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Long 3d Level Lifetimes in Highly Charged Ions of the Iron Group Elements: a Nuisance or a Feature?

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INTRODUCTION

In a hydrogen-like atomic system, 3d levels are short lived.

In an atomic system with several core electrons, the coupling of angular momenta and spins may result in 3d levels that cannot decay by electric dipole (E1) decays. This may result in fine structure levels of a given term that differ in lifetime by some 6 orders of magnitude. Very different experiments are necessary to address the one or the other lifetime range. While beam-foil spectroscopy has been useful to measure many short (pico- to nanosecond) lifetimes, millisecond- to second-lifetimes require ion trapping techniques.

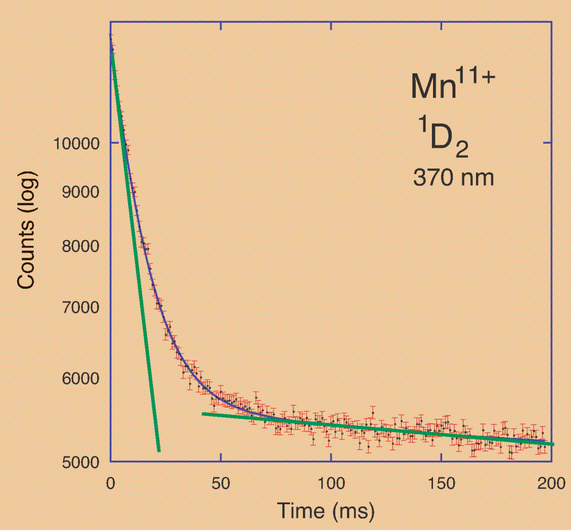
In an atomic system with three (or more) electrons in the n=3 shell (Al-like and higher), something is different - and it shows in time-dependent data. Lifetime measurements on the long-lived 3d levels face many practical problems, of which a few are illustrated below. One key problem is that most of the decays of interest have not yet been observed individually, and their wavelengths so far have only been computed, but not yet measured.

Does one actually see the 3d cascade(s) in 3p-shell ion spectra or decay curve measurements?

Heavy-ion storage ring data from Heidelberg feature massive cascade tails from a superposition of one or more 3d level decays.

According to theory, in the Al- and Si-like ions of Fe and neighbouring elements, the lifetimes of the 3p level in the ground configuration and of the long-lived 3d level in an excited configuration are very close to each other (but with slightly different Z dependences).

The Tokyo EBIT laboratory group is looking successfully for the 3d level decays in their ultraviolet spectra obtained at one of their compact EBITs.



Si-like ions at the TSR storage ring: First decay (3p and 3d) component lifetime approx. 15 ms, Second component lifetime approx. 300 ms. The identity of the second component is undetermined.

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EXAMPLES

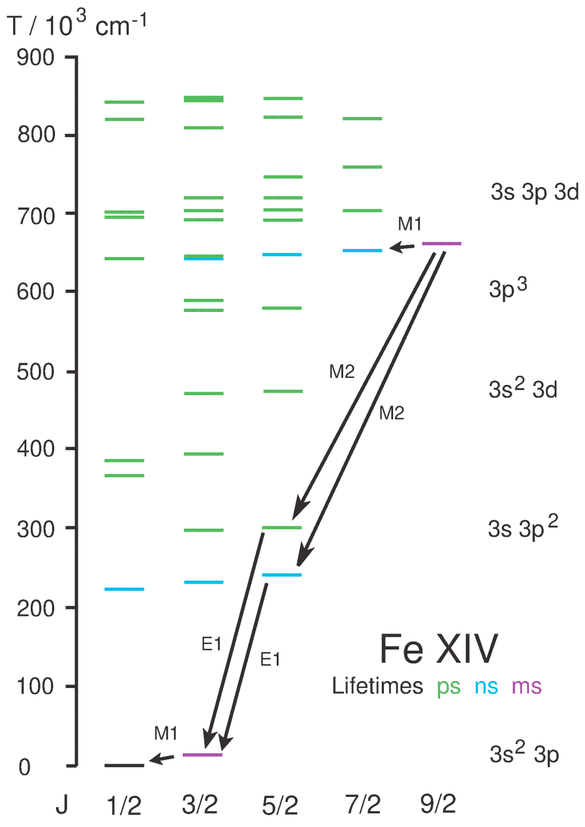
Al-like Fe XIV

There is a single 3s3p3d quartet level that has no electric dipole (E1) decay channel.

The only open decay channels are M1 and M2 transitions to levels that in turn can decay by E1 transitions. Thus the decay curve of that particular level will contribute cascades to the decay curves of many lower levels.

Does that matter?
The lifetime of that level is of the same order of magnitude as that of the upper fine structure level in the ground term. It may affect the lifetime measurement result of that level (by ion trap, at a heavy-ion storage ring, in an EBIT).

Is this situation unique?
No.



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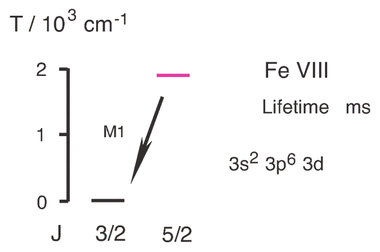
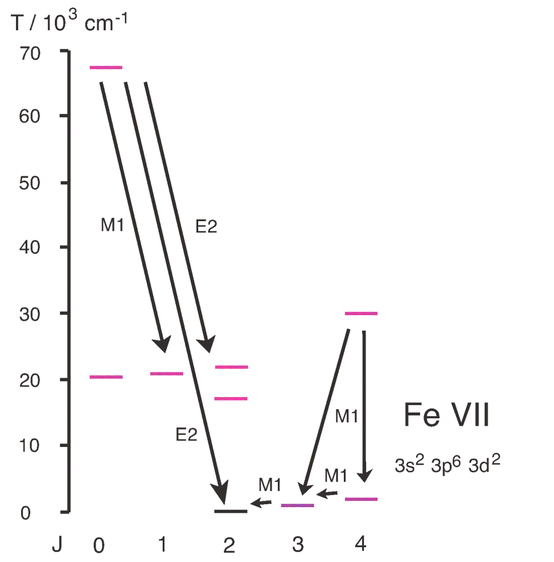


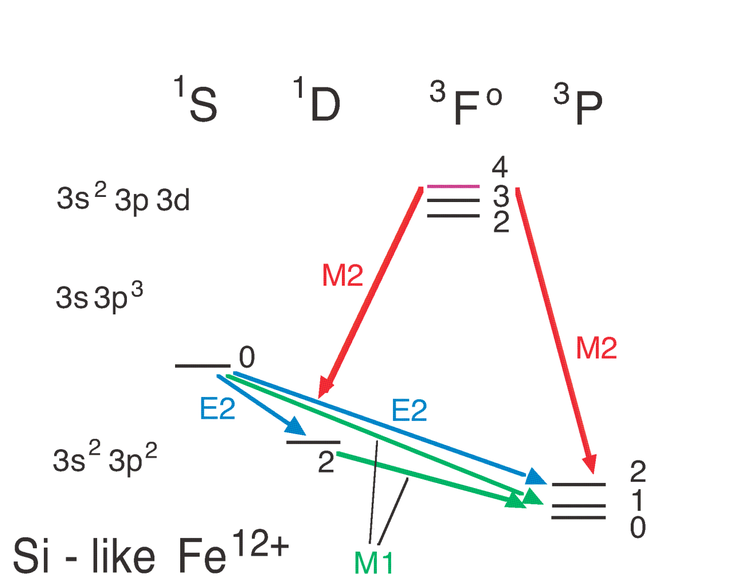
K-like Fe VIII

M1 (E2) transition in the ground term
(see the scale change)



Ca-like Fe VII

All of the levels are 3d levels in the ground configuration - no E1 transitions!



E1-forbidden transitions in low configuations of Si-like ions.

In the lowest excited configurations of Si-like ions (e.g. Fe XIII) (many more levels than shown in the above diagram) there is a single level without any E1 decay channels.

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CONCLUSION

What has looked like a nuisance that spoils accurate lifetime measurements in atoms with an open 3p shell, actually corresponds to the only type of transitions within the open 3d shell atomic systems beyond Ar-like ions.

There is no choice ... just a wide range of data to explore. The first lifetime measurements on the upper fine structure 3d level in K-like Kr XVIII have been undertaken at the Livermore EBIT (Träbert et al. PRA 64, 042511 (2001)) and at a „unitary“ ion trap attached to the NIST Gaithersburg electron beam ion trap (Guise et al. PRA 89, 040502 (2014)). The lifetime found is about 25 ms, in reasonable agreement with theory.

FUTURE WORK / REFERENCES

More examples will be presented in a companion tutorial intended for the journal Atoms, with level schemes of Na-like to Ca-like ions.

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