High Energy Cosmic-ray Diffusion in Molecular Clouds: A Numerical Approach

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The propagation of high-energy cosmic rays through giant molecular clouds constitutes a fundamental process in astronomy and astrophysics. The diffusion of cosmic-rays through these magnetically turbulent environments is often studied through the use of energy-dependent diffusion coefficients, although these are not always well motivated theoretically. Now, however, it is feasible to perform detailed numerical simulations of the diffusion process computationally. While the general problem depends upon both the field structure and particle energy, the analysis may be greatly simplified by dimensionless analysis. That is, for a specified purely turbulent field, the analysis depends almost exclusively on a single parameter -- the ratio of the maximum wavelength of the turbulent field cells to the particle gyration radius. For turbulent magnetic fluctuations superimposed over an underlying uniform magnetic field, particle diffusion depends on a second dimensionless parameter that characterizes the ratio of the turbulent to uniform magnetic field energy densities. We consider both of these possibilities and parametrize our results to provide simple quantitative expressions that suitably characterize the diffusion process within molecular cloud environments. Doing so, we find that the simple scaling laws often invoked by the high-energy astrophysics community to model cosmic-ray diffusion through such regions appear to be fairly robust for the case of a uniform magnetic field with a strong turbulent component, but are only valid up to ~ 50 TeV particle energies for a purely turbulent field. These results have important consequences for the analysis of cosmic-ray processes based on TeV emission spectra associated with dense molecular clouds.

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