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Non-exponential relaxation: multiscale or nonlinear phenomenon?

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A distribution of relaxation times results in relaxation describable by formulae more complex than a single decreasing exponential function. A known example is the stretched exponential function

`<b><i>u(t)=exp(-(t/ )<sup> </sup>)</i></b>, (1)`

encountered in systems of very different nature starting from mechanical strain, electric and magnetic polarisation through electronic transitions to photoluminescence [1]. An official report of the National Academy of Sciences of USA calls it a "universal function for slow processes" [2]. The function possesses its inverse Laplace transform that allows one to treat it as a continuous linear combination of purely exponential decays [3]. This kind of behaviour would be, thus, a signature of a set of linear subsystems relaxing in all possible time scales. The corresponding impulse response function (Green's function), i.e. the response of the system to the Dirac's delta-like perturbation, can be obtained in the following way

<i>g(t)=-∂u(t)⁄∂t=t^{α-1}exp(-(t/τ)^α)⁄τ^α</i>. (2)

Noteworthy is a singularity at t = 0 for 0 < &alpha < 1. An experiment providing both the relaxation function and the impulse response, and verifying their relation (eq. (2)), would be an evidence of a multiscale origin of the phenomenon. On the other hand, a non-exponential decay may be described as a relaxation of a single anharmonic element without any recourse to different time scales. An example is a power-law decay <i>u(t)=u₀⁄(1+(δ-1)u₀^{δ-1}Γ(t-t₀))^{1⁄(δ-1)}</i> resulting from the nonlinear differential equation <i>∂u(t)⁄∂t=-Γu^δ</i> that may represent either an anomalous viscous damping or an ordinary damped motion in an anharmonic potential. The amplitude-dependent response functions will be presented and the selected experimental data will be analyzed with both methods of description. Criteria will be proposed to distinguish the multiscale and nonlinear [4] mechanisms of non-exponential decay. A sonic effect of reverberation with continuous and discrete distribution of relaxation times will be used to demonstrate how the ordinary exponential and stretched exponential regimes affect the intelligibility of speech and music.

References

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