Atomic excitation and ionization by neutrons

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Synopsis Atomic excitation and ionization processes by neutron impact have been studied in the sudden approximation. The electron transition is considered to be induced by the recoil of the target nucleus during neutron-atom collisions. The matrix elements for excitation and ionization due to nuclear recoil are calculated using non-relativistic hydrogenic wave functions. The general expressions of matrix elements for arbitrary atomic shells are obtained analytically in terms of Gauss-type hypergeometric functions. The atomic excitation and ionization probabilities are evaluated in the universal form as a function of recoil momentum transfer.

In ion-atom collisions, excitation and ionization processes are caused primarily by the Coulomb interaction between the incident projectile and target electrons. However, atomic excitation and ionization can also take place due to the recoil effect of the target nucleus during collisions. This effect is important for charged-particle impact only in the close collisions with small impact parameters and plays a minor role in total cross sections.

On the other hand, when the projectile is a neutral particle, the recoil effect is the only possible mechanism to excite target atoms. The neutron-atom system is an ideal case to study the recoil-induced excitation and ionization of atoms.

A simple expression for the ionization probability due to sudden recoil was first obtained by Migdal [1] for hydrogenic atom. Since then several attempts to estimate excitation and ionization probabilities by neutrons have been made, but the number of references is not so large.

In the present work, the 1s-electron excitation and ionization probabilities are calculated within the framework of the sudden approximation. The electron transition is considered to be induced by the recoil of the target nucleus during neutron-atom collisions.

The matrix element for electron transition due to nuclear recoil is given by

$$M_{if} = < \psi_f | e^{i\boldsymbol{qr}} | \psi_i >$$

where $\boldsymbol{q}$ is the momentum transfer, $\boldsymbol{r}$ is the position vector of the electron, ψ_i and ψ_f are the electron wave function for initial and final states, respectively.

By the use of the nonrelativistic hydrogenic wave functions, the general expressions for arbitrary atomic shells can be expressed analytically in terms of Gauss-type hypergeometric functions as a function of recoil momentum transfer.

We introduce the parameters q/Z and p/Z, where Z is the target atomic number and p is the momentum of the ejected electron. By using these parameters, the excitation and ionization probabilities are written in the universal form, i.e. independent of Z.

Figure 1 shows the electron transition probabilities for the 1s-shell electron as a function of q/Z.

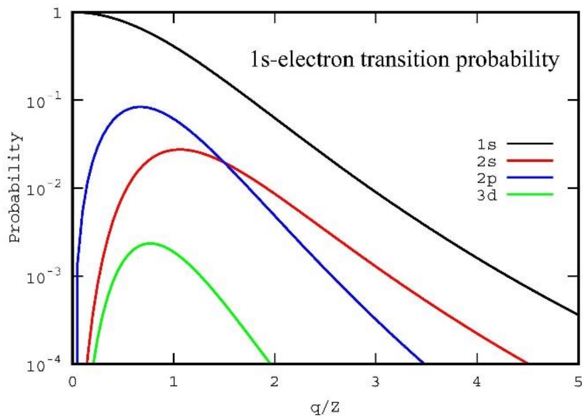

Figure 1. Probabilities for electron transition from the 1s state to the 1s, 2s, 2p, and 3d states as a function of the reduced momentum transfer q/Z.

The 1s curve corresponds to the probability for the 1s electron to remain in the original state and its probability is equal to unity at $q = 0$ because of orthonormality. Other curves are the excitation probabilities from the 1s state to the 2s, 2p, and 3d states, respectively. .

References

[1] Migdal A B 1941 *J. Phys. (USSR)* **4** 449

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