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Atomic electron distribution and recoil effects following beta decay of the halo nucleus helium-6

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Synopsis Following the β decay of a ^{6}He nucleus to form ^{6}Li, the atomic electrons adjust to the sudden change of nuclear charge from 2 to 3. The probabilities for electron shake-up and shake-off are calculated, including recoil effects, by the use of a Stieltjes imaging representation of the final states. The results will be applied to ongoing angular correlation studies in a search for new physics beyond the Standard Model.

There are currently several experiments in progress to search for new physics beyond the Standard Model by high precision studies of angular correlations in the β decay of the helium isotope $^6\text{He} \to {}^6\text{Li} + e^- + \bar{\nu}_e$ [1,2,3]. An essential part of the analysis is to understand the energy distribution and spectra of the recoil ions. After the β decay event, the atomic electrons suddenly find themselves in a ^{6}Li$^+$ environment with nuclear charge $Z = 3$. The electrons redistribute themselves over all possible states of the ^{6}Li$^+$ ion, including the continuum leading to ^{6}Li^{++} and ^{6}Li^{3+}. Evidence for new physics beyond the Standard Model would reveal itself by an additional tensor coupling contribution to the weak interaction, in addition to the simple Gamow-Teller axial-vector mechanism [2,3].

We will present calculations employing Stieltjes imaging techniques in Hylleraas coordinates to study the probabilities for the shake-up and shake-off mechanisms, and especially the additional recoil accompanying the emission of the shake-off electrons. In the sudden approximation, one simply expands the initial ^{6}He atomic state in terms of the complete set of ^{6}Li$^+$ states (including the ionization continuum) to obtain transition probabilities $P_{i\to f}$ in the form

$$P_{i\to f} = \left| \int \Psi_i^*(\text{He}) e^{-i\mathbf{K}\cdot\mathbf{r}} \Psi_f(\text{Li}^+)\, d\mathbf{r}_1 d\mathbf{r}_2 \right|^2 \quad (1)$$

where $\mathbf{r} = \mathbf{r}_1 + \mathbf{r}_2$, and $\mathbf{K}$ is the electronic recoil momentum for the daughter ion, and $K = |\mathbf{K}|$. Since $K_{\text{max}} = 0.097$ a.u. for the β decay process, the factor of $e^{-i\mathbf{K}\cdot\mathbf{r}}$ can be expanded in powers of K, and terms up to order K^2 retained. Recoil terms of $O(K^2)$ come from both $S-S$ and $S-P$ transitions, but because of unitarity, they must sum to zero when summed over all shake-up and shake-off processes. The sum rule is illustrated by the results in Table 1 for the recoil coefficient $B_{i\to f}$, where $P_{i\to f}$ is expressed in the form

$$P_{i\to f} = A_{i\to f} + K^2 B_{i\to f} \quad (2)$$

and $149.2K^2 = E_{\text{rec}}$ is the ion recoil energy in keV. It is clear that the $S-P$ recoil term is canceled by the $S-S$ recoil contribution.

In summary, this work provides the first estimates of the recoil term for the ^{6}Li ions formed by the β decay of neutral ^{6}He atoms, and the validity of a sum rule is directly demonstrated. The total result $0.005(1)K^2$ for Li^{3+} is in reasonable accord with the value $0.0000412E_{\text{rec}} = 0.00615K^2$ obtained by Couratin *et al.* for the corresponding one-electron ^{6}He$^+$ case [1]. Further results extended to higher accuracy for both the singlets and the triplets will be presented at the conference.

Table 1. Recoil contributions $K^2 B_{i\to f}$ [see Eq. (2)] to probabilities for formation of Li$^+$, Li^{++}, and Li^{3+} following β decay of ^{6}He$(1s^2\ ^1S)$.

Ion	B_{S-S}	B_{S-P}	B_{Total}
Li$^+$	–0.665	0.573	–0.092
Li^{++}	–0.078	0.165	0.087
Li^{3+}	–0.009	0.014	0.005
Total	–0.752	0.752	0.000

References

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