Neutron collisions in a thermonuclear plasma

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A method is proposed for the diagnostics of the advanced thermonuclear combustion reaction of a T+D mixture by registering the anomalous neutrons with energy $E > 14$ MeV. Estimates show that a noticeable fraction of the neutrons acquires an energy $E > 14$ MeV whenever more then 6×10^{16} erg is released in one act (combustion of 0.01 g of the mixture).

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The combustion of a T+D mixture at a density 1000—10 000 g/cm^3 and at optimal temperature proceeds so rapidly that the instantaneous neutron concentration becomes appreciable. This results in an appreciable probability that the neutrons will collide with one another. As a result, some of the neutrons acquire an energy exceeding 14 MeV, up to double this value, 28 MeV. Measurement of the anomalous neutrons ($E > 14$ MeV) yields in principle additional data for the diagnostics of an advanced thermonuclear reaction.

At a target mass 0.01 g and a density 3000 g/cm^3, the radius of the sphere is 0.01 cm, $\rho r = 30$ g/cm^2, and the time of flight of the neutrons is 2×10^{-12} sec. The rate of the thermonuclear reaction at a temperature 70 keV$^{1)}$ is characterized by the average product of the velocity by the cross section $\sigma v = 10^{-15}$ cm^3/sec. At a density 3000 g/cm^3, the concentrations of D and T are equal to 3.6×10^{26} cm^{-3}, the number of reactions per unit volume and per unit time is $W = 10^{-15}(3.6 \times 10^{26})^2 = 10^{39}$ cm^{-3}sec^{-1}, and the reaction time $t = 10^{-14}(3.6 \times 10^{26})^{-1} = 3 \times 10^{-12}$ turns out to be just of the order of the time of flight.

Consequently, the maximum neutron density corresponds in order of magnitude to the stoichiometry of the reaction, $n \sim 10^{26}$ cm^{-3}. The scattering cross section of interest to us will be estimated by using the principle of isotropic invariance ($\sigma_{nn} = \sigma_{pp}$, and neglecting the Coulomb interaction) and microscopic reversibility—we take the cross section for the scattering of a 28-MeV proton by an immobile proton to be $\sigma = 1$ b. We then obtain from the most favorable estimate for single scattering $l_{\sigma n} \sim 0.01$ cm $\times 10^{-24}$ cm^2 $10^{26} = 1$. A noticeable fraction of neutrons, about 5 or 10%, might acquire an energy higher than 14 MeV.

Actually, since the reaction takes place at low temperature and not simultaneously over the entire volume, the fraction of the anomalous neutrons will be much lower, but still sufficient to be registered and to be used for diagnostic purposes.

The fraction of the anomalous neutrons decreases greatly when the reaction is stretched out over a time longer than the emission time 2×10^{-12} sec. It is quite difficult to register a reaction duration of this order by direct methods, if for no other reason than the energy spread of the bulk of the "14-MeV" neutrons.

The total energy yield in this case may be insensitive to the conditions of the reaction after the ignition of the D+T mixture.

The scattering and the energy losses by neutrons in the shell alter very little the ratio of the anomalous and principal (14 MeV) neutrons at the exit from the thermonuclear apparatus.

We emphasize, however, that the foregoing calculation requires that in one act the total energy correspond to combustion of 0.01 g of the mixture, i.e., approximately 3×10^{16} erg. This effect has not been observed in model experiments with pure or diluted deuterium without tritium at a lower power.

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1) We note that the total conversion of the energy of the particles of the T+D reaction into radiation energy at the indicated density yields an equilibrium temperature $T=70$ keV in accordance with the condition $aT^4=Qn$ with $Q=4$ MeV.