Researchers model how migration of DNA molecules is affected by charge, salt species, and salt concentration

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Only two mechanisms can move molecules in a fluid. They can follow a temperature gradient or an electrical potential. LMU physicists have modeled how migration of DNA molecules is affected by their charge, the salt species, and salt concentration present in the solution.

Thermophoresis is the migration of molecules in a temperature gradient, migration in an electrical field is termed electrophoresis. Each molecular species reacts to these forces in accordance with its physical characteristics, which determine the velocity and direction of its movement. Some congregate where it is warmer, others prefer the cold; some are drawn to the positive, others move toward the negative pole of a field gradient.

The research group led by Dieter Braun, Professor of Systems Biophysics at LMU and a member of the Nanosystems Initiative Munich (NIM), specializes in the investigation of the thermophoresis of biomolecules. Indeed, their work has given rise to a commercial spin-off, which has developed a rapid and economical analytical method for use in the pharmaceutical industry.

In their latest project, Braun and his colleagues have taken a closer look at how DNA molecules behave in temperature gradients set up within aqueous salt solutions, and constructed a theoretical model that allows them to account for this behavior from first principles. "We have combined several theories that have been proposed to describe why and how molecules move along a temperature gradient," explains Maren Reichl, who is first author on the new study. "Their electrical charge, the composition and concentrations of the salts in the solution, and the ambient temperature all play a role in how they move. We have measured the effects of these factors experimentally and compared them with our theoretical predictions."

Interplay of local and global fields

The experiments were carried out in a narrow glass capillary with a diameter of 50 micrometers, filled with a buffered salt solution containing specially designed DNA molecules. A temperature gradient is set up in the solution by heating it locally with a laser. Maren Reichl explains how the behavior of the DNA molecules is detected: "The DNA is labeled with a fluorescent dye, and we use a fluorescence microscope to follow how the DNA migrates away from the heated spot – usually toward cooler regions. The level of fluorescence remaining in the heated spot tells us what fraction of the molecules migrates when we raise the temperature of the irradiated volume by 4 degrees, say. And we record the experiment on video, so we can also measure how fast the molecules move out."

The team found that two factors are primarily responsible for the movement of the molecules. The intrinsic negative charge on each DNA molecule is shielded locally by the positive ions (produced upon dissolution of the added salts) in its immediate vicinity. As a result, an electrical field is generated in the minuscule space between the charged DNA and the counterions surrounding it, which thus acts as a tiny capacitor. The second relevant factor is the global electric field that scales with the temperature gradient. This arises from the so-called Seebeck effect – the tendency of ions in the solution to become concentrated in cooler or warmer regions of the liquid, with positive and negative ions moving in opposite directions. This charge separation generates a potential difference, which also influences the movement of the molecules by inducing electrophoresis.

Based on the interplay of local and global electric fields, one can precisely predict their overall effect on a given molecular species. For instance, DNA molecules tend migrate at slower rates in concentrated salt solutions, because the many free ions in the solution more effectively screen the charge on the DNA strands. DNA also moves more slowly in a sodium fluoride solution than in sodium chloride because the electric field associated with the former species more strongly retards the movement of the DNA molecules.

Professor Dieter Braun summarizes the wider significance of the work as follows: "We have, for the first time, convincingly demonstrated that the non-equilibrium phenomenon of thermophoresis can be predicted on the basis of local thermodynamic equilibria. In the next step, we plan to study how molecules compete for the coveted slots in the cold zone. And, of course, we will address the question of why uncharged molecules migrate at all."

More information: The complete study is available online: journals.aps.org/prl/abstract/ … ysRevLett.112.198101

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