

# Ultrasound-Driven Nanoparticle Transport in Polymer Networks: A Molecular Stick-and-Release Mechanism

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The transport of nanoparticles through polymer networks is a central problem in soft matter physics and biomedical applications, from drug delivery in tumors to filtration and sensing. In extracellular-matrix-like hydrogels, nanoparticle motion is often strongly hindered by a combination of steric constraints and transient adhesive interactions with the network. Low-intensity ultrasound has been reported to enhance nanoparticle diffusion in such systems, yet experimental observations remain contradictory [1,2] and the underlying mechanisms are still debated. In this talk, I present a molecular-level study of ultrasound-driven nanoparticle transport in hydrogels using coarse-grained Langevin dynamics simulations [3]. After validating the approach against an exact analytical solution in dilute solution, we systematically investigate diffusion in polymer networks with tunable steric and adhesive interactions. We find that ultrasound does not enhance diffusion in purely steric networks. In contrast, enhancement emerges when nanoparticles interact attractively with the network, where ultrasound reduces particle-polymer contact times via a stick-and-release mechanism. This framework explains why acoustic enhancement is observed only under specific interaction strengths and ultrasound conditions, reconciling conflicting experimental observations.

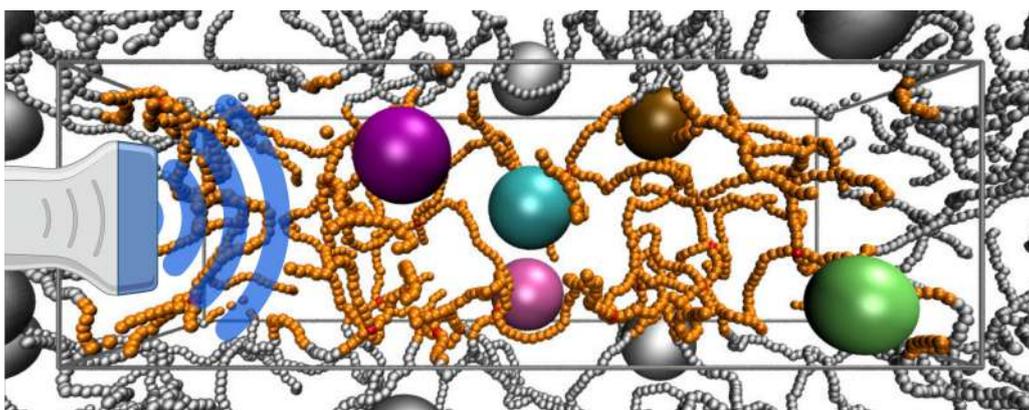


Figure 1: Simulation snapshot of nanoparticles diffusing in a hydrogel under ultrasound, shown for a purely steric network.

[1] C. Einen et al. *Gels* 9 (2023), 9, 771.

[2] D. Ma, J. S. Marshall and J. Wu, *J. Acoust. Soc. Am.* 144(6) (2018) 3496–3502.

[3] P. M. Blanco, H. H. Rønneberg, and R. S. Dias, *JCIS* 704(2) (2026) 2139402.