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Calculation of The Deposited Energy and Stopping Range For The Proton, Deuteron and Carbon Beams In Laser Fusion by Fast Ignition

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ABSTRACT

The main goal of this paper is calculation of deposited energy and as a result evaluation of stopping range of the ionic beams of carbon, deuteron and proton. The deposited energy is the function of two parameters: (a) beam energy and (b) electron temperature. Also the stopping range depends on the temperature, ionic beam energy and density of fuel pellet. Our calculations show that with decreasing the stopping range of particle, the deposited energy is enhanced. In the same temperature and fuel density, carbon has less stopping range and more deposited energy but higher energy is needed to accelerate the beam , this causes carbon has less energy than others. However, deuteron has more stopping range and deposited energy in comparison with carbon also it has better beam gain in comparison with carbon. Stopping range and proton beam gain respect to the other fuels is placed in lower level , but the low threshold intensity to accelerate it, cause it obtain the high gain. The optimum beam gain of the proton is 150 while it is 75 for deuteron and 1 for carbon. The fuel geometry must be considered for more studies in order to increase the beam gain.

Keywords: Carbon. Deuteron, Proton, Laser, Deposited

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INTRODUCTION

Currently, fast ignition scheme has been considered as a robust approach to inertial confinement fusion (ICF) which basically takes different path to bring fuel to final ignition and burn state. It has a two stage process, first of it begins with the fuel pre-compressed state through illumination of a long-pulse (ns) driver (laser beams, x-rays) which then ignite by a short-pulse (ps) laser (particles) beam (Tabak et al., 2005). Fast ignition by laser-driven ion beams (Roth et al., 2001; Temporal, Honrubia, & Atzeni, 2002) offers the advantages of their classical interaction with the imploded fuel and the relatively moderate ignition energies compared to hot electrons. Proton fast ignition (PFI) is a promising option because of the high (approximately 12%) laser-to-proton conversion efficiencies found in experiments (Tabak et al., 2005). Quasi mono-energetic carbon ion beams have been proposed recently as an alternative to the PFI scheme due to their better coupling with the compressed Deuterium-Tritium (DT) core and the lower ion currents required for ignition. However, the feasibility of the carbon ion fast ignition scheme (CFI) is conditioned by the experimental demonstration of conversion efficiencies comparable to those found for protons (Badziak, 2007; J.C. Fernandez et al., 2007).The technological advantage of the fast ignition goes back to less sensitivity of compression process to growth of the Rayleigh-Taylor instability. This is a milestone relative to the standard approach which suffers from hydro dynamical instabilities during implosion phase. In original idea of fast ignition, relativistic electrons produced in the course of laser target interaction are responsible to form an off-center hot spot by local energy deposition. A few years later, the idea gained more attraction and innovative target designs like cone-guided target were proposed. Long range and focusing of hot electrons are issues that motivate researchers to assess the reliability of ion beams (Bychenkov, Rozmus, Maksimchuk, Umstadter, & Capjack, 2001). Protons offer better focusing by providing almost ballistic-like trajectories, but currently, the laser-to-ion converter foils used for proton ion generation give proton beam fluxes several orders of magnitude below the total fluxes required (Fernández et al., 2005). Heavier ions, such as carbon, have been proposed and also studied to further improve focusing and ion yields, but much higher laser intensities needed for this approach will not be available in the immediate future (Berni et al., 2003). Deuteron beams have the advantages over other competitors. Moreover, accelerated deuterons not only provide the required heating in the same condition but also coalesce with the target fuel (both deuteron and triton isotopes) as they are slowing down in the target. Therefore, the ignition energy carried by the deuteron beam can be reduced appreciably. Fusion through fast ignition is done by combination of lasers or combination of laser and accelerated particles. After the first contact of laser with target, a plasma corona is formed around the fuel capsule. This corona prevents the penetration of the laser in the central region of the target. The particle beams have more penetrability, so we use the accelerated particles driver in this paper. The irradiation of particle beam into the fuel capsule is as the same as the sparking in gasoline motors, because it causes the gasoline engines need less temperature and pressure for sparking in comparison with diesel engines. In other ways of laser fusion except fast ignition, such as diesel engine, the whole of fuel is compressed by the lasers in order to ignite. Therefore the high energy is need to approach ignition. As we mentioned in above the different ions are used till now. We use the carbon ion that is noted recently, beside the deuteron and proton ions.

In this paper, we intend to investigate on the deposited energy and stopping range for the proton, deuteron and carbon beams in laser fusion by fast ignition. To achieve this aim, we introduce Deposited energy of light ion beams in fast ignition scheme in section 2. In section 3 have been represented the range of particle beam in the target capsule. In section 4 the Characteristics of short- pulse laser in fast ignitors are studied. In section 5, the transportation gain laser energy to ions is given. Finally, we present conclusion and discussion in section 6.

DEPOSITED ENERGY OF LIGHT ION BEAMS IN FAST IGNITION SCHEME

In discussion of the fast ignitors (Logan et al., 2005) that are used in inertial confinement fusion (ICF), the electron-relativistic beam is observed as the most suitable choice for hot spot ignition that is very smaller than the compressed and dense center of the D-T. Also nowadays, the possibility of use of fast ignitors through the employment of electron beam in many of laboratories is under examination (S. P. Regan et al., 2000; Schlegel et al., 2009; Trubnikov, 1963).The scheme proposed recently, is the use of the external source of ion beam replacing the electron beam formal around the corona (Caruso & Pais, 1996) . The first idea of the fast ignitor has the problem in which laser light that is absorbed by increasing of the density and the range of its operation is decreased thus, the energy transportation to the region in which ignition should occur is decreased and ignition condition is not satisfied. So for compensating this lake of energy in fast ignitors, we need to store energy in the small volume at short time, this energy is provided by the particles that do not cause instability in the plasma. By discovering such high energy and high intensity particles (Roth et al., 2001) and (Snavely et al., 2000), the idea of using them in fast ignitors was proposed. The advantages of using protons instead of electrons or other particles are,

1- The ratio of charge to mass is large for them.2- Ions can be accelerated to very high energies by lasers. 3-In a certain energy, ions can penetrate more deeply into the target in order to increase the density of the target which can be formed the hot spot, because the ionic stopping power is proportional to the square of electric charge. 4-Since that, ions have parabolic geometry, they are accelerated at the surface of the target and concentrated in the compressed fuel. 5-Their high mass and electrical neutral space that ions are placed on it respect to electrons, are influenced less by the instabilities in comparison to the electrons. 6-The quality of the ion beams is very excellent, because they can concentrate on the very small volumes and their pulses are short and the number of ion particles are very large. One of the fast ignitior characteristics is the possibility of focus on the very small volumes. As an example, recent researches show that protons have a good concentration and can be reached to the size of hot spot around $50\mu m$. This size is large for fast ignition, albeit this subject depends on the experimental geometry that plans for co-dense ignition and also on the geometrical distribution of electrons. The ions are not monochromatic, but have an exponential distribution of energy which creates two problems. The first is that due to different energies of ions, the diffusion of ionic pulse from the source to target occurs and cause pulse broadening, so maximum distance less than several millimeters is needed to save the energy of fast ignitor in short time for hot spot. The short distance of fuel pellet makes this worriment that the thin metal foil as the ion source can be such cold that do not transport the density gradient to the behind of the surface and decrease the ion acceleration field. The second is related to stopping power. Due to their different initial velocities, the energy store of the ions with different kinetic energies is done in a large volume. The slow ions stop earlier and do not help to make ignition spark. Fortunately, the recent numerical simulations solve these problems. These simulations are done by Berni and his group (Berni et al., 2003) based on this work ,a protection layer is placed in front of the source, this can be preserved against propagation of x-ray due to fuel pellet and hold the surface of back part of the foil cold enough to accelerate the ions according to mentioned mechanism. The distance between the source and the ignition spot must be a few millimeters. At first, the initial ions with high energies penetrate into the fuel. Passing the time, the number of ions and the temperature are increased and the stopping power is decreased and compensate the low energy of the ions. So more ions store their energy in the same volume. Fast ignition has also the other advantages in comparison to other designed models. 1-The final concentration of ion beam to the fuel, is dependent on the metal foil geometry. 2-Concentration and irradiation of the high energy laser with short pulse is easy and producing the fast ignition ions depends on the metal foil geometry as mentioned. 3-The beam of laser can have the wavelength of several micrometers and disturb the formation of metal foil electrons that in turn these electrons produce the ions. 4- According to this, optical system of short-pulse laser can be placed far away from the center of the reactor; this can increase the long life (Logan et al., 2005).

The first research about the parameters of fast ignition is done by Tabak and his group . In this section ,we describe an effective theory in order to determine the range of light ions including accelerated protons too. The ions inside the D-T plasma lose their energy in collision with electrons. This dissipated energy per unit length according to experimental formula of proton stopping power is (Trubnikov, 1963),

$$\frac{dE}{dx}=\frac{2\pi Z^2 e^4 n_e}{u T_e}\,\Lambda\, F(u) \qquad (1)$$

Where ,the factor 2 is the atomic number of the light ion, $n_e(cm^{-3})$ is the electron density, $T_e(keV)$ is the electron temperature, Λ is the coulomb logarithm and F is $F(u)=\Psi(u)-(m_e/m_i)\Psi'(u)$,where $\Psi(u)$ is,

$$\Psi(u)=\frac{2}{\sqrt{\pi}}\int_0^u dt\,\sqrt{t}\,e^{-t} \qquad (2)$$

$\Psi(u)$ is the derivative of this function respect to u and u itself is: $u=\frac{m_e E}{m_i T_e}$,where energy E is in MeV. To solve the equation (2) , must be used as incomplete Gamma functions, so we have,

$$\Psi(u)=\frac{2}{\sqrt{\pi}}\gamma\left(\frac{1}{2},u\right)=2\,erf\left(\sqrt{u}\right) \qquad (3)$$

Where, erf is the error function. Now for F we have: $F(u)=2\,\mathrm{erf}(\sqrt{u})-(2\,m_e/m_i)e^{-u}$. In this section, we compare the different calculated parameters for carbon, deuteron and proton ions. Recently, carbon ion, has the suitable acceleration and conductivity and heats the fuel better than the other ions. At this moment, there is not 3 dimensional simulation of carbon ponderomotive acceleration, but we can use the deuteron beam simulation in energy range of 10 MeV (S. P. Regan et al., 2000). The Fig1, shows the total fast ignition scheme by cone-guided procedure that imploded unsymmetric from inside by nano-second laser pulse. Then a circular polarized laser beam with a spot size of r_{acc} is propagated along the cone cap in which cone cap is positioned in a distance D from the surface of the compressed region .

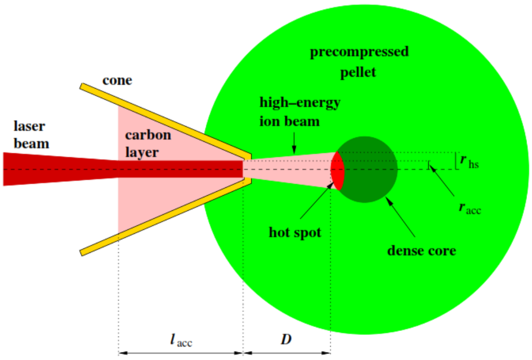

Fig.1 Laser-driven Carbon-ion fast ignition concept based on the CESA acceleration mechanism (C. Regan et al., 2011)

The carbon ions are placed in low- dense but over- critical region inside the cone and be accelerated ponderomotively (Robinson et al., 2009; Schlegel et al., 2009). The advantage of the ponderomotive acceleration process is that the acceleration gain and the ion energies only depends on the β parameter called piston parameter. The β parameter is defined by, $\beta=\sqrt{I_{las}/\rho c^3}$ where I_{las} is the ignition pulse intensity, ρ is the accelerated ion density and c is the light velocity. So production of ion beam with desired energy and low width energy band is possible. The carbon ions are stopped at the center of the D-T capsule, and form a hot spot with average radius of r_{hs} . The carbon density inside the cone must be low enough in order to large ion acceleration and energy can be possible with minimum intensity lasers (S. P. Regan et al., 2000). There are many limitations on the ρ parameter and also for incident laser beam parameters so that ignition can be done. These limitations are:

- The material inside the cone must be super- critical so that the ponderomotive acceleration process can be operational, it means $\frac{n_e}{n_c}$ must be equal to a_0 where n_e is the electron density,n_c is the critical density and a_0 is the dimensionless range of laser pulse (Robinson et al., 2009).
- The total number of the accelerated ions must be so enough to transport the required energy to the center of the fuel.
- The material thickness cone,l_{acc} must be less than Reighley length, L_R of the laser so that the laser intensity is the same for all of the ions.
- The radius of the laser focal spot in the cone,r_{acc} must be less than the radius of the hot spot, because the ion beam has an inherent divergence.
- The average intensity of laser contrast must be very high, that is 10^{-10} in order to prevent the pre-heating and expansion of the ion layer.

In Fig.2, we have shown the 3-dimensional variations of the deposited energy of the light ions like proton, deuteron and carbon in terms of beam energy and the electron temperature.

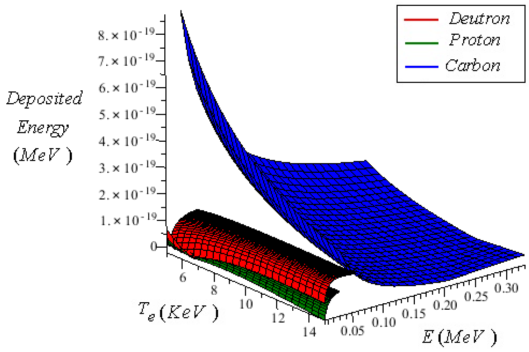

Fig.2 Deposited Energy due to deuteron, proton and carbon beams in terms of energy beam and electron temperature.

As shown in Figure.2, the deposited energy of carbon is more than deuteron and the deposited energy of deuteron is more than proton. Also we see that the deposited energy of deuteron increases with decreasing of the beam energy contrary to deuteron and proton, which is due to the mass differences of the ions. Since that we consider D-T fuel, deuteron and proton transfer their energies in head on collisions better than carbon in high energies, because they have mass near to fuel atoms. But from figure.2 we found that always the deposited energy of the carbon in the fuel is more than deuteron and proton, so the carbon ion deriver appears to be the suitable. In the following, we discus that which of the ions is more suitable for fast ignition fusion. Also according to equation (1) the mathematical term F(u) is entered to the calculations and plays an important role in calculating the deposited energy, it's graphs versus the beam energy and the electron temperature for three light ion of deuteron, proton and carbon is shown in Figure.3.

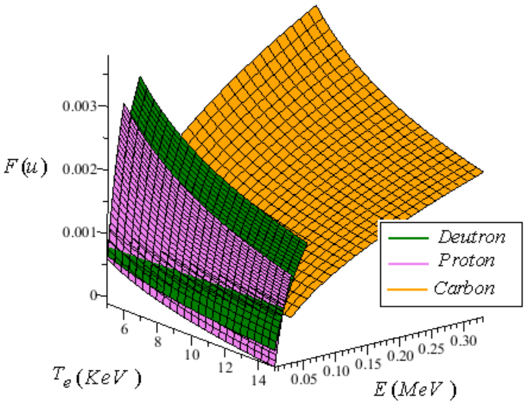

Fig.3 Three dimensional variations of F(u) in terms of incident beam energy and electron temperature for three light ions such as carbon , proton and deuteron.

RANGE OF PARTICLES BEAM IN THE TARGET CAPSULE

One of the methods of determining the radius of the D-T fuel pellet is that to take ion range (the maximum distance that ion travel through the fuel pellet so that it be stopped) equal to the radius of the D-T fuel pellet. Value of the ion penetrability is called ion range and is shown by $R(g/cm^2)$ .Ion range is the position that ion loses it's energy equal to two times of heating energy of the plasma$(3kT_e)$. Now by integrating and simplifying the equation (1) we have:

$$R = 0.06\frac{AT_e^2}{Z^2}\int_{u_0}^{u}\frac{u\,du}{\Lambda\,F} \tag{4}$$

Where $u_0 = 3\,m_e/m_i$, energy is in Mev , T_e is the electron temperature in KeV and ρ is in ${}^{g}/_{cm^3}$ and the range is in g/cm^2. Λ is the coulomb logarithm defined as:

$$\Lambda = \frac{1}{2}\left[13 - ln\left(\frac{\rho(Z^2+5.5\times\frac{10^{-4}Z^3}{Au})}{(1+u)^2T_e^2}\right)\right] \tag{5}$$

For ions with the energy$(0.01ZT_e \ll E \ll AT_e)$ or $\left(0.01\frac{Z}{A} \ll u \ll 1\right)$, we solve the integral of ion range and simplify for ion range and coulomb logarithm, so we have:

$$R = \frac{0.08}{\Lambda Z^2}\sqrt{AT_e^2E} \tag{6}$$

$$\Lambda \simeq 33 - ln\,[Z\sqrt{n_e(1+ZT_e/E)}/T_e^{3/2}(1+u)] \tag{7}$$

$$\Lambda \cong 6.5 - ln\left(Z\sqrt{\rho}/T_e{}^{3/2}\right) \tag{8}$$

As seen in figure 4, the coulomb logarithm for deuteron and proton due to the same atomic numbers have the same graphs.

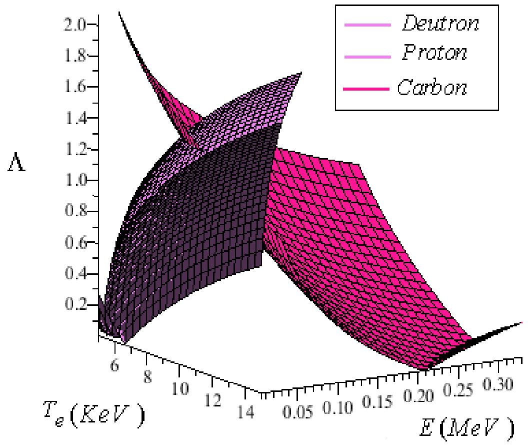

Fig.4 Three dimensional variations of coulomb logarithm in terms of electron temperature and energy for light ions of carbon, deuteron and proton.

In continuation we draw the graphs of the range of particle beam according to equation (6) in terms of energy and the thermal electron temperatures for three ion beams of proton, deuteron and carbon for three fuel density values of ρ =300, 400, 500$\frac{g}{cm^3}$. Here the two- dimensional range graphs are drawn versus beam energy in three different temperatures and densities for better comparison (see Fig 5). As seen in figures 5 for a given beam, the stopping range are increased with increasing of temperature and density. By comparing the stopping range of proton, deuteron and carbon in the same temperature and density we conclude that the deuteron stopping range is more than the proton and the carbon stopping range is less than the others. Carbon has the shortest stopping range and as mentioned before has the high deposited energy, too. After carbon is deuteron and the last is the proton that has the more stopping range and the less deposited energy. For better comparison, the two-dimensional range of the ions versus energy is shown in Fig. 6 in same energy and temperature, the range of the accelerated particles irradiate to pellet is enhanced by increasing the density. The comparison of particle range in the same density shows that as mentioned before the stopping range for carbon, deuteron and proton is increased respectively.

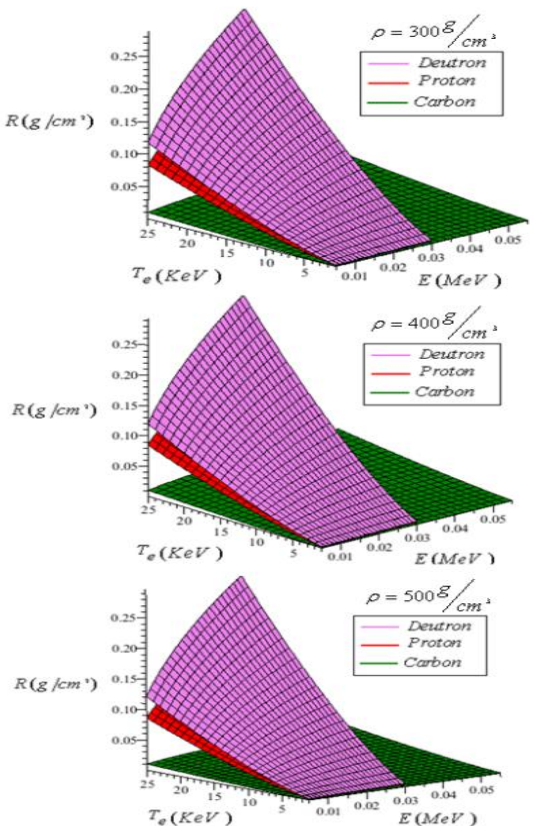

Fig. 5 Comparison the range of proton, deuteron and carbon in terms of electron temperature and energy of ion beam at three different densities$\rho = 300 , 400$ and $500\ g/cm^3$.

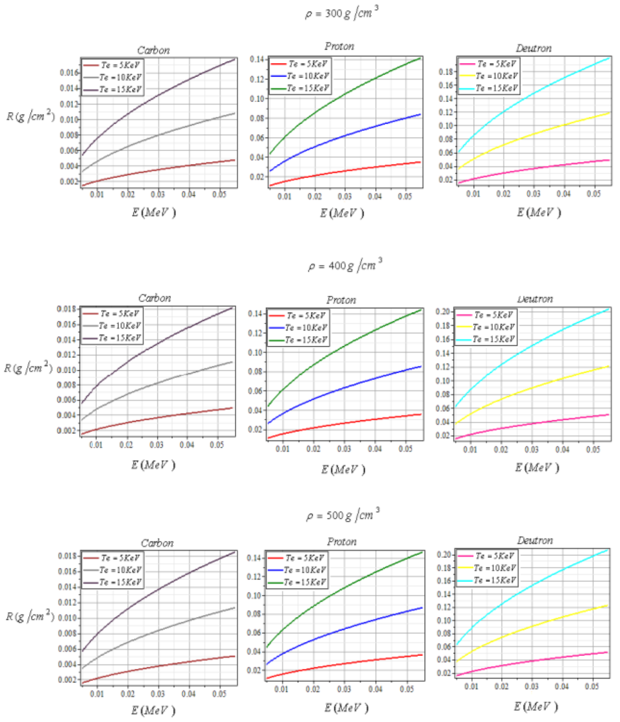

Fig. 6 Two-dimensional comparison of proton, deuteron and carbon range at three different densities $\rho = 300 , 400$ and $500\ g/cm^3$.

In Fig 7, our theoretical obtained results with the available experimental data have been compared (Schlegel et al., 2009) and (Bychenkov et al., 2001). It can be seen that the calculated range values in this paper, always are lower than the experimental values that is due to ignoring the total effects of interaction of particle beams with fuel pellet. However, our obtained values are in good agreement with experimental data.

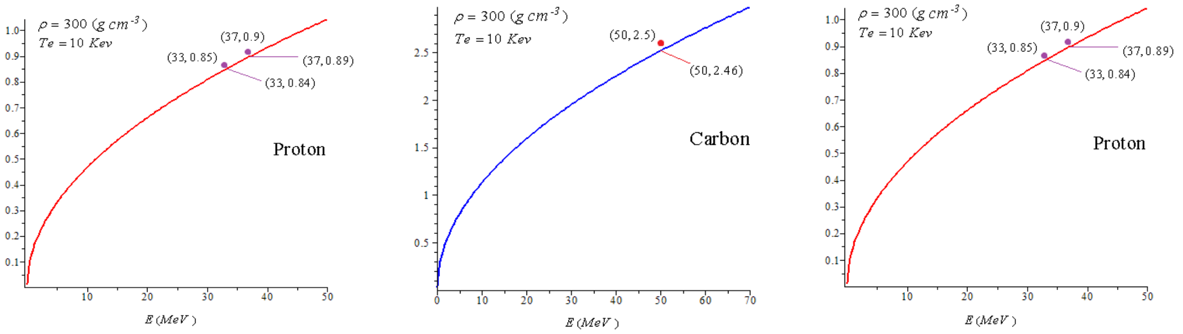

Fig.7 Comparison the range of deuteron, proton and carbon beams, with the available experimental data (S. P. Regan et al., 2000; Robinson et al., 2009).

CHARACTERISTICS OF SHORT-PULSE LASER IN FAST IGNITORS

The high power lasers with short- pulses, because of their good abilities in producing localized electric fields oscillate in a given frequency, is taken into account as a wonderful source for fast ignitors. By increasing the laser intensity peak, the interesting physical regimes are obtained. There are important limitations that effect on the laser peak. One of such limitations is time interval of laser- pulse effect, by increasing the energy of short- pulse laser the higher gain is achieved. Band width and period of the laser pulse must be satisfied in equation $\Delta f_{rms}\Delta t_{rms} > 0.5$, where Δf_{rms} is the square root of the average band width of the laser frequency and Δt_{rms} is the square root of the laser pulse duration (Hatchet S.P., 2000). The minimum pulse intensity of the fast particles required for fast ignition must be less than

$10^{20}\ W/cm^2$. It’s necessary for ignition we assume that I_p equal to $I_p \cong 6.5\times10^{19}\ W/cm^2$(Roth, 2001) and also for ion density n_i we use the neutral condition $n_i \approx n_e/Z$ and we consider the hot electron density as one forth of it’s critical value $n_c/4$, a type of Raman instability that accelerates the electrons forward. The experimental equation of critical density is,

$$\Lambda \cong 6.5 - \ln\left(Z\sqrt{\rho}/T_e^{3/2}\right) n_c \simeq 0.85\times10^{21}\lambda^{-1}\sqrt{I/10^{18}}\,(cm^{-3}) \qquad (9)$$

$$n_c \simeq \frac{0.85\times10^{21}\lambda^{-1}\sqrt{I/10^{18}}}{6.5-\ln\left(Z\sqrt{\rho}/T_e^{3/2}\right)n_c}\,(cm^{-3}) \qquad (10)$$

Where λ is the laser wavelength in μm and I is the laser intensity in W/cm^2 . Now by having the critical density we can obtain the electron density and finally the ion density. Using the upward argument for ion density we have,

$$n_i \approx \frac{0.85\times10^{21}\lambda^{-1}\sqrt{I/10^{18}}}{4Z}\,(cm^{-3}) \qquad (11)$$

In the following we bring the graphs of the critical density and the thermal electron density and the ion density versus the wavelength and intensity of the laser in different three temperature T_e =10, 15, 20 keV and three laser wavelength 0.5 , 1 and 1.5 μm and three density $\rho = 300,400,500 g/cm^3$ for proton ,deuteron and carbon ions. (see Figs.8,9,10)

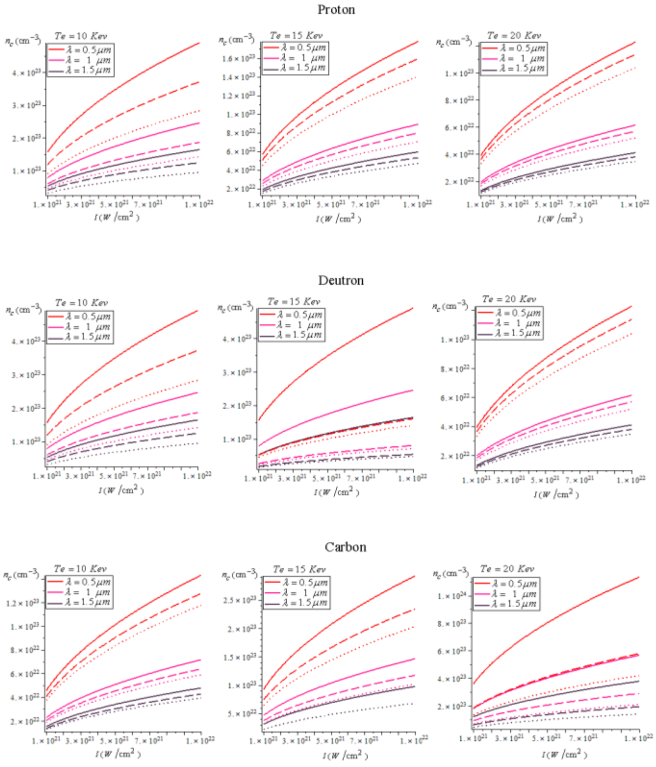

Fig. 8 Comparison of two-dimensional variations of carbon, deuteron and proton critical densities, in terms of laser intensity at three different wavelengths and temperatures and $\rho = 300,400,500 g/cm^3$ that are represented with dash line ,cut line and solid line, respectively

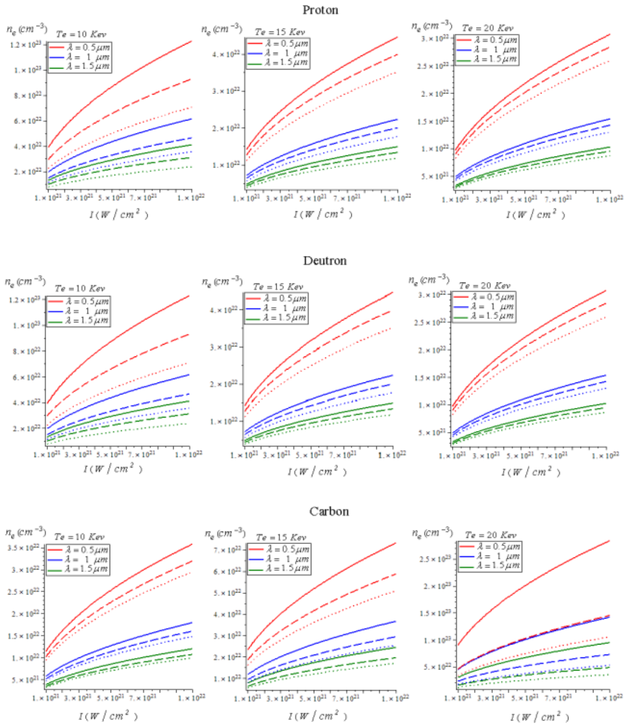

Fig.9 Comparison of two- dimensional variations of thermalized electron of carbon, deuteron and proton ions, in terms of laser intensity at three different wavelengths and temperatures and $\rho = 300,400,500 g/cm^3$, that are represented with dash line, cut line and solid line ,respectively

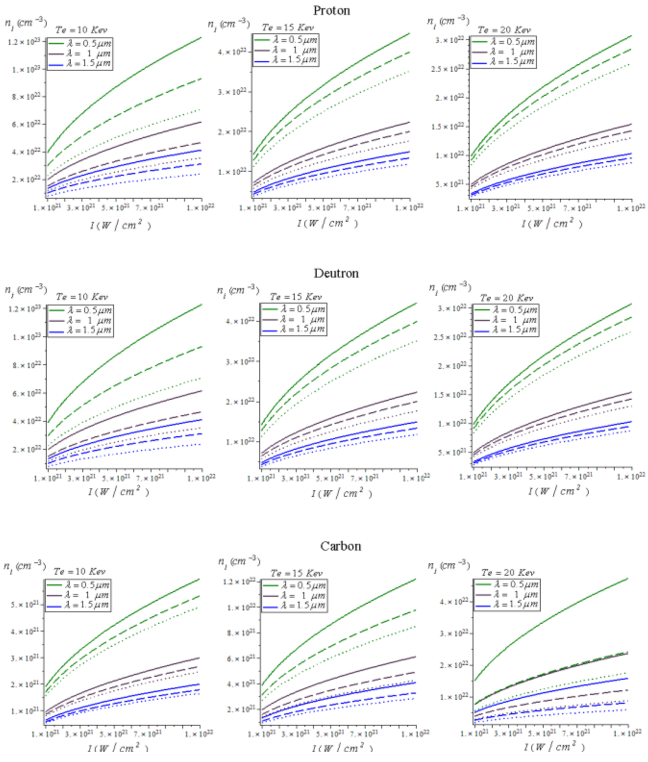

Fig.10 Comparison of two- dimensional variations of ionic density of carbon, deuteron and proton ions, in terms of laser intensity at three different wavelengths and temperatures and $\rho = 300, 400, 500\ g/cm^3$ that are represented with dash line, cut line and solid line, respectively.

As shown in figs. 8,9,10, the critical density and the resulting density of the thermal electron in carbon deriver are enhanced by the increasing of the temperature and intensity of the laser and are decreased by increasing the laser wavelength. In NIF laser organizations laser with the wavelength of 0.53µm is used, because the shorter laser wavelength is, the undesirable effect of the interaction of laser and plasma is more decreased and more energy is transported. The second subject that is more energy transportation is seen in figures 8,9,10. In these figures we see that the critical density and thermal electron density are maximized in wavelength around 0.5µm and regarding the equation (1) the critical density and the thermal electron density are increased with increasing the laser intensity and are decreased in the laser wavelength, however in proton and deuteron drivers the densities are decreased by increasing the temperature. As shown in these figures, critical density and thermal electron density, deuteron and proton drivers are more in temperature and 10keV and the density ρ=500 $\frac{\mathrm{g}}{\mathrm{cm}^3}$, so this temperature and density can be the suitable conditions for fusion. Also note that, the deuteron and proton due to their same atomic number have the same graphs. Using experimental data for ion energies, the appropriate formula for these data is,

$$E \approx 0.5\, Z\, \lambda \sqrt{I/10^{18}}\ \ MeV \qquad (12)$$

The equation (12) estimates the ion energy which charge number of z in a multi-section containing the light ions (with charge number less than z). The heavy ions due to less change ability have less chance for being accelerated. In figure 11 we see that according to previous anticipation, the ion energies are increased by the increasing of the laser intensity.

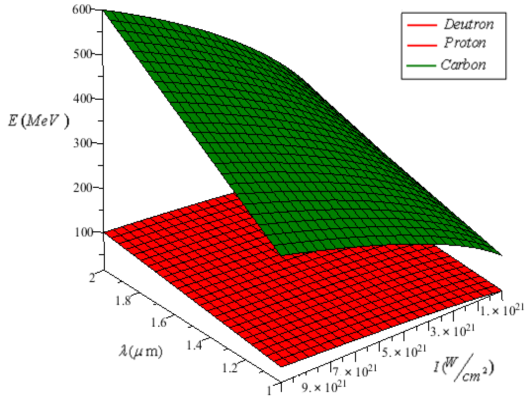

Fig.11 Three-dimensional variations of carbon ,proton and deuteron ions in terms of the carbon ion energy, laser intensity and wavelength (based on an empirical equation(9)).

We can see in Fig.11, as expected, with increasing incident laser intensity, the ion energy increases. By using the equation (5) and given value of the ion density and ion energy flux $I_i \cong n_i (2/m_i)^{1/2} E^{3/2}$ we have:

$$I_i \approx \frac{0.85\times10^{21}\lambda^{-1}\sqrt{I/10^{18}}}{4Z}\sqrt{\frac{2}{Am_p}}\,E^{3/2} \qquad (13)$$

Where, m_p= 938.2MeV. With comparing of energy flux of carbon, deuteron and proton in figure 12 we see that ion flux in carbon, is less than deuteron and proton but ion energy flux in proton is more than carbon and deuteron.

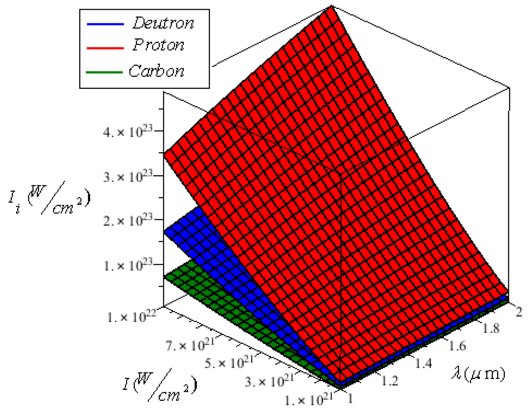

Fig.12 Three-dimensional variations of ion energy flux in terms of laser wavelength and intensity for carbon, deuteron and proton ions

We used this parameter in laser intensity equation eq.(14) and the beam energy gain eq.(15). And as described more lately, the laser intensity and the ion beam energy gain have the direct relation, so the proton gain is more than the other beam gain. The ion energy flux is increased by increasing of the intensity and wavelength of laser, therefore the increase in intensity and wavelength of laser can increase the energy gain of the beam. But we know that the long wavelengths, will increase the undesirable effects of interactions between laser and plasma. So we have the limitation in increasing the wavelength. We suppose ion velocities as no relativistic. From the condition L_i=I_p where I_p is the threshold intensity of fast particles for ignition $I_p \cong 6.5\times 10^{19}$MeV, we obtain the threshold intensity for laser with the wavelength of 1µm. In order to do this, we must obtain the threshold intensity of the laser versus ion energy , laser wavelength and the minimum ion flux.

$$I = 1.03\times10^{-20}\,\frac{AZ^2\lambda^2 I_i{}^2}{E^3}\,W/cm^2 \qquad (14)$$

Fig. 13 shows the laser intensity in terms of ion energy flux and laser wavelength.

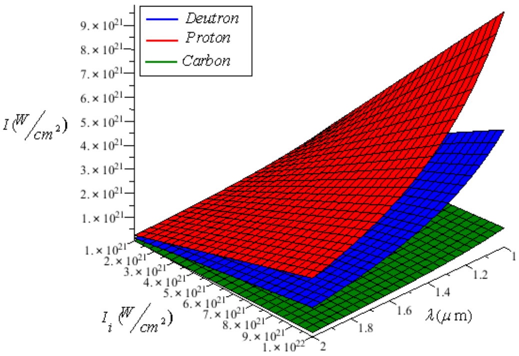

Fig.13 Three- dimensional variations of laser intensity in terms of ion energy flux and wavelength for carbon, proton and deuteron ions.

By replacing $I_i = I_p$ we have,

$$I_{Th} = 4.38 \times 10^{19} \frac{AZ^2\lambda^2}{E^3} W/cm^2 \qquad (15)$$

In figure 14, the carbon and deuteron graphs of threshold intensity laser due to have the same ratio of atomic number to mass number is placed on each other.

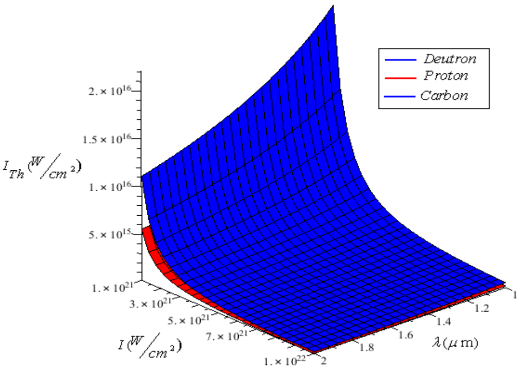

Fig.14 Three-dimensional variations of threshold laser intensity in terms of laser intensity and wavelength for light ions of carbon, deuteron and proton

THE TRANSPORTATION GAIN LASER ENERGY TO IONS

The transportation gain laser energy to ion is obtained by dividing the ion flux to laser intensity.

$$G_{conv} = \frac{I_i}{I} = \frac{0.85\times10^{21}\lambda^{-1}\sqrt{1/10^{18}}}{4Z\sqrt{I}} \sqrt{\frac{2}{Am_p}} E^{3/2} \qquad (16)$$

Substituting the equation (9) in upward equation, we can see that the conversion gain is proportional to $I^{1/4}$ (Bychenkov et al., 2001) energy gain of the ion beams of carbon, deuteron and proton is shown in Fig 15.

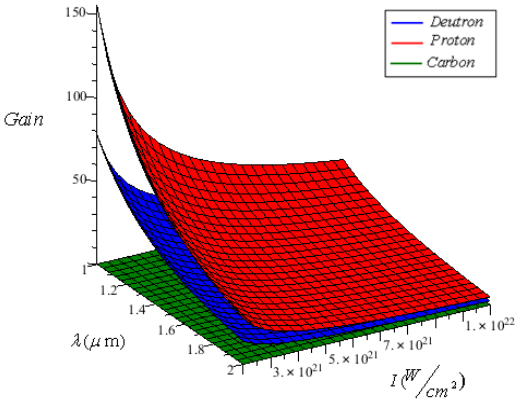

Fig.15 Comparison of three-dimensional gain variations for carbon, proton and deuteron light ion beams.

Proton and carbon have the highest and lowest gain ,respectively. The difference energy gain is proportional to inverse of wavelength and intensity. The difference of the ion beam gain in high intensity and wavelength are closed to each other, but its value is much smaller than the gain in wavelengths around the 1µm. Since these calculations are doing for the wavelengths more than 1µm, the wavelength range in figure 15 begins from 1µm. It is obvious that shorter wavelengths have higher gains, by regarding all side of the objects; the wavelength of 0.5µm is the most suitable.

DISCUSSION AND CONCLUSION

In this paper, we calculate the different parameters like deposited energy, range and gain of different particle beams. For having minimum range of particle we must have maximum deposited energy. In the same temperature and density, carbon has the less range and more deposited energy but more energy is required to accelerate the carbon beam, it means that power and intensity of laser light should be higher. This subject cause that carbon beam gain to be less than the other particles of course, carbon has the advantages that one cannot withdraw it simply, those advantages are its suitable acceleration and conductivity. However deuteron has higher range and less deposited energy, has better gain in comparison with carbon and can be a suitable selection for fast ignition. Proton is placed in the last situation from the aspects of range and the deposited energy, but the low threshold intensity of laser for acceleration causes the high gain (near to twice value of the gain of the deuteron beams) for it. The employment of which of the ion drivers for fusion through fast ignition can be dependent on the fuel geometry, too; the lower range means the higher deposited energy in the pellet but how much distance should this energy deposited in? Here the fuel geometry and the size of the ignition region become important. The order quantities calculated in this paper are the laser intensity, the laser threshold intensity and the ion energy flux that we calculate them versus the laser wavelength. The laser wavelength is the determiner quantity. The wavelength of 0.5 µm is suitable, so in NIF organization that is the strongest laser all over the world, use the wavelength of 0.53 µm.

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