Mesons and neutrinos under supercompression. Cumulative and inductive increase of particle energies to meson values in microbursts of energy release

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The possibliity is considered of supercompression generation of mesons and neutrinos by increasing the particle energies through energy bursts that ensure the collapse of the streams of the expanding plasma, compression of the magnetic field, and inductive acceleration of the particles, as well as by inductive compression of strong ion beams.

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1. It was recently proposed to obtain microbursts of thermonuclear (TN)[1] and nuclear (N) energy [2] by supercompression [1] of small particles of matter via ablation pressure[3] applied by an optical of corpuscular beam.

This paper analyzes the possibility of obtaining neutrino radiation and attaining meson temperatures with such energy bursts. For TN and N bursts it is customarily assumed that in supercompression the number of acts is $\sim 10^{20}$, so that the total number of neutrinos can be estimated.

In the N case,[2] β-active fragments that emit neutrinos (approximately 6 neutrinos per decay chain) within a time on the order of minutes, with an average energy 2–3 MeV, so that a short supercompression time offers no advantage over the use of pulsed reactors. If neutron radiation of TN and N bursts is used, it is possible to obtain β-active isotopes that yield more energetic neutrinos and decay more rapidly, for example in the reactions $\mathrm{Li}^7(n,\gamma)\,\mathrm{Li}^8$; Li^8 is β-active with a half-life ~ 1 sec and produces a neutrino with average energy ~ 6–7 MeV and maximum energy ~ 13 MeV.

Although the efficiencies of these neutrino-emitter variants can be increased (using simultaneous supercompression of the radiating center and the neutron-moderator layer—to increase the cross section for the production of Li^8 and of an Li^7 layer with subsequent transport to the block with the shield—these schemes were discussed by us with V.A. Namiot and G.V. Domogatskiĭ in 1975), the main shortcomings of these variants are low neutrino energies and long bursts. Neutrinos with such energies have very small cross sections for interaction with matter and release little energy in their rare interaction acts, so that their registration is difficult. Of much greater interest in this respect are neutrinos obtained with the aid of particle beams, for example in the reaction $p +$ target $\rightarrow \pi \rightarrow \mu + \nu + 30$ MeV or $\mu \rightarrow e + \nu + \tilde{\nu} + 100$ MeV, which result in a much higher neutrino energy, more than several dozen or hundreds of MeV.

In this paper we consider the possibility of realizing this beam variant of meson and neutrino generation under supercompression conditions.

Assume that ablation and inertial compression have produced a supercompressed layer in the form of a thin hollow shell of radius a, that an energy-release burst was produced in the layer, so that it begins to spread inward and outward with velocities on the order of $v \sim 2c_s/(\gamma - 1)$; c_s is the speed of sound in the nuclearly heated layer. Usually energy-release bursts under supercompression result in temperatures up to or of the order of a megaelectron volt. By cumulation in the interior it is possible to realize temperatures and densities several times larger, but the poor convergence accuracy, the small expansion time, and small fraction of time that the matter exists in the stage of a heated focus have prompted us to seek also other means of raising the temperature.

We consider the possibility of using strong magnetic and induction fields for bulk acceleration of plasma particles in supercompression. We note that in energy bursts we can obtain, owing to the abrupt increase of the pressure, maximum magnetic fields $H \approx \sqrt{8\pi n \epsilon} \gtrsim 10^{11}$ Oe at $n \approx 10^{27}$ cm^{-3} and $\epsilon \approx 1$ MeV, i.e., much higher than the fields[2] produced in compression by ablation pressure.

Assume that the radius of a spherical or cylindrical layer of radius a_0, containing a less dense substance and acted upon by a magnetic field $H_0 \lesssim 10^6$ Oe, was decreased upon compression by one order of magnitude, and that inside the supercompressed layer of thickness $a_1 \approx 10^{-2}$ cm and with concentration $n \sim 10^{27}$ cm^{-3} the substance was compressed to $n \lesssim 10^{25}$ cm^{-3} and with a magnetic field $H_1 \approx H_0 a_0^2/a_1^2 \approx 10^8$ Oe. When an energy-release burst is produced in the layer, the inward expansion will cause further compression of the substance and of the field (the inductive heating of the substance is analogous to the heating produced when a liner collapses and compresses the magnetic flux together with the plasma). Given the wall-motion law $a(t)$ and the condition of freezing-in the magnetic field $\Phi = \pi a^2 H =$ const, we obtain the induction fields

$$E(r, a(t)) \approx \frac{1}{2c} r H_1 a_1^2 \frac{d}{dt} \frac{1}{a^2(t)} \approx 10^7 \text{ CGSE},$$

which cause the acceleration of the particles.

We note first that in view of the high starting temperatures in the burst ($T \sim 1$ MeV) we can neglect the collisions of the particles and consider acceleration of quasi-free particles in a magnetic field that increases in time. In fact, the collision frequency is $\nu(t) \approx n\sigma_s v < v/a$, where the cross section for scattering in nuclear and Coulomb interactions is $\sigma_s \lesssim 1$ b at $T \sim 1$ MeV. For $n \approx 10^{25}$ cm^{-3} and $v \approx 10^9$ cm/sec we get $\nu \approx 10^{10}$ sec^{-1}, whereas the compression time is $a/v \approx 10^{-2}/10^9 \approx 10^{-11}$, and the period of the Larmor revolution is $T = 2\pi m_d c/eH < 10^{-12}$ sec. The fact that the acceleration processes preserve adiabaticity yields for the energy-accumulation the condition $u/H \approx$const, from which we get, when the radius is contracted by one order of magnitude, an energy increase

$$w_2 \approx w_1 H_2/H_1 \approx w_1 a_1^2/a_2^2 \approx 10^2 w_1 \quad \text{at} \quad a_2 \approx 0.1 a_1.$$

That is to say, the nuclear particles can acquire energies on the order of a hundred MeV, which is close to the meson-production threshold. We note that the conditions for the acceleration "whizzing by" is realized for practically the entire mass of the particles.

The magnetic field, which is frozen-in and closed internally and externally, can facilitate the supercompression of the hollow layer, by acting as a magnetic wall against which the layer is pressed. Furthermore, by choosing the initial radial distribution of the field (stronger inside and weaker in the layer), it is possible to increase insignificantly the elasticity of the layer, but at the same time to produce inside a "magnetic anvil" that acts in all directions (the longitudinal elasticity is produced by the closed field).

The magnetic field does not affect adversely the effectiveness and symmetry of the supercompression of the material, if it does not decrease noticeably the thermal conductivity and the heat transfer from the corona, where the heat is released, to the surface of the evaporating core of the particle. In the case of electronic thermal conductivity this condition $\omega_H < \nu_s$ is satisfied for $H_0 < 10^6$ Oe at values in the corona $n_c \approx 10^{21}$ cm^{-3} and at a temperature on the order of a kiloelectron volt even at $Z \approx 1$. Since compression of the core increases its distance to the corona it follows that, notwithstanding the increase of the magnetic field in the core, its stray magnetic field in the corona region is

$$H_c \sim M/r^3 \sim Ha^3/r^3 \sim a, \qquad \text{since} \qquad Ha^2 \approx \text{const},$$

i.e., it decreases when the field is compressed in the core. The increase of H as the center is approached is immaterial here, since it is offset by the increased density and the lowered temperature, so that $\omega_H \tau_s$ changes little. The use of large n_c and large Z and a change to radiant thermal conductivity permits an even greater increase of H_0.

We note that the increase of the magnetic field in the core greatly decreases the inward thermal conduction at energies 1–100 MeV and makes it possible to prevent the heat from departing to the dense compressing layer. For a cylindrical geometry, this is sufficient for complete insulation; in the quasispherical case, local compression of the field is necessary–magnetic mirrors at the entrance and exit of the force lines (the analog of the magnetic bottle) to limit the departure of the heat along the force lines.

It is most important that in the considered model the accelerated particles can experience opposing collisions when the Larmor orbits are tangent to each other and are in the same plane. This increases the effective energy, and the meson-production cross section can reach several dozen millibarns.[4] The number of produced pions is in this case $N_\pi \sim n^2\sigma_\pi vt\,(4\pi/3)a_2^3 \approx 10^{18}$ in a time $t_2 \approx 10^{-11}$ sec, i.e., it can be commensurate with the number of particles in the supercompressed region.

In the expansion, over times $\tau_\pi \sim 10^{-8}$ sec, the pions decay and form a cloud of muons and neutrinos, while the muons produce, upon decay or interaction, a burst of neutrinos with energy ≈ 100 MeV and duration $\tau_\mu \approx 10^{-6}$ sec; a neutrino burst of strength

$$\dot{N}_\nu \approx N_{0\pi} \times$$

$$\times \left\{ \frac{1}{\tau_\pi} e^{-t/\tau_\pi} + \frac{2}{\tau_\mu - \tau_\pi} \left[e^{-t/\tau_\mu} - e^{-t/\tau_\pi} \right] \right\} \approx 10^{26} \quad \text{neutrinos/sec},$$

at a total number of 10^{19} neutrinos is of interest for many branches of neutron physics. We note once more that these neutrinos have much higher energies than neutrinos from pulsed reactors.

A meson cluster can also be used to investigate mesic reactions, to inject mesons into accelerators, and when mesons are needed for applications.

2. A meson-neutrino burst can be produced by injection and compression of powerful mega-ampere and megavolt ion beams[5] by strong magnetic fields that increase in time by hundreds of times (e.g., from 10^{3-5} to 10^{5-7} Oe[6]). The burst in this case has a much lower intensity and is much longer (since $\dot{N}_\pi \sim N_i n_i$), provided the inductively accelerated ions are not dumped rapidly on the target. An even smaller burst is produced by electron beams or quanta, because of the small cross sections of the electro- and photoproduction of mesons.

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