



Determination of Cross Section for Different Fusion Reactions in Terms of Lattice Effects in Solid State Internal Conversion for Different Metallic Crystalline Environments

S. N. Hosseinimotlagh^{1*} and M. Shahamiri²

¹Department of Physics, Shiraz Branch Islamic Azad University, Shiraz, Iran.

²Sama Technical and Vocational College, Islamic Azad University, Kazeroon Branch, Kazeroon, Iran.

Authors' contributions

This work was carried out in collaboration between all authors. Author SNH designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors SNH and MS managed the literature searches, analyses of the study performed. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2015/9685

Editor(s):

(1) Martin Kröger, Professor, Computational Polymer Physics, Swiss Federal Institute of Technology (ETH Zürich), Switzerland.

(2) Shi-Hai Dong, Department of Physics, School of Physics and Mathematics National Polytechnic Institute, Building 9, Unit Professional Adolfo Lopez Mateos, Mexico.

Reviewers:

(1) Pasquale Avino, Air Chemical Laboratory, DIPIA, INAIL Settore Ricerca, Via IV Novembre 144, 00187 Rome, Italy.

(2) Anonymous, The First Technical School TESLA, Croatia.

Complete Peer review History: <http://www.sciencedomain.org/review-history.php?iid=758&id=31&aid=7116>

Original Research Article

Received 22nd February 2014

Accepted 18th November 2014

Published 8th December 2014

ABSTRACT

In the present paper, the cross section of the $D(d,p)T$, $D(d,\gamma)^4\text{He}$, $T(d,n)^4\text{He}$ and $D(p,\gamma)^3\text{He}$ fusion reactions in terms of the lattice effect in solid state internal conversion for different structures and different metallic crystalline environments in comparison with palladium environment has been determined. Elements that we used in this article are Ni, Ru, Rh, Pt, Ta, Ti, Zr, which are contained FCC, BCC and HCP lattice structures. Fusionable particles are solved as a sublattice in mentioned crystalline metals. Fusion reactions are generated by the flux of incoming fusionable particles. We took lattice effect part in our calculations with regard the Bloch functions for the initial and final state of a three body system. Three-body system involved the host lattice, sublattice and incident particles. The cross section to perform each fusion reaction inside different metal is computed using the state of initial and final system. Then our results for cross section of different metal are compared with palladium metal. Finally, the solid state internal conversion coefficient is obtained by considering the lattice effect.

*Corresponding author: E-mail: hoseinimotlagh@hotmail.com;

Keywords: Internal conversion; fusion cross section; lattice effect in solid state internal conversion.

1. INTRODUCTION

Now a days using nuclear energy is very important as a clean source of energy. There are two kinds of nuclear reactions, fusion and fission. Since the fusion reaction has less radioactive radiation and the fusion fuels required for these reactions are more sufficiently available in the nature, therefore fusion reactions are important to study.

In 1995, many experimental works are done on gaseous metals for determining screening effect [1]. From 1998 to 2001, these experiments continued on metallic environments [2-4]. In 2000, the electron screening effect on the cold fusion reaction was studied for D + D in the metallic environment [5]. In 2002, they released a report, "Thermal and nuclear aspects of the Pd/D₂O system," with a plea for funding [6]. In 2002, the enhancement of cold fusion and solid state effect were studied in deuterated metal for D+D [7]. From 2002 to 2004, the screening effect on 50 metals and insulators is checked by a series of experiments [8-10]. In 2003, the enhancement of deuteron-fusion reactions in metals and experimental implications were studied for electron screening effect [11]. In 2004, the subject of solid state internal conversion came up [12]. In 2005, many efforts were cleared to create an apparatus according to the Fleischmann and Pons' works; finally, Cold fusion apparatus was made in San Diego Space and Naval Warfare Systems Center. They used other names instead of cold fusion to reduce the effect of previous failures. Often they prefer to name their field Low Energy Nuclear Reactions (LENR) or Chemically Assisted Nuclear Reactions (CANR), also Lattice Assisted Nuclear Reactions (LANR), Condensed Matter Nuclear Science (CMNS) and Lattice Enabled Nuclear Reactions [13-16].

In 2002, Peter Kalman and Thomas Keszthelyi studied this problem (enhancing cross section) on different metals. They studied many different factors to explain the enhancement of cross section. For example, the electron screening was checked for 29 deuterated metals and 5 deuterated insulators/semiconductors from periodic Tables. Among them, metals were most convenient. Some of the other factors that they considered were: stopping power, thermal motion, channeling, diffusion, conductivity, and crystal structure and electron configuration. None

of them could explain the observed enhanced cross section [7,9,11,17-19]. In 2004, they found a reason to explain the enhancement of cross section that was called solid state internal conversion [12]. In 2008, screening effect is studied for the first time on metals by considering solid state; actually solid state of metals is expressed in experiments [20]. Finally, in 2009, they considered a metal with its lattice structure and entered the lattice shape of the solid in their internal conversion calculations [21]. Their calculations were just for D(p, γ)³He reaction.

In this paper, different metals are considered. We choose such metals that show the best results in term of screening effect and the density of deuterium [22]. In this article, in order to compare internal conversion(IC) with lattice effect in solid state internal conversion(LEISSIC), we calculate cross section for different seven particles plus palladium for D(p, γ)³He, D(d,p)T, D(d, γ)⁴He, T(d,n)⁴He.

The objective of this study is to determine fusion cross section (FCS) for above reactions in different metallic environments regarding LEISSIC in order to find the reason of enhanced FCS in these metallic media then recommend the best metal. To come on this aim, following steps are studied: First, right after introduction, the aspects of IC, SSIC and LEISSIC are explained. Second, different special lattice such as Face Cubic Centered (FCC), Body Cubic Centered (BCC) and Hexagonal close Packed (HCP) is introduced in details. Third, LEISSIC and other required quantities to determine FCS and LEISSIC coefficient for Pd environment are computed. Fourth, all calculations in the third step are repeated for Ni, Ru, Rh, Pt, Ta, Ti, Zr. Fifth, microscopic FCS for all elements are determined in different reaction in the case that these metals are considered as a host particle in lattice. Finally, we can suggest the best kind of lattice, fusion reaction and metallic environment which have high value LEISSIC when cold fusion happening.

2. INTERNAL CONVERSION (IC) AND SOLID STATE INTERNAL CONVERSION (SSIC)

Internal conversion is a radioactive decay process where an excited nucleus interacts with an electron in one of the lower atomic or bitals, causing the electron to be emitted from the atom

(See Fig. 1). Thus, in an internal conversion process, a high-energy electron is emitted from the radioactive atom, but without beta decay taking place. Since no beta decay takes place in internal conversion, the element atomic number does not change, and thus (as is the case with gamma decay) no transmutation of one element to another is seen. Also, no neutrino is emitted in internal conversion. Most internal conversion electrons come from the K shell (1s state, see electron shell), as these two electrons have the highest probability of being found inside the nucleus. After the electron has been emitted, the atom is left with a vacancy in one of the inner electron shells. This hole will be filled with an electron from one of the higher shells and subsequently a characteristic x-ray or Auger electron will be emitted [23,24]

The enhancement in the fusion rate, which is observed in solid metallic environments, is attributed to the presence of solid state material but up to now the theoretical explanation of the phenomenon is still missing [25-27]. In what

follows, we suggest a possible mechanism called solid state internal conversion process that should be considered when trying to understand the extra fusion events. [28].

A similar process to IC can take place on a solid between fusionable nuclei and any charged particle in the crystal. The solid state internal conversion process, e.g. $D(p,\gamma)^3He$ nuclear reaction, can be processes consisting of (a) a bound-free electron transition

$$p + d + (e) \rightarrow {}^3He + e \text{ and (b) a bound-free deuteron transition}$$

$p + d + (d) \rightarrow {}^3He + d$. Therefore, an internal conversion happened in a solid environment in addition of electron channel, we have deuteron channel too [12]. Increasing absorption that in a solid material, nuclear fusion reactions (NFR) can happen in solid state internal conversion that creates transit for every charged particle by electromagnetic reaction [12].

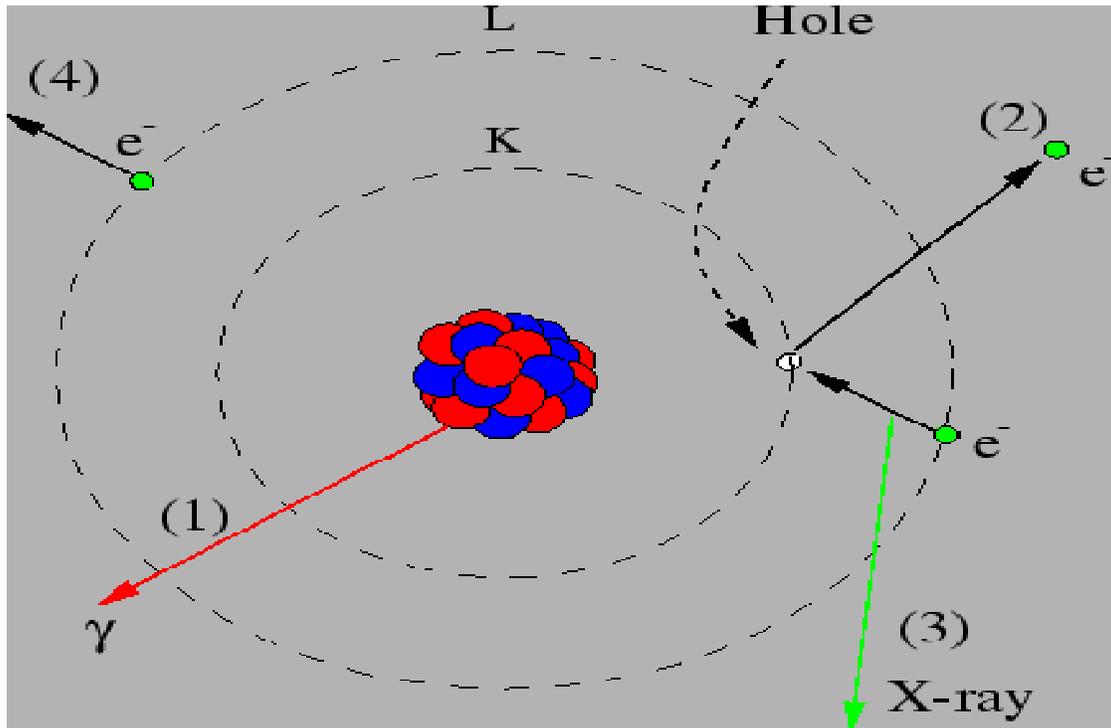


Fig. 1. Internal conversion(internal conversion, laboratory exercise in nuclear physics, autumn 2005, K. S. Krane, Introductory nuclear physics)

3. DESCRIBING MENTIONED LATTICE STRUCTURE IN THIS ARTICLE: FCC, BCC, HCP

In this paper, these elements are studied: Ni, Ru, Rh, Pt, Ta, Ti, Zr. Which, Ni, Pt, Rh have an FCC lattice such as Pd. Ru, Ti, Zr have an HCP lattice and the lattice of Ta is BCC.

After investigating prior experimental work, finally in 2008 solids are considered without their lattice crystal [20]. Then, in 2009, calculations are continued for Pd and with regard the crystalline lattice [21]. Before studying for solid state internal conversion the scientists examined screening effect on metals, to find the reasons of the enhancement FCS of metals which was observed [22]. In this article chosen elements are significant in screening effect or deuterium density. For example, Ti and Zr showed the most screening potential in the experiments [11]. Ta and Zr had the most solved deuterium density [22]. Whereas having a maximum deuterium density in Ti depends on having high temperature [12].

The most important quantities that change during calculations are unit cell volume and the number of atoms that belongs to each kind of lattice. Those quantities are explained for each lattice that is following.

In each unit cell of FCC and BCC lattice, eight atoms stand on the corner of cubic that are collaborations between eight other closed cubic (Fig 2, a_1 and a_2), thus, each unit cell has one

atom from corners ($8 \times \frac{1}{8} = 1$). For FCC there is one atom which belongs to two closed cubic but for BCC one atom locates in the center of each unit cell. So, FCC and BCC lattice have respectively 3 atoms from all 6 sites ($6 \times \frac{1}{2} = 3$) and one atom from its center. Therefore, FCC and BCC have four ($1 + 3 = 4$) and two ($1 + 1 = 2$) atoms in each unit cell respectively.

HCP lattice: In each unit cell of HCP (see Fig.2, a_3), there are two atoms at the top and down sides that are shared between two closed unit cells ($2 \times \frac{1}{2} = 1$), on the other sides of the unit cell there are six atoms. Each atom belongs, two closed unit cells ($6 \times \frac{1}{2} = 3$). There are twelve atoms in the corners that are collaborating between three closed unit cells ($12 \times \frac{1}{3} = 4$). Consequently, there are eight atoms that are completely belonged to one unit cell. In this lattice there are two lattice constants: c height of unit cell and a, the face of hexagonal.

The volume of unit cell for each lattice is defined by equation 1 [29]

$$v_{cell} = \left\{ \begin{array}{l} \frac{a^3}{4} FCC \\ \frac{a^3}{2} BCC \\ \frac{3\sqrt{3}}{16} a^2 c HCP \end{array} \right\}, (a, c: latticeconstant) \quad (1)$$

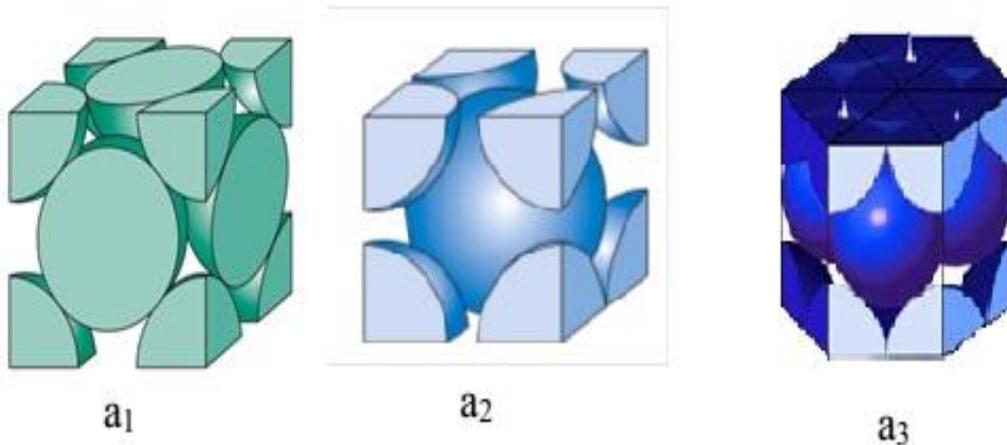


Fig. 2. Shape of unit cell; a_1 : FCC unit cell, a_2 : BCC unit cell, a_3 : HCP unit cell

4. LATTICE EFFECT IN SOLID STATE INTERNAL CONVERSION

$$m_n = m_i + m_{He}, i = \text{dort} \tag{6}$$

4.1 Cross Section Theory of LEISSIC

$$\omega_n = \frac{\text{binding energy of He (MeV)}}{\hbar} \tag{7}$$

In this case to insert LEISSIC into the cross section formula, we break through the procedure that is mentioned at ref 20 completely. So, only those important formulas that are really needed here are written. For comparison the fusion cross section with and without LEISSIC we have to determine the macroscopic cross section [20].

$$\Sigma = N\sigma_2 \tag{2}$$

In previous equation, σ_2 the cross section of fusion reaction between host and target fusonable particles is obtained at the following [20],

$$\sigma_2 = C_0 \frac{\exp(-2\pi\eta)}{E} \tag{3}$$

E is the energy of incoming particle and C_0 contains all the properties of the lattice that is determined by [20],

$$C_0 = |F_{Cb}|^2 A_0 k_\mu \left(\frac{\beta_2}{K_Q}\right)^3 \langle |\tilde{\chi}|_{K=K_Q}^2 \rangle_{\Omega_K} \tag{4}$$

All parts of equation 4 and the way that it obtained are presented in ref 20. m_n , nucleons mass, ω_n angular frequency of binding energy are calculated for each reaction separately (Table 3) [20,30].

$$\lambda = \frac{\sqrt{m_n \omega_n}}{\hbar} \tag{5}$$

Here, C_0 is calculated for one d or one Pd. In order to compare C_0 with astrophysical factor (S(0)) in ordinary state, it must be calculated considering the density of these particles. So, we use the Eq.8 [20],

$$NC_0 = A\Delta R_h C_1, N(\text{Pd}) = V_{eff}/v_{cell} \text{ and } N(\text{d}) = u V_{eff}/v_{cell} \tag{8}$$

Where $v_{cell} = d^3/4$, $V_{eff} = A\Delta R_h$ and $d = 3.89 \times 10^{-8} \text{cm}$ is the lattice constant. In Eq.8, u is the ratio of deuteron to palladium number density. For electron $u = 10$ which is the number of electron valence in palladium.

4.2 Results of Numerical Calculations for Each reaction

There are two Tables for all reactions that can aid in plotting the cross section and compared with the ordinary state. The suppositions of hosts, sublattice and incoming particles are expressed for all reactions in this way: the host particles are Pd, d, e for Palladium. The sublattice is deuterium for all reactions. The incoming particles are proton (p) in D(p, γ)He, deuterium (d) in D(d,p)T and D(d, γ)⁴He and tritium (t) in T(d,n)⁴He. In order to get to the equation 4 and obtain fusion cross section, all our calculation and requirements for all three kinds of host particles are summarized in Tables 1, 2 and 3 to according to the formulas in ref 20.

Table 1. Our numerical calculation of necessary quantities for obtaining C_0 for all chosen reactions

Type of reactions	Host particles	$A_0(\text{MeV})$	$(\text{gr})\mu$	$K_Q(\text{cm}^{-1})$	$ \tilde{\chi} _{K=K_Q}^2(\text{cm}^3)$	ξ
D(p, γ)3He	Pd	175	5.013×10^{-24}	8.91×10^{12}	3.95×10^{-38}	10.755
	d	0.0827	2.005×10^{-24}	5.64×10^{12}	5.13×10^{-38}	0.1477
	e	0.0103	-----	2.78×10^{11}	6.11×10^{-38}	-560382
D(d,p)T	Pd	349	6.686×10^{-24}	8.82×10^{12}	3.15×10^{-38}	14.462
	d	0.165	2.229×10^{-24}	5.09×10^{12}	3.97×10^{-38}	0.181
	e	0.021	-----	2.05×10^{11}	4.45×10^{-38}	-0.0011
D(d, γ)4He	Pd	349	6.686×10^{-24}	7.93×10^{12}	3.69×10^{-38}	16.075
	d	0.165	2.229×10^{-24}	4.58×10^{12}	4.51×10^{-38}	0.202
	e	0.021	-----	1.65×10^{11}	4.98×10^{-38}	-0.0022
T(d,n)4He	Pd	524	8.35×10^{-24}	2.05×10^{13}	2.89×10^{-39}	5.863
	d	0.248	2.387×10^{-24}	1.10×10^{13}	4.24×10^{-39}	0.09
	e	0.031	-----	8.90×10^{11}	4.30×10^{-38}	-4.228

Table 2. Our numerical calculation C_0 and C_1 for different host particle and different reactions

Type of reactions	Host particles	$k_\mu(\text{cm}^{-1})$	$ F_{cb} ^2$	$C_0(\text{MeV b})$	$C_1(\text{MeV b})$
D(p, γ) ³ He	Pd	1.42×10^{14}	3.14×10^{-28}	4.92×10^{-38}	3.36×10^{-24}
	d	0.57×10^{14}	0.61	2.30×10^{-13}	$u \times 15.6$
	e	-----	1	9.10×10^{-13}	6.18×10^2
D(d,p)T	Pd	1.90×10^{14}	3.27×10^{-38}	1.11×10^{-47}	7.53×10^{-34}
	d	0.63×10^{14}	0.5371	1.88×10^{-13}	$u \times 12.78$
	e	-----	1	2.48×10^{-12}	1.687×10^3
D(d, γ) ⁴ He	Pd	1.90×10^{14}	7.02×10^{-41}	3.83×10^{-50}	0.26×10^{-35}
	d	0.63×10^{14}	0.4964	2.70×10^{-13}	$u \times 18.35$
	e	-----	1	4.31×10^{-36}	2.93×10^{-21}
T(d,n) ⁴ He	Pd	2.37×10^{14}	4.44×10^{-15}	2.05×10^{-25}	1.39×10^{-12}
	d	0.68×10^{14}	0.7438	4.45×10^{-15}	$u \times 0.3024$
	e	-----	1	1.87×10^{-13}	127.1

Table 3. Our obtaining required quantities which are calculated for determination of different fusion

Type of reactions	$\lambda(\text{cm}^{-1})$	$\beta_2(\text{cm}^{-1})$	Q (MeV)	Binding energy (MeV)
D(p, γ) ³ He	9×10^{12}	4.81×10^{14}	5.49	7.718
D(d,p)T	10×10^{12}	4.81×10^{14}	4.04	8.482
D(d, γ) ⁴ He	9.63×10^{12}	4.81×10^{14}	3.27	28.3
T(d,n) ⁴ He	21.8×10^{12}	4.81×10^{14}	17.59	28.3

We can calculate the required parameters such as C_0 and C_1 which are important for estimating cross section of the fusion reactions.

Since each palladium unit cell has 4 Pd atoms purely and since we suppose that the number of host and sublattice particles are equal, then we have

$$N_{Pd} = \frac{1}{4} \times 4.22 \times 10^{22} \tag{9}$$

4.3 Calculations the Solid State Internal Conversion Coefficient for Different Fusion Reactions in Palladium Crystal Environment

With regarding to definition that exists in Ref.11, we can write $v_{eff} = A\Delta R_h$, where A is the cross section of the beam, ΔR_h is the “differential” range, that is, the distance within which the energy of the incoming particle can be considered unchanged. The $\Delta R_h \ll R_h$ condition helps in an order of magnitude estimate of ΔR_h , where R_h is the stopping range of a proton which is about $8 \times 10^{-2} \mu\text{m}$ at $E = 0.01 \text{ MeV}$ in Pd [22].

The quantities A and R_h were measured in mm^2 and $10^{-3} \mu\text{m}$ units. The solid state internal conversion coefficient is introduced as [20],

$$\alpha_{SSIC} = A\Delta R_h C_1 / S(0) \tag{10}$$

S(0) is the astrophysical factor and the amounts of S(0) were calculated completely in the ref 27. Here since the issue is studied on the low energy (5-30 eV), the amounts of S(0) for each reaction is a constant that are shown in Table 4.

By using the amounts exist in Tables 2, 4 and replacing them into Eq.9 the solid state internal conversion coefficient for different reactions can be found. This coefficient indicates the internal conversion rate in different reactions. The result of the calculations summarized in Table 5.

We find out the solid state internal conversion happens in D(p, γ)³He and D(d,p)T reactions with more rates. All calculations in this part are shown for palladium. In the next part we show the results for other elements in detailed.

Table 4. The amounts of astrophysical S-factor for different reactions in ordinary state in low energy

Reactions	D(p,γ) ³ He	D(d,p)T	D(d,γ) ⁴ He	T(d,n) ⁴ He
Astrophysical factor				
S(0)MeV barn	0.2 × 10 ⁻⁶	0.056	0.054	10

Table 5. Solidstate internal conversion coefficient in different reactions for e, 4d and d channels

Type of reactions	α _{SSIC,d} AΔR _h	α _{SSIC,e,4d} AΔR _h
D(p,γ) ³ He	u × 7.8 × 10 ⁵	3.1 × 10 ⁹
D(d,p)T	u × 3.03 × 10 ⁴	3.2 × 10 ⁶
D(d,γ) ⁴ He	u × 3.398 × 10 ²	5.42 × 10 ⁻²⁰
T(d,n) ⁴ He	u × 0.03	12.7

5. CALCULATIONS OF LEISSIC FOR OTHER ELEMENTS

5.1 Tables of Calculation for Different Elements and Reactions

By using all formulas in section 3, such as what we have done for palladium, all required quantities can be computed for mentioning elements. Because other host particles (deuterium and electron) don't change in these calculations and the only thing that changes is the first row of the Table 1. Meanwhile, C₁ and C₀ which changes only for the elements are respectively shown in Table 6 and 7.

For comparing C₀, the microscopic FCS of these metallic environments for all elements, numerical values from Table 6 can be useful. For studying the comparison of the C₁ quantity see Table 7.

According to Table 7, we find out that: wherever elements themselves are considered as host particles, the results of C₁ from large to small values for all reactions are: Ti, Ni, Zr, Ru, Rh, Pd, Ta and Pt. For cases that deuterium and electron are host particles, our comparing values lead to Ru, Ni, Ti, Rh, Pd, Pt, Zr, Ta and Ni, Ru, Pd, Pt, Rh, Ti, Ta, Zr respectively. In case that electron is host the number of electrons in capacity layer is too important indeed whatever the numbers of electrons increases the screening effect is enhanced. Between all reactions, D(p,γ)³He, D(d,p)T and D(d,γ)⁴He have larger values of C₁ than T(d,n)⁴He.

(According Table 7 the result of comparing C₁ for different host particles in different metallic

environments are: element host particle, C_{1,Ti} > C_{1,Ni} > C_{1,Zr} > C_{1,Ru} > C_{1,Rh} > C_{1,Pd} > C_{1,Ta} > C_{1,Pt}; deuterium host particle, C_{1,Ru} > C_{1,Ni} > C_{1,Ti} > C_{1,Rh} > C_{1,Pd} > C_{1,Pt} > C_{1,Zr} > C_{1,Ta}; electron host particle, C_{1,Ni} > C_{1,Ru} > C_{1,Pd} > C_{1,Pt} > C_{1,Rh} > C_{1,Ti} > C_{1,Ta} > C_{1,Zr}

In the each environment, IC coefficient shows internal conversion rate and determined the cross section enhancement in each environment. By studying Table 8, we find out that the internal conversion coefficient of deuterium for D(p,γ)³He is the largest one. The IC coefficient for D(p,γ)³He for different reactions from larger to smaller value is: Ru, Ni, Rh, Pt, Zr, Ta, Ti and Pd. As you see in this reaction Pd has the last rank. In D(d,p)T, the arrangement of the elements is: Pd, Ru, Ni, Ti, Rh, Pt, Zr and Ta.

Electronic internal conversion coefficient arrangement for different elements is:

$$Ni, Ru, Pd, Rh, Ti, Ta, Zr, Pt. (\alpha_{e,Ni} > \alpha_{e,Ru} > \alpha_{e,Pd} > \alpha_{e,Rh} > \alpha_{e,Ti} > \alpha_{e,Ta} > \alpha_{e,Zr} > \alpha_{e,Pt})$$

(According to Table 8, comparing ICC values of deuterium host particle for the two largest reactions D(p,γ)³He and D(d,p)T are respectively:

$$\alpha_{d,Ru} > \alpha_{d,Ni} > \alpha_{d,Rh} > \alpha_{d,Pt} > \alpha_{d,Zr} > \alpha_{d,Ta} > \alpha_{d,Ti} > \alpha_{d,Pd} \text{ and } \alpha_{d,Pd} > \alpha_{d,Ru} > \alpha_{d,Ni} > \alpha_{d,Ti} > \alpha_{d,Rh} > \alpha_{d,Pt} > \alpha_{d,Zr} > \alpha_{d,Ta})$$

6. MICROSCOPIC CROSS SECTION FOR ALL ELEMENTS IN DIFFERENT REACTIONS

Microscopic FCS for all metallic environments when metal considers as a host particle are plotted by replacing numerical values from Table

6 in Eq.3. All FCS are divided into two groups in order to show changes clearly: 16 maximum and 16 minimum which are respectively shown in Fig 3. Numbers 1 to 4 besides the name of the elements shows D(p,γ)³He , D(d,p)T , D(d,γ)⁴He and T(d,n)⁴He .

Table 6. Our numerical calculations of C₀ for different elements and reactions with FCC, BCC and HCP lattice

Quantity Elements	C _{0,D(p,γ)³He} (MeV barn)	C _{0,D(d,p)T} (MeV barn)	C _{0,D(d,γ)⁴He} (MeV barn)	C _{0,T(d,n)⁴He} (MeV barn)
Pd (FCC)	4.92 × 10 ⁻³⁸	1.11 × 10 ⁻⁴⁷	3.83 × 10 ⁻⁵⁰	2.05 × 10 ⁻²⁵
Ni (FCC)	3.44 × 10 ⁻²⁷	6.79 × 10 ⁻³³	2.56 × 10 ⁻³⁵	6.98 × 10 ⁻²³
Pt (FCC)	1.34 × 10 ⁻⁵⁷	1.95 × 10 ⁻⁷⁴	1.21 × 10 ⁻⁸¹	1.63 × 10 ⁻⁴⁵
Rh (FCC)	1.08 × 10 ⁻³⁶	7.43 × 10 ⁻⁴⁷	6.61 × 10 ⁻⁵¹	1.38 × 10 ⁻²⁴
Ru (HCP)	8.49 × 10 ⁻³⁷	5.07 × 10 ⁻⁴⁶	5.56 × 10 ⁻⁵⁰	1.21 × 10 ⁻³⁰
Ti (HCP)	1.10 × 10 ⁻²³	4.63 × 10 ⁻²⁸	6.49 × 10 ⁻³⁰	1.93 × 10 ⁻²¹
Zr (HCP)	2.25 × 10 ⁻³⁴	1.01 × 10 ⁻⁴²	2.69 × 10 ⁻⁴⁶	6.27 × 10 ⁻²⁹
Ta (BCC)	1.30 × 10 ⁻⁵⁴	3.10 × 10 ⁻⁷⁰	5.79 × 10 ⁻⁷⁷	2.64 × 10 ⁻⁴³

Table 7. Our numerical calculations of C₁ for different elements and reactions with FCC, BCC and HCP lattice

Quantity Elements	C _{1,D(p,γ)³He} (MeV barn)	C _{1,D(d,p)T} (MeV barn)	C _{1,D(d,γ)⁴He} (MeV barn)	C _{1,T(d,n)⁴He} (MeV barn)	
Pd (FCC)	Pd	3.36 × 10 ⁻²⁴	7.53 × 10 ⁻³⁴	0.26 × 10 ⁻³⁵	1.39 × 10 ⁻¹²
	d	u × 15.6	u × 12.78	u × 18.35	u × 0.30
	e	6.18 × 10 ²	1.68 × 10 ³	2.93 × 10 ⁻²¹	127.1
Ni (FCC)	Ni	3.15 × 10 ⁻¹³	6.23 × 10 ⁻¹⁹	2.35 × 10 ⁻²¹	6.40 × 10 ⁻⁹
	d	u × 21.1	u × 17.25	u × 24.8	u × 4.08
	e	8.35 × 10 ²	2.27 × 10 ³	3.96 × 10 ⁻²¹	1.71 × 10 ²
Pt (FCC)	Pt	6.86 × 10 ⁻⁴⁴	1.30 × 10 ⁻⁶⁰	8.07 × 10 ⁻⁶⁸	1.08 × 10 ⁻³¹
	d	u × 15.27	u × 12.48	u × 17.93	u × 2.955 × 10 ⁻¹
	e	6.04 × 10 ²	1.65 × 10 ³	2.86 × 10 ⁻²¹	1.242 × 10 ²
Rh (FCC)	Rh	7.93 × 10 ⁻²³	5.41 × 10 ⁻³³	4.82 × 10 ⁻³⁷	1.01 × 10 ⁻³⁰
	d	u × 16.76	u × 13.71	u × 19.68	u × 3.24 × 10 ⁻¹
	e	5.97 × 10 ²	1.63 × 10 ³	2.83 × 10 ⁻²¹	122.75
Ru (HCP)	Ru	5.20 × 10 ⁻²³	3.10 × 10 ⁻³²	3.40 × 10 ⁻³⁶	7.41 × 10 ⁻¹⁷
	d	u × 14.08	u × 11.51	u × 16.53	u × 0.27
	e	4.46 × 10 ²	1.21 × 10 ³	2.11 × 10 ⁻²¹	91.60
Ti (HCP)	Ti	5.21 × 10 ⁻¹⁰	2.19 × 10 ⁻¹⁴	3.07 × 10 ⁻¹⁶	9.12 × 10 ⁻⁸
	d	u × 10.86	u × 8.88	u × 12.76	u × 0.21
	e	172.02	469.22	8.15 × 10 ⁻²²	3.53 × 10 ²
Zr (HCP)	Zr	8.05 × 10 ⁻²¹	3.61 × 10 ⁻²⁹	9.62 × 10 ⁻³³	2.25 × 10 ⁻¹⁵
	d	u × 8.24	u × 6.73	u × 9.67	u × 16.12
	e	1.30 × 10 ²	3.55 × 10 ²	6.18 × 10 ⁻²²	26.80
Ta (BCC)	Ta	7.17 × 10 ⁻⁴¹	1.71 × 10 ⁻⁵⁶	3.19 × 10 ⁻⁶³	1.46 × 10 ⁻²⁹
	d	u × 12.68	u × 10.37	u × 14.89	u × 0.25
	e	2.51 × 10 ²	6.84 × 10 ²	1.19 × 10 ⁻²¹	51.59

Table 8. Our numerical calculations of LEISSIC for all elements in different reactions

Quantity	$\alpha_{D(p,\gamma)^3He} \times A\Delta R_h$	$\alpha_{D(d,p)T} \times A\Delta R_h$	$\alpha_{D(d,\gamma)^4He} \times A\Delta R_h$	$\alpha_{T(d,n)^4He} \times A\Delta R_h$
Elements				
Pd (FCC)	d	$u \times 7.80 \times 10^5$	$u \times 3.03 \times 10^4$	$u \times 3.40 \times 10^2$
	e	3.1×10^9	3.2×10^6	5.42×10^{-20}
Ni (FCC)	d	$u \times 1.05 \times 10^8$	$u \times 3.08 \times 10^2$	$u \times 4.59 \times 10^2$
	e	4.17×10^9	4.07×10^4	7.33×10^{-20}
Pt (FCC)	d	$u \times 7.63 \times 10^7$	$u \times 2.23 \times 10^2$	$u \times 3.32 \times 10^2$
	e	3.02×10^8	2.94×10^4	5.3×10^{-20}
Rh (FCC)	d	$u \times 8.38 \times 10^7$	$u \times 2.45 \times 10^2$	$u \times 3.65 \times 10^2$
	e	3.00×10^9	2.91×10^4	0.52
Ru (HCP)	d	$u \times 7.04 \times 10^7$	$u \times 2.06 \times 10^2$	$u \times 3.06 \times 10^2$
	e	2.23×10^9	2.17×10^4	3.91×10^{-20}
Ti (HCP)	d	$u \times 5.43 \times 10^7$	$u \times 1.59 \times 10^2$	$u \times 2.36 \times 10^2$
	e	8.60×10^8	8.38×10^3	1.51×10^{-20}
Zr (HCP)	d	$u \times 4.12 \times 10^7$	$u \times 1.20 \times 10^2$	$u \times 1.79 \times 10^{-2}$
	e	6.52×10^8	6.35×10^3	1.14×10^{-20}
Ta (BCC)	d	$u \times 6.34 \times 10^7$	$u \times 1.85 \times 10^2$	$u \times 2.76 \times 10^2$
	e	1.25×10^9	1.22×10^4	2.20×10^{-20}

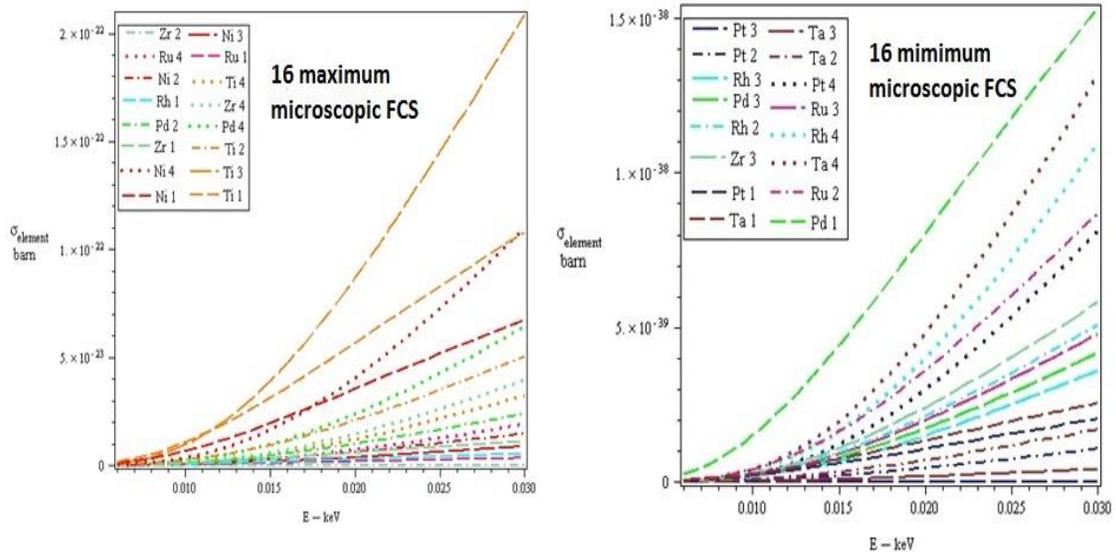


Fig. 3. 16 maximum and minimum measurements of microscopic FCS in terms of incoming energy for all reactions are represented

In the above graph, different colors shows kinds of elements and the styles of shape introduce kinds of reactions. $D(p,\gamma)^3He$ by “dash”, $D(d,p)T$ by “dash dot”, $D(d,\gamma)^4He$ by “long dash” and $T(d,n)^4He$ by “dot” are shown. The color of Pd, Ni, Pt, Rh, Ru, Ti, Zr, and Ta are respectively: Green, red, navy, cyan, dark pink, coral, aquamarine and brown. As you see Ti and Ni have the larger cross section. After them palladium shows up just in the $T(d,n)^4He$ reaction.

To realize the best kinds of lattice structure, microscopic FCS related to element host particles are plotted for each fusion reactions separately. Here in these graphs, colors shows kinds of elements and the styles of the graph indicate the kind of the lattice. BCC shows by “dot”, FCC by “long dash” and CP by “dash dot”.

For $D(p,\gamma)^3He$, $D(d,p)T$, $D(d,\gamma)^4He$ (Fig.4), Ti with HCP lattice has the largest microscopic FCS and Pd with FCC lattice is respectively in the

sixth, second and fifth place. Ni with FCC lattice is in the first place of microscopic FCS and Pd is the fifth for T(d,n)⁴He. Now the data that are corresponded to Figs. 3 are summarized in Table 9.

7. DISCUSSION AND CONCLUSION

According to Table 7, the result of comparing C₁ for different host particles in different metallic

environments are: when the metals are considered as host particle, C_{1,Ti} > C_{1,Ni} > C_{1,Zr} > C_{1,Ru} > C_{1,Rh} > C_{1,Pd} > C_{1,Ta} > C_{1,Pt}; whenever deuterium considered a host particle, C_{1,Ru} > C_{1,Ni} > C_{1,Ti} > C_{1,Rh} > C_{1,Pd} > C_{1,Pt} > C_{1,Zr} > C_{1,Ta}; electron host particle, C_{1,Ni} > C_{1,Ru} > C_{1,Pd} > C_{1,Pt} > C_{1,Rh} > C_{1,Ti} > C_{1,Ta} > C_{1,Zr}.

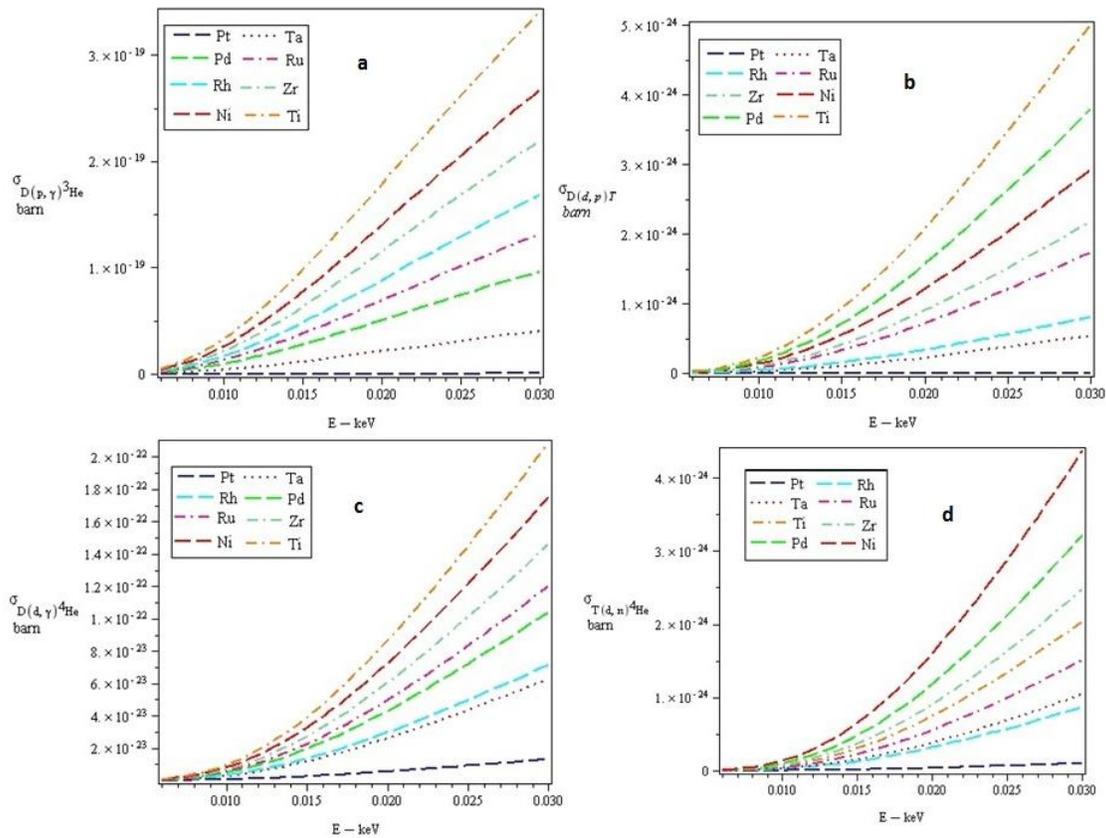


Fig. 4. Microscopic FCS of all elements for different fusion reaction are presented

Table 9. Numerical microscopic cross sectioned values in special energy (0.025MeV) for different elements in different reactions

Quantity	$\sigma_{\text{element}}^{\text{D(p,}\gamma\text{)3He (MeV)}}$	$\sigma_{\text{element}}^{\text{D(d,p)T (MeV)}}$	$\sigma_{\text{element}}^{\text{D(d,}\gamma\text{)4He (MeV)}}$	$\sigma_{\text{element}}^{\text{T(d,n)4He (MeV)}}$
Pd (FCC)	1.19×10^{-38}	8.35×10^{-49}	2.89×10^{-51}	8.51×10^{-28}
Ni (FCC)	8.19×10^{-28}	5.12×10^{-34}	1.93×10^{-36}	2.89×10^{-24}
Pt (FCC)	2.46×10^{-58}	1.48×10^{-75}	9.18×10^{-83}	6.78×10^{-47}
Rh (FCC)	2.59×10^{-37}	5.61×10^{-48}	5.02×10^{-52}	5.77×10^{-46}
Ru (HCP)	2.02×10^{-37}	3.81×10^{-47}	4.21×10^{-51}	5.02×10^{-32}
Ti (HCP)	2.62×10^{-24}	3.50×10^{-29}	4.93×10^{-31}	7.97×10^{-23}
Zr (HCP)	5.37×10^{-37}	7.59×10^{-44}	2.03×10^{-47}	2.61×10^{-30}
Ta (BCC)	3.10×10^{-55}	2.34×10^{-71}	4.36×10^{-78}	1.10×10^{-44}

As one can see in Table.9 the best cross sections belong to $D(p,\gamma)^3\text{He}$ and $D(d,p)\text{T}$ reactions. In order to achieve our goals we need to look back to our data about internal conversion coefficient by considering lattice effect.

In Table 8, we find out that the internal conversion coefficient of deuterium for $D(p,\gamma)^3\text{He}$ is the largest one. The IC coefficient for $D(p,\gamma)^3\text{He}$ for different reactions from larger to smaller value is: Ru, Ni, Rh, Pt, Zr, Ta, Ti and Pd. As you see in this reaction Pd has the last ICC. In $D(d,p)\text{T}$, the arrangement of the elements is: Pd, Ru, Ni, Ti, Rh, Pt, Zr and Ta.

Electronic internal conversion coefficient arrangement for different elements is: Ni, Ru, Pd, Rh, Ti, Ta, Zr, Pt. ($\alpha_{e,\text{Ni}} > \alpha_{e,\text{Ru}} > \alpha_{e,\text{Pd}} > \alpha_{e,\text{Rh}} > \alpha_{e,\text{Ti}} > \alpha_{e,\text{Ta}} > \alpha_{e,\text{Zr}} > \alpha_{e,\text{Pt}}$)

According to Table.8, comparing ICC values of deuterium host particle for the two largest reactions $D(p,\gamma)^3\text{He}$ and $D(d,p)\text{T}$ are respectively:

$$(\alpha_{d,\text{Ru}} > \alpha_{d,\text{Ni}} > \alpha_{d,\text{Rh}} > \alpha_{d,\text{Pt}} > \alpha_{d,\text{Zr}} > \alpha_{d,\text{Ta}} > \alpha_{d,\text{Ti}} > \alpha_{d,\text{Pd}} \text{ and } \alpha_{d,\text{Pd}} > \alpha_{d,\text{Ru}} > \alpha_{d,\text{Ni}} > \alpha_{d,\text{Ti}} > \alpha_{d,\text{Rh}} > \alpha_{d,\text{Pt}} > \alpha_{d,\text{Zr}} > \alpha_{d,\text{Ta}})$$

As one can see Ti and Ni have the larger cross section. After them palladium shows up just in the $T(d,n)^4\text{He}$ reaction.

Looking at Fig 4, can show that what the best lattice is, kinds of environment and kinds of reactions are. Ti with HCP lattice has the largest mic FCS and Pd with FCC lattice is respectively in the sixth, second and fifth place. From Fig.4d we can understand that Ni with FCC lattice is in the first place of mic FCS and Pd is the fifth. FCC and HCP are the best lattice structures and Ti and Ni are best elements, Ru has a largest ICC. In the case that deuterium is the host particle.

By comparing FCS in term of LEISSIC, Ti and Ni show maximum data. By comparing internal conversion coefficient in term of LEISSIC, the best results belong to Ni and Ru. So Ni can be the best option for the next experimental works.

The other investigations show that: FCC and HCP lattice have a much closed results. Palladium shows good results just in the $D(p,\gamma)^3\text{He}$ and $D(d,\gamma)^4\text{He}$.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Rolfs C, Somorjai E, Nucl. Instrum. Methods B. 1995;99:297.
2. Czerski K, Huke A, Heide P, Hoefft M, Ruprecht G, in Nuclei in the Cosmos V. Proceedings of the International Symposium on Nuclear Astrophysics, edited by. Prantzos N, Harissopulos S. Editions Frontieres, Volos, Greece. 1998;152.
3. Czerski K, Huke A, Biller A, Heide P, Hoefft M, Ruprecht G. Europhys. Lett. 2001;54:449.
4. Huke A. Die Deuteronen-fusionsreaktionen in Metallen, PhD Thesis, Technische Universität, Berlin; 2002.
5. Horaand H, Miley GH. Heavy nuclide synthesis by neutrons in astrophysics and by screened protons in host metals, CZECH J PHYS. 2000;50(3):433-439.
6. Szpak S, Mosier-Boss PA: Thermal and nuclear aspects of the Pd/D2O system; 2002.
7. Raiola F, et al. Enhanced electron screening in $D(d,p)\text{T}$ for deuterated Ta, Eur. Phys. J. A. 2002;13:377.
8. Raiola F, et al. Electron screening in $D(d,p)\text{T}$ for deuterated metals and the periodic table, Phys. Lett. 2002;193:547.
9. Bonomo C, et al. Enhanced Electron Screening in $D(d,p)\text{T}$ for deuterated metals in a possible classical explanation, Nucl. Phys. 2003;37:719.
10. Raiola F, et al. Enhanced electron screening in $D(d,p)\text{T}$ for deuterated metals, Eur. Phys. J. 2004;19:283.
11. Huke A, Czerski K, Heide P. Experimental techniques for the investigation of the electron screening effect for d+d fusion Reactions in Metallic Environments, Nucl. Phys. 2003;279:719.
12. Kalman P, Keszthelyi T. Phys. Rev. 2004;69. 031606(R).
13. Broad 1989b, Voss 1999, Platt 1998, Goodstein 1994, Van Noorden 2007, Beaudette 2002, Feder 2005, Adam 2005, Kruglinksi 2006, Adam 2005, Alfred 2009.
14. Simon B. Undead science: Science studies and the afterlife of cold Fusion, Rutgers, NJ: Rutgers University Press; 2002.

15. Seife C. Sun in a bottle: The strange history of fusion and the science of wishful thinking, New York University Press. 2008;154–155.
16. Hubler G. Anomalous effects in hydrogen-charged palladium – a review. J. of Surface & Coatings Technology; 2007. 10.1016/j.surfcoat.2006.03.062.
17. Czernski K, et al. Eurouphys. Lett. 54, 449 (2001); Nucl. Instrum. Methods Phys. B. 2002;193:183.
18. Huke A, et al. Enhancement of deuteron-fusion reactions in metals and Experimental Implications, Phys. Rev. 2008;78. 015803.
19. Huke A, Czernski K, Chun SM, Biller A, Heide P. Eur. Phys. J. 2008;35:243.
20. Kalman P, Keszthelyi T. Lattice effect in solid state internal conversion, Phys. Rev. 2009;79. 031602(R).
21. Hagino K, Balantekin AB. Phys. Rev. 2002;66. 055801.
22. Kimura S, et al. Influence of tunneling on electron screening in low-Energy Nuclear Reaction in Laboratories, Phys. Rev. 2003;67. 022801.
23. Walter DL. Wiley J. Modern Nuclear Chemistry. 2005;232. ISBN 0471115320.
24. Kenneth SK. J. Wiley & Sons, Introductory Nuclear Physics; 1988. ISBN 0-471-80553-X.
25. Fiorentini G, et al. Fusion rate enhancement due to energy spread of Colliding Nuclei, Phys. Rev. 2003;67. 014603.
26. Hamilton JH. Internal conversion processes, Academic, New York; 1966.
27. Angulo C, et al. Nucl. Phys. 1999;3:656.
28. Ziman JM. Principles of the theory of solids. Cambridge University Press, Cambridge. 1964;148-150.
29. Kittel C. Introduction of solid state physics, 7th Edition, John Wiley& Sons; 1996.
30. Alder K, et al. Study of nuclear structure by electromagnetic excitation with accelerated ions, Rev. Mod. Phys. 1956;28:432.

© 2015 Hosseinimotlagh and Shahamiri; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<http://www.sciencedomain.org/review-history.php?iid=758&id=31&aid=7116>