GRAVITY-INDUCED SYMMETRY BREAKING IN CHEMICAL GARDENS

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ABSTRACT

Chemical gardens are hollow precipitates with a plant-like appearance (Figure 1) formed when a metal salt seed is immersed in an alkaline aqueous solution containing silicate, phosphate, or carbonate ions.

Figure 1: Silicate chemical gardens grown under normal gravity conditions. The morphological aspect observed is typical of chemical gardens obtained by the seed growth method.

While interest in chemical gardens was previously restricted mainly to science fair projects, nowadays they have become a hot research topic with direct applications in the development of new materials and technologies and in the understanding of life's emergence on Earth and Mars. Notwithstanding the increasing interest in the formation and growth of chemical gardens under micro and normal gravity conditions, very little is known about the subject. In fact, there are only a few publications [1; 2] in the literature that report the formation and growth of metal silicate precipitates under microgravity conditions. According to these papers, when compared with the precipitates formed under normal gravity, the precipitates obtained in a microgravity environment grow randomly, and their formation is much slower, suggesting that gravity plays an important role in the selection of dissipative structures.

Hence, in this work, the influence of the gravitational field on the formation and growth of chemical gardens formed via the seed growth method is examined through the nonequilibrium sensitivity theory [3; 4]. To this end, the chemical garden is regarded as a chemical system sufficiently far from equilibrium whose spatio-temporal evolution is described by a solution-diffuusion model with reaction. The results obtained from the non-equilibrium sensitivity analysis show that the gravitational field plays a role that goes beyond forming a concentration gradient in the medium. Under microgravity conditions, thermal fluctuations are predominant near the critical point, making the system insensitive to the gravitational field. However, under normal gravity conditions, the strength of the gravitational field is sufficient to favor the upward growth pattern. To quantify these conclusions, the degree of asymmetry between the bifurcating states that emerge as the system passes through a critical point is numerically evaluated. This quantity, also called the non-equilibrium sensitivity of the chemical garden to gravitational fields, indicates that the upward growth pattern will be the most probable dissipative structure as long as the gravitational field magnitude is larger than $\sim 10^{-5}\,\mathrm{m\,s^{-2}}$.

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