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Fission fragments and primary electrons' energy distribution in helium-3 plasma irradiated by neutron flux

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Boltzmann kinetic equations governing energy spectra distribution of fast particles in nuclear induced plasma are defined and presented for continuous fissionable plasma interacting with neutrons.

The formation of electrons energy distribution crucially depends on energy distribution of fission fragments and cannot be treated separately and their distributions self consistently affect on electrons energy spectra time evolution and their degradation in space. So the self-consistent system of Boltzmann kinetic equations for both electrons and fission fragments are proposed and discussed for helium-3 plasma. Primary electrons spectra analytical expressions are derived and the first order approximation presented on the assumption that energy spectra of protons and tritium nuclei have monochromatic energy spectra created by helium-3 fissioning in neutron flux. Any gas irradiated by highly energetic particles demonstrates its modified chemical abilities as well as a great variety of energy transformation channels including the selection of some definite chemical reactions leading to innovative transformation in technology [1-5]

Key words: fissioning plasma, Boltzmann equation, helium-3.

1. Introduction

Any gas irradiated by highly energetic particles demonstrates its modified chemical abilities as well as a great variety of energy transformation channels including the selection of some definite chemical reactions leading to innovative transformation in technology [1-5]. In some cases when the testing gas contains fissionable component interacting with neutrons like helium-3 or uranium-235 the plasma creates specific physical conditions owing to fission fragments and presents by itself a unique physical object, which in general makes it possible to realize direct transformation their nuclear energy into electromagnetic radiation. In [6] the kinetic Boltzmann equation governing electron energy distribution in plasmas generated by fission fragments is developed. It should be pointed out that the requirements to self-consistency of external electric field are taken into consideration and presented by means of an bipolar diffusion. Recombination processes are also partially included

in system of kinetic equation governing electrons energy distribution and confined by boundary conditions [7].

Definition of highly energetic fission fragments energy distribution spectra including primary electrons is the key and not yet solved problem, which reveals how and in what way their transformation might be realized [6,7]. Well-known famous Boltzmann equation was applied to solution of a plenty of physical problems, and was used even in description of gravitational interactions, gravitational redshift and dilation. So, the profound meaning of Boltzmann equation reveals the problems and presents clear understanding of them not only in physics of non uniform gases but practically in all branches of physics and continues to penetrate its applications further on. Plasma generated by fission fragments also might be described by Boltzmann equation which certainly should be mathematically adjusted to that physical conditions for gaseous mixtures containing fissionable components and which set into the

neutron flux, like, for instance, ampulla with helium-3 gas tested in the center on nuclear reactor core.

Since the appearance of outstanding in its importance Theory of Non – Uniform Gases developed by S. Chapman and T. Cowling [8] sufficient number publications devoted to this problem were released. Most of them were focused to modify Boltzmann kinetic equation in different fields of applications. One of the most cited is [9] in which the high frequency gas discharges for slightly ionized plasma are studied within which the following limited conditions assumed. The densities of electrons, ions, and excited molecules are very small compared to the density of molecules of buffer gas, elastic collisions prevail over the inelastic ones, gas has the density when the hydrodynamic approach is reasonable and the frequencies of external electric field is higher the plasma frequencies. The major of [9] devoted to the development of methods for calculating the energy distributions in a gas of low ion density influenced by high frequency a. c. field. Taken assumption that initial and final velocities are very close to each other leads to sufficient number of limitations for definite applications. As it was noted in [10] incident electrons interact with field particles not in the way like rigid spheres, but act with a complex dynamical system of charged particles moving in the state of dynamical equilibrium and actually interact initially with cycling electrons moving on the upper orbits. How the primary electrons were originated also were not discussed and identified in [9]. Further detailed expansions of the function of energy distribution into the series and correspondent results are losing their applicability even in neighboring physical conditions. Electrons energy distribution at high values of external electric field in nitrogen gas from 100 Td up to 3000 Td obtained and discussed in [11]. The ionization coefficients, drift velocity and mean energies in steady state conditions are calculated using simplified secondary electron energy distribution taken from experiments. Rotational excitation and momentum transfer differential cross section for low energy electrons are obtained from mobility and diffusion coefficients by calculating electron energy distribution functions in hydrogen and nitrogen plasma by the authors in [12]. Here Boltzmann equation for electrons was regarded in the way like in [9] without any discussion of primary electrons spectra formation. Calculations of the steady state electron swarm parameters in rare gases and

mixtures are reported in [13]. The presence of electron density gradient implies the external electric field to be self-consistent and secondary electrons spectra also is also the subject of Townsend ionization processes which should be initially included in Boltzmann kinetic equation, but not taken as a priori by analytical expression which should be taken into consideration in initial equations. Electrons beam impact nitrogen gas and further electrons degradation spectra taken in energy scale were also studied in [14, 15]. Green's function method was used to obtain ionization coefficients, which made possible to evaluate external electric field breakdown level [15, 16]. Only in [14] the source of ionization by electron beam, which was included reasonably and solved. In [17] the Townsend ionization coefficient and the electron drift velocity were calculated in the cold cathode discharge gap and are in good agreement with experimental data.

Following to [18] in fully ionized plasma in a sufficiently strong electric field so-called runaway electrons are created and the main part of them on the mean free path, receives more energy from the electric field than it loses in elastic and inelastic collisions, and the electrons are continuously should be accelerated. This was declared also in [19, 20] and steady state Boltzmann equation was taken in use without no information about how this processes (bremsstrahlung as a force of friction) were originated.

In weakly ionized plasma the formation of runaway electrons seems to be practically impossible due to very detailed analysis made in [21]. On the contrary the authors [19,21] are sure that for arbitrarily small values of the electric field strength the majority of electrons might be accelerated to the level of energy possible to ionize neutrals forming secondary electrons and the number of ionization events will exponentially rise as well as their average velocity and energy does not depend on the distance from cathode [19]. The equation for mean energy electrons balance is not sufficient to make such strong deductions about formation runaway electrons by some definite reasons. The force of friction also was taken as a key point in formation of run away electrons [19, 21]. It does not give clear answer because of the following reasons.

The identification of fast electrons with energy around Mev region (runaway electron) not discussed or presented as well as the fact that where the radiation (bremsstrahlung) starts and ends and how

the formation of X-rays should be included in kinetic equation. [19]. The X-rays [22,23] also might be treated like electrons (the de Broglie wave length) and the next coming question is that weather or not the absorption of X-ray by electrons leads to rise its kinetic energy lifting them to the MeV level where usually neutrino oscillations connected with presence the beta electrons are existing. [24]

2. Boltzmann equation for continuous plasma irradiated by fission fragments. General case

The system of Boltzmann kinetic equation to define the energy spectra of fission fragments and born as a result of this irradiation primary electrons energy distribution are as follows:

$$\begin{aligned}
 \partial_{\mu} ff_j = & S_j^{ff} (n \rightarrow {}^3\text{He}_{235}\text{UF}_6 \rightarrow ff_j) + S_{ff_j}^{PE} (ff_j(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^+ + PE + ff_j(\boldsymbol{\epsilon}'_{ff} - I - \boldsymbol{\epsilon}_{PE})) \\
 & - L_{ff_j}^{PE} (ff'_j(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^+ + PE + ff'_j(\boldsymbol{\epsilon}'_{ff} - I - \boldsymbol{\epsilon}_{PE})) + \\
 & S_{ff_j}^{exc} (ff_j(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^{exc} + ff_j(\boldsymbol{\epsilon}'_{ff} - I^{exc}) - \\
 & - L_{ff_j}^{exc} (ff'_j(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^{exc} + ff'_j(\boldsymbol{\epsilon}'_{ff} - I^{exc})) + \\
 & + S_{ff_j}^{el} (ff_j(\boldsymbol{\epsilon}') + bg \rightarrow bg + ff_j(\boldsymbol{\epsilon}'_{ff} - \Delta E^{el}) - \\
 & - L_{ff_j}^{el} (ff'_j(\boldsymbol{\epsilon}') + bg \rightarrow bg + ff'_j(\boldsymbol{\epsilon}'_{ff} - \Delta E^{el}) - \\
 & - L_{ff_j}^{rec} (ff^{+}_j(\boldsymbol{\epsilon}') + e \rightarrow ff^0_j(\boldsymbol{\epsilon}'_{ff}))
 \end{aligned} \tag{1}$$

In equation (1) the following notations are used:

Bg-buffer gas, PE-primary electrons, S, L- source and outflow of charged particles in definite

phase volume.

For electrons the following coupling equations are to be used:

$$\begin{aligned}
 \partial_{\mu} f_e = & S_{ff_j}^{PE} (ff_j(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^+ + PE + ff_j(\boldsymbol{\epsilon}'_{ff} - I - \boldsymbol{\epsilon}_{PE})) \\
 & + S_{f_e}^{ion} (f'_e(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^+ + e + f_e(\boldsymbol{\epsilon}'_{f_e} - I - \boldsymbol{\epsilon}_{se})) + \\
 & - L_{f_e}^{ion} (f_e(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^+ + e + f_e(\boldsymbol{\epsilon}'_{f_e} - I - \boldsymbol{\epsilon}_{se})) + \\
 & + S_{f_e}^{exc} (ff'_j(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^{exc} + ff_j(\boldsymbol{\epsilon}'_{f_e} - I^{exc}) - \\
 & - L_{f_e}^{exc} (ff'_j(\boldsymbol{\epsilon}') \rightarrow bg \rightarrow bg^{exc} + ff_j(\boldsymbol{\epsilon}'_{f_e} - I^{exc})) + \\
 & + S_{f_e}^{el} (ff'_j(\boldsymbol{\epsilon}') + bg \rightarrow bg + ff_j(\boldsymbol{\epsilon}'_{f_e} - \Delta E^{el}) - \\
 & - L_{f_e}^{el} (f_e(\boldsymbol{\epsilon}') + bg \rightarrow bg + f_e(\boldsymbol{\epsilon}'_{f_e} - \Delta E^{el}) - \\
 & - L_{f_e}^{rec} (ff^{+}_j(\boldsymbol{\epsilon}') + e \rightarrow ff^0_j(\boldsymbol{\epsilon}'_{ff})) + e'
 \end{aligned} \tag{2}$$

where [25]:

$$S_{\mu}^{\nu} = \int_I^{E \max} \Omega(E_{ff}, \Delta E) g(V' \rightarrow V) f_{\mu}^{\nu}(t, r, E_{\mu}) d\Delta E \tag{3}$$

$$\Omega(E_{ff}, \Delta E) = \frac{\sigma_0}{(\Delta E_{ff})^2} \frac{1}{E_{ff}} f_{bg} \left[\frac{I_{bg}}{E_{ff}} + \frac{4}{3} \ln \left(2.7 + \frac{V_{ff}}{V_e} \right) \right]$$

$$f_{bg} = \left[\frac{\bar{V}_e}{V_{ff}} \right]^2$$

Due to the experimental measurements [4-5] we take ³He isotope gas in thermal neutral flux and the value of fission fragments energy in its first

approximation equal to the delta function from its initial energy is E0:

$$f_{pe}(V_i) = 6.56 * 10^{-14} [BG] \sum_{k=1}^N Z_{j,k}^2 \int_I^{E_{j,k}^0} dV_{j,k} * \delta(V_{j,k} - \frac{1}{2} V_{j,k}^0) * \frac{8}{m_{j,k} m_e^2 V_i^4 V_{j,k}^2} \left\{ \frac{\sqrt{\frac{2I_{bg}}{m_e}}}{V_{j,k}} \right\}^{22} * \left[1 + \frac{4}{3} \ln \left(2.7 + \frac{E_{j,k}}{I_{bg}} \right) \right] \quad (4)$$

3. Conclusion

Boltzmann kinetic equations governing energy spectra of fast particles in nuclear induced plasma are defined as a coupled system of fission fragments and electrons which should be treated as self-consistent system and presents sensible approach to detailed description of fissionable plasma interacting with neutrons. This type of Boltzmann kinetic equations system applied and discussed for helium-3 plasma. Major part of primary electrons spectra analytical expressions derived on the assumption that helium-3 isotope fission products have monochromatic energy spectra.

In weakly ionized plasma the formation of runaway electrons seems to be practically impossible due to very detailed analysis made in [26, 27]. On the contrary the authors [19, 21] are sure that for arbitrarily small values of the electric field strength the majority of electrons might be accelerated to the level of energy possible to ionize neutrals forming secondary electrons and the

number of ionization events will exponentially rise as well as their average velocity and energy does not depend on the distance from cathode [19]. The equation for mean energy electrons balance is not sufficient to make such strong deductions about formation runaway electrons by some definite reasons. The force of friction also was taken as a key point in formation of run away electrons [19, 21]. It does not give clear answer because of the following reasons.

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