Electron screening effects in low energy nuclear reactions in laboratories

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Screening effects on nuclear reactions play an important role for the synthesis of elements and generation of energy in stars. The well-known Debye-Hückel theory is applicable to estimate the enhancement of the rate of thermonuclear reactions in the case of weak screening limit [1], where the interaction energy between the screening charged particles is negligible compared with their thermal energy. If the temperature of the system is not high enough and the interaction energy cannot be ignored, another approach is needed to properly determine the rearrangement of the environmental charged particles by the reacting charged particles and its influence on the reaction rate. The metal environment for nuclear reactions in matter is one example of such situation. Deuteron induced fusion reactions in metals have been performed to experimentally investigate the interplay between nuclei and their surroundings [2, 3, 4]. According to the authors, the nuclear reaction rates are strongly enhanced by the environments. The enhancement is much larger than that encountered in experiments using gas or solid targets without host material [5, 6, 7]. Furthermore, the enhancement strongly depends on the host material.

We discuss the screening effects on nuclear reactions in matter by taking non-linear effects into account. We respect the quantum effect of electrons, which is ignored in the Debye-Hückel theory and rather requires a quantum treatment such as the Thomas-Fermi approximation [8]. Quantum effects will be important because the experiments are run at room temperatures. Practically, we use the Kohn-Sham equation [9] to analyze the response of electrons to the reacting nuclei in the background of positive ions, which are treated by the jellium model. Comparing the results with those of the linear response theory, we demonstrate the importance of non-linear effects.

Besides nuclear reactions in matter, we also discuss the effects of electron capture by the projectile and the Coulomb explosion of a molecular projectile on the electron screening in low energy nuclear reactions in laboratory [5, 6, 7]. Using the idea of equilibrium charge, we show that the electron capture of projectile leads to a screening energy which significantly exceeds the adiabatic limit in the simple consideration for the D(d,p)T reaction and provides a possibility to explain the large screening energy claimed in the analysis of experimental data. As for the Coulomb explosion, we show that it can result in a large apparent screening energy as large as that encountered in the analysis of $^{3}$He(d,p)$^{4}$He reactions induced by the molecular $D_2^+$ and $D_3^+$ projectiles at very low energies.

References