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RESEARCH ARTICLE

NEW APPROACH TO THE PLASMA QUANTUM CONDENSATE, AS A NEW STATE OF MATTER

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ABSTRACT

Theoretically predicted and experimentally confirmed the existence of the new states of matter, called the authors of the "plasma quantum condensate" and connecting symptoms normal fluid and ionized plasma. The theoretical foundation of plasma condensate formed was given. It is shown that the phase transformation of up to 1 MJ/g latent heat that exceeds the heat the most efficient fuels. Seven basic properties of energy allocation in the formation of non-ideal pinching plasma were founded: formation of specific ionized conglomerate, pulse energy output, in which the plasma's liquid becomes a laser (or razer), spontaneous generation of magnetic field, self-similarity of process in laser and pinching plasma, etc. The calculations of energy allocation when plasma quantum condensate formation was shown; the possibility of its application in science, engineering and technology was described. Corpuscular radiation generation process is designed in quantum non-ideal plasma, flowing in two modes: acceleration on the front of the MHD-shock waves; acceleration in plasma focus. Plasma quantum condensate is fundamentally new, alternative, renewable and sustainable energy source. This source is environmentally friendly, does not pollute the atmosphere of the planet; his use of cleanses the environment.

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INTRODUCTION

Status of liquefied plasma (quantum condensate) is a completely new state of matter that combines in itself the signs of normal fluid (fluidity, surface tension, internal correlations) and ionized plasma in the usual sense. Theoretical notions about this condition are based on quantum theory of exchange forces in condensed mediums (Kulakov and Rumyantsev, 1988; Kulakov *et al*., 1990; Kulakov and Rantsev-Kartinov, 2015). The main feature of such forces is their collective (unpaired) character, which makes it ultimately far in the order of the interatomic interactions. Generally molecular force and especially the forces behind a distant order, have a purely quantum nature. The main idea is that the electron shells in liquefied plasma (e.g. plasma discharge) overlap, and this overlap that has through-stripes character, i.e. the overlap of diffraction peaks and dips of the wave function, however, effectively leads to quantum forces of attraction between ions of the discharge. Quantum forces are the natural fact because experimenters, dealing with discharges, have repeatedly seen this on experience. Exchange interaction of electrons under these conditions leads to ion gravitation towards each other; its binding energy becomes a negative. Such status often spontaneously implemented in nature. Quantum forces due to successive overlapping electronic shells belonging to neighboring atoms or ions. This overlap creates the effect of a first-order with respect to the de Broglie wavelength between ion destinations. If in substances that are in the normal phase condition, overlapping also exists, but exponentially decreases with increasing distances between atoms, that in the plasma (because the spectrum of quantum energy states is continuous) effect of reducing the intensity ceilings of membranes with growth slowing considerably of inter-particle distances significantly is slows down and describes the power dependence. The result is this picture of mutual coupling of particles, which corresponds to a chain of sequentially overlapping electron clouds, and each of the branches of the chain covers a distance of the order of escape radius. In general the chain spans the entire plasma: plasma ions, "captured" in this chain, attracted to each other, and going to phase transformation of plasma. The transition to a new state accompanied by energy allocation, equal to the heat of transformation. At the indicated concentrations, quantum forces provides strong adhesion of particles, i.e. create attraction, and binding energy between them becomes a negative. The fact that overlapping electronic membranes leads to the effective coupling, well known from the theory of the chemical bond. Shall refer to the Heitler-London classical theory of molecular forces, in which such forces are detected when calculating the

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simplest molecules based on variations. Variational methods in physics refer to the category of intuitive, a posteriori. Consistently heuristic can be only theory based on direct solution of the fundamental equations of quantum theory that is the Schrödinger equation. Perturbation theory taking into account exchange forces (Pauli principle), common to the class of conditions of continuous spectrum, which is being implemented in respect of states of electrons in the plasma, allowed to explain already observed features of plasma phase, as well as predict the properties of this phase, that can and should be used with modern equipment and technology (Kulakov and Rumyantsev, 1988; Kulakov *et al*., 1990).

In today's plasma physics virtually all research effort focused on high-temperature plasma. While the emphasis is on "hot" fusion, difficulties which are well known in the Earth conditions. At the same time, there are plasma-phase power sources defined by the collective nature of particle interactions, most clearly manifested in sufficiently dense plasma (with the concentration of particles n= 10^{19}-$10^{21} sm^{-3}$) in the low temperature area (Kulakov and Rumyantsev, 1988). This plasma is obtained much easier than plasma, intended for nuclear fusion. One way to obtain such plasma is compression with pulsed electric discharge. Plasma becomes imperfect at relatively low temperature, because the energy of Coulomb interaction of particles in such plasma turns out to be comparable with the energy of the thermal background. However, the main feature of such plasma, and this circumstance is the principal, is that her condition significantly determined by the emerging quantum forces in it. In accordance with the usual classification, plasma is not degenerate, at the same time the average inter-electrons distance is several times longer than the de-Broglie wavelength of thermal electrons, characterizing quantization of particle systems and inter-atoms distance satisfies the following inequality (Kulakov and Rumyantsev, 1988; Kulakov *et al*., 1990):

$$r < 10\lambda < r_d, \quad (1)$$

i.e. the escape radius the order exceeds the Debye radius.

Such conditions occur (and often is) in gas discharges, however, are not monitored and investigated by virtue of uncontrollability and lack of understanding of the processes occurring in them. Quantum forces create plasma effect forces driving order, which are known to cause phase transformation in substance. Exchange the clutch between the electron-ion complexes increases sharply with increasing concentrations of plasma, so that *plasma formed a kind of condensate*, where the degree of ionization is preserved, but at the same time manifest the properties inherent in liquid phase state, – going to phase transformation. The latter, as in normal phase transitions in substances, accompanied by allocation of energy, which, however, turns out to be significantly higher than in normal phase processes.

Specific energy (per one complete of electron-ion), corresponding to latent heat of phase transformation, is the following amount (Kulakov and Rumyantsev, 1988):

$$E_0 = 10 z^3 e^2 n^{1|3} / m_i, \quad (2)$$

where: e= – 4.8 $10^{-10} cgs$ – the charge of an electron, z – the degree of ionization of atoms, m_i – ion mass.

Believing $n = 10^{21} sm^{-3}$, for evaluation z=2, $m_i = 2 \cdot 10^{-23} g$, we get $E_0 = 10^{13}$ *erg/g*=1 *MJ/g*, that *exceeds the most effective allocation of energy fuels* (except, of course, nuclear materials). Energy sources of the type have a number of properties that should determine particular attention here to the physical phenomenon:

1. The allocation of energy is not connected with nuclear transformations or chemical reactions, but with the formation of specific ionized conglomerate, which has properties inherent to light liquid, in particular surface tension increased its resistance to decay.
2. The allocation of energy in pinching plasma comes in the form of intense light or x-ray radiation. Possible energy pulse output, in which the liquid plasma becomes a laser (or *razer*).
3. Phase transformation in plasma focus accompanied by spontaneous generation of magnetic field in our plasma modification (Kulakov and Rumyantsev, 1988). Energetically advantageous turns out to be such a condition, in which the orbital (and hence magnetic) electron orbital moments of origin are oriented in the same direction.

Intensity of the magnetic field will evaluate by formula (Kulakov and Rumyantsev, 1988):

$$H = 4\pi n\mu = \sim 10^6\text{-}10^7 gs. \quad (3)$$

Here: $\mu \sim 10^{-19} cgs$ – orbital magnetic moment of the plasma electrons.

Generates a pretty intense radiation at the formation of these fields.

4. The formation of quantum non-ideal plasma is auto-modeling and implemented as plasma values specified above, and in laser' and pinching plasma.
5. In the natural state plasma modification resulting from the phase transitions is implemented, for example, in ball lightning (b.l.) (Kulakov and Rumyantsev, 1991). Energy output in it is determined by the formula (1), which should be considered z=1, as the temperature of a b.l. substance is unlikely to exceed one to two thousand degrees. We get the top rated power output from a b.l. in the order of 100 *KJ*, that is in good agreement with observation data.

The State of the plasma was analyzed here, appears to be relatively common in space and stellar conditions. While transitions in modification of quantum not ideality lead, in our opinion, to the cataclysms of the type of solar flares, explosive phenomena in the atmosphere and the internal layers of the stars.

6. To the state of not ideality the closest plasma, containing ions of carbon, nitrogen, oxygen and other elements belonging to the middle groups of D.I.Mendeleev table. While not essential, what connection is composed of the members of the seed material: it is only important to ensure a sufficient degree of ionization of the elements. It follows that, as the source material for the realization of phase transformation processes can use waste industries, mining dumps, landfills, etc. This is a radical ecological

importance! Considered by the phenomena can initiate the creation of a new industry to obtain useful (including rare) materials with desired physical and chemical properties by chemical transformations in the process of "phase" plasma processing.

7. Plasma ribbons in the state of liquid modifications relatively easy to generate a magnetic field and, obviously, in turn, effectively controlled by external magnetic fields. This makes the plasma should be used as a coolant in MHD-generators, when trying to create difficulties of this plan.

Various studies have *obtained experimental proof of the existence of quantum plasma condensation*: in pinching plasma achieved the necessary compression of plasma at intermediate between adiabatic and isothermal modes (Kulakov and Rantsev-Kartinov, 2015), aspects of non-ideal quantum plasma are effects in gases (Bashkin *et al*., 1986; Petrov *et al*., 2013). Note that exchange linking is proportional to the cube of the charge of ions, therefore, binding and release of energy is implemented only in the case of plasma formed lot-chargers ions.In the case of one-charging, for example ionization of alkali atoms, gain in energy proves to be less than the decrease of energy, resulting in chemical reactions or during the formation of complexes, associates of ions and atoms. That is why, so far, has not been experimentally detected examined here phenomenon: experiments were carried out mainly on alkaline chemical compounds. Phase transition (a type of phase transition of the first kind in ordinary substances) in the condensed state of such plasma turns possible at temperatures of several thousand degrees, ions concentration $n\sim 10^{19} sm^{-3}$ and pressue$p$ the order of several tens of atmospheres. The ionization, compressing and heating energy is spent (per 1 g of substance) equal

$$W_1 = \frac{zI}{m_i} + \frac{kT}{m_i}\frac{1}{(\gamma-1)}, \quad (4)$$

where: $z\leq 6$ – ion charge, m_i – its weight, I – ionization energy in one electron per, k – Boltzmann constant, T – temperature. Believing for evaluation $T\sim 4\cdot 10^{3\circ} K$, $m_i = 2\cdot 10^{-23}\ g$, $I= 10^{-11} erg$,get$W_1 \approx 3\cdot 10^{12}\ {}^{erg}/_{g}$,($\gamma \approx {}^{5}/_{3}$).

Energy that meets latent heat of phase transformation and made by cooling (regular or random) plasma, when its parameters are such that the inequality (1), is negative and equal to (Kulakov and Rumyantsev, 1988; Kulakov *et al*., 1990):

$$W_2 = -\pi z^3 e^2 n^{-1/3} \Lambda/m_i, \quad (5)$$

where: $e=4{,}8\cdot 10^{-10} sgc$ – the charge of an electron,$\Lambda\sim$ a few units is logarithm of Coulomb type. Believing $n\sim 10^{19}$, z=6,Λ=4, find $W_2 = 6\cdot 10^{13}$ *erg/g*. This is almost an order exceeds the specific energy yield during the combustion of gasoline. The resulting energy can be used in a variety of ways: for heating, lighting, a transformation by photocells or MHD-movements into electrical energy. RatioW_2 /W_1=20 is determines a sufficient stock to use excess energy for demonstration and industrial aspects. This means that a plasma with certain composition can "burn" (as in chemical process) and to provide energy of the "combustion". Of course, this energy is continuous origin: here the plasma behaves as a single molecule or unitary medium.

Define the energy emitted in some ball volume when switching the plasma discharge in the new state of actions quantum collective forces (1):

$$E=\frac{z^3}{r_d} e^2 n R^3, \quad (6)$$

where: z – the charge of ions, n – their concentration, R – the radius of the sphere covering the plasma.

Adopt for evaluations $T^{(0)}=2000\ {}^0K(T=4\cdot 10^{-13} erg)$;$n\sim 3\cdot 10^{19} sm^{-3}$;$r_d = 10^{-7} sm$; $z = 10$ (plasma containing easily ionized elements).

Energy that can be obtained for R =10*sm*, is equal to:

$E = 10^3\cdot 2\cdot 10^{-19}\cdot 10^7\cdot 3\cdot 10^{19}\cdot 10^3 = 3\cdot 10^{22} = 6\cdot 10^{13} erg =$ 6 MJ.

This is much energy, comparable with the energy of nuclear fusion in one liter of sea water. However, they do not require implementing a thermonuclear reaction. The allocation of energy can be continuous (progressive) or pulse, depending on phase transformation. The allocation of energy from plasma ball can occur relatively slowly due to the flashing. When the ball with tempo radiates energy determined by luminance. When this ball emits energy with speed defined luminosity:

$$L=4\pi R^2\ \sigma_{cT} T^{(0)4}, \quad (7)$$

where:$\sigma_{cT} \approx 0{,}5.10^{-4} cgs$ – Stephen constant;
believing $T^0 = 2000\ {}^0K$,get: $L\sim 10^{11}$*erg/sec*=10*kW*.

Therefore, the duration of radiation:

$$\tau=\frac{E}{L}=600\ sec. \quad (8)$$

You can implement the conditions under which into the scope of the discharge (into the "firebox" discharge) serves all new portions of the hot dense gas. Then the process will be continuous. Note that the energy spent on heating (creation of discharge), less than producing energy, if:

$$k\cdot T^{(0)} \ll \frac{z^3}{r_d}.e^2, \quad (9)$$

that is typically done.

Similar phenomena (while in "unmanaged" form and when the random circumstances) are observed in the laboratory and other conditions. For example, such a glow emanating from some clots were found in submarines, near aircraft when flying in the air, in experiments with high voltages. These phenomena are sometimes described by eyewitnesses, explained them as annoying interference. Fluid (and conductive current) plasma easily controlled by magnetic field and can form closed loops and jets that can be sent in a working part of MHD-generator and determine the pumping jet energy into the electromagnetic energy. Plasma, apparently, will be chemically fairly inert, that would remove many of the technological problems. The resulting product is a liquid (but with a relatively low density) and represents a particular chemical compound, other than material which is loaded into a power generator. In this sense, the thermodynamic closed loop absent (the ashes of burnt firewood should not turn back into firewood). But exhaust material may have a special interest, such as in chemical technology. Plasma state analyzed here are implemented, and, apparently, a relatively common in space environment. While transitions in modification of quantum non-ideality lead (in our view) to the cataclysms of the type of solar flares, to the explosive phenomena in the atmosphere and the internal layers of the stars.

Corpuscular radiation generation in quantum non-ideal plasma

Plasma with a temperature of $3 \div 10 \cdot 10^{30}$C and the concentration of $n \sim 10^{19} \div 10^{20} sm^{-3}$ has special quantum properties associated with consistent overlap of electronic shells when the de Broglie wavelength of electrons is not more than an order of magnitude less than the average distances between ions;it forms condensate with a large release of energy in excess of the costs of its ionization and compression. The initial ionization of such plasma can be achieved in three ways:

1) adiabatic compression of gas with increased pressure in 10-20 times from initial atmospheric; This gas may be CO_2 or other compounds with admixtures of oxygen, nitrogen, silicon, calcium, magnesium and other elements that contain a sufficient number of electrons in the valence shell;
2) compression with pulsed electric discharge using units of type Z- and ϑ-pinches. In pinching plasma achieved the required compression ratio in the interim between adiabatic and isothermal modes;
3) ionization of liquid medium (type of liquid carbon disulfide or other fluids containing the above chemical elements); while additional compression is not required.

In the laboratory the fact of spontaneous acceleration of charged particles when the hydrodynamic plasma compression installed at Filippov's articles (Filippov, 1983). Processes of particle acceleration recorded on the installations, designed to study the so-called plasma focus in pinching plasma. Total energy consumed for compressing of plasma was 10-20 *kJ*. It was found that particle acceleration occurs at the reflected waves of impact type. Surely detected particles – are ions and electrons with energy of 100-300 *KeV*. Also detected x-ray quanta, daytons, moving toward the cathode, as well as neutrons with the same characteristic energies that are specified above. Generation of high energy particles using MHD-shock turbulence had been researched in article (Kulakov and Rumyantsev, 1979). The fronts of the MHD-shock waves formed in the pinch are unstable, that manifests itself at the stage of reflection (after collapse of pinching plasma) and leads to the formation of the chaotically moving shock fronts conglomerate with smaller Mach numbers, which is experiencing, crossing each other. It is formed of the shock turbulence that contributes to the acceleration of charged particles. Particles from Maxwell "tail" involved in acceleration (no-injection way) it is on the periphery of the pinch particles, originally having the energy of the order of ten times the heat energy.

1. Acceleration on the front of the MHD-shock waves

Acceleration of particles on the front of the MHD-shock waves occurs with tempo (Kulakov and Rumyantsev, 1988):

$$\dot{\varepsilon} = pu\omega_H, \qquad (10)$$

where: p – the momentum of a particle, u – front speed, ω_H – Larmor frequency. If denote the number of particles with energy ε through n(ε), the quasi-stationary process takes place ratio:

$$\varepsilon \frac{d\dot{n}(\varepsilon)}{d\varepsilon} = \frac{n(\varepsilon)}{\tau_0}. \qquad (11)$$

where:$\tau_0 = l^2/\upsilon r_H$ – time for diffusion of particles to the periphery of the pinch,υ –particles speed, $l -$ linear (transverse) scale for accelerating field, $r_H -$ Larmor the radius of the particles. Integration of (10) leads to the decision defines the energy spectrum of the accelerated particles:

$$n(\varepsilon) = \text{const}\,\varepsilon^{-\lambda} \qquad (12)$$

$$\lambda = {}^{\tau}/_{\tau_0} \sim \frac{\delta}{l}\frac{q}{1-q}\frac{H}{\Delta H}.$$

Here: $\delta -$ the thickness of the fronts of the chaotic shock waves, ΔH – amplitude change of magnetic tension on them, q – fraction of particles, not returning to the front, i.e. leaving the pinching plasma. The particles create the x-ray background radiation, its spectral density can be determined on the basis of the theory of braking processes; we have the following formula for this value (9):

$$W_\omega = \frac{16\pi}{3}\frac{ze^2}{\hbar v_\omega} c r_0^2 n_e^2 \lambda \left(\frac{\varepsilon_0^{\lambda-1}}{\hbar\omega^{\lambda-1}}\right)\frac{\Lambda(\omega)}{\omega}. \qquad (13)$$

Here: $r_0 \sim 3 \cdot 10^{-13} sm$ – classical electron radius, ε_0 – initial energy of the accelerated particles, z·e – the charge of ions, $\boldsymbol{v_\omega} = \left({}^{\varepsilon_0}/_{2m}\right)^{1/2}$, m – electron mass, $\boldsymbol{n_e} -$ the concentration of electrons, notation n_e $\boldsymbol{\Lambda(\omega)} = \mathbf{ln}\frac{\varepsilon_0 + \sqrt{\varepsilon_0 + \omega\hbar}}{\varepsilon_0 + \sqrt{\varepsilon_0 - \omega\hbar}}$.

Here is some numerical evaluation. Let the particle concentration in the plasma n= $10^{17} sm^{-3}$ (meets the primary pressure 1 *Torr.*), magnetic field strength H ~ 1 *Ke* (at the currentI~ $200\ kA$), $\ell \sim 100 sm$ – the length of the pinch; when this characteristic duration of particle acceleration and diffusion are accordingly equal $3.10^{-8} secu\ 10^{-8} sec$,indicator λ =3.Initial energy $\varepsilon_o \sim 10 Kev$, the number of particles involved in the process $\sim 10^{16} \div 10^{17}$, and the number of particles, the energy of which reaches the magnitude of ε ~ 1 *Mev*, will be$10^{11} \div 10^{12}$. Amount limit pace accelerating α can be obtained from the following considerations. Let $r_o$is radius of pinch in original state, r – its radius at the moment of maximum compression. Maximum limit energy, such as electrons, accelerated on the fronts of the shock waves is determined by the equality r_H (ε)= ${}^{\varepsilon}/_{eH}$ =r_o,moreover, H= ${}^{2I}/_{cr}$. *The desired* value of α is equal in this ${}^{2eI}/_{cr} = 10\ Мэв/r$. Assuming the compression of a plasma $r_o/r = 30$, then the value $\chi = \frac{300\ Mew}{r_o} \sim 30\ \frac{Mew}{sm}$when $r_0 = 10\ sm$.

2. Acceleration in plasma focus

Plasma is compacted in the point of shock waves, reaching concentrations of $10^{24} sm^{-3}$, and temperature of T≅ $1 million^0 K$. Plasma origin of this type have a needle shape and called *a plasma focus*. Attention to these entities is determined by the fact that they are generating fast charged particles (Trubnikov, 1990; Airapetyan *et al*., 1988). Usually there is considered the phenomenon of the current breakage, resulting in arise of Faraday electrical fields that accelerate the particles. However, all these mechanisms meet with considerable difficulties (it is not clear how breakage occurs of the current, which leads to spontaneous violation of its continuity, because this requires external influences, etc.). Consider the mechanism of quantum type not associated with any artificial assumptions. According to the theory, developed in the work of the (Kulakov and Rumyantsev, 1988), *the plasma in focus is an analogue of liquid substances*. The status of this non-ideal plasma is determined by quantum forces, arising from overlapping fixing electronic shells of electrons, related by Coulomb's forces with atomic nuclei and ionic parts. The result is formed a specific plasma-liquid condensate and energy is allocated. While plasma is magnetized;the resulting magnetic moment due to mutual orientation of the orbital moments of electrons. Induction of fieldis equals:

$$B=4\pi n\mu, \qquad (14)$$

where:$\mu \sim 10^{19} cgs$ – orbital magnetic moment of the plasma electrons (Bohr magneton). Intensity of the electric field, arising under the law of induction, equal to $E=\frac{\upsilon}{c}H$, whereυ – plasma compression speed. Believing $\upsilon=3\cdot10^{8}$ *sm/sec*, $H=3\cdot10^{6} G$, get $E=3\cdot10^{3} cgs$.

The energy of the particles, accelerated this field is proportional to focal length and equal $\varepsilon = eEl$.When$l = 1\, sm$get$\varepsilon = 10^{-3} erg \approx 1\, GeV$.Energy spectrum (the number of particles *n(ε)* with energy *ε*) can be calculated as follows. On the particles acts accelerating force *eE*, at the same time, particles, drifting across the spotlight needle radius *r*, leave the region accelerate over time $\tau = r/\vartheta_d$,where ϑ_d – drift speed. Balance equation in stationary conditions have the form:

$$\dot{\varepsilon}\frac{dn(\varepsilon)}{d\varepsilon} = -\frac{n(\varepsilon)}{\tau} \qquad (15)$$

By integrating this equation, for example in the case of electrons (its speed$\upsilon \approx c$), get finally:

$$n(\varepsilon) = n_0 \exp(-\varepsilon/_{eBr}) \qquad (16)$$

Believing here $r=0{,}1 sm$,$B=3\cdot10^{6} G$,find $n(\varepsilon) = n_o \exp(-\varepsilon/\varepsilon_o)$;$\varepsilon_0 = 0{,}15\cdot10^{-3} erg \approx 0.1\, Gev$.

The particles are accelerated in the so-called "runaway" mode, when the electric field strength exceeds the energy of particles, i.e., when running the following inequality $eE\iota > \varepsilon, \iota = \frac{\varepsilon^2}{ne^4}\Delta^{-1}or\varepsilon > \frac{ne^3\Delta}{E} \sim 3\cdot10^{8} erg$(where$\Delta$ –Coulomb logarithm).

Such energy particles are generated on shock fronts. Therefore, the primary role of the shock fronts is the preliminary acceleration of particles, i.e. injection of particles into the main phase of acceleration in quantum zone of plasma focus. Thus, *we have developed a fundamentally new direction in the theory and technology of the non-ideal plasma*. Researchers have made it possible *to predict, then experimentally in the laboratory to detect the existence of fundamentally new states of matter, that is the quantum plasma condensate, which combines the signs inherent in normal fluid (fluidity, surface tension, inner correlations), and signs characteristic of ionized plasma in normal understanding*. Theory, developed in our research, based on direct solution of the Schrödinger equation and widespread to the state class of continuous spectrum (*perturbation theory taking into account exchange forces*), allowed to explain already observed features of plasma phases, that can and should be used with modern equipment and technology (Kulakov and Tyutyunnik, 2016). Described studies have predicted and confirmed the existence of fundamentally new, alternative, renewable and sustainable energy source on the planet Earth, there is plasma quantum condensate. This source is the only ecological clean, does not deplete and not polluting the Planet, and its use clears the surrounding medium of Planet Earth.

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