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HAL Id: in2p3-00021944
https://hal.in2p3.fr/in2p3-00021944

Submitted on 16 Jun 2004

WHAT IS A TRULY NEUTRAL PARTICLE?

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An electrically charged particle is necessarily different from its antiparticle while an electrically neutral particle is either identical with or different from its antiparticle. A truly neutral particle is a particle identical to its antiparticle which means that *all* its algebraic intrinsic properties are equal to zero since particle and antiparticle have *all* their algebraic intrinsic properties opposite. We propose two complementary methods to *recognize* the true nature of any electrically neutral particle. On the one hand, any non null algebraic intrinsic property of a particle (properties such as Q, magnetic moment already known in classical physics or quantum numbers such as baryonic number A, lepton number L or flavours which are meaningful only in quantum world) reveals that it is distinct from its antiparticle. On the other hand, any particle decaying through a self-conjugate channel or/and through both two conjugate channels is a truly neutral particle implying then that all algebraic intrinsic properties, known or yet unknown, of this particle are null. According to these methods, the neutrino, like any fermion, cannot be its own antiparticle: so neutrinoless double beta decay cannot take place in nature. We point out the internal contradiction required by the existence of hypothetical neutrinoless double beta decay. We suggest that persistent failures to put this long sought hypothetical key decay into evidence despite huge efforts dedicated to this aim would indeed reflect its absence. The immediate consequence would be that limits of neutrino mass deduced from neutrinoless double beta decay cannot be used as constraints in contrast with mass limits deduced from the behaviour of end point in simple beta spectra.

1.Introduction   In the 1930s, the existence of antiparticles was anticipated by the equation of Dirac. And the unexpected observation of positrons by Anderson at the same epoch validated the concept of antiparticle. Electrons and antielectrons (positrons) have same mass, same spin but are different because their charges are opposite. Indeed mass is representative of a set of intrinsic properties defined by arithmetic quantities which should be the same for particle and antiparticle. For example, like mass, halflife of a particle should be the same as its antiparticle. Likewise, electric charge Q and magnetic moment already known in classical physics are typical examples of intrinsic properties defined by algebraic quantities which should be opposite for particle and antiparticle. Hadrons are now known to be composite particles (quark and antiquark for mesons and three quarks for baryons). Magnetic moments of hadrons and of their own antihadrons are opposite since every quark is replaced by its antiquark with opposite charge. The neutron with its overall zero charge has a non null moment due to its structure in charged quarks. In contrast, leptons are believed to be elementary particles. The magnetic moment of a given particle, expressed in Bohr magneton,is a real number. On the contrary, Q of an experimentally observed isolate particle is an integer number when the charge of the electron is taken to be –1. In particle physics, Q is conserved and comes in units. Q is a typical example of quantum number. Baryon number A, lepton number L and flavours are other examples of additive quantum numbers which play a primordial role in conservation laws. If we focus our attention to charge which seems to be the essential difference between particle and antiparticle, then the extension of the concept of particles to antiparticles is very similar to the extension of the notion of positive numbers to negative numbers. A real number is positive, negative or zero. A number and its opposite number are different. The only exception is 0 which is the only number equal to its opposite number. Similarly, particle and antiparticle which have opposite electric charges are clearly different. Particle and antiparticle are both real particles in the sense that they could be both experimentally observed. Positron and electron were clearly distinguished by opposite curvatures in a magnetic field.

2.Particles distinct from antiparticles. Particles identical with antiparticles   The concept of antiparticles multiplies the number of particles by two. Each particle has a corresponding antiparticle. One question immediately raises: are there particles identical to their antiparticles, or in other words, are there particles playing the same role as zero in numbers. It is clear that, if they exist, they must be electrically neutral particles. At that time, electric charge was the only known algebraic property of particles and it was tempting to assume that neutral particles are not distinct from their also neutral antiparticles. It is in this context that Majorana **(1)** first introduced the crucial concept of a Truly Neutral Particle (TNP) which is a particle *identical* to its antiparticle : it means that particle and antiparticle are indiscernible and are thus indistinguishable in *all* circumstances. CP transforms a particle into its antiparticle. If

CP does not change any property of a neutral particle *N* or CP(*N*)=*N* then *N* is a TNP. If it changes at least one property of *N* then *N* is not a TNP. A neutral particle distinct from its antiparticle by at least one algebraic property, is a Not Truly Neutral Particle (NTNP). Majorana had the intuition that electric charge was not the only charge, there would be indeed other yet unknown charges. And a TNP should have *all* charges equal to zero while a NTNP should have at least one yet unknown charge different from zero. Indeed, Majorana put forward a new theory assuming that the two then known neutral fermions, neutron and neutrino were identical to their own antiparticles. The knowledge in 1930s, limited to null charge for these two particles did not allow to choose between the two mutually exclusive possibilities (identical to or different from their own antiparticles). Majorana raised the question about the nature of neutron and neutrino but he did not suggest criteria or experiments to decide between his new theory and a simple extension of the Dirac equation to distinct neutral particles. Racah **(2)** pointed out immediately that the neutron is necessarily different from the antineutron since it has a non null magnetic moment. Ambiguity remained and always remains about the neutrino. In effect, the limit of the magnetic moment of the neutrino is smaller and smaller (1/7000 μ_B in 1930s, 1.5 10^{-10} μ_B now and very recently 1.0 10^{-10} μ_B **(3)**). However, the considerable improvement of limit does not change the fundamental problem : we still do not know now if the magnetic moment of the neutrino is zero or different from zero. Undoubted non zero magnetic moment of the neutrino (whatever the value is) would indicate that it has an internal structure involving a distribution of charge and above all would imply that the neutrino is certainly different from the antineutrino. However, so far unfortunately from our sole knowledge on magnetic moment and Q we cannot decide what is the true nature of the neutrino.

In the 1930s, one ignored that a particle is characterized by many quantities *other* than those defined in macroscopic objects such as mass, magnetic moment and Q. The completely unknown quantities in classical physics such as baryon number A, lepton number L, flavours, colours which are significant only in microscopic physics were subsequently introduced in order to understand why certain reactions allowed by classical conservation laws were observed and certain other reactions allowed also by classical laws were never observed. These additional quantum numbers play in some sense the same role as Q. In the level of particles, the conservation of Q although necessary *is not sufficient* to explain why certain reactions conserving Q are never observed. It is necessary to introduce other material conservation laws to explain why certain reactions are observed and certain other reactions are never observed even if Q is manifestly conserved. Unlike motional conservation laws (of energy, linear momentum and angular momentum), deeply related to space-time symmetries, which are universal (valid for all interactions known or yet unknown), material conservation laws (A, L, flavours, colours even if some of them A, L, Q seem to be also universally

conserved in the sense that they are really conserved in all observed reactions governed by one of the well-known interactions of the Standard Model), are specific to interactions. Each fundamental interaction has its own conservation laws. So, strong interaction and electromagnetism do conserve electric charge Q, baryon number A, lepton number L, individual flavours...while weak interaction does not conserve individual flavours but conserves nevertheless Q, A and L. We point out that conservation (or not conservation) of a quantum number such as A, L, Q, flavours is a property of interaction and not of particle. But it would be meaningless to say that a reaction (governed by an interaction) conserves or does not conserve A, L, Q ... if these numbers are not unambiguously defined for each particle involved either in the entrance channel or in the exit channel. Thus, these numbers, once determined are part and parcel of intrinsic properties of particle and they contribute to establish with more and more precision the characteristics of particle. And we have to take into account every established property. It is particularly important when this property is algebraic and is conserved in certain interactions and not necessarily conserved in other interactions. For example, an individual flavour is conserved in electromagnetism and strong interaction but is not necessarily conserved in weak interaction (but it can be also conserved in weak interaction via the exchange of neutral messenger Z). By contrast, A, L and Q are conserved in all known interactions: electromagnetism, strong interaction and weak interaction.

We can imagine a new interaction that does not conserve for example L, but we can no more ignore that A, L, Q, ...of a given particle have perfectly definite values. For example, the following main constituents of matter, proton, neutron, electron and neutrino are defined by: p (A=1, L=0, Q=1); n (A=1, L=0, Q=0) ; e (A=0, L=1, Q=-1); ν (A=0, L=1, Q=0). A reaction governed by a given interaction has to obey *all* conservation laws of this interaction. Conversely, if a reaction does not obey all conservation laws of a given interaction, it cannot be governed by this interaction.

Any particle of nature is either identical with its antiparticle or different from its antiparticle. It cannot be sometimes identical with and sometimes distinct from its antiparticle. A charged particle is necessarily distinct from its antiparticle. On the contrary, a neutral particle N can be a priori either indiscernible from its antiparticle (a TNP) or distinct from its antiparticle (a NTNP). But, whatever the assumption is, we have to follow our ideas through to their logical conclusions: all available experimental results should be accounted for with *the same statement*. And as soon as a new information on N is known, it is necessary to show that it does not contradict the same statement. The crucial problem is thus to find out objective criteria allowing to recognize the true nature of a neutral particle N (TNP or NTNP). In other words, if N is really a NTNP ($N \neq \overline{N}$), what are the criteria allowing us to identify with certainty it as a NTNP? Conversely, if N is really a TNP ($\overline{N} = N$), what are the criteria allowing

us to identify with certainty it as a TNP? It is clear that the nature (TNP or NTNP) of a neutral particle once determined is definitive.

3. Method I: How to recognize that a neutral particle is a NTNP   Particle and antiparticle have opposite algebraic properties. This simple observation gives immediately rise to a powerful method to recognize the NTNP nature of a neutral particle if it is actually a NTNP: if any quantity of algebraic properties is not zero, then the particle in question is a NTNP. For example, Racah **(2)** knowing that the magnetic moment of the neutron is different from zero, inferred immediately that the neutron is different from the antineutron. However, conversely, even if all known algebraic quantities are zero, it does not mean that N is necessarily a TNP. Indeed, it is only potentially a TNP but we cannot be sure, because a yet unknown quantity could be different from zero. The finding of any non zero algebraic properties, if conclusive, signs univocally the NTNP nature of N. One way to settle the issue is thus to examine all available algebraic properties of N. If any of them is not zero, then N is a NTNP. It is clear that if N is actually a TNP then any attempt to try to find an algebraic property different from zero should fail. A sole non null algebraic intrinsic property is *sufficient* to reveal the NTNP nature of a neutral particle whatever the other algebraic properties are (equal to or different from zero)

4. Method II: How to recognize that a neutral particle is a TNP   CP transforms a particle into its antiparticle and vice versa. It means that it changes all algebraic properties of a particle into opposite algebraic properties of its antiparticle. If the particle N in question is a TNP, then we obtain the same particle N since in this case particle and antiparticle are indiscernible. It is thus important to find out TNP revealing processes which, if *unambiguously observed*, imply that N is identical with its antiparticle.

Let p an experimentally observed process involving an electrically neutral particle N. If p is still a possible process when N is replaced by its antiparticle $\overline{N}$, then N is a TNP ($\overline{N} = N$).

if $N + a \rightarrow b + c + ...$ (1) is an observed process, and if

$\overline{N} + a \rightarrow b + c + ...$ (2) is still an observed process, then $\overline{N} = N$.

If $N \neq \overline{N}$ then (2) is an impossible process. If (2) is not observed, then there is no evidence that $\overline{N} = N$ but it is not impossible that the non observation of (2) is due to another reason (physical reason or insufficient sensitivity). Non observation of (2) is thus a strong hint that $N \neq \overline{N}$ but does not imply necessarily that $N \neq \overline{N}$.

In 1955, Davies **(4)** pointed out that $v + ^{37}Cl \rightarrow ^{37}Ar + e^-$ (3) is an allowed process, being the inverse process to the electron capture decay of ^{37}Ar. This process later was used to detect solar neutrinos proving that fusion provides the energy from the sun. The sun emits neutrinos while a nuclear reactor emits antineutrinos. Could they be the same particle because they are both neutral? If $\overline{v} + ^{37}Cl \rightarrow ^{37}Ar + e^-$ (4) is also an

observed process, then we should deduce that $v = \bar{v}$. But, experimentally, (4) has never been observed in a dedicated experiment using antineutrinos of the Brookhaven reactor. Davis "found that the argon-37 production was a factor 20 below the expected rate for neutrinos and antineutrinos being identical particles" **(5)**. There is thus no evidence that $v = \bar{v}$.

One particular case is the transformation or the decay of a neutral particle N.

If $N \rightarrow a + b+...(5)$ is an observed or possible reaction then the CP conjugate of this reaction is a possible reaction. We have:

$\bar{N} \rightarrow \bar{a} + \bar{b} +...$ (6)

Generally, (5) and (6) are different. For example:

$n \rightarrow p + e^{-} + \bar{v}$ (7) is an observed decay. The CP conjugate of (7) is:

$\bar{n} \rightarrow \bar{p} + e^{+} + v$ (8) which is a possible process. If the neutron could decay through $n \rightarrow p + e^{-} + \bar{v}$ *and* through $n \rightarrow \bar{p} + e^{+} + v$, then the neutron should be a TNP. The fact that $n \rightarrow \bar{p} + e^{+} + v$ is not observed is in agreement with the fact that the neutron is not a TNP (deduced from non zero magnetic moment).

If $a + b+...= \bar{a} + \bar{b} +...$ (self-conjugate channel), then $\bar{N} = N$. We deduce immediately in this way that γ, π^0, Z^0, K^0_S, K^0_L, J/ψ are TNP.

$\gamma = e^{-} + e^{+}$

$\bar{\gamma} = e^{+} + e^{-}$

γ is a TNP since this transformation is self-conjugate.

If N transforms into both a channel and its conjugate channel then N is a TNP. For example, the decay of K^0_L can be either $\pi^+ e^- \bar{v}$ or $\pi^- e^+ v$

if $N \rightarrow a + b+...$ and $N \rightarrow \bar{a} + \bar{b} +...$, then $\bar{N} = N$.

Observation of these TNP revealing reactions means then that the particle in question is necessarily a TNP (and if other conditions are required, they should be also *all* fulfilled to allow TNP revealing process to take place), implying that all defined algebraic properties are null. Positive result without ambiguity of any TNP revealing process is *sufficient* to reveal the TNP nature of a neutral particle.

5. Undecidable case These two ways of recognition are the two faces of the same coin allowing to give an univocal answer to the nature of a given neutral particle. Obviously, these two complementary methods should give consistent results: we cannot have a neutral particle with a non-zero value algebraic quantity and observe a TNP revealing reaction or observe a TNP revealing process with N which has a non zero algebraic property. These features reflect simply that a neutral particle cannot be both TNP and NTNP. The nature of a neutral particle remains ambiguous until one of these two procedures gives an *univocal positive response*.

Less we know the properties of a particle, more the situation is ambiguous leading to undecidable case. It is important to determine intrinsic properties of N (any non zero algebraic property is sufficient to infer that N is a NTNP) or/and the behaviour

of *N* through an interaction. Its TNP nature could be revealed by any TNP revealing reaction. Method I and method II cannot give both positive results but they can give both negative results especially when very few algebraic properties are known or/and when TNP revealing reactions are difficult to perform. The nature of *N* remains ambiguous in this case.

6.Three kinds of elementary particles   There are three kinds of elementary particles:

1) Quarks (u, d, s, c, b and t) are characterized by A=1/3 and L=0, they are manifestly different from their antiparticles since they are charged (or since A is different from zero or since there exists at least one individual flavour different from zero). Quarks have also colour charge different from zero (we can thus also say that quarks are distinct from antiquarks since their colour charge is not null). From the fact that a baryon with A=1 is formed by three quarks, it is deduced that quarks which are not observed isolately have A=1/3. From Gell-Mann and Nishijima formulae, Q(u)=2/3 and Q(d)=-1/3. Q of quarks are not integer but are rational number.

2) leptons (e$^-$, ν_e; μ^-, ν_μ, τ^-, ν_τ) are characterized by A=0 and L=1   They are different from their antiparticles since L=1. Exchange of W and Z respects the family number (e$^-$, ν_e characterized by L_e=1 and TF=-1 for e$^-$ and TF=1 for ν_e; μ^-, ν_μ characterized by L_μ=1 and TF=−1 f or μ^- and TF=1 for ν_μ; ; τ^-, ν_τ characterized by L_τ=1 and TF=−1 for τ^- and TF=1 for ν_τ). Another way to characterize a given lepton is to precise its leptonic flavour, for example, e is characterized by L=1 and D_l=-1, ν_e is characterized by L=1 and U_l=1. **(6)**

3) Messengers particles which mediate interactions are characterized by A=0 and L=0. Unlike quarks and leptons which are fermions, messenger particles are bosons. Only neutral messengers could be TNP since they are the only elementary particles with A=0 and L=0. Indeed the following neutral messengers are TNP: γ, Z^0, gluons such as $R\overline{R}$.

We point out that all known TNP are bosons: composite bosons like mesons formed by a quark and its antiquark or elementary messenger bosons like γ, Z^0, $R\overline{R}$. A fermion is always associated to A$\neq$ 0 or L$\neq$ 0 thus cannot be a TNP **(6,7,8)**.

7.Question about the nature of neutron and neutrino in 1930s In   1937,   Majorana **(1)** conjectured that neutrons and neutrinos are TNP and examined the modifications of Dirac's theory in this case. Immediately, Racah **(2)** pointed out that the neutron has to be   distinct from the antineutron since its magnetic moment is *different* from zero. Indeed, Racah used method I to settle the issue. This inference was in agreement with the fact that the neutron only decays into p + e$^-$ + $\overline{\nu}$ channel (if the conjugate channel were also observed, the neutron should be a TNP). The negative result of method II showed the coherence of Dirac neutron. In the 1930s, one ignored that besides electric charge Q, particles are also characterized by a set of additional quantum numbers such

as A, L, flavours, colours ..., otherwise Racah could have drawn the same conclusion by remarking for example that the baryon number A of the neutron is not zero. Antineutron was discovered in 1956.

However the reasoning of Racah was not applicable to the neutrino because there was no evidence that its magnetic moment was different from zero. All known algebraic properties at that time could be considered to be zero. We remark that, even now, more than sixty years later, despite considerable improvements of sensitivity, we do not yet know if its magnetic moment is zero or different from zero. The nature of the neutrino (TNP or NTNP) remains an open question as long as its magnetic moment can be zero if Q and magnetic moment are the only known algebraic intrinsic properties of the neutrino and if we continue to consider only these two properties and not to take into account other properties unknown in 1930s but well established nowadays. A TNP has necessarily a null magnetic moment but it is not impossible that a NTNP has a null magnetic moment.

8.ββ0ν decay was originally proposed as a means to recognize univocally the nature of the neutrino In 1935, Goeppert-Meyer **(9)** explained that some even-even nuclei are only apparently stable because in reality they could decay through a postulated process ββ decay. Her calculations based on Fermi theory (second order process) showed that the expected lifetimes of this process were exceedingly slow even on a geologic time scale and were out of reach of experiments of that time.

It was in this context that, triggered by Majorana's ideas, Furry **(10)** realized that within the framework of the knowledge of that time, ββ decay could give a firm answer to the nature of the neutrino. Basically, beta decay transforms a neutron into three particles: proton, electron and neutrino. And ββ decay transforms two neutrons of a parent nuclei of atomic number Z into a daughter nuclei with Z+2, two electrons and two neutrinos. For example:

$$^{76}Ge \longrightarrow {}^{76}Se + 2e^- + 2\bar{\nu}$$

It is clear that Q is conserved in this so-called ββ2ν process, whether the neutrino is TNP (Majorana particle) or NTNP (Dirac particle) since in any case Q(ν)= Q($\bar{\nu}$)=0 (at that time, no other intrinsic property of the neutrino was known). In other words, ββ2ν is always an allowed process whatever the nature of the neutrino is. In these conditions, if we assume now moreover that ν = $\bar{\nu}$, then another *additional* process is possible, the so-called ββ0ν process where no neutrino is emitted, the first neutrino emitted by the first neutron being absorbed by the second neutron giving at last only two electrons. In our example, it corresponds to the following reaction:

$$^{76}Ge \longrightarrow {}^{76}Se + 2e^- .$$
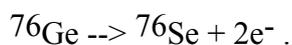
ββ0ν decay should be enhanced by a very huge phase factor of many orders of magnitude over the rate of ββ2ν decay. Geochemical methods could give only the

lifetime of ββ decay but the great difference of lifetime between the two processes should be a powerful means to distinguish them. As soon as sensitivity was sufficient, if ββ decay was detected (relative to ββ0ν, the contribution of ββ2ν should be completely negligible), then $\nu = \bar{\nu}$; if ββ was not detected then the neutrino should be different from its antiparticle.

Subsequent negative results of all then performed ββ decay experiments together with negative results of Davis experiment using antineutrinos from a reactor led then to the conclusion that the neutrino is different from the antineutrino since if $\nu = \bar{\nu}$, in this framework, one should have observed positive signals. So, curiously, ββ0ν decay which is a powerful TNP revealing process (if positive events are observed, N is TNP) was considered to be also a powerful NTNT revealing process (if positive events are not observed above a certain threshold sensitivity, then ββ0ν decay does not occur and N is NTNP).

9. Consequences of the discovery of non conservation of the parity in weak interaction But this simple interpretation was invalidated after the overthrow of parity conservation in β-decay **(11,12)**. It was indeed realized that because of helicity, since the neutrino is assumed to be massless, $\bar{\nu} + {}^{37}Cl \rightarrow e^- + {}^{37}Ar$ and ββ0ν decay were not possible regardless of whether it was a Majorana particle ($\nu = \bar{\nu}$) or not. The impossibility of changing the helicity of the neutrino which was believed to have zero mass, was *sufficient* to explain naturally the absence of Davis process and ββ0ν process whatever the nature of the neutrino is. The nature of the neutrino became again ambiguous and theoretically undecidable, since ββ0ν decay has to be always absent whatever the nature of the neutrino is. Later, it was realized that massless neutrino is only a *theoretical prejudice* and not a clearly established fact. We remark that experiments can never show that a mass which is an analogical quantity is strictly null. Recent evidence of neutrino oscillations was interpreted as a strong hint of massive neutrinos. Massive neutrinos restored thus the original aim of Furry: distinguish the nature of the neutrino from the existence or the non existence of ββ0ν decay. But it was only partly recovered. In effect, existence means now not only $\nu = \bar{\nu}$ but allows to determine with great sensitivity the mass of the neutrino (the lifetime of ββ0ν, *if it exists*, is believed now to be linked to the mass of the neutrino and its lifetime tends to infinity when the mass tends to zero. Even if $\nu = \bar{\nu}$, ββ0ν decay is strictly forbidden if $m_\nu = 0$ due to the impossibility to change helicity). Unfortunately, non existence of ββ0ν decay is now no more *necessarily* associated to $\nu \neq \bar{\nu}$. But it is clear that if $\nu \neq \bar{\nu}$, then ββ0ν decay is an impossible process. Quite curiously existence of ββ0ν decay would show that there exists a reaction governed by weak interaction which violates L conservation in a very specific way ($\Delta A=0$, $\Delta L=2$, $\Delta Q=0$) while it is well established that *all* observed reactions so far do conserve separately A, L and Q. The

stake is extremely high so that there is an implicit consensus to admit that massive neutrinos means de facto massive Majorana neutrinos in order to allow the resurrection of ββ0ν decay (in other words $\nu \neq \bar{\nu}$ was de facto excluded, ββ0ν decay being strictly forbidden in this case). In this framework, non observation of ββ0ν decay would be only a question of sensitivity. So, the obtention of higher and higher limit of the halflife could be used to deduce the lower and lower limit of Majorana mass. And the ultimate aim is to observe an undeniable peak of ββ0ν decay which would validate a posteriori experimentally the correctness of this hypothesis. The possibility of strict absence of ββ0ν decay due to $\nu \neq \bar{\nu}$ has been completely overlooked.

10.State of the art in ββ0ν decay   The present experimental status of ββ0ν decay studies is very well summarized by Fiorini **(13)**: "No evidence, but also not even a hint, has been presented so far for the dreamed peak in the electron sum corresponding to neutrinoless double beta decay ". The only disagreement about this statement came from Klapdor-Kleingrothaus et al **(14)** who used a particular mathematical process (the Bayersian method) for low counting rates to deduce the evidence of neutrinoless double beta decay. The correctness of their deduction was immediately questioned. Aalseth et al **(15)** in a detailed discussion stated that "consideration of these limitations leads to the conclusion that there is no basis for the claim presented in the paper". Ferruglio et al **(16)** expressed a similar doubt ("in conclusion, we do not see a really significant evidence for 0ν2β in published data"). We remark also that, an analysis of the practically same data, by Heidelberg Moscow collaboration **(17)**, led only to an lower limit for the half-life. Sum spectrum presented in **(14)** corresponding to 54.981 kgy of counting was not fundamentally different from spectrum presented in **(17)** corresponding to 53.9 kgy of counting. The evidence of ββ0ν decay was suggested only by new *mathematical process* while experimental spectra were almost identical and did not show evidence of peak at the expected energy. Zdesenko et al **(18)** analyzing the cumulative data sets of the Heidelberg-Moscow and IGEX experiments concluded that the claim of Klapdor-Kleingrothaus et al **(14)** was premature. Recently, the final results of a series of experiments on double beta decay of ^{130}Te led to the following conclusion: "No evidence is found in this experiment for neutrinoless DBD of ^{130}Te with a 90% C.L. lower limit of 2.1 x 10^{23} years" **(19)**. Up to now, non observation of ββ0ν decay is clearly again and again a stubborn experimental fact. Taking advantage of the fact that source and detectors are identical (CdTe and CdZn semiconductor detectors) and of the good energy resolution of semiconductor detectors, Kiel et al **(20)** tried to detect ββ decay events in Cd, Te and Zn. The conclusion is so far : "no signals were observed in all channels under investigation". Potentially, for ββ decay studies, these detectors could be as powerful as Ge detectors which are both source and detector and which give so far the best limit.

11. ββ0ν decay studies are not the only way to reveal the nature of the neutrino

We point out that search for ββ0ν decay has truly significant consequences only if it can be proved *unambiguously* that it really occurs in nature. Ultimately, existence of ββ0ν decay relies on the truth of the assumption $\nu = \bar{\nu}$. It is then paradoxal to continue to stick only to ββ0ν decay despite persistent failures, hoping to find at last an indeniable peak and not to verify by other means that this assumption remains possible and is indeed not clearly false when all now available information is taken into account. Method I, allows to get out of the ambiguity on the nature of the neutrino: L=1 of the neutrino (as A=1 of the neutron) is indeed *sufficient* to deduce that $\nu \neq \bar{\nu}$ and thus ββ0ν decay does not occur. The NTNP nature of the neutrino is the very reason of persistent failures to detect ββ0ν decay. But we cannot deduce the NTNP nature of the neutrino from the absence of ββ0ν decay. **(6)**

12. Non conservation of L and $\nu = \bar{\nu}$ are intimately linked in ββ0ν decay L=1 is clearly a property of any lepton, charged or neutral. L is conserved in all reactions actually observed so far without any exception (including ββ2ν). It is admitted that if L is conserved, then the neutrino is a Dirac particle but if L is not conserved, then the neutrino is a Majorana particle. Curiously, massive Majorana neutrinos imply ββ0ν decay whose existence in turn implies (ΔA=0, ΔL=2, ΔQ=0) reaction and vice versa. Non conservation of L (ΔA=0, ΔL=2, ΔQ=0) in weak interaction and $\nu = \bar{\nu}$ are thus indeed intimately linked and the reasoning is circular. Evidence of ββ0ν decay would require the abandon of the Standard Model in its present form and one should find out a coherent explanation of L conservation (associated to $\nu \neq \bar{\nu}$) in all observed reactions except in ββ0ν decay (associated to opposite statement $\nu = \bar{\nu}$). Indeed, we remark that to be rigorous, if we adopt the conventional point of view (non observation of ββ0ν decay is only a question of sensitivity), we have also to explain these contradictions.

On the contrary, all contradictions disappear with $\nu \neq \bar{\nu}$ (hypothesis not at all considered by physicists convinced that ββ0ν decay has to exist, e.g., the neutrino has to be a massive Majorana particle), since ββ0ν decay does not take place. The circular reasoning: if (ΔA=0,ΔL=2, ΔQ=0) process exists, then $\nu = \bar{\nu}$ and if $\nu = \bar{\nu}$ then there exists (ΔA=0,ΔL=2, ΔQ=0) process would be broken. Indeed there is an internal contradiction to suppose that the neutrino is both a lepton (L=1) and a TNP (L=0). The only possibility is that the neutrino is not a TNP and ββ0ν decay does not take place in nature **(21)**.

13. Conclusion Calculations of the halflife of ββ decay (ββ2ν decay and ββ0ν decay which should be enhanced by a very huge phase factor of many orders of magnitude over the rate of ββ2ν decay if basically the same interaction is at work in ββ2ν decay and ββ0ν decay) assume indeed that ββ decay are second order calculation of simple β decay. Thus they have to respect all characteristics of simple β decay, in

particular, all conservation laws of β decay should be fulfilled in ββ decay. In this framework, only ββ2ν decay is allowed and can be deduced from simple β decay information. In contrast, since ββ0ν decay requires both $\nu = \bar{\nu}$ (property of the neutrino) and non conservation of L (property of interaction governing this reaction), it can not be calculated by assuming a link between simple β decay (which requires on the contrary $\nu \neq \bar{\nu}$ and conservation of L) and ββ0ν decay if it exists. The sole existence of ββ0ν decay would imply simultaneously that $\nu = \bar{\nu}$ (property of the neutrino) and non conservation of L (property of weak interaction) while all other reactions involving the neutrino have been so far explained with opposite assumptions $\nu \neq \bar{\nu}$ and conservation of L. Such fundamental change of our understanding could and should be accepted only if evidence of ββ0ν decay is observed without the least ambiguity. Presently, there is not the slightest hint of its existence. According to Method I, $\nu \neq \bar{\nu}$, thus ββ0ν decay cannot occur. We remind also that the neutrino bears a non-null weak charge (otherwise it would not be sensitive to weak force. Weak charge of the neutrino could be identified to TF(ν)=1 **(7)**), another *sufficient* reason to infer that the neutrino cannot be a TNP. We could predict that all future experiments on ββ0ν decay would only give lower limits of halflife, whatever sensitivity is. In reality, these limits reflect only that the measurement of logical zero (non existence of ββ0ν decay) is obtained with more and more accuracy. We remark that consequently, limits of neutrino mass deduced from experiments based fundamentally on the truth of the assumption $\nu = \bar{\nu}$ (which is false according to our arguments) have no physical sense and cannot be used as constraints. By contrast, mass limit deduced from the behaviour of end-point in simple beta decay which is based on *observed* experimental beta spectra can be safely used as constraints. As long as only limit is obtained, it means that mass of the neutrino is an analogical quantity, has a upper limit but the zero value is not excluded. We remark that oscillations of neutrino **(22)** imply only that $\Delta m^2 > 0$ but do not provide information on the absolute scale of neutrino masses. As a consequence, the zero value for the mass of electron neutrino is not necessarily excluded. We should however remind that physics is essentially an experimental science. So if it turns out that ββ0ν decay events, against all expectation, are univocally observed in the future, then we must conclude that Method I, valid so far to recognize NTNP is not valid in the case of the neutrino. In this case, the internal contradiction L(ν)=1 associated to $\nu \neq \bar{\nu}$ to explain all observed reactions and L(ν)=0 associated to $\nu = \bar{\nu}$ uniquely to explain the existence of ββ0ν decay would be an acute problem to solve.

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