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Measurements of Correlation-Enhanced Collision Rates[1]

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This talk presents the first detailed experimental measurements of the Salpeter collisional enhancement factor $g(\Gamma)$ in strongly correlated plasmas. This factor is predicted to enhance the nuclear reaction rate in dense strongly-correlated plasmas, such as in giant planet interiors, brown dwarfs and degenerate stars;[3] and recent theory establishes that it also applies to the perpendicular-to-parallel collisions in magnetized plasmas described here.[4] The enhancement is caused by plasma screening of the repulsive Coulomb potential between charges, allowing closer collisions for a given particle energy. The enhancement factor is predicted to be large when the plasma correlation parameter $\Gamma \equiv e^2/aT$ is larger than unity, scaling as $g(\Gamma) \sim e^{\Gamma}$. The perp-to-parallel collision rate is then $\nu_{\perp\|} = n\bar{v}b^2\, I(\bar{\kappa})\, g(\Gamma)$, where $I(\bar{\kappa})$ decreases precipitously below $(8\sqrt{\pi}/15)\ln\Lambda$ in the highly magnetized regime of $\bar{\kappa} \equiv \sqrt{2}\, b/r_c \gg 1$. • Our measurements[5] of $\nu_{\perp\|}$ in Mg^+ pure ion plasmas are consistent with the predicted Salpeter correlation enhancement, with the comparison limited mainly by systematic spatial variations in the plasma temperature. The plasma temperatures are controlled over the range $4 \times 10^{-6} < T < 1$eV, with the outer radii being up to $2\times$ hotter. Bulk-averaged collision rates of $1 < \nu_{\perp\|} < 2 \times 10^4$ sec^{-1} are measured by 2 techniques: for slow collisions, $T_\|$ is heated or cooled, and the subsequent relaxation is directly observed; for rapid collisions, sinusoidal modulation of the plasma length at frequency $f_{\rm mod}$ gives maximal heating when $f_{\rm mod} = \nu_{\perp\|}/2\pi c(\Gamma)$, where $c(\Gamma)$ is the specific heat. Two densities are used, 2.0 and 0.12×10^7 cm^{-3}; the lower density has $\sim 2.5\times$ less correlation at any temperature. Experiments clearly show the expected $\nu_{\perp\|} \propto T^{-3/2}$ regime at high temperatures, and show the strong $I(\bar{\kappa})$ suppression of $\nu_{\perp\|}$ for $b/r_c \gg 1$. At low temperatures and high density, the measured $\nu_{\perp\|}$ is enhanced by up to $g \sim 10^{12}$ over the uncorrelated prediction, consistent with the Salpeter-enhanced prediction. At low (uncorrelated) densities, no enhancement is observed. Future experiments may be able to image "burn fronts" propagating from hot regions to cold regions.

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[2]In collaboration with F. Anderegg, D.H.E. Dubin and T.M. O'Neil.
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