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Heuristic Maximization of BioMotor Nano-Transport

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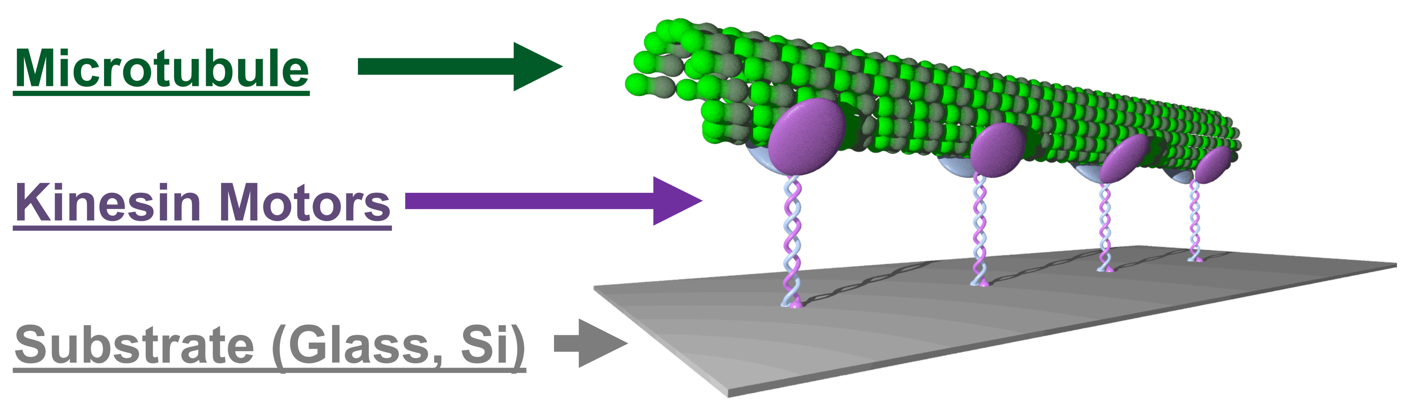
Problem Areas for BioMotor Transport

Reconstitution of molecular motors in minimally engineered systems allows for the active transport of molecular shuttles (microtubules) on two dimensional surfaces. Active transport driven by molecular motors is a bioinspired technology that is central for the continued miniaturization of fluidic systems. In addition to its advantages in energy utilization and systems integration, the motility assay platform is also capable of providing relevant biological insights on transport phenomenon.

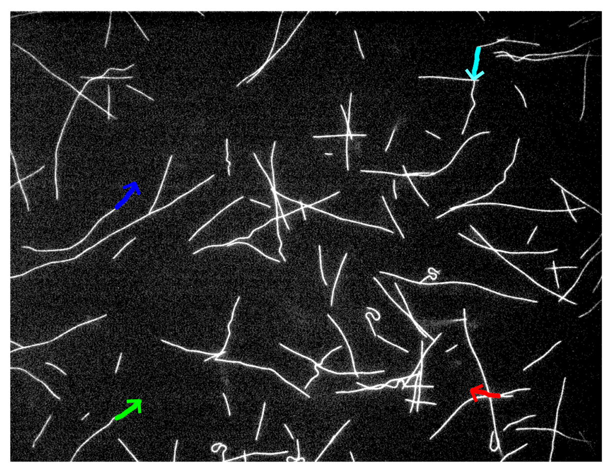


One major limitation arises from the use of molecular shuttles: *they have no on board navigation system and travel with constantly changing path trajectories.*

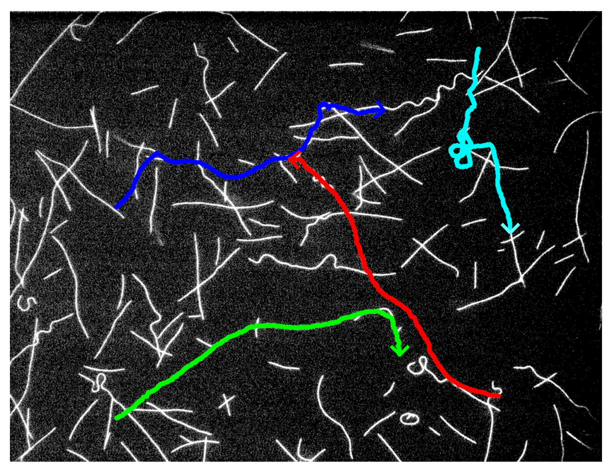
Challenge: Control the random trajectory paths of actively transported molecular shuttles.

Microtubule Shuttle Tracks

Path tracing of microtubule filaments highlights the randomness of active transport.



Leading tip after 2 seconds



Leading tip after 120 seconds

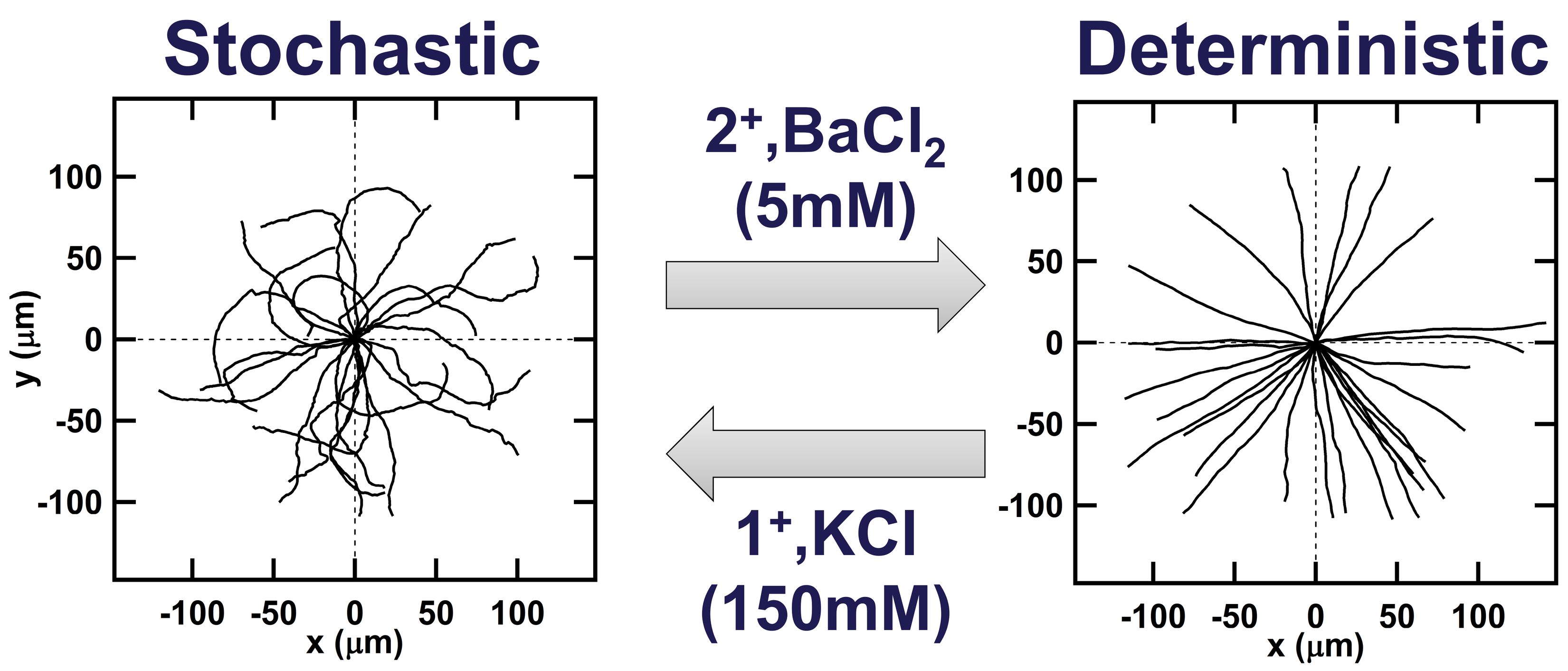
Question: How long would it take for the above filament, highlighted in green, to reach the bottom of the image frame? The answer is specifically unknown due to the stochastic nature of the system.

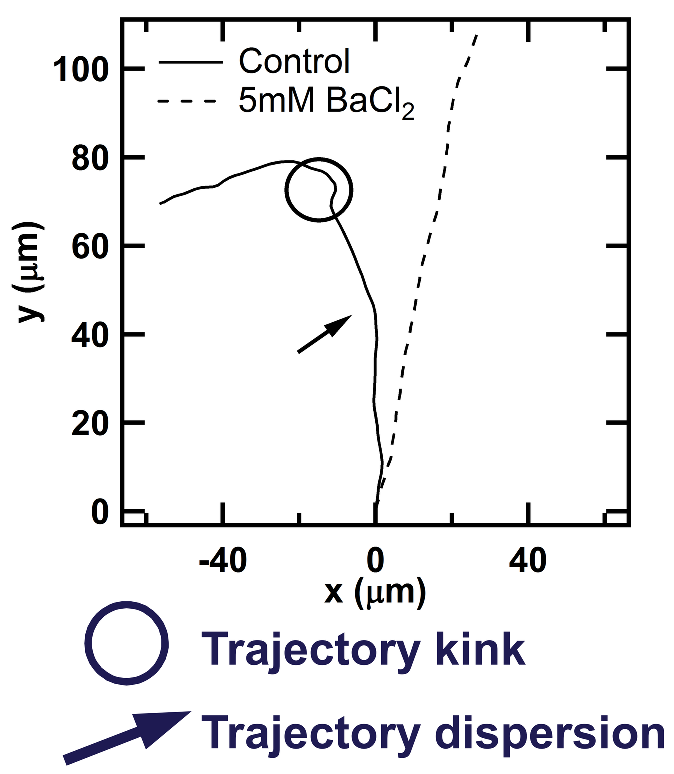
Passive Steering Induced by Electrostatics

The path trajectory of activity transported microtubules in the presences of divalent salts show linear-like trajectories. Common occurrences of path dispersion and kinked directional changes seen in control samples are suppressed in added multivalent salt samples.

Microtubule Shuttle Trajectories

Each line represents the path history of an individual filament normalized to a common origin





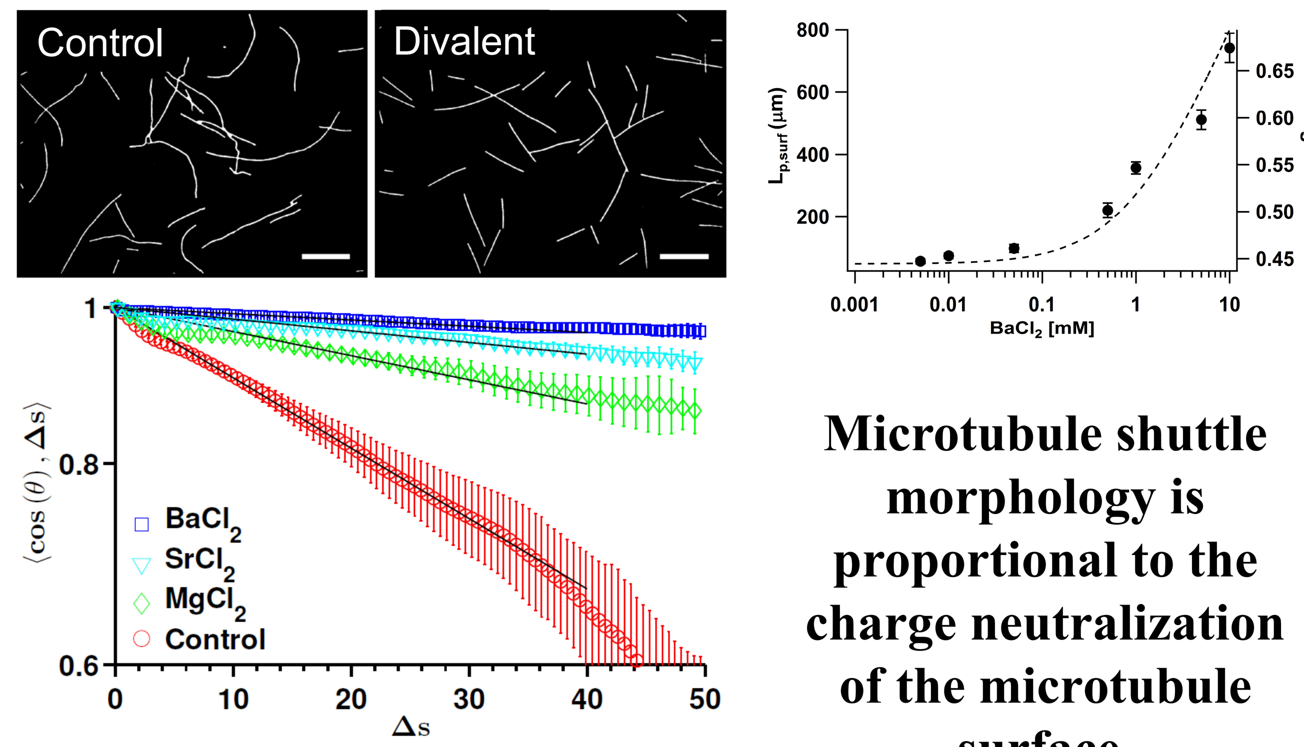
There is a reversible transition between random and controlled motion in the presence of different valence ions.

No applied force is required to trigger the transition, multivalent ions provide a passive steering mechanism and eliminate kinks and dispersion in the trajectory.

Mechanical Property Modification

The correlation length of microtubule shuttles (i.e. surface persistence length, $L_{p,surf}$) increases in the presence of multivalent ions, consequently straightening the filament morphology.

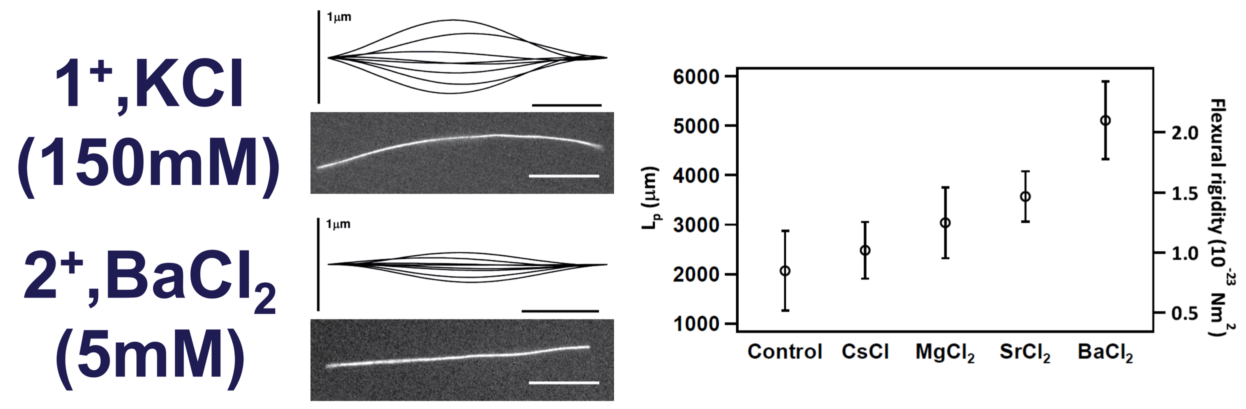
Microtubule Shuttle Correlation Lengths



Microtubule shuttle morphology is proportional to the charge neutralization of the microtubule surface.

$$\langle \cos(\Delta\theta), \Delta s \rangle = \exp\left(-\frac{\Delta s}{2L_{p,\,surf}}\right)$$

Suppression of Thermal Fluctuation



Through an increase in filament stiffness, multivalent ions straighten microtubules. As a consequence, both trajectory dispersion and filament stability can be manipulated by simple buffer exchanges.

Conclusions

In a solution of macro-ions, the interactions are determined by the collective organization of the counterions. Multivalent counterions are especially important in biological self-assembly, particularly in mechanisms such as DNA condensation and filament bundling.

Addition of multivalent ions to the BioMotor transport system maximizes the predictability of path trajectories.

The end goal for nanoscale transport is to move material from point A to point B with minimal external input. Amending the path trajectories of microtubule shuttles to favor deterministic transport aid future development of integrated nanoscale devices that utilize the power generation of molecular motors.

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