Isomer separation and measurement of nuclear moments with the ISOLDE RILIS

U. Köster [a,b,*], R. Catherall [a], V.N. Fedoseyev [c], S. Franchoo [d], U. Georg [a], M. Huyse [d], K. Kruglov [d], J. Lettry [a], V.I. Mishin [c], M. Oinonen [a], H. Ravn [a], M.D. Seliverstov [e], H. Simon [a], P. Van Duppen [d], J. Van Roosbroeck [d], L. Weissman [d], the IS365 Collaboration and the ISOLDE Collaboration [**]

[a] *ISOLDE, CERN, CH-1211 Genève 23, Switzerland*
[b] *Physik-Department, TU München, D-85748 Garching, Germany*
[c] *Institute of Spectroscopy, Russian Academy of Sciences, 142092 Troitsk, Russia*
[d] *Instituut voor Kern- en Stralingsfysica, K.U. Leuven, B-3001 Leuven, Belgium*
[e] *St. Petersburg Nuclear Physics Institute, 188350 Gatchina, Russia*

Short-lived radioisotopes are element selectively ionized by the resonance ionization laser ion source (RILIS) of the on-line isotope separator ISOLDE (CERN). The relative production of low- and high-spin isomers can be significantly changed when a narrow-bandwidth laser is used to scan through the atomic hyperfine structure. This allows the assignment of gamma ray transitions to the decay of the individual isomers. Moreover, the measurement of the hyperfine splitting provides a very sensitive method for the determination of magnetic moments of exotic isotopes. The technical developments are discussed for the example of copper.

Keywords: isomer separation, copper, laser ion source, resonance ionization spectroscopy, hyperfine structure

1. Introduction

At the on-line isotope separator ISOLDE the resonance ionization laser ion source (RILIS) is used to provide beams of short-lived isotopes from a variety of metallic elements; see [1] for an overview. The atomic energy levels used for the resonant excitation of the valence electron represent a “fingerprint” for each element and allow an element selective ionization. In combination with the subsequent mass separation isotopically “pure” beams are provided.

The use of narrow-bandwidth lasers can often allow one to resolve the small difference in the transition energies due to the hyperfine interaction of the atomic electrons with the nucleus. Thus the RILIS can be used as a sensitive tool for atomic spectroscopy with rare short-lived isotopes; see, e.g., [2,3]. Recently this option was

* Corresponding author. E-mail: Ulli.Koster@cern.ch.
** Supported by the European Union: contract ERBFMGEECT980120.

used at ISOLDE for the study of various silver and copper isotopes and isomers. The results for silver are discussed in [4,5].

In 1998 a short scan was performed on the system of ^{70g,m}Cu which enabled the separation of the ground state and isomer and further provided a measure of the magnetic moments of the states. Details of this experiment can be found in [6]. In 1999 another series of scans was made with neutron-rich copper isotopes from ^{63}Cu to ^{77}Cu.

2. Ionization scheme and experimental set-up

For these laser scans two similar ionization schemes were used. Two ultraviolet transitions provide a two-step excitation from the $3d^{10}4s\,^2S_{1/2}$ ground state (g.s.) via one of the $3d^{10}4p\,^2P^0_{1/2,3/2}$ excited states (e.s.) to the autoionizing state (AIS) $3d^94s5s\,^2D_{3/2}$ (see figure 1). For most scans the $3d^{10}4p\,^2P^0_{1/2}$ state served as the intermediate level. For comparison the ^{68}Cu isomers were also scanned with the $3d^{10}4p\,^2P^0_{3/2}$ state as the intermediate level. In both cases the wavelength of the first transition (327.4 and 324.8 nm, respectively) was scanned while that of the second transition was kept fixed (note the large width of the AIS in figure 1).

The ultraviolet light is produced by second harmonic generation of dye laser beams (pumped by copper vapor lasers with 11 kHz repetition rate) in a nonlinear

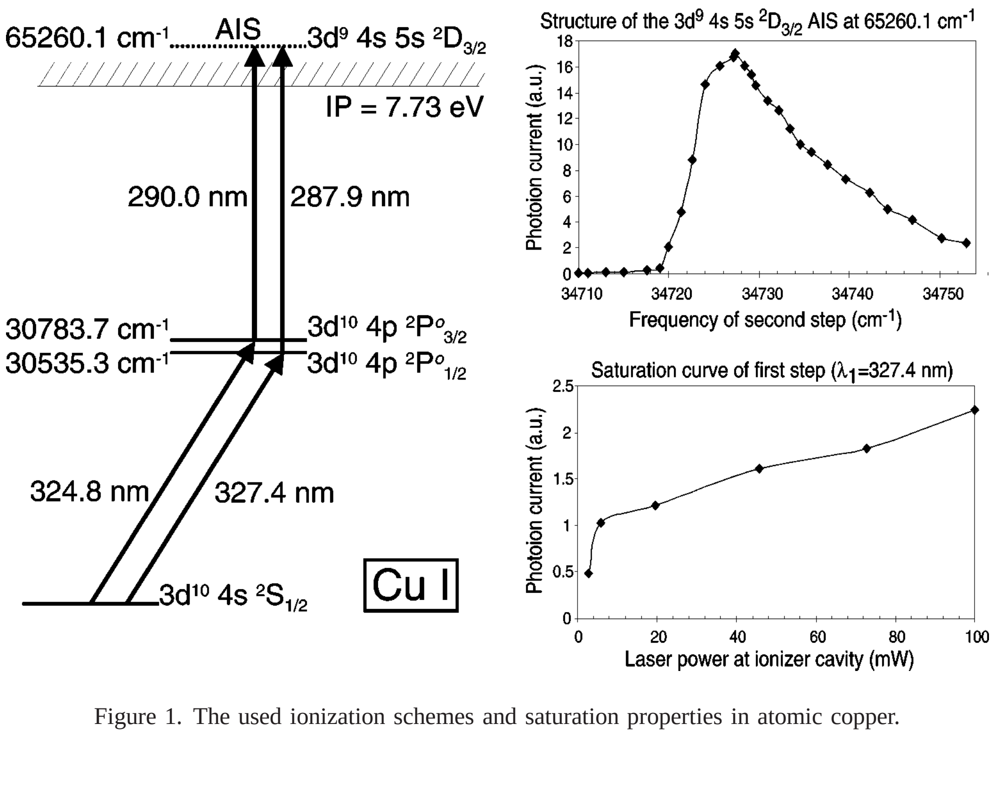


Figure 1. The used ionization schemes and saturation properties in atomic copper.

BBO crystal. The bandwidth of the first step dye laser was reduced to about 1.2 GHz by the introduction of a 6 mm thick glass etalon. The frequency is monitored with a lambdameter (resolution <300 MHz). For the second step a broad-band (about 25 GHz bandwidth) dye laser was used which was kept at a constant wavelength.

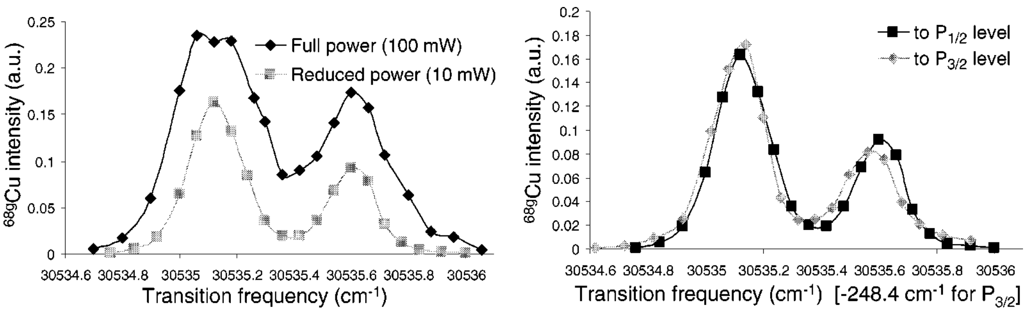
The produced photoions were detected *simultaneously* at three beamlines of the ISOLDE general purpose separator (see [6, figure 2]):

- The central mass was sent to the ISOLDE monitoring tape station where the activity was implanted into a tape and moved into a 4π plastic scintillator for beta detection. A 30% Ge (Li) detector was also positioned at this set-up, in close geometry, and was used to provide γ-ray identification of isomeric and ground state decays.
- At the low mass side (GLM) a stable copper beam (^{63}Cu and ^{65}Cu) was measured in a Faraday cup and used for continuous monitoring of the laser intensity fluctuations.
- The heavier isotopes $^{75-77}$Cu were detected via β-delayed neutrons with the Göteborg neutron long counter installed at the high mass beamline (GHM).

The experimental width of the resonance line is dominated by the Doppler broadening in the hot ionizer cavity: about 3–4 GHz for heavy copper isotopes. With full laser intensity (about 100 mW at the ionizer cavity) also a significant saturation broadening occurs. To reduce it the intensity was attenuated to about 10 mW which corresponds to a reduction of the ion beam intensity by about 50% (see figure 1). The effect on the linewidth is clearly seen in figure 2(a). Note that the saturation affects also the relative amplitude of the peaks.

With full laser power the ion yields were about 2.3×10^7 per μC of 1 GeV proton beam for ^{68g}Cu and 1.1×10^8 per μC protons for ^{68m}Cu. Using a broad-band laser for the first transition these yields are a factor of three higher.

The observed hyperfine splitting is dominated by that of the g.s. The splitting of the $3d^{10}4p\,^2P^0_{1/2}$ level only amounts to about 8.6% of the former. The use of the



(a) (b)

Figure 2. Scans of the hyperfine structure of ^{68g}Cu (identified by the 1077 keV γ-line and corrected for the ^{68m}Cu contribution) with full and reduced laser power (a) and comparison of the transition to the $^2P^0_{1/2}$ and the $^2P^0_{3/2}$ levels (b). Note that for a common representation the curve of the latter was shifted by -248.4 cm^{-1} and the intensities were individually normalized.

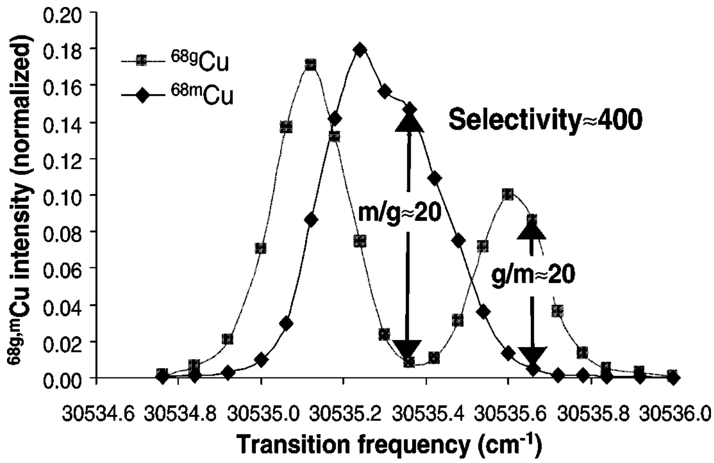


Figure 3. Separation of ^{68g}Cu and ^{68m}Cu. The intensities were normalized individually. In reality the ^{68m}Cu intensity is four to five times the ^{68g}Cu intensity.

transition to the higher lying $3d^{10}4p\,^2P^0_{3/2}$ level incurs a further quadrupole splitting, which arises from the nonspherical symmetry of the electron orbit, but the resulting hyperfine splitting of the three subpeaks remains below 10% of the ground state splitting and is not resolved (see figure 2(b)). The relative amplitude is determined by the selection rules between the m_F substates when using linearly polarized light. Note that the intensity ratio is changed when the transition is strongly saturated.

The isomeric selectivity depends on the difference of the respective hyperfine splittings. In the case of ^{68g,m}Cu the intensity ratio of the low- and high-spin state can be varied by a factor of about 400 (see figure 3).

3. Outlook

The newly measured magnetic moments of heavy copper isotopes up to ^{77}Cu are now under evaluation. New experiments are already planned to extend this powerful method to other elements.

References

[1] V.N. Fedoseyev et al., this issue.

[2] G.D. Alkhazov et al., Nucl. Instrum. Methods B 69 (1992) 517.

[3] M.D. Seliverstov et al., this issue.

[4] K.L. Kratz et al., in: *Proc. of Internat. Conf. on Fission and the Properties of Neutron-rich Nuclei*, Sanibel Island, ed. J.H. Hamilton (World Scientific, Singapore, 1998) p. 586.

[5] V. Sebastian et al., in: *Proc. of the 2nd Internat. Conf. on Exotic Nuclei and Atomic Masses*, Bellaire, eds. B.M. Sherrill, D.J. Morrissey and C.N. Davids, AIP Conference Proceedings, Vol. 455 (Amer. Inst. Phys., New York, 1998) p. 126.

[6] U. Köster et al., Nucl. Instrum. Methods B, in press.