5. 核研ニュートリノ質量測定実験における原子・分子効果

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Many Physicists are now very interested in the neutrino mass from the viewpoint of particle physics and cosmology. Several groups in the world are doing the neutrino mass measurement experiments. There are three methods to measure the neutrino mass, i.e. by (1) the rate of the double beta decay (2) the neutrino oscillation (3) the spectrum of tritium beta decay. The most direct method is (3) and at present four groups are doing this experiment.[1,2] The result of ITEP (the Institute for Theoretical and Experimental Physics in Moscow) is remarkable, 20 eV $\leq m_\nu \leq$ 45 eV and no other groups could get the finite lower limit of the electron anti-neutrino mass. However, there are some claims[3,4] to the ITEP procedure for obtaining the instrumental response function.

In the experiment of INS (the Institute for Nuclear Study, University of Tokyo) on the tritium beta spectrum, they can measure the spectrum with very high accuracy (the energy resolution is $\sim$ 10 eV). (See Table 1 and Fig. 1.) To analyze the experimental data, it is important to calculate the atomic and the molecular effects in the tritium beta decay theoretically. To determine the instrumental response function, we must calculate the atomic and the molecular effects of the calibration lines theoretically. For the former, there are many calculations[5,6,7,8] and to the INS experiment, there are two[9,10]. For the latter, INS experiment uses the Ag K-LL Auger lines as the calibration lines and we calculated the atomic effects of these Auger lines. To calculate these effects, we need the atomic wave functions. We used the fortran program code[11] of the relativistic Hartree-Fock method[12]. (K-LL Auger transitions are inner processes and Auger electron energy is 18 keV, so we cannot neglect the relativistic effects.) In K-LL Auger transitions, the largest atomic effect is the shake up effects. We estimated this effects using the sudden approximation and the results are shown in Fig. 2. We estimated how much did this results affect the neutrino mass using the method of Ref. 3 and found that the shake up effects affected the neutrino mass as much as 7.5 eV.

This calculation is only the beginning, and draws many related problems. For example, the accuracy of the atomic wave function is not enough, the sudden approximation used in this calculation is not very good, no molecular effects are considered, etc.

Experimental group	ΔE (eV)	N	^3H source	m_ν (eV)
INS	8	5 K	in $C_{20}H_{40}O_2$	< 33
ITEP	23	60 K	in $C_5H_{11}NO_2$	20 - 40
Zurich	27	100 K	in C	< 18
Los Alamos	52	1 K	$^3H_2$ beam	< 36

ΔE is the energy resolution of the spectrometer. N is the accumulated event number at $E_{max} \sim E_{max} - 100$ eV. "^3H source" is the material of the source. m_ν is the reported $\bar{\nu}_e$ mass.

Table 1. The experimental parameters of the four groups.

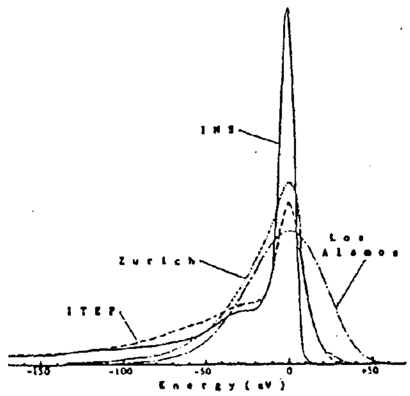

Fig. 1. The response function of the four experimental groups. These include not only the instrumental response function but also the effects of the energy loss and back scattering of the source.

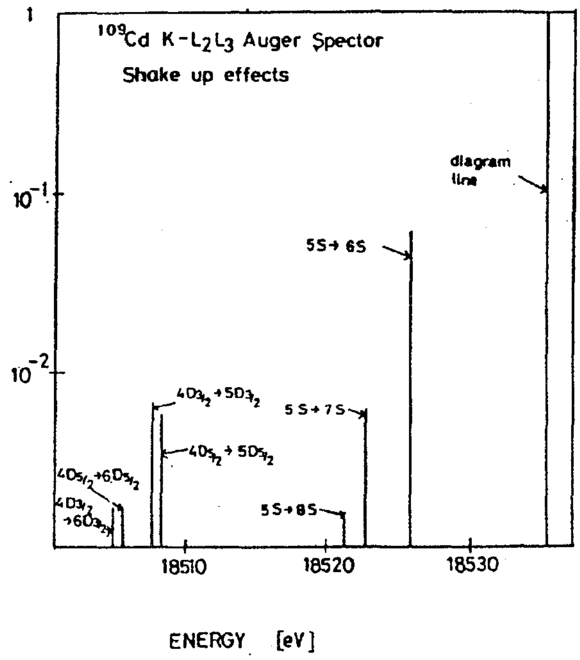

Fig. 2.

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