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Spatial spectrum of quasi-magnetostatic turbulence at the growth, saturation and decay phases of Weibel instability in collisionless plasma

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Evolution of the self-consistent currents and magnetic field is considered for a practically important and quite general case of the purely aperiodic Weibel instability in a collisionless plasma, relativistic or not, in which the particle distribution function exhibits mirror symmetry with respect to a certain plane, and a wave vector of an ordinary wave perturbation is parallel to this plane. In this case, we obtain a practical analytical criterion of the Weibel instability using its similarity with the long-wave soft-mode instability which is well known in solid state physics. By means of analytical methods and computer modeling of the growth, saturation and decay stages of the instability, we describe the main spectral features of the self-consistent magnetic field and current structures originated from chaotic initial perturbations. Our results give a clear interpretation ofand agree with the results of the Weibel instability studies for specific particle distributions, including bi-Maxwellian, power-law, and parallelepipedic, as well as different variants of so-called waterbag distributions [1].

We rigorously compare various known estimates of the magnetic field strength at saturation of the Weibel instability and pay particular attention to the case when its value cannot achieve an equipartition one due to weak anisotropy of the initial particle distribution. In this poorly studied case, a relatively large-scale magnetic field is generated and, during the inverse growth-rate time, most particles follow the diffusive transport law and undergo displacements over many wavelengths of the field. We estimate the number of particles subject to bounce-oscillations in these conditions and come to a general criterion of the saturation of the Weibel instability [1] valid for an arbitrary degree of plasma anisotropy. We show that it accords with previously known analytical and numerical results in the case of rather strong anisotropy as well as with numerical simulations carried out for some examples of the weak anisotropy of particle distribution.

We also give valuable examples on how to use both criterions and to describe the evolution of the spatial spectrum of quasi-magnetostatic turbulence for typical situations in space and laboratory anisotropic collisionless plasmas.

References

1. Kocharovsky V. V., Kocharovsky Vl. V., Martyanov V. Yu., Tarasov S. V., Phys. Uspekhi, 59, 1165 (2016)