Average charges of heavy ions in a gas mixture

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At present, gas-filled separators are typically filled with either pure helium (He) or pure hydrogen (H_2). Hydrogen seems to provide better suppression of background related to target-like ions [1]. However, as the average charges are lower than in pure He, a stronger dipole magnet is needed to separate evaporation residues. Therefore, at the gas-filled separator TASCA, experiments were performed with a fill-gas mixture of these two gases to investigate whether this allows for a combination of the advantages of the two gases, i.e., which allows a good suppression of the background while still keeping rather high average charges of evaporation residues. However, no data exists how to predict the average charges of heavy ions in gas mixtures. Thus, we aimed to study systematically average charges of heavy ions.

Earlier studies at TASCA clearly showed that the average charge is a function of the gas pressure [1]. This so called "density effect" was investigated on ^{252,254}No ions and a corresponding semi-empirical expression for the determination of the average charges was given in [1]. These expressions were used for the prediction of pressure dependent average charges of No ions in pure He and H_2. The experimental setup and the nuclear reactions used in the studies reported here are the same as in [1]. Magnetic rigidities were deduced as described in [2].

Measured magnetic rigidities of ^{254}No ions in the mixtures at certain relative amounts of the gases ν (He/H_2), are shown in Fig. 1 as a function of the pressure. Clearly, the "density effect" is observed also in the mixtures.

Charge equilibration of heavy ions moving in the gas is determined by a system of coupled homogeneous linear equations for fractions of each charge state and cross-sections of "charge-exchange" collisions (see [3] for details).

Let us assume that the charge equilibration is also occurring in gas mixtures, and that heavy ions (with initial charge state fractions of F_i) after the "charge-exchange" collisions have fractions F_i^{mix} ($\sum F_i^{mix} = 1$) for each *i*-th charge state. Each heavy ion with an *i*-th charge state has a probability $P_{He}=\nu/(\nu+1)$ and $P_{H2}=1/(\nu+1)$ to collide with either a He or a H_2 atom, respectively, with $P_{He}+P_{H2}=1$. Then, the fraction of each *i*-th charge state in gas mixtures can be written as: $F_i^{mix} = F_i \cdot P_{He} + F_i \cdot P_{H_2}$.

Average equilibrated charges in the gas mixtures can be derived as:

$$\bar{q}^{mix} = \sum q_i \cdot F_i^{mix} = \frac{\bar{q}^{He} \cdot \nu + \bar{q}^{H_2}}{\nu + 1}$$

where, q^{He} and q^{H2} are average charges of ^{254}No ions in pure He and H_2 at the same pressure as the gas mixture, respectively. Corresponding magnetic rigidities can be put into the following expression:

$$(B\rho)^{mix} = \frac{(B\rho)^{He} \cdot (B\rho)^{H_2} \cdot (1+\nu)}{(B\rho)^{He} \cdot (\upsilon/\upsilon_0)_{H_2} + (B\rho)^{H_2} \cdot (\upsilon/\upsilon_0)_{He} \cdot \nu} \cdot (\upsilon/\upsilon_0)_{mix}$$

where (υ/υ_0) with different indices are the velocities of the ^{254}No ions in different gases (He and H_2 cases are given in [2]). In our experiments: $(\upsilon/\upsilon_0)_{mix}$=2.39±0.03. Predicted magnetic rigidities from the above expression with $(\upsilon/\upsilon_0)_{mix}$=2.39 are shown in Fig. 1 by open dots. Experimental magnetic rigidities are well reproduced for ν=1 and 2, except for some underestimations at 0.8 mbar. Slightly underestimated magnetic rigidities were also observed in the case of ν=3 and 4. Again, in these cases gas pressures were 0.8 mbar. This discrepancy could be due to the linear function which was used to fit the observed "density effect" within the region (1-2) mbar in the case of pure H_2 [2]. More detailed information will be given in [4].

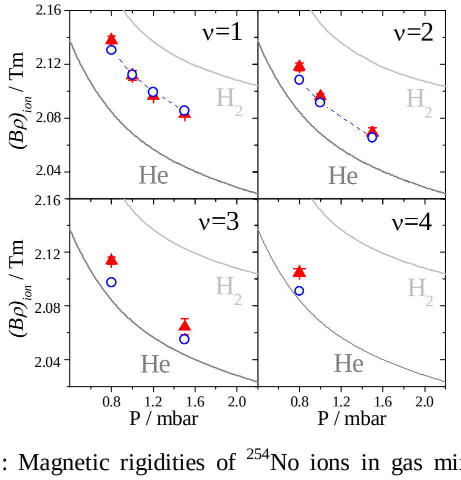

Figure 1: Magnetic rigidities of ^{254}No ions in gas mixtures ν depending on gas pressures P. Triangles and open circles are showing the measured and predicted magnetic rigidities, respectively. Lines are showing the fitted results for pure He and H_2 gases [1].

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