Physics

Focus: Particles Sorted by Entropy

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A proposed device improves on past designs and would sort small particles from large ones to a purity of over 99 percent, without any moving parts.

Ordinarily, a mixture of two types of randomly-moving particles doesn't spontaneously unmix. But a newly proposed device relies on random motion to separate particles of different sizes. As explained in *Physical Review Letters*, the device is a tube whose interior walls have a variable diameter with a saw-tooth profile. Although similar "ratchet" shapes have been proposed before, the team has added an external force—coming from an electric field, perhaps—that could be tuned to allow particles of different sizes to emerge from opposite ends of the tube. Simulations suggest that the separation "purity" for sorting DNA strands, for example, could be over 99 percent, which is better than current methods.

Sorting particles by size as they move through a liquid is important in biochemistry to analyze DNA or proteins and also in engineering to generate colloidal solutions with uniform particle size. One separation technique is to let the particles move randomly but inhibit one direction, so that there is a net progression in some other direction. Separation occurs because the strength of this effect depends on the size of the particle. Over the last decade researchers have proposed several separation techniques, many based on ratchetlike geometries ([1] for example). Some of these have been built, but their effectiveness has been limited, says Miguel Rubí of the University of Barcelona in Spain.

Rubí and Peter Hänggi of the University of Augsburg, Germany, led a team that has developed a new approach to these ratchet sorters. They start with a mathematical framework in which the entropy of the system is treated like potential energy, with entropy "barriers" that repel particles. These are regions where particles are restricted to a small space, which reduces the number of states (locations and velocities) that a particle can occupy. Fewer states means lower entropy. Like balls rolling down a hill, particles tend to move away from these low entropy spots.

The team applies this formalism to a tube with walls that periodically ramp from a narrow diameter to a wide diameter and back, with an asymmetric or "sawtooth" profile. This shape forms distinct but still connected chambers, or segments, each of which is a few microns long. Entropic barriers inhibit travel between segments; however, the barriers are steeper going to the left, so the net motion of the particles is to the right.

In order to clearly see the entropic effect in their computer simulation and analytical calculations, the researchers apply an oscillating force that essentially shakes the particles back and forth inside the tube. In a real experiment, this force could be an oscillating electric field.

Their results in two dimensions show that larger particles move faster on average because the entropic barrier is steeper for them and thus better at preventing "backwards" steps to the left. This size-dependent velocity could be used to separate particles (as in [2]), but the authors go a step further and apply a static force (which could be another electric field) pointing to the left.

This force opposes the effective entropic force just enough that small particles move predominantly to the left, while large particles continue to move to the right. “The advantage we have over other separating techniques is that the particles go in different directions,” says Hänggi. The team can also vary the strength of the static force to select for different sizes.

As a demonstration of their entropic splitter, the team ran a simulation mimicking DNA separation. They assumed a tube with 3 segments and introduced a mixture of two lengths of DNA strands that differed in their effective radius by 25 percent. After about a minute, nearly all the strands coming out the left end of the tube were the smaller ones, and those coming from the right end were the larger ones, with a purity of 99.997 percent. This DNA separation is significantly better than the standard lab technique of electrophoresis, which would only achieve about 70 percent under the same conditions, according to Rubí.

By placing molecular dynamics on the “entropy landscape,” this paper opens up completely new options for separation devices, says Jörg Kärger of the University of Leipzig in Germany. However, Fabio Marchesoni from the University of Camerino in Italy wonders whether the applied forces—both static and oscillating—will have the desired effect in cases where the particles have different chemical or geometric properties. “Entropic segregation might well be an option, but at this stage there are still some unknowns to be addressed,” Marchesoni says.

–Michael Schirber

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References

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Highlighted article

Entropic Splitter for Particle Separation

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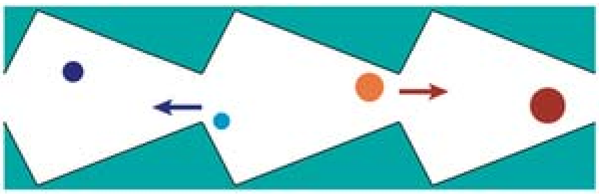
Figures

+Enlarge image 

D. Reguera *et al.*, Phys. Rev. Lett. (2012)

Two-way traffic. On average, small particles in the tube move to the left under the influence of an applied force. But large particles are prevented from going left by the steepness of the walls in that direction and thus move mostly to the right.

More Information

Focus story on ratchet mechanisms from 2010

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