# Particle Charging Using Ultra-Short Pulse Laser in the Ideal Maxwellian Cold Plasma for Cancer Treatment Based on Hadron Therapy

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**Abstract.** In biomedicine the utilization of accelerators, enables the arrangements of mixes to be utilized in cancer treatment. Accelerators are the standout among the most imperative uses of the electric and attractive fields manage the movement of charged particles. Additionally, the investigation of the plasma requires the examination of the charged particle movements in an electromagnetic field. The laser driven acceleration of particles is a standout among the most critical utilization of the laser plasma interaction. This plan depends on the alteration of the laser electromagnetic field into the plasma wave. These high stage velocity plasma waves can trap and quicken plasma electrons to exceptionally high energies. The plasma condition of issue might be characterized as a blend of decidedly charged ions, electrons and impartial atoms which comprises a perceptible electrically unbiased medium which reacts to the electric and attractive fields in an aggregate mode. In ideal Maxwellian plasma, the energy distribution function of charged particles is Maxwellian and subordinates from Maxwell-Boltzmann distribution. Cold plasma spoke to extremely helpful apparatuses empowering interaction with organic tissue without the warm harm and this innovation improvement brought about the quick formation of another field of plasma medication. Consequently, Hadron therapy is a high-precision procedure in cancer radiation therapy, which permits getting a better conformal treatment with deference than conventional radiation therapy strategies which depends on particle accelerating. This paper surveys on ions importance as charged particles with ultra-short pulse laser in an ideal Maxwellian cold plasma due to cancer treatment via Hadron therapy.

**Keywords:** Charged particle · Electromagnetic field · Ponderomotive force · Ultra-short pulse laser accelerator · Ideal Maxwellian cold plasma · Cancer treatment · Hadron therapy

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## 1 Introduction

Amid the most recent two decades, the hypothetical and connected research on vortex electromagnetic wave beam conveying photon orbital angular momentum has an extraordinary improvement. The azimuth phase distribution of vortex wave beam prompts a Helicity wave front and can exchange angular momentum from photon to issue particles. Many cutting-edge innovations depend on this impact [1]. The issue of particle motion in electromagnetic fields is principal and permeates both research facility and plasma material science. The electromagnetic interaction administers numerous parts of our day by day lives. In spite of the fact that the solidarity of the electric and the phenomenon is built up through Physics hypotheses. The motion of charged particles in an electromagnetic field is of incredible functional significance. It is utilized in observation instruments, accelerators, mass spectroscopy, and the consideration of particle reactions [2]. In the sequence of cancer look into, the laser is connected as a kind of smaller scale careful instrument of incredible precision for use in investigation in science, cytology, cytogenetics, spectroscopy, and in the cancer treatment [3]. For some scientists and physicists, laser innovation opens an altogether new, net and even brilliant field [4]. The laser beam is monochromatic, coherent and has direction since the light can be engaged by any focal point framework lastly, it has huge high energy and high power [3]. The vitality of the laser at that point is basically a framework which optically rams a mass and energizes the atoms to a higher energy and as the energy drops there is stimulated emission of radiation [5]. The steady propagation of ultra-short pulse laser in plasma is basic to the realization of particle accelerators. For the plasma oscillation to effectively quicken an electron pack it must have a high-level of cognizance [6]. With ultra-short and high exceptional laser beats the physical lead of the medium changes profoundly in a period equal or shorter than the beat span. This ultra-quick change in the physical traits of the medium starts spatial and ghostly adjustments in the multiplying laser beats. Examination of these changes could redesign the perception of how extreme optical heartbeats incite in plasma [7].

The ideal Maxwellian cold plasma is widely used to describe biomedical approaches. For plasma that is in positional thermodynamic harmony and non-balance, an assortment of hypothetical approximations and physical models have been created to manage the conduct of particles and the related photon emission forms in cold plasma with ion temperatures nigh room temperature [8]. Ideal Maxwellian cold plasma is utilized for medical aims for treatment of cancer, explicitly, in Hadron therapy and productive particle acceleration. Hadron therapy is a particular sort of oncological radiotherapy, which makes utilization of quick Hadrons to get better dose depositions when contrasted and the ones of X-rays utilized in usual radiotherapy [9]. This technique is a settled way to deal with treat cancer because of the positive ballistic properties of ion beams which advance the solution of one of the primary issues of radiation therapy, in particular, the radiance of a cancerous tumor with an adequately powerful and homogeneous portion, guaranteeing that the radiance of the encompassing healthy tissues and organs is insignificant. The approach depends on the productive particle acceleration [10].

### 1.1 Motivation

Charged particle beams fill two segregated aims in biomedical research: (i) They might be used for examination and diagnosing aims from one viewpoint (ii) and for fitting material properties and for therapy on the other. Various applications of high-energy electron beams incorporate radiation sterilization of medical instruments, radiation science, and radiation treatment [11]. Hadron therapy is a powerful approach for cancer treatment. Compelling particle charging in ultra-fast laser, can intensify the acceleration energy. Moreover, utilizing ideal Maxwellian cold plasma in therapeutic manners, causes remarkable outcomes. As an important consequence, surveying on the ion properties, obtains better results in cancer treatment through Hadron therapy. This paper investigates multiple procedures around the benefits of cancer treatment with ions in comparison to other conventional particles in Hadron therapy and demonstrates the superiority of ions as dose carrier particles. This paper is organized as follows. Section 2 gives an explanation about the Contribution. Section 3 presents Hadron Therapy Procedure Based on Charged Particles. In Sect. 4 Simulations and Experimental Results is expounded. Section 5 is devoted to Conclusion and Prospective Works.

## 2 Contribution

### 2.1 Charged Particle Specifications in Applied Fields

The motion of a charged particle in the concurrent attendance of both electric and magnetic fields has an assortment of manifestations such as straight line motion to the cycloid and other wrapped motion. Both electric and magnetic fields confer acceleration of the charged particle. However, there is a qualification for magnetic field as acceleration because of magnetic field relates just to the alteration of the path of motion. Magnetic force being constantly ordinary to the velocity of the particle will in general move the particle about a circular direction. Then again, electric force is along electric field and is able to realize alter in both path and greatness relying on the underlying direction of the velocity of the charged particle of regard to electric field. On the off chance that velocity and electric vectors are at an angle that the particle pursues a parabolic way.

It can understand the origin of electromagnetic field in heavy-ion collisions by considering collision of two ions of radius "$R$" with electric charge $Ze$ ("$e$" is the magnitude of electron charge) at impact parameter "$b$". According to the Biot and Savart law, the electromagnetic field in the center-of-mass frame has magnitude [12]:

$$\overline{EM} \sim \gamma Ze \frac{b}{R^3} \tag{1}$$

and points in the direction perpendicular to the reaction plane (span by the momenta of ions). Here, $\gamma = \sqrt{S_{NN}}/sm_N$, is the Lorentz factor.

### 2.2 Ultra-Short Pulse Laser Propagation in the Plasma Channel

Lasers are a standout among the hugest inventions of the twentieth century. At the point when laser made its presentation in 1960, it was known as a solution searching for an issue. Around then, unique gatherings over the world were attempting to comprehend the conduct of issue, especially atom, within the sight of an external field. Lasers gave an amazing source of high field to help up these examinations to better dimension. The invention of pulsed lasers opened energizing exploration openings in the field of laser-matter interaction. Laser plasma interaction physics is one of the most superb, innovative and entrenched tributary in physics. The inclusion of ultra-short lasers is, in any case, moderately quiet later. This section is about the physics and innovation concerned with the generation of ultra-short laser pulses that was activated by the invention of laser mode-locking, a standout among the most striking interference phenomena in nature. Synchronous oscillation of an expansive number of exceedingly coherent, phase-locked longitudinal modes a laser yield a resultant field equivalent to zero more often than not with the exception of short interim. Because of productive interference between the wavering waves, the whole energy of the radiation field is thought inside these brief periods. As an outcome, laser mode-locking prompts the formation of a short light pulse circling in the resonator. Each time the pulse hits a halfway reflecting mirror, a little portion of its energy is coupled out of the oscillator, bringing about a train of ultra-short beats at the output of the mode-locked laser [7].

To comprehend the stimulation of electron plasma waves (Langmuir) in plasma utilizing lasers, one needs to comprehend the idea of ponderomotive force. "*F*" is free electrons, for example, the ones extant in plasma, can shudder in the electric field related to the electromagnetic wave. The motion of the electron within the sight of electric field is represented by the Lorentz force. In the case of higher, non-uniform electromagnetic (or purely electric) field, the expression for the Lorentz force has a second order term known as the ponderomotive force $(F_P)$, which is proportional to the gradient of the second power of electric field [7]:

$$F_P \propto \nabla E^2 \tag{2}$$

or in terms of laser intensity [7]:

$$F_P \propto \nabla I \tag{3}$$

where, "*E*" is the electric field and "*I*" is the intensity of the laser pulse. In this way, one can see from the above equation that any spatial variation in the laser intensity profile will act to push the electrons/ions from the region of higher force to the region of lower intensity through the ponderomotive force, which is proportional to the slope (gradient) of the light intensity.

### 2.3 Maxwell-Boltzmann Distribution

The Maxwell–Boltzmann distribution is broadly used to portray astrophysical, fusion, and other research facility plasma. In ion, the charge particles may experience collisions with one another, and sometimes with alternate species (ions, electrons, and/or

neutrals) in the plasma. In this manner, it is impossible to investigate the motion of every particle to get a naturally visible image of the plasma forms that is valuable for evaluating the execution and life of the devices. Luckily, much of the time it is not important to follow singular particles to comprehend the plasma elements. The impact of collisions is to build up a distribution of the speeds for every species. In the normal, and without different forces, every particle will at that point move with a speed that is exclusively a function of the naturally visible temperature and mass of that species. The charged particles in the thruster, hence, can more often be described by different velocity distribution functions, and the arbitrary motions can be determined by taking the moments of those distributions [13].

### 2.4 Cold Plasma

Ongoing advancement in plasma types prompted the production of the cold plasma with ion temperatures near room temperature. This makes these plasma not the same as run of the generic low-temperature plasma of a run of the generic electrical release. Such plasma speaks to helpful tools empowering interaction with natural tissue without the thermal harm. Cold plasma innovation and improvement brought about fast formation of another field of plasma medication [14]. A normal cold plasma source appears in Fig. 1. The plasma source is outfitted with a couple of High-Voltage (HV) electrodes- a focal terminal (which is disconnected from the immediate contact with the plasma by ceramics) and an external ring anode as appeared in Fig. 1.

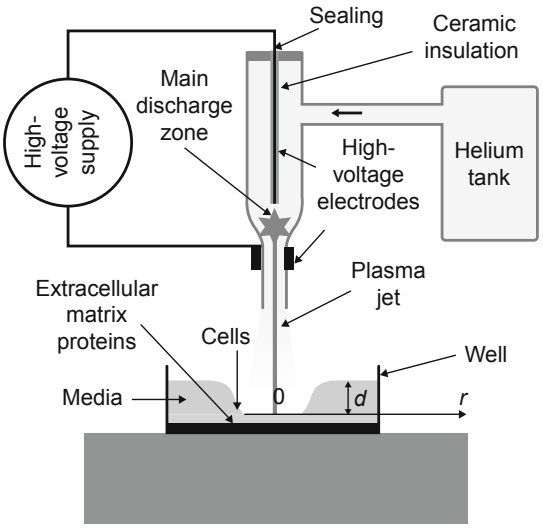


**Fig. 1.** Schematic view of the plasma gun [15].

Electrodes are associated with an auxiliary twisting of a HV resonant transformer which makes a voltage "V" of up to 10 kV at a frequency of approximately 30 kHz [15]. Each charged particle in a plasma has an electric charge. Any alternative motion

of plasma can be disjointed into a superposition of sinusoidal oscillations with frequency "$\omega$", and wavelength "$\lambda$". Here, we will consider that any quantities (density "$n$", velocity "$v$", and electric field "$E$") have a sinusoidal waveform. Thus, the plasma density is represented as [15]:

$$n = \bar{n}Exp(j[\boldsymbol{k}.\boldsymbol{r} - \omega t]) \tag{4}$$

where, $\bar{n}$ is the density amplitude, "$\boldsymbol{k}.\boldsymbol{r}$" is the wave propagation, and "$t$" is the time.

While the impacts of an electric field on cells have been known for quite a while, cold plasma offers a lot bigger exhibition of conceivable pathways because of the nearness of different chemically active species and charged particles. Cold non-thermal atmospheric plasma can have enormous applications in biomedical instruments. Specifically, plasma treatment can conceivably offer a minimum-invasive medical procedure that permits specific cell expulsion without affecting the entire tissue. Conventional laser medical procedure depends on thermal interaction and prompts unintentional cell passing, i.e., corruption, and may cause changeless tissue harm. Conversely, non-thermal plasma interaction with tissue may permit explicit cell evacuation without necrosis. These interactions incorporate cell separation without influencing cell suitability, and controllable cell death. It can be also additionally utilized for corrective strategies for recovering the reticular engineering of the dermis. The point of plasma interaction with tissue is not to denature the tissue yet rather to work under the limit of thermal damage and to instigate a chemically explicit reaction or modification. The presence of the plasma can advance a substantial reaction that would prompt the ideal impact. The synthetic reaction can be advanced by turning the pressure, gas composition, and energy. In this manner, the essential issues are to discover conditions that produce impact on tissue without thermal treatment. Overall, plasma treatment offers favorable position that could have never been thought of even with the most exceptional laser medical procedure. For example, cold plasma has exhibited extraordinary guarantee in cancer treatment. As of late, cold plasma interaction with tissues has turned into an extremely dynamic research point because of its potential [15].

### 2.5 Plasma Particle Phenomena

Plasma particles change their momentum, energy, and states of excitation or charge through particle collisions. Two sorts of collisions in plasma can be recognized, specifically, elastic and non-elastic. Elastic collisions can be comprehensively characterized as occasions in which the total kinetic energy of the particles is monitored and the particles hold their original charges [16]. Elastic collisions in which momentum is redistributed between the particles involved are described as follows [15]:

$$A_{fast} + B_{slow} \rightarrow A_{slow} + B_{fast} \tag{5}$$

Non-elastic collisions are those in which the kinetic energy is redistributed between the particles and is moved into some inside mode of at least one impacting particles or into the creation of another particle(s). Non-elastic collisions lead to immediate and invert forms, which incorporate particle excitation and de-excitation, ionization and

recombination, charge exchange, dissociation, and charge neutralization. These elementary processes are described by Eq. 6 [15]:

$$A_{fast} + B \leftrightarrow A_{slow} + B^{*} \tag{6}$$

Several major ionization pathways can be recognized in the typical plasma systems which are depicted in Table 1.

**Table 1.** Types of collisions in the typical plasma system [15–18].

| Types of collisions | Definitions | Equations |
|---|---|---|
| Direct ionization | By electron impact is the ionization of neutrals from the ground state by electrons having a high enough energy to cause ionization in a single act. The reverse process is the recombination by which ions capture the free electrons to neutralize the ion into an atom | $A + e \leftrightarrow A^{+} + 2e$ or $A + e \leftrightarrow A^{+} + e + e(hv)$ |
| Stepwise ionization | By electron impact is the ionization of a previously excited neutral species | $A + e \rightarrow A^{*} + e$ and then $A^{*} + e \rightarrow A^{+} + 2e$ |
| Ionization by collisions of heavy atoms | In which the particle's kinetic energy can lead to the ionization process | $A_{fast} + B \rightarrow A_{slow} + B^{+} + e(ionization)$ |
| The photoionization | Process in which the ionization is caused by the photons' interaction with neutral atoms | $A + hv \leftrightarrow A^{+} + e$ |
| Charge exchange collisions | Positive ions can collide with atoms and capture a valence electron, resulting in charge transfer from the atom to the ion | $A^{+} + B \rightarrow A + B^{+}$ |
| Associative ionization | It is a gas phase chemical reaction in which two atoms/molecules collide and form an ion via interaction. The energy that is released as a result of the chemical reaction is transferred into the electron's energy | $A + B \rightarrow AB^{+} + e$ |
| Penning ionization | Involves a reaction between neutral atoms/molecules | $A^{*} + B \rightarrow B^{+} + e + A$ |
| Coulomb collisions | They are elastic collisions between charge particles, such as Electron-electron, electron-ion, and ion-ion collisions | – |

## 3 Hadron Therapy Procedure Based on Charged Particles

### 3.1 Definition

The cells in the body duplicate and pass on. While recreating, they pass their deoxyribonucleic corrosive (DNA) to daughter cells. DNA encodes the hereditary instructions utilized in the advancement and functioning of all known living creatures. This hereditary information is encoded as a grouping of nucleotides to be specific adenine, thymine, cytosine and guanine. DNA has a twofold helix structure comprising of two strands of nucleotides that are associated by hydrogen bonds. The DNA spine is impervious to cleavage and the twofold stranded structure gives atoms an implicit copy of the encoded information. DNA is composed into long structures called chromosomes. The DNA figures out which proteins the cells can create. Cells with functional DNA harm don't deliver suitable daughter cells. Radiation treatment works by harming the DNA. It can be realized that the DNA in presence 3.5 billion years prior needed to manage cosmic rays and other antagonistic elements. In this manner, it was exposed to common selection. When one of the strands of DNA is harmed, another strand can fix it. At times the DNA can be utilized from another chromosome. Siege with substantial ions is considerably more successful in harming the two strands of DNA than X-rays since they hit the objective all the more accurately and produce progressively predictable harm [19]. For the treatment of tumors that are found all the more profoundly in body tissue, the particle accelerator must create beams with higher energy communicated in electron volts (eV). Tumors closer to the body surface are dealt with utilizing low-energy particles. The accelerators utilized in Hadron treatment commonly produce particles with energies in the range 70–250 MeV. Tumor cell damage can be expanded by altering the energy of the particles amid treatment. Tissues closer the body surface (outside the tumor volume) experience-less radiation harm and profound tissues inside the body is presented to a low number of particles; subsequently, their radiation portion presentation is less. The characteristic precision of a Hadron beam as far as the portion conveyed to tumor tissue is the primary favorable position of Hadron treatment, as contrasted and traditional treatment including photons and electrons [19].

Exactly when a charged molecule goes through a medium, it ionizes particles in its way and passes on a portion of radiation. As referenced in advance, while plotting the vitality of this ionizing radiation as the molecule experiences issue, there is a sharp apex called Bragg crest, which is seen with particles, alpha-particles and particles going before they stop. Therefore, the vitality crest occurs in light of the fact that the cooperation cross segment of the molecule increases with reducing vitality. This wonder is used in the Hadron treatment to center the effect of the pillar on the tumor being managed, while constraining the unfavorable ramifications for the including solid tissue. Figure 2 demonstrates our implementation on how X-ray and particle beams infiltrate human tissue [19]. For particles and heavy ions, the radiation dose increments as the particles enter through tissue and consistently lose energy (i.e., the dose increments with expanding tissue thickness until the Bragg peak is achieved), which happens close as far as possible of the movement scope of the particle. Note that past the Bragg peak the dose goes to zero for particles and about zero for heavy ions. Figure 2 likewise demonstrates that X-rays infiltrate further. However the radiation portion

consumed by the tissue demonstrates an exponential decay with increasing thickness [19]. For this propose, we used the Bethe-Bloch equation that describes an energy loss. For a particle with charge "$z$" (in products of the electron charge), and the energy "$E$", voyaging a separation "$x$" into an objective of an electron with a number density "$n$" and the mean excitation potential "$I$", the relativistic rendition of the equation peruses in SI units, and the Bethe-Bloch equation is as follows [18]:

$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left( \frac{e^2}{4\pi\varepsilon_0} \right)^2 \cdot \left[ ln\left( \frac{2m_e c^2 \beta^2}{I.(1-\beta^2)} \right) - \beta^2 \right] \tag{7}$$

where "$c$" is the speed of light and, "$\varepsilon_0$" is the vacuum permittivity, $\beta = \frac{u}{c}$, "$e$" and "$m_e$" are the electron charge and rest mass, respectively.

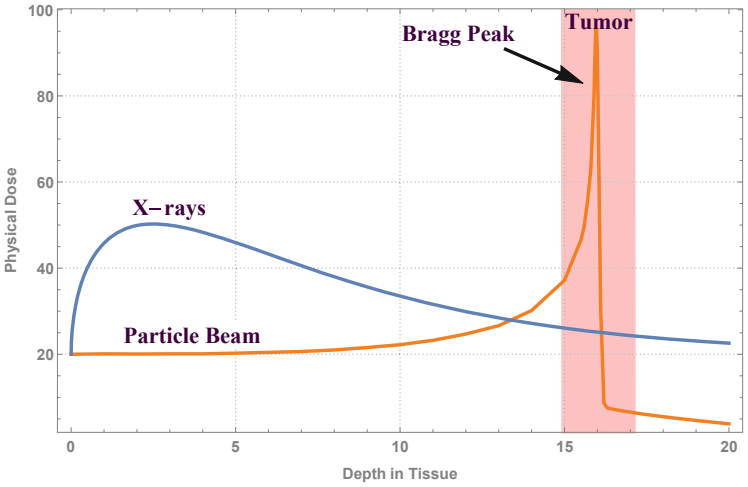


**Fig. 2.** Proposed simulation of the Bragg peak.

### 3.2 Hadron Therapy Methods

**(A) Fast Neutrons Therapy:** This approach is a particular and exceptionally powerful type of outside beam radiation treatment. Usually used to treat certain tumors that are radio-resistant, which means they are exceptionally hard to kill utilizing conventional X-ray radiation treatment. It has ended up being viable at treating salivary organ tumors and certain types of cancer, for example, adenoid cystic carcinoma [20].

**(B) Proton Therapy:** This technique is a developing treatment approach for cancer that may have particular points of interest over conventional radiotherapy. This identifies with its capacity to limit the high-dose treatment zone to the tumor volume and subsequently limiting radiation portion to encompassing ordinary tissue [21].

**(C) Negative Pions Therapy:** Negative pions with energies of 60–90 MeV (expand 12–23 cm in tissue) are the energy for radiotherapy. The organic adequacy for about monoenergetic negative pions at the pinnacle of the profundity portion dispersion was seen to be essentially higher than at the entry. For pion light emissions force spread that are remedially significant, the qualifications in natural feasibility are diminished widely [22].

**(D) Ion Therapy:** This is a type of outer beam radiotherapy utilizing beams of energetic ions for cancer treatment. Carbon-ion radiotherapy has progressively earned logical attention as mechanical conveyance options have improved and clinical examinations have shown its treatment focal points for some cancers, for example, prostate, head and neck, lung, and liver cancers, bone and delicate tissue sarcomas, locally intermittent rectal cancer, and pancreatic cancer, including privately propelled infection. This technique utilizes particles more monstrous than protons or neutrons. Carbon ions have potential focal points over protons: They give a superior physical portion distribution since sidelong dispersing is reduced; and they have higher relative organic adequacy and a lower oxygen improvement proportion; alluring highlights for eradication of radio-resistant, hypoxic tumors. The distinction between thickly ionizing cores and scantily ionizing X-rays and protons offers further potential radiological points of interest, for example, diminished fix a limit, diminished cell-cycle reliance, and conceivably more grounded immunological reactions [23].

Neon ion radiotherapy has natural and physical points of interest over mega-voltage X-beams. Organically, the neon shaft diminishes the oxygen improvement proportion and expands relative natural viability. Cells irradiated by neon ions show-less variation in cell-cycle related radiosensitivity and diminished fix of radiation damage. The physical conduct of heavy charged particles permits the exact conveyance of high radiation doses to tumors while limiting irradiation of typical tissues [24]. In radiotherapy, oxygen particles have more natural points of interest than light columns. Oxygen particles have a higher Linear Energy Transfer (LET) and greater Relative Biological Effectiveness (RBE) than lighter ones. High vitality ionizing radiation, through passing on portion to issue, and making Bragg tops in a particular zone in the goal, is an appropriate alternative for radiation treatment. What's more, the portion of the oxygen shaft toward the completion of the Bragg crest prompts a generous inclination that keeps the assimilation of unwanted doses to delicate organs [9].

Cancer treatment with ions is favored in correlation with different strategies for Hadron treatment, on account of some physical properties. Ions, store their greatest energy thickness in the Bragg peak toward the end of their range. Ions infiltrate the patient for all intents and purposes without diffusion. Being charged, they can without much of a stretch be framed as barely engaged 'pencil beams' penetration profundity, so any piece of a tumor can be precisely and quickly eliminated. In this way ions, permits exceedingly conformal treatment of profound situated tumors with millimeter exactness, giving a negligible dose to the encompassing tissues. The physical and radiological contentions can be abridged as pursues. In a cell, an ion leaves around multiple times more energy than a proton having a similar range. This creates a thick section of ionization, particularly close to the Bragg peak region of the track, causing

many 'Double Strand Breaks' and 'Different Damaged Sites', when crossing the DNA contained in the cell core. Thus, the consequences for the cell are subjectively not quite the same as the ones delivered by meagerly ionizing radiations, for example, X-beams and protons. Truth be told, these radiations connect chiefly by implication with the DNA through the production of dynamic radicals that, achieving the DNA, produce for the most part repairable 'Single Strand Breaks'. Consequently, high ionizing ions demonstrate their viability against hypoxic and other shrewd radio-resistant tumors, for example, tumors that need to keep portions of 2–3 multiple times higher in the event that they are to be controlled with either photons or protons [23].

Because of the much larger proportion of direct impact, ions have at the Bragg peak, or many endpoints and conveyed doses, a Radio Biological Effectiveness (RBE) which is around multiple times bigger than the one for X-rays and protons. In the backing off of an ion in tissue this impact winds up essentially when the Linear Energy Transfer (LET), the 'stopping power' in physicist speech, ends up bigger than $\approx 20\,\mathrm{keV/\mu m}$. Because of this generally high 'threshold', protons carry on along their full range– with the exclusion of the last tenth of a millimeter– for all intents and purposes as the electrons which are placed in motion by the high-energy photons created with therapeutic linacs (linear accelerator) and have a LET in the range $0.2-0.5\,\mathrm{keV/\mu m}$. Therefore, the broad radiological and clinical involvement with photon radiation treatment can be connected to proton treatment [25]. The presence or absence of oxygen in cells has a strong impact in the biological effects of radiation and hypoxic tissues are known to be less radiosensitive. This impact– which is communicated regarding Oxygen Enhancement Ratio (OER) – is especially subject to LET. For low LET radiation, for example, X-rays or protons, hypoxia speaks to a genuine limitation factor to the viability of the treatment. For high LET this impact is restricted and carbon ions speak to a powerful apparatus for the treatment of hypoxic radio-resistant tumors [26].

## 4 Simulations and Experimental Results

### 4.1 Particles in the Plasma Channel with Electromagnetic Field

To afford a quantitative estimate of magnetic field, we need to take into account a realistic distribution of protons in a nucleus. The magnetic field at point "$r$" created by two heavy ions moving in the positive or negative $z$-direction can be calculated using the Lienard-Wiechert potentials as follows [12]:

$$e\boldsymbol{E}(t,\boldsymbol{r}) = \alpha_{em}\sum_{a}\frac{\left(1-v_a^2\right)\boldsymbol{R}_a}{R_a^3\left[1-\frac{(\boldsymbol{R}_a\times\boldsymbol{v}_a)^2}{R_a^2}\right]^{3/2}} \tag{8}$$

$$e\boldsymbol{B}(t,\boldsymbol{r}) = \alpha_{em}\sum_{a}\frac{\left(1-v_a^2\right)(\boldsymbol{v}_a\times\boldsymbol{R}_a)}{R_a^3\left[1-\frac{(\boldsymbol{R}_a\times\boldsymbol{v}_a)^2}{R_a^2}\right]^{3/2}} \tag{9}$$

with $\boldsymbol{R}_a = \boldsymbol{r} - \boldsymbol{r}_a(t)$, where sums run over all $Z$ particles in each nucleus, their positions and velocities being $\boldsymbol{r}_a$ and $\boldsymbol{v}_a$. The magnitude of velocity $v_a$ is determined by the collision energy $\sqrt{S_{NN}}$ as mentioned in Eq. 1 and the particle mass $m_p$, $v_a^2 = 1 - \left(2m_p/\sqrt{S_{NN}}\right)^2$. These equations are derived in the eikonal approximation, assuming that particles travel in straight lines before and after the scattering. This is a good approximation since baryon stopping is a small effect at high energies [12]. It should be noted that in theoretical physics, the eikonal approximation is an approximate method useful in wave scattering equations which occur in optics, seismology, quantum mechanics, quantum electrodynamics, and partial wave expansion.

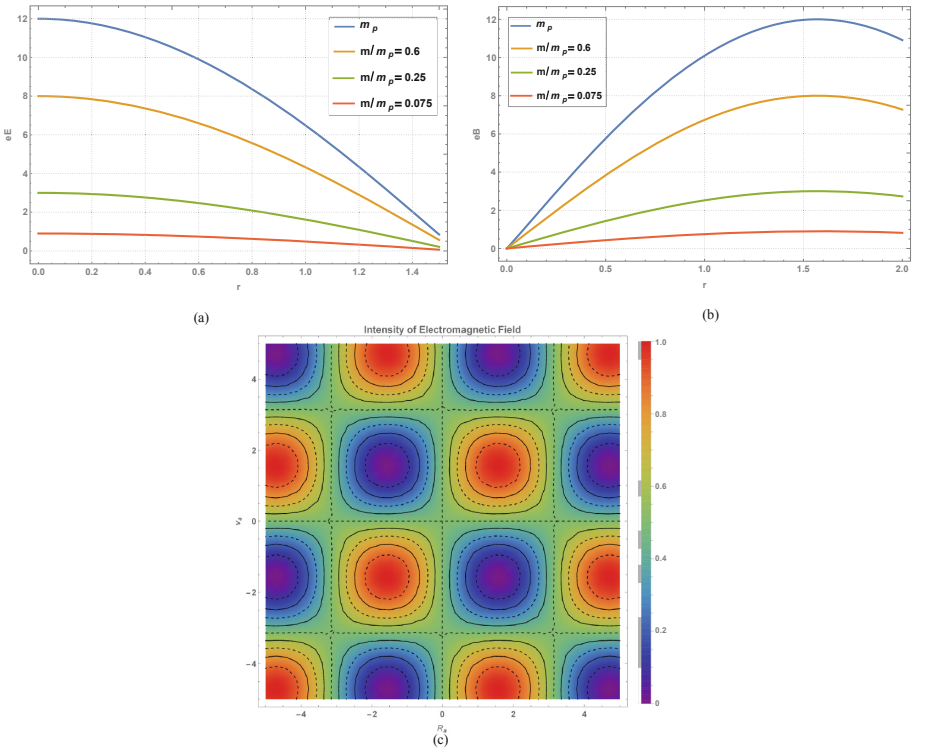


**Fig. 3.** Proposed Simulations of the absolute value of (a) electric field, (b) magnetic field at $t = 0$, as a function of $r$, for collision at $\sqrt{S_{NN}} = 100\,\text{GeV}$, for $m_p$, $m/m_p = 0.6$, $m/m_p = 0.25$, and $m/m_p = 0.075$, and (c) The intensity Plot of electromagnetic field based on $\boldsymbol{R}_a \times \boldsymbol{v}_a$ variatons.

Figure 3 shows our simulation on the electric and magnetic field components at $t = 0$, at the origin in a collision at $\sqrt{S_{NN}} = 100\,\text{GeV}$ for $m_p$, $m/m_p = 0.6$, $m/m_p = 0.25$, and $m/m_p = 0.075$. Based on Fig. 3, the actual distribution in a given event shows that there is not only magnetic field along the axes directions, but also

other components of electric and magnetic fields. This leads to event-by-event fluctuations of the electromagnetic field. According to Eqs. 8 and 9, the manner of electric and magnetic field for a charged particle is proportional to the particle mass. Hence, Fig. 3 illustrated the electric (Fig. 3(a)) and magnetic (Fig. 3(b)) field for different masses of particle toward proton mass. Based on the results of Fig. 4, as the particle mass, decreases, the electric and magnetic fields decrease and by increasing of particle mass, the electric (Fig. 3(a)) and magnetic (Fig. 3(b)) fields, increase too. Figure 3(c), also demonstrates the Intensity plot of electromagnetic field in terms of $\boldsymbol{R}_a$ and $\boldsymbol{v}_a$. Based on mentioned plot, the intensity of the electromagnetic field is alternatively as a function of the position and velocity vectors. Therefore, for suitable angle between fore-said vectors the intensity of electromagnetic field is maximum. As mentioned, ions are heavier particles in comparison with Neutrons, Protons, and Pions. So, using ions for cancer treatment in Hadron therapy can strengthen the electromagnetic fields and cause effective and better results in the treatment of cancerous tissues. Also, in amplified electromagnetic field, the particle will be accelerated more, then, the initial gained energy increases, so the energy loss through the matter decreases and the received dose in cancerous target, which, carried by accelerated ion, increases. Also, based on Eq. 2, the ponderomotive force gained by the particle, in an ultra-short laser pulse, is proportional to gradient of the second power of electric field. As a result, heavy ions will get more ponderomotive energy, which causes better acceleration. Further, as shown in Eq. 4, by increasing in an electromagnetic wave, the wave propagation, increases, which causes an increase in plasma density. Finally, this section shows that using heavy ions, can cause better results in Hadron therapy. Energy loss due to the particle accelerator and shoot through patient body, is inversly proportional to $X^2$ paramiter. The $X^2$ parameter defined as [12]:

$$X^2 = \frac{h^2(eB)^2}{4\pi^2 m^6} P^2 \left(Sinh^2\eta + Cos^2\varphi\right) \tag{10}$$

where, "$h$" is the Planck constant, "$e$" is the electron charge, "$m$" is the particle mass, "$p$" is the particle momentum, also, "$\eta$" and "$\varphi$" are azimuth angles. Figure 4 shows the $X^2$ parameter in terms of particle mass and azimuth angles, based on Eq. 10. As shown in Fig. 4(a), the variations of $X^2$ parameter is precipitate for different values of particle mass. Also, as the particle mass increases, the intensity of mentioned parameter decreases. Accordingly, by particle mass increasing, the energy loss decreases. So, using heavy ions will decrease the energy loss in Hadron therapy. Figure 4(b), also shows the front view of mentioned plot for better conception. On the other hand, the initial energy of charged particles, origins from ponderomotive force, and as defined in Eq. 3, the ponderomotive force is proportional to the gradient of laser intensity. So, by decreasing of the energy loss, the secondary energy increases and the effective laser intensity increase too. Therefore, based on obtaining results from fore-said Fig. 4, using heavy ions can decrease the energy loss through matter, in cold plasma perimeter, which is an important approach in Hadron therapy, that means receiving a maximum dose in cancerous target.

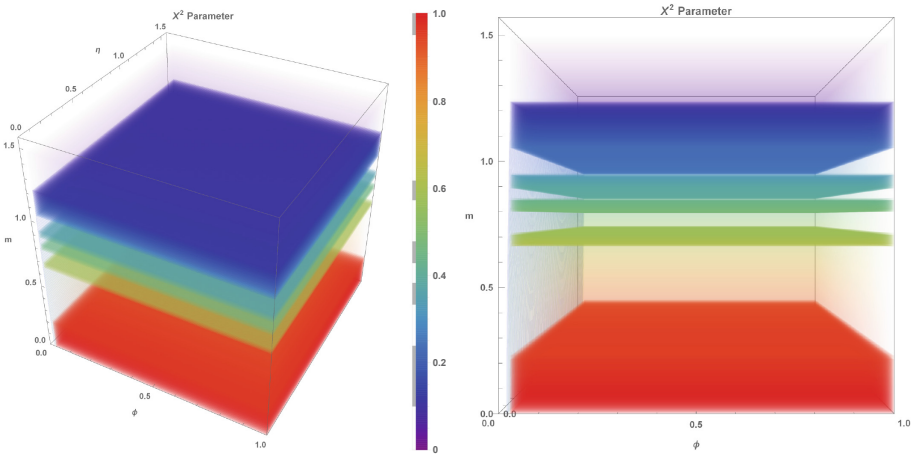


**Fig. 4.** Proposed Simulations of the $X^2$ parameter. (a) in terms of particle mass and azimuthal angles, and (b) in the front view of plot.

### 4.2 Ideal Maxwellian Energy Distribution for Charged Particles

The system of interest (which is ideal cold plasma in this paper) contains a large number of particles (ideal cold plasma constitutive particles), have a Maxwellian velocity distribution, which is the most probable distribution of velocities for a group of particles (plasma constitutive particles) in thermal equilibrium. In one dimension, the Maxwellian velocity distribution function is [13]:

$$f(v)dv = \left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} 4\pi v^2 e^{\frac{-mv^2}{2kT}} dv \tag{11}$$

and, molar mass is defined as:

$$M = mN_a \tag{12}$$

where "$m$" is the mass of plasma constitutive particles, "$k$" is Boltzmann's constant, and the width of the distribution is characterized by the temperature "$T$". Moreover, "$v$" is the velocity of perimeter particle and "$N_a$" is Avogadro number. It should be noted that in this section, the purpose of "particles", is the "perimeter constitutive particles". Figure 5, shows the proposed implementation of Maxwell-Boltzmann particle velocity distributions for Helium, Neon, Argon, Xenon, and Ideal Cold Plasma, respectively, based on Eqs. 11 and 12. According to Fig. 5(a), the probability of particle density in higher velocities is major. Also, plasma density strongly dependent on the degree of ionization and collision mean free path of electron- atom impact, voltage which are applying for discharge is another fact. Particles in unit volume is increased (atoms, ions electrons). It means that the mass density is not changed. Plasma density is not combined density of species, but it is density of any species (either electron or ion).

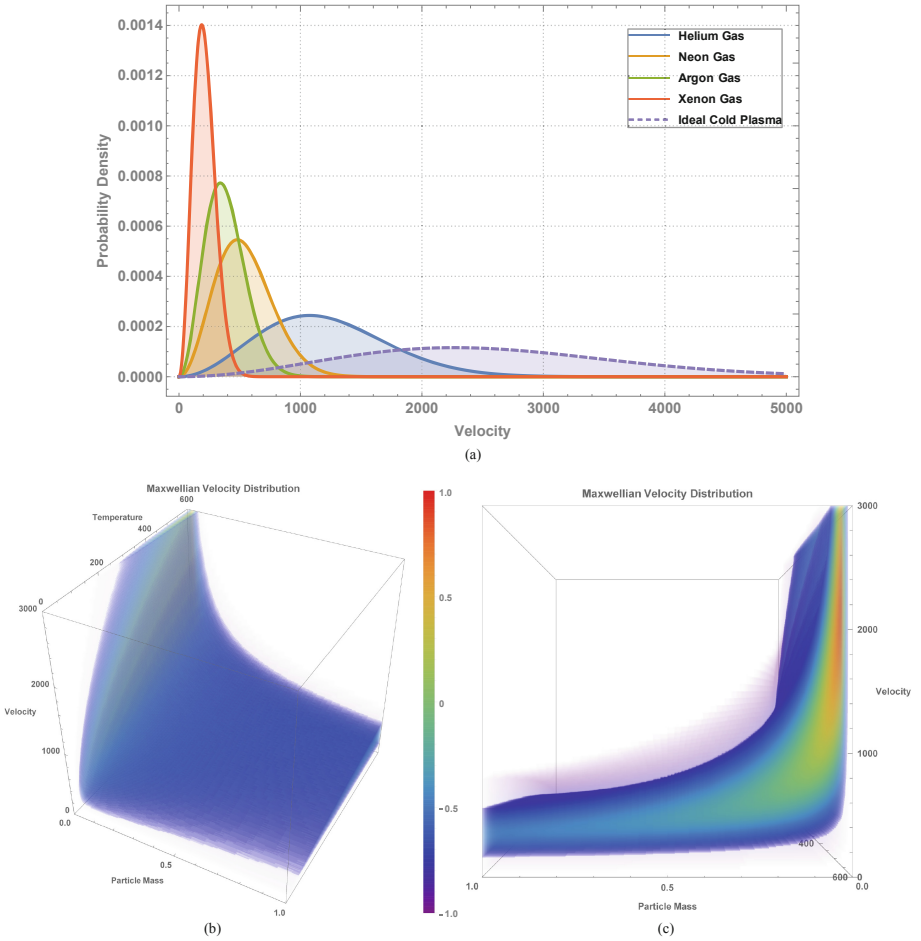


**Fig. 5.** Proposed Maxwellian Implementations. (a) Maxwell-Boltzmann particle velocity distributions. (b), and (c) Maxwellian velocity distribution in terms of particle mass, velocity, and temperature, respectively.

Therefore, the plasma density is less than the gas density in contents of ion and accordingly it is lighter than gas. Hence, in ideal cold plasma, gaining major values of velocity is probable and according to Eq. 6 and Table 1, the collisions of a fast particle (ion) and ideal cold plasma may cause ionization. Effective ionization during the interaction of an ultra-short laser pulse with matter is one of the most important procedures for accelerating particles [27]. Therefore, ideal Maxwellian cold plasma can cause better particle acceleration in Hadron therapy. According to Fig. 5(b) and (c), the Maxwell–Boltzmann distribution is the chi distribution with a scale parameter estimating speeds in units proportional to the square root of the proportion of temperature and particle mass, respectively. Also, it can be concluded that, however, the density is more probable in light particles, but high-speed values only occur for heavy particles.

Additionally, the thermal equilibrium distribution function for a particle defined as Eq. 13 [27]:

$$f = \frac{\rho}{4\pi m^4 T\beta} e^{-\beta P v} \tag{13}$$

where, "$\rho$" is the mass density, "$m$" is particle mass, "$T$" is temperature; $\beta = 1/T$, "$P$" is particle momentum, and "$v$" is the velocity. Figure 6, demonstrates the thermal equilibrium distribution for a particle with mass "$m$" and velocity "$v$". As can be concluded from mentioned figure, incretion in particle mass and velocity, can cause reduction in thermal equilibrium distribution.

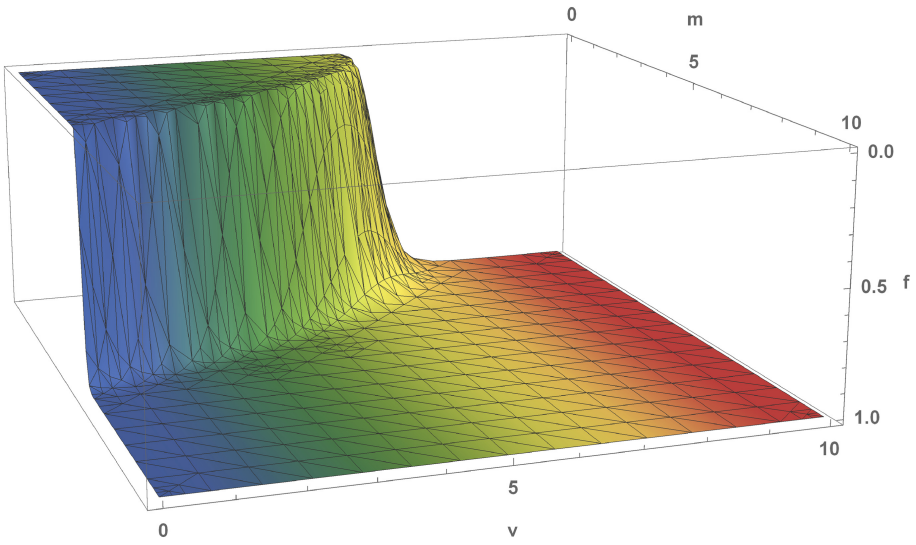


**Fig. 6.** Proposed Simulation of thermal equilibrium distribution in room temperature, in terms of particle mass and velocity.

## 5 Conclusion and Prospective Works

The motion of charged particles in an electromagnetic field is of incredible functional significance. The investigation of particle motion in electromagnetic fields is essential and pervades plasma physics. For some biologists and physicists, laser innovation opens an altogether new, special and even great field. Additionally, an ultra-short pulse laser is a powerful instrument for accelerating Hadrons in cancer treatment. The ideal Maxwellian cold plasma is utilized to improve biomedical thoughts for accelerating particles in Hadron treatment. Mentioned approaches are on the transfer of Hadron treatment for treatment of wide range cancer types. Hadron treatment speaks to the significant contribution to the fix of patients and many intriguing advancements, at the front line of science and innovation, are in advancement. Thus, the creators give this

paper the point of better cancer treatment by means of Hadron treatment. Based on surveys on Hadron therapy methods done in this paper, ions can provide acceptable results in Hadron therapy because of their amazing properties.

This paper demonstrates that using ions, as heavy particles, can strengthen the electromagnetic fields and causes effective and better results in the treatment of cancerous tissues. Also, in the amplified electromagnetic field, the particle will be accelerated more, then, the initial gained energy increases, so the energy loss through the matter decreases and the received dose in cancerous target, which, carried by accelerating ion, increases. In addition, heavy ions will get more ponderomotive energy, which causes better acceleration. Further, by increasing in electromagnetic wave, the wave propagation, increases, which causes an increase in plasma density. Besides, using heavy ions can decrease the energy loss through matter, in cold plasma perimeter, which is an important approach in Hadron therapy, that means receiving a maximum dose in cancerous target. Moreover, this paper demonstrates the collisions of the ion, as a fast particle and ideal cold plasma may cause ionization, and effective ionization during the interaction of an Ultra-Short Laser Pulse with matter is one of the most important procedures for accelerating particles. Therefore, ideal Maxwellian cold plasma can cause better particle acceleration in Hadron therapy.

The advancement of Hadron treatment methods over late years drives directly to a quickly expanding number of working frameworks which may result in saturation of the quantity of particle facility installations in creating nations in certain years. Nevertheless, there are as yet progressing necessities of ideal techniques for precise cancer treatment. Forthcoming, authors have decided to investigate other parameters which improve the quality of Hadron therapy procedures.

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