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Stepwise Evolution of Coronal Magnetic Field Leading to Large Scale Solar Eruption

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The solar magnetic field in and below the photosphere is considered to be composed of filamentary flux tubes. These flux tubes tend to concentrate in the convective cell boundaries, sinks of horizontal flows, where vortices can be generated by any lateral force imbalance. Thus, flux tubes may easily be twisted to form filamentary flux ropes. While staying in or below the photosphere, these filamentary structures are separated by dense plasma. After emerging into the higher atmosphere with low plasma beta, those filamentary magnetic structures come into contact and spontaneously reconnect with each other. If the total magnetic helicity of the system is nonzero, such magnetic reconnection will eventually lead to formation of a large scale flux rope structure. However, the line-tying condition does not allow a direct merging process such as observed in laboratory plasma experiments. Rather, the system stepwise goes through complex intermediate states, which generally involve interwound flux ropes with mutual helicities. These intermediate states evolve into a simpler helical system of a larger scale as mutual helicities transform to self-helicity by magnetic reconnection. Thus, the resulting flux rope has a large winding number and tends to erupt. In this paper, the evolution of an idealized active region, which initially comprises small scale flux tubes, is followed until a large scale erupting flux rope is generated and expelled beyond several solar radii. An observational example supporting our theory will also be presented.