Asymmetric molecular interactions may hold the secret to living matter

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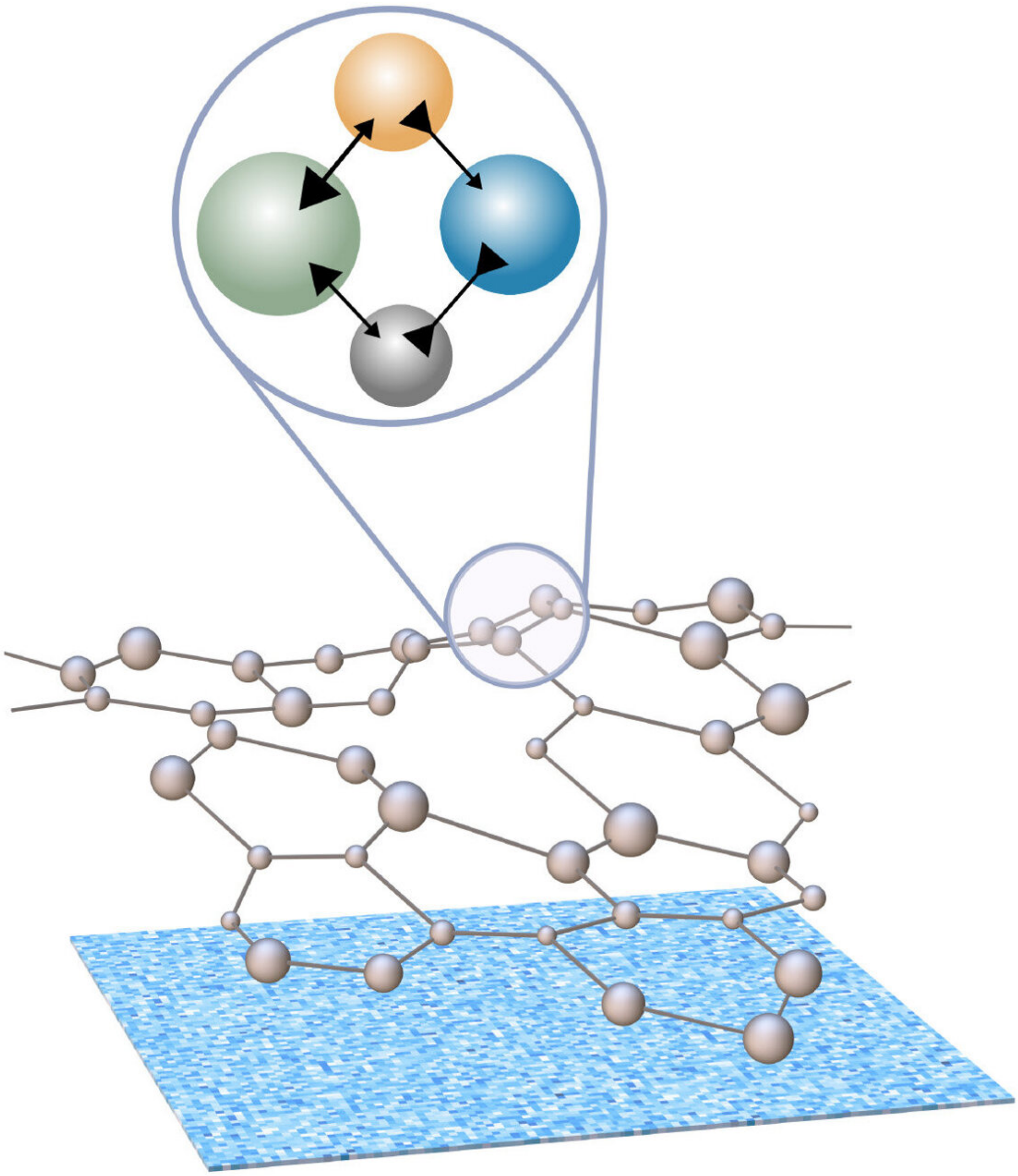

Non-reciprocal interaction networks can induce stability in a biological system and allow it to adopt different activity states. Credit: MPI-DS

Asymmetric interactions between molecules may serve as a stabilizing factor for biological systems. A new model by researchers in the Department of Living Matter Physics at the Max Planck Institute for Dynamics and Self-Organization (MPI-DS) reveals the regulatory role of non-reciprocity.

The scientists aim to understand the physical principles based on which particles and molecules are able to form living beings, and eventually, organisms. The work is published in the journal *Physical Review Letters*.

Most organizations, including companies, societies, or nations, function best when each member carries out their assigned role. Moreover, this efficiency often relies on spatial organization, which arose due to rules or emerged naturally via learning and self-organization. At the microscopic level, cells operate in a similar way, with different components handling specific tasks.

The scientists from MPI-DS aimed to understand how complex biological structures are created in the first place. In their models, they investigate the basic ingredients required for the formation of ordered structures, which are only based on simple interactions between different components.

"In a passive system, random interactions between particles are balanced and lead to the formation of stable patterns," explains Laya Parkavousi, first author of the study.

"However, if we add non-reciprocal interactions to the system, meaning that one particle is attracted by another, which in turn is repelled, we observe activity that can homogenize the mixture," she continues. In other words, non-reciprocal interactions, which were also investigated in previous studies, allow us to control the state of the particle organization.

"By tuning the non-reciprocity, we enable the system to adapt to different states," says Navdeep Rana, shared first author of the study. "These states can be so-called molecular condensates within a cell that are not separated by a membrane or also waves of traveling information that is used in cellular signaling pathways," he explains.

The study thus offers a new route to understanding how complex patterns and structures emerge and how cellular functions can be maintained.

More information: Laya Parkavousi et al, Enhanced Stability and Chaotic Condensates in Multispecies Nonreciprocal Mixtures, *Physical Review Letters* (2025). DOI: 10.1103/PhysRevLett.134.148301

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