ELECTRON CAPTURE:
A MORE COMPLETE EQUATION

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ABSTRACT

The *Electron Capture*(*EC*) is a peculiar phenomenon that unstable atoms can use to become more stable. During *EC*, an electron(e^-) in an atom's inner shell is drawn into the nucleus where it combines with a proton(*P*), forming a neutron(*N*) and a neutrino(ν):

$$P + e^- \rightarrow N + \nu \qquad (1).$$

Electrons are usually captured from the inner K layer, leaving 'holes' process or Auger's e^-_s. Such a capture may also leave the nucleus in an excited state, causing it to release γ rays.

This emission of highly energetic electro-magnetic radiation(EMR), generally originates the production of pairs of light particles:

$$\gamma \rightarrow e^- + e^+ \qquad (2),$$

or:

$$\gamma \rightarrow \nu + \bar{\nu} \qquad (3),$$

where $\bar{\nu}$ is an anti-neutrino.

Yet, if this phenomenon of *materialization* of the EMR that accompanies the *EC*, manifesting in the production of lepton pairs(described in this case by the Eq.3), was represented in the equation describing the *EC*, we could better justify that ν appeared *ex abrupto* in Eq.(1).

Therefore, taking into account also the EMR(γ) emitted at the time of the *EC*, and inserting it in Eq.(1) on the side of the *captured* e^-, we have:

$$P + e^- + \gamma \rightarrow P + e^- + \bar{\nu}_e .+ \nu_e \rightarrow N + \nu_e \qquad (4),$$

that is:

$$P + e^- + \bar{\nu}_e .+ \nu_e \leftrightarrow N + \nu_e \qquad (5).$$

However, as the ν_e mass is considered ≤ 2eV, Eqs,(1) and (5) show a conspicuous *mass gap problem*, since according to Pauli and Fermi the ν proposed to compensate for the mass gap of the *N decay* must have the same mass of e^-. Unless one wishes to hypothesize the existence of the *neutral electron*(e°). In this case, Eq.(5) should be rewritten as follows:

$$P + e^- + \bar{e}^\circ + e^\circ \leftrightarrow N + e^\circ \qquad (6).$$

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1. INTRODUCTION

The *Electron Capture* (*EC*) is one process that unstable atoms can use to become more stable. During *EC*, an electron(e^-) in an atom's inner shell is drawn into the nucleus where it combines with a proton (*P*), forming a neutron(*N*) and a neutrino(ν). The ν is ejected from the atom's nucleus. Since an atom loses a *P* during *EC*, it changes from one element to another[1]. When Fermi wrote his famous paper about the *N* decay[2], very little was known about Weak Interaction. The only observed process of this type was the beta decay(*βd*) with emission of electrons (e^-_s). At the beginning of 1934**,** the artificial radioactivity induced by α particles was discovered by the Joliot Curie[3] and revealed a new kind of radioactive bodies which emit positrons(e^+_s) instead of negative electrons (e^-_s). Immediately Wick pointed out that Fermi's theory contains naturally the possibility of the *inverse process*[4]. Wick wrote: "Transformation of a *P* into a *N* and destruction of an e^- and a ν. For such a process to take place, however, it is essential that in the vicinity of the nucleus there is a certain density of ν_s. This density is just provided by the ν_s of negative energy; the destruction of one of them is equivalent to the formation of a particle (ν's hole) perfectly analogous to the ν. If the electron which is absorbed by the *P* is an electron of negative energy(e^-), one has the emission of a e^+. It is natural to identify this phenomenon with that observed by Curie and Joliot. If, on the contrary, the destroyed e^- is one of the K, L,M e^-_s belonging to the external structure of the atom one has the emission of X-rays, or of Auger e^-_s , i. e. a phenomenon, which in our case, can be observed only with considerable difficulty"[5]**.**

As Amaldi reminds us "Wick does not enter in the formal details of the new phenomenon he predicted: *the capture of orbital electrons*"(*EC*)[4]. This is based on the elementary process[6]:

$$P + e^- \rightarrow N + \nu \qquad (1),$$

where ν, namely, indicates an electronic neutrino(ν_e). The detailed theory of this type of *β instability* was developed in 1935 by Yukawa and Sakata[7].

This important phenomenon was observed for the first time by Alvarez who studied many elements, with particular attention to the case of $Ga^{67} \rightarrow Zn^{67}$ [8]. Alvarez writes: "In the Fermi theory of β-ray emission, the e^- and e^+ are pictured as being created at the moment they are ejected, during *N-P* transitions. The continuous β-ray spectrum and the conservation of spin are explained by the simultaneous emission of a ν and e^-. One may represent the transition involved in *e^- and e^+ decay* by the following equations:

$$N \rightarrow P + e^- + \nu \qquad (2),$$

$$P \rightarrow N + e^+ + \nu \qquad (3).$$

On the basis of Dirac's theory, however, the e^+ is merely the "hole"left in the continuum of negative energy electrons when one of these e^- is given a positive energy by the addition of at least $2mc^2$. The *P* in Eq.(3) does not transform into a *N* and e^+, but rather captures an e^- and turns into a *N*, leaving the hole in the negative energy sea, or e^+. Eq.(3) may then be written: $e^- + P \rightarrow N + \nu$"[8] (equal to Eq.1). Alvarez adds: "The experimental observation that e^+_s may be annihilated (an e^+ falling into the hole), shows that there is no essential difference between electrons in the two energy states. Therefore, there is no *a priori* reason why Eq.(1) demands the use of a negative energy electron(e^-). In fact, when the energy difference between parent and daughter nucleus is less than $2mc^2$, it would be impossible for the relation to be satisfied unless a *P* could capture an ordinary electron(e^-). Since there are many cases of *negative β-ray decay* with an energy release of less than this value, it is natural to suppose that there would be excited nuclei whose desire to emit e^+_s could not be allowed on energetic grounds. Yukawa suggested that in these cases, the *decay* would proceed by the *capture of an orbital e⁻*. In addition, he calculated that even when there was enough energy to create a pair, a certain fraction of the excited nuclei would *decay by EC*. The branching ratio of the two processes was found to depend on the energy available, the spin change involved, and the nuclear charge (density of $e^{-}{}_{s}$ at the nucleus).

EC should become more probable as the energy decreases, and as the spin change, atomic number and half-life increase. Alpha-decay and the two well-established methods of *β-decay* are easy to observe, since ionizing radiations are emitted in these processes. Eq.(1) shows that only the undetectable ν is given off by the nucleus in this new type of transition, so that more refined experimental methods must be employed if the effect is to be demonstrated. A rigorous experimental proof of the hypothesis is given for the case of Ga^{67}. The properties of Ga^{67} are described in considerable detail, and include the first evidence for internal conversion in artificially radioactive atoms."[8].

2. DISCUSSION

2.1 *ELECTRON CAPTURE* PROCESS

In short, *EC* is a comparatively *minor decay mode* caused by the Weak Interaction(WI). The best-known example is of potassium 40: 11% of the nuclei of that isotope of potassium present in our body decay by *EC* [9]. The *EC* trigger the emission of an invisible ν by the nucleus.

The *capture* of an e^{-} has the same effect on a nucleus as the emission of a e^{+} : one of its *P*s transforms into a *N*, diminishing the global electric charge of the nucleus by 1 unit. *EC*, along with β-positive decay(βd^{+}), is Nature's way of guaranteeing that no nucleus becomes too proton-heavy. Ordinary β-minus decay, or β-negative decay(βd^{-}), has no competitor on Earth however to reduce an excess of *N*s, since the *capture* of $e^{+}{}_{s}$ would occur in an world made of antimatter.

The captured e^{-} belongs to the group of $e^{-}{}_{s}$ orbiting around the nucleus. Such captures turn out to be difficult. Most of the $e^{-}{}_{s}$ orbit the nucleus at distances large compared to the nucleus. Even the innermost electron K-layer $e^{-}{}_{s}$ are far from the very small volume of the nucleus where the WI_{s} operate and transform the e^{-} into a ν. WI_{s} are behind e^{+} emission and *EC*.

EC occurs much less frequently than the emission of a e^{+}. Whereas *βd* can occur spontaneously when energetically allowed, for an *EC* the WI requires that the e^{-} come into *close contact* with a *P* of the nucleus. The probability that an e^{-} , even one belonging to the innermost 'K' shell, would find itself inside the nucleus is very low indeed (for potassium 40, the volume of the nucleus is less than a billionth of the K layer volume)[9].

This explains why *EC* is difficult and therefore rare. However, *EC* is more economical in energy than e^{+} emission, its competitor. The creation of a e^{+} requires 511 keV, that is the *inertial* mass energy, or *Zero Point Mass*[10], of the e^{+}. If the energy released in the *decay* is smaller than 511 keV, the emission of a e^{+}, or β-plus decay(βd^{+}), is not allowed. Below this energy threshold, *EC* becomes the only process available to reduce an excess of *P*s.

It is as saying that everything depends on the *energy difference* (Δ_E) between the parent atom and the daughter atom. That is, if $\Delta_E \geq 1.022$ MeV then the βd^{+} can occur. On the contrary, if $\Delta_E < 1.022$ MeV, the energetic quantity is not enough for the *materialization* of a pair e^{-} e^{+}, thus the *EC occurs instead of* the βd^{+} . Electrons are usually captured from the inner K layer, leaving 'holes' process or

Auger's $e^-{}_s$. Such a capture may also leave the nucleus in an excited state, at a higher energy its ground state, causing it to release γ rays[9].

The latter phenomenon, constantly associated to the *EC*, represents in our opinion a particular of considerable importance. In fact, the nucleus emission of highly energetic electro-magnetic radiation (EMR), generally originates the production of pairs of light particles:

$$\gamma \rightarrow e^- + e^+ \qquad (4),$$

or:

$$\gamma \rightarrow \nu_e + \bar{\upsilon}_e \qquad (5),$$

where $\bar{\upsilon}_e$ is an electronic anti-neutrino. This phenomenon, which is accompanied by the *EC*, is completely superimposable to the so-called *photoannihilation*: also this process induces the production of pairs (particle with relative antiparticle) [11] exactly as represented in the Eqs.(4) and (5). Yet, if this phenomenon of *materialization* of the EMR, manifested in the production of lepton pairs, were represented in the equation describing the *EC*, one could better justify that ν appeared *ex abrupto* in Eq.(1).

Therefore, taking into account also the EMR (γ) emitted at the time of the *EC*, represented e.g. from Eq.(5), and inserting it into Eq.(1) on the side of the *captured* e^-, we should obtain a more complete and congruous description of the *EC* process:

$$e^- + P + \gamma \rightarrow e^- + P + \bar{\upsilon}_e.+ \nu_e \;\rightarrow\; N + \nu_e \qquad (6),$$

that is:

$$e^- + P + \bar{\upsilon}_e.+ \nu_e \;\leftrightarrow\; N + \nu_e \qquad (7).$$

Just to emphasize the importance of the role played by the EMR issued with the *EC*, as well as confirm its presence during the process, it may be useful to recall with Alvarez (the 1st to detect the *EC*) that for a safe *EC* detection is essential track down the effects of such EMR materialization!

In fact, Alvarez precises: "In the methods suggested for detecting the *capture of electrons*, no advantage was taken of the fact that the e^- was originally part of the stable electronic system of the parent atom, and that this system is disturbed by the loss of one of its component parts. It is well known that x-rays are given off by an atom which has lost one of its inner $e^-{}_s$ by *photo-ionization*, and the same will be true of one which has lost an inner e^- to the nucleus.. The vacant place in the inner shell will be immediately filled, and a quantum of x-radiation (or an Auger e^-) will be emitted in the process. It is this phenomenon which is the basis of a method of detection. Walke has shown that a strong positron activity of 16 days half-life is induced in titanium when it is bombarded with high energy deuterons (Phys. Rev.,51,1011,1937). The energy of the e^+ shows that the transition is not an allowed one (second Sargent curve), and this fact, together with the long life and relatively high *atomic number* for a e^+ emitter, suggested that it would be an ideal starting point in a search for the x-rays following *EC*[8].

They are just these physical processes, such as the "*photoannihilation* and the *Couple Production processes*"[11], generated by the *materialization* of the EMR emitted with the *EC*, which help us to better understand the *EC* in all its complexity. In fact, with the *materialization* of the EMR we have found the $\bar{\upsilon}_e$ which is missing in the *EC* equation (Eq.1), where only the ν_e is described, but without the counterpart. We wonder: where does the ν_e come from, placed at the right member? In fact, it is well known that when a particle is created *from scratch*, i.e. when a new particle materializes, its antiparticle is simultaneously generated. Likewise, a fundamental rule of Physics states that "matter and antimatter particles are always produced as a couple"[12], it's unequivocal! And so: what happened to the relative antiparticle of ν_e, i.e. the $\bar{\upsilon}_e$, which not represented in Eq.(1)?

And where is the $\bar{\upsilon}_e$? The $\bar{\upsilon}_e$ is present in the 1st member of Eq.(7) together with *P* and e^-, arranged in sequence, one after the other, to form a *multiplet*, corresponding to the *N* placed at the 2nd member of Eq.(7) itself, and to the 2nd member of Eq.(1), describing the *EC*. In this way, also implying the presence of a couple $\nu_e\ \bar{\upsilon}_e$ (generated by *photoannihilation*), and allocable to the 1st member of(1), this equation becomes more appropriate and physically more valid: see Eq.(7).

As it is known, according to the 1st Equivalence Principle (of Equations) we are allowed to subtract the ν_e present in the two members of (7), obtaining a new equation equivalent to the previous one:

$$e^- + P + \bar{\upsilon}_e \leftrightarrow N \qquad (8).$$

2.2 MASS GAP PROBLEM OF THE NEUTRON DECAY (*βd⁻*)

Let's try to read Eq.(8) in reverse:

$$N \rightarrow e^- + P + \bar{\upsilon}_e \qquad (9).$$

It is surprising: Eq. (9) shows exactly the decay products of *N*. In fact, this equation corresponds precisely to the famous equation describing the *N decay* or βd^- formulated by Fermi, in relation to the intuition of Pauli. In fact, Pauli and Fermi added a 3rd particle (represented by the $\bar{\upsilon}_e$) to the *N decay*, until then formulated as follows:

$$N \rightarrow e^- + P \qquad (10).$$

As already pointed out by Madame Curie, in the *N decay* emerges a conspicuous *mass-energy gap problem*, clearly visible in the Eq.(10). With a *brilliant stroke* Pauli proposes the solution: with the βd^- a 3rd particle is also emitted, of neutral charge, and with the same mass and spin of e^- [13]. Fermi fully agrees with Pauli's proposal, and inserts it in his equation of the *N decay* (see Eq.9) through the $\bar{\upsilon}_e$, considering the ν_s elementary particles, with neutral electric charge, and having the same mass of e^- [14].

In short, to solve the obvious *mass gap problem* of the *N decay*, the solution proposed by Pauli, fully shared by Fermi, is precise and detailed: the 3rd particle emitted must have the same mass of e^- and be sufficiently accelerated, since it must transport a mass of ~50% more than the *inertial mass* (0.511MeV) of the e^-.

In fact, let's try to analyze the mass-energy gap emerging from the βd^-. Let's evaluate the masses of the particles represented in Eq.(10), that is without the $\bar{\upsilon}$. The *N* weighs $1.67492728\cdot10^{-24}$[g], while the *P* weighs $1.67262171\cdot10^{-24}$[g]; on its turn the e^- weighs $9.1093826\cdot10^{-28}$[g]. The mass difference between *N* and *P* corresponds to Δ_M ($0.00230557\cdot10^{-24}$[g]), that is $\Delta_M = 2.30557\cdot10^{-27}$ [g]. According to the mass-energy conversion factors, if we consider with Feynman that "1 MeV is about $1.782\cdot10^{-27}$[g]" [15], and follow the *cgs* metric system, we have:

$$(2.30557/1.782)\cdot10^{-27}[g] = 1.29381\ MeV/c^2 \qquad (11).$$

This is the energy value that in the βd^- must be carried away by the e^- and a 3rd particle, in order to safeguard the energy-mass balance in this process[16]. The energy value expressed in Eq.(11) represents the maximum value of the energy spectrum ($\eta = E_{Max}$) of the β radiation emitted with βd^-. The minimum energy carried away by an e^- corresponds to 0.511MeV, thus the value of Eq.(11) is more than double than the energy of an e^- not particularly accelerated. With the decay of the *N*, instead, the *β ray* is accelerated to a very high speed, showing a marked *kinetic energy* (E_{Kin}). Nevertheless, only in very limited circumstances, and coincidentally, the total energy carried away by the β radiation is able to compensate for the difference in mass-energy between *N* and *P*. If we substract the *minimum energy* of an e^- from the energy value expressed by Eq.(11), we obtain the maximum value of the energy(Δ_E) that could be covered by the 3rd particle of the *βd* **:**

$$\Delta_E = 0.78281MeV \qquad (12).$$

This value exceeds the 53.1413 % the energy of an e^- *at rest*. But it is worth pointing out that this is the maximum value the 3rd particle can reach (considering that at the same time the e^- is emitted too). This does not mean that it always has so much energy, rather the contrary. In fact in the value expressed by Eq.(11) we must also consider the E_{Kin} of the β-ray, whose energy spectrum, as Fermi had reported [2][14], may also coincide with the entire energy value described by Eq.(11).

We wonder: can a single $\bar{\upsilon}_e$ compensate for the *mass gap* emerged from Eq.(10)? How heavy is a ν_e? Up until a few years ago it was even considered massless! Then, after the evidence for oscillation of atmospheric ν_s, carried out at the Super-Kamiokande [17], it had to be recognized a mass to the ν, albeit infinitesimal. Maiani states: "The current upper limits of the mass of the ν emitted with the *β-decay* are of the type m_ν <2eV" [18], a value corresponding to <1/250000 of the electronic mass!

At this point it may be useful to review the basic requirements originally requested by Pauli and Fermi for the ν, i.e. for the 3rd particle in the βd^-.

These requests are essentially three: 1) it is electrically neutral; 2) it has the mass of an e^-; 3) it has the same spin of the e^- [13][14].

Well, why not to think immediately to the possible existence of a neutral electron (e°)?

All requests would be satisfied. It seems the most *logical* answer, and physically more than adequate to meet the demands of Pauli and Fermi. Even in this way the energy balance in the *N* disintegration is restored, thus safeguarding the Laws of Conservation of Mass and Energy and at the same time safeguarding the Law of Conservation of Electric Charge, Angular Momentum and Lepton Number[19]. Moreover, we want to emphasize that referring to this 3rd neutral particle emitted with the *βd*, Pauli wrote: "it has spin ½ and its mass should be of the same order of magnitude of the e^-"[13]. That is, Pauli's opinion, this 3rd particle should be a fermion, with the mass of the e^-, but without carrying electric charge: you could really think of an e^- without electric charge, a *neutral electron* (e°).

2.3 *INDIRECT* DETECTION of the 3rd PARTICLE of the βd^-

In this regard, a fundamental clarification must be made: every time it was considered that the ν_s had been detected, they were always *indirect detections* thanks to traces left by a *ghost particle* never detected *de visu,* never directly identified. Generally, these indirect detections of the 3rd particle of the βd^-, indicated as ν, are represented by the so-called *Cherenkov Effect* [20]. It is the detection of the impacts' effects, such as the *Cherenkov Effect* (CE), to prove the existence of ν, although it might be another particle to induce the CE.

In Nature the CE is only elicited by $e^-{}_s$ [21]. That is the mark that distinguishes events sought is therefore a double coincidence in a pair of scintillators, separated by a time of a few microseconds. If instruments had revealed γ rays exactly of two energies provided, separated by suitable intervals, the investigators would have caught the $\bar{\upsilon}$. Thus, this was enough to believe to have found, specifically and unequivocally the effects of the elusive $\bar{\upsilon}$.

With good conscience, this statement seems to us a *stretch* in the interpretation of the findings. That statement, in our view, requires a preconceived, a *dogma*: that the 3rd particle emitted with βd^- must be only and unquestionably an $\bar{\upsilon}$, no other type of particle.

On the contrary, in our opinion the minimal mass attributed to the $\bar{\upsilon}_e$ will never be able to solve the *mass gap problem* of the *N decay*.

An anti-neutral electron (ē°), instead, would have all requirements to represent the 3rd particle of the βd^-.

3. CONCLUSIONS

However, it could be said that the same results reached by an e° are obtained similarly even with a ν. And then: e° does not exist, this is an invention! The only known electrons are those carrying an electric charge: e^- and e^+.

Yet even the ν, when suggested by Pauli, was an invention. Moreover the ν was a particle totally unknown, invented from *scratch*. Indeed, it was forced to introduce in Physics, *compulsorily*, a new family of particles, with their own characteristics, and with presumed properties quite different from the other elementary particles known at the time.

The e°, instead, refers to one of the fundamental particles more widespread in Nature, even if only those electrically charged are known.

In addition, a not negligible result, with the e° it is not necessary to invent a new category of particles to be added to the *Standard Model* (SM), maintaining the symmetry of the SM and further simplifying it, according to the *reductionist* approach preferably adopted in Physics [22].

Yet, one might object: why the e° has never been detected, even accidentally? Electron decay products emerge continuously in the *colliders*!

But it is clear: the crucial difference lies in the fact that we are talking about electrons without electricity charge, they do not interact with matter for all the same reasons ν_s do not interfere.

If e° really exists, then the equation of *N decay*, or βd^- (Eq.9), can be written as follows:

$$N \rightarrow e^- + P + \bar{e}^\circ \qquad (13).$$

Moreover, as regards the *EC*, considering also the effects induced by the EMR, produced during the *EC*, we should have a more complete and congruous description of this phenomenon, as illustrated in Eq.(7).

So, if the existence of the e° should be real, then Eq.(7) describing the *EC* should be rewritten as follows:

$$e^- + P + \bar{e}^\circ + e^\circ \leftrightarrow N + e^\circ \qquad (14).$$

In this way, similarly to the *mass gap problem* related to the *N decay*, or βd^-, the e° would brilliantly solve also the *mass gap* easily readable in Eq.(7), even more evident in Eq.(1) describing the *EC* from the beginning.

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