to be applied in studies of fast ion-atom collisions by recoil-ion-momentum spectroscopy (RIMS), is being constructed at Stockholm University. The gas-jet target project is a collaboration between Stockholm University, Frankfurt University, and the GSI, Darmstadt.

In Fig. 1, we show a sketch of the gas-jet target in its position in one of the experimental sections of the storage ring CRYRING. Pre-cooled helium gas, at a pressure of $p_0 = 2$ bar, expands isentropically through a 30 μm aperture, leading to cooling to a temperature of <5 mK. On its way to the region of interaction with the ion beam inside of CRYRING, the gas-jet passes four differential pump stages. At the intersection with the ion beam, the gas jet has a diameter of 1 mm and a density of the order of 10^{12} cm^{-3}. Finally, the jet is disposed of in a jet-dump containing three differential pump stages (stages 6 to 8 of Fig. 1), which are separated by conductance-limiting tubes. The detailed design of the target is described in ref. [1].

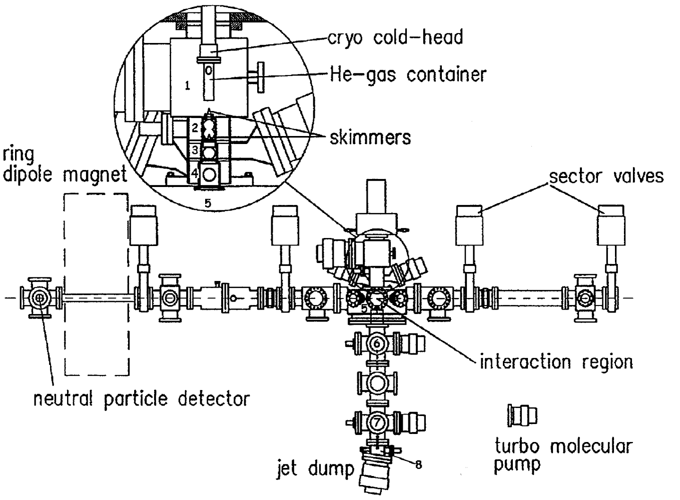

Fig. 1. Schematic drawing of the gas-jet target installed in one of the straight experimental sections of the CRYRING. The inset shows the jet-formation stages in somewhat more detail.

The RIMS technique is unique in allowing at the same time a very high resolution and a 4π solid angle. The strength of this technique has clearly been demonstrated over the past few years [2]. The combination of this strong technique with the high-intensity electron-cooled CRYRING beams is expected to provide the necessary tool to investigate a number of fundamental collision processes which, so far, has not been accessible for experimental investigations. Among the plans for the first experiments are investigations of the detailed dynamics of transfer ionization in p-He collisions as well as studies of double capture and transfer ionization in collisions between bare ions of higher charges and He atoms.

2. First gas-target tests

For the design of the gas target a set of standard parameter values, reflecting the highest demands for the system, was defined. In this standard situation the container, from which the gas jet expands through the 30 μm nozzle, is kept at a temperature of 30 K and a He pressure of 2 bar.

The test setup, illustrated in Fig. 2, was built up and run for a first series of tests. First of all it was confirmed that the

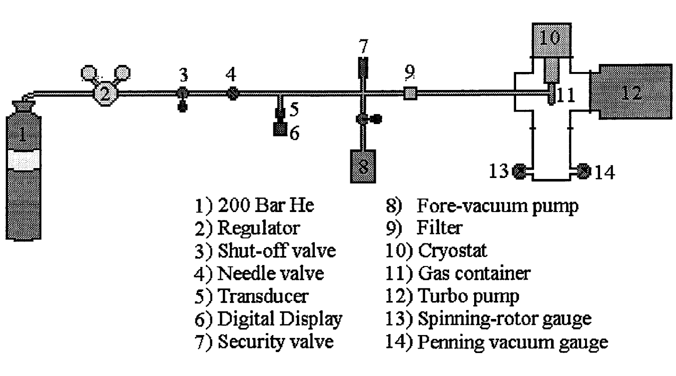

Fig. 2. Setup used for the first gas-target test described here.

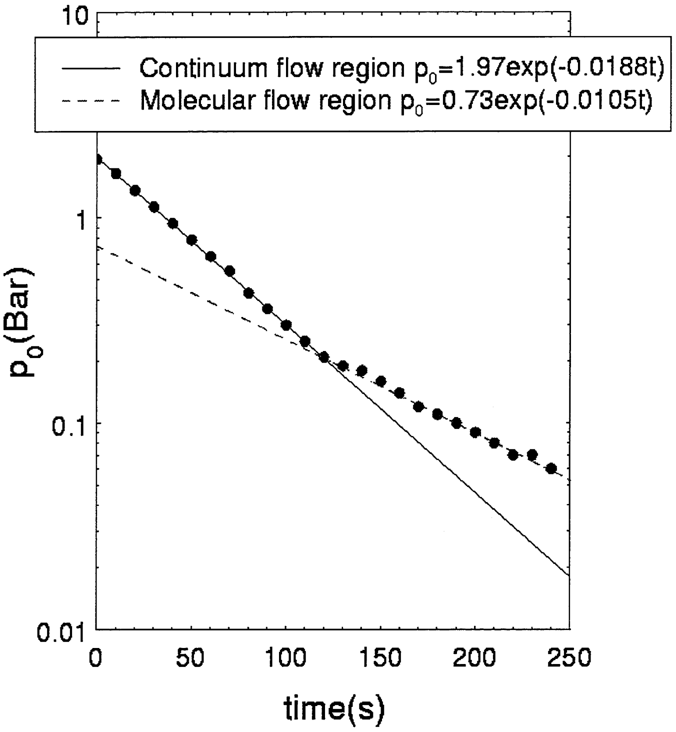

Fig. 3. The pressure in the gas container measured as a function of time after closing a valve in the gas line. The two different slopes correspond to the gas flowing out of the nozzle in a supersonic expansion for high pressures, and a free effusive expansion at lower pressure, respectively.

1000 l/s turbomolecular pump, pumping on the expansion chamber, could hold its nominal pumping speed at the high load of the running 'standard' jet. At the same time, it was established that the increased pressure of helium in this chamber did not lead to any substantial increase in the thermal conduction between vacuum chamber walls at room temperature and the cold container.

When gas is flowing through an aperture from a high pressure region into vacuum, its behavior dramatically depends on the gas density in the high-pressure region. For high densities, we are in the "continuum-flow" range, where an atom collides more often with another atom than with the container walls. Gas flow from such a region will be an adiabatic and quasistatic process leading to a supersonic expansion and hence to a low temperature and a well defined flow velocity. For low densities atom-atom collisions may be neglected and we get an effusive free expansion at constant temperature and with a very broad velocity distribution. For our future collision experiments we need a well defined jet velocity, and it is therefore crucial that we are in the high pressure "continuum-flow" range. To check this, we performed the following test.

We were running the jet at the standard settings of $p_0 = 2$ bar and $T_0 = 30$ K. We then closed a valve in the He line and measured the pressure p_0 in the inlet line and the cold container as a function of the time t after closing the valve. The result of this measurement is shown in Fig. 3.

3. Results of the first tests

We interpret the results shown in Fig. 3 as follows. At high pressures we have the continuum flow conditions and therefore a supersonic expansion. As the pressure drops below 0.2 bar (see Fig. 3) we get an abrupt transition to an effusive flow situation. To strengthen this interpretation we consider the expected pressure decay relations in the cases of continuum and molecular flow. In continuum flow we have [1]:

$$p_0^{\mathrm{CF}}(t) = C_1 \exp\left(-\frac{3}{16}\frac{A_T}{V_0}\sqrt{\frac{15kT_0}{M}}t\right),$$

whereas in the case of molecular flow [3]:

$$p_0^{\mathrm{MF}}(t) = C_2 \exp\left(-\frac{A_T}{V_0}\sqrt{\frac{kT_0}{2\pi M}}t\right).$$

Here C_1 and C_2 are constants, A_T is the area of the aperture, V_0 is the volume of the enclosed gas and M is the mass of a He atom. From these two pressure-time relations we can predict the ratio of the slopes for the pressure curves in continuum and molecular flow. The predicted slope ratio is $R = \frac{3}{16}\sqrt{30\pi} = 1.82$. By fitting two lines to the data in Fig. 3 we find this ratio experimentally to be $R = 1.79 \pm 0.07$ in agreement with the expected ratio and thereby confirming that the observed transition at $p_0 = 0.2$ bar is the transition from supersonic to effusive free expansion. This critical pressure is expected to be a function of the temperature T_0 of the gas container, but so far we have only determined it at one temperature ($T_0 = 30$ K).

After finishing the assembly of the full system the next step will be to test the vacuum in all pump stages with a running jet. After this test is performed with a satisfactory outcome, the target will be ready for installation in the CRYRING.

Acknowledgments

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