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# A Direct Approach to Determine the Perpendicular Mean Free Path of Solar Energetic Particles in a Turbulent and Spatially Varying Magnetic Field

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A direct approach to explicitly determine the perpendicular mean free path of solar energetic particles (SEPs) with the influences of parallel diffusion and composite dynamical turbulence in a spatially varying magnetic field is presented. As theoretical applications of the direct approach, we investigate the inherent relations between the perpendicular mean free path and various parameters concerning physical properties of SEPs as well as those of interplanetary conditions such as solar wind and the turbulent magnetic field. Comparisons of the perpendicular mean free paths with and without adiabatic focusing are also presented. The direct method shows encouraging agreement with spacecraft observations, suggesting it is a reliable and useful tool in theoretical investigations and space weather forecasting. In the typical parameter regimes, $\lambda_\perp(r) \propto r^{0.29}$ and $\lambda_\perp(r)/\lambda_\parallel(r) \propto r^{-0.58}$ in the inner heliosphere; $\lambda_\perp(r) \propto r^{0.11}$ and $\lambda_\perp(r)/\lambda_\parallel(r) \propto r^{-0.22}$ in the outer heliosphere. Generally, the ratio $\lambda_\perp/\lambda_\parallel$ is in the range $0.01 - 0.20$. However, when the turbulence strength $\delta B/B$ is sufficiently large, the ratio $\lambda_\perp/\lambda_\parallel$ would approach or exceed unity. The critical value of the turbulence strength $\delta B/B$ for $100$ MeV protons is about $2.34$, beyond which the perpendicular mean free path $\lambda_\perp$ becomes increasingly larger than the parallel mean free path $\lambda_\parallel$.