Theoretical Study on Two Neutrino and Neutrinoless Double Beta Decay

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Introduction

Double beta decay is a radioactive decay process where a nucleus releases two beta rays as a single process. Here two neutrons in the nucleus are converted to two protons, and two electrons and two electron antineutrinos are emitted. In order for beta decay to be possible the final nucleus must have larger binding energy than the original nucleus. Double beta decay is difficult to study in most practically interesting cases, because both beta decay and double beta decay are possible, with probability favouring beta decay, the rarer double beta decay process is masked by these events. Thus double beta decay is usually studied only for beta stable nuclei. Like single beta decay, double beta decay does not change the mass number A. It is a second-order weak process in which two neutrons inside a nucleus spontaneously transform into two protons. More than 60 naturally occurring isotopes are capable of undergoing double beta decay. Only ten of them were observed to decay via two neutrino mode. The ββ decay can be broadly classified into four experimentally distinguishable modes. The present work is an attempt to study the Two Neutrino and Neutrinoless Double Beta Decay processes.

Studies on single beta decay process

We have made an attempt to study[1] the possibility of β^- decay from various isotopes in the heavy region with Z ranging from 80-99 using the empirical formula of Fiset and Nix. It is clear from the computed values that, beta decay half lives decreases with increase in neutron number. That is, beta decay occurs in isotopes which are neutron rich. Atoms which undergo beta decay are located below the line of stable elements on the chart of the nuclides, and are typically produced in nuclear reactors. The *Q* value for a reaction is the amount of energy released by that reaction. The value relates to the enthalpy of a chemical reaction or the energy of radioactive decay products. It is obvious that neutron number of the parent and the decay energy have a good role in the beta decay half lives. Hence we modified the empirical formula of Fiset and Nix and is given as,

$$T_\beta = \frac{540 m_e^5}{\rho(W_\beta^6 - m_e^6)} x10^5 + 0.03992\sqrt{NQ^{3/2}} - 1.21404 \sec \qquad (1)$$

From experimental beta decay half-life values of 101 nuclei, the estimated standard deviation for the present formula prediction and the formula predictions of Fiset and Nix are 1.991417 and 2.333264 respectively. It is clear that the present formula prediction is better than the formula prediction of Fiset and Nix.

One of the main applications of Bethe-Weizsacker semi empirical mass formula is the prediction of the most stable isobar of a given A against beta decay. The Z value of such isobar (Z_A) is given by minimizing the atomic mass including the mass of electron from the semi empirical mass formula. We have computed the Z_A value for different isobars in the heavy region with mass number varies from 200 to 250. It is found from the plot that Z_A values show a linear relationship with the mass number. From the linear dependence of mass number and Z_A value, we have developed an empirical formula [2] for the most stable isobar of a given A against beta decay. We have also compared the present formula predictions with those obtained from Bethe-Weizsacker formula. It is found that our present formula predictions are in close agreement with the formula predictions of Bethe-Weizsacker formula. We would like to point out that the present formula is much simpler as compared to other empirical formulae. Hence the present equation is better to identify the stability of the isotopes against beta decay in the heavy region. We have also studied the mass parabolas for different nuclides with mass number ranging from 200-223. There is good matching between our formula prediction of Z and minimum of mass parabola for the considered range of mass numbers. The mass parabolas for the different isobars fall in two categories according to whether A is odd or even. In the case of odd A, a single parabola is obtained irrespective of whether the nucleus is odd-even or even-odd. In this case the pairing term in the binding energy does not change from isobar to isobar and the question of stability relies on the balance between the symmetry term which prefers equal numbers of protons and neutrons and the Coulomb term which prefers fewer protons. For such nuclides there is only one stable isobar with some atomic number Z_A. The nuclides falling on either side of this isobar are all unstable. The isobars on the lower Z side have too many neutrons for stability and are β^- active and those on the higher Z side have too many protons and hence undergo β^+ decay. The minima in mass parabolas show stability of the isobar against beta decay. Hence we would like to mention that it will be a guide to the future experiments in beta decay in the heavy region.

Studies on 2ν and neutrinoless ββ decay

We have developed an empirical formula for phase space factor and nuclear matrix element to study two neutrino double beta decay[3]. The computed half lives are in better agreement with the values of other predictions. The estimated standard deviation of phase space factor from the present formula to that of Vogel is 2.5126 and from Primakoff-Rosen approximation to Vogel is 11.81606. It is clear from these values that phase space factors using the present formula are in good agreement with other formula predictions.

We have also computed nuclear matrix elements and are compared with other predictions. The estimated standard deviation of half lives from the present formula to the experimental half lives is found to be 0.5886. The standard deviation of half lives for Primakoff-Rosen approximation is found to be 4.0274. It is clear from these values that half lives using the present formula are in good agreement with experimental values than that of Primakoff-Rosen approximation. The present formulae for computing the phase space factor, nuclear matrix element and half life are applied for various Ca, Ge, Se, Zr, Mo, Pd, Cd, Sn, Te, Xe, Nd, Sm, Gd and Pt isotopes that exhibiting single beta decay. With these values we can predict the possibility of two neutrino double beta decay for the above isotopes which will be very useful for the future experiments.

A semi empirical formula [4] is developed for both phase space factor and nuclear matrix element for computing the neutrinoless double beta decay half life. It is found from the studies that the present formula is in close agreement with the experimental values. We have also computed the standard deviation of the present formula, QRPA, NSM and Truncated Shell Model values with the experimental neutrinoless double beta decay data. It is clear that the values obtained from the present formula are better than NSM values and slightly greater than QRPA and Truncated Shell Model values. But the present formula is very simple for computation than the other two models. We have also applied the present formula for computing the phase space factor, nuclear matrix element and half life for various Ge, Se, Zr, Mo, Pd, Cd, Sn, Te, Xe, Nd and Sm isotopes. With these values we can predict the possibility of neutrinoless double beta decay for the above isotopes which is very useful for future experiments.

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