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# Internal Conversion and Electron-bridge Processes in Intense Laser Fields

Summary of Ph.D. thesis

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## **Introduction**

The investigation of electromagnetic fields induced nuclear transitions has been boosted in '80s due to the appearance of high intensity sources such like impulse lasers. Nuclei with a long-lifetime nuclear state, the so-called isomers, decay mainly by internal conversion process (IC), where the energy of the decay is taken off by one of the electrons of the atom. The probability per unit time of the IC process is influenced strongly by the electrons of the atom, which state can be modified by switching on outer radiation fields. Therefore the IC process is such a mechanism where one may intervene in nuclear processes by modifying the states of the electrons of the atom instead of the ordinary way of nuclear reactions. Whether does any laser field induced electron-nucleus processes exist, where the decay of isomers would be accelerated by switching on outer radiation fields?

This Ph.D. thesis was made at the Department of Experimental Physics, Budapest University of Technology and Economics. This work presented here belongs to fundamental research and summarizes my results that I have attained by the theoretical investigation of laser induced IC processes.

## Aim of the work

The main goal of the work was to elaborate a general model with which one can treat the electron-nucleus-laser coupled processes effectively, and on the other hand, which model shows the physical content behind the investigated effects more clearly than those in this field so far.

Results of calculations based on previous models showed that one may expect significant acceleration of the IC decay only in case of a few isomers, which especially have very low nuclear excitation energy, i. e., the energy of nuclear transition is in the same order of magnitude as the binding energy of the atomic electrons. It is worth examining those processes where one takes energy from outer radiation field into the system, and this way the initially energetically forbidden, strongly bound electronic shells are also switched on opening new channel for the IC decay.

It is worth investigating the effect of the radiation field on nuclear processes not only from energetic point of view. Namely, in the presence of radiation field some  $n$  photon assisted decay channels may take place, which initially, before switching on the radiation field, were forbidden due to the law of angular momentum conservation. Thus the aim of my work was to introduce a model in which one can treat these new decay channels as well, and the transition probability per unit time can also be calculated.

## Applied methods

I have treated the electron-nucleus-laser processes employing the perturbation theory of quantummechanics. Processes discussed in my thesis are at least third ordered ones, and it was inevitable to use some approximations to carry out the calculations. For instance calculating the rate of the processes I have approximated the wave functions of bound electrons as nonrelativistic, hydrogen-like wave functions in most cases. Moreover, it has been neglected that in the presence of intense radiation fields atoms may become manifold ionized. Thus the state of the electrons that plays important role at the IC process also alters. As a consequence the calculated transition probabilities have some uncertainty, and the presented results should be considered qualitatively instead.

## Novel scientific results

I summarize my novel results as it is written below:

- 1) I have examined the possibility of ignition of the energetically forbidden IC process in case of  $Tc^{99m}$ . Switching on the 2p electronic shell of  $Tc^{99m}$  into the IC decay was examined previously by Zon and Chernov [1996]. This process requires the presence of a X-ray source with photon energy about 0.5keV and about 0.62 keV (in case of one photon absorption). On the basis of my calculations (which I have carried

out in case of bound-bound as well as bound-free electronic transitions) for halving the metastable life-time of the nucleus one would need an X-ray source with 14 order of magnitude higher intensity than that Zon and Chernov had predicted.

- 2) I have investigated theoretically the electron-bridge (EB) decay of the exotic  $\text{Th}^{229\text{m}}$ , which has very low nuclear excitation energy ( $E_\gamma=3.5 \pm 1$  eV). The experimental work of Irwin and Kim [1997], where they reported the observation of EB decay of  $\text{Th}^{229\text{m}}$ , gave rise to several publications in the last few years. Theorists of the field took also part in the discussion [Karpeshin et al., 1999]. I have shown that their theoretical predictions were false. Utilizing and expanding a known model [Kálmán and Keszthelyi, 1994] I have calculated the rate of EB decay of  $\text{Th}^{229\text{m}}$ . Taking into account my numerical results I have reinterpreted the published experimental results as well, stating that the decay of exotic nuclear state of  $\text{Th}^{229\text{m}}$  was probably not observed in the experiments. I have suggested an experimental set-up, which can help observing this exotic nuclear state more effectively.
- 3) I have introduced a general model for treating electron-nucleus-laser processes. In my model – contrary to similar models of the field – one can easily follow the mechanism how the laser field modifies the electron-nucleus interaction. This model in case of weak field limit, i. e. taking

into account the interaction with the laser field in the lowest order, leads to formally equal formula as of a previous model [Kálmán and Keszthelyi, 1994] with the difference that my model takes the retardation of the radiation field into account and it includes inherently the magnetic-magnetic interaction of the electron and the nucleus as well. The elaborated model is able to treat processes with many photon absorption and emission; the formalism of these processes has also been presented.

- 4) With the aid of my model I have recalculated the energetically forbidden IC of  $\text{Tc}^{99\text{m}}$  taking into account processes with many photon absorption as well. As an outstanding feature of my model the conservation of angular momentum can be traced well in the investigated electron-nucleus-laser coupled processes. This property of the derived model opens up vistas on several possible decay channels.
- 5) I have compared my new results on  $\text{Tc}^{99\text{m}}$  – which I have carried out in case of bound-bound as well as bound-free electronic transitions – to my previous ones also reported in a preceding chapter of the thesis. This comparison shows the following: in case of a decay channel (bound-free transition) the retardation effect plays significant role in the rate of the induced nuclear decay. The predictable acceleration of the decay rate may be considerable, just growing up to the natural decay rate, e.g. by applying free-electron lasers working in soft X-ray range, which

intensity is supposed to reach the required level in the near future.

- 6) I have investigated the role of electronic resonance in case of laser assisted electron-nucleus processes. I have examined the effect of electronic resonance on the rate of processes occurring in the initial, intermediate or in the final states of the process. I have shown that in case of resonance occurring in the initial or intermediate states the character of resonance does not appear in the calculated rate of the process. I have investigated in details the effect of resonance in the final state of the process and I have shown generally that the character of resonance does not appear in the probability per unit time of the process, either. Finally I have concluded that if any increase is observed at the rate of laser assisted IC processes that should not be attributed to the effect of any resonance character of the process.

### Utilization of the results

The results of my research written in the thesis are fundamental ones, so they primarily contribute to the progress of the science of physics. In my opinion the importance of my theoretical thesis would be that it may open new vistas of the theorists of the field and, on the other hand, it may inspire several experiments, which would be essential in getting to know these very complex electron-nucleus-laser processes better.

### References

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- Karpeshin F.F. et al, 1999, *Phys. Rev. Lett.* **83** 1072.
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### Connected scientific publications

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### **Directly not connected publications**

**Bükki T.** és Kálmán P.: Can metastable states of atomic nuclei be made to decay faster?, *Fizikai Szemle*, 2001/4.

Kálmán Péter és **Bükki Tamás**: Interaction of Electromagnetic Radiation and Matter, Univ. lecture, Ser. Modern Optics, Vol 5., Chapter 12. , Editor: Richter Péter (Műegyetemi Kiadó, Budapest, 2001).