ENHANCEMENT OF THERMONUCLEAR REACTION RATE DUE TO STRONG SCREENING

N. Itoh*, H. Totsuji**, S. Ichimaru***, H.E. DeWitt****
* Department of Physics, Sophia University, Tokyo, Japan
** Department of Electronics, Okayama University, Japan
*** Department of Physics, University of Tokyo, Japan
**** Lawrence Livermore Laboratory, University of California, U.S.A.

The enhancement factor for the rate of thermonuclear reactions which involve two kinds of nuclei with charges Z_i and Z_j in the strong-screening regime is given for general cases of surrounding nuclear plasmas by the formula, $\exp[1.25\Gamma_{ij} - 0.095\tau_{ij}(3\Gamma_{ij}/\tau_{ij})^2]$. Here, $\Gamma_{ij} = 2Z_iZ_je^2/(a_i+a_j)T$; $a_i = [3Z_i/4\pi\Sigma_k Z_k n_k]^{1/3}$; $\tau_{ij} = [(27\pi^2/4)(2\mu_{ij}Z_i^2Z_j^2e^4/T\hbar^2)]^{1/3}$; μ_{ij} is the reduced mass for the two reacting nuclei Z_i and Z_j; and n_k is the number density of nuclei Z_k. The calculation is based on the recent results of Monte Carlo computations for binary ion mixtures, which have shown that the screening functions $h_{ij}(r)$ at intermediate distances $[0.5 \leq r/[(a_i+a_j)/2] \leq 1.6]$ can be expressed to a good degree of accuracy by

$$\frac{h_{ij}(r)}{T} = \Gamma_{ij}[1.25 - 0.39\frac{r}{(a_i+a_j)/2}].$$

Application to the calculation of carbon ignition in the carbon-oxygen core of a highly evolved star is discussed. The carbon ignition temperature is found to be single-valued as a function of the density in contrast to the work of Graboske.

DISCUSSION

Schatzman: The results of Jancovici and Alastney concerning the increased rate factor confirms, within perhaps a factor 3, your results. R. Mochkovitch has also reconsidered binary mixtures and finds that, for a constant electron density, the increased rate factor is independent of the chemical composition.

Itoh: These confirmations are very gratifying.

Sugimoto: As you said at the beginning of your talk, your results change the rate by an order of magnitude. This occurs because the quantities involved are in the exponent. By the same token, the uncertainty in your results could be large. How large is it?

D. Sugimoto, D. Q. Lamb, and D. N. Schramm (eds.), Fundamental Problems in the Theory of Stellar Evolution, 318–319.

https://doi.org/10.1017/S007418090007412X Published online by Cambridge University Press

Itoh: Let us define the dense plasma parameter $\Gamma \equiv E_{Coul}/kT$. The error bar of our result caused by the noise in the Monte Carlo data for the binary ion mixture is $\sim\exp(0.05\Gamma)$.

Salpeter: When $\Gamma \equiv E_{Coul}/kT$ is very large, the value of the screening factor may not be unique: The matter is "almost" solid, and the structure may depend on the previous history.

Itoh: We are concerned with the region in which $\Gamma \lesssim 160$. In this region the matter is in the liquid state.

Nomoto: When accretion onto a white dwarf is slow, helium ignites at a density as high as 3×10^8 g cm^{-3}. At this density the matter is a quantum liquid, i.e., the temperature is lower than the Debye temperature. Could you calculate the correct screening factor even for this region?

Itoh: Near the Debye temperature, the classical turning point radius for thermonuclear reactions is comparable to the mean distance between nuclei. Therefore it would seem to be rather difficult to extend the theory to this region, but we might nevertheless try to solve it.

Wheeler: There is a particular astrophysical problem that depends very much on the ignition in just the region where you have re-calculated it. That is the problem of accretion and carbon ignition in a cold white dwarf, and whether the white dwarf collapses before it ignites carbon or not. Drs. Schatzman, Mazurek, Tutukov, and I, at least, have worked on this problem and have all disagreed. Have you considered the application of your results to this problem?

Itoh: Your problem appears to be extremely interesting. I have heard from Dr. Nomoto that he is in the process of attacking this problem by applying our theory.