Study of Shaking Process during Nuclear Transfer Reactions

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Introduction

Sudden change in nuclear charge or in electrostatic environment may lead to instability in atomic/ionic stable configuration. Due to the perturbation the electrons get excited to a new level or ionized. This type of process is called shaking process, in which atom/ion stabilizes itself after the sudden perturbation by changing in its configuration. Excitation of electrons to unoccupied higher (or lower) bound states is called shakeup (or shakedown), whereas ionization of electrons is called shakeoff [1]. There are substantial work done on the study of shaking process since the early scrutiny works of Migdal [2] and Fienberg [3]. These shaking processes solely depend on the suddenness of the perturbation and how quickly the atom/ion stabilizes itself after the perturbation [4]. Theoretically shaking processes are treated under the sudden approximation limit [4]. It is worth to note that a perturbation is called sudden if the time period τ of perturbation is less than that of periodic motion, $2\pi\omega_n^{-1}$, of the orbital electron [5]. Interestingly during nuclear transfer reactions this condition is valid for sudden change in nuclear charge in the short time scale 10^{-21} - 10^{-22} sec. [6] compared to slow electron orbital motion of about 10^{-16} sec. For the span of sudden perturbation the orbital electrons are unable to rearrange themselves in a new system and get excited to unoccupied bound state or get ionized. In the present work we plan to discuss the role of the change in atomic number on the shaking processes during the nuclear transfer reactions.

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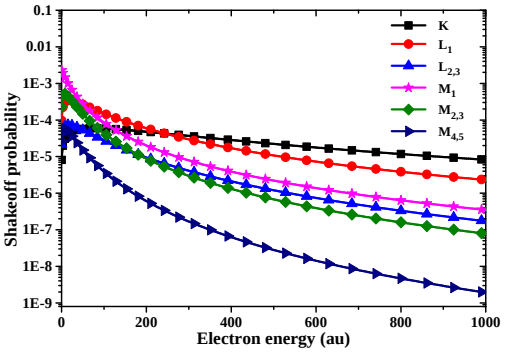

FIG. 1: Shakeoff probability versus electron energy (au) for K-, L- and M-shell electrons of the projectile like fragment ions in the case of ${}^{56}_{26}Fe + {}^{12}_{6}C \rightarrow {}^{60}_{28}Ni + {}^{8}_{4}Be$.

Results and Discussion

Using the Mukoyama formalism [7] for non-relativistic hydrogenic wavefunctions shakeoff probabilities of K-, L_1-, $L_{2,3}$-, M_1-, $M_{2,3}$- and $M_{4,5}$- shell have been calculated for the specific case of ${}^{56}_{26}Fe + {}^{12}_{6}C \rightarrow {}^{60}_{28}Ni + {}^{8}_{4}Be$ (α-transfer reaction) with respect to emitted electron energy, as shown in the Fig. 1. Interestingly it is observed that shakeoff probability decreases rapidly with the increase in electron energy for higher n and l values. In the next step, shaking (shakeup and shakedown) probabilities are calculated for same system. The results are plotted against the principle quantum numbers in Fig. 2. The plot clearly indicates that (i) for the nearby shells i.e. $\triangle n = \pm 1$ the shakeup or the shakedown probability is maximum and (ii) subshells which have lower l with the same n quantum number are more susceptible for shakeup and shakedown processes.

Further, electron shakeoff probabilities have

been calculated for the α-transfer reaction in the range of Z=10-50. The Z-dependence on the shakeoff probabilities so obtained has been represented by an analytical equation with two parameters as follows

$$P_{SO} = \frac{a}{(Z+b)^2} \quad (1)$$

The values of parameters a and b are given in the Table I for K-, L- and M-shell electrons.

TABLE I: Parameters obtained from the fitting of shakeoff probability v/s atomic number (Z) curves.

Case of	a	b
K e^-	1.36 ± 0.0037	3.1134 ± 0.0224
L_1 e^-	4.9321 ± 0.0531	7.2652 ± 0.115
$L_{2,3}$ e^-	0.9537 ± 0.0106	7.1 ± 0.1181
M_1 e^-	2.644 ± 0.0453	9.015 ± 0.2015
$M_{2,3}$ e^-	6.083 ± 0.1725	13.9 ± 0.4197
$M_{4,5}$ e^-	0.656 ± 0.019	13.7 ± 0.4244

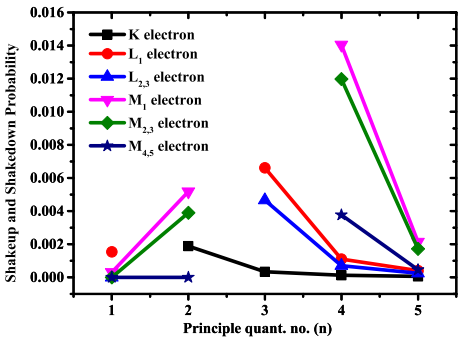

FIG. 2: Electron shakeup and shakedown probabilities for various shells of projectile like fragment ion for the reaction $^{56}_{26}Fe+^{12}_{6}C \rightarrow^{60}_{28} Ni+^{8}_{4}Be$. All solid lines are to guide eye only.

From the Eq. 1 it can be inferred that for nuclear transfer reactions the shakeoff probability gradually decreases with the increase in atomic number of the parent atom. It is further clear that the shakeoff processes are more prone in the lighter systems.

Conclusion

In this work different aspects of shaking process (shakeup, shakedown and shakeoff process) has been studied. It is observed that in the sudden approximation limit, nuclear transfer reactions can alter the electronic configuration of projectile and target atomic systems.

Acknowledgments

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