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Advection-diffusion equations with sign-varying diffusion

We study the spectrum of the advection-diffusion operator

$$L = -\partial_\theta - \epsilon \partial_\theta (\sin \theta \partial_\theta)$$

subject to the periodic boundary conditions on $[-\pi, \pi]$. We prove that the operator is closed in $L^2_{\rm per}(-\pi, \pi)$ with the domain in $H^1_{\rm per}(-\pi, \pi)$ for $|\epsilon| < 2$, its spectrum consists of an infinite sequence of isolated eigenvalues and the set of corresponding eigenfunctions is complete. By using numerical approximations of eigenvalues and eigenfunctions, we show that all eigenvalues are simple, located on the imaginary axis and the angle between two subsequent eigenfunctions tends to zero for larger eigenvalues. As a result, the complete set of linearly independent eigenfunctions does not form a basis in $L^2_{\rm per}(-\pi, \pi)$.