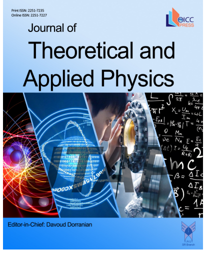

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Investigating the resonance in the palladium surface plasmon electrons for inverse $-\beta$ reaction in electrolysis process

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Abstract:
The resonance effect happens in very number of natural oscillators and very important in a lot of phenomena. In the surface of a hydride metal, the resonance effect causes the kinetic energy of electrons is increased until they can cooperate inverse $-\beta$ interaction. This reaction can be done in the electrolysis of palladium and platinum in water electrolyte. In this research, a new method for calculating the rate of inverse $-\beta$ interaction is introduced. This method is based on the Feynman equations that is more understandable and simpler compared to other methods. The inverse $-\beta$ interaction is created by high energy electrons. Surface electrons accelerate by resonance effect which it is produced by electrolysis process. The atomic electrons of metal behave as a forced oscillator with very small damping which cause the resonance effect. We will indicate this resonance effect is satisfied by the new equations. The theoretical results have good agreement with experimental results.

Keywords: Feynman equations; Nuclear reactions; Fleischmann–Pons study

1. Introduction

Weak nuclear interactions are considered the same as strong nuclear interactions and are used in different fields. In weak nuclear interactions, boson W and Z boson are Intermediately transported particles. The inverse beta interaction is a type of weak nuclear interaction. In the inverse beta interaction, a proton particle interacts with an electron particle and a neutron and a neutrino particles are produced.($W = 782.3$ keV [1])

$$W_{electric} + p + e \rightarrow n + \nu \tag{1}$$

In 2001, Mizuno and his colleagues performed experiments in a metal-hydrogen system and measured the emission of neutrons [2]. In 2006, a conceptual model was introduced to explain the interactions and then considered the formulation of the inverse $-\beta$ interaction and neutron production. In this model, the metal-hydrogen system is subjected to test conditions and at the metal-hydrogen interface, the metal atomic electrons and the protons of the hydrogen atom nucleus are affected and the inverse $-\beta$ reaction occurs [3]. This reaction requires a significant amount of primary energy, although most of this energy is converted and the product of this interaction is low-energy neutrons. In 2010, the following formula was presented for the neutron production rate based on their conceptual model [4]:

$$\Gamma = \left(\frac{(2\pi)^3 G_F m_e^2 c}{h^3}\right)^2 \left(\frac{2\pi m_e c^2}{h}\right) \left(\frac{\beta - \beta_0}{\beta_0}\right) \tag{2}$$

here, G_F is the Fermi coupling constant, m_e is the rest mass of the electron, β_0 is a constant equal to 2.53, and β is the electron mass renormalization factor. By multiplying β by the rest mass of the electron, an electron with more mass (or energy) is obtained and is called a heavy electron. β is equal to [3]:

$$\beta = \frac{\widetilde{m}_e}{m_e} = \sqrt{1 + 19.6\frac{|u^2|}{a^2}} \tag{3}$$

here, $\widetilde{m}_e$ is the mass of the heavy electron, m_e is the mass of the stationary electron, and u is the displacement of the proton in its oscillation in palladium metal hydride.

u is obtained from the oscillating electric field E of the proton [3]:

$$E = \sqrt{\left(\frac{m_e^2\omega^2c^2}{q^2}\right)\times\left(1-(\frac{m_ec^2}{K+m_ec^2})^2\right)} \quad (4)$$

$$u = \frac{Eq}{m_p\omega^2} \quad (5)$$

here, ω is the frequency of proton oscillation on the palladium surface, K is the kinetic energy of the electron, m_e and m_p are the mass of the electron and the mass of proton, respectively. There are two theories to explain the initial energy of the electron in the inverse beta interaction. The first theory suggests that the free palladium electrons gain a lot of energy due to the vector potential of the field, which is called a heavy electron. The second theory suggests that due to the electric field of electrolysis and regular strikes of deep electrons to surface electrons, then the surface electrons gain a lot of energy due to the resonance phenomenon, which our article is based on this theory. In 2005, Scully has studied photoexcitation of a volume plasmon in Carbon ions [5]. In 2008, Kooyman has explained the surface plasmon resonance [6]. In 2010, Yanchuk has studied the Fano resonance in plasmonic nano structures and metamaterias [7]. In 2012, Nathalie has studied quantum plasmonic circuits [8]. In 2012, Jonathan has studied the quantum plasmon resonances in individual metallic noanoparticles [9]. In 2013, Li has studied landau damping of quantum plasmons in metal nanostructures and Asenjo has studied the plasmon electron energy gain spectroscopy [10, 11]. In 2014, Zhang has studied the theory of quantum plasmon resonances in the doped semiconductor nanocrystals [12]. In 2015, benjamin has studied quantum plasmonic sensing [13]. In 2017, quantum noise reduction in intensity-sensitive surface plasmon resonance sensors and electrical tuning of a quantum plasmonic resonance have been studied [14, 15]. The electron-hole resonance in epitaxial graphene and varying wavelength dependent quantum plasmon tunneling with the thickness of graphene space have been done [16, 17]. In 2020, Mokkath has studied an asymeteric aluminum active plasmon resonance devise and Arabkhorasani has studied performance evaluation of metal photocathode based on plasmonic nano gating [18, 19]. In this paper, inverse beta interaction phenomenon in the metal-hydrogen electrolysis system has been modeled using Feynman equations and its calculations have been done. In this system, the required energy to perform the inverse beta reaction is provided by the electron surface plasmon. The required energy is caused by resonance of surface electron plasmon and it obtains by a new method. This resonance phenomena can be applied to every oscillations, that have very little damping.

2. Method

To calculate the resonance equations, we first consider the undamped oscillator state, which there is an oscillating force increases its amplitude. We have [20]:

$$m\frac{d^2x}{dt^2} + m\omega_0^2 x = F_0\cos(\omega t) \quad (6)$$

This equation has the solution

$$x = \frac{F_0}{m(\omega_0^2-\omega^2)}\cos(\omega t) \quad (7)$$

Now suppose that $\omega_0 = \omega$. Obviously, we cannot use Eq. (7) because it is equal to infinite in $\omega_0 = \omega$. In this condition we guess the solution is equal to $x = At\cos(\omega t) + Bt\sin(\omega t)$. Therefore we put this solution of (x) in Eq. (6), we have:

$$x = At\cos(\omega t) + Bt\sin(\omega t) \quad (8)$$

$$2B\omega\cos(\omega t) - 2A\omega\sin(\omega t) = \frac{F_0}{m}\cos(\omega t) \quad (9)$$

If $A = 0$, according to Eq. (9), B is equal to:

$$B = \frac{F_0}{2m\omega} \quad (10)$$

Putting$A$ and B in Eq. (8), we have:

$$x = \frac{F_0}{2m\omega}t\sin(\omega t) \quad (11)$$

Eq. (11) is the answer of undamped oscillator in Eq. (6) in $\omega_0 = \omega$. Now suppose we have an oscillator with very low damping. In this condition we will have the resonance equation and the amplitude of oscillator increase step by step. We can obtain amount of (x) for this oscillator. The equation of this damped oscillator is equal to [21]: (Υ is damping coefficient)

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + m\omega_0^2 x = F_0\cos(\omega t) \quad (12)$$

$$b = 2m\gamma \Rightarrow m\frac{d^2x}{dt^2} + 2m\gamma\frac{dx}{dt} + m\omega_0^2 x = F_0\cos(\omega t) \quad (13)$$

If we calculate integral of both side of Eq. (13), we have:

$$m\frac{dx}{dt} + 2m\gamma x + m\omega_0^2\int xdt = \frac{F_0}{\omega}\sin(\omega t) \quad (14)$$

We guess the solution of (x) is equal to:

$$x = \frac{F_0}{2m\omega}t\sin(\omega t) + f(t) \quad (15)$$

If we put Eq. (15) in Eq. (14), we have:

$$m\frac{F_0}{2m\omega}\sin(\omega t) + m\frac{F_0}{2m}t\cos(\omega t) + 2m\gamma\frac{F_0}{2m\omega}t\sin(\omega t) + m\omega_0^2\int(\frac{F_0}{2m\omega}t\sin(\omega t) + f(t))dt = \frac{F_0}{\omega}\sin(\omega t) \quad (16)$$

For equality in Eq. (16), $f(t)$ is equal to: ($\omega = \omega_0$)

$$f(t) = -\frac{F_0\gamma}{2m\omega^2}t\cos(\omega t) - \frac{F_0\gamma}{2m\omega^3}\sin(\omega t) \quad (17)$$

Therefore (x) is equal to:

$$x = \frac{F_0}{2m\omega}t\sin(\omega t) - \frac{F_0\gamma}{2m\omega^2}t\cos(\omega t) - \frac{F_0\gamma}{2m\omega^3}\sin(\omega t) \quad (18)$$

Eq. (18) is the answer of Eq. (12) in $\omega = \omega_0$. In $\omega = \omega_0$, damping part is approximately equal to zero ($b \sim 0$) therefore if ($b \sim 0$) Eq. (12) is equal to Eq. (6).
For correctness test of Eq. (18) we can put Eq. (18) in Eq. (6). By putting Eq. (18) in (6),we have:

$$\frac{dx}{dt} = \frac{F_0}{2m\omega}\sin(\omega t) + \frac{F_0}{2m}t\cos(\omega t) - \frac{F_0\gamma}{2m\omega^2}\cos(\omega t) + \frac{F_0\gamma}{2m\omega}t\sin(\omega t) - \frac{F_0\gamma}{2m\omega^2}\cos(\omega t) \tag{19}$$

$$\frac{d^2x}{dt^2} = \frac{F_0}{2m}\cos(\omega t) + \frac{F_0}{2m}\cos(\omega t) - \frac{F_0\omega}{2m}t\sin(\omega t) + \frac{F_0\gamma}{2m\omega}\sin(\omega t) + \frac{F_0\gamma}{2m\omega}\sin(\omega t) + \frac{F_0\gamma}{2m}t\cos(\omega t) + \frac{F_0\gamma}{2m\omega}\sin(\omega t) \tag{20}$$

According to ($\omega_0 \sim \omega$), after putting d^2x/dt^2 and $\omega_0^2 x$ in (6), we have: ($\Upsilon/\omega \sim 0.01$)

$$\frac{F_0\gamma}{2m\omega}\sin(\omega t) \approx 0.01\frac{F_0}{2m}\sin(\omega t) \Rightarrow \omega_0 \approx \omega \Rightarrow \frac{F_0}{2m}\cos(\omega t) + \frac{F_0}{2m}\cos(\omega t) = \frac{F_0}{m}\cos(\omega t) \tag{21}$$

According to equality in Eq. (21), so Eq. (18) is correct answer of Eq. (12) and the resonance effect happen when damping is very low ($b \sim 0$).

3. Results and discussion

3.1 Plasmon electron energy

Eq. (18) is a general equation for all of damped oscillators which contains very low damping coefficient (Υ). We use from Eq. (18) for oscillation in palladium electron surface plasmon. The oscillator equation in plasmon is equal to [21]:

$$m_e\frac{d^2x}{dt^2} + m_e\gamma\frac{dx}{dt} + m_e\omega_0^2 x = E_0 q\cos(\omega t) \tag{22}$$

here Υ is angular frequency of collision between electrons which is equal to 10^{14} Hz. E_0 is the electric field of cathode wire applied to Plasmon electrons which it is equal to $E_0 \sim 0.05$ V/m. The resonance equation for palladium plasmon is equal to [21]:

$$x = \frac{E_0 q}{2m_e\omega}t\sin(\omega t) - \frac{E_0 q\gamma}{2m_e\omega^2}t\cos(\omega t) + \frac{E_0 q\gamma}{2m_e\omega^3}\sin(\omega t) \tag{23}$$

The kinetic energy (K) in this vibration is equal to:

$$K = \frac{1}{2}m_e\omega_0^2 x_{max}^2 = \frac{1}{2}m_e\omega_0^2\left(\frac{E_0^2 q^2}{4m^2\omega^2}t^2\sin^2(\omega t)\right)$$

$$\omega_0 \approx \omega \Rightarrow K = \frac{1}{8}\frac{E_0^2 q^2}{m_e}t^2\sin^2(\omega t) \tag{24}$$

The period of one cycle is given by $T = 2\pi/\omega$. For calculation of average amount of $\sin^2(\omega t)$ we have:

$$avarage - amount = \frac{1}{T}\int_0^T \sin^2(\omega t)dt = \frac{1}{2} \tag{25}$$

Therefore, kinetic energy (K) is equal to:

$$K = \frac{1}{16}\frac{E_0^2 q^2}{m_e}t^2 \tag{26}$$

In the electrolysis of palladium and platinum by water electrolyte, amount of proton or deuteron due to electrolysis process is given by Faraday equation in below [22]:

$$n = \left(\frac{It}{F}\right)\left(\frac{1}{z}\right) \tag{27}$$

here, n is the mole of produced proton or deuteron. F is Faraday constant which is equal to $F = 96485$ C/mole. z is the number of transited electrons per one ion which here is equal to $z = 1$. I is current in ampere unit. t is the time of electrolysis. Eq. (27) indicates the maximum of produced neutron in the electrolysis system. The electric field (E) inside of wire which it contain electricity is equal to [23]:

$$E = \frac{Im_e}{n_F A q^2 \tau} \tag{28}$$

here I is the current flowing through the conductor in amperes. n_F is the number of free electrons inside of wire per unit of volume. q is the charge of an electron in Coulombs. A is the area of the cross section of the conductor in m^2. τ is the time of without collision between electrons which is equal to $\tau = 10^{-14}$ s. If we put for A, the area of the cross section of palladium electrode. We obtain the amount of E_0 in Eq. (28). Therefore by placing Eq. (28) in Eq. (26) we obtain the relation between the kinetic energy of plasmon (K) and the electrolysis amprage (I). We have:

$$K = \frac{1}{16}\left(\frac{I^2 m_e}{n_F^2 q^2 A^2 \tau^2}\right)t^2 \tag{29}$$

For example, we have:

$$I = 0.08t \tag{30}$$

Placing Eq. (30) in Eq. (29) we have:

$$K = \frac{1}{2500}\left(\frac{m_e}{n_F^2 q^2 A^2 \tau^2}\right)t^4 \tag{31}$$

Fig. 1 indicates the relation between the kinetic energy of plasmon electron and electrolysis time. According to Fig. 1, the plasmon electron in $t = 8.0762$ s gets the threshold energy for start of inverse $-\beta$ interaction which it is equal to $K = 0.7823$ MeV. After the plasmon electron gets this energy it exit from its location and it don't get upper energies in the times after $t = 8.0762$ s but if it stays in its location its energy is increased like Fig. 1 plot.

3.2 Calculation of reaction rate and comparison with experimental results

In this section we will obtain neutron production rate per unit of time in the inverse $-\beta$ interaction by Feynman equations. Interaction of inverse $-\beta$ is:

$$W_{electric} + p + e \rightarrow n + \nu \tag{32}$$

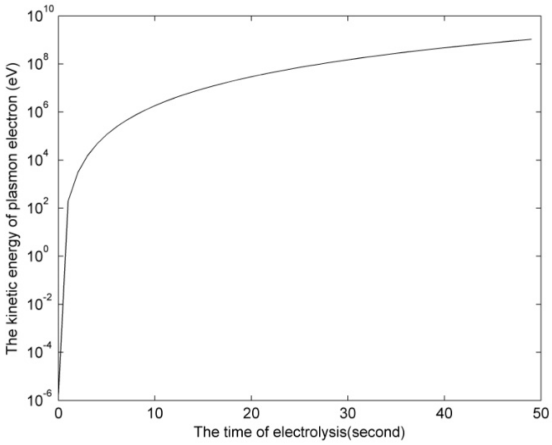

Figure 1. Relation between the kinetic energy of plasmon electron and the time of electrolysis.

Which we know, we can use amplitude (M) of positron decay interaction for inverse $-\beta$ interaction [24]:

$$p \to e^{+}n+\nu \tag{33}$$

Widom and Larsen have calculated amplitude of (M) by Feynman equations and they have used from heavy electron theory in their calculations for obtain Eq. (2) but we have used Feynman equations for calculate (M) without using of heavy electron theory. By using of Feynman diagram for Eq. (33), amplitude (M) is equal to [24, 25]:

$$iM=\sum\left[\bar{u}(3)\left[\frac{ig_W}{2\sqrt{2}}\gamma^{\mu}(1-\gamma^{5})\right]u(1)\right]\frac{-i(g_{\mu\nu}-\frac{q_\mu q_\nu}{)}M_W^2c^2}{q^2-(M_Wc)^2} \times\left[\bar{u}(4)\left[\frac{ig_W}{2\sqrt{2}}\gamma^{\nu}(1-\gamma^{5})\right]u(2)\right] \tag{34}$$

Because $q^2 \ll (M_Wc)^2$, we can use $ig_{\mu\nu}/(M_Wc)^2$ instead of $-i(g_{\mu\nu}-q_\mu q_\nu/(M_Wc)^2)/(q^2-(M_Wc)^2)$,we have:

$$iM=\sum\left[\bar{u}(3)\left[\frac{ig_W}{2\sqrt{2}}\gamma^{\mu}(1-\gamma^{5})\right]u(1)\right]\frac{ig_{\mu\nu}}{(M_Wc)^2} \times\left[\bar{u}(4)\left[\frac{ig_W}{2\sqrt{2}}\gamma^{\nu}(1-\gamma^{5})\right]u(2)\right] \tag{35}$$

$$M=\frac{g_W^2}{8(M_Wc)^2}\sum[\bar{u}(3)[\gamma^{\mu}(1-\gamma^{5})]u(1)] \times[\bar{u}(4)[\gamma_{\mu}(1-\gamma^{5})]u(2)] \tag{36}$$

$$\sum_{spin}|M|^2=\left(\frac{g_W^2}{8(M_Wc)^2}\right)Tr[\gamma^{\mu}(1-\gamma^{5})(\gamma^{\mu}p_1+m_pc)\gamma^{\nu} (1-\gamma^{5})(\gamma^{\mu}p_3+m_nc)]\times Tr[\gamma_{\mu}(1-\gamma^{5})(\gamma^{\mu}p_2+m_ec)\gamma_{\nu} (1-\gamma^{5})\gamma^{\mu}p_4] \tag{37}$$

$$\sum_{spin}|M|^2=\left(\frac{g_W^2}{8(M_Wc)^2}\right)[8(p_1^{\mu}p_3^{\nu}+p_1^{\nu}p_3^{\mu}-g^{\mu\nu}(p_1.p_3) -i\varepsilon^{\mu\nu\lambda\sigma}p_{1\lambda}p_{3\sigma})]\times[8(p_{2\mu}p_{4\nu}+p_{2\nu}p_{4\mu}-g_{\mu\nu}(p_2.p_4) -i\varepsilon_{\mu\nu K\tau}p_2^{K}p_4^{\tau})] \tag{38}$$

$$\sum_{spin}|M|^2=4\left(\frac{g_W^2}{(M_Wc)^2}\right)(p_1.p_2)(p_3.p_4) \tag{39}$$

Because initial particles are electron and proton and number of spins for both particles are two of spins, therefore average spins for each particle is half of number of spins so is one spin, so we have:

$$\frac{1}{2}\sum_{initial1}e\frac{1}{2}\sum_{initial2}p\sum_{spin}|M|^2=\frac{1}{2}\times2\times\frac{1}{2}\times2\times4(\frac{g_W^2}{(M_Wc)^2})^2 (p_1.p_2)(p_3.p_4)\Rightarrow|M|^2=4(\frac{g_W^2}{(M_Wc)^2})^2(p_1.p_2)(p_3.p_4) \tag{40}$$

here p_1, p_2, p_3, p_4 are respectively the momentum of proton and the momentum of electron and the momentum of neutron and the momentum of neutrino. The value of can be calculated as follows:

$$p_3.p_4=m_nc\times\frac{E_\nu}{c}=m_nE_\nu \tag{41}$$

$$p_4\approx0,(p_1+p_2)^2=(p_3+p_4)^2$$

$$p_1p_2=\frac{p_3^2-p_2^2-p_1^2}{2}+p_3p_4 \tag{42}$$

$$(p_1.p_2)(p_3.p_4)=(\frac{(m_n^2-m_p^2-m_e^2)c^2}{2}+m_nE_\nu)(m_nE_\nu) \tag{43}$$

If we put Eq. (43) in Eq. (40),we obtain:

$$\langle|M|^2\rangle=4\left(\frac{g_W}{M_Wc}\right)^4m_nE_\nu\left(\frac{(m_n^2-m_p^2-m_e^2)c^2}{2}+m_nE_\nu\right) \tag{44}$$

The differential rate of neutron production is equal to [24]:

$$d\Gamma=\frac{\langle|M|^2\rangle}{2\hbar m_p}\left(\frac{cd^3p_2}{(2\pi)^32E_2}\right)\left(\frac{cd^3p_3}{(2\pi)^32E_3}\right)\left(\frac{cd^3p_4}{(2\pi)^32E_4}\right) (2\pi)^4\times\left(m_pc+\frac{E_2}{c}-\frac{E_3}{c}-\frac{E_4}{c}\right)\delta^3(p_2+p_3+p_4) \tag{45}$$

where, E_2, E_3 and E_4 are equal to:

$$E_2=c\sqrt{p_2^2+m_e^2c^2}$$

$$E_3=c\sqrt{p_3^2+m_n^2c^2},\ \ E_4=c|p_4|$$

After calculating integral in Eq. (45), we obtain:

$$d\Gamma=\frac{2c^3\langle|M|^2\rangle d^3p_2d^3p_4}{(4\pi)^5\hbar m_pE_2E_3E_4}\delta\left(m_pc+\frac{E_2}{c}-\frac{E_3}{c}-\frac{E_4}{c}\right) \tag{46}$$

We have:

$$\left(\frac{E_3}{c}\right)^2=|p_2+p_4|^2=p_2^2+p_4^2+2p_2p_4 =\frac{1}{c^2}(E_2^2+E_4^2+2E_2E_4\cos(\theta)) \tag{47}$$

$$d^3p_4=\left(\frac{E_4}{c}\right)^2\frac{dE_4}{c}\sin(\theta)d\theta d\varphi \tag{48}$$

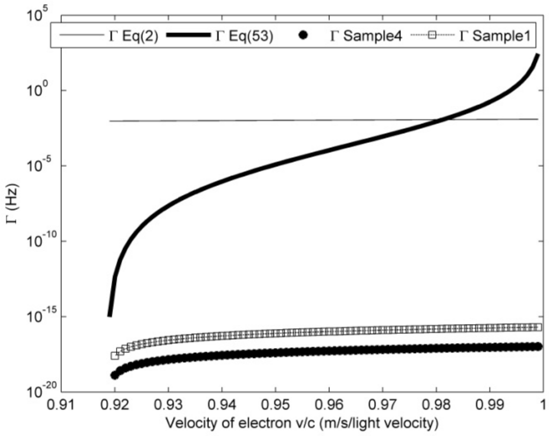

Figure 2. Comparing between Γ in the theoretical results Eq. (2) and Eq. (53) and the experimental results [2].

Assuming that the z-axis is along p_3, we have:

$$E_3 = c\sqrt{|p_2|^2 + |p_4|^2 + 2|p_2||p_4|\cos(\theta) + m_n^2 c^4} = cx \tag{49}$$

$$\frac{E_4 \sin(\theta) d\theta}{E_3} = -\frac{dx}{|p_2|} \tag{50}$$

$$d^3 p_2 = 4\pi |p_2|^2 d|p_2| = \frac{4\pi}{c^2} |p_2| E_2 dE_2 \tag{51}$$

If we put the values and delete dirac delta function in Eq. (46), we have:

$$\frac{d\Gamma}{dE} = -\frac{4\pi}{h\pi^3}\left(\frac{g_W}{2M_W c^2}\right)^4 E\sqrt{E^2 - m_e^2 c^4}[(m_n - m_p)c^2 - E]^2 \tag{52}$$

After calculating the integral of Eq. (53) from E_1 to E_2 we obtain: ($E_1 = m_e c^2$, $E_2 = m_e c^2 + (m_p - m_n)c^2 + W$)

$$\Gamma \approx (2\pi)^7 \frac{0.026}{h} \frac{G_F^2}{(hc)^6} (m_e c^2)^5 (1 + \frac{W}{m_e c^2} - \beta_0)^5 \tag{53}$$

By comparing plots in Fig. 2, is observed that the result of Eq. (53) is closer to experimental results. Table 1 indicates the average neutron production in Mizuno experiment [2]. If we write the rate of neutron production per unit of time

Table 1. The average neutron detection per unit of second (n/s).

Sample n	Average n	Sample n	Average n
1	8772	4	7869

(Γ_{Total}) at the speed of 0.919c with Eq. (2) and Eq. (53), we will have:

$$\Gamma_{Th}(\text{Eq.}(2)) = 0.0089\text{Hz} \tag{54}$$

$$\Gamma_{Th}(\text{Eq.}(53)) = 2.37 \times 10^{-16}\text{Hz} \tag{55}$$

$$\Gamma_{Total} = \Gamma \times n_e \times \text{volume} \tag{56}$$

$$\Gamma_{Total}(\text{Eq.}(2)) = 0.0089 \times 4.39 \times 10^{28} \times 0.9 \times 10^{-6} = 3.51 \times 10^{20} \text{n/S} \tag{57}$$

$$\Gamma_{Total}(\text{Eq.}(53) = 1.3 \times 10^{-16} \times 4.39 \times 10^{28} \times 0.9 \times 10^{-6} = 5.21 \times 10^{6} \text{n/S} \tag{58}$$

For the rate of produced neutrons (Γ_{Total}) and measured neutrons (φ), we have:

$$\varphi = \Gamma_{Total} \times T \tag{59}$$

The fraction of neutron passing through the material (T) is obtained from the following Equation (26) [26]:

$$T = \frac{e^{\frac{-R}{L}}}{4\pi RD} = 1.54 \times 10^{-3} \quad 1/\text{cm}^2 \tag{60}$$

Here, n_0 is the primary neutron production per second and per unit area, L is the thermal diffusion length, D is the diffusion coefficient, and R is the radius of the sphere, we have:

$$\varphi_{Eq.(2)} = 3.51 \times 10^{20} \times 1.54 \times 10^{-3} = 5.41 \times 10^{17} \quad \text{n/Scm}^2 \tag{61}$$

$$\varphi_{Eq.(53)} = 5.21 \times 10^{6} \times 1.54 \times 10^{-3} = 8.02 \times 10^{3} \quad \text{n/Scm}^2 \tag{62}$$

According to the average measured neutron rate (listed in Table (1)), the obtained data from Eq. (62) is in good agreement with the experimental results. So, the results of Eq. (53) compared to Eq. (2) is in better agreement with the experimental results.

4. Conclusion

The behavior of the surface plasmon electron with the resonance phenomena is investigated. Resonance phenomena can be applied to every oscillation, that have very little damping. In general, the results clearly show that surface plasmon resonance, is an effective method to increase the plasmon electron energy. By changing the plasmonic resonance quantities of the structure, the desired conditions of maximum plasmon electron energy at the desired wavelength can be achieved.In this paper, plasmon electron energy, and inverse beta rection amplitude and neutron production rate per unit of time have been calculated and finally compared with experimental results. A method based on Feynman's equations is presented to calculate the inverse beta interaction and neutron production and is introduced resonance phenomenon as a creator for this interaction. The results of this presented method have been compared with the theoretical data and experimental results of other works. The obtained data is in good agreement with the experimental results.

Conflict of interest statement:
The authors declare that they have no conflict of interest.

References

[1] K. Krane and D. Halliday. *Introductory nuclear physics*. John Wiley, New York, 1988.

[2] T. Mizuno and T. Akimoto. "Neutron evolution from a palladium electrode by alternate absorption treatment of deuterium and hydrogen". *Japanese Journal of Applied Physics*, **40**:L989, 2001.

[3] A. Widom and L. Larsen. "Theoretical standard model rates of proton to neutron conversions near metallic hydride surfaces". *arXiv preprint nucl-th/0608059*, :147, 2006.

[4] A. Widoma, L. Larsen, and Y. N. Srivastava. "A primer for electroweak induced low-energy nuclear reactions". *Pramana*, **75**:617, 2010.

[5] S. W. J. Scully, E. D. Emmons, M. F. Gharaibeh, and R. A. Phaneuf. "Photoexcitation of a volume plasmon in C 60 ions". *Physical review letters*, **94**:065503, 2005.

[6] Rob P. H. Kooyman. "Physics of surface plasmon plasmon resonance". *Royal Society of Chemistry*, **30**:15, 2008.

[7] Boris L. Yanchuk, Nikolay I. Zheludev, Stefan A. Maier, Naomi J. Halas, P. Nordlander, H. Giessen, and Chong T. Chong. "The Fano resonance in plasmonic nanostructures and metamaterials". *Nature Materials*, **9**:707, 2010.

[8] P. Nathalie and D. Leon. "Lukin quantum plasmonic circuits". *IEEE Journal of Selected Topics in Quantum Electronics*, **18**:1781, 2012.

[9] A. Jonathan, A. Jonathan, A. Koh, A. Jennifer, Leen A, and A. Dionne. "Quantum plasmon resonances of individual metallic nanoparticles". *Nature*, **483**:421, 2012.

[10] X. Lee and Di Z. Zhang. "Landau damping of quantum plasmons in metal nanostructures". *New Journal of Physics*, **15**:023011, 2013.

[11] A. Asenjo Garcia and F. J. Garcia de Abajo. "Plasmon electron energy-gain spectroscopy". *New Journal of Physics*, **15**:103021, 2013.

[12] H. Zhang, V. Kulkarni, E. Prodan, and P. Nordlander. "Theory of quantum plasmon resonances in doped semiconductor nanocrystals". *The Journal of Physical Chemistry C*, **118**:16035, 2014.

[13] J. Benjamin, L. Wenjiang, and C. Raphael. "Quantum plasmonic sensing". *Physical Review A*, **92**:053812, 2015.

[14] J. S. Lee, T. Huynh, S. Y. Lee, K. G. Lee, J. Lee, M. Tame, C. Rockstuhl, and Ch. Lee. "Quantum noise reduction in intensity-sensitive surface-plasmon-resonance sensors". *Physical Review A*, **96**:033833, 2017.

[15] X. Liu, J. H. Kang, H. Yuan, J. Park, S. J. Kim, Y. Cui, H. Y. Hwang, and M. L. Brongersma. "Electrical tuning of a quantum plasmonic resonance". *Nature nanotechnology,12,(2017), 866–*, **12**:866, 2017.

[16] C. Tegenkamp andH. Pfnur, T. Langer, and J. Baringhaus H. W. Schumacher. "Plasmon electron-hole resonance in epitaxial graphene". *Journal of Physics: Condensed Matter*, **23**:012001, 2018.

[17] K. J. Lee, S. Kim, W. Hong, H. Park, M. S. Jang, K. Yu, and S-Y. Choi. "Observation of wavelength-dependent quantum plasmon tunneling with varying the thickness of graphene spacer". *Scientific Reports*, **9**:1, 2019.

[18] J. Mokkath and J. Henzie. "An asymmetric aluminum active quantum plasmonic device". *Physical Chemistry, ChemicalPhysics*, **22**:1416, 2020.

[19] A. Arabkhorasani, J. Khalilzadeh, H. Zaki Dizaji, and Y. Shahamat. "Performance evaluation of metal photocathodes based on plasmonic nano grating". *Optik*, **252**:168538, 2020.

[20] R. Fitzpatrick. *Oscillation and waves: An introduction*. CRC Press, 2018.

[21] Stefan A. Maier. *Plasmonics: Fundamentals and Applications*. Springer, 2007.

[22] W. Berkson. *Fields of Force: The Development of a World View from Faraday to Einstein*. Routledge, 2014.

[23] D. Halliday, R. Resnick, J. Walker, F. Edwards, and John J. Merrill. *Fundamentals of Physics*. John Wiley and Sons, 2010.

[24] F. Halzen, Alan D. Martin, and N. Mitra. "Quarks and Leptons: An introductory course in modern particle physics". *Am. J. Phys.*, **53**:287, 1985.

[25] David J. Griffiths. *Introduction to Elementary Particles*. John Wiley and Sons, 2008.

[26] H. Cember. *Introduction to Health Physics*. Mac Grew Hill Medical, 2009.