Promising Results for Tellurium Isotopes ^{128}Te and ^{130}Te

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Abstract: In this work pn-QRPA , pn-RQRPA , full-RQRPA and SQRPA techniques with small and large basis of Hilbert space have been used to study the (2νββ) and (0νββ) decay modes for the isotopes ^{128,130}Te. It is found that: (1) The nuclear structure of tellurium isotopes can be described with a good accuracy by using pn-RQRPA, full-RQRPA with (0νββ) decay mode and SQRPA with (2νββ) decay mode. (2) the study of (0νββ) decay mode in ^{128}Te is more promising than ^{130}Te. (3) SQRPA technique improves the yield of the 0νββ decay mode for ^{128}Te significantly in comparison with in pn-RQRPA and full RQRPA techniques. (4) the use of small basis rater than large basis in Hilbert space increases the yield of the 0νββ decay mode for ^{128}Te.(5) the best experimental ratio between the total half lives of ^{130}Te and ^{128}Te is 2673.8. (6) pn-QRPA is better than pn-RQRPA , full-RQRPA and SQRPA techniques for determination of neutrino mass. (7) a new value of neutrino mass is determined to be 0.21945 ± 0.0036 eV which is more precise than previous experimental determinations.

[M. H. Sidky. **Promising Results for Tellurium Isotopes ^{128}Te and ^{130}Te.** *J Am Sci* 2013;9(4):322-]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 44

Keywords: Promising Results; Tellurium; Isotopes; ^{128}Te; ^{130}Te

1.Introduction

There are 38 known isotopes and 17 nuclear isomers of tellurium (Te) with atomic masses that range from 105 to 142 [1]. Naturally occurring tellurium on Earth consists of 8 isotopes [1]. Two of these have been found to be radioactive: ^{128}Te and ^{130}Te undergo double beta decay [1]. The very-long-lived radioisotopes ^{128}Te and ^{128}Te are the most common isotopes of tellurium. They have prompted many groups to study it for the following advantages:
(1) The large difference between the decay energies of ^{128}Te and ^{130}Te simplifies the theoretical analysis of their half lives.(2) There are many factors affecting the calculation of the theoretical half life time of the ββ decay. One of these factors is the nuclear matrix element. The uncertainty in the estimation of the nuclear matrix elements is improved by calculating the ratio between the half lives of ^{128}Te and ^{130}Te instead of the individual half life time of a decay mode. This is because the ratio of their respective relevant nuclear matrix element factors should be nearly unity.
(3) Geochemical experiments [2] with ββ active isotopes with noble gas decay products benefit from the strong depletion of these gases in minerals at the time of crystallization and from the high sensitivity with which the tiny radiogenic accumulations can be measured by mass spectroscopy. The ββ decays in which the daughter nucleus is a noble gas are:

$$^{82}Se \rightarrow {}^{82}Kr$$
$$^{128}Te \rightarrow {}^{128}Xe$$
$$^{130}Te \rightarrow {}^{130}Xe$$

(4) Many possible sources of systematic errors in measurements of the individual half lives can be avoided by measuring the ratio between the total ββ–decay half lives of ^{128}Te and ^{130}Te.

Ratio between the half lives of ββ–decay for ^{128}Te and ^{130}Te

The neutrino-less double beta decay (0νββ) besides the two-neutrino double beta decay (2νββ) are two modes of double beta decay. The half lives T228, T028 of the (2νββ), (0νββ) modes for ^{128}Te are combined with the half lives T230, T030 of the same modes respectively for ^{130}Te to get the following expressions:

R2ν = T228 / T230 (1)
R0ν = T028 / T030 (2)
RT = Tt28 / Tt30 (3)

Where: (1/Tt28) = [(1/ T228) + (1/T028)]
(1/Tt30) = [(1/ T230) + (1/T030)]

R2ν is the ratio between the half lives of ^{128}Te, ^{130}Te for the (2νββ) decay mode. R0ν is the ratio between the half lives of ^{128}Te, ^{130}Te for the (0νββ) decay mode. RT is the ratio between the total half lives Tt28, Tt30 of ^{128}Te, ^{130}Te respectively. It can be shown that RT is related to R2ν and R0ν by:

RT = R2ν (1 + x) / (1 + y) (4)
RT = R0ν [1 + (1/x)] / [(1 + (1/ y)] (5)

where: x = T230/T030
y = T228/T028

There are 3 possible cases:

Case (1): x = y

This corresponds to either RT = R2ν [see equation (4)] which means that the (0νββ) mode is not probable and the decay of each isotope is (2νββ) only or RT = R0ν [see equation (5)] which means that the

($2\nu\beta\beta$) mode is not probable and the decay of each isotope is ($0\nu\beta\beta$) only.

Case (2): x < y

In equations (4), (5) this case corresponds to $R0\nu < RT < R2\nu$.

Case (3): x > y

In equations (4), (5) this case corresponds to $R2\nu < RT < R0\nu$.

Previously [2] the equations which calculate the half lives T228, T230 and T028, T030 have been used in this work to express equations (1) and (2) in another form:

$R2\nu = A2\nu\,(M2\nu)^2$ (6)

$R0\nu = A0\nu\,(M0\nu)^2$ (7)

M2ν is the ratio between the nuclear matrix elements of ^{130}Te to that of ^{128}Te for the ($2\nu\beta\beta$) mode and M0ν has the same definition of M2ν but for ($0\nu\beta\beta$) mode. A2ν is the ratio between the phase space factor of ^{130}Te to that of ^{128}Te for the ($2\nu\beta\beta$) mode and A0ν has the same definition of A2ν but for ($0\nu\beta\beta$) mode. In an earlier work [3] A2ν and A0ν were calculated by using their integral form for the ($2\nu\beta\beta$), ($0\nu\beta\beta$) modes such that eqns. (6) and (7) can be expressed in the following form:

$R2\nu = 5647.06\,(M2\nu)^2$ (8)

$R0\nu = 24.94\,(M0\nu)^2$ (9)

As mentioned before M2ν and M0ν should satisfy the following criterion:

$M2\nu \approx 1,\ M0\nu \approx 1$ (10)

Therefore:

$R2\nu > R0\nu$ (11)

According to equation (11) the three cases mentioned above can be classified as follows:

case (3) is forbidden while cases (1) , (2) are allowed and can be expressed as:

$R0\nu \le RT \le R2\nu$ (12)

3.Results and Discussion

(1) Determination of RT, R2ν, R0ν

(1-1)Experimental measurement of RT

Table (1) Experimental determinations of RT collected from different laboratories

RT	Reference
1590.00	[4]
1569.86	[5]
2000.00	[6]
2540.00	[7]
2550.00	[7]
2470.00	[8]
2350.00	[8]
2673.80	[9]

(1-2)Theoretical calculation of R2ν, R0ν

The variation of the nuclear matrix elements of the ($2\nu\beta\beta$), ($0\nu\beta\beta$) decay modes with the strength of the particle- particle interaction gpp has been studied [3] by using pn-QRPA, pn-RQRPA, full-RQRPA, SQRPA techniques.

The proton-neutron quasi particle random phase approximation (pn-QRPA) have clarified that the particle-particle interaction, which is the counterpart of the particle-hole interaction, enhances the spin-isospin correlations in the ground-state wave functions. The SQRPA technique uses the boson expansion for the phonon and β operators associated with pn-QRPA technique [10]. An alternative approach for extending pn-QRPA is based on the idea of partial restoration of the Pauli exclusion operator involved in the derivation of the pn-QRPA equations [3]. The commutator is replaced by its expectation value in the RPA (correlated) g.s and this leads to a renormalization of the relevant operators and of the forward and backward going QRPA amplitudes as well. This technique is called pn-RQRPA. It has been extensively used for both ($2\nu\beta\beta$), ($0\nu\beta\beta$) decay modes and for transition to g.s. and excited states and for different nuclei [11,12]. The extension of this technique when the proton-neutron pairing interactions, besides the proton-proton and neutron-neutron ones, are also included was called the full-RQRPA [13].

Two different basis have been used with the pn-QRPA, pn-RQRPA, full-RQRPA, SQRPA techniques to see the dependence of nuclear matrix elements on the Hilbert space. There are two choices [3] for the Hilbert space used to generate the basis needed in the calculations. For nuclei with $A \le 100$: (i) the full (3-4) $\hbar\omega$ oscillator shells and (ii) the full (2-4) $\hbar\omega$ oscillator shells are included. For nuclei with $A > 100$: (i) the full (3-5) $\hbar\omega$ oscillator shells and (ii) the full (2-5) $\hbar\omega$ oscillator shells are included. From here (i), (ii) are called small, large basis respectively.

In another work [3] the variation of nuclear matrix elements of the ($2\nu\beta\beta$), ($0\nu\beta\beta$) decay modes with gpp has been shown graphically in different figures by using pn-QRPA, pn-RQRPA, full-RQRPA, SQRPA techniques with small and large basis of Hilbert space. The available data shown on these figures have been used in equations (8), (9) to generate distributions of R2ν, R0ν versus gpp as shown in figures (1), (2), (3), (4).

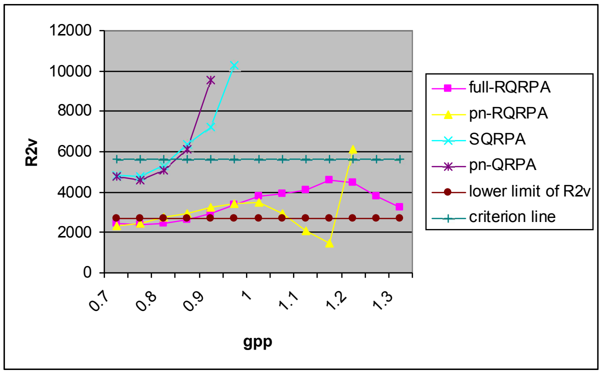

Fig. (1) Variation of R2ν versus gpp using different nuclear models (listed to the right of the graph) with small basis of Hilbert space. Lower limit of R2ν = 2673.8, criterion line R2ν = 5647.06

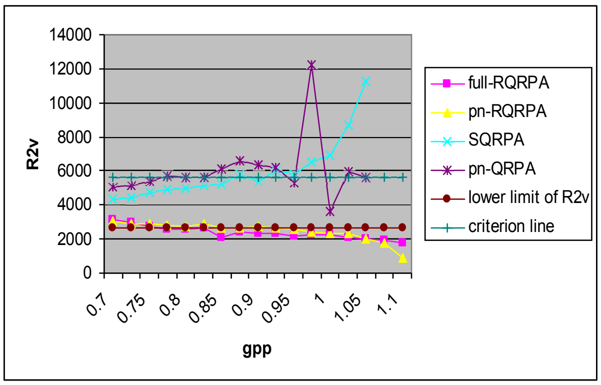

Fig. (2) Variation of R2ν versus gpp using different nuclear models (listed to the right of the graph) with large basis of Hilbert space. Lower limit of R2ν = 2673.8, criterion line R2ν = 5647.06

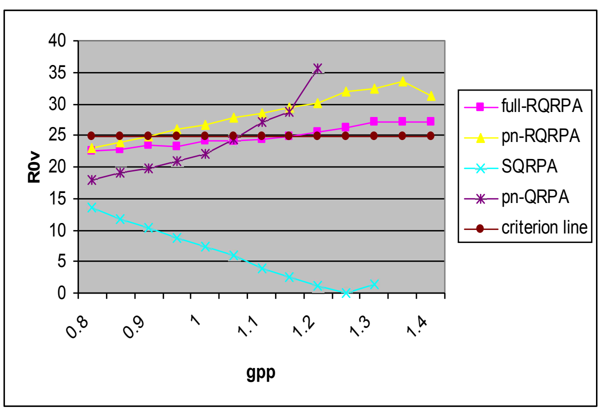

Fig. (3) Variation of R0ν versus gpp using different nuclear models (listed to the right of the graph) with small basis of Hilbert space. Criterion line R0ν = 24.94

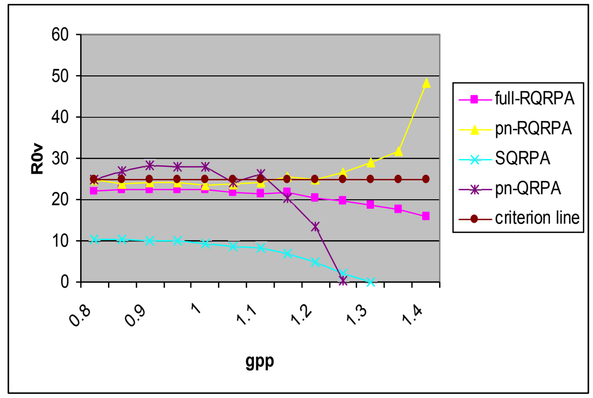

Fig. (4) Variation of R0ν versus gpp using different nuclear models (listed to the right of the graph) with large basis of Hilbert space. Criterion line R0ν = 24.94

(1-3) Items on figures (1), (2), (3), (4)

(1-3-1)Criterion line

The specific values M2ν =1 and M0ν =1 correspond to R2ν = 5647.06 and R0ν = 24.94. [see equations (8), (9)]. In figures (1), (2), (3), (4) R2ν = 5647.06 and R0ν = 24.94 are plotted as horizontal lines called criterion line.

(1-3-2)Lower limit of R2ν

The values of R2ν which construct the distributions shown in figures (1, 2) are confined within the range 60 < R2ν < 80000. Some of the values within this range are close to the criterion line R2ν = 5647.06 shown in figures (1, 2) and greater than the values of RT listed in table (1). This means that they are successfully verify the criterion M2ν ≈ 1 [see eqn. (10)] and the relation RT ≤ R2ν [see eqn. (12)]. The experimental values of RT listed in table (1) are different lower limits of R2ν. They are close to the criterion line R2ν = 5647.06 shown in figures (1, 2). So, the best one should be the closest one to that line. Thus, the best lower limit of R2ν is selected to be:

R2ν > 2673.8 (13)

(1-3-3) Upper limit of R0ν

The values of R0ν which construct the distributions shown in figures (3, 4) are confined within the range 1 < R0ν < 120. Most of the values within this range are very close to the criterion line R0ν = 24.94 shown in figures (3, 4) and lower than the values of RT listed in table (1). This means that they are successfully verify the criterion M0ν ≈ 1 [see eqn. (10)] and the relation R0ν ≤ RT [see eqn. (12)]. The experimental values of RT listed in table (1) are different upper limits of R0ν so the best one should be the largest one to make agreement between R0ν and all values of RT. Thus, the best upper limit of R0ν is selected to be:

R0ν < 2673.8 (14)

It should be noticed that the upper limit R0ν = 2673.8 is not shown in figures (3, 4) because it is out of the local scale of graphs. It can be concluded that RT = 2673.8 is the best experimental datum which has been used in this work as lower and upper limits of R2ν and R0ν respectively.

(2) Nuclear structure of tellurium isotopes ^{130}Te and ^{128}Te

In figures (1-4) the distributions of R2ν and R0ν versus gpp are plotted at different vertical distances from the criterion line. The distribution which has a shortest vertical distance from the criterion line verify the criterion given by eqn. (10) more accurately than other distributions. In figures (1, 2) it can be noticed that SQRPA technique satisfy the criterion more accurately than pn-RQRPA and full-RQRPA techniques within the ranges 0.7 ≤ gpp ≤ 0.95, 0.7 ≤ gpp ≤ 1.05 respectively. On the other hand figures (3, 4) indicate that pn-RQRPA and full-RQRPA techniques verify the criterion more accurately than SQRPA technique within the range 0.8 ≤ gpp ≤ 1.35. This means that the boson expansion for the phonon and β operators used with SQRPA technique is appropriate to describe the nuclear structure of tellurium isotopes for (2νββ) decay mode while the renormalization of the relevant operators used with pn-RQRPA and full-RQRPA techniques is suitable for describing the nuclear structure of tellurium isotopes for (0νββ) decay mode.

(3) Yield of a double beta decay mode

It should be mentioned that considerable attention has been noted for the (0νββ) decay mode [14, 15, 16, 17]. The yields of tellurium isotopes Y128 and Y130 for the (0νββ) decay mode are defined by

Y128 = Tt28 / T028 (15)

Y130 = Tt30 / T030 (16)

It can be easily shown that:

Y128 = (R2ν – RT) / (R2ν - R0ν) (17)

Y130/Y128 = R0ν / RT (18)

(3-1) Yield of (0νββ) decay mode for ^{130}Te

According to the data reported in this work the factor R0ν / RT in equation (18) is about 0.02. In another words Y128 is about 50 times Y130. This means that the (0νββ) decay mode is rarely occurred in ^{130}Te. That is why the (0νββ) decay mode of ^{130}Te is not studied in this work.

(3-2) Conditions for yield of (0νββ) decay mode for ^{128}Te

(3-2-1) 0 ≤Y128 ≤ 100 %

Relation (12) contains three relations: (1) RT ≤ R2ν (2) R0ν ≤ R2ν (3) RT ≥ R0ν. Using these relations in equation (17) indicate that the first two relations verify that 0 ≤Y128 while the third one satisfies that Y128 ≤ 100 %.

(3-2-2) Range of gpp for the distribution of Y128

The available ranges of gpp in figures (1- 4) are: gpp ≥ 0.7 for R2ν and gpp ≥ 0.8 for R0ν. The common range for both R2ν and R0ν is gpp ≥ 0.8. This range should be the available range to distribute Y128 versus gpp.

In figure (2) the available data for R2ν obtained from full-RQRPA technique with large basis satisfy relation (13) within the narrow range 0.7 < gpp < 0.8. On the other hand, the available range for distribution of R0ν versus gpp is gpp ≥ 0.8 as mentioned before. This means that there is no common range for both R2ν and R0ν. Therefore full-RQRPA technique with large basis can not be used to distribute Y128 versus gpp.

(3-2-3) Validity of the criterion

The values of R2ν and R0ν used to calculate Y128 in equation (17) should be close to the criterion lines R2ν = 5647.06 and R0ν = 24.94 shown in figures (1, 4) such that the criterion M2ν ≈ 1 , M0ν ≈ 1 is valid.

In figures (1- 4) the values of R2ν and R0ν which satisfy the above conditions have been used with RT = 2673.8 [the best experimental datum as illustrated in (1-3-3)]

in equation (17) to generate a new distributions of Y128 versus gpp as shown in figures (5), (6). In these figures the distributions above Y128 = 50% points out that the 0νββ decay mode is more probable than the 2νββ decay mode. On the other hand the distributions below Y128 = 50% points out that the 0νββ decay mode is less probable than the 2νββ decay mode.

(3-3) Factors improve the yield of the (0νββ) decay mode for ^{128}Te

The comparison between the distributions shown in figures (5), (6) points out that:

(1) the use of small basis rater than large basis in Hilbert space increases the yield of the (0νββ) decay mode for ^{128}Te.

(2) the use of boson expansion for the phonon and β operators in SQRPA technique instead of renormalization of the relevant operators in pn-RQRPA and full RQRPA techniques with small and large basis of Hilbert space improves the yield of the (0νββ) decay mode for ^{128}Te significantly.

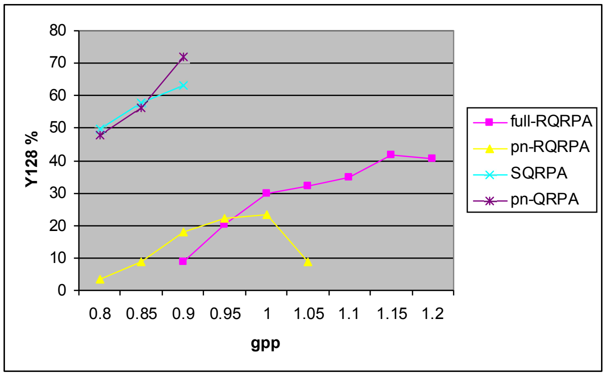

Fig.(5) Variation of Y128 versus gpp using different nuclear models (listed to the right of the graph) with small basis of Hilbert space.

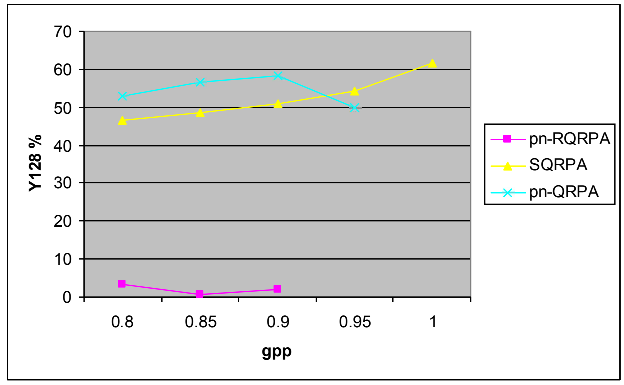

Fig.(6) Variation of Y128 versus gpp using different nuclear models (listed to the right of the graph) with large basis of Hilbert space.

(4) Choice of nuclear technique

Table (2) Comparison between different nuclear techniques

Nuclear technique	Advantages	Disadvantages
pn-QRPA	(1)in figures (1), (2) the deviation from the criterion line is smaller than that of pn-RQRPA , full-RQRPA techniques within the ranges $0.7 \le gpp \le 0.95$, $0.7 \le gpp \le 1.05$ for (2νββ) decay mode. (2)in figures (3), (4) the deviation from the criterion line is smaller than that of SQRPA technique within the range $0.8 \le gpp \le 1.25$ for (0νββ) decay mode. (3)in figures (5), (6) the yield is larger than that of pn-RQRPA , full-RQRPA techniques within the ranges $0.8 \le gpp \le 0.90$, $0.8 \le gpp \le 0.95$ for (0νββ) decay mode.	
pn-RQRPA , full-RQRPA	(1)in figures (3), (4) the deviation from the criterion line is smaller than that of SQRPA technique within the range $0.8 \le gpp \le 1.35$ for (0νββ) decay mode.	(1)in figures (1), (2) the deviation from the criterion line is larger than that of pn-QRPA, SQRPA techniques within the ranges $0.7 \le gpp \le 0.95$, $0.7 \le gpp \le 1.05$ for (2νββ) decay mode. (2)in figures (5), (6) the yield is smaller than that of pn-QRPA , SQRPA techniques within the ranges $0.8 \le gpp \le 0.90$, $0.8 \le gpp \le 0.95$ for (0νββ) decay mode.
SQRPA	(1)in figures (1), (2) the deviation from the criterion line is smaller than that of pn-RQRPA , full-RQRPA techniques within the ranges $0.7 \le gpp \le 0.95$, $0.7 \le gpp \le 1.05$ for (2νββ) decay mode. (2)in figures (5), (6) the yield is larger than that of pn-RQRPA , full-RQRPA techniques within the ranges $0.8 \le gpp \le 0.90$, $0.8 \le gpp \le 0.95$ for (0νββ) decay mode.	(1)in figures (3), (4) the deviation from the criterion line is larger than that of pn-RQRPA , full-RQRPA techniques within the range $0.8 \le gpp \le 1.35$ for (0νββ) decay mode

Table (2) presents a comparison between the nuclear techniques used in this work. It is clear that pn-QRPA technique is the best one for applications which require acceptable yield and deviation from the criterion given by equation (10) for (2νββ), (0νββ) decay modes of the isotopes ^{128}Te, ^{130}Te.

(5) Neutrino mass

The neutrino mass m_ν is one of a set of parameters which have been used to calculate the half life time T028 of the (0νββ) decay mode of ^{128}Te from the following expression [2]:

$$T028 = 1 / [F028 (M028\, m_\nu)^2] \quad (19)$$

Equations (15), (19) can be combined to give the following expression for m_ν:

$$m_\nu = (Y128)^{1/2} / [M028\, (Tt28)^{1/2}\, (F028)^{1/2}] \quad (20)$$

Where M028, F028 are the nuclear matrix element and the phase space factor of the (0νββ decay) mode of ^{128}Te. Previously [3], F028 has been calculated to be 6.36×10^{-27} y^{-1} eV^{-2}. The determination of the parameters Y128, M028 depends on the nuclear technique. As noted before pn-QRPA has been selected to be the best technique for double beta decay of tellurium isotopes ^{128}Te, ^{130}Te. The distributions of Y128, M028 versus gpp which belong to pn-QRPA technique are shown graphically in this work [see figures (5), (6)] and in another work [3] respectively for small and large basis of Hilbert space. They have been utilized in equation (20) to generate a new distribution of m_ν versus gpp. This is shown in figure (7) for two different experimental determinations of Tt28:

Tt28 = 2.41 x 10^{24} y [9]

Tt28 = 1.5 x 10^{24} y [18]

Two different laboratories determine m_ν within the following ranges:

0.21 eV ≤ m_ν ≤ 0.27 eV [19]

0.15 eV ≤ m_ν ≤ 0.30 eV [20]

The whole range which contain the above two ranges is 0.15 eV ≤ m_ν ≤ 0.30 eV. The limits of such range are plotted as two horizontal lines in figure (7).

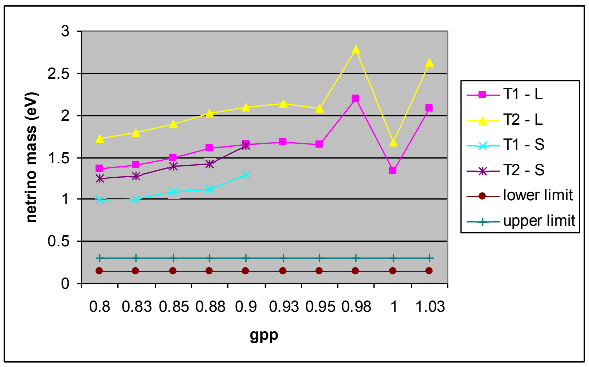

Figure (7) distribution of neutrino mass versus gpp for pn-QRPA technique with 4 different cases:

(1) T1 - L: Tt28 = 2.41 x 10^{24} y [9] with large basis of Hilbert space

(2) T2 - L: Tt28 = 1.50 x 10^{24} y [18] with large basis of Hilbert space

(3) T1 - S: Tt28 = 2.41 x 10^{24} y [9] with small basis of Hilbert space

(4) T2 - S: Tt28 = 1.50 x 10^{24} y [18] with small basis of Hilbert space

lower limit : m_ν = 0.15 eV

upper limit : m_ν = 0.30 eV

In figure (7) all the distributions of m_ν versus gpp disagree with the range 0.15 eV ≤ m_ν ≤ 0.3 eV . To make consistency with this range there are 4 different cases:

Case (1):

In this case Y128, Tt28 , M028 are kept without change and F028 is multiplied at least by a factor of about 25. This corresponds to multiply the Q-value of ^{128}Te by 1.9 because F028 is approximately proportional to Q^5 [2]. It is not possible to verify this case because the Q-value of ^{128}Te is well determined by the Atomic Mass Evaluation [21].

Case (2):

In such case Y128, F028, M028 are kept constant. The values of Tt28 listed above should be multiplied at least by a factor of about 25.

Case (3):

In such case Y128, F028, Tt28 are kept constant while M028 is multiplied at least by a factor of about 5. Such multiplication produces a new value of M028 which is far from the normal range determined by many groups [3,22,23,24,25,26,27,28]. Therefore this case is not acceptable.

Case (4):

In such case M028, F028, Tt28 are kept constant and Y128 is multiplied at least by a factor of about 0.04. This means that the (0νββ) decay mode is rarely occurred in ^{128}Te. Thus it is not possible to accept this case.

The best candidate one from the above 4 cases is case (2). This work suggests to determine Tt28 in alternative way by using equation (3):

Tt28 = (RT) (Tt30)

RT = 2673.8 is the best experimental datum as illustrated in (1-3-3). Using the above relation equation (20) can be written in another form:

$$m_\nu = (Y128)^{1/2} \; / \; [M028 \; (2673.8)^{1/2} \; (Tt30)^{1/2} \; (F028)^{1/2} \;] \qquad (23)$$

The procedure used before in this work to generate the graphs shown in figure (7) has been utilized in equation (23) to generate another distributions for m_ν versus gpp. This is shown in figure (8) for two different experimental determinations of Tt30:

Tt30 = 0.023 x 10^{24} y [2]

Tt30 = 2.800 x 10^{24} y [29]

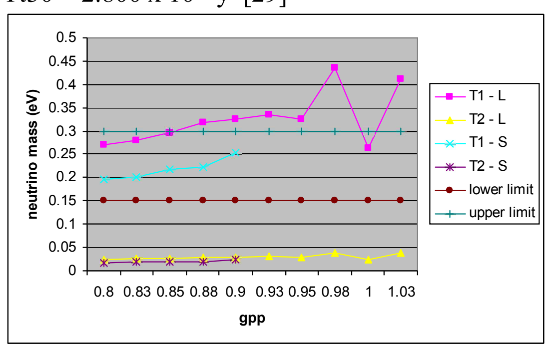

Figure (8) distribution of neutrino mass versus gpp for pn-QRPA technique with 4 different cases:

(1) T1 - L: Tt30 = 0.023 x 10^{24} y [2] with large basis of Hilbert space

(2) T2 - L: Tt30 = 2.800 x 10^{24} y [29] with large basis of Hilbert space

(3) T1 - S: Tt30 = 0.023 x 10^{24} y [2] with small basis of Hilbert space

(4) T2 - S: Tt30 = 2.800 x 10^{24} y [29] with small basis of Hilbert space

lower limit : m_ν = 0.15 eV

upper limit : m_ν = 0.30 eV

In figure (8) all the distributions of m_ν which belong to Tt30 = 2.800 x 10^{24} y disagree with the range 0.15 eV ≤ m_ν ≤ 0.3 eV . In the same figure the distributions of m_ν which belong to Tt30 = 0.023 x 10^{24} y agree with the range 0.15 eV ≤ m_ν ≤ 0.3 eV within the following ranges : 0.8 ≤ gpp ≤ 0.9 for small basis and 0.8 ≤ gpp ≤ 0.85 for large basis. The range of gpp with small basis is longer than that with large basis. So pn-QRPA with small basis is the best candidate to determine m_ν.

Table (3) results of some parameters for pn-QRPA technique with small basis

Gpp	0.8	0.825	0.85	0.875	0.9
m_ν (eV)	0.195	0.1998	0.2169	0.222	0.2546
Y128 %	47.7	48.975	56.4	57.23	72.13
M2ν	0.95	0.96	1.04	1.05	1.3
M0ν	0.848	0.857	0.877	0.882	0.889

Table (3) collects the results of calculations of m_ν ,Y128 ,M2ν ,M0ν for gpp=0.8, 0.825, 0.85, 0.875, 0.9 by using pn-QRPA technique with small basis. This is carried out for Tt30 = 0.023 x 10^{24} y to select the best value of m_ν which should verify the following conditions:

(1) small deviation from the criterion given by equation (10). This means that the values of M2ν ,M0ν are close to unity.

(2) the (0νββ) decay mode is more probable than the (2νββ) decay mode in ^{128}Te. This corresponds to Y128 > 50%.

At gpp =0.8, 0.825 the first condition is verified while the second one is not valid. At gpp= 0.85, 0.875 both conditions are satisfied. At gpp = 0.9 the first condition is not verified while the second one is valid. Therefore the acceptable values of m_ν are 0.2169, 0.222 eV. Their mean value and standard deviation are 0.21945 and 0.0036 eV which can be expressed as:

$m_\nu \pm \delta\, m_\nu = 0.21945 \pm 0.0036$ eV

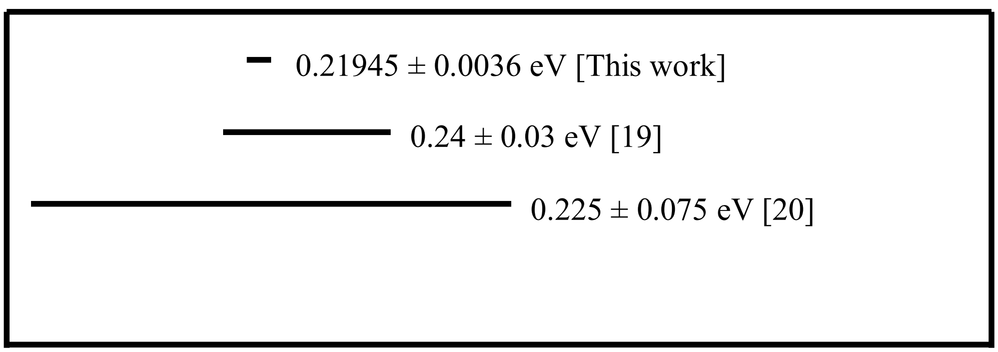

Figure (9) Different values of $m_\nu \pm \delta m_\nu$ obtained from different sources

Figure (9) presents a comparison between different determinations of $m_\nu \pm \delta\, m_\nu$ gathered from different sources. It is obvious that this work agrees with other sources and improves the best previous uncertainty [19] by a factor of about 10.

Conclusion

In this work the distribution of ratio between the half lives of ^{128}Te and ^{130}Te versus the strength of the particle-particle interaction is presented graphically for (2νββ), (0νββ) decay modes with small and large basis of Hilbert space as shown in figures (1), (2), (3), (4). In these figures a horizontal line called criterion line is plotted to:

(I) search for the best experimental ratio between the half lives of ^{130}Te and ^{128}Te which has been found to be 2673.8.

(II) select the suitable nuclear techniques to describe the nuclear structure of decay modes. They are SQRPA for (2νββ) decay mode and pn-RQRPA, full-RQRPA for (0νββ) decay mode.

The distribution of the yield of (0νββ) decay mode for ^{128}Te versus the strength of the particle-particle interaction is shown graphically in figures (5), (6) for small and large basis of Hilbert space. The yield is improved by using: (I) small basis rater than large basis of Hilbert space. (II) SQRPA instead of pn-RQRPA and full RQRPA techniques.

A comparison has been done between pn-QRPA , pn-RQRPA , full-RQRPA and SQRPA techniques with small and large basis of the Hilbert space to select the appropriate one for determination of neutrino mass. It is found that pn-QRPA is the best candidate technique. This work succeeds in generating a new acceptable distribution of neutrino mass versus the strength of the particle-particle interaction. A new precise value of neutrino mass has been determined to be 0.21945 ± 0.0036 eV.This value agrees with a previous experimental determinations and improves the relative uncertainty from 12.5 % to 1.64 %.

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