

ON THE POSSIBILITY OF SYNTHESIS OF NUCLEI OF DIFFERENT CHARGES IN A PLASMA WITH A STRONG ELECTRIC CURRENT

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1970

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Abstract

Full Text

UDC 533.92:621.039.61

PHYSICS

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ON THE POSSIBILITY OF SYNTHESIS OF NUCLEI OF DIFFERENT CHARGES IN A PLASMA WITH A STRONG ELECTRIC CURRENT

(Presented by Academician A. D. Sakharov on 23 IX 1969)

A. V. Gurevich ⁽¹⁾ has shown the possibility of establishing two stationary states of motion of impurity multicharged ions (with charge Z) in a plasma with principal ions (charge $Z_{i0} < Z$) in an electric field. The impurity multicharged ions, in a coordinate system in which the principal ions are at rest, follow the electron flux with characteristic velocities (for $T_e = T_i$, $Z_{i0} = 1$)

$$v(E) \sim \frac{Z-1}{Z} \left(\frac{m}{M_{i0}} \right)^{1/2} \frac{E}{E_\kappa} v_e^T \quad \text{in state I, } 0 < v < v_i^T,$$

$$v(E) \sim \frac{Z-1}{Z} \frac{E}{E_\kappa} v_e^T \quad \text{in state II, } v_i^T < v < v_e^T,$$

where v_e^T , v_i^T are the thermal velocities of the electrons and the principal ions of the plasma; m/M_{i0} is the ratio of the masses of the electron and the principal ion; $v(E)$ is the velocity of the impurity ion in a field of intensity E ; E_κ is the value of the electric-field intensity critical with respect to electron runaway,

$$E_\kappa = 4\pi e^3 Z_{i0} n \ln \Lambda / kT,$$

where e is the electron charge; n is the electron density; $\ln \Lambda$ is the Coulomb logarithm; k is Boltzmann's constant; T is the plasma temperature.

Of great interest is the considerable magnitude of the energy of impurity ions in the second state,

$$\mathcal{E}_Z^E = \frac{M_Z^2 v}{2} \simeq \frac{M_Z}{m} \left(\frac{Z-1}{Z} \frac{E}{E_\kappa} \right)^2 \mathcal{E}_e^T,$$

Figure 1

Figure 1: Figure 1

where M_Z/m is the ratio of the masses of the impurity ion and the electron; \mathcal{E}_e^T is the thermal energy of the plasma electrons.

Let us discuss the possibilities of synthesis of nuclei of impurity ions, which are in the second state, with the principal ions of the plasma. Since the directed velocity of the impurity ions in this case is much greater than the thermal velocities of the ions, $v_Z^E \gg v_{i0}^T > v_Z^T$, the distribution functions of the principal and impurity ions may be represented for the calculation in the form

$$f_{i0}(v) = N\delta(v), \quad f_Z(v) = NX\delta(v - v_Z^E),$$

where N is the number of principal ions per unit volume, and X is the relative impurity content.

As an example, let us consider the reactions $\text{Li}^6 + \text{D}^2 \rightarrow \text{Li}^7 + \text{p} + 5 \text{ MeV}$, $\text{Li}^6 + \text{D}^2 \rightarrow 2\text{He}^4 + 22.4 \text{ MeV}$, $\text{He}^3 + \text{D}^2 \rightarrow \text{He}^4 + \text{p} + 18.3 \text{ MeV}$.

For various values of the relative velocity of the multicharged and principal ions v (the corresponding deuteron energy in the rest system of the heavy nucleus is $\mathcal{E}_D = M_{Dv}^2/2$), we shall calculate the following quantities: the plasma temperature

$$T = \frac{m}{3k}(v_e^T)^2 = \frac{2}{9\pi} \frac{m}{k} \left(\frac{Z}{Z-1} \frac{E_\kappa}{E} \right)^2 v^2,$$

the quantities $\langle v\sigma \rangle$ and $W/N^2 = \langle v\sigma \rangle X\varepsilon$, where ε is the energy released in the given reaction, and W is the power released per unit volume.

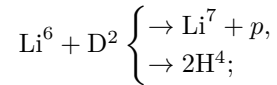
The second state is established for $E \geq E_{\text{II}} = \lambda(T_e/T_i)E_1$ ⁽¹⁾, where $\lambda(T_e/T_i) \simeq 1.2$ for $T_e = T_i$,

$$E_1 = \frac{Z}{Z-1} \left(\frac{3}{2\pi} \frac{m}{M_i^0} \right)^{1/3} E_k \sim \frac{Z}{Z-1} \cdot 0.051 E_k.$$

Since the second state is possible only for $E_{\text{II}} < E < E_k$, we shall carry out the calculation for two cases: a) $E = 0.2E_k$, b) $E = 0.6E_k$. The result of the calculation

Fig. 1. Dependence of the powers of various processes in a plasma on temperature (logarithmic scale). a— $E = 0.2E_k$; b— $E = 0.6E_k$. 1— W/N^2 (erg · cm³/sec) for the reaction (thermonuclear) $\text{D}^2 + \text{D}^2 +$ secondary reactions;

2— W/N^2 for the reaction $\text{He}^3 + \text{D}^2 \rightarrow \text{He}^4 + p$;
 3— W/N^2 for the reaction



4— W/N^2 , γ -radiation of the plasma (90% deuterium, 10% helium);
 5— W/N^2 , γ -radiation of a plasma with the cosmic (solar photosphere) abundance of impurities.

is presented in Fig. 1 (with $X = 0.1$ adopted); for comparison, the same figure also shows the quantities W_γ/N^2 , where W_γ is the power of γ -radiation with allowance for line radiation, recombination radiation, and bremsstrahlung⁽²⁾.

Fig. 1 makes it possible to judge qualitatively the energy balance in the plasma. It is seen that the reactions Li^6, D and He^3, D yield an energy output exceeding the radiation of the plasma at $T \sim (10^5 \div 10^7)^\circ\text{K}$.

Conclusions. There exists a fundamental possibility of synthesizing nuclei of various charges in a plasma with a strong electric current under conditions of Coulomb conductivity. Additional heating of the plasma due to the He^3, D reaction may in this case facilitate the attainment of conditions for thermonuclear synthesis in the D, D reaction.

The conclusion about the possibility of the realization of two stationary states of motion of impurity ions was drawn⁽¹⁾ on the basis of consideration of single-particle collisions. The question remains open as to how strongly collective processes in the plasma will affect this phenomenon.

In view of the above, the necessity is evident of investigating the possibility of realizing the second state in laboratory installations. Synthesis reactions, incidentally, provide the possibility of detecting the second state from the products of synthesis reactions, along with the usual spectral methods.

I express my gratitude to A. V. Gurevich for support and discussion of the work, and also to the participants of the seminar of the I. V. Kurchatov Institute of Atomic Energy, who took part in the discussion of the work.

Received
 7 VII 1969

CITED LITERATURE

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Note: Figure translations are in progress. See original paper for figures.

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