Ordering by Motion

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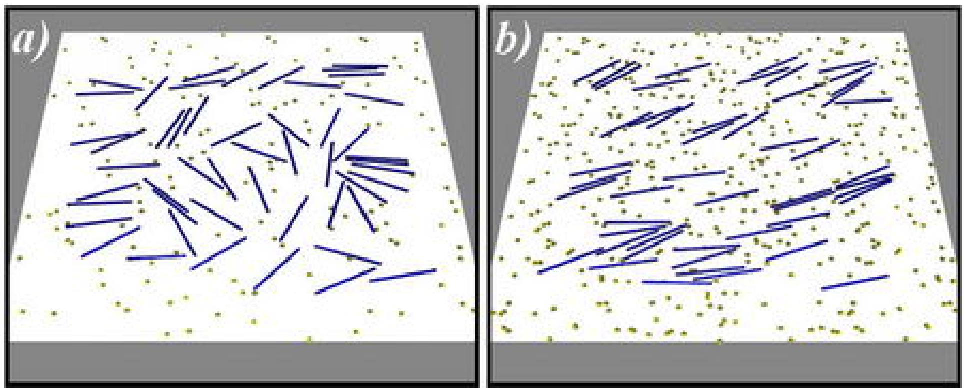

Two snapshots of rodlike filaments (blue) on a surface coated with immobilized molecular motors (yellow). (a) At low motor surface density the filaments display no order. (b) Above a threshold value for the motor density, the filaments spontaneously order into a parallel pattern. This "active nematic ordering" is caused by the interplay of filament collisions and their motor-driven motion. Image: Max Planck Institute of Colloids and Interfaces

The molecules within the living cell sustain a high degree of spatial order even though they are constantly in motion. This seems to defy basic physical principles which stress the strong interplay between motion and disorder. Indeed, the simplest way to increase the motion of molecules is by heating which leads to the melting of crystals and the evaporation of liquids, i.e., to the destruction of spatial order.

Scientists at the Max Planck Institute of Colloids and Interfaces in Potsdam, Germany, have now proposed a simple biomimetic model system for the opposite effect, i.e., for the creation of spatial order by increased molecular motion. This system consists of molecular motors anchored to a substrate surface in contact with an isotropic liquid of cytoskeletal filaments.

As one increases the density of the molecular motors, this liquid is predicted to undergo a phase transition towards a nematic liquid crystal with long-range orientational order. This ordering effect arises from the interplay of motor activity and steric filament interactions, a mechanism that should also be effective for the pattern formation processes in the living cell (*Physical Review Letters* 96, 258103, 30 June 2006).

The cytoskeleton is responsible for the mechanical stability of biological cells and plays an important role in intracellular transport and dynamics. Motor proteins perform directed walks on cytoskeletal filaments and enable fast transport over large intracellular distances along the filament-like 'rails' provided by the cytoskeleton. In addition to their function as nano-tractors, motor proteins are also actively involved in the constant re-organization of the cytoskeleton itself, which is necessary for cell motility and mitosis. During these processes, cytoskeletal filaments are constantly in motion, yet highly ordered structures such as the mitotic spindle are assembled in this dynamic state. In order to understand the principles governing the motor-driven dynamics and dynamic pattern formation by cytoskeletal filaments, researchers have to study biomimetic model systems such as motility assays, which contain only a few ingredients.

In such motility assays molecular motors are attached and immobilized on a surface, over which they pull cytoskeletal filaments. Scientists at the Max Planck Institute of Colloids and Interfaces have now developed a new theory which shows how this pulling motion in combination with collisions between different filaments can give rise to a spontaneous ordering into a parallel arrangement of filaments as demonstrated in a simulation snapshot in Figure 1.

This ordering of filaments into parallel patterns is very similar to the ordering of rod-shaped molecules in the so-called nematic phase of a liquid crystal system, in which the rod-shaped molecules orient in a parallel fashion. But whereas the alignment of molecular rods in a liquid crystal system can only be triggered by increasing the density or the length of rods, the ordering in the motility assay can also be triggered by increasing the density of molecular motors which are moving the filaments. Surprisingly, the motor-driven motion of filaments enhances the tendency to order, which seems to defy basic physical principles according to which the microscopic motion of molecules usually destroys their order; a well-known example is provided by the melting of crystals.

The enhanced tendency of filaments for orientational order in the presence of motor activity is demonstrated in computer simulations as shown in Figure 1. In Figure 1(a), the motor density is low and filaments do not order. In Figure 1(b), only the motor density has been increased and the filaments start to align parallel to each other. This effect can be theoretically explained using the concept of an effective filament length, which is increased by the motor activity: Because motors move filaments along their axis, moving filaments acquire an increased effective length and, therefore, start to interact and align already at lower densities.

This general theoretical concept should also apply to other filament-motor systems. In particular, several experimental studies indicate that also bulk solutions of filaments and motor proteins exhibit an orientational ordering of filaments as a result of motor activity.

Citation: Pavel Kraikivski, Reinhard Lipowsky, and Jan Kierfeld, Enhanced ordering of interacting filaments by molecular motors, *Phys. Rev. Lett.* 96, 258103, (2006) Source: Max Planck Society