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The Brownian Scale of Life

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Following my experience in teaching cellular biophysics for students of physics and biology, I propose a sequence of topics that bridge fundamental physics with biological complexity. Beginning with the discovery of Brownian motion, students learn how microscopic random motion reveals the underlying atomistic nature of matter. This naturally leads into discussions on how thermal fluctuations drive the behavior of particles at small scales. This in turn underscores why cell dimensions are optimized for rapid and efficient molecular interactions. Further, the exploration of thermal fluctuations and concepts like Maxwell's demon and the Feynman ratchet shows how biological systems can harness randomness to perform work, providing a vivid example of how energy conversion at the nanoscale differs from macroscopic systems. Finally, applying these ideas to molecular machines such as DNA polymerase and kinesin links theory to function, demonstrating how cells overcome the challenges of Brownian motion to achieve precise and directed movement. Together, this integrated progression—from basic physical principles to their application in biological systems—not only deepens students' understanding of the biophysical foundations of life but also illustrates the strategies that cells employ to operate in a thermally noisy world.