State-Selective Studies of Radiative Recombination at the ESR Electron Cooler

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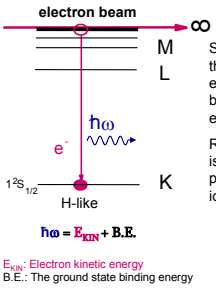
Radiative Recombination (RR)

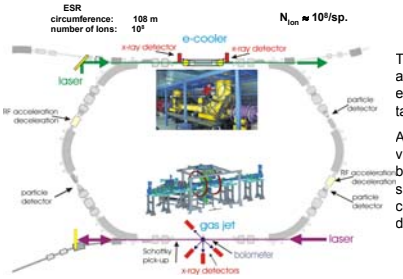


E_{KIN}: Electron kinetic energy
B.E.: The ground state binding energy

Schematic presentation of the RR process of free electrons into the initially bare ions at relative energies close to 0 eV.

Radiative Recombination is the time reversed process of photo-ionization.

The Experimental Storage Ring ESR

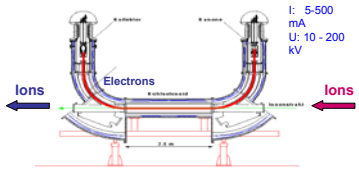


Two experimental areas are available in the ESR: the electron cooler and the gas target.

At high beam-energies relativistic kinematics are one of the biggest challenges in X-ray spectroscopy. Therefore the cooled and stored ions are decelerated.

300 MeV/u ⇨ **Deceleration** ⇨ **43 / 15 MeV/u**

Electron cooling



Ions interact 10^6 1/s with a collinear beam of cold electrons

Properties of the cold ions

Momentum spread: $\Delta p/p$: $10^{-5} – 10^{-6}$
Diameter : 2 mm
Well defined absolute beam energy

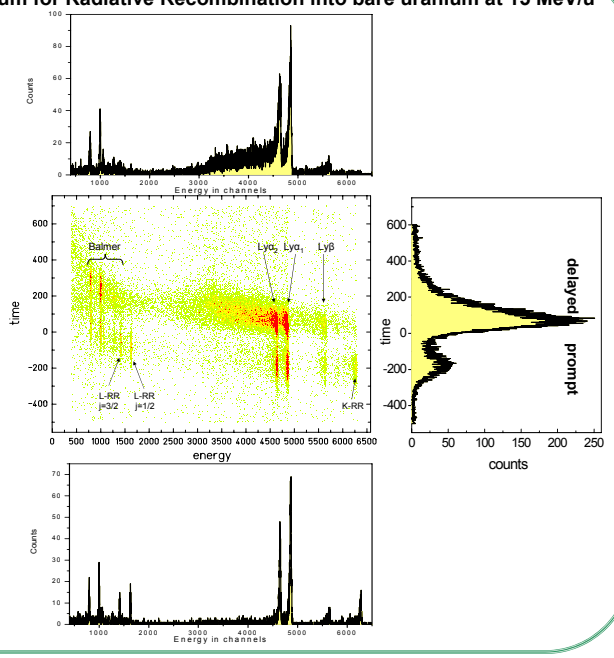
The observed X-ray spectrum for Radiative Recombination into bare uranium at 15 MeV/u

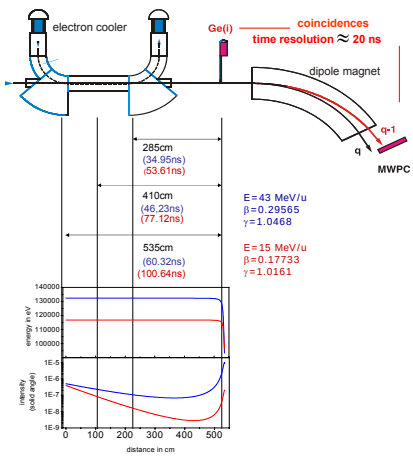
Recombination into Rydberg states and subsequent cascades lead to delayed Lyman emission by up to one microsecond. Delayed emissions can take place just in front of the detector and due to the Doppler Shift appear at lower energies.

The cascades also lead to delayed Balmer emission. Since the transition energies are much lower the relativistic energy shift is not that pronounced.

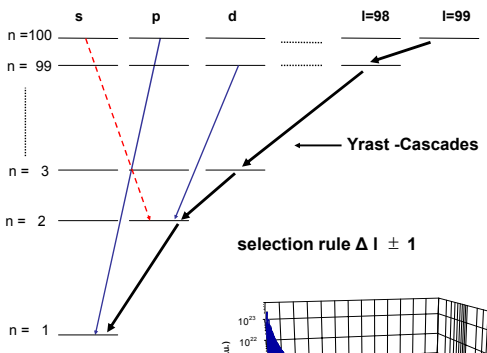
Dividing the energy spectrum into several parts and applying individual time conditions we are able to extract energy spectra containing only prompt (lower) and delayed (upper) events respectively.

Since direct recombination is only possible inside the electron cooler, those events should appear promptly. This is confirmed by the fact that L-RR as well as K-RR lines are present in the prompt spectrum only. In contrast the tails resulting from the energy shift of delayed events soley show up in the delayed spectrum.



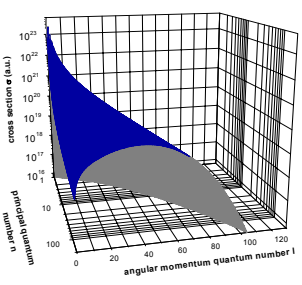


Electrons recombine with bare uranium ions inside the electron cooler. The emitted photon is measured in coincidence with the down charged ion. Some electrons recombine into highly excited states with high angular momentum l and therefore do not undergo a fast groundstate transition. These long-lived states decay at some time after the ion has already left the cooler and therefore have a different time signal.



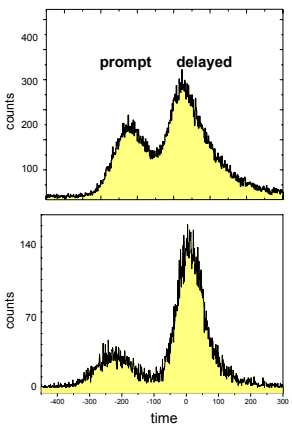
Electrons captured into low angular momentum states decay fastly, while electrons in higher l states decay mainly via slow cascade transitions.

The capture cross-section decreases with increasing principal quantum number n, but it has higher values for $\frac{n}{3} < l < \frac{2}{3}n$ states, which leads to a considerable number of cascade transitions.



O. Brinzanescu, 2000

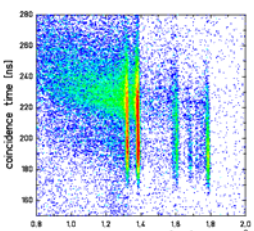
Comparision to a former experiment at 43 MeV/u



Time spectra for the Lyman-transitions in H-like uranium at 43 MeV/u (upper) and 15 MeV/u (lower). It is clearly visible that for 15 MeV/u a better resolution of the prompt and delayed time peak is achieved. Comparing the intensity ratio of prompt to delayed events yields 1:2 for the higher energy and 1:3 for the lower.

From this we can conclude that there must be a significant number of long-living states which contribute to the Lyman-transitions even after 100 ns. On the other hand this deviation cannot be caused by delayed transitions only. Due to the lower energy also the emission characteristics are different. For higher energies the relativistic solid angle correction results is an enhanced emission towards forward angles for promptly occuring events. Hence less prompt events are observed for the lower energy. A correction of about 30% due to this effect has to be considered.

2D-spectrum (time versus energy) of the Lyman- and K-RR lines for 43 MeV/u. There is no separation of prompt and delayed events visible. ⟶



A. Gumberidze et al., 2003

References:
O. Brinzanescu, PhD Thesis, University of Heidelberg, 2000

A. Gumberidze et al. Nucl. Instr. Meth. B 205 (2003) 374