Practical criteria for the Weibel instability and its saturation

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We consider the Weibel, purely aperiodic instability in a collisionless plasma, relativistic or not, for the important in practice case when 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 novel analytical criterion for the Weibel instability using its analogy with a long-wavelength soft-mode instability which is well known in the solid state physics. It facilitates an analysis of the Weibel instability and agrees with the results which have been known for the certain particle distributions, including the bi-Maxwellian, power-law, and parallelepiped ones as well as various variants of the so-called waterbag distributions. Also, for a series of the special cylindrically-symmetric particle distributions we find the analytical dependence of the Weibel-instability growth rate on the wavenumber of perturbation and show that it agrees well with the criterion presented [1]. We compare in detail the various known estimates of a magnetic field saturating the Weibel instability and, in particular, point to the case when this field cannot achieve an equipartition value due to a weak anisotropy of the initial particle distribution. In the latter, 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 this field. We estimate a number of particles which are subject to bounce-oscillations under these conditions and come to a general criterion of the saturation of the Weibel instability [1]. We show that it is consistent with the analytical results obtained previously for the case of a strong anisotropy as well as with the numerical simulations carried out for the particular examples of a weak anisotropy of particle distribution. Finally, we present the practical examples of an implementation of both criteria for the typical situations in the space and laboratory collisionless plasmas with anisotropic particle distributions.

References

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