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Theoretical Scrutiny on the Atomic and Molecular Formation Rates in Stau Catalyzed Fusion

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Authors' contributions

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

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ABSTRACT

In this work, we briefly introduce the Stau particle and Stau catalyzed nuclear fusion method. The main parameters in this method, are Stau-atoms and molecules formation rates for fusion reactions in which calculated and the obtained results compared with each other. Since that these parameters are very important in the Stau catalyzed fusion

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and their values are directly related to energy production and therefore the fusion fuel selection.

Keywords: Fusion; Stau; formation rate; sleptons.

1. INTRODUCTION

The world needs new, cleaner ways to supply our increasing energy demand, as concerns grow over climate change and declining supplies of fossil fuels. Power stations using fusion would have a number of advantages: a: No carbon emissions, b: Abundant fuels, c: Energy efficiency, d: No long-lived radioactive waste, e: Safety and f: Reliable power. In order to carry out this plan, two methods have been proposed and studied which are hot fusion and cold fusion.

In hot fusion the two commonly recognized paths to controlled thermonuclear fusion energy have proven to be long and costly. Physicists are generally aware of two approaches to achieving controlled fusion reactions, magnetic confinement fusion (MCF) and inertial confinement fusion (ICF). ICF uses lasers and the MCF uses magnets to add pressure and heat the atoms enough so that they fuse. MCF was thought to be likely to be more successful at first, and different countries came together to make the International Thermonuclear Experimental Reactor, which uses MCF. Instead ICF is becoming more and more promising and scientists are expecting more advances in this field. Another approach to fusion is fundamentally different from either the magnetic or inertial confinement concepts. This approach, called ‘‘cold fusion” or “muon-catalyzed fusion,” might make it possible to bypass the requirement for extremely high temperatures that make the magnetic and inertial approaches so difficult. If it were possible to “shield” the electric charge of one of the nuclei in a fusion reaction, one nucleus could get very close to another nucleus without being repelled. In this case, fusion reactions could occur at far lower temperatures than would otherwise be required, since the extreme temperatures needed to overcome the mutual repulsion of two electrically charged nuclei would be unnecessary. Such shielding can in fact be provided by a subatomic particle called the muon. The muonlike the electron has a charge that cancels out the charge of a hydrogen nucleus. But unlike the electron, the muon binds so tightly to the nucleus that the nuclear charge is shielded even down to the distances where fusion reactions can take place. Therefore, once a muon becomes bound to a nucleus, the combination can approach a second nucleus closely enough to fuse without the need for extreme temperature. If, the muon is freed in the subsequent fusion reaction, it can become captured by another hydrogen nucleus to repeat the process. In this way it serves as a catalyst, enabling fusion energy to be released without itself being consumed. However, since the muon is unstable, muon catalysis can be practical only if each muon generates more than enough energy during its 2.2-microsecond lifetime to make its own replacement. Muon-catalyzed fusion reactions were actually observed in high-energy physics experiments in the 1950s. However, the muons were rarely observed to induce more than one fusion reaction each before decaying, compared to the hundreds of reactions per muon that would be necessary to make the process worthwhile. More recent experimental and theoretical work has shown that the number of fusion reactions that can be catalyzed by a single muon depends on parameters such as the density and temperature of the deuterium-tritium mixture into which the muon is injected. Experiments have shown that muons are capable of catalyzing many reactions during their lifetime.

There is another heavy stable charged particle, which called as a quasi-stable supersymmetric tau lepton ("stau"). This stable stau would cross detectors without decaying, resembling a muon, and produce signatures of high momentum or high ionization energy loss. The purpose of this paper is to present a detailed of Stau catalyzed fusion. This method is similar Muon catalyzed fusion ([1], [2] and [3]) with the difference that instead of Muon, Stau particle ($\tilde{\tau}$) has been used as a catalyst. This particle such as the Muon has negative charge but its mass much greater than the Muon mass and considered in our calculations is about$m_{\tilde{\tau}} = 100\ (GeV/c^2)$. We have named this method the Stau catalyzed fusion or abbreviation has called SCF. In [4] and [5] this method for pure deuterium and mixed deuterium- tritium fuel has been studied.

This method that we will discuss on it in this work, is a theoretical proposed approach to the scientific community and at this time there is not experimental result on it. But we want to develop the theoretical findings on this process such that progressively be provided the experimental backgrounds.

In this article, we first briefly introduce the Stau particle and then a brief description Stau catalyzed fusion. Finally, we calculate the atoms and molecules formation rate for Stau with $m_{\tilde{\tau}} = 100\ (GeV/c^2)$mass for traditional fusion fuels which main objective of this article.

In this direction, the characteristics of stau particle are described briefly in section II. Also Stau catalyzed fusion are described in section III. The atoms and molecules formation rates for Stau with mass of $m_{\tilde{\tau}} = 100\ (GeV/c^2)$ for traditional fusion fuels which are main objective of this article are calculated in section IV. Finally, from the nature of this theoretical work, discussion and conclusions are performed.

1.1 Stau Particle

In fact, Super symmetry is one of the most interesting topics beyond the standard model. This theory involves not only problems of the standard model, but also paved the way for us to describe the density of dark matter in the universe. One of the most important models in this theory is the MSSM model (Minimal super symmetry Standard Model) ([6], [7] and [8]). Various particles predicted in this model, one of them has been identified as the Stau. In fact, MSSM model is the first extension of the standard model to the super symmetry theory. Strong interacting between the super partner namely Gluinos and Squarks with masses less than $2.5\ TeV$can be discovered at the Large Hadron Collider at CERN (LHC). Physicists at the LHC have started this project from 2008. Among the supersymmetric particles, the lightest particle (LSP) plays the essential role and in cosmology as one of the main candidates for dark matter is considered. Lightest supersymmetric particle is probably that a Neutralino $\tilde{\chi}_1^0$ which escape from the detector and its effectsleaves as a missing energy E_T. Another possibility for the lightest particle is Gravitino($\tilde{G}$)that is in fact a superpartner of graviton in the standard model.Our desired model for classifying supersymmetric particles and introduce the lightest supersymmetric particle is minimal supergravity orabbreviated mSUGRA.In this model the lightest particle is Gravitino. Gravitino are paired in a very small sector of the MSSM with other supersymmetric particles [7]. The next lightest supersymmetric particle (NLSP) in this model is scalar Stau in the Stau's groups which we show it with $\tilde{\tau}_1$ and it is significantly lighter than other sleptons. Stau is a super partner of tau lepton in the standard model. Stau's decay necessarily contains the Gravitino. Also Stau has a long lifetime due to the small sector which Gravitino are paired the MSSM with other supersymmetric particles [7].It should be noted that the Stau group is one type particle with various mass because the Stau mass depends on the production energy and Gravitino mass which itself is variable. But in this article we have done calculations for the Stau with $m_{\tilde{\tau}} = 100\ (GeV/c^2)$ mass. To study more about supersymmetry and supersymmetric particles see references [8] to [18].

The Stau lifetime's using the decay width of Stau to Gravitino and Tau is obtained by following expression: ([5], [9], [10] and [11]).

$$\tau_{\tilde{\tau}_1} = \frac{1}{\Gamma_{\tilde{\tau}_1}^{2-body}(\tilde{\tau}_1 \to \tau + \tilde{G})} = \frac{1}{\frac{(m_{\tilde{\tau}}^2 - m_{3/2}^2 - m_{\tau}^2)^4}{48\pi m_{3/2}^2 M_p^2 m_{\tilde{\tau}}^3}\left[1 - \frac{4m_{3/2}^2 m_{\tau}^2}{(m_{\tilde{\tau}}^2 - m_{3/2}^2 - m_{\tau}^2)^2}\right]^{\frac{3}{2}} \times \frac{1}{\hbar^2 c}} \quad \text{(Sec)} \qquad (1)$$

Where $M_{\tilde{\tau}}$, $M_{\tilde{G}}$ and M_{τ} are mass of Stau, Gravitino and Tau, respectively. M_p is reduced plank mass such that:

$$M_p = (8\pi G_N)^{-\frac{1}{2}} \qquad (2)$$

Here G_N is the gravitational constant: $G_N = 6.70881 \times 10^{-39} \hbar c (\frac{GeV}{c^2})^{-2}$ thus we have: $M_p^2 = (8\pi G_N)^{-1} = \frac{(2.435328254 \times 10^{18})^2}{\hbar c} (\frac{GeV}{c^2})^{-2}$. Also $1/\hbar^2 c$ coefficient in the equation (1) is written for transform scale to time. Now by inserting the values $m_{\tau} = 1.78\ (GeV/c^2)$, $m_{\tilde{\tau}} = 100\ (GeV/c^2)$ and $m_{3/2} = 20\ (GeV/c^2)$ inside equation (1), Stau lifetime is given by: $\tau_{\tilde{\tau}_1} = 2.77623389 \times 10^7 (\text{sec}) = 0.8803379922\ (\text{years})$.

Also, for more description of the Stau with mass $m_{\tilde{\tau}} = 100\ (GeV/c^2)$ refers to a method of producing it. One way to generate Stau-particle is scattering reaction between fixed target of nucleons and a Muon $(\mu + N\ (nucleon))$ [5]. Stau production cross section is dependent on the SUSY particle spectrum. Suppose that the production cross section of sleptons is $O(1) fb$([12]), and Muon energy has been fired toward the target in the lab frame is about $E_{\mu} = 1000\ TeV$. Since almost all SUSY particles decay rapidly to Stau, therefore the Stau production cross section is $O(1) fb$. Now, with assuming "Fe" target with $O(1) Km$ length and $n_N = 5 \times 10^{24} cm^{-3}$ nucleons density, then the number of produced Stau per Muonis given by: $= \sigma \times n_N \times 10^3 \approx 10^{-8}$. The reader should be notice that the stopping range of the Muon inside the Fe target is $O(1)\ Km$ for $E_{\mu} = 1000\ TeV$ [6,20]. Using this $n_{\tilde{\tau}}$, we conclude that the energy required to produce one Stau is: $E_{\tilde{\tau}} \simeq 10^8 \times 1000\ TeV \simeq 10^{17} (MeV)$. For more information about Stau and other supersymmetric particles you can see References [6] to [18]. Also ref. [18] implies on thedirect production of Stau.

1.2 Stau Catalyzed Nuclear Fusion

In this method, the fusion reaction occurs by injecting the Stau particle into the liquid fusion fuel (e.g. deuterium) with the density of $N_{fuel} = 4.25 \times 10^{22}\ atoms/cm^3$. During this process the Stau trapped by the Coulomb field of the atomic nucleus of fuel, in which lead to formation atoms in their orbits such that its electron exchanged by Stau particle. First the Stau-atom is formed in the excited state and then transition to the ground state is occurred by a cascade process. In the next step the Stau-atom with other atom collides to form Stau-molecule and finally in this molecule nuclear fusion reaction will occur. The main reasons to perform the fusion between nuclei of Stau-molecules are huge mass and negatively charged of Stau particle. Because of the large mass of Stau, and according to famous Bohr's relationship the Stau atomic radius reduce to about some Fermi which are calculated in the next section. Also the negative charge of Stau leading to neutralize the Coulomb barrier between the nuclei that will make Stau-molecule such that this barrier is the main factor in preventing the occurrence nuclear fusion. Under these conditions, the distance between deuterium nuclei is $50\,fm$ or less and so the probability of fusion between the fuel atoms significantly increases. Also, after the fusion event between the nucleus of Stau-molecule, Stau is released and re-enter another cycle.However, immediately it is possible that released Stau particle is captured by the Coulomb attraction between produced particles due to nuclear reactions such as ^4He and Stau this process is called Stau sticking ([4] and [5]). The Stau Sticking probability parameter is very important in Stau catalyzed fusion but not discussed in this paper.

For example, in Fig. (1) the mechanisms that are occurred in Stau catalyzed nuclear fusion for pure deuterium fuel is given [4].

1.3 Stau Atomic Bohr Energy and Radius

For calculating the Stau-atoms and Stau-molecules formation rates, we need to calculate the Bohr radius of the atoms in the ground state for electron and Stau.

Bohr radius and Bohr energy of atoms in ground state for hydrogen isotopes can be calculated using below relationships:

$$E_B = \frac{M}{8n^2}\left(\frac{e^2}{\varepsilon_0 hc}\right)^2 \text{(eV)} \tag{3}$$

$$a_B = \frac{e^2}{8\pi\varepsilon_0 E_B}\text{(m)} \tag{4}$$

In these relations, M is atomic reduce mass, n is Bohr quantum number and other parameters are physical constant ($e = 1.602176487 \times 10^{-19}\text{C}$, $\varepsilon_0 = 8.854187817 \times 10^{-12}\,\text{F/m}$, $h = 6.62606896 \times 10^{-34}\text{JS}$ and $c = 2.99792458 \times 10^8\,\text{m/s}$). Also for calculating radius of Stau-helium atom in ground state we used numerical values in reference [17]. In this section note that unit of mass of particles is eV/c^2.

In Table (1) the calculated values of Bohr radius and Bohr energy for different fuel atoms in ground state are presented.

1.4 Stau Atomic and Molecular Formation Rate

In this section we calculate the atom and molecule formation rate for Stau and similarly for Muon. Formation of atoms and molecules are performed by the following reactions:

We can see that from Fig. 1, firstly high energy Stau particles are injected to a chamber of contains deuterium atoms, due to electromagnetic interactions, the electron of deuterium atom are separated from its and Stau is replaced with it ($\tilde{\tau}d$ formation mechanism in excited state). Then, during of the cascade process due to photon emission, transition to the ground state is occurred and Stau atom is formed. After that $\tilde{\tau}d$ in ground state collides with other deuterium atoms to form $\tilde{\tau}dd$molecules. As we have known, similarly, these processes also occur for the Muon catalyzed fusion. Atoms and molecules formation rates depend on the following factors:

1.5 Energy and Temperature

Formation of atoms or molecules are increased by enhancement temperature and energy, since with increasing temperature the kinetic energy of the particles increases and therefore the effective collisions are growth for formation of atoms and molecules. Our numerical calculated results are given in Figs. (2) to (6).

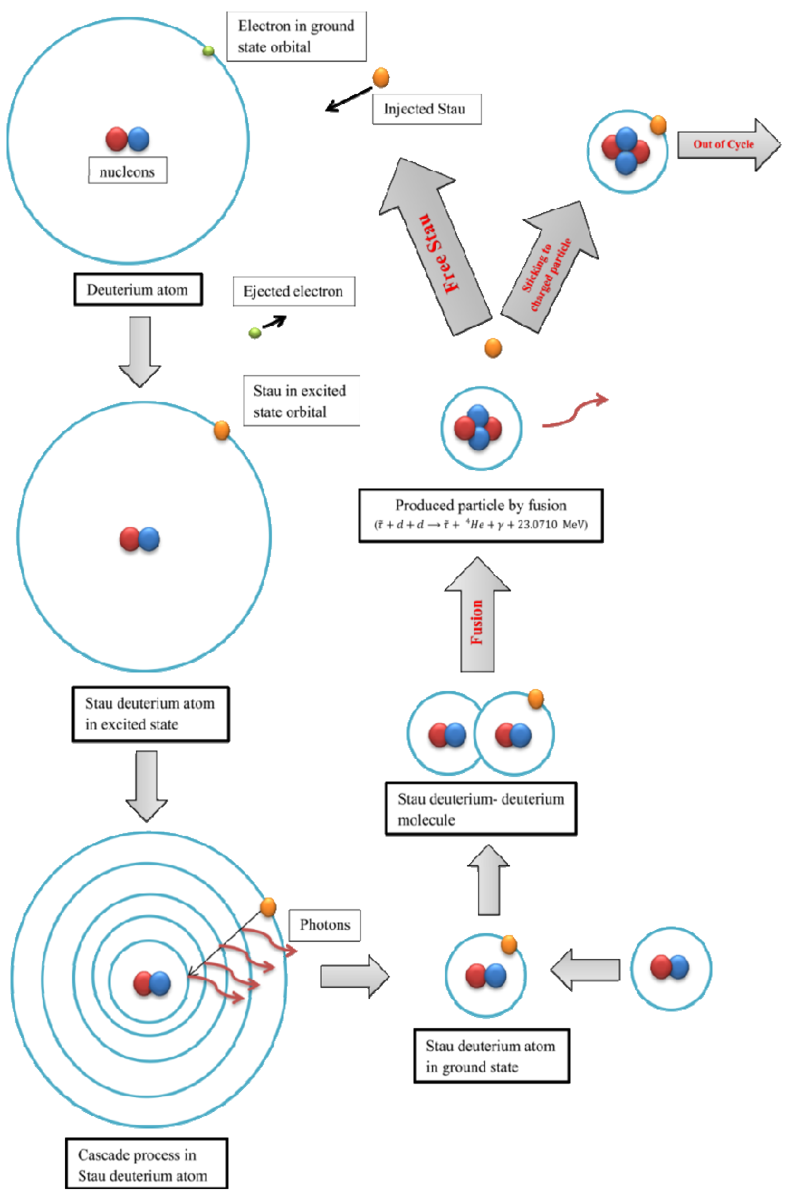


Fig. 1. The mechanisms of Stau- atom and Stau-molecule formation into the pure deuterium fuel in Stau catalyzed fusion

1.6 The mass of Catalyst Particle

With increasing mass of catalyst particle, formation rates of atoms and molecules are reduced; because the catalyst with higher mass will have lower velocity in the fuel liquid that imply on decreasing the effective collision for formation Stau-atoms and molecules. For this reason, Stau-atoms formation is different from Stau-molecules. Because the atoms with catalyst due to possess higher mass have lower velocity which causes to decrease effective incident with other atoms in order to molecule formation.

1.7 Scattering Cross Section

Increasing the scattering cross section leads to raising formation rates of atoms and molecules. For that reason the comparison values in Figs. (2) and (6) we can see that the formation rates of Stau-atoms and molecules form pure hydrogen channel (proton) more than any other channels and from pure helium is less than other channels. Since we assume a circular shape for cross section of Stau-atoms or molecules, therefore, Bohr radius of lighter atoms or molecules in ground state is more than the radius of heavier atoms or molecules. Therefore, this point leads to the increasing the cross section atoms or molecules with less mass.

1.8 Fuel Density

Density of fuel particles are highly effective direct relation with the formation rates of atoms and molecules. Because with increasing fuel density of the particles, the effective collisions for formation of atoms and molecules have the catalyst increases.

In the following relations, we are provided the process of forming Stau-atoms and molecules for Conventional different types of fusion reactions.

$$\tilde{\tau} + p \xrightarrow{\lambda_a^{\tilde{\tau}p}} \tilde{\tau}p \ + \ p \xrightarrow{\lambda_m^{\tilde{\tau}pp}} \tilde{\tau}pp \xrightarrow{Fusion} \tilde{\tau} + d + e^+ + \nu_e + 0.88431 \text{ MeV} \tag{5}$$

$$\tilde{\tau} + \begin{Bmatrix} p \underset{\lambda_a^{\tilde{\tau}p}}{\longrightarrow} \tilde{\tau}p \ + \ d \underset{\lambda_m^{\tilde{\tau}p-d}}{\longrightarrow} \\ d \xrightarrow{\lambda_a^{\tilde{\tau}d}} \tilde{\tau}d \ + \ p \xrightarrow{\lambda_m^{\tilde{\tau}d-p}} \end{Bmatrix} \to \tilde{\tau}pd \xrightarrow{Fusion} \tilde{\tau} + \ {}^3He + \gamma + 5.3148 \text{ MeV} \tag{6}$$

$$\tilde{\tau} + \begin{Bmatrix} p \underset{\lambda_a^{\tilde{\tau}p}}{\longrightarrow} \tilde{\tau}p \ + \ t \underset{\lambda_m^{\tilde{\tau}p-t}}{\longrightarrow} \\ t \xrightarrow{\lambda_a^{\tilde{\tau}t}} \tilde{\tau}t \ + \ p \xrightarrow{\lambda_m^{\tilde{\tau}t-p}} \end{Bmatrix} \to \tilde{\tau}pt \xrightarrow{Fusion} \tilde{\tau} + \ {}^4He + \gamma + 19.1695 \text{ MeV} \tag{7}$$

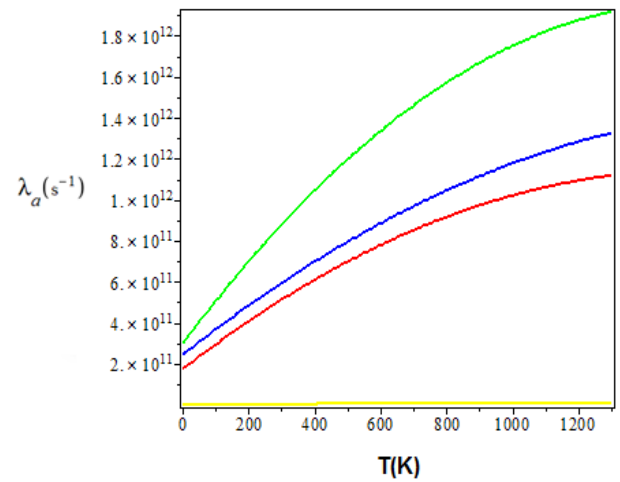
$$\tilde{\tau} + \begin{Bmatrix} p \underset{\lambda_a^{\tilde{\tau}p}}{\longrightarrow} \tilde{\tau}p \ + \ {}^3He \underset{\lambda_m^{\tilde{\tau}p-\,^3He}}{\longrightarrow} \\ {}^3He \xrightarrow{\lambda_a^{\tilde{\tau}\,^3He}} \tilde{\tau}\,{}^3He \ + \ p \xrightarrow{\lambda_m^{\tilde{\tau}\,^3He-p}} \end{Bmatrix}$$
$$\to \tilde{\tau}p\,{}^3He \xrightarrow{Fusion} \tilde{\tau} + \ {}^4He + e^+ + \nu_e + 19.1515 \text{ MeV} \tag{8}$$

$$\tilde{\tau} + d \xrightarrow{\lambda_a^{\tilde{\tau}d}} \tilde{\tau}d \ + \ d \xrightarrow{\lambda_m^{\tilde{\tau}dd}} \tilde{\tau}dd \xrightarrow{Fusion} \begin{cases} \tilde{\tau} + \ {}^3He + n + 3.1446\text{MeV} \\ \tilde{\tau} + t + p + 3.9015 \quad \text{MeV} \\ \tilde{\tau} + \ {}^4He + \gamma + 23.0710 \ \text{MeV} \end{cases} \tag{9}$$

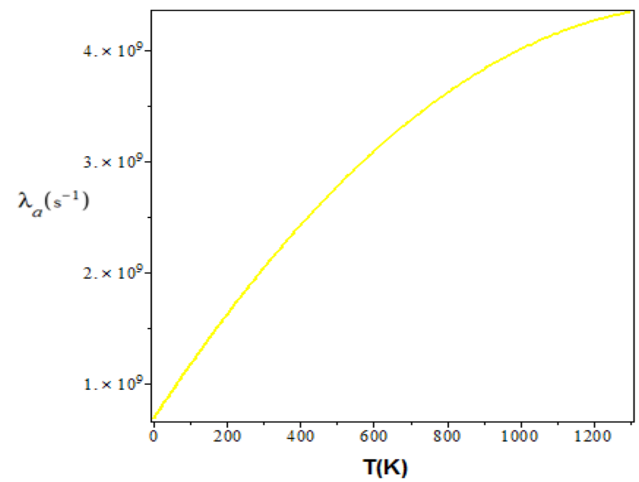
$$\tilde{\tau} + \begin{Bmatrix} d \underset{\lambda_a^{\tilde{\tau}d}}{\longrightarrow} \tilde{\tau}d \ + \ t \underset{\lambda_m^{\tilde{\tau}d-t}}{\longrightarrow} \\ t \xrightarrow{\lambda_a^{\tilde{\tau}t}} \tilde{\tau}t \ + \ d \xrightarrow{\lambda_m^{\tilde{\tau}t-d}} \end{Bmatrix} \to \tilde{\tau}dt \xrightarrow{Fusion} \tilde{\tau} + \ {}^4He + n + 17.0172 \text{ MeV} \tag{10}$$

Table 1. The calculated values of Bohr radius and Bohr energy of different fuel atoms in ground state

	$\tilde{\tau}p$	$\tilde{\tau}d$	$\tilde{\tau}\,^{3}He$	$\tilde{\tau}t$	p	d	^{3}He	t
a_B(m)	2.909×10^{-14}	1.468×10^{-14}	4.81×10^{-15}	9.895×10^{-15}	5.294×10^{-11}	5.293×10^{-11}	3.307×10^{-12}	5.292×10^{-11}
E_B(eV)	2.474×10^{4}	4.902×10^{4}	2.99×10^{5}	7.275×10^{4}	13.598	13.601	217.651	13.603

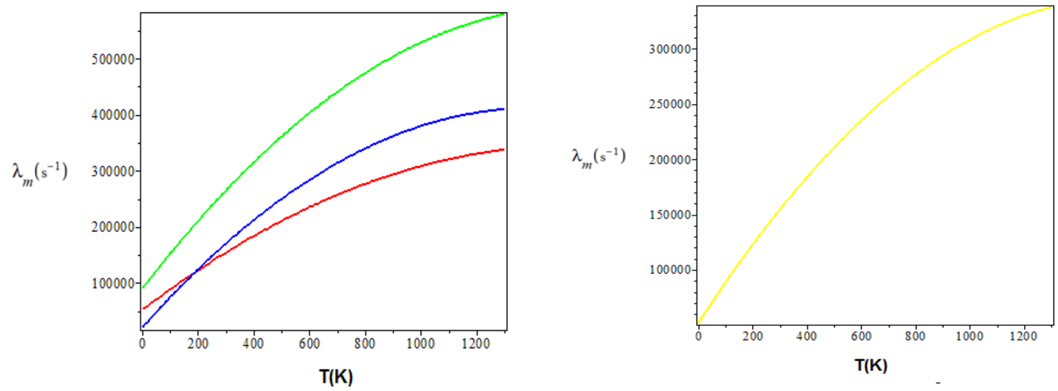


(A)



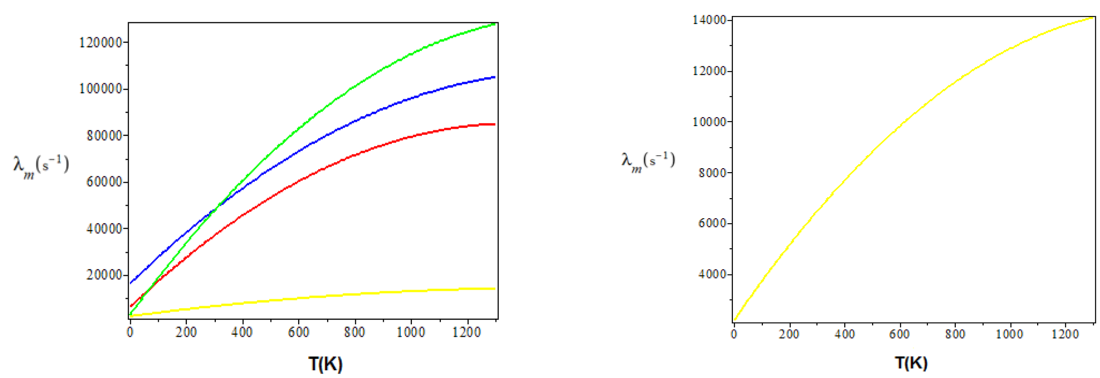
(B)

Fig. 2A. Comparison of calculated values of Stau-atoms formation rates in terms of temperature for $\tilde{\tau}p(Green)$, $\tilde{\tau}d(Blue)$, $\tilde{\tau}t(Red)$ and $\tilde{\tau}\,^{3}He(Yellow)$ atoms. B) Calculated values of Stau-atoms formation rates in terms of temperature for $\tilde{\tau}\,^{3}He(Yellow)$ atom only



(A) **(B)**

Fig. 3A. Comparison of calculated values of Stau-molecules formation rates in terms of temperature from τ̃ p atom channel for τ̃ pp(Green), τ̃ pd(Blue), τ̃ pt(Red) and τ̃ p(_^3)He(Yellow) molecules. B) Calculated values of Stau-molecules formation rates in terms of temperature from τ̃ p atom channel for τ̃ p(_^3)He(Yellow)molecule only



(A) **(B)**

Fig. 4. A) Comparison of calculated values of Stau-molecules formation rates in terms of temperature from τ̃ d atom channel for τ̃ pd(Green), τ̃ dd(Blue), τ̃ dt(Red) and τ̃ d(_^3)He(Yellow) molecules. B) Calculated values of Stau-molecules formation rates in terms of temperature from τ̃ d atom channel for τ̃ d(_^3)He(Yellow)molecule only

$$\tilde{\tau} + \left\{ \begin{array}{c} d \xrightarrow[\lambda_a^{\tilde{\tau}d}]{} \tilde{\tau}d \;+\; {}^3He \xrightarrow[\lambda_m^{\tilde{\tau}d-\,^3He}]{} \\ {}^3He \xrightarrow{\lambda_a^{\tilde{\tau}\,^3He}} \tilde{\tau}\,^3He \;+\; d \xrightarrow{\lambda_m^{\tilde{\tau}\,^3He-d}} \end{array} \right\} \rightarrow \tilde{\tau}d\,^3He \xrightarrow{Fusion} \tilde{\tau} + \,^4He + p + 17.7742\ \text{MeV} \tag{11}$$

$$\tilde{\tau} + t \xrightarrow{\lambda_a^{\tilde{\tau}t}} \tilde{\tau}t \;+\; t \xrightarrow{\lambda_m^{\tilde{\tau}tt}} \tilde{\tau}tt \xrightarrow{Fusion} \tilde{\tau} + \,^4He + 2n + 10.9635\ \text{MeV} \tag{12}$$

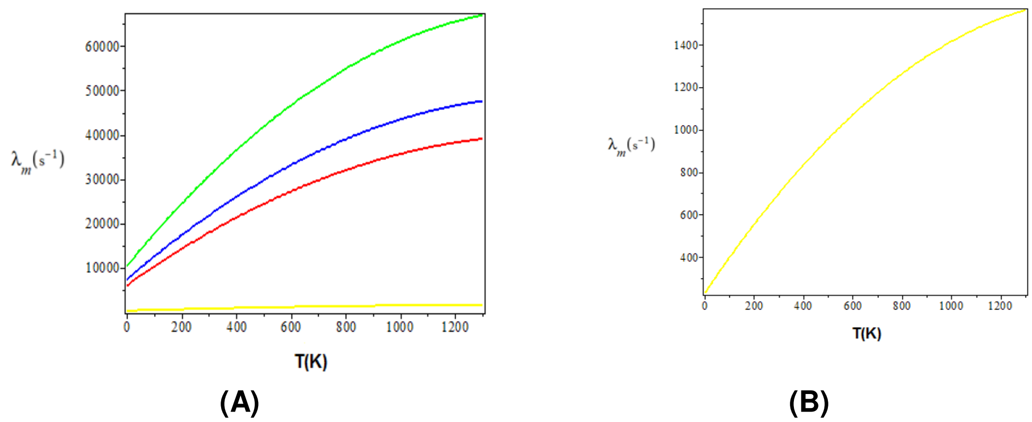


Fig. 5. A) Comparison of calculated values of Stau-molecules formation rates in terms of temperature from $\tilde{\tau}$ t atom channel for $\tilde{\tau}$ pt(Green), $\tilde{\tau}$ dt(Blue), $\tilde{\tau}$ tt(Red) and $\tilde{\tau}$ t(_^3)He(Yellow) molecules. B) Calculated values of Stau-molecules formation rates in terms of temperature from $\tilde{\tau}$ t atom channel $\tilde{\tau}$t(_^3)He(Yellow) molecule only

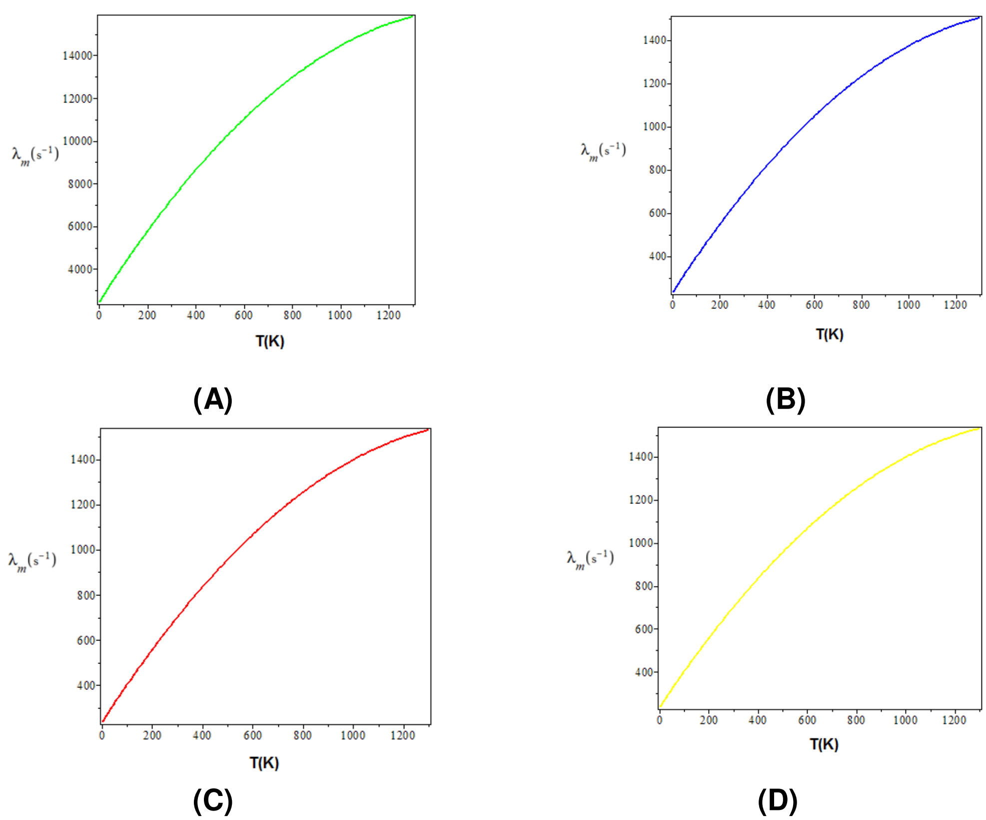


Fig. 6. Calculated values of Stau-molecules formation rates in terms of temperature from $\tilde{\tau}$ (_^3)He atom channel for A) $\tau^{\sim}$p(_^3)He,B) $\tau^{\sim}$d(_^3)He,C) $\tau^{\sim}$t(_^3)He andD) $\tau^{\sim}$(_^3)He (_^3)He molecules

$$\tilde{\tau}+\left\{\begin{array}{c} t \xrightarrow[\lambda_a^{\tilde{\tau}t}]{} \tilde{\tau}t \;+\; {}^3He \xrightarrow[\lambda_m^{\tilde{\tau}t-\,{}^3He}]{} \\ {}^3He \xrightarrow{\lambda_a^{\tilde{\tau}\,{}^3He}} \tilde{\tau}\,{}^3He \;+\; t \xrightarrow{\lambda_m^{\tilde{\tau}\,{}^3He-t}} \end{array}\right\} \rightarrow \tilde{\tau}t\,{}^3He \xrightarrow{Fusion} \tilde{\tau}+\;{}^4He+p+n+12.4593\text{ MeV} \quad (13)$$

$$\tilde{\tau}+\;{}^3He \xrightarrow{\lambda_a^{\tilde{\tau}\,{}^3He}} \tilde{\tau}\,{}^3He+\;{}^3He \xrightarrow{\lambda_m^{\tilde{\tau}\,{}^3He\,{}^3He}} \tilde{\tau}+\;{}^3He\,{}^3He \xrightarrow{Fusion} \tilde{\tau}+\;{}^4He+2p+12.4413\text{ MeV} \quad (14)$$

We show Stau-atoms and molecules formation rates for above relationship with Lambda $\lambda_{formation\ rate}$ and calculated it using the following relationship ([1] and [3]):

$$\lambda_{formationrate}=N_{fuel}\langle\sigma v\rangle(s^{-1}) \quad (15)$$

Here $N_{fuel}=4.25\times10^{22}\,atoms/cm^3$ is fuel density (e.g. deuterium, tritium and…). Considering that the particle collides (e.g. Stau, deuterium, and …) to the target leads to the production of catalytic atoms and molecules at different temperatures, this issue become the cause of having different speeds in all possible directions, therefore Lambda is dependent on the average of Sigma-vee parameter. Sigma-vee parameter average is shown by $\langle\sigma v\rangle$ and are defined as following ([1], [3], [19] and [20]):

$$\langle\sigma v\rangle=\frac{(8/\pi)^{1/2}}{M^{1/2}(kT)^{3/2}}\int_0^\infty \sigma E exp(-E/kT)dE(m^3/s) \quad (16)$$

Then

$$\lambda_{formation\ rate}=N_{fuel}\frac{(8/\pi)^{1/2}}{M^{1/2}(kT)^{3/2}}\int_0^\infty \sigma E exp(-E/kT)dE(m^3/s) \quad (17)$$

Here σ is scattering cross section on target. M represents the reduced mass of the system and T is the temperature. $k=1.3806504\times10^{-23}$ J/K is the Boltzmann constant.

For the forming of Stau-atoms, firstly, we assume that the atoms are in the electronic ground state and with circular cross section. In this state, the circular radius cross sections for these atoms are the electron Bohr radius in the ground state. So to calculate the formation rate of these atoms we use the following relation [3].

$$\sigma\simeq\pi a_{B(electron)}^2 \quad (18)$$

In order to determine formation of Stau-molecules we use the same equation, except that the electron Bohr radius is exchanged by Stau. So for calculating the formation rate of these molecules we use the following relation [3].

$$\sigma\simeq\pi a_{B(Stau)}^2 \quad (19)$$

In Table (1), Bohr radius is presented for each atom that is introduced in the previous section. The calculated values of formation rates of Stau-atoms and molecules in the temperature range 20 to 1300 K in Figs. (2) to (6) are presented.

2. CONCLUSION

From this paper, for the first time we could determine theoretically the numerical values of Stau-atoms and molecules formation rates for different fusion reactions. The important point about values of formation rate values is that the numerical values of Stau-atoms and molecules formation rate for specific reaction are increased thus number of fusion events are increased, and therefore increases the efficiency of energy production. For this reason, the selection of fusion fuel formation rate parameter plays an important role. According to Fig. (2), we observe that the numerical values of Stau-atoms formation rates for the proton, deuterium and tritium is the same order of $O(11)$, and only for ^{3}He this parameter is in order of the $O(9)$. Form the obtained numerical values of Stau-molecules formation rates according to the Figs. (3) to (6) we see that, the reaction which at least has one proton as a reactant particles, they will have the highest values of molecular formation rate and are in the first group. After that, the reaction which at least has one deuterium as a reactant particles, they are the highest values of molecular formation rate and are in the second group. Similarly, the reaction which at least has one tritium or ^{3}He as a reactant particles are in the third and fourth group respectively (in fact, these results indicate that the values of Stau-atoms and molecules formation rates inversely depend on the mass of the reactants that was mentioned in the previous section). So the choice of nuclear fuel in addition to the selection the reaction with high values for energy production, should be considered values of Stau-atoms and molecules formation rates of each reaction. So that can be selected as a fuel with more efficiently.

COMPETING INTERESTS

Authors declare that there are no competing interests.

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