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Two-photon decay of the 1s2s $^1S_0$ state in $_{36}Kr^{34+}$ produced by resonant transfer and excitation

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The doubly excited 2s2p $^1P_1$ level of Kr^{34+} populated via resonant transfer and excitation (RTE) feeds selectively the metastable 1s2s $^1S_0$ state which can only decay via simultaneous emission of two photons to the ground state $1s^2$ $^1S_0$. X-ray/X-ray coincidence measurements in heavy ion-atom collisions enable the direct measurement of the spectral distribution of the two-photon decay in He-like ions. In addition, we observe strong photon cascades induced by radiative electron capture.

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In two-electrons ions the primary decay mode for the 2^1S_0 state for all Z is the two-photon (2E1) decay to the 1^1S_0 ground state. The two photons are emitted simultaneously and the sum of their energies is equal to the 2 $^1S_0$ - 1 $^1S_0$ energy separation. As in the case of the 2E1 decay in H-like ions the resulting photon spectrum shows a continuous energy distribution, symmetric around the energy midpoint [1]. The theoretical spectral distribution for low Z helium-like ions [2] shows a broadening of the distribution with increasing Z as a result of decreasing importance of electron-electron interaction, whereas the hydrogen-like distributions [3] demonstrate a narrowing of the spectrum at higher Z due to the increasing importance of relativistic contributions. For the lowest Z the distribution for hydrogenic ions is wider than the corresponding one for He-like species.

The few experimental studies of the two photon decay have been concentrated on measuring the 2 $^1S_0$ lifetime ([4], reviewed in Ref. [5]) utilizing the beam foil technique. No information about the spectral distribution was given in these experiments. In this paper a method to study the spectral distribution is presented [6] [7]: the metastable 2 $^1S_0$ level is fed by the decay of the 2s2p $^1P_1$ state populated via the KLL-RTE resonance in collisions between hydrogenic projectiles and light gas atoms (H_2).

Within the impulse approximation RTE is considered as the time reversed Auger process: The energy gained by the capture of one quasi free target electron is used to excite one electron of the incident projectile forming a doubly excited intermediate state which may stabilize radiatively. For the KLL-resonances (the Auger-notation is used, i.e. excitation from K to the L shell by simultaneous capture into the L shell) of H-like projectiles this process leads to doubly excited states with two electrons in the L-shell and two K-shell vacancies. Therefore, the fingerprint for this process is the simultaneous emission of two K-photons. The resonance condition for the KLL-resonance is given by the adiabaticity parameter $\eta = 1/2$ ($\eta = (v/v_k)^2$, where v is the projectile velocity and v_k the velocity of the K-shell electron) [6] [7]. Only one of the KLL-resonances the 2s2p $^1P_1$ level feeds the metastable 1s2s $^1S_0$ state via emission of one K_α hypersatellite. The following 2E1 decay can then be observed via the x-ray/x-ray coincidence method (each detector measures the energy of one of the two photons) as already demonstrated in $Ge^{31+} \rightarrow H_2$ collisions [6] [7].

Measuring x-ray/x-ray coincidences for projectiles having captured one electron in the collision, we studied the two-photon decay of He-like Kr^{34+} ions in collisions between hydrogenic Kr^{35+} projectiles and H_2 gas atoms at the KLL-resonance, i.e. at 16.7 MeV/u. A charge state analysed beam was focused onto a differential pumped gas target. Additionally the ions were charge state analysed by a dipol magnet behind the target area. The projectiles associated with one captured electron were then registered by a fast scintillator counter and measured in coincidence with the x-rays from the target area. The target area was viewed by two Si(Li) detectors mounted perpendicular to the beam axis with an effective solid angle of 1% of 4π each.

The resulting cluster plot of coincident two photon events is shown in Fig. 1. A broad peak at (13 keV,13 keV) is found due to radiative stabilisation of the doubly excited intermediate states. Additionally, three prominent continuous ridges can be seen at x-ray energies corresponding to (K_α,E_1), (E_2,K_α), and (E_1,E_2) with $E_1 + E_2 = K_\alpha$. These structures are caused by the detection of the K_α-photon of the $2s2p^1P_1$ - $1s2s^1S_0$ transition in coincidence with one photon of the 2E1-decay, (E_2,K_α) or (K_α,E_1), and by the detection of both photons of the 2E1-decay (E_1,E_2).

Using the energy condition for the sum energy of the two-

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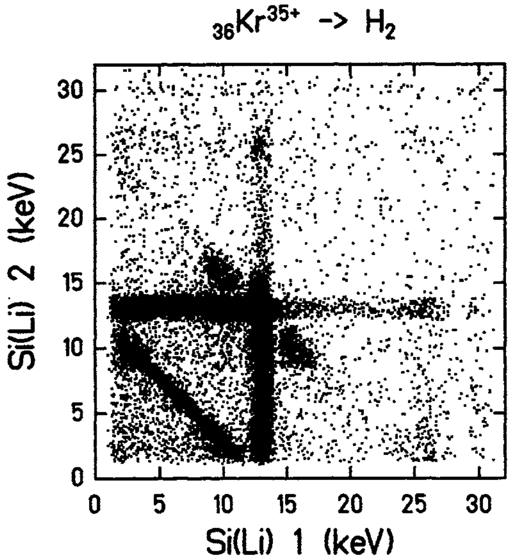

Fig. 1: x-ray/x-ray cluster plot for $Kr^{35+} \rightarrow H_2$ collisions measured in coincidence with projectiles having captured one electron.

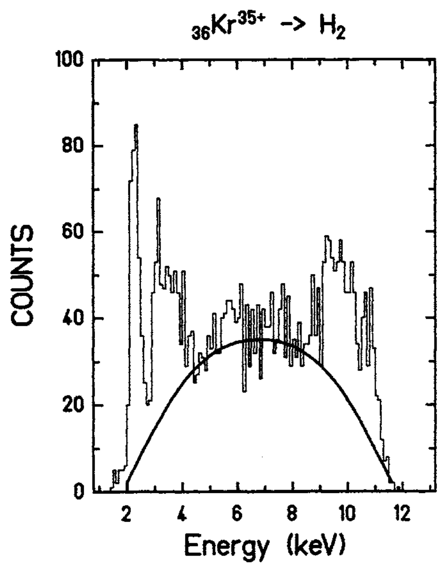

Fig. 2: Spectral distribution of the 2E1 decay of Kr^{34+} measured by one of the detectors.

photon decay the resulting spectral distribution measured by one detector is plotted in Fig. 2. In addition the theoretical predicted spectral distribution [8] convoluted with the response function for x-ray detection is shown in Fig. 2. The expected line shape is superimposed by broad structures on the high energy side and by Kr contributions like L radiation in the low energy regime. Both features can be explained by radiative electron capture (REC). Due to the resonance condition for KLL-RTE the energy of the L-REC photon has an energy equivalent to the K_α transition energy. Therefore REC into higher projectile shells and a following electron transition into the L-shell leads also to a simultaneouse emission of two photons with the sum energy equivalent to a K_α x-ray (e.g. M-REC/L_α coincidence). The additional diagonal ridge which is indicated partially in Fig. 1 at a sum energy of $2\times$ K_α can also be explained by the REC process. Here the electron is captured radiatively into higher projectile shells followed by a direct transition into the K-shell (e.g. M-REC/K_β coincidence). Consequently, the diagonal has a cut off at an energy corresponding to capture into Rydberg states at the series limit.
Due to the additional REC contributions it is difficult to extract information on the spectral distribution for the 2E1 decay of our Z system in a straight forward manner. The REC contributions have first to be modelled very precisely and then subtracted from the measured distribution. This work is in progress now. At high Z systems this situation is more fortunate: Here the REC contributions are better resolved and can be separated more easily from the 2E1 spectral distribution.

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