NUCLEAR EXCITATION BY ELECTRON TRANSITION

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ABSTRACT

When an electron hole moves from an inner orbit to an adjacent one, the energy corresponding to the difference of the binding energies for these two orbits is usually carried away by the emitted characteristic X ray or the Auger electron. In addition to these two processes, there is another possible mode of this energy release by exciting the atomic nucleus. This is called the nuclear excitation by electron transition, in short NEET. The probability of NEET is generally small compared with that of the X-ray or Auger-electron emission. It is, however, measurable in some cases. The reason why NEET has been studied theoretically is described. Preliminary data in 1890s experiments are introduced. The implications of NEET are also discussed.

INTRODUCTION

In this presentation, I would like to discuss a possible new mode of nuclear excitation by deexcitation of the orbital electron system. That is, when an electron hole is created in one of the inner shells by bombarding the atom with electrons or X rays or some other reason such as the orbital electron capture, an orbital electron of the adjacent shells jumps into the vacancy immediately. The energy corresponding to the difference of the binding energies for these two shells, $E_1 - E_2$, is usually carried away by the emitted characteristic X ray or the Auger electron. On certain favorable conditions which I shall describe later, this excess energy is transferred to the nucleus so that it is excited from the ground state to one of its higher energy states. In this
process, real photons are not emitted or absorbed. Photons are virtually exchanged between the nucleus and the relevant electron. That is, the process is not a two-step transition, but it is a one-step transition. We call this process nuclear excitation by electron transition, in short NEET.

The motivation for studying NEET is to produce atomic nuclei in their excited states by a new method other than the well-known excitation mechanisms, such as nuclear reactions with slow neutrons or accelerated charged hadrons, nuclear transmutations in alpha, beta, and gamma decays. A radiochemist, Otozai in Osaka, has been searching for a long time for a possible new method of enriching 235U. He explained to me that one can separate 235U from natural uranium which is a mixture of 238U, 235U, and 234U, if the nucleus of 235U is in its excited state. The isomer state of the 235U is located at 30 eV above the ground state. It decays back to the ground state through the internal conversion process with a half life of 26 min. In this case the 235U atom is ionized, because one of the orbital electrons is ejected. Consequently, it may not be difficult to collect such atoms chemically or electrically. (An isotope separation using the recoil or hot-atom effect at nuclear transformation has been known since 1934, as the Szillard-Chalmers method.)

In the conventional methods for producing nuclear excited states, we usually adopt the nuclear reactor, van de Graaff, Cyclotron, or large-scale linear accelerator. Contrary to these, a new method involving an electron gun is used to accelerate electrons at relatively low energies. The accelerated electrons interact mainly with the orbital electrons of the relevant atoms, whose nuclei are in the ground state, and the bombarding electrons can kick off the electrons of the inner orbits. In this way, the energy of the bombarding electrons is stored in the orbital electron cloud. A part of this energy is transferred to the nucleus if there is an interaction between the nucleus and the orbital electrons. The bombardment of electrons can be replaced by irradiation of X-rays.

In a similar process, the nuclear fine structure in the muonic atom was studied theoretically, and the nuclear excitation due to deexcitation of the muonic levels was observed in the muonic X-ray experiment.

PROBABILITY OF NEET

A simple theory of NEET is as follows. See Fig. 1. We have the ground state \( \psi_1 \) and the excited state \( \psi_2 \) with the nuclear excitation energy \( E_N \). The orbital electron system has an electron hole in an inner orbit \( \phi_1 \) with the binding energy \( E_1 \). This hole will move immediately to the state \( \phi_2 \) with \( E_2 \), either by a radiative or by nonradiative process, and so on. The resultant system \( \Psi \) of the nucleus and orbital electrons has, therefore,