MEASUREMENT AND CALCULATION OF U^{28+} BEAM LIFETIME IN SIS

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Abstract

As part of the high-current upgrade measurements of U^{28+} beam lifetime between 10-150 MeV/u have been performed in the GSI synchrotron SIS. The lifetime is limited by stripping in the residual gas.

Comparison with detailed atomic calculations [1] still show a discrepancy of 2-3 between measurement and theory. Lifetime measurements have also revealed that beam losses at injection lead to large outgassing and corresponding increase of the dynamic pressure. Similar observations where reported in Ref. [2]. From beam current decay together with time resolved pressure measurements it was possible to obtain information about the pumping speed and the desorption coefficient.

In addition the beam lifetime of U^{73+} was measured too. Here the lifetime is limited by electron capture in the residual gas.

In support of the high current upgrade a dedicated test-stand has been set up to measure molecular desorption induced by heavy ions between 1 MeV/u and 1 GeV/u.

1 LIFETIME MEASUREMENTS

For the beam lifetime measurements the uranium ions were injected from the UNILAC into the SIS at an energy of 8.6 MeV/u. Then we observed the decay of the beam current measured with a beam transformer. The measured decay curve was fitted with an exponential decay function to gain the ion beam lifetime. The average static pressure in SIS was about $P=8.7 \cdot 10^{-11}$ mbar. The composition of the residual gas was measured with a number of residual gas analysers and was assumed to be 65% H_2, 17% O_2/H_2O, 8% CO/N_2, 4% Cl, 4% Ar and 1% CO_2. Thereby one has to consider that these measurements where done without ion beam in SIS. The lifetimes were measured for U^{73+} and U^{28+} in dependence of the beam energy.

1.1 U^{73+} beam lifetime

The lifetime of U^{73+} ions in SIS is displayed in figure 1. The measured data are in good agreement with the theoretical calculations of Shevelko [1] (dotted line in figure 1) and Franzke [3] (dashed line). One has to note that for the calculations the residual gas pressure was adjusted in a way that the lifetime meets the experimental data. This is allowed because the dynamic pressure was not exactly known during the experiment.

For the lifetime of U^{73+} the heavy ion induced desorption plays a minor role, because the number of injected (10^8 ions) and therefore lost ions is smaller.
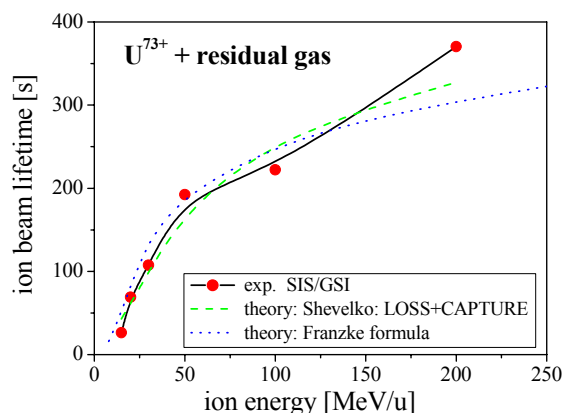

Figure 1: Comparison of measured beam lifetime (points) with calculations of Shevelko [1] (dotted line) and the formula given by Franzke [3] (dashed line) for U^{73+} for various beam energies at SIS.

1.2 U^{28+} beam lifetime

In figure 2 the lifetimes of U^{28+} ions measured for various beam energies are shown.
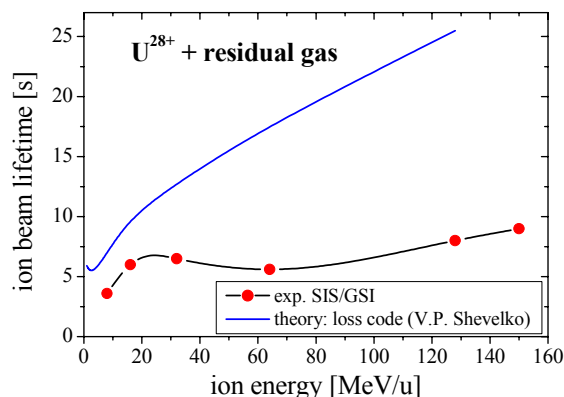

Figure 2: Experimentally measured ion beam lifetimes for U^{28+} (dots) in comparison with theoretical calculations of Shevelko [1] (line).

In comparison with the experimental data the calculated lifetimes of Shevelko [1] are displayed. The calculations have been performed for single-electron processes in the Born approximation using the LOSS code. We did not compare our measured data with the Franzke formulas because they are only valid if the charge state is higher than the equilibrium charge state. One can see that there is a discrepancy of a factor of 2-3 between theory and experiment. The problem is, that for the different beam energies, the total vacuum pressure was not stable. The

pressure varied with the ion current. Furthermore the composition of the residual gas was not known exactly during the beam time. Due to ion losses during injection molecules/atoms/ions from the vacuum chamber wall are desorbed. The ion induced desorption leads to a dynamic pressure increase and to a change of the residual gas composition in SIS. Similar observations were made at CERN [2]. Here the reported desorption coefficient is about 10^4 atoms/molecules per incident ion.

Ion induced desorption in SIS can be caused by three different processes. The first one is the primary ion beam loss during injection. The second one is the loss of charge exchanged primary beam ions due to collisions with residual gas ions. In this two processes the ions hit the wall at high energies. The third process is the creation of residual gas ions due to collisions with the ion beam. The residual gas ions are accelerated to the wall in the electrical field of the beam. The space charge potential in SIS-18 for U^{28+} ions at injection energy is about 50 eV. This means that for fully ionised Argon the maximum collision energy with the wall is 900 eV. We expect a large number of multiple ionised residual gas ions because the cross section is in the order of $\sigma(q=10)=10^{-15}$ cm^2 for 9.4 MeV/u U^{65+} on Argon [4]. The ion induced desorption yield for low energy collisions is between 0.1 and 10 molecules/atoms/ions per incident ion [5,6].

Another possible problem are the electrons produced by ionising collisions with the residual gas and by ion induced desorption. Experiments at AGS Booster revealed an electron yield of $9.3 \cdot 10^4$ electrons per incident 0.9 MeV/u Au^{31+} ion [7]. A more detailed study of Thieberger et al. [8] gave values between 0-100 for 28 MeV protons, 20 and 8000 for 7.9 MeV/u O^{8+} and 200-40000 for 0.92 MeV/u Au^{31+}. The yield scales with the $\cos^{-1}(\theta)$ of the incident angle, i.e. 0° means perpendicular incidence. The secondary electron yield has a $q^{1.7}$ dependence [9]. If electron multipacting plays a role at SIS is still under investigation.

In addition we observed that the lifetime changes with the number of injected ions. The lifetime of the ions in this case is in the order of the pumping time (about 1sec). Thus a local ion loss leads to a pressure bump that effects the lifetime. On the other hand the calculations did not take multiple ionisation processes into account. But it is known that these can contribute up to 50% to the total ionisation cross section [10]. Also not included in the theoretical calculation is the effect of post-collision autoionisation. This is known to be important at energies larger 100 MeV/u and increases the total ionisation cross section by up to a factor of 8 over the direct ionisation values [4]. At low ion beam energies (<10 MeV/u) the dominant process is no longer electron loss, but electron capture [1]. This effect is getting stronger for lower energies and causes the dip in the theoretical lifetime curve.

2 PUMPING SPEED AND DESORPTION YIELD CALCULATIONS

The evolution of vacuum pressure P and beam current I in the SIS can be calculated with the following formulas:

$$\frac{dP}{dt} = -\frac{S}{V}(P - P_e) + \frac{\sigma \eta L}{VeZ} IP \qquad (1)$$

$$\frac{d}{dt}\ln\left(\frac{I}{I_0}\right) = -\frac{\sigma L n_l}{T} P = \frac{1}{\tau_{life}} \qquad (2)$$

where S is the pumping speed, V the volume of the vacuum chamber, L the length of the SIS, T the revolution time, σ the cross sections of charge exchange of the beam ions with the residual gas molecules, η the desorption yield, P the averaged pressure over the whole ring, P_e the equilibrium vacuum pressure in the absence of beam, I_0 the initial value of the beam current, eZ the charge of the ions and $n_l = 2.7 \cdot 10^{25}$ m^{-3} the Loschmidt constant. With these two formulas we where able to fit our measured pressure and ion current evolution. As free fit parameters we used the pumping speed, the charge exchange cross section, the desorption yield and the initial pressure. The results of the fit of the data measured at injection energy (8.6 MeV/u) are shown in table 1. The fitted values for the cross sections can be compared with the theoretical values given by Shevelko ($\sigma = 0.2 \cdot 10^{-20}$ m^2). One can see that we have a discrepancy up to a factor of 10 between our out of the experiment calculated cross sections and the theoretical ones. Shevelko assumed that the residual gas composition is Hydrogen dominated (80%). But from measurements at CERN [2] it is known that the main components of the desorbed gas are CO and CO_2. The nominal pumping speed in the SIS is about S=80 l/s per pump station. The desorption yield measured at CERN [2] and AGS in Brookhaven [11] is $\eta = 10^4$ resp. $\eta = 10^5$. One can see, that our fitted data are in good agreement with the theoretical values and the measurements performed elsewhere.

It is interesting to note that recent experiments at RHIC with 8.6 GeV/u fully stripped gold ions led to a dramatic increase of the vacuum pressure in the ring (>10^{-5} Torr) [12]. These pressure bumps are believed to be a combined effect of electron multipacting and residual gas ions.

Table 1: Calculated pumping speed, charge exchange cross sections, desorption yield and vacuum pressure in SIS for the storage of 8.6 MeV/u U^{28+} ions.

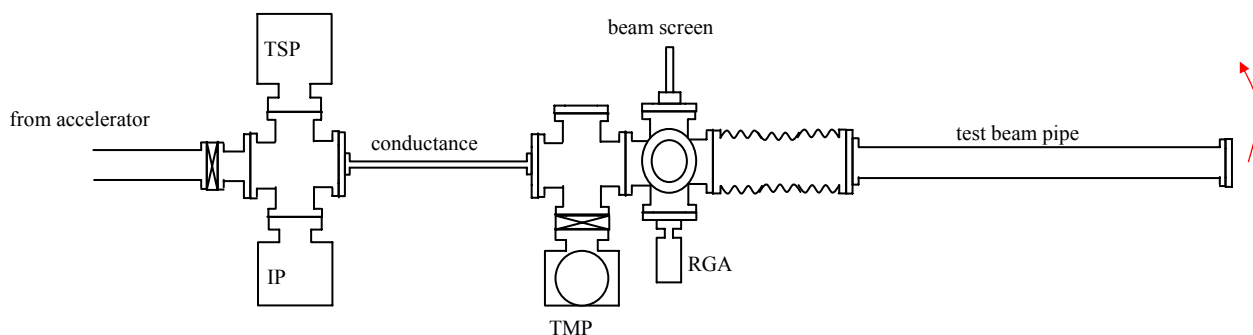| injected ion current [mA]	pumping speed [l/s per pump station]	σ charge exchange cross section [10^{-20} m^2]	desorption yield η	initial pressure [10^{-11} mbar]
1.08	160	1.1	7200	6.0
1.40	120	0.8	10000	14
1.97	160	1.3	6000	6.5
5.36	150	2.1	4200	10

Figure 3: Planned set-up to measure the ion induced desorption yield.

3 POSSIBLE CURES

Experimental studies at CERN showed that there is no major effect on the ion induced desorption yield due to different coatings and cleaning techniques applied to the beam pipe. A more promising way is to apply NEG (Non-Evaporable Getter) stripes in the tubes to increase the local pumping speed [13]. Another proposed cure for LEIR is beam-scrubbing, which is widely used in synchrotron machines [14]. But this effect was never tested in a hadron machine. Only at PSR it was shown that beam scrubbing helped to reduce the electron cloud effect [15].

At GSI a combination of collimators and pumping ports is discussed [16]. The idea is to produce deduced ion losses in a collimator and to put a high pumping speed in front of it to remove the beam induced molecules.

4 A NEW TEST-STAND

A new experimental test-stand is set-up to measure the ion induced desorption yield at GSI. The idea is to get more information on the mechanism of desorption. Therefore we would like to measure the yield in dependence of the charge state of the desorbed ion, the beam energy, the incident angle and the mass of the ion. Although different kinds of beam pipe material (stainless steel, copper, ceramics) and different types of surface treatments (electro-polishing, chemo-polishing,…) will be examined. Furthermore we think about various coatings (Gold, NEG, TiN) to reduce the ion induced desorption yield. A schematical drawing of the experimental set-up is shown in figure 3. The ion beam is coming from the left. The first chamber is pumped with an ion (IP) and a titan sublimation pump (TSP). Next follows a conductance to get a defined pumping speed in the analysing chamber independent of the conditions of the vacuum pumps. The analysis chamber is equipped with a beam screen, an extractor ion gauge and a residual gas analyser (RGA). The test beam pipe is connected with a bellow to the analysis chamber so it can be tilted.

The ion beam hits the beam pipe under a well defined angle. The pressure increase due to desorption is measured with a residual gas analyser (RGA). The analysis chamber is connected to a turbomolecular pump

(TMP) and a scroll pump. These were used to evacuate the chamber and during bake out. The TMP is separated from the analysis chamber with a metal valve which will be closed during the measurements. In addition it's planned to install a test chamber with a target manipulator instead of the beam pipe to test more than one sample at a time. The chamber and the sample will be bakeable up to 250°C.

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