From Callen (1951) – an intuitive explanation of *Dissipation-Fluctuation:*

I. INTRODUCTION

THE parameters which characterize a thermodynamic system in equilibrium do not generally have precise values, but undergo spontaneous fluctuations. These thermodynamic parameters are of two classes: the "extensive" parameters,[1] such as the volume or the mole numbers, and the "intensive" parameters[2] or "generalized forces," such as the pressure or chemical potentials.

An equation relating particularly to the fluctuations in voltage (a "generalized force") in linear electrical systems was derived many years ago by Nyquist,[3] and such voltage fluctuations are generally referred to as Nyquist or Johnson "noise." The voltage fluctuations are related, not to the standard thermodynamic parameters of the system, but to the electrical resistance. The Nyquist relation is thus of a form unique in physics, correlating a property of a system in *equilibrium* (i.e., the voltage fluctuations) with a parameter which characterizes an irreversible process (i.e., the electrical resistance). The equation, furthermore, gives not only the mean square fluctuating voltage, but provides, in addition, the frequency spectrum of the fluctuations. The proof of the relation is based on an ingenious union of the second law of thermodynamics and a direct calculation of the fluctuations in a particular simple system (an ideal transmission line).

VIII. CONCLUSION

The generalized Nyquist relation establishes a quantitative correlation between dissipation, as described by the resistance, and certain fluctuations. It seems to be possible to give an intuitive interpretation of such a connection.

A dissipative process may be conveniently considered to involve the interaction of two systems, which we characterize as the "source system" and the "dissipative system." The dissipative system, explicitly considered in Secs. II and III, is necessarily a system with densely distributed energy levels and is capable of absorbing energy when acted upon by a periodic force. The source system is the system which provides this periodic force and which delivers energy to the dissipative system.

Assume the source system to be first isolated from the dissipative system and to be given some internal energy. If the source system is a simple dynamical system, its subsequent dynamics will be periodic (as, for instance, the oscillations of a pendulum or of a polyatomic molecule). The system may be thought of as possessing a sort of internal coherence. If, now, the source system is allowed to act on the dissipative system, this internal coherence is destroyed, the periodic motion vanishes and the energy is sapped away, and the source system is left at last with only the random disordered energy ($\simeq kT$) characteristic of thermal equilibrium. This loss of coherence within the source system may be thought of as being *caused* by the random fluctuations generated by the dissipative system and acting on the source system. The dissipation thus appears as the macroscopic manifestation of the disordering effect of the Nyquist fluctuations and, as such, is necessarily quantitatively correlated with the fluctuations.