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Neoclassical Bootstrap Current in High β_p Tokamak Plasmas

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One of the most important predictions of neoclassical transport theory is the existence of bootstrap current. With the advent of advanced tokamak concept, vigorous study of non-inductive current in the past decade has diminished any doubt of its existence. It becomes increasingly evident that an economically feasible steady-state tokamak reactor will rely on the bootstrap effect to drive most of its plasma current. Moreover, it is believed that bootstrap current plays an important role in determining edge stability of the H-mode plasmas. Although various formulas for the bootstrap current coefficients were derived based on approximate analytic theories or exact numerical calculations, their dependence on plasma β's has not been systematically explored. In this work, we wish to point out that the bootstrap current coefficients are decreasing functions of poloidal β(β_p) and have a strong dependence while the plasma is near its equilibrium β_p limit. The large Shafranov shift in a high β_p equilibrium effectively decreases the depth of magnetic well and the inverse aspect ratio ε of a flux surface under consideration, hence, particle trapping effects and bootstrap current. Another important feature of a high β_p equilibrium is weakening of the in-board poloidal magnetic field which makes the field line lingering on the high-field side longer. This in turn reduces collisional coupling between trapped and passing particles, therefore, bootstrap current. To quantitatively demonstrate the effects described above, we make use of the large aspect ratio Hass-Freidberg model equilibrium to calculate the bootstrap current coefficients of the Lorentz gas in the banana regime. It is shown that at the equilibrium β_p limit the edge bootstrap current vanishes in the leading order of $\sqrt{\varepsilon}$. This drastic dependence can be correlated to the appearance of a separatrix at the high-field side of the plasma at the equilibrium limit. Implications of the results obtained for the edge bootstrap current in diverted tokamak plasmas will be discussed.