On origin of 1/f noise in manganites: memoryless transport against mysterious slow fluctuators

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An alternative explanation of 1/f-noise in manganites is suggested and discussed.

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1. Introduction.
The so-called perovskite manganites, or colossal magneto-resistance manganites [1 2], are materials known as “1/f-noise champions”. For proper references see works [3 4], since just their extremely interesting experimental results stimulated my present communication. Namely, first, observation of very high level of 1/f noise in good bulk crystals (instead of thin films as usually). Second, very weak dependence of this noise (expressed in standard relative units via \( S_R(f)/R^2 \) on temperature in wide from the room one down to 79ºK. At 79ºK transition to strongly non-ohmic regime was

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where \( f_2 \) and \( f_1 \) are upper and lower 1/f-noise frequencies under measurements, and \( N \) is number of fluctuators in the observed volume \( \Omega \approx LA \) (though may be \( \Omega \sim L^3 \) is more reasonable estimate). Comparison of [2] with [1] gives \( N \sim 10^9 \), and thus typical fluctuator takes in a volume with linear size \( l \sim (\Omega/N)^{1/3} \sim 10^{-4} \text{ cm} \) (if not \( l \sim (L^3/N)^{1/3} \sim 2 \cdot 10^{-5} \text{ cm} \)).

Likely, that are too large space regions to be characterized by so small activation energy barriers as \( k_BT \ln (f_2/f_1) \).

4. Alternative interpretation.
The possibility of coexistence of different phases in CMR manganites means that they are materials with “strongly correlated electrons” (see e.g. [1 2] and references in [3 5]). “Strong correlations” (resulting, in particular, from Coulomb interactions and Coulomb blockade) may strongly decrease effective number of free charge carriers, i.e. simultaneously and independently movable ones (see e.g. example in [8]).

The remaining free carriers can be considered from viewpoint of another popular empirical model [3 10]

\[ \frac{S_V(f)}{V^2} = \frac{S_R(f)}{R^2} \approx \frac{4 \cdot 10^{-11}}{f} \]

with \( N \) being number of carriers in the observed volume, and \( \alpha \) called “Hooge constant”. In usual crystal materials, when inelastic lattice (phonon) scattering dominates, \( 10^{-3} \lesssim \alpha \lesssim 10^{-1} \) [3 11]. Taking \( \alpha = 10^{-2} \) for rough comparison of [3] and [1], we have again \( N \sim 10^9 \), but now with movable carriers in the role of “fluctuators”.

The corresponding characteristic length \( l \sim (\Omega/N)^{1/3} \sim 10^{-4} \text{ cm} \) seems, of course, very large. But, nevertheless, it is well compatible with the experimental conductivity,

\[ \sigma = L/RA \approx 2.5 \cdot 10^{-3} \div 2.5 \cdot 10^{-1} \text{ Ohm}^{-1} \text{ cm}^{-1} \]

if we assume that this conductivity is determined by inelastic jumps of carriers between relatively isolated spatial regions (“grains”) with volumes \( \sim \Omega \).

Indeed, if elementary transition through a boundary between neighbor regions take a time \( \sim \tau \), then maximal (saturation) current per one elementary boundary (with area \( \sim l^2 \)) is on order of \( J_{\text{max}} \sim e/\tau \) (the saturation just reflects the “strong correlations”). Then in
ohmic (low-voltage) regime the current must be

\[ J \approx \frac{eU}{k_B T} J_{\text{max}} = \frac{e^2 U}{k_B T \tau}, \]

where \( U \approx V/L \) is potential drop across the boundary. This means, evidently, that ohmic conductivity of such medium obeys estimate

\[ \sigma \sim \frac{e^2}{k_B T \tau} \lesssim \frac{e^2}{\hbar d} \sim 1 \text{ Ohm}^{-1} \cdot \text{cm}^{-1} \]

(due to natural restriction \( \tau \gtrsim \hbar/k_B T \)), which agrees with above experimental values.

5. Free carriers as 1/f-type fluctuators

Specific characteristics of the “grains” are not principally important for low-frequency electric noise produced by the free (movable) carriers. The only principal thing is that the system constantly forgets history of their jumps.

If it is so, then possible fluctuations in amount of charge transport grow with time like most probable amount do, i.e. nearly proportionally to time (for, figuratively speaking, the system without memory can not distinguish between a “norm” of transport events and their “excess” or “1 deficiency”).

This just means that rate of transport (PSD of transport noise and the system’s conductance) undergoes scaleless 1/f-type fluctuations (so that time-averaged rate varies from one experiment to another). In terms of individual carriers, their diffusivities/mobilities have no certain value but fluctuate with 1/f-type spectrum.

First statistical theory of these fluctuations was published in [12, 13] presenting, in particular, clear explanation of the “Hooge constant” (see also [8, 11, 14–16] and references therein).

6. Conclusion.

The essence of the appointed view is that 1/f-noise comes not from hierarchy of long memory times but, in opposite, from absence of long memory at all. Such 1/f-noise is trivially compatible with finiteness of “residence times” of particular carriers in a sample (as well as finiteness of their life-times under generation-recombination processes, etc.). Thus we eliminate both the corresponding farfetched questions [7, 10] and need in mysterious slow “fluctuators” inside the sample.

Unfortunately, inertia of scientific prejudices is so strong that these simple ideas were not assimilate during 30 years after the works [11, 13].

The matter is that transport processes traditionally are thought as “stochastic” ones, in the sense of probability theory, with \textit{a priori} certain (let numerically unknown) rates. But in reality they obey the Hamiltonian dynamics which, as honest considerations do show \[ [8, 11, 14–21] \], always predicts 1/f fluctuations in transport rates. Thus, fundamental quantitative theory of 1/f-noise in manganites requires, first of all, a good Hamiltonian model of charge transport in these materials.

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