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Nuclear fusion in ordered crystal targets bombarded by monochromatic beams of light or middle-mass isotopes

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ABSTRACT

In ordered crystal lattice there is very strong influence of crystal axes and planes electrical field on motion and interaction of fast charged particles with crystal atoms and nuclei. It is shown that in mono-crystal targets like *LiD* the rate of fusion process with the participation of both target nuclei (e.g. *D*) and beam of fast nuclei (e.g. *T*), directed at *Lindhard* angle, may be increased by 10–100 times compared to the alternative process of deceleration on atomic electrons. Such changes are based on the use of specific channeling physics regime of motion – "overbarrier motion". At such regime the processes of spatial redistribution and dechanneling of accelerated ions take place. In this article the methods of optimization and practical realization of such a nuclear fusion are discussed in details.

Another method for radical optimization of fusion processes with the use of monochromatic beams of middle mass isotopes is proposed. The features of optimized nuclear fusion model based on resonant tunneling effect were considered. This leads, in combination with the use of particle beams with optimum energy and energy spread, which correspond to total transparency "window" of reaction barrier, to the possibility of positive nuclear fusion energy release on one atomic monolayer! Such effect can be regarded as nuclear super absorption of accelerated beam. The possibility of nuclear reactions $C^{12} + O^{16}$ and $C^{12} + O^{18}$ at such motion regime with positive energy release is examined.

1. Introduction

The problem of optimizing nuclear fusion is one of the most important in modern physics.

It is well known that the total probability of nuclear reactions to occur with the participation of charged particles at low energy (for $E \ll Z_1Z_2e^2/R$) is defined, in the first approximation, by the action of the Coulomb barrier $Z_1Z_2e^2/R$ and, as a result, is limited by the very small probability of the tunnel effect.

This fundamental limitation sharply complicates the solution of the problem of nuclear synthesis and stimulates the use of fast particles in the volume of a hot thermonuclear plasma, which leads to the necessity of solving the extremely complicated technological problems related to the formation and confinement of such plasma. The results of research performed in various countries for 50 years showed that the perspective for realizing the large-scale power-releasing thermonuclear synthesis remains unclear and unfavorable for the time being even for lightest particles (d and t). It is also obvious that the choice of the "thermonuclear" way makes any attempt to use, under the terrestrial conditions, the reactions of synthesis on the base of isotopes heavier than deuterium or tritium (they in turn are not optimum candidates) absolutely unrealistic.

From another point of view the optimal energy for effective interaction of light particles (e.g. $E_{opt} \approx 130$ keV for $d + t$ interaction) is much lower than the energy release at fusion reaction with the participation of these nuclei ($Q_R \approx 17.6$ MeV). Such circumstance leads to the possibility of "accelerated way" of nuclear fusion with energy release. The common assertion that a controlled nuclear fusion reaction with a positive energy release cannot be achieved by bombarding a target with a fast particle beam is usually based on the vanishingly small value of $\sigma_f/\sigma_e \approx 10^{-6}$, the ratio of the fusion cross-section σ_f to the cross-section for ionization and radiation losses, σ_e. A more systematic analysis leads to a fundamentally different estimation (Vysotskii and Kuzmin, 1981, 1983)

The additional way of nuclear fusion optimization is connected with the increase of the very small probability of the tunnel effect on the surface of target $D(E)$ by the optimized effect of resonance tunneling of light and middle mass isotopes.

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2. On the possibility of optimized nuclear fusion on ordered crystal target with the participation of monochromatic oriented beams of light isotopes

In ordered crystal lattice very strong influence of crystal axes and planes electrical field on motion and interaction of fast charged particles with crystal atoms and nuclei exists. It was shown by Vysotskii and Kuzmin (1981, 1983) that in monocrystal targets like *LiD* the probability of fusion process with the participation of both target nuclei (e.g. d, t) and a beam of fast nuclei (e.g. d) with angular divergence less than *the Lindhard* angle, increases by 10–100 times relative to the probability of alternative process of deceleration on atomic electrons. Such changes are based on the use of specific channeling physics regime of motion – "overbarrier motion". At such regime the processes of very essential spatial redistribution of accelerated ions takes place (e.g., see Fig. 1a and b).

The mechanisms of energy loss competing with the fusion reaction are the excitation and ionization of the target atoms, with typical cross-sections $\sigma_e \leqslant 10^{-16}\,\text{cm}^2$ for the outer electrons and $\sigma_e \approx 10^{-23}\,\text{cm}^2$ for the inner electrons of intermediate elements. Since the incident particle loses an energy $\delta E \approx E_{ion,exc} \approx 1-10$ eV at each interaction, the number of successive collisions involving ionization and excitation of target atoms, which is required to remove a particle from fusion process is $\Delta E/\delta E$, where ΔE is the energy interval around the optimum particle energy E_0 in which $\sigma_f(E)$ is at its maximum. The change in the beam intensity resulting from the loss of particles which are slowed in the medium is

$$\Delta J_e = J\sigma_f n_0(\delta E/\Delta E)\Delta z \qquad (1)$$

The condition for a reaction with a positive energy release takes the form

$$(\Delta J_n + \Delta J_e)E_0 < \Delta J_n E_1,$$

and for the normalized parameters this condition can be written as

$$P_0 \equiv (\sigma_f + \sigma_e \delta E/\Delta E)E_0 < \sigma_f Q_R \equiv P_1 \qquad (2)$$

or

$$\delta_Q \equiv P_1/P_0 > 1 \qquad (2a)$$

Here $Q_R = E_1$ is the energy released in each fusion reaction.

For the optimum of $d + t$ reaction, with $Q_R = 17.6$ MeV, $E_0 = 130$ keV, $\Delta E \approx 60$ keV, $\sigma_f \approx 5$ bn, we find that the reduced absorbed power density is $P_0 \approx 2 \times (10^{-15}\text{–}10^{-16})\,\text{eV/cm}^3\text{s}$.

On the other hand for the same parameters we have $P_1 \approx 9 \times 10^{-17}\,\text{eV/cm}^3\,\text{s}$.

Comparison of P_0 and P_1 reveals that the opposite of the necessary condition 2) always holds, i.e. $P_0 > P_1$ and $\delta_Q \approx 0.3$–0.03. At the same time, estimations show that the relative efficiency δ_Q is not negligibly small, as implied by comparison of the cross-sections σ_f/σ_e. The fact that P_1 and P_0 are not greatly different raises the hope that events might be arranged to satisfy condition (1) by the use of certain real physical effects. In particular, it follows from 2) that if the ratio σ_f/σ_e could be increased by a factor of $1/\delta_Q \approx 3$–30 a total positive energy release could be achieved with an accelerated monochromatic beam.

It was shown (Vysotskii and Kuzmin, 1981, 1983) that this change can be arranged by bombardment of a crystalline target by particles with kinetic energy of transversal motion close to the potential barrier in the crystal $V(0)$. At the same time the use of the channeled motion of high-energy deuterons result in a decrease in σ_f/σ_e ratio due to the fact that channeled particles move mainly in the regions between atomic planes, where the density of outer electrons is substantial but the density of nuclei is zero (see Fig. 1a).

The physical reasons of σ_n/σ_e ratio increase is connected with the periodical space self-focusing of the beam of moving charged particles to crystal planes (see Fig. 1b). Such self-focusing results directly from two reasons:

- At the channeling of positive ion (with a full momentum p) longitudinal motion along crystal planes is free and is characterized by a fixed momentum $p_z = p \cos \theta|_{z=0}$.

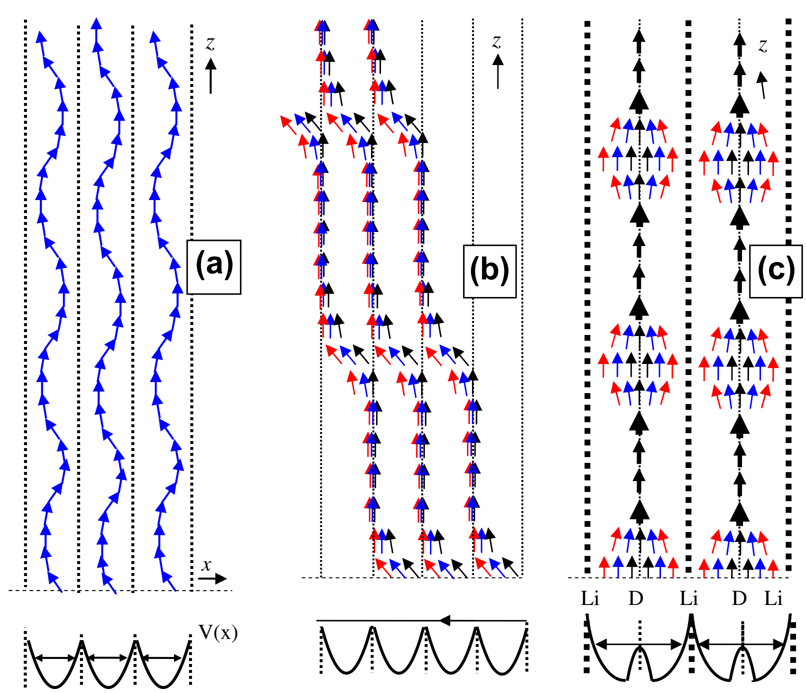

Fig. 1. The scheme of orientational motion of positive ions in different modes: (a) channeling in the system of crystal planes, (b) overbarrier quasi-channeling in crystals consisting of identical atoms at initial Lindhard angle $\theta_L = \sqrt{V(0)/E_0}$, (c) overbarrier quasi-channeling in crystals, consisting of atoms of different types (for example *LiD*). Diagrams under each figure correspond to the structure of interplane potential energy $V(x)$ and to direction of interplane ion motion.

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