BB

CRN 95-05

SCAN-9508208

CERN LIBRARIES, GENEVA

Swgs 34

TABLES OF DOUBLE BETA DECAY DATA

V.I. TRETYAK^{1,2}, and Yu.G. ZDESENKO¹

¹ Institute for Nuclear Research of the Ukrainian National Academy of Sciences, 252028 Kiev, Ukraine

² Centre de Recherches Nucléaires, IN2P3-CNRS et Université Louis Pasteur, 67037 Strasbourg, France

Submitted to Atomic Data and Nuclear Data Tables

**CENTRE DE RECHERCHES NUCLEAIRES
STRASBOURG**

IN2P3
CNRS

UNIVERSITE
LOUIS PASTEUR

TABLES OF DOUBLE BETA DECAY DATA

V.I. TRETYAK^{1,2} and Yu.G. ZDESENKO¹

¹ Institute for Nuclear Research of the Ukrainian National Academy of Sciences,
252028 Kiev, Ukraine

² Centre de Recherches Nucléaires, IN2P3-CNRS et Université Louis Pasteur,
67037 Strasbourg, France

A compilation of experimental data on double beta decay is presented. The tables contain the most stringent known experimental limits or positive results for 2β transitions of 69 natural nuclides to ground and excited states of daughter nuclei for different channels ($2\beta^-$; $2\beta^+$; $\epsilon\beta^+$; 2ϵ) and modes (0ν ; 2ν ; $0\nu M$) of decay.

Submitted to Atomic Data and Nuclear Data Tables

CONTENTS

INTRODUCTION

Theoretical situation

Experimental status

SUPPLEMENT. Energy and angular distributions of electrons in different modes of 2β decay

POLICIES

EXPLANATION OF TABLES

EXPLANATION OF FIGURES

TABLES

I. Experimental values (or limits) and theoretical estimations of half-life for different 2β processes ($2\beta^-$; $2\beta^+$; $\epsilon\beta^+$; 2ϵ)

II. List of known 2β nuclides absent in natural mixture of elements

FIGURES

REFERENCES

INTRODUCTION

Research in double beta (2β) decay has been very active during the last decade in part triggered by a revived interest in the neutrino mass. A great number of results have been obtained at a level of precision which looked unattainable during the early history of investigations beginning from the theoretical prediction of 2β decay by M. Goepfert-Mayer in 1935 [Goe35] and W.H. Furry in 1939 [Fur39] and the first experimental work of E. Fireman in 1948 [Fir48].

We distinguish between neutrinoless double beta decay ($0\nu 2\beta$), a process that violates lepton number conservation and thus is of current interest as it may provide evidence for new physics (neutrino mass, right-handed coupling, Majoron decay), and two-neutrino double beta decay ($2\nu 2\beta$), a higher order transition allowed by conservation laws.

The following are some highlights of recent developments in this field:

- a half-life limit greater than 10^{24} y for $0\nu 2\beta$ decay of ^{76}Ge [Cal90, Kir92, Kla93a];
- a level of 10^{23} y for the limit of $T_{1/2}^{0\nu}$ of ^{136}Xe [Vui93] and 10^{22} y for ^{82}Se [Ell92], ^{100}Mo [Als93], ^{116}Cd [Dan93] and ^{130}Te [Ale94b];
- $2\nu 2\beta$ decay of ^{76}Ge [Vas90a, Mil90, Bro93, Bal94], ^{82}Se [Ell87a], ^{100}Mo [Vas90b, Eji91, Ell91, Das94a], ^{116}Cd [Kum94, Dan94, Das94b], ^{150}Nd [Art93, Ell93] observations in direct counting experiments;
- a large scale experiment on ^{76}Ge with enriched HP Ge detectors [Kla93a];
- low temperature high energy resolution bolometer with a TeO_2 crystal to study the 2β decay of ^{130}Te [Ale92];
- progress in the theoretical interpretation of the phenomenon [Eng88, Gro90, Tom91, Boe92, Kla93b].

These achievements are related to the special role 2β decay plays as a tool to study fundamental properties: it provides a unique and a very sensitive probe for nonzero neutrino mass, right-handed admixtures in the weak interaction and possible Majoron

couplings. Double beta decay, therefore, can provide information on new physics beyond the Standard Model and continues to be an interesting and important field of research.

The goal of the present article is to collect systematically the known experimental limits and positive results on values of 2β decay half-lives, decay energies, and also to give some another information useful for people working in this field of research. In the following two sections we briefly discuss the present status of 2β decay. We do not aim to cover the material contained in excellent reviews [Zel54, Del60, Laz67, Fio72, Bry78, Zde80a, Pri81, Doi81, Hax84, Sch84, Doi85, Ver86, Avi88, Fae88, Mut88, Cal89, Gro90, Tom91, Moe91a, Boe92, Kla93b, Moe93, Moe94b] but rather to draw attention to recent developments in 2β decay research.

Theoretical situation

Significant limits for neutrino mass, right-handed admixtures (and other parameters, for example, masses of supersymmetrical particles [Sin88]) from measured limits on $0\nu 2\beta$ decay rates are possible only if the nuclear matrix elements which enter the half-life formulae can be calculated reliably. Since the $0\nu 2\beta$ decay has not been observed up to now, it is impossible to check the theoretical $0\nu 2\beta$ rates directly but we have to resort to the $2\nu 2\beta$ decay data to test the assumptions made in nuclear structure calculations.

Three main approaches have been used for the most part to calculate nuclear matrix elements: the nuclear shell model, the quasiparticle random phase approximation (QRPA) and the operator expansion method (OEM). Full scale computations in the shell model [Hax81, Hax82, Hax84, Tsu84, Cau90, Pan90, Hax93] were unattainable because the number of basic states in the model space increased explosively for nuclei heavier than ^{48}Ca and various simplifications had to be introduced. From this point of view the QRPA [Vog86, Gro86, Civ87, Tom87, Eng88, Mut88, Mut89, Sta90, Tom91, Pan92, Suh93, Hir94a, Pan94] is more attractive in so far as the new vacuum is determined for quasiparticles and nuclear wave function can be described in terms of a small number of quasiparticles' degrees of freedom.

Calculations in the framework of QRPA revealed that the $2\nu 2\beta$ decay rates could be strongly suppressed by taking into account the ground state correlations in nuclei which are enhanced by the particle-particle interaction. Predicted $2\nu 2\beta$ decay rates are found to be very sensitive to the value of the strength of the particle-particle interaction g_{pp} , and calculated half-lives can be tuned to agree with all experimental data in the region of $g_{pp} \sim 1$. In order to remove or at least decrease these difficulties several attempts were undertaken. In [Sto92] the $2\nu 2\beta$ nuclear matrix elements were calculated taking into account the self-consistent self-energy corrections to the single particle spectra. In this way the QRPA instability around $g_{pp} \sim 1$ was avoided and a reasonably good agreement between calculated matrix elements and the experimental values was achieved. Paper [Sto93] reports the results of the investigation of high order corrections upon the QRPA nuclear matrix elements; it was found that the HQRPA corrections display a weak dependence on a particle-particle strength g_{pp} and become important in the region of $g_{pp} \sim 1$ where QRPA values vanish.

As regards the $0\nu 2\beta$ decay, QRPA calculations of 0ν rates are comparably insensitive to various types of ground state correlations (and to particle-particle correlations in par-

ticular). This is because in the neutrinoless mode the transitions are possible not only through intermediate states with $J^\pi=1^+$ but mainly through other multipoles J^π whose corresponding matrix elements are much less affected by the change of g_{pp} . Most of the authors agree that quite certain computation of $0\nu 2\beta$ decay rates are possible.

The tedious calculations of matrix elements in the shell model and the drastic sensitivity of $2\nu 2\beta$ decay rates on the value of g_{pp} in QRPA stimulated the development of alternative approaches. In the operator expansion method [Chi88, Chi89, Gmi90, Wu91, Wu92, Hir94b] the intermediate 1^+ energy spectrum is not explicitly used in the calculation of the $2\nu 2\beta$ decay amplitude. In this way the dependence on g_{pp} is strongly reduced and the 2ν nuclear matrix elements become comparatively constant in the physical region of g_{pp} . So the dependence on g_{pp} in the QRPA is considered as artificial [Kla93b]. OEM assumptions are criticized in [Eng92] as generating values of the nuclear matrix elements which are too small. Instead, another approach eliminating the explicit summation over intermediate states is proposed [Eng92] for the exact evaluation of Green's function based on a Lanczos algorithm for inverting linear operators. This method removes the need of the Green's function approximation used in OEM.

Calculations of the 2β half-life for several heavy deformed nuclei were performed in [Cas94, Hir95]. The pseudo SU(3) shell model scheme and a developed summation procedure without closure approximation for 2ν were used in these works. See [Mut88, Gro90, Tom91, Mut91, Boe92, Kla93b, Hax93, Moe93, Moe94b] for a discussion and comparison between the calculations of matrix elements in the shell model, QRPA and OEM.

The approach to calculate 2β decay rates in the framework of a relativistic quark confinement model was developed in [Ver85, Lus85, Suh90, Suh91].

The theoretical formulae for the energy and angular distributions of electrons in different modes and mechanisms of 2β decay are given in the Supplement.

Experimental status

There are two different classes of direct double β decay experiments: a) with an active source (source = detector); b) with a passive source. Both of these can be divided into two kinds – with detectors which measure only the energy and those which also track the electrons. In the first class of experiments the effect can be studied on the basis of one property only of 2β decay – the distribution of the total energy of the electrons. In the experiments with a passive source and energy detectors it is possible to use time coincidence between the two electrons and to measure the single and sum energy distributions. Full information about all properties of 2β decay events can be obtained in the most complete class of the experiments – time coincidence, tracks and vertex of the electrons, energy and angular distributions.

Below, we briefly discuss some of the recent and most sensitive 2β decay experiments.

^{76}Ge . During the past 6 years the Max-Planck Institute in Heidelberg in collaboration with the Kurchatov Institute in Moscow have performed the most sensitive experiment to study ^{76}Ge by using high purity (HP) Ge semiconductor detectors made from 16.9 kg enriched in ^{76}Ge . At first three HP Ge detectors (0.93, 2.76 and 2.3 kg active mass) enriched in ^{76}Ge to 86% with energy resolution 2.4 keV at 1.3 MeV were operational in the Gran Sasso Underground Laboratory (Italy). The background rate around 2 MeV

was 0.23 counts/(y·keV·kg). From 1133 kg·d of operation time the following half-life limit for the $0\nu2\beta$ decay of ^{76}Ge has been obtained: $T_{1/2}^{0\nu} > 1.93 \cdot 10^{24}$ y (90% CL) [Kla93a]. This result corresponds to a neutrino mass less than 1.1 eV (we use theoretical values of $T_{1/2}^{0\nu} \cdot < m_\nu >^2$ [Sta90] to calculate the limits on the neutrino mass). In addition the $2\nu2\beta$ decay of ^{76}Ge has been confirmed with high statistics: $T_{1/2}^{2\nu} = (1.42 \pm 0.03(\text{stat.}) \pm 0.13(\text{syst.})) \cdot 10^{21}$ y [Bal94].

There is another international project (IGEX) to study 2β decay of ^{76}Ge [Bro93] which is now under preparation. Three detectors each composed of ~ 1 kg of germanium and one of ~ 2 kg enriched to 87.4% of ^{76}Ge have been produced and tested to date. The goal of the IGEX project is to obtain five ~ 3 kg detectors which could provide a sensitive measurement of the $0\nu2\beta$ decay of ^{76}Ge .

^{82}Se . The $2\nu2\beta$ decay of ^{82}Se has been measured by the University of California Irvine group with a time projection chamber (TPC) placed in a magnetic field of ~ 700 G [Ell92]. The TPC records the electron tracks, and the energies and opening angle are determined from each track. The discovery of the $2\nu2\beta$ decay of ^{82}Se with $T_{1/2}^{2\nu} = 1.08_{-0.06}^{+0.26} \cdot 10^{20}$ y (68% CL) has been claimed after a 20244 h run and a limit of $T_{1/2}^{0\nu} > 2.7 \cdot 10^{22}$ y (68% CL) has been set for the $0\nu2\beta$ decay of ^{82}Se [Ell92].

^{100}Mo . Five groups have performed measurements with ^{100}Mo . In 1982 the INR (Kiev) used plastic scintillator-wafer stacks with sheets of ^{100}Mo [Zde82]. A limit of $T_{1/2}^{0\nu} > 2.2 \cdot 10^{21}$ y (90% CL) has been set. Recently a similar technique (but with semiconductor-wafer stacks) was used by the LBL+MHC+UNM+INEL collaboration [Als93]. A limit of $T_{1/2}^{0\nu} > 4.4 \cdot 10^{22}$ y (68% CL) was reached in this work. Three other groups used the apparatus with tracking and energy detectors and all groups have claimed the discovery of the $2\nu2\beta$ decay of ^{100}Mo : Moscow group - $T_{1/2}^{2\nu} = (3.3_{-1.0}^{+2.0}) \cdot 10^{18}$ y (90% CL) [Vas90b]; Osaka - $T_{1/2}^{2\nu} = (1.15_{-0.20}^{+0.30}) \cdot 10^{19}$ y (68% CL) [Eji91]; Irvine - $T_{1/2}^{2\nu} = (1.16_{-0.03}^{+0.34}) \cdot 10^{19}$ y (68% CL) [Ell91]. Recently, the Osaka and Irvine results were confirmed by the NEMO collaboration with the help of the NEMO 2 apparatus with a good tracking device (square source ~ 1 m²) and 2x64 plastic scintillators: $T_{1/2}^{2\nu} = (0.95 \pm 0.04(\text{stat.}) \pm 0.09(\text{syst.})) \cdot 10^{19}$ y [Das94a]. The NEMO collaboration is now building the NEMO 3 tracking detector which is scaled up in comparison with the previous by a factor of 20 in size (square source ~ 20 m²) and by a factor of 1000 in sensitivity. With ~ 10 kg of ^{100}Mo they plan to reach a limit of $T_{1/2}^{0\nu} \sim 10^{25}$ y.

The detector resolution will play a decisive role to distinguish between allowed in the Standard Model $2\nu2\beta$ and forbidden $0\nu2\beta$ decays [Moe91b]. On fig. 1 the sum energy distributions for the $0\nu2\beta$ decay of ^{100}Mo with $T_{1/2}^{0\nu} = 10^{24}$ and 10^{25} y are shown together with a tail from the $2\nu2\beta$ decay with $T_{1/2}^{2\nu} = 10^{19}$ y. These distributions were calculated for an energy resolution (FWHM) equal to 10, 15 and 20% at an energy of 1 MeV. It is clear that reaching a sensitivity of more than 10^{24} y with poor resolution (worse than 10%) appears very questionable especially if we take into account the problems of low statistics (for instance, in 10 kg of ^{100}Mo only 42 (4.2) $0\nu2\beta$ decays will occur during a period of one year if $T_{1/2}^{0\nu} = 10^{24}$ (10²⁵) y).

^{116}Cd . $^{116}\text{CdWO}_4$ crystal scintillators enriched in ^{116}Cd to 83% have been developed by the Kiev group (Institute for Nuclear Research) [Dan89, Zde91]. The experiment was performed in the Solotvina Underground Laboratory with three enriched crystal scintillators $^{116}\text{CdWO}_4$ (19, 14 and 13 cm³) as well as with natural CdWO_4 (8, 9 and 57 cm³)

detectors. The energy resolution of the crystals was about 7.5% at 2.6 MeV and the background rate in the energy interval 2.7–2.9 MeV was equal to 0.57 counts/(y·keV·kg) [Dan93, Dan94]. After a 5822 h run a lower limit of $T_{1/2}^{0\nu} > 2.9 \cdot 10^{22}$ y (90% CL) was set, which corresponds to $m_\nu < 4.1$ eV [Dan94]. By subtracting the spectra of natural CdWO_4 scintillators from the spectra of enriched $^{116}\text{CdWO}_4$ detectors indications for a $2\nu 2\beta$ decay of ^{116}Cd have been reported with $T_{1/2}^{2\nu} = 2.7_{-0.4}^{+0.5}(\text{stat.})_{-0.6}^{+0.9}(\text{syst.}) \cdot 10^{19}$ y [Dan94]. INR (Kiev) and MPI (Heidelberg) have recently proposed [Dan94] a project for a big scale experiment with $^{116}\text{CdWO}_4$ crystal scintillators (~ 20 kg of the ^{116}Cd) in which the limit of $T_{1/2}^{0\nu} > 10^{25}$ y can be reached ($m_\nu < 0.3$ eV). $^{116}\text{CdWO}_4$ crystals could also be used as the cryogenic thermal detectors (an energy resolution ~ 5 keV at 1 MeV has recently been obtained in the first tests with a CdWO_4 crystal of mass 58 g [Ale94a]).

The $2\nu 2\beta$ decay of ^{116}Cd was also observed by the Osaka group in 1875 h measurements with ELEGANTS V ($T_{1/2}^{2\nu} = 2.6_{-0.5}^{+0.9} \cdot 10^{19}$ y [Kum94]) and by the NEMO collaboration with modified NEMO 2 installation during 2460 h (preliminary result $T_{1/2}^{2\nu} = (3.6_{-0.5}^{+0.6}(\text{stat.}) \pm 0.3(\text{syst.})) \cdot 10^{19}$ y [Das94b]).

^{130}Te . The Milano group has used the crystal TeO_2 (334 g) as a cryogenic thermal detector for 2β decay research in ^{130}Te [Ale94b]. The energy resolution of the crystal is about 10 keV at 1.3 MeV. After 9234 h of operation time in the Gran Sasso Underground Laboratory the background rate near 2.53 MeV was 3.4 counts/(y·keV·kg). A limit of $T_{1/2}^{0\nu} > 1.8 \cdot 10^{22}$ y (90% CL) has been established for the $0\nu 2\beta$ decay of ^{130}Te ($m_\nu < 5.2$ eV) [Ale94b]. In the near future with four TeO_2 crystals (full mass ≈ 1.2 kg) a limit of 10^{23} y can be set ($m_\nu < 2.2$ eV) and with an enriched $^{130}\text{TeO}_2$ crystal a level of 10^{24} y can be reached after several years ($m_\nu < 0.7$ eV). It should be mentioned that the development of this technique is an important step in 2β decay research because it can be applied to different crystals which could contain the possible 2β active nuclei.

^{136}Xe . The Caltech (Pasadena) + Institut de Physique (Neuchatel) + Paul Scherrer Institute (Villigen) collaboration [Vui93] have constructed a time projection chamber with an active volume of 180 l, which has operated with 5 atm of xenon enriched in ^{136}Xe to 62.5%. The energy resolution of the TPC is 6.6% at 1.6 MeV. The track reconstruction capability of the TPC provides a powerful means of background rejection. As a result the background rate around 2.48 MeV (within FWHM energy interval) is 0.01 counts/(y·keV·kg). From 6830 h of data taking in the Gotthard Underground Laboratory a limit of $T_{1/2}^{0\nu} > 3.4 \cdot 10^{23}$ y (90% CL) has been set for the $0\nu 2\beta$ decay of ^{136}Xe [Vui93] ($m_\nu < 2.5$ eV). In the near future and after some improvements of the apparatus this collaboration plans to reach the limit of $T_{1/2}^{0\nu} > 10^{24}$ y ($m_\nu < 1.5$ eV). One should note that the equipment developed in this work combines the advantages of both classes of direct 2β decay experiments: reasonable high efficiency plus tracking information. Naturally the next step in this direction – large-volume liquid Xe TPC [Gir92] and self-triggered drift chamber filled by liquid enriched ^{136}Xe [Pro94] – has been proposed to enable a sensitivity level of $\sim 10^{25}$ y ($m_\nu < 0.5$ eV) to be reached. In order to surpass even this level of sensitivity, a new approach has been proposed making use of the coincident detection of $^{136}\text{Ba}^{2+}$ ions (resulting from the 2β decay of ^{136}Xe at the atomic level) and the $0\nu 2\beta$ signal of ^{136}Xe with an energy of 2.5 MeV in a TPC filled by liquid Xe [Moe91b, Miy91]. Such an apparatus with 1000 kg of ^{136}Xe should be capable of investigating the Majorana neutrino mass in the 0.01 eV region assuming zero background [Moe91b].

^{150}Nd . In an early experiment of the Moscow group plastic scintillators with sheets of

Table 1: Limits on neutrino mass from the most advanced direct experiments. We use the recalculation [Moe94b] (if needed) of theoretical values of $T_{1/2}^{0\nu} \cdot \langle m_\nu \rangle^2$ from different works for $g_A=1.25$

Isotope	Experimental limit $T_{1/2}^{0\nu}$, y 68%(90%) CL	$T_{1/2}^{0\nu} \cdot \langle m_\nu \rangle^2$, y·eV ² and upper limit on m_ν , eV 68%(90%) CL				
		[Hax84]	[Eng88]	[Eng89]	[Sta90]	[Tom91]
⁷⁶ Ge	$3.2(1.9) \cdot 10^{24}$ [Kla93a]	$1.7 \cdot 10^{24}$ 0.7(0.9)	$1.4 \cdot 10^{25}$ 2.1(2.7)	$2.3 \cdot 10^{24}$ 0.8(1.1)	$2.3 \cdot 10^{24}$ 0.8(1.1)	$2.2 \cdot 10^{24}$ 0.8(1.1)
⁸² Se	$2.7(-) \cdot 10^{22}$ [Ell92]	$5.8 \cdot 10^{23}$ 4.6(-)	$5.6 \cdot 10^{24}$ 14.4(-)	$9.2 \cdot 10^{23}$ 5.8(-)	$6.0 \cdot 10^{23}$ 4.7(-)	$6.0 \cdot 10^{23}$ 4.7(-)
¹⁰⁰ Mo	$4.4(-) \cdot 10^{22}$ [Als93]	— —	— —	— —	$1.3 \cdot 10^{24}$ 5.4(-)	$2.6 \cdot 10^{23}$ 2.4(-)
¹¹⁶ Cd	$5.4(2.9) \cdot 10^{22}$ [Dan94]	— —	— —	— —	$4.9 \cdot 10^{23}$ 3.0(4.1)	— —
¹³⁰ Te	$2.8(1.8) \cdot 10^{22}$ [Ale94b]	$1.6 \cdot 10^{23}$ 2.4(3.0)	$6.6 \cdot 10^{23}$ 4.9(6.1)	$2.4 \cdot 10^{23}$ 2.9(3.7)	$4.9 \cdot 10^{23}$ 4.2(5.2)	$5.2 \cdot 10^{23}$ 4.3(5.4)
¹³⁶ Xe	$6.4(3.4) \cdot 10^{23}$ [Vui93]	— —	$3.3 \cdot 10^{24}$ 2.3(3.1)	— —	$2.2 \cdot 10^{24}$ 1.9(2.5)	$1.5 \cdot 10^{24}$ 1.5(2.1)
¹⁵⁰ Nd	$-(2.1) \cdot 10^{21}$ [Moe94a]	— —	— —	— —	$3.4 \cdot 10^{22}$ -(4.0)	$4.5 \cdot 10^{22}$ -(4.6)

¹⁵⁰Nd were used and a limit of $T_{1/2}^{0\nu} > 1.7 \cdot 10^{21}$ y (95% CL) was established for the $0\nu 2\beta$ decay of ¹⁵⁰Nd ($m_\nu < 4.5$ eV) [Kli86]. The Irvine group for a 6342 h TPC run with 11.2 g of ¹⁵⁰Nd has set a limit of $T_{1/2}^{0\nu} > 2.1 \cdot 10^{21}$ y (90% CL), which corresponds to a neutrino mass $m_\nu < 4.0$ eV [Moe94a]. Due to the high sensitivity of ¹⁵⁰Nd to neutrino mass (large decay energy) a scale up of the TPC with ~ 400 g of ¹⁵⁰Nd could push the limit of the neutrino mass down to 0.5 eV [Moe94a]. The two-neutrino 2β decay of ¹⁵⁰Nd was recently observed with $T_{1/2}^{2\nu} = (1.7^{+1.1}_{-0.5}(\text{stat.}) \pm 0.35(\text{syst.})) \cdot 10^{19}$ y [Art93] (the preliminary result of the Irvine group is $T_{1/2}^{2\nu} = 1.0 \cdot 10^{19}$ y [Ell93]).

The results of the recent and most advanced 2β decay experiments are summarized in the table. It is clear that research in ⁷⁶Ge and ¹³⁶Xe give us the most stringent limits on the Majorana neutrino mass (1-2 eV). Fig. 2 shows the sensitivity of these experiments to neutrino mass.

Fig. 3 from [Zde93] shows the actual status of the most advanced experiments, the expected improvements of current results and the most realistic projects up to the year 1999.

Acknowledgement

We gratefully acknowledge the discussions with prof. F. Boehm and his suggestions which helped to improve our manuscript.

Figure 1. Distributions for the sum of electron energies in $0\nu 2\beta$ and $2\nu 2\beta$ decays of ^{100}Mo ($Q_{\beta\beta} = 3034 \text{ keV}$) determined for different resolution of the detector: 1 - $FWHM(E_0) = 100 \text{ keV}$; 2 - $FWHM(E_0) = 150 \text{ keV}$; 3 - $FWHM(E_0) = 200 \text{ keV}$; $E_0 = 1 \text{ MeV}$. The dependence $FWHM(E) = FWHM(E_0)\sqrt{E/E_0}$ is assumed

Figure 2. Sensitivity of the most advanced experiments to neutrino mass. Theoretical values of $T_{1/2}^{0\nu} \cdot \langle m_\nu \rangle^2$ [Sta90] and 90% CL experimental limits of $T_{1/2}^{0\nu}$ were used

Figure 3. Actual status and expected improvements for 2β results

SUPPLEMENT. Energy and angular distributions of electrons in different modes of 2β decay

In this Supplement the theoretical formulae based on [Doi81, Sch84, Moh88, Car93] for the energy and angular distributions of electrons for different modes and mechanisms of 2β decay are given. In cases where formulae for the distributions of single electron energy $F_1(T_1)$ or sum electron energies $F(T)$ were absent in the original articles, they were obtained from basic 3-dimensional distributions $F_{12\theta}(T_1, T_2, \cos\theta)$ in the following way:

$$F_{12}(T_1, T_2) = \int_0^\pi F_{12\theta}(T_1, T_2, \cos\theta) d\cos\theta, \quad (1)$$

$$F_1(T_1) = \int_0^{T_0-T_1} F_{12}(T_1, T_2) dT_2, \quad (2)$$

$$F(T) = \int_0^T F_{12}(T - T_2, T_2) dT_2, \quad (3)$$

where T_i – kinetic energy of i -th electron (in units of electron mass); T_0 – energy available for electrons ($Q_{\beta\beta}$ for decay to ground state and $Q_{\beta\beta} - E_{level}$ for decay to excited state of daughter nucleus with energy E_{level}) in the same units; $T = T_1 + T_2$; θ – angle between the electron directions. The Primakoff-Rosen (PR) approximation for the Fermi function taking into account the influence of the electric field of the nucleus on emitted electrons was used to obtain all formulae in an analytical way. It should be stressed here that the PR approximation is adequate for $2\beta^-$ decay but is not so reliable in the case of $2\beta^+$ decay; see [Boe92, Doi92, Doi93] where exact distributions are compared with those calculated in the PR approximation.

1. $0\nu 2\beta$ -decay with neutrino mass, $0^+ - 0^+$ transition, $2n$ -mechanism

$$F_{12\theta}(T_1, T_2, \cos\theta) = (T_1 + 1)^2 (T_2 + 1)^2 \delta(T_0 - T_1 - T_2) (1 - \beta_1 \beta_2 \cos\theta), \quad (4)$$

$$F_{12}(T_1, T_2) = (T_1 + 1)^2 (T_2 + 1)^2 \delta(T_0 - T_1 - T_2), \quad (5)$$

$$F_1(T_1) = (T_1 + 1)^2 (T_0 + 1 - T_1)^2, \quad (6)$$

$$F(T) = \delta(T_0 - T), \quad (7)$$

where β_i – velocity of i -th electron, $\beta_i = \sqrt{T_i(T_i + 2)} / (T_i + 1)$. Corresponding $F_1(T_1)$ and $F(T)$ distributions are shown in Fig. 4.1.

2. $0\nu 2\beta$ -decay with right-handed currents, $0^+ - 0^+$ transition, $2n$ -mechanism

The exact expression for $F_{12\theta}(T_1, T_2, \cos\theta)$ [Doi81, Sch84] is quite complicated and depends on different nuclear matrix elements. Therefore, the Primakoff-Rosen approximation as well as further simplifications recommended in [Doi81, Sch84] were used.

$$F_{12\theta}(T_1, T_2, \cos\theta) = (T_1 + 1)^2 (T_2 + 1)^2 (T_1 - T_2)^2 \delta(T_0 - T_1 - T_2) (1 + \beta_1 \beta_2 \cos\theta), \quad (8)$$

$$F_{12}(T_1, T_2) = (T_1 + 1)^2 (T_2 + 1)^2 (T_1 - T_2)^2 \delta(T_0 - T_1 - T_2), \quad (9)$$

$$F_1(T_1) = (T_1 + 1)^2(T_0 + 1 - T_1)^2(T_0 - 2T_1)^2, \quad (10)$$

$$F(T) = \delta(T_0 - T). \quad (11)$$

The $F_1(T_1)$ and $F(T)$ distributions are shown in Fig. 4.2.

3. $0\nu 2\beta$ -decay with right-handed currents, $0^+ - 0^+$ transition, N^* -mechanism

$$F_{12\theta}(T_1, T_2, \cos\theta) = E_1 E_2 [2P_1^2 P_2^2 \cos^2\theta - P_1 P_2 \cos\theta [(E_1 + E_2)^2 + 4(E_1 E_2 + 1)] + 3(E_1 E_2 + 1)(P_1^2 + P_2^2)] \delta(T_0 - T_1 - T_2), \quad (12)$$

$$F_{12}(T_1, T_2) = E_1 E_2 [4P_1^2 P_2^2 + 9(E_1 E_2 + 1)(P_1^2 + P_2^2)] \delta(T_0 - T_1 - T_2), \quad (13)$$

$$F_1(T_1) = E_1 E_2 [4P_1^2 P_2^2 + 9(E_1 E_2 + 1)(P_1^2 + P_2^2)], \quad (14)$$

$$F(T) = \delta(T_0 - T), \quad (15)$$

where $E_i = T_i + 1$, $P_i = \sqrt{T_i(T_i + 2)}$, $T_2 = T_0 - T_1$. The $F_1(T_1)$ and $F(T)$ distributions are shown in Fig. 4.3.

4. $2\nu 2\beta$ -decay, $0^+ - 0^+$ transition, $2n$ -mechanism

$$F_{12\theta}(T_1, T_2, \cos\theta) = (T_1 + 1)^2(T_2 + 1)^2(T_0 - T_1 - T_2)^5(1 - \beta_1\beta_2\cos\theta), \quad (16)$$

$$F_{12}(T_1, T_2) = (T_1 + 1)^2(T_2 + 1)^2(T_0 - T_1 - T_2)^5, \quad (17)$$

$$F_1(T_1) = (T_1 + 1)^2(T_0 - T_1)^6[(T_0 - T_1)^2 + 8(T_0 - T_1) + 28], \quad (18)$$

$$F(T) = (T^4 + 10T^3 + 40T^2 + 60T + 30)T(T_0 - T)^5. \quad (19)$$

The $F_1(T_1)$ and $F(T)$ distributions are shown in Fig. 4.4.

5. $0\nu 2\beta$ -decay with emission of Majoron, $0^+ - 0^+$ transition, $2n$ -mechanism

For $0\nu 2\beta$ -decay with emission of Majoron [Gel81]

$$F_{12\theta}(T_1, T_2, \cos\theta) = (T_1 + 1)^2(T_2 + 1)^2(T_0 - T_1 - T_2)(1 - \beta_1\beta_2\cos\theta), \quad (20)$$

$$F_{12}(T_1, T_2) = (T_1 + 1)^2(T_2 + 1)^2(T_0 - T_1 - T_2), \quad (21)$$

$$F_1(T_1) = (T_1 + 1)^2[(T_0 + 1 - T_1)^4 - 4(T_0 + 1 - T_1) + 3], \quad (22)$$

$$F(T) = (T^4 + 10T^3 + 40T^2 + 60T + 30)T(T_0 - T). \quad (23)$$

The $F_1(T_1)$ and $F(T)$ distributions are shown in Fig. 4.5.

6. $0\nu 2\beta$ -decay with double Majoron emission, $0^+ - 0^+$ transition,
2n-mechanism. Decay with charged $L = -2$ Majoron and
massive vector Majoron

For decay as with double Majoron emission [Moh88] as with emission of Majoron with lepton number -2 [Bur93a]

$$F_{12\theta}(T_1, T_2, \cos\theta) = (T_1 + 1)^2 (T_2 + 1)^2 (T_0 - T_1 - T_2)^3 (1 - \beta_1 \beta_2 \cos\theta), \quad (24)$$

$$F_{12}(T_1, T_2) = (T_1 + 1)^2 (T_2 + 1)^2 (T_0 - T_1 - T_2)^3, \quad (25)$$

$$F_1(T_1) = (T_1 + 1)^2 (T_0 - T_1)^4 [(T_0 - T_1)^2 + 6(T_0 - T_1) + 15], \quad (26)$$

$$F(T) = (T^4 + 10T^3 + 40T^2 + 60T + 30)T(T_0 - T)^3. \quad (27)$$

For the decay with emission of a vector Majoron with mass m [Car93]

$$F_{12\theta}(T_1, T_2, \cos\theta) = (T_1 + 1)^2 (T_2 + 1)^2 [(T_0 - T_1 - T_2)^2 - m^2]^{3/2} (1 - \beta_1 \beta_2 \cos\theta). \quad (28)$$

In case $m = 0$ this distribution (and all subsequent) turns into the distribution for double Majoron emission. Corresponding $F_1(T_1)$ and $F(T)$ distributions are shown in Fig. 4.6.

7. $0\nu 2\beta$ -decay with right-handed currents, $0^+ - 2^+$ transition,
2n-mechanism

$$F_{12\theta}(T_1, T_2, \cos\theta) = E_1 E_2 [3P_1^2 P_2^2 \cos^2\theta - P_1 P_2 \cos\theta (10(E_1 E_2 + 1) + P_1^2 + P_2^2) + \quad (29)$$

$$+ 5(E_1 E_2 + 1)(P_1^2 + P_2^2) - P_1^2 P_2^2] \delta(T_0 - T_1 - T_2),$$

$$F_{12}(T_1, T_2) = E_1 E_2 [P_1^2 P_2^2 + 5(E_1 E_2 + 1)(P_1^2 + P_2^2)] \delta(T_0 - T_1 - T_2), \quad (30)$$

$$F_1(T_1) = E_1 E_2 [P_1^2 P_2^2 + 5(E_1 E_2 + 1)(P_1^2 + P_2^2)], \quad (31)$$

$$F(T) = \delta(T_0 - T), \quad (32)$$

where $E_i = T_i + 1$, $P_i = \sqrt{T_i(T_i + 2)}$, $T_2 = T_0 - T_1$. Corresponding $F_1(T_1)$ and $F(T)$ distributions are shown in Fig. 4.7.

8. $0\nu 2\beta$ -decay with right-handed currents, $0^+ - 2^+$ transition,
 N^* -mechanism

In this case the theoretical formulae are the same as for the $0\nu 2\beta$ -decay with right-handed currents, $0^+ - 0^+$ transition, N^* -mechanism. However T_0 value is not the same and one or more γ -quanta are emitted additionally.

9. $2\nu 2\beta$ -decay, $0^+ - 2^+$ transition, $2n$ -mechanism

$$F_{12\theta}(T_1, T_2, \cos\theta) = (T_1 + 1)^2(T_2 + 1)^2(T_1 - T_2)^2(T_0 - T_1 - T_2)^7(1 + \frac{1}{3}\beta_1\beta_2\cos\theta), \quad (33)$$

$$F_{12}(T_1, T_2) = (T_1 + 1)^2(T_2 + 1)^2(T_1 - T_2)^2(T_0 - T_1 - T_2)^7, \quad (34)$$

$$F_1(T_1) = (T_1 + 1)^2(T_0 - T_1)^8[(T_0 - T_1)^4 - 6(T_1 - 1)(T_0 - T_1)^3 + 11(T_1^2 - 4T_1 + 1)(T_0 - T_1)^2 + 110T_1(T_1 - 1)(T_0 - T_1) + 495T_1^2], \quad (35)$$

$$F(T) = T^3(T^4 + 14T^3 + 84T^2 + 140T + 70)(T_0 - T)^7. \quad (36)$$

(The formula for $F_1(T_1)$ in [Sch84] is slightly incorrect; we give the right expression.) The formulae for N^* -mechanism in this mode of decay are the same as for $2n$ -mechanism. Corresponding $F_1(T_1)$ and $F(T)$ distributions are shown in Fig. 4.8.

Figure 4. Theoretical distributions for the energy of single electron (e_1) and for sum of electrons energies (e_1+e_2) for ^{100}Mo ($Q_{\beta\beta}=3034$ keV, $E(2^+)=540$ keV) for different modes and mechanisms of 2β decay:

- 1 - $0\nu 2\beta$ decay with neutrino mass, 0^+-0^+ -transition, $2n$ -mechanism;
- 2 - $0\nu 2\beta$ decay with right-handed currents, 0^+-0^+ -transition, $2n$ -mechanism;
- 3 - $0\nu 2\beta$ decay with right-handed currents, 0^+-0^+ -transition, N^* -mechanism;
- 4 - $2\nu 2\beta$ decay, 0^+-0^+ -transition, $2n$ -mechanism;
- 5 - $0\nu 2\beta$ decay with Majoron emission, 0^+-0^+ -transition, $2n$ -mechanism;
- 6 - $0\nu 2\beta$ decay with double Majoron emission, 0^+-0^+ -transition, $2n$ -mechanism;
- 7 - $0\nu 2\beta$ decay with right-handed currents, 0^+-2^+ -transition, $2n$ -mechanism;
- 8 - $2\nu 2\beta$ decay, 0^+-2^+ -transition, $2n(=N^*)$ -mechanism

POLICIES

Literature coverage. All available experimental papers were covered, including articles, conference proceedings, preprints and theses up to December, 1994. If the same data have been described in several papers, we have given only the most extensive and recent reference. We present in the table all known positive results on 2β search and – in the case of limits on $T_{1/2}$ – only the most stringent current experimental limit. We quote theoretical half-lives for a few of the more successful theoretical models. The sources with the most extensive list of calculated nuclei were used enabling a comparison with theoretical values for different 2β isotopes in the same approach. Additional theoretical calculations are referenced in the Introduction.

Data presentation. All values of half-lives in the table are rounded to the 2-nd decimal place. We regard this as an accuracy achievable on the current level of experimental technique.

Errors. Full error is calculated as the square root of the sum of squares of systematic and statistic errors (if both were presented in the original paper).

Confidence levels. Confidence level (CL) is given *only* if it was quoted in the original paper. If a few limits on half-life were calculated for different CL in the article, the limit with higher CL only is chosen for presentation in the table. No effort has been made to recalculate all data for the same confidence level.

EXPLANATION OF TABLES

TABLE I. Experimental values (or limits) and theoretical estimations of half-life for different 2β processes ($2\beta^-$; $2\beta^+$; $\epsilon\beta^+$; 2ϵ)

In the table I the most stringent known experimental limits or positive results for 2β decay half-lives are given (as per December, 1994) for transitions of 69 natural nuclides to ground and excited states of daughter nuclei for different channels and modes of decay. The atomic mass differences ΔM_A of parent and daughter isotopes [Aud93] and abundances of parent nuclides δ [Bar91] are also presented in the table together with theoretical estimations of half-lives for comparison. For 0ν decay, the theoretical half-lives are given for $m_\nu = 1$ eV; in calculations [Ver83] the Majoron coupling constant $g = 5 \cdot 10^{-3}$. The results [Eng88] are given for $\alpha_1' = -390$ MeV·fm³. The generalized seniority calculations [Eng89] are given without monopole proton-neutron interaction; we use the phase space factors [Eng88] to calculate the values of $T_{1/2}$.

A	Mass number
Z	Atomic number
ΔM_A	Mass differences between parent and daughter atoms
δ	Abundance of parent nuclide
$2\beta^-$	Double electron decay
$2\beta^+$	Double positron decay
$\epsilon\beta^+$	Electron capture and β^+ decay

$K\beta^+$	Electron capture from K-shell and β^+ decay
2ε	Double electron capture
$2K$	Double electron capture from K-shell
2ν	Two neutrino mode of process
0ν	Neutrinoless mode of process
$0\nu M$	Neutrinoless mode with emission of Majoron
$0\nu MM$	Neutrinoless mode with double Majoron emission
g.s.-g.s.	Ground state - ground state 2β transition
g.s.- 2_1^+ , 0_1^+ , ...	2β transitions to excited levels of daughter nucleus

TABLE II. List of known 2β nuclides absent in a natural mixture of elements

Table II contains the list of 19 other known 2β nuclides [Led78] which are absent in a natural mixture of elements because of short half-life decays through other channels.

α	Alpha decay
sf	Spontaneous fission

EXPLANATION OF FIGURES

In the figures the data of the table I are reproduced in graphical form. Fig. T1 and T2 show the atomic mass differences and abundances of parent nuclides, Fig. T3-T5a give the positive results and limits on half-lives which have been reached in direct 2β decay experiments for 0ν , 2ν and $0\nu M$ transitions accordingly (for the transition to ground state of daughter nuclei only). Fig. T5b represents the results of indirect (geochemical and radiochemical) 2β decay experiments. For confidence levels of presented limits see table I.

TABLE I. Experimental values (or limits) and theoretical estimations of half-life for different 2β processes ($2\beta^-$; $2\beta^+$; $\epsilon\beta^+$; 2ϵ)

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confidence level	Reference and remark
$^{36}_{18}\text{Ar}-^{36}_{16}\text{S}$ 433.5(0.3) keV 0.337(0.003)%	Exper. 2ϵ Theor. 2ϵ			- -		
$^{40}_{20}\text{Ca}-^{40}_{18}\text{Ar}$ 193.78(0.29) keV 96.941(0.018)%	Exper. 2ϵ Theor. 2ϵ	g.s.-g.s.		- > $1.2 \cdot 10^{33}$		Qin84
$^{46}_{20}\text{Ca}-^{46}_{22}\text{Ti}$ 990.4(2.4) keV 0.004(0.003)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν	> $6.9 \cdot 10^{11}$		Fre52 ¹
		g.s.-g.s.	2ν	= $5.1 \cdot 10^{23}$		Hax84 ²
$^{48}_{20}\text{Ca}-^{48}_{22}\text{Ti}$ 4272(4) keV 0.187(0.004)%	Exper. $2\beta^-$	g.s.-g.s.	0ν	> $2.0 \cdot 10^{21}$	80%	Bar70 ³
				> $9.5 \cdot 10^{21}$	76%	Key91
			2ν	> $3.6 \cdot 10^{19}$		Bar70
			$0\nu\text{M}$	> $7.2 \cdot 10^{20}$	90%	Bar70 ⁴
		g.s.- 2^+_1	0ν	> $1.0 \cdot 10^{21}$	90%	Bar70 ⁴
		g.s.- 0^+_1	0ν	> $8.0 \cdot 10^{18}$	95%	Alb86
	Theor. $2\beta^-$	g.s.-g.s.	0ν	= $3.8 \cdot 10^{24}$		Doi83
			2ν	= $3.6 \cdot 10^{19}$		Doi83
				= $2.7 \cdot 10^{20}$		Ver83
				= $2.9 \cdot 10^{19}$		Hax84
				= $5.5 \cdot 10^{19}$		Cau90
		g.s.- 2^+_1	2ν	= $5.0 \cdot 10^{26}$		Hax84
		g.s.- 2^+_2	2ν	= $3.6 \cdot 10^{26}$		Hax84
$^{50}_{24}\text{Cr}-^{50}_{22}\text{Ti}$ 1171.3(1.2) keV 4.345(0.013)%	Exper. $\epsilon\beta^+$ Theor. $\epsilon\beta^+ + 2\epsilon$	g.s.-g.s.	$0\nu + 2\nu$	> $1.8 \cdot 10^{17}$ -	68%	Nor85
$^{54}_{26}\text{Fe}-^{54}_{24}\text{Cr}$ 680.1(0.6) keV 5.8(0.1)%	Exper. 2ϵ Theor. 2ϵ			- -		
$^{58}_{28}\text{Ni}-^{58}_{26}\text{Fe}$ 1925.9(0.7) keV 68.077(0.009)%	Exper. $\epsilon\beta^+$ $\epsilon\beta^+ + 2\epsilon$	g.s.-g.s.	$0\nu + 2\nu$	> $7.0 \cdot 10^{20}$	68%	Vas93
		g.s.- 2^+_1	$0\nu + 2\nu$	> $4.0 \cdot 10^{20}$	68%	Vas93
		g.s.- 2^+_1	$0\nu + 2\nu$	> $4.0 \cdot 10^{19}$	90%	Bel82

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confi- dence level	Referen- ce and remark
^{58}Ni (continue)	Theor. 2ε $\varepsilon\beta^+$	g.s.- 2_2^+	$0\nu + 2\nu$	$> 4.0 \cdot 10^{19}$	90%	Bel82
			0ν	$> 2.1 \cdot 10^{19}$	68%	Nor84
		g.s.-g.s.+ 2_1^+	0ν	$= 5.1 \cdot 10^{28}$		Ver83
			0ν	$= 1.1 \cdot 10^{29}$		Bal89
		2ν	0ν	$= 1.9 \cdot 10^{24}$		Ver83
			0ν	$= 5.5 \cdot 10^{25}$		Hir94a
		$0\nu\text{M}$	0ν	$= 7.6 \cdot 10^{23}$		Ver83
			0ν	$= 1.8 \cdot 10^{38}$		Ver83
		2ν	0ν	$= 2.8 \cdot 10^{25}$		Ver83
			0ν	$= 3.9 \cdot 10^{24}$		Hir94a
	2ε	$0\nu\text{M}$	0ν	$= 2.4 \cdot 10^{24}$		Ver83
			0ν	$= 2.4 \cdot 10^{24}$		Ver83
		$0\nu\text{M}$	0ν	$= 2.4 \cdot 10^{24}$		Ver83
			0ν	$= 2.4 \cdot 10^{24}$		Ver83
^{64}Zn - ^{64}Ni $1096.3(0.9)$ keV $48.6(0.3)\%$	Exper. $\varepsilon\beta^+$	g.s.-g.s.	$0\nu + 2\nu$	$> 2.3 \cdot 10^{18}$	68%	Nor85
	2ε		$0\nu + 2\nu$	$> 8.0 \cdot 10^{15}$		Ber53
	Theor. $\varepsilon\beta^+ + 2\varepsilon$			-		
^{70}Zn - ^{70}Ge $1001(3)$ keV $0.6(0.1)\%$	Exper. $2\beta^-$	g.s.-g.s.	0ν	$> 4.8 \cdot 10^{14}$		Fre52 ¹
	Theor. $2\beta^-$		0ν	$= 9.8 \cdot 10^{25}$		Sta90
		2ν	0ν	$= 4.5 \cdot 10^{21} - 3.6 \cdot 10^{24}$		Sta90
			0ν	$= 1.4 \cdot 10^{24}$		Hir94b
^{76}Ge - ^{76}Se $2038.7(0.5)$ keV $2038.58(0.31)$ keV [Hyk93] $7.44(0.02)\%$	Exper. $2\beta^-$	g.s.-g.s.	0ν	$> 1.9 \cdot 10^{24}$	90%	Kla93a
			2ν	$= (1.4 \pm 0.1) \cdot 10^{21}$		Bal94
			0ν	$= (9.0 \pm 1.0) \cdot 10^{20}$	68%	Vas90a
			0ν	$= 1.1^{+0.6}_{-0.3} \cdot 10^{21}$	95%	Mil90
		g.s.- 2_1^+	0ν	$= 8.4^{+1.0}_{-0.8} \cdot 10^{20}$	95%	Bro93
			$0\nu\text{M}$	$> 3.9 \cdot 10^{22}$	90%	Kla93a
			0ν	$> 8.2 \cdot 10^{23}$	90%	Mai94
			$0\nu + 2\nu$	$> 3.7 \cdot 10^{20}$	90%	Bec92
		g.s.- 0_1^+	0ν	$> 3.0 \cdot 10^{21}$	90%	Bar92
			0ν	$> 2.0 \cdot 10^{22}$	68%	Bus90
			$0\nu + 2\nu$	$> 3.7 \cdot 10^{20}$	90%	Bec92
			0ν	$> 4.1 \cdot 10^{21}$	90%	Bar92
	Theor. $2\beta^-$	g.s.- 2_2^+	$0\nu + 2\nu$	$> 2.4 \cdot 10^{20}$	90%	Bec92
			0ν	$> 3.3 \cdot 10^{21}$	90%	Bar92
			0ν	$= 9.4 \cdot 10^{24}$		Doi83
			0ν	$= 2.7 \cdot 10^{25}$		Eng88 ⁵
		g.s.-g.s.	0ν	$= 4.1 \cdot 10^{24}$		Eng89 ⁶
			0ν	$= 2.3 \cdot 10^{24}$		Sta90
			0ν	$= 2.3 \cdot 10^{24}$		Sta90
			0ν	$= 2.3 \cdot 10^{24}$		Sta90
		g.s.-g.s.	0ν	$= 2.3 \cdot 10^{24}$		Sta90
			0ν	$= 2.3 \cdot 10^{24}$		Sta90
			0ν	$= 2.3 \cdot 10^{24}$		Sta90
			0ν	$= 2.3 \cdot 10^{24}$		Sta90

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei	Half-life, years	Confidence level	Reference and remark
^{76}Ge (continue)					
			$= 2.2 \cdot 10^{24}$		Tom91
			$= 2.8 \cdot 10^{24}$		Hir94b
		2ν	$= 2.3 \cdot 10^{21}$		Doi83
			$= 5.0 \cdot 10^{20} - 6.3 \cdot 10^{21}$		Vog86
			$= 1.3 \cdot 10^{21}$		Eng88
			$= 7.0 \cdot 10^{19} - 3.0 \cdot 10^{21}$		Sta90
			$= 2.6 \cdot 10^{20}$		Hir94b
			$= 1.3 \cdot 10^{21}$		Dhi94
		g.s.- 2_1^+	2ν	$= 1.2 \cdot 10^{30}$	Hax84
			$= 5.8 \cdot 10^{23}$		Dhi94
$^{74}\text{Se}-^{74}\text{Ge}$	Exper. $\varepsilon\beta^+ + 2\varepsilon$		-		
1209.4(0.6) keV	Theor. $\varepsilon\beta^+ + 2\varepsilon$		-		
1209.53(0.48) keV [Hyk93]					
0.89(0.02)%					
$^{80}\text{Se}-^{80}\text{Kr}$	Exper. $2\beta^-$		-		
134(4) keV	Theor. $2\beta^-$	g.s.-g.s.	0ν	$= 1.1 \cdot 10^{27}$	Sta90
49.61(0.10)%			2ν	$= 7.5 \cdot 10^{28} - 1.9 \cdot 10^{30}$	Sta90
				$= 2.7 \cdot 10^{29}$	Hir94b
$^{82}\text{Se}-^{82}\text{Kr}$	Exper. $2\beta^-$	all modes		$= (1.4 \pm 0.2) \cdot 10^{20}$	Kir69 ⁷
2995.0(2.0) keV				$= (1.7 \pm 0.3) \cdot 10^{20}$	Kir69 ⁷
2995.8(1.5) keV [Nxu93]				$= (1.3 \pm 0.3) \cdot 10^{20}$	Kir69 ⁷
8.73(0.06)%				$= (1.4 \pm 0.7) \cdot 10^{20}$	Kir69 ⁷
				$= (1.3 \pm 0.4) \cdot 10^{20}$	Kir69 ⁷
				$= (2.8 \pm 0.9) \cdot 10^{20}$	Sri73 ⁷
				$= (1.5 \pm 0.2) \cdot 10^{20}$	Kir83b ⁷
				$= (2.1 \pm 0.3) \cdot 10^{20}$	Kir83b ⁷
				$= 9.7_{-4.5}^{+3.6} \cdot 10^{19}$	Mar85 ⁷
				$= (1.0 \pm 0.4) \cdot 10^{20}$	Man86 ^{7*}
				$= (1.3 \pm 0.1) \cdot 10^{20}$	Kir86 ^{7*}
				$< (1.7 \pm 0.2) \cdot 10^{20}$	Lin86 ⁷
				$= 1.0_{-0.4}^{+0.3} \cdot 10^{20}$	Mur87 ⁷
				$= (1.2 \pm 0.1) \cdot 10^{20}$	Lin88a ⁷
				$= 1.0 \cdot 10^{20}$	Man91 ^{7*}
		g.s.-g.s.	0ν	$> 2.7 \cdot 10^{22}$	68% Ell92
			2ν	$= 1.1_{-0.1}^{+0.3} \cdot 10^{20}$	68% Ell92
			$0\nu\text{M}$	$> 1.6 \cdot 10^{21}$	68% Moe88

Transition (A,Z)-(A,Z±2); $\Delta M_A; \delta$	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confi- dence level	Referen- ce and remark
$^{82}_{34}\text{Se}$ (continue)	Theor. $2\beta^-$	g.s.- 2_1^+ g.s.-g.s.	0ν	$> 3.4 \cdot 10^{21}$	68%	Moe88
			0ν	$= 3.2 \cdot 10^{24}$		Doi83
				$= 1.1 \cdot 10^{25}$		Eng88 ⁵
				$= 1.7 \cdot 10^{24}$		Eng89 ⁶
				$= 6.0 \cdot 10^{23}$		Sta90
				$= 6.0 \cdot 10^{23}$		Tom91
				$= 7.0 \cdot 10^{23}$		Hir94b
			2ν	$= 1.5 \cdot 10^{20}$		Doi83
				$= 5.5 \cdot 10^{19} - 6.3 \cdot 10^{20}$		Vog86
				$= 1.2 \cdot 10^{20}$		Eng88
				$= 2.9 \cdot 10^{18} - 5.9 \cdot 10^{21}$		Sta90
				$= 8.5 \cdot 10^{19}$		Hir94b
				$= 1.5 \cdot 10^{20}$		Dhi94
		g.s.- 2_1^+	2ν	$= 5.5 \cdot 10^{21}$		Dhi94
$^{78}_{36}\text{Kr}-^{78}_{34}\text{Se}$ 2867(7) keV 0.35(0.02)%	Exper. $2\beta^+$ $K\beta^+$	g.s.-g.s.	$0\nu + 2\nu$	$> 2.0 \cdot 10^{21}$	68%	Sae94
		g.s.-g.s.	0ν	$> 5.1 \cdot 10^{21}$	68%	Sae94
			2ν	$> 1.1 \cdot 10^{20}$	68%	Sae94
	Theor. $2\beta^+$	g.s.-g.s.	0ν	$= 1.6 \cdot 10^{27}$		Hir94a
				$= 1.7 \cdot 10^{28}$		Bal89
			2ν	$= 2.3 \cdot 10^{26}$		Hir94a
	$\epsilon\beta^+$	g.s.-g.s.		$= 3.7 \cdot 10^{25}$		Bal89
			0ν	$= 6.5 \cdot 10^{26}$		Hir94a
				$= 4.2 \cdot 10^{28}$		Bal89
			2ν	$= 5.3 \cdot 10^{22}$		Hir94a
	2ϵ	g.s.-g.s.		$= 2.2 \cdot 10^{23}$		Bal89
			2ν	$= 3.7 \cdot 10^{22}$		Hir94a
				$= 1.4 \cdot 10^{23}$		Bal89
$^{86}_{36}\text{Kr}-^{86}_{38}\text{Sr}$ 1258(5) keV 17.3(0.2)%	Exper. $2\beta^-$			-		
	Theor. $2\beta^-$	g.s.-g.s.	0ν	$= 2.8 \cdot 10^{25}$		Sta90
			2ν	$= 1.6 \cdot 10^{22} - 2.2 \cdot 10^{24}$		Sta90
				$= 3.4 \cdot 10^{23}$		Hir94b
$^{84}_{35}\text{Sr}-^{84}_{36}\text{Kr}$ 1787(4) keV 0.56(0.01)%	Exper. $\epsilon\beta^+$	g.s.-g.s.	0ν	$> 7.3 \cdot 10^{13}$		Fre52 ¹
	Theor. $K\beta^+$	g.s.-g.s.	0ν	$= 9.7 \cdot 10^{28}$		Bal89
			2ν	$= 4.3 \cdot 10^{25}$		Bal89
			2ν	$= 6.9 \cdot 10^{23}$		Bal89
	2K	g.s.-g.s.	2ν			Bal89

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confi- dence level	Referen- ce and remark
$^{94}_{40}\text{Zr}-^{94}_{42}\text{Mo}$ 1143.6(2.0) keV 17.38(0.04)%	Exper. $2\beta^-$	g.s.-g.s.	0ν	$> 1.5 \cdot 10^{16}$	68%	Bar90b
			2ν	$> 6.0 \cdot 10^{15}$	68%	Bar90b
			$0\nu\text{M}$	$> 1.5 \cdot 10^{16}$	68%	Bar90b
	Theor. $2\beta^-$	g.s.- 2_1^+	$0\nu + 2\nu$	$> 1.3 \cdot 10^{19}$	68%	Nor87
			0ν	$= 4.0 \cdot 10^{25}$		Sta90
		g.s.-g.s.	2ν	$= (1.7 - 7.4) \cdot 10^{22}$		Sta90
				$= 1.7 \cdot 10^{24}$		Hir94b
$^{96}_{40}\text{Zr}-^{96}_{42}\text{Mo}$ 3350.3(2.9) keV 2.80(0.02)%	Exper. $2\beta^-$	all modes		$= (3.9 \pm 0.9) \cdot 10^{19}$	68%	Kaw93 ^{7,8}
		g.s.-g.s.	0ν	$> 3.0 \cdot 10^{19}$	68%	Zde81
			2ν	$> 1.0 \cdot 10^{17}$	68%	Bar90b
			$0\nu\text{M}$	$> 1.3 \cdot 10^{17}$	68%	Bar90b
	Theor. $2\beta^-$	g.s.- 2_1^+	$0\nu + 2\nu$	$> 4.1 \cdot 10^{19}$	90%	Arp94
			$0\nu + 2\nu$	$> 3.3 \cdot 10^{19}$	90%	Arp94
		g.s.- 0_1^+	$0\nu + 2\nu$	$> 3.3 \cdot 10^{19}$	90%	Arp94
			$0\nu + 2\nu$	$> 2.4 \cdot 10^{19}$	90%	Arp94
		g.s.- 2_2^+	$0\nu + 2\nu$	$> 2.4 \cdot 10^{19}$	90%	Arp94
			$0\nu + 2\nu$	$> 3.1 \cdot 10^{19}$	90%	Arp94
		g.s.- 2_3^+	$0\nu + 2\nu$	$> 3.1 \cdot 10^{19}$	90%	Arp94
			$0\nu + 2\nu$	$> 1.8 \cdot 10^{18}$	68%	Nor87
		g.s.- 4_1^+	$0\nu + 2\nu$	$> 1.8 \cdot 10^{18}$	68%	Nor87
			0ν	$= 7.8 \cdot 10^{24}$		Eng88
		g.s.-g.s.	0ν	$= 5.3 \cdot 10^{23}$		Sta90
			2ν	$= 3.2 \cdot 10^{17} - 8.5 \cdot 10^{18}$		Vog86
				$= 8.5 \cdot 10^{18}$		Eng88
				$= 1.9 \cdot 10^{18} - 1.9 \cdot 10^{19}$		Sta90
				$= 2.0 \cdot 10^{20}$		Hir94b
$^{92}_{42}\text{Mo}-^{92}_{40}\text{Zr}$ 1650(4) keV 14.84(0.04)%	Exper. $\epsilon\beta^+$	g.s.-g.s.	0ν	$> 2.7 \cdot 10^{18}$	68%	Ell87b
			$0\nu + 2\nu$	$> 3.0 \cdot 10^{17}$	68%	Nor85
			$0\nu + 2\nu$	$> 3.0 \cdot 10^{18}$	90%	Bel82
	$\epsilon\beta^+ + 2\epsilon$	g.s.- 2_1^+	$0\nu + 2\nu$	$> 3.0 \cdot 10^{18}$	90%	Bel82
			$0\nu + 2\nu$	$> 4.0 \cdot 10^{18}$	90%	Bel82
			$0\nu + 2\nu$	$> 6.0 \cdot 10^{18}$	90%	Bel82
	Theor. $\epsilon\beta^+$	g.s.- 0_1^+	$0\nu + 2\nu$	$> 6.0 \cdot 10^{18}$	90%	Bel82
			0ν	$= 4.1 \cdot 10^{30}$		Ver83
				$= 1.3 \cdot 10^{28}$		Bal89
		2ν		$= 1.4 \cdot 10^{25}$		Ver83
				$= 6.5 \cdot 10^{26}$		Bal89
			$0\nu\text{M}$	$= 9.6 \cdot 10^{25}$		Ver83
		2ϵ	0ν	$= 2.5 \cdot 10^{39}$		Ver83
			2ν	$= 5.7 \cdot 10^{24}$		Ver83
				$= 2.8 \cdot 10^{24}$		Bal89
			$0\nu\text{M}$	$= 9.2 \cdot 10^{24}$		Ver83

Transition (A,Z)-(A,Z±2); $\Delta M_A; \delta$	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confi- dence level	Referen- ce and remark
$^{98}\text{Mo}-^{98}\text{Ru}$ 112(6) keV 24.13(0.07)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν	$> 1.0 \cdot 10^{14}$		Fre52 ¹
			0ν	$= 1.1 \cdot 10^{27}$		Sta90
			2ν	$= 3.4 \cdot 10^{29} - 3.6 \cdot 10^{30}$		Sta90
				$= 6.2 \cdot 10^{30}$		Hir94b
$^{100}\text{Mo}-^{100}\text{Ru}$ 3034(6) keV 9.63(0.03)%	Exper. $2\beta^-$	g.s.-g.s.	0ν	$> 4.4 \cdot 10^{22}$	68%	Als93
			2ν	$= 3.3^{+2.0}_{-1.0} \cdot 10^{18}$	90%	Vas90b
				$= 1.2^{+0.5}_{-0.3} \cdot 10^{19}$	90%	Eji91
				$= 1.2^{+0.3}_{-0.1} \cdot 10^{19}$	68%	Ell91
				$= (9.5 \pm 1.0) \cdot 10^{18}$		Das94a
			$0\nu\text{M}$	$> 7.9 \cdot 10^{20}$	68%	Tan93
			$0\nu\text{MM}$	$> 5.3 \cdot 10^{19}$	68%	Tan93
			$0\nu + 2\nu$	$> 2.3 \cdot 10^{21}$	90%	Bar93
			$0\nu + 2\nu$	$> 1.2 \cdot 10^{21}$	90%	Blu92
				$= 6.3^{+2.1}_{-1.2} \cdot 10^{20}$		Avi94
			0ν	$> 6.3 \cdot 10^{20}$		Kud92
			2ν	$> 5.1 \cdot 10^{19}$		Kud92
			$0\nu + 2\nu$	$> 2.5 \cdot 10^{21}$	90%	Bar93
			$0\nu + 2\nu$	$> 1.5 \cdot 10^{21}$	90%	Bar93
			0ν	$= 1.9 \cdot 10^{24}$		Eng88
				$= 1.3 \cdot 10^{24}$		Sta90
				$= 2.6 \cdot 10^{23}$		Tom91
			2ν	$= 8.0 \cdot 10^{17} - 3.7 \cdot 10^{19}$		Vog86
				$= 6.0 \cdot 10^{18}$		Eng88
				$= 1.3 \cdot 10^{17} - 1.1 \cdot 10^{20}$		Sta90
				$= 3.6 \cdot 10^{19}$		Hir94b
				$= (2.9 - 7.7) \cdot 10^{18}$		Suh94
			2ν	$= (5.3 - 7.5) \cdot 10^{20}$		Suh94
			2ν	$= (6.7 - 7.0) \cdot 10^{19}$		Suh94
			2ν	$= (1.9 - 2.1) \cdot 10^{23}$		Suh94
$^{96}\text{Ru}-^{96}\text{Mo}$ 2725(8) keV 5.52(0.06)%	Exper. $2\beta^+$ $\epsilon\beta^+$	g.s.-g.s.	$0\nu + 2\nu$	$> 3.1 \cdot 10^{16}$	68%	Nor85
			$0\nu + 2\nu$	$> 6.7 \cdot 10^{16}$	68%	Nor85
			$0\nu + 2\nu$	$> 6.0 \cdot 10^{16}$	68%	Nor85
			$0\nu + 2\nu$	$> 4.5 \cdot 10^{16}$	68%	Nor85
			$0\nu + 2\nu$	$> 5.5 \cdot 10^{16}$	68%	Nor85
			$0\nu + 2\nu$	$> 5.3 \cdot 10^{16}$	68%	Nor85
			$0\nu + 2\nu$	$> 5.3 \cdot 10^{16}$	68%	Nor85
			0ν	$= 5.1 \cdot 10^{29}$		Ver83

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei	Half-life, years	Confidence level	Reference and remark
⁹⁶ Ru (<i>continue</i>)					
			$= 8.7 \cdot 10^{27}$		Hir94a
		2ν	$= 1.6 \cdot 10^{28}$		Ver83
			$= 5.8 \cdot 10^{26}$		Hir94a
	$\epsilon\beta^+$	$g.s.-g.s.$	$0\nu M$	$= 1.1 \cdot 10^{26}$	Ver83
			0ν	$= 2.3 \cdot 10^{29}$	Ver83
				$= 7.5 \cdot 10^{26}$	Hir94a
			2ν	$= 2.6 \cdot 10^{24}$	Ver83
				$= 1.2 \cdot 10^{22}$	Hir94a
		$g.s.-0_1^+$	$0\nu M$	$= 6.0 \cdot 10^{24}$	Ver83
			0ν	$= 2.0 \cdot 10^{30}$	Ver83
			2ν	$= 3.8 \cdot 10^{29}$	Ver83
			$0\nu M$	$= 9.2 \cdot 10^{25}$	Ver83
	2ϵ	$g.s.-g.s.$	0ν	$= 2.8 \cdot 10^{34}$	Ver83
			2ν	$= 6.5 \cdot 10^{24}$	Ver83
				$= 2.1 \cdot 10^{21}$	Hir94a
		$g.s.-0_1^+$	$0\nu M$	$= 3.2 \cdot 10^{24}$	Ver83
			2ν	$= 5.2 \cdot 10^{27}$	Ver83
			$0\nu M$	$= 4.5 \cdot 10^{24}$	Ver83
¹⁰⁴ Ru- ¹⁰⁴ Pd 1300(4) keV 18.7(0.2)%	Exper. $2\beta^-$ Theor. $2\beta^-$	$g.s.-g.s.$	0ν	- $= 4.2 \cdot 10^{24}$	Sta90
			2ν	$= 3.2 \cdot 10^{20} - \infty$ $= 3.1 \cdot 10^{22}$	Sta90 Hir94b
¹⁰² Pd- ¹⁰² Ru 1172.1(2.6) keV 1.02(0.01)%	Exper. $\epsilon\beta^+ + 2\epsilon$ Theor. $\epsilon\beta^+ + 2\epsilon$			- -	
¹¹⁰ Pd- ¹¹⁰ Cd 2000(11) keV 11.72(0.09)%	Exper. $2\beta^-$ Theor. $2\beta^-$	all modes $g.s.-g.s.$	2ν	$> 6.0 \cdot 10^{17}$ $> 6.0 \cdot 10^{16}$	Win52 Win52 ⁹
			$0\nu M$	$> 6.0 \cdot 10^{16}$	Win52 ⁹
		$g.s.-g.s.$	0ν	$= 2.0 \cdot 10^{24}$	Sta90
			2ν	$= 8.5 \cdot 10^{18} - \infty$ $= 1.2 \cdot 10^{21}$	Sta90 Hir94b
¹⁰⁶ Cd- ¹⁰⁶ Pd 2771(8) keV 1.25(0.04)%	Exper. $2\beta^+$	$g.s.-g.s.$	0ν	$> 1.4 \cdot 10^{18}$	90% Dan94
			$0\nu + 2\nu$	$> 2.6 \cdot 10^{17}$	68% Nor84
		$g.s.-2_1^+$	0ν	$> 5.1 \cdot 10^{17}$	90% Dan94
			$0\nu + 2\nu$	$> 2.2 \cdot 10^{17}$	68% Nor84

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confi- dence level	Referen- ce and remark
$^{106}_{48}\text{Cd}$ (<i>continue</i>)	$\epsilon\beta^+$	g.s.-g.s.	0ν	$> 1.1 \cdot 10^{19}$	90%	Dan94
			$0\nu + 2\nu$	$> 5.7 \cdot 10^{17}$	68%	Nor84
		g.s.- 2^+_1	0ν	$> 4.0 \cdot 10^{18}$	90%	Dan94
			$0\nu + 2\nu$	$> 4.9 \cdot 10^{17}$	68%	Nor84
		g.s.- 2^+_2	0ν	$> 3.0 \cdot 10^{18}$	90%	Dan94
			0ν	$> 1.5 \cdot 10^{17}$	68%	Nor84
	2 ϵ 2K Theor. $2\beta^+$	g.s.-g.s.+ 2^+_1	0ν	$> 5.8 \cdot 10^{17}$	90%	Dan94
			2ν	$> 5.8 \cdot 10^{17}$		
		g.s.-g.s.	0ν	$= 4.8 \cdot 10^{27}$		Hir94a
			2ν	$= 3.9 \cdot 10^{28}$		Bal89
		g.s.-g.s.	0ν	$= 4.2 \cdot 10^{26}$		Hir94a
			2ν	$= 6.1 \cdot 10^{26}$		Bal89
	$\epsilon\beta^+$	g.s.-g.s.	0ν	$= 3.4 \cdot 10^{26}$		Hir94a
			2ν	$= 2.2 \cdot 10^{28}$		Bal89
		g.s.-g.s.	0ν	$= 4.1 \cdot 10^{21}$		Hir94a
			2ν	$= 5.2 \cdot 10^{23}$		Bal89
		g.s.-g.s.	0ν	$= 8.7 \cdot 10^{20}$		Hir94a
			2ν	$= 7.5 \cdot 10^{22}$		Bal89
$^{108}_{48}\text{Cd}-^{108}_{46}\text{Pd}$ 269(6) keV 0.89(0.02)%	Exper. 2 ϵ	g.s.-g.s.	0ν	$> 3.3 \cdot 10^{16}$	90%	Dan94
	2K		2ν	$> 4.1 \cdot 10^{17}$	90%	Dan94
	Theor. 2 ϵ			-		
$^{114}_{48}\text{Cd}-^{114}_{50}\text{Sn}$ 536(3) keV 28.73(0.28)%	Exper. $2\beta^-$	g.s.-g.s.	0ν	$> 2.0 \cdot 10^{20}$	90%	Dan94
			2ν	$> 9.2 \cdot 10^{16}$	99%	Dan94
	Theor. $2\beta^-$	g.s.-g.s.	0ν	$= 5.1 \cdot 10^{25}$		Sta90
			2ν	$= 7.3 \cdot 10^{23} - 1.8 \cdot 10^{24}$		Sta90
$^{116}_{48}\text{Cd}-^{116}_{50}\text{Sn}$ 2804(4) keV 7.49(0.12)%	Exper. $2\beta^-$	g.s.-g.s.	0ν	$> 2.9 \cdot 10^{22}$	90%	Dan94
			2ν	$> 1.8 \cdot 10^{19}$	99%	Dan94
				$= 2.7^{+1.0}_{-0.7} \cdot 10^{19}$	68%	Dan94
				$= 2.6^{+0.9}_{-0.5} \cdot 10^{19}$	68%	Kum94
				$= 3.6^{+0.7}_{-0.6} \cdot 10^{19}$		Das94b ¹⁰
			$0\nu\text{M}$	$> 1.0 \cdot 10^{21}$	90%	Dan94
		g.s.- 2^+_1	0ν	$> 4.4 \cdot 10^{21}$	90%	Dan94
			$0\nu + 2\nu$	$> 2.4 \cdot 10^{21}$	90%	Pie94
			$0\nu + 2\nu$	$> 2.1 \cdot 10^{21}$	90%	Pie94
		g.s.- 0^+_1	$0\nu + 2\nu$	$> 2.1 \cdot 10^{21}$	90%	Pie94
			$0\nu + 2\nu$	$> 2.1 \cdot 10^{21}$	90%	Pie94
		g.s.- 0^+_2	$0\nu + 2\nu$	$> 2.1 \cdot 10^{21}$	90%	Pie94
			$0\nu + 2\nu$	$> 1.7 \cdot 10^{20}$	68%	Bar90a

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei	Half-life, years	Confi- dence level	Referen- ce and remark
$^{116}_{48}\text{Cd}$ (<i>continue</i>)					
	Theor. $2\beta^-$	g.s.- 2_3^+ g.s.-g.s.	$0\nu + 2\nu > 1.0 \cdot 10^{20}$ $0\nu = 4.9 \cdot 10^{23}$ $= 5.8 \cdot 10^{23}$	68%	Bar90a Sta90 Hir94b
			$2\nu = 7.5 \cdot 10^{19} - 1.9 \cdot 10^{21}$ $= 2.9 \cdot 10^{18} - 1.2 \cdot 10^{20}$ $= 1.5 \cdot 10^{20}$ $= 1.2 \cdot 10^{19}$		Vog86 Sta90 Hir94b Pie94
		g.s.- 2_1^+ g.s.- 0_2^+	$2\nu = 2.0 \cdot 10^{23}$ $2\nu = 1.6 \cdot 10^{22}$		Pie94 Pie94
$^{112}_{50}\text{Sn}-^{112}_{48}\text{Cd}$ 1923(4) keV 0.97(0.01)%	Exper. $\epsilon\beta^+$ Theor. $K\beta^+$	g.s.-g.s. g.s.-g.s.	$0\nu > 6.1 \cdot 10^{13}$ $0\nu = 1.7 \cdot 10^{29}$		Fre52 ¹ Bal89
			$2\nu = 1.2 \cdot 10^{26}$		Bal89
	2K	g.s.-g.s.	$2\nu = 1.2 \cdot 10^{24}$ $= 1.0 \cdot 10^{25}$		Bal89 Ber83
		g.s.- 0_3^+	$0\nu > 1.0 \cdot 10^{25}$		Ber83
$^{122}_{50}\text{Sn}-^{122}_{52}\text{Te}$ 359(3) keV 4.63(0.03)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s. g.s.-g.s.	$0\nu > 5.8 \cdot 10^{13}$ $0\nu = 1.3 \cdot 10^{26}$ $2\nu = 4.9 \cdot 10^{25} - 1.6 \cdot 10^{28}$ $= 1.3 \cdot 10^{26}$		Fre52 ¹ Sta90 Sta90 Hir94b
$^{124}_{50}\text{Sn}-^{124}_{52}\text{Te}$ 2287.5(1.5) keV 5.79(0.05)%	Exper. $2\beta^-$		$0\nu > 2.4 \cdot 10^{17}$	95%	Kal52
		g.s.-g.s.	$2\nu > 1.0 \cdot 10^{17}$		Kal52 ¹¹
			$0\nu\text{M} > 1.0 \cdot 10^{17}$		Kal52 ¹¹
		g.s.- 2_1^+	$0\nu + 2\nu > 4.1 \cdot 10^{19}$	95%	Smo85
		g.s.- 2_2^+	$0\nu + 2\nu > 2.0 \cdot 10^{18}$	68%	Nor87
		g.s.- 0_1^+	$0\nu + 2\nu > 2.2 \cdot 10^{18}$	68%	Nor87
	Theor. $2\beta^-$	g.s.-g.s.	$0\nu = 1.4 \cdot 10^{24}$ $2\nu = 3.6 \cdot 10^{19} - 1.6 \cdot 10^{22}$ $= 1.5 \cdot 10^{21}$		Sta90 Sta90 Hir94b
$^{120}_{52}\text{Te}-^{120}_{50}\text{Sn}$ 1703(11) keV 0.096(0.002)%	Exper. $\epsilon\beta^+$ Theor. $\epsilon\beta^+ + 2\epsilon$	g.s.-g.s.	$0\nu > 4.2 \cdot 10^{12}$ -		Fre52 ¹
$^{128}_{52}\text{Te}-^{128}_{54}\text{Xe}$ 867.2(1.5) keV 867.2(1.0) keV [Dyc90]	Exper. $2\beta^-$	all modes	$= (1.5 \pm 0.2) \cdot 10^{24}$ $> 8.0 \cdot 10^{24}$ $= (1.4 \pm 0.4) \cdot 10^{24}$	95%	Hen75 ⁷ Kir83a ⁷ Man86 ⁷⁻

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei	Half-life, years	Confidence level	Reference and remark
$^{128}_{52}\text{Te}$ (continue) 31.69(0.01)%			$> 5.0 \cdot 10^{24}$ $= (1.8 \pm 0.7) \cdot 10^{24}$ $= 2.0 \cdot 10^{24}$ $= (7.7 \pm 0.4) \cdot 10^{24}$ $> 1.3 \cdot 10^{19}$ $> 4.7 \cdot 10^{21}$ $= 6.0 \cdot 10^{26}$ $= 2.5 \cdot 10^{25}$ $= 9.1 \cdot 10^{24}$ $= 7.8 \cdot 10^{24}$ $= 9.5 \cdot 10^{24}$ $= 1.3 \cdot 10^{25}$ $= 1.3 \cdot 10^{25}$ $= (1.0 - 8.2) \cdot 10^{23}$ $= 5.5 \cdot 10^{23}$ $= 2.0 \cdot 10^{22} - 3.4 \cdot 10^{27}$ $= 2.1 \cdot 10^{23}$	68% 90% 68%	Kir86 ^{7*} Lin88b ⁷ Man91 ^{7*} Ber92 ⁷ Mit88 Bel87 Doi83 Eng88 ⁵ Eng89 ⁶ Sta90 Tom91 Hir94b Doi83 Vog86 Eng88 Sta90 Hir94b
$^{130}_{52}\text{Te}$ - $^{130}_{54}\text{Xe}$ 2528.1(2.1) keV 2528.8(1.3) keV [Dyc90] 33.80(0.01)%	Exper. $2\beta^-$	all modes	$= 1.4 \cdot 10^{21}$ $= (8.2 \pm 0.6) \cdot 10^{20}$ $= 6.2 \cdot 10^{20}$ $= (3.0 \pm 0.4) \cdot 10^{20}$ $= (2.2 \pm 0.7) \cdot 10^{21}$ $= (2.0 \pm 0.3) \cdot 10^{21}$ $= (2.8 \pm 0.3) \cdot 10^{21}$ $= (2.1 \pm 0.3) \cdot 10^{21}$ $= (2.2 \pm 0.3) \cdot 10^{21}$ $= (3.1 \pm 0.4) \cdot 10^{21}$ $= (2.7 \pm 0.3) \cdot 10^{21}$ $= (1.1 \pm 0.1) \cdot 10^{21}$ $= (8.9 \pm 1.1) \cdot 10^{20}$ $= (2.6 \pm 0.3) \cdot 10^{21}$ $= (2.6 \pm 0.1) \cdot 10^{21}$ $= (7.0 \pm 2.0) \cdot 10^{20}$ $= (1.5 - 2.8) \cdot 10^{21}$ $= (1.0 \pm 0.3) \cdot 10^{21}$ $= (2.0 \pm 0.3) \cdot 10^{21}$ $= (1.9 \pm 0.3) \cdot 10^{21}$ $= (1.2 \pm 0.2) \cdot 10^{21}$		Ing50 ⁷ Tak66 ⁷ Kir67 ⁷ Ger68 ⁷ Kir68 ⁷ Ale69 ⁷ Sri72a ⁷ Sri72b ⁷ Sri72b ⁷ Sri72b ⁷ Sri72b ⁷ Sri72b ⁷ Hen75 ⁷ Hen75 ⁷ Kir83a ⁷ Kir83b ^{7*} Man86 ^{7*} Kir86 ^{7*} Ric86 ⁷ Ric86 ⁷ Ric86 ⁷ Ric86 ⁷

Transition (A,Z)-(A,Z±2); ΔM _A ; δ	Kind of the result	Channel and mode of the 2β-process; levels of nuclei		Half-life, years	Confidence level	Referen- ce and remark
¹³⁰ ₅₂ Te (continue)				= (2.3 ± 0.1) · 10 ²¹		Ric86 ⁷
				= (1.0 ± 0.3) · 10 ²¹		Ric86 ^{7*}
				< (1.3 ± 0.1) · 10 ²¹		Lin86 ⁷
				= (7.5 ± 0.3) · 10 ²⁰		Lin88a ⁷
				= 8.0 · 10 ²⁰		Man91 ^{7*}
				= (2.7 ± 0.1) · 10 ²¹	68%	Ber92 ⁷
		g.s.-g.s.	0ν	> 1.8 · 10 ²²	90%	Ale94b
			2ν	> 1.0 · 10 ¹⁶		Zde80b ¹²
			0νM	> 1.0 · 10 ¹⁶		Zde80b ¹²
		g.s.-2 ₁ ⁺	0ν + 2ν	> 4.5 · 10 ²¹	68%	Bel87
	Theor. 2β ⁻	g.s.-g.s.	0ν	= 2.5 · 10 ²⁵		Doi83
				= 1.3 · 10 ²⁴		Eng88 ⁵
				= 4.5 · 10 ²³		Eng89 ⁶
				= 4.9 · 10 ²³		Sta90
				= 5.2 · 10 ²³		Tom91
				= 7.2 · 10 ²³		Hir94b
			2ν	= 2.6 · 10 ²¹		Doi83
				= 4.4 · 10 ¹⁹ - 2.5 · 10 ²⁰		Vog86
				= 2.2 · 10 ²⁰		Eng88
				= 6.9 · 10 ¹⁸ - 1.7 · 10 ²⁴		Sta90
				= 7.9 · 10 ¹⁹		Hir94b
¹²⁴ ₅₄ Xe- ¹²⁴ ₅₂ Te						
2865.9(2.2) keV	Exper. 2β ⁺	g.s.-g.s.	0ν	> 4.2 · 10 ¹⁷	68%	Bar89b
0.10(0.01)%			2ν	> 2.0 · 10 ¹⁴		Bar89b
	Kβ ⁺	g.s.-g.s.	0ν	> 1.2 · 10 ¹⁸	68%	Bar89b
			2ν	> 4.8 · 10 ¹⁶	68%	Bar89b
	Kβ ⁺	g.s.-2 ₁ ⁺	0ν	> 4.2 · 10 ¹⁷	68%	Bar89b
	Theor. 2β ⁺	g.s.-g.s.	0ν	= 3.0 · 10 ²⁷		Hir94a
				= 2.7 · 10 ²⁸		Bal89
			2ν	= 1.4 · 10 ²⁷		Hir94a
				= 1.6 · 10 ²⁵		Bal89
	εβ ⁺	g.s.-g.s.	0ν	= 1.6 · 10 ²⁶		Hir94a
				= 1.8 · 10 ²⁸		Bal89
			2ν	= 3.0 · 10 ²²		Hir94a
				= 4.3 · 10 ²²		Bal89
	2ε	g.s.-g.s.	2ν	= 2.9 · 10 ²¹		Hir94a
				= 6.4 · 10 ²¹		Bal89

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confidence level	Reference and remark
$^{126}_{54}\text{Xe}-^{126}_{52}\text{Te}$ 897(6) keV 0.09(0.01)%	Exper. 2ε Theor. 2ε			— —		
$^{134}_{54}\text{Xe}-^{134}_{56}\text{Ba}$ 830(3) keV 10.4(0.2)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν 2ν	$> 8.2 \cdot 10^{19}$ $> 1.1 \cdot 10^{16}$	68%	Bar89b Bar89b
		g.s.-g.s.	0ν 2ν	$= 1.7 \cdot 10^{25}$ $= 5.4 \cdot 10^{22} - 1.9 \cdot 10^{25}$ $= 2.7 \cdot 10^{23}$		Sta90 Sta90 Hir94b
$^{136}_{54}\text{Xe}-^{136}_{56}\text{Ba}$ 2467(7) keV 8.9(0.1)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	$0\nu(m_\nu)$ $0\nu(\text{rhc})$ 2ν $0\nu\text{M}$	$> 3.4 \cdot 10^{23}$ $> 2.6 \cdot 10^{23}$ $> 2.1 \cdot 10^{20}$ $> 4.9 \cdot 10^{21}$	90% 90% 90% 90%	Vui93 Vui93 Vui93 Vui93
		g.s.- 2_1^+ g.s.-g.s.	0ν	$> 6.5 \cdot 10^{21}$ $= 6.3 \cdot 10^{24}$ $= 2.2 \cdot 10^{24}$ $= 1.5 \cdot 10^{24}$ $= 4.3 \cdot 10^{24}$	90%	Bel91 Eng88 ⁵ Sta90 Tom91 Hir94b
			2ν	$= 1.5 \cdot 10^{20} - 1.5 \cdot 10^{21}$ $= 8.2 \cdot 10^{20}$ $= 1.5 \cdot 10^{19} - 2.1 \cdot 10^{22}$ $= 1.0 \cdot 10^{21}$		Vog86 Eng88 Sta90 Hir94b
$^{130}_{56}\text{Ba}-^{130}_{54}\text{Xe}$ 2610(7) keV 0.106(0.002)%	Exper. $2\beta^+$ $\varepsilon\beta^+$ Theor. $2\beta^+$	g.s.-g.s.	0ν	$> 2.7 \cdot 10^{11}$ $> 1.5 \cdot 10^{12}$		Fre52 ¹ Fre52 ¹
		g.s.-g.s.	0ν	$= 1.6 \cdot 10^{28}$ $= 3.3 \cdot 10^{28}$		Hir94a Bal89
			2ν	$= 1.7 \cdot 10^{29}$ $= 1.2 \cdot 10^{27}$		Hir94a Bal89
	$\varepsilon\beta^+$	g.s.-g.s.	0ν	$= 1.7 \cdot 10^{26}$ $= 5.0 \cdot 10^{27}$		Hir94a Bal89
			2ν	$= 1.0 \cdot 10^{23}$ $= 8.9 \cdot 10^{22}$		Hir94a Bal89
	2ε	g.s.-g.s.	2ν	$= 4.2 \cdot 10^{21}$ $= 4.0 \cdot 10^{21}$		Hir94a Bal89

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confidence level	Reference and remark
$^{132}_{56}\text{Ba}-^{132}_{54}\text{Xe}$ 840(3) keV 0.101(0.002)%	Exper. 2ε Theor. 2ε			- -		
$^{136}_{58}\text{Ce}-^{136}_{56}\text{Ba}$ 2400(50) keV 0.19(0.01)%	Exper. $2\beta^+ + \varepsilon\beta^+ + 2\varepsilon$ Theor. $2\beta^+$	g.s.-g.s.	0ν	- $= 2.4 \cdot 10^{29}$ $= 5.9 \cdot 10^{28}$		Hir94a Bal89
			2ν	$= 5.2 \cdot 10^{31}$ $= 5.9 \cdot 10^{27}$		Hir94a Bal89
	$\varepsilon\beta^+$	g.s.-g.s.	0ν	$= 4.7 \cdot 10^{26}$ $= 5.3 \cdot 10^{27}$		Hir94a Bal89
			2ν	$= 9.2 \cdot 10^{23}$ $= 1.2 \cdot 10^{23}$		Hir94a Bal89
	2ε	g.s.-g.s.	2ν	$= 1.7 \cdot 10^{22}$ $= 3.5 \cdot 10^{21}$		Hir94a Bal89
$^{138}_{58}\text{Ce}-^{138}_{56}\text{Ba}$ 693(11) keV 0.25(0.01)%	Exper. 2ε Theor. 2ε			- -		
$^{142}_{58}\text{Ce}-^{142}_{60}\text{Nd}$ 1417.1(2.1) keV 11.08(0.10)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν	- $= 2.8 \cdot 10^{24}$		13 Sta90
			2ν	$= 2.2 \cdot 10^{20} - 4.2 \cdot 10^{21}$ $= 3.3 \cdot 10^{22}$		Sta90 Hir94b
$^{146}_{60}\text{Nd}-^{146}_{62}\text{Sm}$ 70.0(2.9) keV 17.19(0.09)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν	- $= 4.4 \cdot 10^{26}$ $= 1.2 \cdot 10^{28}$		13 Sta90 Hir95
			2ν	$= 1.1 \cdot 10^{30} - \infty$ $= 7.3 \cdot 10^{30}$ $\geq 2.1 \cdot 10^{31}$		Sta90 Hir94b Cas94
$^{148}_{60}\text{Nd}-^{148}_{62}\text{Sm}$ 1928.8(1.9) keV 5.76(0.03)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.- 2_1^+ g.s.- 2_2^+ g.s.-g.s.	$0\nu + 2\nu$	$> 3.0 \cdot 10^{18}$ $> 2.7 \cdot 10^{18}$	90% 90%	Bel82 ¹³ Bel82
			0ν	$= 1.4 \cdot 10^{24}$ $= 6.8 \cdot 10^{24}$		Sta90 Hir95
			2ν	$= 1.1 \cdot 10^{19} - \infty$ $= 1.2 \cdot 10^{21}$ $\geq 6.0 \cdot 10^{20}$		Sta90 Hir94b Cas94

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei	Half-life, years	Confidence level	Reference and remark
$^{150}_{60}\text{Nd}-^{150}_{62}\text{Sm}$ 3367.5(2.2) keV 5.64(0.03)%	Exper. $2\beta^-$	g.s.-g.s.	$0\nu > 2.1 \cdot 10^{21}$ $0\nu(m_\nu) > 1.7 \cdot 10^{21}$ $0\nu(\text{rhc}) > 1.1 \cdot 10^{21}$ $2\nu > 1.8 \cdot 10^{19}$ $= 1.7^{+1.1}_{-0.6} \cdot 10^{19}$ $= 1.0 \cdot 10^{19}$	90% 95% 95% 95%	Moe94a Kli86 Kli86 Kli86
		g.s.- 2^+_1	$0\nu M > 5.3 \cdot 10^{20}$	90%	Moe94a
		g.s.- 0^+_1	$0\nu + 2\nu > 8.0 \cdot 10^{18}$	90%	Arp94
		g.s.- 4^+_1	$0\nu + 2\nu > 8.8 \cdot 10^{18}$	90%	Arp94
		g.s.- 4^+_1	$0\nu + 2\nu > 2.0 \cdot 10^{19}$	90%	Arp94
		g.s.- 2^+_2	$0\nu + 2\nu > 1.3 \cdot 10^{19}$	90%	Arp94
		g.s.- 2^+_3	$0\nu + 2\nu > 2.7 \cdot 10^{18}$	90%	Bel82
		g.s.- 0^+_2	$0\nu + 2\nu > 2.1 \cdot 10^{18}$	90%	Bel82
	Theor. $2\beta^-$	g.s.-g.s.	$0\nu = 3.4 \cdot 10^{24}$ $= 3.4 \cdot 10^{22}$ $= 4.5 \cdot 10^{22}$ $= 5.6 \cdot 10^{22}$ $= 1.1 \cdot 10^{24}$ $2\nu = 3.9 \cdot 10^{19}$ $= 6.1 \cdot 10^{16} - 3.9 \cdot 10^{20}$ $= 1.7 \cdot 10^{19}$ $\geq 6.0 \cdot 10^{18}$		Doi83 Sta90 Tom91 Hir94b Hir95 Doi83 Sta90 Hir94b Cas94
$^{144}_{62}\text{Sm}-^{144}_{60}\text{Nd}$ 1781.6(1.9) keV 3.1(0.1)%	Exper. $\epsilon\beta^+ + 2\epsilon$ Theor. $\epsilon\beta^+ + 2\epsilon$		- -		13
$^{154}_{62}\text{Sm}-^{154}_{64}\text{Gd}$ 1251.4(1.3) keV 22.7(0.2)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	$0\nu = 1.4 \cdot 10^{24}$ $2\nu = 2.7 \cdot 10^{20} - 2.5 \cdot 10^{21}$ $= 1.5 \cdot 10^{22}$ $= \infty$		Sta90 Sta90 Hir94b Cas94
$^{152}_{64}\text{Gd}-^{152}_{62}\text{Sm}$ 56.0(1.2) keV 0.20(0.01)%	Exper. 2ϵ Theor. 2ϵ		- -		13
$^{160}_{64}\text{Gd}-^{160}_{66}\text{Dy}$ 1729.7(1.3) keV 21.86(0.04)%	Exper. $2\beta^-$	g.s.-g.s.	$0\nu > 1.4 \cdot 10^{19}$ $2\nu > 1.3 \cdot 10^{17}$ $0\nu M > 2.7 \cdot 10^{17}$	90% 99% 99%	Bur93b Bur93b Bur93b

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confidence level	Reference and remark
$^{160}_{64}\text{Gd}$ (continue)		g.s.- 2_1^+	0ν	$> 1.3 \cdot 10^{19}$	90%	Bur93b
			2ν	$> 1.2 \cdot 10^{17}$	99%	Bur93b
	Theor. $2\beta^-$	g.s.-g.s.	0ν	$= 8.6 \cdot 10^{23}$		Sta90
			2ν	$= 4.9 \cdot 10^{18} - 9.9 \cdot 10^{20}$		Sta90
				$= 2.8 \cdot 10^{21}$		Hir94b
				$= \infty$		Cas94
$^{156}_{66}\text{Dy}-^{156}_{64}\text{Gd}$ 2011(6) keV 0.06(0.01)%	Exper. $\epsilon\beta^+ + 2\epsilon$ Theor. $\epsilon\beta^+ + 2\epsilon$			- -		13
$^{158}_{66}\text{Dy}-^{158}_{64}\text{Gd}$ 283.2(2.4) keV 0.10(0.01)%	Exper. 2ϵ Theor. 2ϵ			- -		13
$^{162}_{68}\text{Er}-^{162}_{66}\text{Dy}$ 1844.7(2.8) keV 0.14(0.01)%	Exper. $\epsilon\beta^+ + 2\epsilon$ Theor. $\epsilon\beta^+ + 2\epsilon$			- -		13
$^{164}_{68}\text{Er}-^{164}_{66}\text{Dy}$ 24.3(2.5) keV 1.61(0.02)%	Exper. 2ϵ Theor. 2ϵ			- -		13
$^{170}_{68}\text{Er}-^{170}_{70}\text{Yb}$ 653.7(1.7) keV 14.9(0.2)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν 2ν	- $= 1.4 \cdot 10^{25}$ $= 1.7 \cdot 10^{23} - 1.6 \cdot 10^{26}$ $= 2.5 \cdot 10^{23}$		13 Sta90 Sta90 Hir94b
$^{168}_{70}\text{Yb}-^{168}_{68}\text{Er}$ 1422(4) keV 0.13(0.01)%	Exper. $\epsilon\beta^+ + 2\epsilon$ Theor. $\epsilon\beta^+ + 2\epsilon$			- -		13
$^{176}_{70}\text{Yb}-^{176}_{72}\text{Hf}$ 1085.5(2.1) keV 12.7(0.2)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν 2ν	- $= 1.4 \cdot 10^{24}$ $= 1.3 \cdot 10^{20} - 3.7 \cdot 10^{24}$ $= 4.9 \cdot 10^{21}$ $= \infty$		13 Sta90 Sta90 Hir94b Cas94

Transition (A,Z)-(A,Z $\pm$ 2); ΔM_A ; δ	Kind of the result	Channel and mode of the 2β -process; levels of nuclei		Half-life, years	Confidence level	Reference and remark
$^{174}_{72}\text{Hf}-^{174}_{70}\text{Yb}$ 1102.1(2.5) keV 0.162(0.003)%	Exper. $\varepsilon\beta^+ + 2\varepsilon$ Theor. $\varepsilon\beta^+ + 2\varepsilon$			— —		13
$^{180}_{74}\text{W}-^{180}_{72}\text{Hf}$ 146(5) keV 0.13(0.04)%	Exper. 2ε Theor. 2ε	g.s.-g.s.	0ν	$> 5.0 \cdot 10^{16}$ —	90%	Dan94 ¹³
$^{186}_{74}\text{W}-^{186}_{76}\text{Os}$ 487.9(1.7) keV 28.6(0.2)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν 2ν 0ν 0ν 2ν	$> 2.7 \cdot 10^{20}$ $> 5.9 \cdot 10^{17}$ $> 2.4 \cdot 10^{20}$ $= 6.4 \cdot 10^{24}$ $= 5.1 \cdot 10^{25}$ $= 7.1 \cdot 10^{23} - 1.2 \cdot 10^{25}$ $= 1.3 \cdot 10^{24}$ $\geq 6.1 \cdot 10^{24}$	90% 90% 90%	Dan94 ¹³ Dan94 Dan94 Sta90 Hir95 Sta90 Hir94b Cas94
$^{184}_{76}\text{Os}-^{184}_{74}\text{W}$ 1451.5(1.4) keV 0.02(0.01)%	Exper. $\varepsilon\beta^+$ Theor. $\varepsilon\beta^+ + 2\varepsilon$	g.s.-g.s.	0ν	$> 9.9 \cdot 10^9$ —		Fre52 ^{1,13}
$^{192}_{76}\text{Os}-^{192}_{78}\text{Pt}$ 413.5(3.0) keV 41.0(0.8)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s. g.s.-g.s.	0ν 0ν 2ν	$> 9.8 \cdot 10^{12}$ $= 4.1 \cdot 10^{24}$ $= 3.3 \cdot 10^{26}$ $= 1.3 \cdot 10^{24} - 2.0 \cdot 10^{25}$ $= 2.4 \cdot 10^{24}$ $\geq 9.0 \cdot 10^{25}$		Fre52 ^{1,13} Sta90 Hir95 Sta90 Hir94b Cas94
$^{190}_{78}\text{Pt}-^{190}_{76}\text{Os}$ 1383(6) keV 0.01(0.01)%	Exper. $\varepsilon\beta^+$ Theor. $\varepsilon\beta^+ + 2\varepsilon$	g.s.-g.s.	0ν	$> 3.1 \cdot 10^{11}$ —		Fre52 ^{1,13}
$^{198}_{78}\text{Pt}-^{198}_{80}\text{Hg}$ 1047(3) keV 7.2(0.2)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s. g.s.-g.s.	0ν 0ν 2ν	$> 3.2 \cdot 10^{14}$ $= 4.7 \cdot 10^{23}$ $= 4.8 \cdot 10^{21} - 4.8 \cdot 10^{23}$ $= 1.1 \cdot 10^{22}$		Fre52 ^{1,13} Sta90 Sta90 Hir94b
$^{196}_{80}\text{Hg}-^{196}_{78}\text{Pt}$ 819.9(3.0) keV 0.15(0.01)%	Exper. 2ε Theor. 2ε	g.s.-g.s. + 2^+_1	$0\nu + 2\nu$	$> 2.5 \cdot 10^{18}$ —	68%	Buc90 ¹³

Transition (A,Z)-(A,Z±2); $\Delta M_A; \delta$	Kind of the result	Channel and mode of the 2β -process; levels of nuclei	Half-life, years	Confidence level	Reference and remark
$^{204}_{80}\text{Hg}-^{204}_{82}\text{Pb}$ 416.4(1.5) keV 6.87(0.04)%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν 2ν	- $= 8.2 \cdot 10^{24}$ $= 3.1 \cdot 10^{25} - 2.5 \cdot 10^{27}$ $= 1.8 \cdot 10^{25}$	Sta90 Sta90 Hir94b
$^{232}_{90}\text{Th}-^{232}_{92}\text{U}$ 841.7(2.6) keV 100%	Exper. $2\beta^-$ Theor. $2\beta^-$	g.s.-g.s.	0ν 2ν	- $= 3.1 \cdot 10^{23}$ $= 4.2 \cdot 10^{21} - 1.8 \cdot 10^{23}$ $= 4.0 \cdot 10^{21}$ $= \infty$	13 Sta90 Sta90 Hir94b Cas94
$^{238}_{92}\text{U}-^{238}_{94}\text{Pu}$ 1146.7(1.4) keV 99.2745(0.0060)%	Exper. $2\beta^-$ Theor. $2\beta^-$	all modes g.s.-g.s.	0ν 2ν	$= (2.0 \pm 0.6) \cdot 10^{21}$ $= 2.6 \cdot 10^{23}$ $= 1.0 \cdot 10^{24}$ $= 9.7 \cdot 10^{20} - 3.8 \cdot 10^{23}$ $= 9.1 \cdot 10^{20}$ $\geq 1.4 \cdot 10^{21}$	68% Tur91 ^{14,13} Sta90 Hir95 Sta90 Hir94b Cas94

¹ From results of [Fre52] with corrections on the decay energy and the natural abundance of the isotope.

² The phase space estimate.

³ An ordinary β^- decay $^{48}\text{Ca}(0^+) \rightarrow ^{48}\text{Sc}(6^+, 5^+, 4^+)$ is possible ($Q_\beta = 278(5)$ keV [Aud93]). The calculated half-life of the most probable of them $T_{1/2}(^{48}\text{Ca}(0^+) \rightarrow ^{48}\text{Sc}(5^+)) = 7.6 \cdot 10^{20}$ y [War85]. Experimental limit $T_{1/2}(^{48}\text{Ca}, \beta^-) > 6.0 \cdot 10^{18}$ y with 95% CL [Alb85].

⁴ This result was obtained in [Bar89a] using the experimental data of [Bar70].

⁵ The recalculations [Moe94b] of the results [Eng88] for $g_A = 1.25$ give the values of $T_{1/2}^{0\nu} \cdot < m_\nu >^2$: $^{76}\text{Ge} - 1.4 \cdot 10^{25}$, $^{82}\text{Se} - 5.6 \cdot 10^{24}$, $^{128}\text{Te} - 1.5 \cdot 10^{25}$, $^{130}\text{Te} - 6.6 \cdot 10^{23}$, $^{136}\text{Xe} - 3.3 \cdot 10^{24}$ y·eV².

⁶ The recalculations [Moe94b] of the results [Eng89] for $g_A = 1.25$ give the values of $T_{1/2}^{0\nu} \cdot < m_\nu >^2$: $^{76}\text{Ge} - 2.3 \cdot 10^{24}$, $^{82}\text{Se} - 9.2 \cdot 10^{23}$, $^{128}\text{Te} - 4.5 \cdot 10^{24}$, $^{130}\text{Te} - 2.4 \cdot 10^{23}$ y·eV².

⁷ The result of the geochemical experiment.

^{7*} Recommended value based on latest geochemical experiments.

⁸ An ordinary β^- decay $^{96}\text{Zr}(0^+) \rightarrow ^{96}\text{Nb}(6^+)$ is possible ($Q_\beta = 164(4)$ keV [Aud93]). Experimental limit $T_{1/2}(^{96}\text{Zr}, \beta^-) > 3.8 \cdot 10^{19}$ y with 90% CL [Arp94].

⁹ This result was obtained in [Bar87] using the experimental data of [Win52].

¹⁰ Preliminary result.

¹¹ This result was obtained in [Bar87] using the experimental data of [Kal52].

¹² This result was obtained in [Bar87] using the experimental data of [Zde80b].

¹³ Parent 2β isotope is (potentially) α radioactive. The corresponding Q_α values and half-lives:

	Q_α , keV [Aud93]	$T_{1/2}^{\alpha,exp}$, y		$T_{1/2}^{\alpha,calc}$, y [Poe86]	[Alb88]
¹⁴² ₅₈ Ce	1299(4)	$> 5 \cdot 10^{16}$	[Mac61]	—	$3.8 \cdot 10^{27}$
¹⁴⁶ ₆₀ Nd	1182.0(2.2)	—	—	—	—
¹⁴⁸ ₆₀ Nd	599(3)	—	—	—	—
¹⁴⁴ ₆₂ Sm	77(19)	—	—	—	—
¹⁵² ₆₄ Gd	2205.0(1.5)	$= 1.1 \cdot 10^{14}$	[Led78]	$1.0 \cdot 10^{14}$	—
¹⁵⁶ ₆₆ Dy	1757(6)	$> 1 \cdot 10^{18}$	[Rie58]	$5.0 \cdot 10^{24}$	$4.3 \cdot 10^{24}$
¹⁵⁸ ₆₆ Dy	874.7(2.4)	—	—	—	—
¹⁶² ₆₈ Er	1646(3)	$> 1.4 \cdot 10^{14}$	[Por56]	$4.0 \cdot 10^{29}$	$2.2 \cdot 10^{29}$
¹⁶⁴ ₆₈ Er	1304.3(2.5)	—	—	—	$9.2 \cdot 10^{39}$
¹⁷⁰ ₆₈ Er	50.4(2.4)	—	—	—	—
¹⁶⁸ ₇₀ Yb	1951(4)	$> 1.3 \cdot 10^{14}$	[Por56]	$5.0 \cdot 10^{24}$	$1.9 \cdot 10^{24}$
¹⁷⁶ ₇₀ Yb	571(4)	—	—	$2.5 \cdot 10^{96}$	—
¹⁷⁴ ₇₂ Hf	2495.8(2.6)	$= 2.0 \cdot 10^{15}$	[Led78]	$6.3 \cdot 10^{16}$	—
¹⁸⁰ ₇₄ W	2514(5)	$> 1 \cdot 10^{15}$	[Bea60]	$2.5 \cdot 10^{18}$	$7.5 \cdot 10^{17}$
¹⁸⁶ ₇₄ W	1123(7)	$> 2 \cdot 10^{17}$	[Bea60]	$2.5 \cdot 10^{57}$	—
¹⁸⁴ ₇₆ Os	2964(4)	$> 5.6 \cdot 10^{13}$ 95% CL	[Spe76]	$5.0 \cdot 10^{13}$	$2.1 \cdot 10^{13}$
¹⁹² ₇₆ Os	362(4)	—	—	$1.3 \cdot 10^{15.4}$	—
¹⁹⁰ ₇₈ Pt	3249(6)	$= 6 \cdot 10^{11}$	[Led78]	$6.3 \cdot 10^{11}$	—
¹⁹⁸ ₇₈ Pt	87(4)	—	—	$6.3 \cdot 10^{39.1}$	—
¹⁹⁶ ₈₀ Hg	2027(4)	$> 1 \cdot 10^{14}$	[Mac61]	$1.3 \cdot 10^{33}$	$1.0 \cdot 10^{32}$
²³² ₉₀ Th	4082.7(1.4)	$= 1.41 \cdot 10^{10}$	[Led78]	$2.0 \cdot 10^{10}$	—
²³⁸ ₉₂ U	4269.8(2.9)	$= 4.468 \cdot 10^9$	[Led78]	$6.3 \cdot 10^9$	—

For 6 daughter isotopes α radioactivity was observed experimentally:

	Q_α , keV [Aud93]	$T_{1/2}^{\alpha,exp}$, y [Led78]
¹⁴⁴ ₆₀ Nd	1905.1(1.8)	$2.1 \cdot 10^{15}$
¹⁴⁶ ₆₂ Sm	2529.0(2.9)	$1.03 \cdot 10^8$
¹⁴⁸ ₆₂ Sm	1985.8(1.2)	$8 \cdot 10^{15}$
¹⁸⁶ ₇₆ Os	2822.0(1.7)	$2 \cdot 10^{15}$
²³² ₉₂ U	5413.55(0.14)	72
²³⁸ ₉₄ Pu	5593.20(0.19)	87.74

¹⁴ The result of the radiochemical experiment.

TABLE II. List of known 2β nuclides absent in a natural mixture of elements

N	Parent nuclide	Main channel of decay and $T_{1/2}$ [Led78]	Potential 2β transition and daughter nuclide	ΔM_A , keV [Aud93, Led78]
1	$^{148}_{64}\text{Gd}^1$	α 98 y	$2\beta^+ + \epsilon\beta^+ + 2\epsilon$ $^{148}_{62}\text{Sm}$	3066.9(2.0)
2	$^{150}_{64}\text{Gd}$	α $1.8 \cdot 10^6$ y	$\epsilon\beta^+ + 2\epsilon$ $^{150}_{62}\text{Sm}$	1289(6)
3	$^{154}_{66}\text{Dy}$	α $\approx 1 \cdot 10^7$ y	$2\beta^+ + \epsilon\beta^+ + 2\epsilon$ $^{154}_{64}\text{Gd}$	3316(8)
4	$^{216}_{84}\text{Po}$	α 0.15 s	$2\beta^-$ $^{216}_{86}\text{Rn}$	1534(8)
5	$^{212}_{86}\text{Rn}$	α 23 m	$\epsilon\beta^+ + 2\epsilon$ $^{212}_{84}\text{Po}$	1711.1(3.0)
6	$^{214}_{86}\text{Rn}$	α 0.27 μs	2ϵ $^{214}_{84}\text{Po}$	149(9)
7	$^{220}_{86}\text{Rn}$	α 55.6 s	$2\beta^-$ $^{220}_{88}\text{Ra}$	344(10)
8	$^{218}_{88}\text{Ra}$	α 14 μs	$\epsilon\beta^+ + 2\epsilon$ $^{218}_{86}\text{Rn}$	1432(11)
9	$^{226}_{88}\text{Ra}$	α $1.60 \cdot 10^3$ y	$2\beta^-$ $^{226}_{90}\text{Th}$	476(5)
10	$^{224}_{90}\text{Th}$	α 1.04 s	$\epsilon\beta^+ + 2\epsilon$ $^{224}_{88}\text{Ra}$	1171(12)
11	$^{230}_{92}\text{U}$	α 20.8 d	2ϵ $^{230}_{90}\text{Th}$	747(5)
12	$^{236}_{94}\text{Pu}$	α 2.85 y	2ϵ $^{236}_{92}\text{U}$	453.4(2.1)
13	$^{244}_{94}\text{Pu}^2$	α $8.1 \cdot 10^7$ y	$2\beta^-$ $^{244}_{96}\text{Cm}$	1352(5)
14	$^{242}_{96}\text{Cm}$	α 162.8 d	2ϵ $^{242}_{94}\text{Pu}$	86.2(0.9)
15	$^{248}_{96}\text{Cm}$	$\alpha + \text{sf}$ $3.5 \cdot 10^5$ y	$2\beta^-$ $^{248}_{98}\text{Cf}$	153(7)
16	$^{254}_{98}\text{Cf}$	$\alpha + \text{sf}$ 60.5 d	$2\beta^-$ $^{254}_{100}\text{Fm}$	436(12)
17	$^{256}_{98}\text{Cf}$	sf 12 m	$2\beta^-$ $^{256}_{100}\text{Fm}$	≈ 0.9 MeV
18	$^{252}_{100}\text{Fm}$	α 25.4 h	2ϵ $^{252}_{98}\text{Cf}$	783(7)
19	$^{258}_{102}\text{No}$	sf 1.2 ms	$\epsilon\beta^+ + 2\epsilon$ $^{258}_{100}\text{Fm}$	1060(280)

¹ Theoretical calculations [Sta91]: $T_{1/2}^{0\nu} \cdot \langle m_\nu \rangle^2 = 1.6 \cdot 10^{28} \text{ y} \cdot \text{eV}^2$, $T_{1/2}^{2\nu} \geq 2.2 \cdot 10^{26} \text{ y}$.

² Result of recent radiochemical experiment [Moo92]: $T_{1/2}(^{244}_{94}\text{Pu}, \text{all } 2\beta^- \text{ modes}) > 1.1 \cdot 10^{18} \text{ y}$ with 95% CL. Theoretical calculations [Sta90]: $T_{1/2}^{0\nu} \cdot \langle m_\nu \rangle^2 = 5.7 \cdot 10^{23} \text{ y} \cdot \text{eV}^2$, $T_{1/2}^{2\nu} = 9.3 \cdot 10^{21} - 6.9 \cdot 10^{22} \text{ y}$. Work [Cas94] predicts that $2\nu 2\beta$ decay of $^{244}_{94}\text{Pu}$ is forbidden.

Figure T1. Atomic mass difference between parent 2β nuclides and daughter isotopes:
a – for parent $2\beta^-$ nuclides, b – for parent $2\beta^+, \epsilon\beta^+, 2\epsilon$ nuclides

Figure T2. Natural abundances of 2β isotopes: a – for parent $2\beta^-$ nuclides, b – for parent $2\beta^+$, $\epsilon\beta^+$, 2ϵ nuclides

Figure T3. Limits of half-lives for neutrinoless 2β processes (g.s. - g.s. transitions) measured in direct experiments: a - for parent $2\beta^-$ nuclides, b - for parent $2\beta^+$, $\epsilon\beta^+$, 2ϵ nuclides ($2\beta^+$ results - filled circles, $\epsilon\beta^+$ - empty circles, 2ϵ - boxes)

Figure T4. Positive results and limits of half-lives for two-neutrino processes (g.s. – g.s. transitions) measured in direct experiments: a – for parent $2\beta^-$ nuclides, b – for parent $2\beta^+$, $\epsilon\beta^+$, 2ϵ nuclides ($2\beta^+$ results – filled circles, $\epsilon\beta^+$ – empty circles, 2ϵ – boxes). Positive results are marked by arrows

Figure T5. a – limits of half-lives for 2β decay with Majoron emission (g.s. – g.s. transitions) measured in direct experiments; b – positive results for $T_{1/2}(2\beta)$ measured in indirect (geochemical and radiochemical) experiments

References

- [Alb85] D.E. Alburger and J.B. Cumming, *Phys. Rev. C* **32**, 1358 (1985)
- [Alb86] D.E. Alburger and J.B. Cumming, *Phys. Rev. C* **33**, 2169 (1986)
- [Alb88] B. Al-Bataina and J. Janecke, *Phys. Rev. C* **37**, 1667 (1988)
- [Ale69] E.C. Alexander, Jr., B. Srinivasan, and O.K. Manuel, *Earth Planet. Sci. Lett.* **5**, 478 (1969)
- [Ale92] A. Alessandrello, C. Brofferio, D.V. Camin, O. Cremonesi, E. Fiorini, G. Gervasio, A. Giuliani, M. Pavan, G. Pessina, E. Previtali, and L. Zanotti, *Phys. Lett. B* **285**, 176 (1992)
- [Ale94a] A. Alessandrello, C. Brofferio, D.V. Camin, O. Cremonesi, F.A. Danevich, P. de Marcillac, E. Fiorini, A. Giuliani, V.N. Kouts, A.S. Nikolayko, M. Pavan, G. Pessina, E. Previtali, C. Vignoli, L. Zanotti, and Yu.G. Zdesenko, *Nucl. Phys. B (Proc. Suppl.)* **35**, 394 (1994)
- [Ale94b] A. Alessandrello, C. Brofferio, D.V. Camin, O. Cremonesi, E. Fiorini, E. Garcia, A. Giuliani, P. de Marcillac, A. Nucciotti, M. Pavan, G. Pessina, E. Previtali, and L. Zanotti, *Phys. Lett. B* **335**, 519 (1994)
- [Als93] M. Alston-Garnjost, B.L. Dougherty, R.W. Kenney, R.D. Tripp, J.M. Krivich, H.W. Nicholson, C.S. Sutton, B.D. Dieterle, S.D. Foltz, C.P. Leavitt, R.A. Reeder, J.D. Baker, and A.J. Caffrey, *Phys. Rev. Lett.* **71**, 831 (1993)
- [Arp94] C. Arpesella, A.S. Barabash, E. Bellotti, C. Brofferio, E. Fiorini, P.P. Sverzelati, and V.I. Umatov, *Europhys. Lett.* **27**, 29 (1994)
- [Art93] V.A. Artem'ev, E.V. Brakhman, O.Ya. Zel'dovich, A.K. Karelin, V.V. Kirichenko, O.M. Kozodaeva, V.A. Lyubimov, A.I. Mitin, V.N. Paramokhin, T.N. Tsvetkova, S.I. Vasil'ev, A.A. Klimenko, S.B. Osetrov, A.A. Pomanskii, and A.A. Smol'nikov, *JETP Lett.* **58**, 262 (1993)
- [Aud93] G. Audi and A.H. Wapstra, *Nucl. Phys. A* **565**, 66 (1993)
- [Avi88] F.T. Avignone III and R.L. Brodzinski, *Prog. Part. Nucl. Phys.* **21**, 99 (1988)
- [Avi94] F.T. Avignone III, *Prog. Part. Nucl. Phys.* **32**, 223 (1994)
- [Bal89] S.K. Balaev, A.A. Kuliev, and D.I. Salamov, *Bull. Ac. Sci. USSR, phys. ser.* **53**, 2136 (1989)
- [Bal94] A. Balysh, M. Beck, S.T. Belyaev, F. Bensch, J. Bockholt, A. Demehin, A. Gurov, G. Heusser, H.V. Klapdor-Kleingrothaus, I. Kondratenko, D. Kotel'nikov, V.I. Lebedev, B. Maier, A. Muller, F. Petry, A. Piepke, A. Pronsky, H. Strecker, M. Vollinger, and K. Zuber, *Phys. Lett. B* **322**, 176 (1994)
- [Bar70] R.K. Bardin, P.J. Gollon, J.D. Ullman, and C.S. Wu, *Nucl. Phys. A* **158**, 337 (1970)

- [Bar87] A.S. Barabash, preprint ITEP 56 (Moscow, 1987)
- [Bar89a] A.S. Barabash, Phys. Lett. B 216, 257 (1989)
- [Bar89b] A.S. Barabash, V.V. Kuzminov, V.M. Lobashev, V.M. Novikov, B.M. Ovchinnikov, and A.A. Pomansky, Phys. Lett. B 223, 273 (1989)
- [Bar90a] A.S. Barabash, A.V. Kopylov, and V.I. Cherehovsky, Phys. Lett. B 249, 186 (1990)
- [Bar90b] A.S. Barabash, O.K. Egorov, A.A. Klimenko, E.D. Kolganova, E.A. Pozharova, T.Yu. Skorodko, V.A. Smirnitsky, and A.A. Smolnikov, preprint ITEP 131-90 (Moscow, 1990)
- [Bar91] I.L. Barnes, T.L. Chang, T.B. Coplen, P. De Bievre, J.W. Gramlich, J.Ch.R. Hagemann, N.E. Holden, T.J. Murphy, K.J.R. Rosman, and M. Shima, Pure and Appl. Chem. 63, 991 (1991)
- [Bar92] A.S. Barabash, A.V. Derbin, L.A. Popeko, and V.M. Yumatov, preprint LNPI 1763 (St.-Petersburg, 1992); Z. Phys. A, to be published
- [Bar93] A.S. Barabash, F.T. Avignone III, C.K. Guerard, R.L. Brodzinski, H.S. Miley, J.H. Reeves, and V.I. Umatov, *Proc. 3-rd Int. Symp. on Weak and Electromagn. Interactions in Nuclei WEIN-92. Dubna, Russia, June 16-22, 1992* (World Sci. Publ. Co., 1993), p.582
- [Bea60] G.B. Beard and W.H. Kelly, Nucl. Phys. 16, 591 (1960)
- [Bec92] M. Beck, J. Bockholt, J. Echternach, G. Heusser, M. Hirsch, H.V. Klapdor-Kleingrothaus, A. Piepke, H. Strecker, K. Zuber, A. Bakalyarov, A. Balysh, S.T. Belyaev, A. Demehin, A. Gurov, I. Kondratenko, V.I. Lebedev, A. Pronsky, and A. Muller, Z. Phys. A 343, 397 (1992)
- [Bel82] E. Bellotti, E. Fiorini, C. Liguori, A. Pullia, A. Sarracino, and L. Zanotti, Lett. Nuovo Cim. 33, 273 (1982)
- [Bel87] E. Bellotti, C. Cattadori, O. Cremonesi, E. Fiorini, C. Liguori, A. Pullia, P.P. Sverzellati, and L. Zanotti, Europhys. Lett. 3, 889 (1987)
- [Bel91] E. Bellotti, O. Cremonesi, E. Fiorini, G. Gervasio, S. Ragazzi, L. Rossi, J. Szarka, P.P. Sverzellati, T. Tabarelli, and L. Zanotti, J. Phys. G: Nucl. Part. Phys. 17, s231 (1991)
- [Ber53] A. Berthelot, R. Chaminade, C. Levi, and L. Papineau, Comp. Rend. 236, 1769 (1953)
- [Ber83] J. Bernabeu, A. De Rujula, and C. Jarlskog, Nucl. Phys. B 223, 15 (1983)
- [Ber92] T. Bernatowicz, J. Brannon, R. Brazzle, R. Cowsik, C. Hohenberg, and F. Podosek, Phys. Rev. Lett. 69, 2341 (1992)

- [Blu92] D. Blum, J. Busto, J.E. Campagne, D. Dassie, F. Hubert, Ph. Hubert, M.C. Isaac, C. Izac, S. Jullian, V.N. Kouts, B.N. Kropivnyansky, D. Lalanne, T. Lamhamdi, F. Laplanche, F. Leccia, I. Linck, C. Longuemare, P. Mennrath, F. Natchez, F. Scheibling, G. Szklarz, V.I. Tretyak, and Yu.G. Zdesenko, *Phys. Lett. B* 275, 506 (1992)
- [Boe92] F. Boehm and P. Vogel, *Physics of Massive Neutrinos* (2-nd ed., Cambridge University Press, Cambridge, 1992)
- [Bro93] R.L. Brodzinski, F.T. Avignone, J.I. Collar, H. Courant, E. Garcia, C.K. Guerrard, W.K. Hensley, I.V. Kirpichnikov, H.S. Miley, A. Morales, J. Morales, R. Nunez-Lagos, S.B. Osetrov, V.S. Pogosov, A.A. Pomansky, J. Puimedo, J.H. Reeves, K. Ruddick, C. Saenz, A. Salinas, M.L. Sarsa, A.A. Smolnikov, A.S. Starostin, A.G. Tamanyan, S.I. Vasiliev, and J.A. Villar, *Nucl. Phys. B (Proc. Suppl.)* 31, 76 (1993)
- [Bry78] D. Bryman and C. Picciotto, *Rev. Mod. Phys.* 50, 11 (1978)
- [Buc90] E. Bukhner, I.N. Vishnevskii, F.A. Danevich, Yu.G. Zdesenko, Kh.V. Klapdor, B.N. Kropivnyanskii, V.N. Kuts, A. Piepke, V.I. Tretyak, G. Heusser, J. Schneider, and H. Strecker, *Sov. J. Nucl. Phys.* 52, 193 (1990)
- [Bur93a] C.P. Burgess and J.M. Cline, *Phys. Lett. B* 298, 141 (1993)
- [Bur93b] S.F. Burachas, F.A. Danevich, Yu.G. Zdesenko, V.D. Ryzhikov, and V.I. Tretyak, preprint KINR-93-2 (Kiev, 1993); *Sov. J. Nucl. Phys.*, to be published
- [Bus90] J. Busto, D. Dassie, O. Helene, Ph. Hubert, P. Larrieu, F. Leccia, P. Mennrath, M.M. Aleonard, and J. Chevallier, *Nucl. Phys. A* 513, 291 (1990)
- [Cal89] D.O. Caldwell, *Int. J. Mod. Phys. A* 4, 1851 (1989)
- [Cal90] D.O. Caldwell, R.M. Eisberg, F.S. Goulding, B. Magnusson, A.R. Smith, and M.S. Witherell, *Nucl. Phys. B (Proc. Suppl.)* 13, 547 (1990)
- [Car93] C.D. Carone, *Phys. Lett. B* 308, 85 (1993); private communication (1993)
- [Cas94] O. Castanos, J.G. Hirsch, O. Civitarese, and P.O. Hess, *Nucl. Phys. A* 571, 276 (1994)
- [Cau90] E. Caurier, A. Poves, and A.P. Zuker, *Phys. Lett. B* 252, 13 (1990)
- [Chi88] C.R. Ching and T.H. Ho, *Comm. Theor. Phys.* 10, 45 (1988)
- [Chi89] Ching Chehg-rui, Ho Tso-hsiu, and Wu Xing-rong, *Phys. Rev. C* 40, 304 (1989)
- [Civ87] O. Civitarese, A. Faessler, and T. Tomoda, *Phys. Lett. B* 194, 11 (1987)
- [Dan89] F.A. Danevich, Yu.G. Zdesenko, A.S. Nikolaiko, and V.I. Tretyak, *JETP Lett.* 49, 476 (1989)

- [Dan93] F.A. Danevich, V.V. Kobychiev, V.N. Kouts, V.I. Tretyak, and Yu. Zdesenko, *Proc. 3-rd Int. Symp. on Weak and Electromagn. Interactions in Nuclei WEIN-92. Dubna, Russia, June 16-22, 1992* (World Sci. Publ. Co., 1993), p.575
- [Dan94] F.A. Danevich, A.Sh. Georgadze, V.V. Kobychiev, B.N. Kropivnyanskii, V.N. Kouts, A.S. Nikolaiko, V.I. Tretyak, and Yu.G. Zdesenko, *Sov. J. Nucl. Phys.*, to be published
- [Das94a] D. Dassié, R. Eschbach, F. Hubert, Ph. Hubert, M.C. Isaac, C. Izac, F. Leccia, P. Mennrath, A. Varella, C. Longuemare, F. Mauger, F. Danevich, V. Kouts, V.I. Tretyak, Yu. Vassilyev, Yu. Zdesenko, A.S. Barabash, V.N. Kornoukov, Yu.B. Lepikhin, V.I. Umatov, I.A. Vanushin, C. Augier, D. Blum, J.E. Campagne, S. Jullian, D. Lalanne, F. Laplanche, F. Natchez, G. Pichenot, G. Szklarz, R. Arnold, J.L. Guyonnet, T. Lamhamdi, I. Linck, F. Piquemal, F. Scheibling, V. Brudanin, V. Egorov, O. Kochetov, A. Nozdrin, Ts. Vylov, Sh. Zaparov, H.W. Nicholson, and C.S. Sutton, preprint LAL 94-46 (Orsay, 1994); *Phys. Rev. D*, to be published
- [Das94b] D. Dassié, R. Eschbach, F. Hubert, Ph. Hubert, F. Leccia, P. Mennrath, F. Piquemal, A. Varella, C. Longuemare, F. Mauger, V.I. Tretyak, Yu. Vassilyev, V. Zerkov, A.S. Barabash, V.N. Kornoukov, Yu.B. Lepikhin, V.I. Umatov, I.A. Vanushin, C. Augier, D. Blum, J.E. Campagne, S. Jullian, D. Lalanne, F. Laplanche, G. Szklarz, R. Arnold, J.L. Guyonnet, I. Linck, F. Scheibling, V. Brudanin, V. Egorov, O. Kochetov, V. Kovalenko, A. Nozdrin, Ts. Vylov, H.W. Nicholson, and C.S. Sutton, *JETP Lett.*, submitted
- [Del60] G.F. Dell'Antonio and E. Fiorini, *Suppl. Nuovo Cim.* 17, 132 (1960)
- [Dhi94] S.K. Dhiman and P.K. Raina, *Phys. Rev. C* 50, 2660 (1994)
- [Doi81] M. Doi, T. Kotani, H. Nishiura, K. Okuda, and E. Takasugi, *Prog. Theor. Phys.* 66, 1739 (1981); 66, 1765 (1981)
- [Doi83] M. Doi, T. Kotani, H. Nishiura, and E. Takasugi, *Prog. Theor. Phys.* 69, 602 (1983)
- [Doi85] M. Doi, T. Kotani, and E. Takasugi, *Prog. Theor. Phys. Suppl.* 83, 1 (1985)
- [Doi92] M. Doi and T. Kotani, *Prog. Theor. Phys.* 87, 1207 (1992)
- [Doi93] M. Doi and T. Kotani, *Prog. Theor. Phys.* 89, 139 (1993)
- [Dyc90] G.R. Dyck, M.H. Sidky, J.G. Hykawy, C.A. Lander, K.S. Sharma, R.C. Barber, and H.E. Duckworth, *Phys. Lett. B* 245, 343 (1990)
- [Eji91] H. Ejiri, K. Fushimi, T. Kamada, H. Kinoshita, H. Kobiki, H. Ohsumi, K. Okada, H. Sano, T. Shibata, T. Shima, N. Tanabe, J. Tanaka, T. Taniguchi, T. Watanabe, and N. Yamamoto, *Phys. Lett. B* 258, 17 (1991)
- [Eli87a] S.R. Elliott, A.A. Hahn, and M.K. Moe, *Phys. Rev. Lett.* 59, 2020 (1987)
- [Eli87b] S.R. Elliott, A.A. Hahn, and M.K. Moe, *Phys. Rev. C* 36, 2129 (1987)

- [Ell91] S.R. Elliott, M.K. Moe, M.A. Nelson, and M.A. Vient, J. Phys. G: Nucl. Part. Phys. **17**, s145 (1991)
- [Ell92] S.R. Elliott, A.A. Hahn, M.K. Moe, M.A. Nelson, and M.A. Vient, Phys. Rev. C **46**, 1535 (1992)
- [Ell93] S.R. Elliott, M.K. Moe, M.A. Nelson, and M.A. Vient, Nucl. Phys. B (Proc. Suppl.) **31**, 68 (1993)
- [Eng88] J. Engel, P. Vogel, and M.R. Zirnbauer, Phys. Rev. C **37**, 731 (1988)
- [Eng89] J. Engel, P. Vogel, Xiangdong Ji, and S. Pittel, Phys. Lett. B **225**, 5 (1989)
- [Eng92] J. Engel, W.C. Haxton, and P. Vogel, Phys. Rev. C **46**, 2153 (1992)
- [Fae88] A. Faessler, Prog. Part. Nucl. Phys. **21**, 183 (1988)
- [Fio72] E. Fiorini, Riv. Nuovo Cim. **2**, 1 (1972)
- [Fir48] E. Fireman, Phys. Rev. **74**, 1238 (1948)
- [Fre52] J.H. Fremlin and M.C. Walters, Proc. Phys. Soc. London A **65**, 911 (1952)
- [Fur39] W.H. Furry, Phys. Rev. **56**, 1184 (1939)
- [Gel81] G.B. Gelmini and M. Roncadelli, Phys. Lett. B **99**, 411 (1981)
- [Ger68] E.K. Gerling, J.A. Shukolyukov, and G.Sh. Ashkinadze, Sov. J. Nucl. Phys. **6**, 226 (1968)
- [Gir92] T.A. Girard, E. Aprile, and R.C. Fernholz, Nucl. Instrum. Meth. A **316**, 44 (1992)
- [Gmi90] M. Gmitro and F. Shimkovits, Bull. Ac. Sci. USSR, phys. ser. **54**, 1780 (1990)
- [Goe35] M. Goeppert-Mayer, Phys. Rev. **48**, 512 (1935)
- [Gro86] K. Grotz and H.V. Klapdor, Nucl. Phys. A **460**, 395 (1986)
- [Gro90] K. Grotz and H.V. Klapdor, *The Weak Interaction in Nuclear, Particle and Astrophysics* (Adam Hilger, Bristol, 1990)
- [Hax81] W.C. Haxton, G.J. Stephenson, Jr., and D. Strottman, Phys. Rev. Lett. **47**, 153 (1981)
- [Hax82] W.C. Haxton, S.P. Rosen, and G.J. Stephenson, Jr., Phys. Rev. D **26**, 1805 (1982)
- [Hax84] W.C. Haxton and G.J. Stephenson, Jr., Prog. Part. Nucl. Phys. **12**, 409 (1984)
- [Hax93] W.C. Haxton, Nucl. Phys. B (Proc. Suppl.) **31**, 88 (1993)
- [Hen75] E.W. Hennecke, O.K. Manuel, and D.D. Sabu, Phys. Rev. C **11**, 1378 (1975)

- [Hir94a] M. Hirsch, K. Muto, T. Oda, and H.V. Klapdor-Kleingrothaus, *Z. Phys. A* **347**, 151 (1994)
- [Hir94b] M. Hirsch, X.R. Wu, H.V. Klapdor-Kleingrothaus, Ching Cheng-rui, and Ho Tso-hsiu, *Phys. Rep.* **242**, 403 (1994)
- [Hir95] J.G. Hirsch, O. Castanos, and P.O. Hess, *Nucl. Phys. A* **582**, 124 (1995)
- [Hyk93] J.G. Hykawy, J.N. Nxumalo, P.P. Unger, C.A. Lander, R.D. Peters, R.C. Barber, K.S. Sharma, and H.E. Duckworth, *Nucl. Instrum. Meth. A* **329**, 423 (1993)
- [Ing50] M.G. Inghram and J.H. Reynolds, *Phys. Rev* **78**, 822 (1950)
- [Kal52] M.I. Kalkstein and W.F. Libby, *Phys. Rev.* **85**, 368 (1952)
- [Kaw93] A. Kawashima, K. Takahashi, and A. Masuda, *Phys. Rev. C* **47**, 2452 (1993)
- [Key91] Ke You, Yucan Zhu, Junguang Lu, Hanseng Sun, Weihua Tian, Wenheng Zhao, Zhipeng Zheng, Minghan Ye, Chengrui Ching, Tsohsiu Ho, Fengzhu Cui, Changjiang Yu, and Guojing Jiang, *Phys. Lett. B* **265**, 53 (1991)
- [Kir67] T. Kirsten, W. Gentner, and O. Muller, *Z. Naturforsch. A* **22**, 1783 (1967)
- [Kir68] T. Kirsten, O.A. Schaeffer, E. Norton, and R.W. Stoenner, *Phys. Rev. Lett.* **20**, 1300 (1968)
- [Kir69] T. Kirsten and H.W. Muller, *Earth Planet Sci. Lett.* **6**, 271 (1969)
- [Kir83a] T. Kirsten, H. Richter, and E. Jessberger, *Phys. Rev. Lett.* **50**, 474 (1983); *Z. Phys. C* **16**, 189 (1983)
- [Kir83b] T. Kirsten, *AIP Conference* **96**, 396 (1983)
- [Kir86] T. Kirsten, E. Heusser, D. Kaether, J. Oehm, E. Pernicka, and H. Richter, *Proc. Int. Symp. on Nuclear Beta Decays and Neutrino. Osaka, Japan, June 1986* (World Sci., 1986), p.81
- [Kir92] I.V. Kirpichnikov, *Nucl. Phys. B (Proc. Suppl.)* **28A**, 210 (1992)
- [Kla93a] H.V. Klapdor-Kleingrothaus (for the Heidelberg-Moscow Collaboration), *Nucl. Phys. B (Proc. Suppl.)* **31**, 72 (1993)
- [Kla93b] H.V. Klapdor-Kleingrothaus, *Proc. 3-rd Int. Symp. on Weak and Electromagn. Interactions in Nuclei WEIN-92. Dubna, Russia, June 16-22, 1992* (World Sci. Publ. Co., 1993), p.201
- [Kli86] A.A. Klimenko, A.A. Pomansky, and A.A. Smolnikov, *Nucl. Instrum. Meth. B* **17**, 445 (1986)
- [Kud92] N. Kudomi, H. Ejiri, K. Nagata, K. Okada, T. Shibata, T. Shima, and J. Tanaka, *Phys. Rev. C* **46**, 2132 (1992)

- [Kum94] K. Kume, H. Ejiri, K. Fushimi, R. Hazama, K. Kawasaki, V. Kouts, N. Kudo, K. Nagata, V. Malishko, H. Ohsumi, K. Okada, H. Sano, T. Senoo, T. Shibata, T. Shima, J. Tanaka, and Yu. Zdesenko, Nucl. Phys. A 577, 405c (1994)
- [Laz67] V.R. Lazarenko, Sov. Phys. Usp. 9, 860 (1967)
- [Led78] *Table of isotopes*, ed. by C.M. Lederer and V.S. Shirley (7-th ed., Wiley, New York, 1978)
- [Lin86] W.J. Lin, O.K. Manuel, L.L. Oliver, and R.I. Thorpe, Nucl. Phys. A 457, 285 (1986)
- [Lin88a] W.J. Lin, O.K. Manuel, G.L. Cumming, D. Krstic, and R.I. Thorpe, Nucl. Phys. A 481, 477 (1988)
- [Lin88b] W.J. Lin, O.K. Manuel, S. Muangnoicharoen, and R.I. Thorpe, Nucl. Phys. A 481, 484 (1988)
- [Lus85] M. Lusignoli and M.G. Schepkin, Nucl. Phys. B 261, 143 (1985)
- [Mac61] R.D. Macfarlane and T.P. Kohman, Phys. Rev. 121, 1758 (1961)
- [Mai94] B. Maier (for the Heidelberg-Moscow Collaboration), Nucl. Phys. B. (Proc. Suppl.) 35, 358 (1994)
- [Man86] O.K. Manuel, *Proc. Int. Symp. on Nuclear Beta Decays and Neutrino. Osaka, Japan, June 1986* (World Sci., 1986), p.71
- [Man91] O.K. Manuel, J. Phys. G: Nucl. Part. Phys. 17, s221 (1991)
- [Mar85] K. Marti and S.V.S. Murty, Phys. Lett. B 163, 71 (1985)
- [Mil90] H.S. Miley, F.T. Avignone, III, R.L. Brodzinski, J.I. Collar, and J.H. Reeves, Phys. Rev. Lett. 65, 3092 (1990)
- [Mit88] L.W. Mitchell and P.H. Fisher, Phys. Rev. C 38, 895 (1988)
- [Miy91] M. Miyajima, S. Sasaki, and H. Tawara, KEK Proc. 91-5, 19 (1991)
- [Moe88] M.K. Moe, S.R. Elliott, and A.A. Hahn, preprint Univers. of California Neutrino-88-11 (Irvine, 1988)
- [Moe91a] M.K. Moe, Nucl. Phys. B (Proc. Suppl.) 19, 158 (1991)
- [Moe91b] M.K. Moe, Phys. Rev. C 44, 931 (1991)
- [Moe93] M.K. Moe, Int. J. Mod. Phys. E 2, 507 (1993)
- [Moe94a] M.K. Moe, M.A. Nelson, and M.A. Vient, Prog. Part. Nucl. Phys. 32, 247 (1994)
- [Moe94b] M. Moe and P. Vogel, Ann. Rev. Nucl. Part. Sci. 44, 247 (1994)

- [Moh88] R.N. Mohapatra and E. Takasugi, Phys. Lett. B 211, 192 (1988)
- [Moo92] K.J. Moody, R.W. Lougheed, and E.K. Hulet, Phys. Rev. C 46, 2624 (1992)
- [Mur87] S.V.S. Murty and K. Marti, Geochim. Cosmochim. Acta 51, 163 (1987)
- [Mut88] K. Muto and H.V. Klapdor, in *Neutrinos*, ed. by H.V. Klapdor (Springer-Verlag, Berlin, 1988), p.183
- [Mut89] K. Muto, E. Bender, and H.V. Klapdor, Z. Phys. A 334, 177 (1989); A 334, 187 (1989)
- [Mut91] K. Muto, E. Bender, and H.V. Klapdor-Kleingrothaus, Z. Phys. A 339, 435 (1991)
- [Nor84] E.B. Norman and M.A. De Faccio, Phys. Lett. B 148, 31 (1984)
- [Nor85] E.B. Norman, Phys. Rev. C 31, 1937 (1985)
- [Nor87] E.B. Norman and D.M. Meekhof, Phys. Lett. B 195, 126 (1987)
- [Nxu93] J.N. Nxumalo, J.G. Hykawy, P.P. Unger, C.A. Lander, R.C. Barber, K.S. Sharma, and H.E. Duckworth, Phys. Lett. B 302, 13 (1993)
- [Pan90] G. Pantis and J.D. Vergados, Phys. Lett. B 242, 1 (1990)
- [Pan92] G. Pantis, A. Faessler, W.A. Kaminski, and J.D. Vergados, J. Phys. G: Nucl. Part. Phys. 18, 605 (1992)
- [Pan94] G. Pantis and J.D. Vergados, Phys. Rep. 242, 285 (1994)
- [Pie94] A. Piepke, M. Beck, J. Bockholt, D. Glatting, G. Heusser, H.V. Klapdor-Kleingrothaus, B. Maier, F. Petry, U. Schmidt-Rohr, H. Strecker, M. Vollinger, A.S. Barabash, V.I. Umatov, A. Muller, and J. Suhonen, Nucl. Phys. A 577, 493 (1994)
- [Poe86] D.N. Poenaru, W. Greiner, K. Depta, M. Ivascu, D. Mazilu, and A. Sandulescu, At. Data Nucl. Data Tabl. 34, 423 (1986)
- [Por56] W. Porschen and W. Riezler, Z. Naturforsch. A 11, 143 (1956)
- [Pri81] H. Primakoff and S.P. Rosen, Ann. Rev. Nucl. Part. Sci. 31, 145 (1981)
- [Pro94] A.G. Prokopets, S. Sasaki, and M. Miyajima, KEK Proc. 94-7, 60 (1994)
- [Qin84] Qing Cheng-rui, He Zuo-xiu, and Zhao Wei-qin, Acta Phys. Sin. 33, 441 (1984)
- [Ric86] J.F. Richardson, O.K. Manuel, B. Sinha, and R.I. Thorpe, Nucl. Phys. A 453, 26 (1986)
- [Rie58] W. Riezler and G. Kauw, Z. Naturforsch. A 13, 904 (1958)

- [Sae94] C. Saenz, E. Cerezo, E. Garcia, A. Morales, J. Morales, R. Nunez-Lagos, A. Ortiz de Solorzano, J. Puimedon, A. Salinas, M.L. Sarsa, J.A. Villar, A. Klimenko, V. Kuzminov, N. Metlinsky, V. Novikov, A. Pomansky, and B. Pritychenko, *Phys. Rev. C* 50, 1170 (1994)
- [Sch84] M.G. Schepkin, *Sov. Phys. Usp.* 27, 555 (1984)
- [Sin88] J. Sinatkas, L.D. Skouras, and J.D. Vergados, *Phys. Rev. C* 37, 1229 (1988)
- [Smo85] A.A. Smolnikov, PhD Thesis, INR AN SSSR (Moscow, 1985)
- [Spe76] R.F. Sperlein and R.L. Wolke, *J. Inorg. Nucl. Chem.* 38, 27 (1976)
- [Sri72a] B. Srinivasan, E.C. Alexander, Jr., and O.K. Manuel, *Econ. Geolog.* 67, 592 (1972)
- [Sri72b] B. Srinivasan, E.C. Alexander, Jr., and O.K. Manuel, *J. Inorg. Nucl. Chem.* 34, 2381 (1972)
- [Sri73] B. Srinivasan, E.C. Alexander, Jr., R.D. Beaty, D.E. Sinclair, and O.K. Manuel, *Econ. Geolog.* 68, 252 (1973)
- [Sta90] A. Staudt, K. Muto, and H.V. Klapdor-Kleingrothaus, *Europhys. Lett.* 13, 31 (1990)
- [Sta91] A. Staudt, K. Muto, and H.V. Klapdor-Kleingrothaus, *Phys. Lett. B* 268, 312 (1991)
- [Sto92] D.B. Stout and T.T.S. Kuo, *Phys. Rev. Lett.* 69, 1900 (1992)
- [Sto93] S. Stoica and W.A. Kaminski, *Phys. Rev. C* 47, 867 (1993)
- [Suh90] J. Suhonen, S.B. Khadkikar, and A. Faessler, *Phys. Lett. B* 237, 8 (1990)
- [Suh91] J. Suhonen, S.B. Khadkikar, and A. Faessler, *Nucl. Phys. A* 529, 727 (1991); 535, 509 (1991)
- [Suh93] J. Suhonen and O. Civitarese, *Phys. Lett. B* 308, 212 (1993)
- [Suh94] J. Suhonen and O. Civitarese, *Phys. Rev. C* 49, 3055 (1994)
- [Tak66] N. Takaoka and K. Ogata, *Z. Naturforsch. A* 21, 84 (1966)
- [Tan93] J. Tanaka and H. Ejiri, *Phys. Rev. D* 48, 5412 (1993)
- [Tom87] T. Tomoda and A. Faessler, *Phys. Lett. B* 199, 475 (1987)
- [Tom91] T. Tomoda, *Rep. Prog. Phys.* 54, 53 (1991)
- [Tsu84] T. Tsuboi, K. Muto, and H. Horie, *Phys. Lett. B* 143, 293 (1984)
- [Tur91] A.L. Turkevich, T.E. Economou, and G.A. Cowan, *Phys. Rev. Lett.* 67, 3211 (1991)

- [Vas90a] A.A. Vasenko, I.V. Kirpichnikov, V.A. Kuznetsov, A.S. Starostin, A.G. Djanyan, V.S. Pogosov, S.P. Shachysisyan, and A.G. Tamanyan, *Mod. Phys. Lett. A* **5**, 1299 (1990)
- [Vas90b] S.I. Vasil'ev, A.A. Klimenko, S.B. Osetrov, A.A. Pomanskii, and A.A. Smol'nikov, *JETP Lett.* **51**, 622 (1990)
- [Vas93] S.I. Vasil'ev, A.A. Klimenko, S.B. Osetrov, A.A. Pomanskii, and A.A. Smol'nikov, *JETP Lett.* **57**, 631 (1993)
- [Ver83] J.D. Vergados, *Nucl. Phys. B* **218**, 109 (1983)
- [Ver85] J.D. Vergados, *Nucl. Phys. B* **250**, 618 (1985)
- [Ver86] J.D. Vergados, *Phys. Rep.* **133**, 1 (1986)
- [Vog86] P. Vogel and M.R. Zirnbauer, *Phys. Rev. Lett.* **57**, 3148 (1986)
- [Vui93] J.-C. Vuilleumier, J. Busto, J. Farine, V. Jorgens, L.W. Mitchel, M. Treichel, J.-L. Vuilleumier, H.T. Wong, F. Boehm, P. Fisher, H.E. Henrikson, D.A. Imel, M.Z. Iqbal, B.M. O'Callaghan-Hay, J. Thomas, and K. Gabathuler, *Phys. Rev. D* **48**, 1009 (1993)
- [War85] E.K. Warburton, *Phys. Rev. C* **31**, 1896 (1985)
- [Win52] R.G. Winter, *Phys. Rev.* **85**, 687 (1952)
- [Wu91] X.R. Wu, A. Staudt, H.V. Klapdor-Kleingrothaus, Cheng-rui Ching, and Tso-hsiu Ho, *Phys. Lett. B* **272**, 169 (1991)
- [Wu92] X.R. Wu, A. Staudt, T.T.S. Kuo, and H.V. Klapdor-Kleingrothaus, *Phys. Lett. B* **276**, 274 (1992)
- [ZdeS0a] Yu.G. Zdesenko, *Sov. J. Part. Nucl.* **11**, 542 (1980)
- [ZdeS0b] Yu.G. Zdesenko, I.A. Mytsyk, A.S. Nikolaiko, and V.N. Kuts, *Sov. J. Nucl. Phys.* **32**, 312 (1980)
- [ZdeS1] Yu.G. Zdesenko, V.N. Kuts, I.A. Mytsyk, and A.S. Nikolaiko, *Bull. Ac. Sci. USSR, phys. ser.* **45**, 1856 (1981)
- [ZdeS2] Yu.G. Zdesenko, V.N. Kuts, I.A. Mitsik, and A.S. Nikolaiko, *Proc. Int. Conf. Neutrino-82, Balatonfured, Hungary, 1982* (Budapest, 1982), p.209
- [Zde91] Yu. Zdesenko, *J. Phys. G: Nucl. Part. Phys.* **17**, s243 (1991)
- [Zde93] Yu. Zdesenko, *invited talk on the Int. School of Nucl. Phys. "Neutrinos in Cosmology, Astro, Particle and Nuclear Physics", Erice, Italy, 8-17 Sept. 1993*
- [Zel54] Ya.B. Zel'dovich, S.Yu. Luk'ianov, and Ya.A. Smorodinskii, *Usp. Fiz. Nauk* **54**, 361 (1954)