Cell motility and swimming: universal description and generic trajectories

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Motility is a key feature of many active systems at microscopic scale. Some living cells can crawl on a substrate or in a 3D matrix. Others can swim in fluids. Non-living microparticles capable of active locomotion have been successfully tested in experiments. Some motile systems have the direction of their motion predefined by their own geometrical features, such as body shape, flagella position, and so on. However, several types of active particles, such as ameoboid cells or autophoretic droplets, are isotropic at rest and the direction of their motion is chosen by a spontaneous symmetry breaking. The autophoretic particles have been observed in experiments to move along several types of trajectories, such as straight, helical, or chaotic. The helical trajectories are usually attributed to the particle asymmetry or the visco-elastic properties of the fluid. Living cells often show chaotic motion, which is often attributed to the out-of-equilibrium nature of the cell dynamics and the amplification of the thermal fluctuations by the cell activity.

Advection–diffusion dynamics in active systems can also show a symmetry breaking instability, in which a homogeneous concentration field becomes unstable and a peak of concentration appears. A rotationally symmetric peak of concentration is stationary but as the activity in the system is increased, the peak can loose its symmetry via a secondary bifurcation. The concentration peak moves along a more or less complex trajectory in this case. An example of such systems is the distribution of myosin motors within the cortex of amoeboid cells, which shows an accumulation at some spot after cell polarization or myosin dynamics in active tissues. Similar dynamics is encountered in a theoretical model of phase field crystals.

The goal of this talk is to present a general theory which describes these bifurcations and the resulting trajectories of active particles or the dynamics of the concentration peaks. The main focus is on the case when the concentration fields at different moments of time can be made identical by an appropriate rotation and translation of the space, what we call self-congruent solutions. It will be shown that such solutions allow straight, circular, or helical trajectories of the particles. It will also be shown how these trajectories can appear through a sequence of pitchfork bifurcations from a stationary solution. Finally, a simple phenomenological model that shows a sequence of transitions from stationary state to straight motion to circular motion and, finally, to helical motion will be presented. Further topics addressed in this talk include the case when the symmetry breaking is described by a Hopf bifurcation and some examples of periodic and chaotic dynamics in such systems. This study shows that the complexity of different motions in several active systems can be captured by a simple phenomenological model without stochastic effects [1,2].

References

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