Microscopic study of Muon-Capture Rates for Sn isotopes

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Introduction

Nuclear structure physics and weak interaction physics are quite correlated as the former governs the rate of later and in turn weak interaction processes help in establishing the nuclear structure. One of the major challenges for present generation nuclear physicists is to better under understand the process of double beta decay and its long lasting significances on the standard model. This problem particularly, is challenging from nuclear structure as well as weak interaction, both point of views. It is therefore natural to look at other physical phenomenon too, which could help in understanding the underlying nuclear structure effects in double beta decay and precise determination of nuclear wavefunction in general and neutrino mass in particular. The capture of negative muons by nuclei via the weak interactions has been studied for many years. Earlier studies showed that the information could be used to study the weak interactions themselves, but in fact the major difficulty has been the understanding of nuclear effects. Unfortunately, the total capture rate is not simple to calculate as the final nucleus is excited to an unknown energy, which from the theoretical point of view is a critical parameter. However, from the experimental point of view the measurement is straight forward, as it is simply the determination of the muon life time when stopped in the relevant material. This number is often needed in other experiments, so precision measurements of the lifetime to continue to have their usefulness. The prototype weak absorption reaction is

$\mu^- + \text{p} \longrightarrow \nu_\mu + \text{n}$

becomes more complicated in the nuclear environment

$\mu^- + (\text{A, Z-1})^* \longrightarrow \nu_\mu + (\text{A,Z})$

where (A, Z-1)* represents nucleus in the excited state. The main challenge lies in the mean excitation energy of the residual nucleus in which the giant dipole excitations are very important. In above context muon capture, a semileptonic weak process, has been measured for many stable nuclei, however first attempts on measuring muon capture rates for double beta decay elements have only recently been started. The nuclear response in muon capture is governed by the momentum transfer which is of the order of the muon mass. The phase space and the nuclear response favor lower nuclear excitation energies. As momentum transfer in muon capture is order of muon mass. The phase space and nuclear response prefer lower nuclear exitation energies, thus the giant resonance region dominant in nuclear states. Study of muon capture rates is not only interesting from weak interaction or nuclear structure view point but could be considered as a more general test of nuclear models.

Method and Parameter

In the present work, the muon capture rates for Sn isotopes, have been calculated using Quasi particle random phase approximation (QRPA) framework [1]. The two-body transition densities in the pn-QRPA theory can be calculated from the pn-QRPA ground state. For present calculations, i.e. for calculating muon capture rate of Sn isotopes, we have used the proton valence space $1f_{7/2}$, $2p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$, $1g_{9/2}$, $1g_{7/2}$, $2d_{5/2}$, $1h_{11/2}$, $2d_{3/2}$, $3s_{1/2}$, $2f_{7/2}$, $1h_{9/2}$, $3p_{3/2}$, $2f_{5/2}$ and $3p_{1/2}$ orbitals for protons as well as neutrons. The corresponding single-particle energies have been obtained by using the Woods Saxon (WS) potential following the parametrization given by Bohr and Mottelson [2].

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Results and Discussion

Tin isotopes have a completely filled $1g_{9/2}$ proton subshell and gradually filled $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$ and $3s_{1/2}$ neutron subshells and hence the dependence of the total capture rates on theWoodsSaxon potential parameters/single particle energies is expected to be stronger than the dependence on the residual interaction coupling constants. The calculated total capture rates in the present work are given table I and compared along with the existing data. It can be seen from the results that theoretical capture rates calculated in the present work are comparable to other calculation as well as the experimental work.

Table 1. Calculated muon capture rates for Sn isotopes.

Nucl.	Total Muon Capture Rate ($10^6 s^{-1}$)		
	Present Work	Theory [3]	Expt. [4]
^{116}Sn	9.379	13.08	-
^{118}Sn	8.226	12.35	-
^{120}Sn	8.316	11.64	-
^{122}Sn	8.246	10.82	-
^{124}Sn	7.386	10.15	-
^{nat}Sn	8.40	11.95	10.44

Conclusion

The present calculation shows that the quasi particle random phase approximation method can be reliably used for calculating muon capture rates. The main possible source of errors and uncertainties in the calculation of muon capture rates lie : in the nuclear-structure calculations (calculating single particle basis correctly) and in the determination of the g_{pp} parameter.The present calculations indicate that these could give considerable change in for capture rates and hence considering proper nuclear structure effects is very important in the study of weak interactions.

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