RPE | Radiation Physics & Engineering
A Peer-Reviewed Journal
Published by K.N. Toosi University of Technology
http://rpe.kntu.ac.ir
Research Article

Radiation Physics and Engineering 2023; 4(2):39–44

Investigation of radiation-matter interaction effects on burn process of nonequilibrium deuterium-tritium plasma in inertial confinement fusion approach

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HIGHLIGHTS

- The burning process of deuterium-tritium fuel and the effect of all the dominant phenomena has been investigated.
- Minimum conditions that are required for starting the thermonuclear reactions in a self-sustaining mode were obtained.
- The effect of the Compton scattering energy from a relativistic point of view is studied.

ABSTRACT

A numerical model was developed and a system of the nonlinear equations of deuterium-tritium burn-up in inertial confinement fusion have been solved to find the minimum conditions which are required for the formation of hot spot and starting the thermonuclear reactions in a self-sustaining mode. The effect of all the dominant phenomena in the nonequilibrium plasma, including the alpha particle energy deposition in the hot spot and transferring to ions and electrons, ions-electron coupling energy, and the main photons-matter interactions, which includes the bremsstrahlung radiation and the Compton scattering, were investigated. By using the Klein-Nishina equation for scattering cross-section of high energy photons, the effects of the photon-matter interactions from a relativistic point of view have also been studied. It was shown that the change of photon distribution shape can have a significant effect on the photon temperature, the photon-electron coupling energy and as a result on the electrons and the ions temperature in a diluted plasma.

KEYWORDS

Compton Scattering Effect
Bremsstrahlung loss
Diluted plasma
Klein-Nishina equation

HISTORY

Received: 29 April 2022
Revised: 27 June 2022
Accepted: 29 July 2022
Published: Spring 2023

1 Introduction

Precise calculation of a physical phenomenon that accrues in fusion medium, plays an essential role in the correct simulation of burn-up process of thermonuclear fuel. The main goal of this paper is to calculate the effect of all the phenomena associated with the absorption and emission of energy, after the nuclear reactions start to happen and the resulting energy releases in the hot spot of inertial confinement fusion (Atzeni and Meyer-ter Vehn, 2004; Lindl, 1998).

According to the Lawson criterion (Lawson, 1957; Zhou and Betti, 2008), when the minimum requirements for initiation of nuclear fusion for an equimolar mixture of deuterium and tritium were prepared, the ignition in the hot spot starts, and the burning wave propagates in the surrounding dense fuel (Christopherson et al., 2020). After deposition of alpha particle energy in the hot spot, it is instantaneously transferred to ions and electrons in certain proportions (Fraley et al., 1974). It was assumed that the ignition model is volume like, the burning medium is infinite and the electrons and ion distribution function is Maxwellian throughout the burn and the interactions between them are in the form of classic Coulomb scattering (Spitzer, 2006). Electron-photons coupling can vary depending on the plasma regime. If the plasma regime is optically thick throughout the burn, the photon distribution is blackbody or Planckian, and the plasma can be described by three temperature model, while if plasma is optically thick and at a certain energy, the photon distribution changed to Bose-Einstein, and plasma regime is also changed to optically thin. In this case, a new pho-

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https://doi.org/10.22034/rpe.2022.339578.1083
https://dorl.net/dor/20.1001.1.26456397.2023.4.2.6.2

ton temperature is defined, which differs from Planckian radiation temperature (Molvig et al., 2009). In the Bose-Einstein distribution, the Compton scattering can boost the photons to high energy without changing the photons numbers. If the scattering calculation is done with nonrelativistic approximation, the energy exchange rate between electrons and photons is not completely precise. So we should consider the Compton scattering from a relativistic point of view which its results have well compatible with Monte Carlo calculations (Cooper, 1971; Corman, 1970).

In this paper, the photon-electron coupling and their effects on the burning process of deuterium-tritium in both relativistic and nonrelativistic cases have been studied.

2 Radiation field calculation

In order to explain the photon-matter interaction in plasma, the equation of the time evolution of photon number density which is called the photon kinetic equation, is used as (Cooper, 1971; Corman, 1970; Rose, 2013, 1996; ZelDovich and Levich, 1969):

$$\begin{aligned}\rho_\varepsilon \frac{\partial n_E}{\partial t} &= \nu_C N_{\gamma 0}(T_e)\frac{T_e}{m_e c^2}\frac{\partial}{\partial \varepsilon}\Big[\varepsilon^4\big(n_\varepsilon(1+n_\varepsilon)\big) \\ &+ \frac{\partial}{\partial \varepsilon}n_\varepsilon\Big] + \Big\{\nu_\beta n_e\sqrt{\frac{m_e c^2}{2T_e}}\frac{\mathrm{e}^{-\varepsilon/2}K_0(\varepsilon/2)}{\varepsilon} \\ &- \nu_\beta \rho_\varepsilon \frac{n_e}{N_{\gamma 0}(T_e)}\sqrt{\frac{m_e c^2}{2T_e}}\frac{\mathrm{e}^{-\varepsilon/2}K_0(\varepsilon/2)(\mathrm{e}^\varepsilon-1)}{\varepsilon^3}n_E\Big\}\end{aligned} \tag{1}$$

In Eq. (1), ε is the photon energy, c is the speed of light, $\rho_\varepsilon = \dfrac{8\pi T_e^3\varepsilon^2}{h^3c^3}$ is the density of states, $\nu_C = c\,\sigma_T n_e$ is the basic Compton rate, $\sigma_T = \dfrac{8\pi\, r_e^2}{3}$ is the Thomson cross-section, $N_{\gamma 0}(T_e) \equiv \dfrac{8\pi\, T_e^3}{h^3c^3}$, and $\nu_\beta = \dfrac{4}{\pi^{3/2}}Z_{\text{eff}}\dfrac{e^2}{\hbar\, c}\nu_C$. The relation between photon Bose-Einstein distribution and photon particle and energy density can be expressed as (Molvig et al., 2009):

$$\begin{aligned}E_R &= \frac{8\pi T_e^4}{h^3c^3}\int_0^\infty \mathrm{d}\varepsilon\ \varepsilon^3\frac{1}{\mathrm{e}^{\alpha+\varepsilon/\gamma}-1} \\ &= \frac{8\pi T_p^4}{h^3c^3}\int_0^\infty \mathrm{d}y\ y^3\frac{1}{\mathrm{e}^{\alpha+y}-1} \\ &= \frac{8\pi T_p^4}{h^3c^3}F(\alpha)\end{aligned} \tag{2}$$

$$N_\gamma = \frac{8\pi T_e^3}{h^3c^3}\int_0^\infty \mathrm{d}\varepsilon\ \varepsilon^3\frac{1}{\mathrm{e}^{\alpha+\varepsilon/\gamma}-1} \tag{3}$$

The Bose-Einstein form of photon distribution in zero-order can be expressed as (Pathria, 2016):

$$n_E^0 = \frac{1}{\mathrm{e}^{(\mu+E)/T_p}-1} = \frac{1}{\mathrm{e}^{\alpha+\varepsilon/\gamma}-1} \tag{4}$$

where μ is chemical potential, α is dilution factor, T_p is the photon temperature, $\gamma = \dfrac{T_p}{T_e}$ is the ratio of photon temperature to electron temperature and $\varepsilon \equiv \dfrac{E}{T_e}$ is the energy variable.

The first term of the right-hand side of Eq. (1) represents the Compton operator, and the second term shows the bremsstrahlung operators. The power radiated power from electrons to photons can be extracted from these operators when they are calculated for the zero-order photon distribution as (Molvig et al., 2009):

$$\begin{aligned}P_{rad} =& P_B + P_C = \nu_C n_e \frac{4}{\pi^{3/2}}Z_{\text{eff}}\frac{e^2}{\hbar\, c}\sqrt{\frac{T_e m_e c^2}{2}} \\ &\times\Big[\int_0^\infty \mathrm{d}\varepsilon\ \mathrm{e}^{-\varepsilon/2}K_0(\frac{\varepsilon}{2})\frac{(\mathrm{e}^{\alpha+\varepsilon/\gamma}-\mathrm{e}^\varepsilon)}{\mathrm{e}^{\alpha+\varepsilon/\gamma}-1}\Big] \\ &+ \nu_C N_{\gamma 0}(T_e)\big(1-\frac{1}{\gamma}\big)\frac{T_e^2}{m_e c^2} \\ &\times\int_0^\infty \mathrm{d}\varepsilon\ \varepsilon\frac{\partial}{\partial\varepsilon}\Big(\varepsilon^4\frac{\mathrm{e}^{\alpha+\varepsilon/\gamma}}{\big(\mathrm{e}^{\alpha+\varepsilon/\gamma}-1\big)^2}\Big)\end{aligned} \tag{5}$$

where K_0 is the modified Bessel function of the second kind. In Eq. (5), the first term of right-side is the bremsstrahlung power, and the second term is the Compton power that can be replaced by

$$P_c = \nu_C\, 4\, E_R\frac{(T_e-T_p)}{m_e c^2} \tag{6}$$

where E_R is the radiation energy density was defined in Eq. (2).

3 Klein-Nishina scattering cross-section

When the energy of photons is comparable or greater than the rest mass of energy of the electron ($m_{0e}c^2$), a quantum treatment is necessary, and the Klein-Nishina formula must be used to calculate of photons cross-section, while for photons energy much smaller than the rest mass of energy of the electron, $h\nu << m_{0e}c^2$, the scattering of photons is described by Thomson formula. According to the Klein-Nishina equation, when the photon energy increases, its cross-section or its collision probability with electrons is decreased. The Klein-Nishina scattering cross section per steradian of solid angle Ω can be written as (Nishina, 1929)

$$\begin{aligned}\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} =& r_0^2\big(\frac{1+\cos^2\theta}{2}\big)\frac{1}{\big(1+h\nu(1-\cos\theta)\big)^2} \\ &\times\Big[\frac{(h\nu)^2\big(1-\cos\theta\big)^2}{\big(1+\cos^2\theta\big)\big[1+h\nu(1-\cos\theta)\big]}+1\Big] \\ &= \frac{1}{2}r_0^2\Big(\frac{k}{k_0}\Big)^2\Big(\frac{k}{k_0}+\frac{k_0}{k}-\sin^2\theta\Big)\end{aligned} \tag{7}$$

where $k_0 = \dfrac{h\nu_0}{m_e c^2}$, $k = \dfrac{h\nu}{m_e c^2}$, and $r_0 = \dfrac{e^2}{4\pi\,\varepsilon_0\, m_{0e}\, c^2}$ is classical electron radius, $h\nu_0$ is the energy of the incident photon, $h\nu$ is the energy of the scattered photon, m_e is the rest mass of the electron, and c is the speed of light. When a high-energy photon collides with an electron, for accuracy of calculations, it is necessary to use a relativistic approximation for describing the Compton scattering phenomenon. According to The Fokker-Planck equation (Cooper, 1971), a correction factor $\varphi_R(\varepsilon)$ applies on the

Compton scattering operator in plasma in a relativistic case

$$C_C(T_e, n_\varepsilon) = \nu_C N_{\gamma 0}(T_e) \frac{T_e}{m_e c^2} \frac{\partial}{\partial \varepsilon} \times \Big[\varphi_R\big(\frac{\varepsilon}{\gamma}\big)\varepsilon^4 \Big(n_\varepsilon(1+n_\varepsilon) + \frac{\partial}{\partial \varepsilon} n_\varepsilon\Big)\Big] \tag{8}$$

Threfore, the Compton scattering power relation in Eq. (6) is changed as (Molvig et al., 2009; Cooper, 1971):

$$\begin{aligned} P_C &= \nu_C\, 4\, E_R \frac{(T_e - T_p)}{m_e c^2} \alpha_R \\ &= \frac{1}{4F(\alpha)} \nu_C\, E_R \frac{(T_e - T_p)}{m_e c^2} \\ &\times \int_0^\infty \mathrm{d}y\; y^4\; \varphi_R(y)\, \csc h^2\big(\frac{a+y}{2}\big) \end{aligned} \tag{9}$$

$$\varphi_R(y) = \frac{1 + \dfrac{a}{1+by}}{1 + gy + \sigma y^2} \tag{10}$$

where

$$a = \frac{5}{2}\Big(\frac{T_e}{m_e c^2}\Big) + \frac{15}{8}\Big(\frac{T_e}{m_e c^2}\Big)^2\Big(1 - \frac{T_e}{m_e c^2}\Big) \tag{11}$$

$$\begin{aligned} b &= 0.02\; T_p\,, \\ g &= 0.009\; T_p\,, \\ \sigma &= 0.0000042\; T_p^2 \end{aligned} \tag{12}$$

Equation (6) is the relativistic form of the Compton scattering energy, and in the following section, we use this relation in DT burn-up equations.

4 Nuclear Ignition and Burn-up Equation

In the four temperature model, the areal density- dependent calculations of the fusion process of DT fuel in an infinite medium such as ion-electron collisions, alpha particle energy deposition, radiation-matter interaction including, the Compton scattering and the bremsstrahlung radiation, were performed. The nuclear reactions are considered in the calculation as follows:

$$\begin{aligned} {}_1D^2 + {}_1T^3 &\longrightarrow {}_2He^4 + {}_0n^1 + 17.6\text{ MeV} \\ {}_1D^2 + {}_1D^2 &\longrightarrow {}_2He^3 + {}_0n^1 + 3.27\text{ MeV} \\ {}_1D^2 + {}_1D^2 &\longrightarrow {}_1T^3 + {}_1p^1 + 4.03\text{ MeV} \end{aligned} \tag{13}$$

We consider the 4-T model (Molvig et al., 2009) for the description of the plasma, in which its components have different temperatures in a nonequilibrium situations. In the 4T model, the radiation temperature is distinguished from photon temperature when the plasma regime undergoes a transition from optically thick to optically thin. The equation of electrons revolution with time are shown as (Molvig et al., 2009):

$$\begin{aligned} &\frac{3}{2} n_e \frac{\partial T_e}{\partial t} = E_\alpha\big(1 - f_{\alpha i}\big)\, n_i^2 \langle \sigma\nu\rangle + P_{ie} - P_C - P_B \\ &P_{ie} = \frac{6}{\sqrt{\pi}}\, \nu_C\, n_i \Big[\frac{m_e}{m_D} + \frac{m_e}{m_T} + 4\Big(\frac{n_{io} - n_i}{n_i}\Big)\frac{m_e}{m_\alpha}\Big] \\ &\qquad \times \Big(\frac{m_e c^2}{2T_e}\Big)^{3/2} \ln(\Lambda)\, (T_i - T_e) \\ &\ln(\Lambda) = 25.127 - \ln\Big(\frac{\sqrt{n_e}}{1000\, T_e}\Big) \\ &f_{\alpha i} = \frac{T_e}{T_e + 32} \end{aligned} \tag{14}$$

where $f_{\alpha i}$ is the fraction of alpha particle energy, E_α, deposited in the hot spot which transferred to ions, $\langle\sigma\nu\rangle$ is the reaction rate and $\ln(\Lambda)$ is the Coulomb logarithm which is defined as the ratio of Debye screening length to the minimum value of the impact parameter in Coulomb collision processes (Mulser et al., 2014).

The equation of ions revolution with time are shown as (Molvig et al., 2009):

$$\frac{3}{2}\big[n_{io} + n_i\big] \frac{\partial T_i}{\partial t} = \big(E_\alpha f_{\alpha i} + \frac{3}{2} T_i\big)\, n_i^2\, \langle\sigma\nu\rangle - P_{ei} \tag{15}$$

where $n_{io} = \dfrac{n_e}{2}$ is the constant initial ion density.

According to Lawsons criterion in inertial confinement fusion, we need to compute the minimum value for the product of initial mass density and initial hot spot radius ($\rho_0 r_0$). So it is required to change the variable from time to areal density ($\rho_0 r_0$), and use Frolovs approach (Frolov et al., 2002), which have been shown in our earlier work (Nazirzadeh et al., 2015, 2017) thus the Eqs. (14) and (15) are changed as

$$\frac{\mathrm{d}T_e}{\mathrm{d}x} = -\frac{3}{x} T_e + \frac{q_e(x, T_i, T_e, T_p, T_R)}{C_{Ve}\, V_{max}} \tag{16}$$

$$\frac{\mathrm{d}T_i}{\mathrm{d}x} = -\frac{3}{x} T_i + \frac{q_i(x, T_i, T_e)}{C_{Vi}\, V_{max}} \tag{17}$$

where $x = \rho_0 r$ is areal density, C_{Ve} and C_{Vi} are specific heat capacity of electrons and ions respectively, $V_{max} = \dfrac{\mathrm{d}r}{\mathrm{d}t}$ is the speed of hot spot expansion, q_e and q_i are the net energy release rate for electrons and ions, which are represented respectively in Eq. (16) and Eq. (17) as

$$q_e = E_\alpha\big(1 - f_{\alpha i}\big)\, n_i^2\, \langle\sigma\nu\rangle + P_{ie} - P_C - P_B \tag{18}$$

$$q_i = \big(E_\alpha f_{\alpha i} + \frac{3}{2} T_i\big)\, n_i^2\, \langle\sigma\nu\rangle - P_{ie} \tag{19}$$

where n_i is the ions number density which its variation with areal density for both the deuterium and tritium can be expressed as

$$\frac{\partial n_i}{\partial x} = -\frac{n_i^2\, \langle\sigma\nu\rangle}{\rho_0 V_{max}} \tag{20}$$

The time evolution of radiation energy in Eq. (2) can be shown as (Molvig et al., 2009):

$$\frac{\partial E_R}{\partial t} = \frac{32\pi}{h^3 c^3} T_P^3\, F(\alpha) \frac{\partial T_P}{\partial t} + \frac{8\pi}{h^3 c^3} T_P^4 \frac{\mathrm{d}F}{\mathrm{d}\alpha} \frac{\partial \alpha}{\partial t} \tag{21}$$

When the dilution factor does not change with time, $\frac{\partial \alpha}{\partial t} = 0$, photons retain their Planckian distribution shape, and time variation of radiation temperature is expressed as

$$\frac{\mathrm{d}T_R}{\mathrm{d}t} = \frac{h^3 c^3}{32\,\pi\, T_P^3\, F(0)} \frac{\partial E_R}{\partial t} \tag{22}$$

otherwise, the time variation of photon temperature can be written as (Molvig et al., 2009):

$$\frac{\partial T_P}{\partial t} = \frac{h^3 c^3}{32\pi\, T_P^3\, F} \frac{\partial E_R}{\partial t} - \frac{T_P}{4} \frac{\mathrm{d}\ln F}{\mathrm{d}\alpha} \frac{\partial \alpha}{\partial t} \tag{23}$$

By changing the variable from time to areal density and use Frolovs approach, Eq. (22) and Eq. (23) are represented as (Nazirzadeh et al., 2015, 2017):

$$\frac{\mathrm{d}T_R}{\mathrm{d}x} = -\frac{3}{4x} T_r + \frac{q_r(x, T_e, T_R)}{C_{Vr}\, V_{max}} \tag{24}$$

$$\begin{aligned}\frac{\partial T_P}{\partial x} &= -\frac{3}{4x} T_P - \frac{1}{4} T_P \frac{\partial F}{\partial \alpha} \frac{\partial \alpha}{\partial x} \\ &+ \frac{q_P(x, T_e, T_P)}{\frac{32\pi}{h^3 c^3}\, T_P^3\, F(\alpha)\, \rho_0\, V_{max}}\end{aligned} \tag{25}$$

where $\frac{\partial \alpha}{\partial x}$ is the variation of dilution factor with respect to areal density that can be expressed as (Molvig et al., 2009; Nazirzadeh et al., 2015):

$$\begin{aligned}\frac{\partial \alpha}{\partial x} =& \Big(-\dot{N}_B + \frac{I_1(\alpha)}{4F(\alpha)} \frac{P_{rad}}{T_P} \Big) \\ &\times \frac{1}{\rho_0\, V_{max}\, N_{\gamma 0} \Big(I_0(\alpha) - \frac{I_1^2(\alpha)}{4F(\alpha)} \Big)}\end{aligned} \tag{26}$$

In the following section, the rules of influential phenomena that participate in the fusion such as ion-electron coupling power, P_{ie}, the Compton scattering power, P_c, in two cases: relativistic and nonrelativistic, the division of alpha particle energy transferred to ions and electrons that were each expressed by known formulas and the bremsstrahlung power were explicitly investigated.

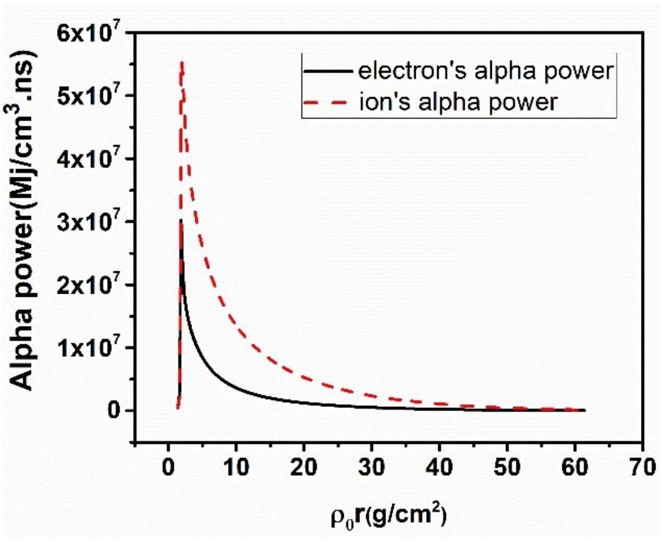

Figure 1: The amount of alpha energy transferred to ions and electrons.

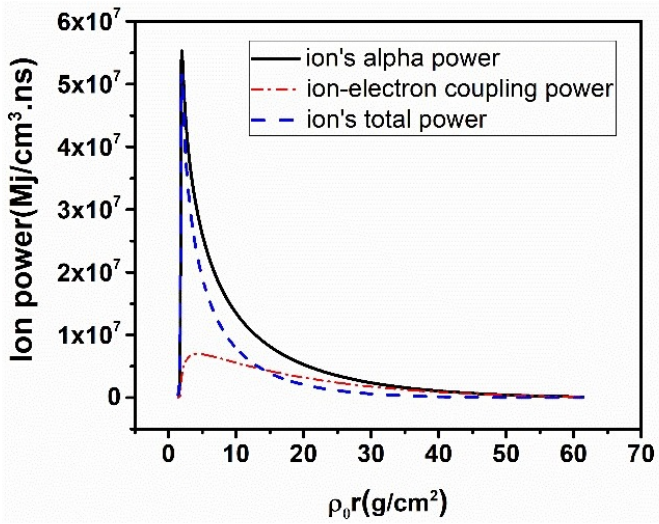

Figure 2: The total ion energy is consists of ion alpha energy and ion-electron coupling energy.

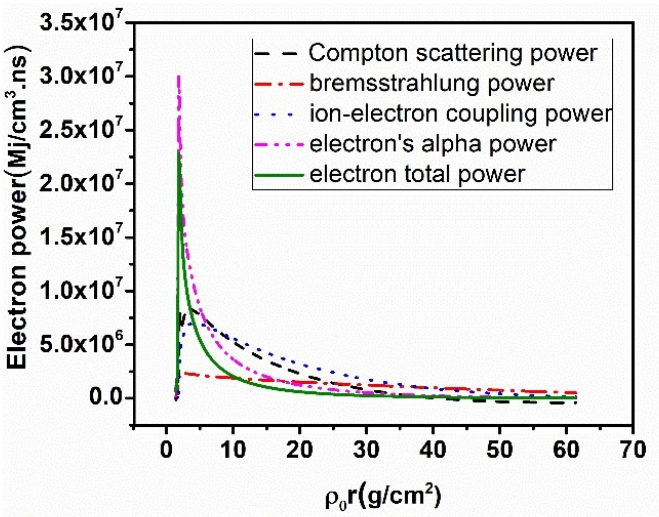

Figure 3: The total electron energy is consists of electron alpha energy and ion-electron coupling energy, the Compton scattering energy, and the bremsstrahlung radiation energy.

5 Results and discussion

In this paper, a Fortran program was used to solve a set of six coupled nonlinear differential equations of deuterium-tritium burn in a four-temperature model. These differential equations include four plasma components (ions, electrons, radiation, and photons), ions number density, and dilution factor revolutions with respect to areal density.

The initial mass density for both deuterium and tritium were chosen to $\rho_0 = 100$ g.cm^{-3}, so the initial ions density is $n_i = 1.2044 \times 10^{25}$ cm^{-3}. The starting ion and electron temperature is set to 5 keV , and the initial photon and radiation temperature were assumed to 2.5 keV.

In Fig. 1, the division of alpha energy which transferred to ions and electrons, was shown. It was assumed that all the neutron energy produced in the fusion reactions is wasted from the system. In Fig. 2, the factors that effects the energy of the ions are depicted. A portion of alpha energy which is transferred to ions and ion-electron coupling energy, are the sources of ions energy, in which the former plays a positive rule, and the latter has a negative effect on ions energy. In Fig. 3, the total energy of electrons is represented, which is consisted of electron alpha energy, ion-electron coupling energy, which both have the positive effect on electron energy, and the Compton scattering energy, and the bremsstrahlung radiation energy, which have negative effects on the electron energy.

It was assumed that the burning process is uniformly in an infinite medium and plasma is in an optically thick regime; in other words, photons distribution is initially Planckian with no dilution factor ($\alpha = 0$), then at certain photon energy when $\alpha > 0$, the plasma undergoes a transition to the optically thin regime, and photons distribution is changed to Bose-Einstein. In an optically thin regime with fixed radiation energy, the dominated photon-matter interaction is the Compton scattering which increases the photon temperature, so for high energy photons, it is necessary to consider the Compton scattering relativistically. In this case, the Compton scattering probability of high energy photons with electrons is smaller than that of the nonrelativistic case.

In Fig. 4, the domination of photon temperature in the relativistic case in comparison to the nonrelativistic case is represented. It was clear that with a low scattering cross-section, the photon temperature decreases less, and as a result, the Compton scattering energy for high energy photons is smaller than that of low energy photons, which is represented in Fig. 5. The bremsstrahlung radiation is almost the same in both models. In Fig. 6, the total radiation power, which is consisted of the Compton scattering and the bremsstrahlung radiation, was shown. As is clear if the burning calculation was done from a relativistic point of view, the total radiation from the hot spot is decreased in comparison to the nonrelativistic case.

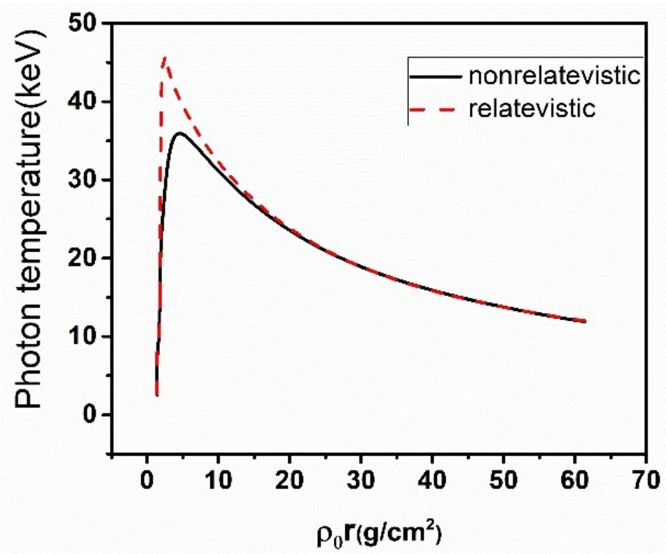

Figure 4: Photon temperature in relativistic and nonrelativistic cases. High energy photons interactions with electrons is decreased.

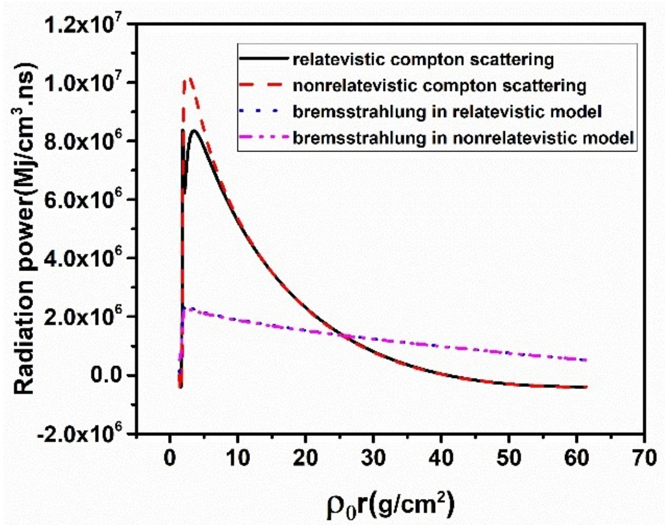

Figure 5: The Compton scattering power and bremsstrahlung radition in relativistic and nonrelativistic cases.

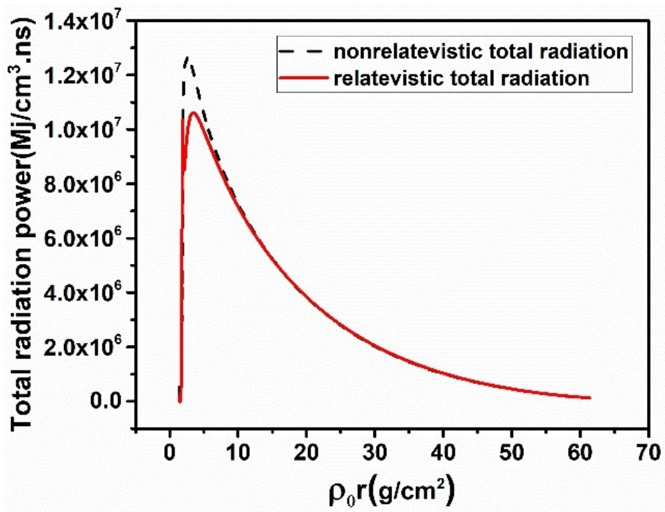

Figure 6: Total radiation power in the relativistic and nonrelativistic cases.

6 Conclusions

In this paper, by using a 4T model, the burning process of deuterium-tritium fuel and the effect of all the dominant phenomena involved in the fusion, including the alpha particle energy transferring to ions and electrons, ion-electron coupling energy, the Compton scattering energy, and the bremsstrahlung radiation in an infinite medium has been investigated.

The effect of the Compton scattering energy from a relativistic point of view is also studied. It was shown that in a diluted plasma, when photons distribution is changed from blackbody radiation to Bose-Einstein, the Compton scattering heats photons to high temperature without change the photons number. So by applying the relativistic model of the Compton scattering in the fusion burn-up calculations, fusion hot spot will stay more time in self-sustaining mode.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

References

Atzeni, S. and Meyer-ter Vehn, J. (2004). *The physics of inertial fusion: beam plasma interaction, hydrodynamics, hot dense matter*, volume 125. OUP Oxford.

Christopherson, A., Betti, R., Miller, S., et al. (2020). Theory of ignition and burn propagation in inertial fusion implosions. *Physics of Plasmas*, 27(5):052708.

Cooper, G. (1971). Compton Fokker-Planck equation for hot plasmas. *Physical Review D*, 3(10):2312.

Corman, E. G. (1970). Relativistic Compton energy exchange. *Physical Review D*, 1(10):2734.

Fraley, G., Linnebur, E., Mason, R., et al. (1974). Thermonuclear burn characteristics of compressed deuterium-tritium microspheres. *The Physics of Fluids*, 17(2):474–489.

Frolov, A. M., Smith Jr, V. H., and Smith, G. T. (2002). Deuterides of light elements: low-temperature thermonuclear burn-up and applications to thermonuclear fusion problems. *Canadian Journal of Physics*, 80(1):43–64.

Lawson, J. D. (1957). Some criteria for a power producing thermonuclear reactor. *Proceedings of the Physical Society. Section B*, 70(1):6.

Lindl, J. (1998). Inertial Confinement Fusion Springer-Verlag. *New York*, 11.

Molvig, K., Alme, M., Webster, R., et al. (2009). Photon coupling theory for plasmas with strong Compton scattering: Four temperature theory. *Physics of Plasmas*, 16(2):023301.

Mulser, P., Alber, G., and Murakami, M. (2014). Revision of the Coulomb logarithm in the ideal plasma. *Physics of Plasmas*, 21(4):042103.

Nazirzadeh, M., Ghasemizad, A., and Khanbabei, B. (2015). Determination of deuterium–tritium critical burn-up parameter by four temperature theory. *Physics of Plasmas*, 22(12):122709.

Nazirzadeh, M., Khanbabaei, B., and Ghasemizad, A. (2017). The investigation of inertial fusion burning requirements of deuterium-helium3 in degenerate plasma. *Physics of Plasmas*, 24(8):082708.

Nishina, Y. (1929). Polarisation of Compton scattering according to Dirac's new relativistic dynamics. *Nature*, 123(3097):349–349.

Pathria, R. K. (2016). *Statistical mechanics*. Elsevier.

Rose, S. (1996). Compton scattering in inertial confinement fusion plasmas. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 55(6):707–713.

Rose, S. (2013). Electron–positron pair creation in burning thermonuclear plasmas. *High Energy Density Physics*, 9(3):480–483.

Spitzer, L. (2006). *Physics of fully ionized gases*. Courier Corporation.

ZelDovich, Y. B. and Levich, E. (1969). Bose condensation and shock waves in photon spectra. *Sov. Phys. JETP*, 28(11):1287.

Zhou, C. and Betti, R. (2008). A measurable Lawson criterion and hydro-equivalent curves for inertial confinement fusion. *Physics of Plasmas*, 15(10):102707.

To cite this article:

Nazirzadeh, M., Khanbabaei, B., Alborznia, H. (2023). Investigation of Radiation-Matter Interaction Effects on Burn Process of Nonequilibrium Deuterium-Tritium Plasma in Inertial Confinement Fusion Approach. *Radiation Physics and Engineering*, 4(2), 39-44.

DOI: 10.22034/rpe.2022.339578.1083

To link to this article: `https://doi.org/10.22034/rpe.2022.339578.1083`