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Physics of neutralization of intense charged particle beam pulses by a background plasma[1]

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Neutralization and focusing of intense charged particle beam pulses by a background plasma forms the basis for a wide range of applications to high energy accelerators and colliders, heavy ion fusion, and astrophysics. From the practical perspective of designing advanced plasma sources for beam neutralization, a robust theory should be able to predict the self-electric and self-magnetic fields during beam propagation through the background plasma. The major scaling relations for the self-electric and self-magnetic fields of intense ion charge bunches propagating through background plasma have been determined taking into account the effects of transients during beam entry into the plasma, the excitation of collective plasma waves, the effects of gas ionization, finite electron temperature, and applied solenoidal and dipole magnetic fields. Accounting for plasma production by gas ionization yields a larger self-magnetic field of the ion beam compared to the case without ionization, and a wake of current density and self-magnetic field perturbations is generated behind the beam pulse. A solenoidal magnetic field can be applied for controlling beam propagation. Making use of theoretical models and advanced numerical simulations, it is shown that even a small applied magnetic field of about 100G can strongly affect beam neutralization. It has also been demonstrated that in the presence of an applied magnetic field the ion beam pulse can excite large-amplitude whistler waves, thereby producing a complex wake structure of plasma density perturbations in the region of the ion beam pulse. The presence of an applied solenoidal magnetic field may also cause a strong enhancement of the radial self-electric field of the beam pulse propagating through the background plasma. If controlled, this physical effect can be used for optimized beam transport over long distances.

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