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Relaxation current drive in spheromaks as a forward energy cascade requiring sufficient Lundquist number

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The minimum Lundquist number required for relaxation current drive in a spheromak is determined from the results of decaying spheromak simulations performed with the NIMROD code, where S is varied over one order of magnitude. As the spheromak decays, a relaxation event occurs, which is a transition from the initial hollow current configuration to a more uniform current configuration. The Sweet-Parker reconnection time is found to be the governing time scale for relaxation based both on the loss time of the $n = 0$ magnetic energy and the full-width half maximum of the $n = 1$ magnetic energy. For sufficiently high S, poloidal flux generation occurs as a result of relaxation and toroidal current increases. During the transition, energy in the $n = 1$ mode is dominant over higher n modes, but all non-axisymmetric modes decay rapidly toward zero after the relaxation event has occurred. The $n = 1$ distortion is apparent in the flux surfaces during relaxation, but significant regions of closed flux persist throughout the evolution. The NIMROD results can be understood in terms of a cascade of the free magnetic energy while helicity is conserved. The cascade model is described by three simple equations governing the flow of magnetic energy between spatial scales. When these equations are integrated numerically, the $n = 1$ and $n = 0$ energy evolutions closely match the NIRMOD results, supporting the 0-D analytic model as a good description of the 3-D nonlinear dynamics computed with NIMROD.