The ultimate aim of investigations connected with the problem of controlled nuclear synthesis is the development of methods making it possible to use deuterium and tritium as new forms of nuclear fuel for power purposes. A necessary condition for intense nuclear reactions to take place in deuterium or a mixture of this with tritium is an extremely high temperature of the substance (order of hundreds of millions of degrees). At such a temperature, nuclear fuel will form a completely-ionized plasma. Apart from high temperature, the plasma must also have fairly high concentration, since the output of nuclear reactions is proportional to the square of the concentration.

Even at the birth of this concept of a controlled nuclear synthesis, it was clear that the main problem to be solved in reaching the goal lay in securing very perfect thermal insulation of the nuclear fuel. The only medium which can be in contact with a hot plasma without the latter instantaneously giving out the thermal energy stored in it is a high vacuum. But in order to isolate a quantity of hot plasma in an evacuated space the pressure of the plasma at its boundary must be countered by some balancing force. Such a force may be created by means of a magnetic field, if the lines of force pass around the region occupied by the plasma. The magnetic field plays the part of an elastic shell the pressure of which balances the gas-kinetic pressure of the plasma.

One must bear in mind, however, that magnetic thermal insulation is not quite ideal, since even in a very strong magnetic field there will be a leakage of energy from the plasma. A suitable measure for the quality of thermal insulation is the time $\tau$ during which the plasma situated in the magnetic field retains its high temperature. In order to determine $\tau$, we must divide the total thermal energy of all the particles in the plasma by the energy flux carried away in unit time by fast particles escaping from the plasma. The parameter $\tau$ may also be regarded as the mean lifetime of a fast particle in the plasma. Clearly a thermonuclear reactor with a positive energy yield can only be constructed after methods for preserving fast particles in the plasma for a fairly long time have been found. In essence all the long history of the problem of controlled synthesis (fusion) has lain in the struggle for large $\tau$.

The problem of controlled nuclear synthesis has been studied in various countries for some fifteen years. Results of such studies were first presented to the Second Geneva Conference on the Peaceful Uses of Atomic Energy in 1958. This summarized the first stage of the investigations, belonging to the time when work was being carried out independently in different countries. Characteristic of this period was a sharp predominance of theoretical ideas over experimental developments. At that time the state of experimental work in no way corresponded to the complexity of the problem in hand. In the years following the Conference, when experiment everywhere came up against severe difficulties, the need to raise experimental techniques to a higher level gradually became apparent. It also became realized that a serious discussion of the technical aspect of controlled synthesis would only become possible when the experimental basis of high-temperature plasma physics had been laid.

In this paper, I shall be recounting how studies in the physics of high-temperature plasma have developed in the Soviet Union in recent years. These investigations took place in various directions. The most important of these are: 1) study of plasma properties in the so-called open magnetic traps, i.e., in magnetic systems inside which plasmoids are held in a region of space with unclosed lines of force; 2) study of the heating of plasma by a current flowing in it in toroidal systems with a very strong stabilizing field; 3) study of plasma behavior in high-frequency electromagnetic fields of great intensity (containment and heating of plasma).

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"STUDIES ON THE PROBLEM OF CONTROLLED NUCLEAR SYNTHESIS AND THE PHYSICS OF HIGH-TEMPERATURE PLASMA IN THE USSR"\(^1\)

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Let us first consider the study of plasma properties in magnetic traps with open ends. The containment of plasma in such systems is based on one law on the motion of charged particles under the influence of a magnetic field. A particle moving along a line of force in the direction of increasing field experiences retardation. If its velocity vector makes a large enough angle with the line of force, the particle is turned back as if from a mirror. Hence, if the magnetic field increases along the lines of force in both directions from some middle region, the possibility of locking the plasma particles in a finite region of space between "magnetic mirrors" arises. The simplest magnetic system of the type in question is the ordinary trap with two magnetic mirrors (Fig. 1). A magnetic field of this form is created by coils passing currents in the same direction. We note that in a trap with two mirrors, the field strength \( H \) rises from the center along the lines of force and falls in the radial direction. If the current in one of the coils is reversed, a magnetic trap with opposite fields is obtained (Fig. 2). The field strength in this trap increases on all sides from the central region. At some point inside the region the value of \( H \) falls to zero. Recently great interest has arisen in magnetic traps with a more complex field structure ("hybrid type"). We shall discuss these later.

At first experimental workers turned their attention to the simplest type of trap with two magnetic mirrors. The first experimental system with magnetic mirrors was put into action in 1957 in the I. V. Kurchatov Institute of Atomic Energy (IAE); in this, plasma with a high ion temperature was stored by the "ion magnetron" method. In this method, ions are drawn out of a cold plasmoid created on the axis of the magnetic system and accelerated by means of a short high-voltage pulse. After application of the voltage, the plasmoid as it were bursts, and the space between the magnetic mirrors is filled with high-temperature plasma at a concentration of \( 10^9-10^{10} \) cm\(^{-3} \). The energy left in the plasma ions after removing the high voltage is 1.5-2 keV, which corresponds to a temperature of the order of \( 2 \times 10^7 \) K. The main purpose of the experiments carried out over a number of years in this apparatus (which has been dubbed the "ionic magnetron" or IM) was to study the properties of plasma caught in the magnetic field after the high-voltage pulse. It was necessary first of all to determine the period of existence of the plasmoid formed, i.e., the lifetime \( \tau \) of the fast ions in the trap. In order to find this quantity, we must establish how the plasma concentration, i.e., the number of fast ions in 1 cm\(^3\), varies with time. Space prevents a description of the measuring procedure, so we shall pass straight on to a discussion of the experimental results.

Analysis of the experimental material which has accumulated in three years work on the IM enables us to draw the following main conclusion: A plasmoid with initial particle concentration \( \sim 10^8-10^{10} \) and mean ion energy of the order of 1.5 keV is unstable and decomposes in a time not exceeding a few hundreds of microseconds. Signs of instability are clearly visible in the oscillograms of the measuring systems used for determining the plasma parameters. The oscillograms are broken up by intense high-frequency oscillations.

These results gave the first convincing support for the theoretical prediction that plasma in fields of the geometric shape typical for simple magnetic-mirror traps was unstable. Theoretical analysis shows that, owing to the fall in magnetic field strength along the radius, deformations having the form of alternating tongues and cavities may develop and grow on the surface of the plasmoid. This kind of wrinkled structure is called "flute" deformation, and its cause is convective instability. It is precisely this convective instability which occurs in the experiments on the IM. This follows in particular from analysis of the observed oscillations in plasma density.

In 1958, when the experiments on the IM were in the very first stages, a large system with magnetic mirrors was constructed in the IAE. This system, which was given the name "Ogra," was intended for studying the possibility of forming a high-temperature plasma by external injection of fast ions. Fast molecular ions of hydrogen injected into the trap dissociated on striking residual-gas atoms or particles created in the volume of the cold plasma. This dissociation produces protons with trajectories having half the radius of curvature of the molecular ions in the magnetic field. This irreversible change of trajectory has the result that the atomic ions are locked in between the two magnetic mirrors.

In the first stage of the experiments carried out in Ogra, the simplest method of storing 80 keV protons by dissociating \( \text{H}_2^+ \) ions in the residual gas was examined. The