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Status report to the ISOLDE and Neutron Time-of-Flight Experiments Committee (INTC) on the experiment IS439

Nuclear moments, spins and charge radii of copper isotopes from N=28 to N=50 by collinear fast-beam laser spectroscopy

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Abstract
This report is a brief summary of the progress of the IS439 project in 2006. It will outline the results from the off-line tests in March and the on-line experiment in September. Future prospects in 2007 based on our present experience will be discussed.

Out of a total of 18 approved shifts, nine were taken during 2006. The isotope shifts, spins, magnetic dipole and electric quadrupole moments of ^{64,66,67,68g,68m,69,70g}*Cu were measured in this running period. Based on these results the collaboration requests that the remaining 19 shifts from the proposal are approved for 2007 and 2008*

1 March 2006 off-line tests

It was outlined in the proposal that commencing a new program of laser spectroscopy on copper isotopes contained many uncertainties. Although the proposed atomic transitions for investigation are strong, it was not clear to what degree these would be populated during the neutralization process. Since this would be the first time that collinear laser spectroscopy would be performed on copper it was necessary to request off-line time to study the population of the atomic ground state through neutralization and optimize the detection efficiency. This would then allow future on-line experiments to make efficient use of the available time.

It was shown that there is little or no population of the atomic metastable states of copper through the neutralization process. To test this, the atomic beam was Doppler tuned across the resonant frequency of the metastable-state transition to the $^2P_{3/2}$ state, this was then monitored through the strong transition to the $^2S_{1/2}$ ground state. It was possible to remove all scattered laser light with the addition of a UG11 filter.

Direct spectroscopy of the $^2S_{1/2} - ^2P_{3/2}$ ground-state transition recorded a total detection efficiency of 1:30 000, based on the ion beam current measured on LA0 FC90. With this efficiency and the quoted yields from the ISOLDE database it would be possible to measure the neutron rich copper isotopes up to and including ^{72}Cu.

2 September 2006 on-line run

The run in September employed a UC$_X$ target (target number 333) with a Ta line, which was used for IS435 in August and then removed. During the IS435 experimental campaign only a modest number of proton pulses (73595 pulses with an average of 1.87×10^{13} protons per pulse) were taken, and the target was kept at a low operating temperature (660A) for the majority of this time. The yield measurements that were made during this period were almost an order of magnitude stronger than those quoted for copper with PSB (see figure 1).

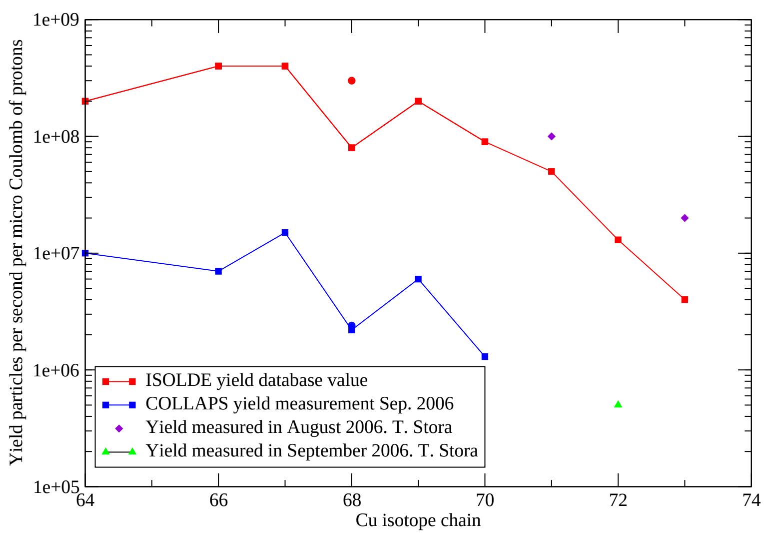

Figure 1: A comparison of yield measurements for UC$_x$ target. Red points show the historic yields from the ISOLDE database. The blue points show the yields determined by COLLAPS and NICOLE. The purple points show the yields measured in August and the green point shows the yield of ^{72}Cu measured in September by T. Stora

It was immediately apparent that conditions had changed after the target was reinstalled for IS439/IS431 in week 36. This can be seen in the yield measurement of ^{72}Cu shown in green in figure 1. Further more, both NICOLE and COLLAPS were able to make consistent yield measurements based on their own detection efficiencies, calibrated to FC490. A full summary of all yield measurements is shown in figure 1.

In the original proposal it was stated that the limit sensitivity for the COLLAPS experiment operating with only fluorescence detection on an atomic beam, would be $10^7 s^{-1}$. This estimate was based on the uncertainties of neutralization efficiency for copper, and the detection efficiency for spectroscopy on the ground-state transitions. Given the conditions during the September on-line period, extensive optimization of the setup was required. This increased the overall detection efficiency to 1:6000 (based on the ion current detected at FC490). The five-fold improvement in detection allowed the COLLAPS setup to detect beams down to $10^6 s^{-1}$ an order of magnitude lower than quoted in the proposal, and permitted ^{70g}Cu to be studied.

The results from the September run are summarized in table 1 in terms of the hyperfine splitting parameters. A total of 7 radioactive isotopes were measured during this run. This is the first time the quadrupole moments and isotope shifts of these isotopes have been measured. From this work it was also shown that the accepted sign of the magnetic moment of ^{66}Cu is incorrect. The magnetic moments of $^{66-70}$Cu have all been improved by 1-2 orders of magnitude.

Isotope/Isomer	A factor ($S_{1/2}$) (MHz)	B factor($P_{3/2}$) (MHz)	Isotope Shift (A=65 ref)
63	+5866.9(5)	-28.1(3)	**-570.0(4)**
64	-856(2)	**+9.8(7)**	**-244.6(9)**
65	+6282.2(5)	-25.8(4)	0
66	**+1104.4(3)**	**+9.9(11)**	**293.5(10)**
67	+6632.7(12)	**-22.8(13)**	**554.4(9)**
68	+9476.4(14)	**-10.3(13)**	**856.3(9)**
68m	+761.2(5)	**-59.1(30)**	**804.3(12)**
69	+7487.1(15)	**-19.2(18)**	**1071.4(10)**
70	+901.1(11)	**-41.0(40)**	**1334.8(23)**

Table 1: Table summarizing all measured hyperfine structure parameters. The bold values represent new or interesting measurements. The isotope shifts represent a totally new measurement.

3 Prospects for further work in 2007

These experimental results are extremely encouraging. This work has demonstrated a lower yield limit of $10^6 s^{-1}$, which requires approximately one shift to collect sufficient statistics for publication. The problem of low yields encountered with target number 333 would not be expected with a new target. Further more initial yields measured during the IS435 campaign are very encouraging for the coming running period.

Based on the yields (purple points in figure 1) measured in August it would appear that the Ta line greatly improves the transfer of copper. The yield of ^{73}Cu has an almost four fold improvement compared to the yield from the ISOLDE database (red point figure 1). A very tentative extrapolation of this trend would place the yield of ^{75}Cu at $> 10^6 s^{-1}$. Although such an extrapolation is not to be trusted it is very encouraging for the IS439 project and its ability to probe far from stability during the next running period.

3.1 ISCOOL and its application to IS439

The decrease in the copper yields as the N=50 shell closure is approached is such that the background of scattered light is too high to study these cases currently. The introduction of a RFQ cooler to the ISOLDE will be crucial for allowing the IS439 experiment to probe the N=50 shell closure. This will be achieved by suppressing the background of scattered light by accepting photons only when an atomic bunch is anterior to the light collection region.

The measured yield of ^{76}Cu (quoted in the database), is sufficient that a reduction of the trapping time can overcome the space charge limits of the Paul trap associated with the large isobaric contamination of ^{76}Ga. For ^{77,78}Cu this method alone will not be sufficient due to their low production rates and additional suppression of surface ionization is required.

Study of the neutron deficient side of stability will greatly benefit from the introduction of the RFQ cooler. The absence of any large isobars makes this a good case to study once the cooler has been commissioned. Based on the ISOLDE database yields it will be possible to measure the magic nuclei ^{57,58}Cu, provided no large molecular contamination is present.

4 Summary and beam time request for 2007

The COLLAPS collaboration has demonstrated the viability of the IS439 project and measured 7 ground and isomeric states in copper in 9 shifts. From these results it is clear that the proposed method of measurement is sound and justifies further work in the coming year. The INTC originally approved 18 out of the 37 shifts requested by the collaboration. The remaining 19 shifts would be approved depending on the initial results from the IS439 experiment. The collaboration now asks that the remaining 19 shifts originally requested are approved for the coming running period in 2007 and 2008.

It is the intention of the collaboration to make further measurements on the neutron rich side of stability. A run of 9 shifts will study the chain as far as ^{73}Cu and possibly up to ^{75}Cu given optimal conditions. Such measurements would be carried out during the next running period, before the installation of the ISCOOL RFQ cooler.

The introduction of the cooler will permit the neutron deficient isotopes down to ^{57}Cu to be measured. A request for 9 shifts for this work will be made once the cooler has been commissioned. The Remaining 10 shifts will be used to push the spectroscopy measurements towards the N=50 shell closure.