OBTAINING HIGH TEMPERATURES AND STRONG MAGNETIC FIELDS IN A LASER PLASMA PRODUCED BY A TUBULAR LIGHT BEAM

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Recently, by using focused beams from powerful lasers, a dense plasma was obtained, heated to high temperatures on the order of hundreds of electron volts in the case of a light spark [1] and a kilovolt in the case when the beam was acting on a target. In the latter case the concentration of the energy release was so high that hard x-rays and neutron radiation were observed [2]. However, the intensities of these processes in the light spark were low, owing to the reduced concentration of the energy release (low density of the medium in the case of a gas, and delocalization of the energy release as the result of breakdown of the surrounding medium).

In this article we call attention to the possibility of greatly raising the temperatures and the pressures by using a tubular laser plasma of a light spark or a flare, and of obtaining large magnetic fields in the plasma.

1. We consider the plasma of a light spark or a flare, produced by a focused tubular light beam (the hole in the center and the sharp edges can be produced in simple fashion by using a small screen). If the geometry is assumed to be quasicylindrical (at a small beam convergence angle), then the amplitude of the converging shock wave is $p \sim r^{-b}$, where $b = 2 \times (1 - a)/a$ is determined from an equation given in [3] and depends on the adiabatic exponent of the medium γ and on the geometry (for example in the cylindrical case we have $a \approx 0.834$ for $\gamma = 7/5$, and $a = 0.810$ for $\gamma \approx 3$, i.e., $b \approx 0.4 - 0.5$ in the case of interest to us). The pressure will increase following compression to the radius r_{min}, at which violations of the axial symmetry or deviations from a cylindrical shape come into play (usually $r_{min} \approx 0.1r_1$, where r_1 is the initial radius of the shock wave), i.e., $p(r) = p_1(r_1/r)^b$, where $p_1 \approx n_{e.sh} \times kT_{sh}$, where $n_{e.sh} \approx Z_{eff}n_{a.sh}$ is the concentration of the electrons in the initial shock wave with allowance for the additional compression, which increases the density of the atoms by several times, $n_{a.sh} \geq n_a(\gamma + 1)/(\gamma - 1)$ (for example, at the readily attainable $n_{e.sh} \approx 10^{21} - 10^{22}$ cm^{-3} and $kT_{sh} \approx 100$ eV we obtain $p_1 \approx 10^5 - 10^6$ atm). In the collapse due to collision of oppositely traveling shock waves, the pressure behind the front after reflection is

$$p \approx \frac{3\gamma - 1}{\gamma - 1}\, p(r_{min}) \approx \frac{3\gamma - 1}{\gamma - 1}\,(r_1/r_{min})^b p_1 \approx Kp_1 \quad .$$

Thus, the pressure is increased by a factor $K \approx 15 - 20$ if the adiabatic exponent of the highly heated gas is such that $b = 0.4 - 0.5$ and if $r_{min} \approx 0.1\, r_1$. This increase of pressure can greatly increase the yield of the hard x-rays and neutrons it is (apparently more advantageous to use a mixture of a strongly absorbing gas with deuterium, liquid deuterium, a solid target containing deuterium, etc).

2. The presence of an initial magnetic field ($H_1 \approx 10^4 - 10^5$ Oe) can lead to capture and compression of the field inside a converging shock wave of a tubular spark or flare, to

a value $H(r) \approx H_1(r_1/r)^2$. The maximum field intensity is determined from the condition that the magnetic pressure be equal to the pressure in the shock wave reflected from the compressed magnetic fields, $H_{max}/8\pi \approx K_{ref}p_1$, which yields a magnetic field intensity $H \geq 10^7$ Oe if $K_{ref} \approx 10$ and $p_1 \approx 10^6$ atm. The velocity of the skin delocalization of the field $v_H \approx c^2/4\pi\sigma r_{min} \leq v_{sh} \leq 10^7$ cm/sec cannot greatly influence the compression of the field. This method of obtaining fields is convenient because it is simple, has small dimensions, and can be readily regulated by choosing the type of gas, the pressure, etc.

The velocity in front of the compressed magnetic field (magnetic mirror) is $v_z = v_\perp/\tan\theta \sim v_\perp/\theta$, where θ is the cone angle. At the attainable $v_\perp \approx 10^7$ cm/sec and $\theta \approx 10^{-2}$, we obtain $v_z \approx 10^9$ cm/sec. Such a moving magnetic mirror can be used to accelerate conductor particles, charged particles, and plasma batches.

[1] M. Vanyukov, V. A. Vechikov, V. I. Isaenko, P. P. Pashinin, and A. M. Prokhorov, ZhETF Pis. Red. 7, 321 (1968) [JETP Lett. 7, 321 (1968) [JETP Lett. 7, 251 (1968)].

[2] N. G. Basov, P. G. Kryukov, S. D. Zakharov, Yu. V. Senatskii, and S. V. Chekalin, ibid. 8, 26 (1968) [8, 14 (1968)].

[3] K. P. Stanyukovich, Neustanovivshiesya dvizheniya sploshnoi sredy (Unsteady Motion of Continuous Media), Gostekhizdat, 1955.

TRACES OF "PHOTON EDDIES"

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According to a hypothesis advanced some time ago [1], in the early universe, during the phase of almost complete homogeneity, there existed local dynamic motions of the photon gas and the plasma dragged by it ("photon eddies") superimposed on the general cosmological expansion. The hydrodynamics of this mixture, in conjunction with the gravitational instability, determines of necessity the subsequent structure of the universe. It will be shown below that the consequences of the hypothesis, which pertain to the velocity and density spectra of metagalactic structures, are confirmed by astronomical observations.

During the course of the cosmological expansion in the primordial eddies, assumed to be initially subsonic, a Kolmogorov velocity spectrum is established:

$$v_k \propto k^{-1/3}. \qquad (1)$$

The wave-number interval in which the spectrum (1) takes place is bounded on the side k by dissipative processes (mainly radiant viscosity). The limit on the side of small k, which is of interest to us here, is determined by the requirement that the hydrodynamic time t_g be small compared with the cosmological time t_{exp}. The upper limit of the scales with the spectrum (1) amounts to, when recalculated to the present time, $30\Omega^{-1}$ Mpsec, encompassing a mass up to $2 \times 10^{15}\Omega^{-2}M_\odot$ ($\Omega = \rho/\rho_{crit}$).

The density inhomogeneities resulting from the hydrodynamic instability at the instant of plasma recombination (at a red shift $z_{recomb} \sim 10^3$), differs significantly in amplitude, depending on the relation $t_g \lessgtr t_{exp}$. At large scales (lower sign) they are small, and their Fourier spectrum has a form characteristic of small alternating-sign perturbations in a