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Diffusive escape through a narrow opening: new insights into a classic problem

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In this talk I overview our recent results [1] on the mean first escape time T of a diffusive particle from a spherical (or a circular) domain enclosed by an impenetrable boundary containing a small escape window. Our settings differ from the classical narrow escape problem in two aspects : First, we introduce explicitly into the model long-range potential interactions of a particle with the boundary, which are always present in realistic situations. Second, we take into account effects of an energy/entropy barrier at the escape window, which were discarded in previous analyses. We develop a self-consistent approximation to derive for T a general expression, akin to the celebrated Collins-Kimball relation in chemical kinetics, which shows that the contibution due to a diffusive search for the escape window and the contribution due to the passage through the escape window are additive. Further on, our analysis reveals that in the true narrow escape limit, where the size of the opening tends to zero, the barrier-induced contribution to T represents the dominant controlling factor such that the narrow escape problem is « barrier-limited » rather than « search-limited ». Next, we analyse the contribution due to diffusive search for the escape window and construct an expansion in powers of the size of the escape window in which the coefficients before the leading terms are expressed as integrals and derivatives of (a rather arbitrary) interaction potential. On example of a triangular-well potential we show that the contribution to T due to diffusive search is non-monotonic with respect to the range of the interaction potential, being minimal for the one having an intermediate extent, neither too concentrated on the boundary nor penetrating too deeply into the bulk. Our analytical predictions are confirmed by numerical simulations.

[1] D. S. Grebenkov and G. Oshanin, Phys. Chem. Chem. Phys. 19, 2723 - 2739 (2017)

Primary author: OSHANIN, Gleb (Laboratoire de Physique Théorique de la Matière Condensée (UMR CNRS 7600) Sorbonne Universités - UPMC, Paris, France)

Co-author: GREBENKOV, Denis (Laboratoire de Physique de la Matiere Condensee Ecole Polytechnique, F-91128 Palaiseau France)

Presenter: OSHANIN, Gleb (Laboratoire de Physique Théorique de la Matière Condensée (UMR CNRS 7600) Sorbonne Universités - UPMC, Paris, France)

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