Whistler Mode Waves Guided by Magnetic Flux Tubes in a Magnetoplasma

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It has long been known that whistler mode waves can be guided by ducts consisting of enhancements or depletions of plasma density (see, e.g., [1, 2] and references therein). In contrast to much previous work which focuses on density ducts, there exists very little theory of phenomena caused by the guiding or trapping of whistler mode waves in structures that are formed by variation in other parameters of a magnetoplasma. In this paper, we study the guided propagation of whistler mode waves in a constant-density magnetoplasma containing a cylindrically symmetric nonuniformity of an external axial dc magnetic field. Although the whistler wave guidance by such plasma structures, also called magnetic flux tubes or magnetic field ducts, was considered for the first time long ago (see, e.g., [3]), earlier studies employed various approximate approaches such as the geometrical optics or the WKB approximation. In the present work, which was motivated by the experimental observations of whistler wave propagation in magnetic tubes [4], the full-wave approach is used to analyze the features of whistler wave guidance by a cylindrically symmetric magnetic tube whose radius can be comparable to or less than typical wavelengths of guided modes.

We consider a cold unbounded magnetoplasma in which the magnitude of an external magnetic field $\boldsymbol{B}_0 = B_0\hat{\boldsymbol{z}}_0$ is a function, $B_0(\rho)$, only of distance ρ from the axis of a cylindrical coordinate system (ρ, ϕ, z), taking constant values in inner and outer regions $\rho < a_0$ and $\rho > a$, respectively, and varying smoothly within the magnetic-tube wall $a_0 < \rho < a$. It is shown that such a structure is capable of guiding surface-type modes bound to the tube wall and volume modes trapped in the inner region. The latter ones turn out to be proper eigenmodes or improper leaky modes if the magnetic field inside the tube is enhanced or depressed, respectively, compared to the ambient field. The dispersion properties and field structures of whistler-range modes guided by magnetic flux tubes under conditions of model laboratory experiments are calculated and analyzed. Recommendations on the possible observations of modes of magnetic flux tubes in the laboratory magnetoplasma will also be summarized.

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