6.4. Dissipation in quantum mechanics

No serious problem is presented by the occurrence of friction or dissipation in classical systems. The transition from a discussion of the motion of a free particle under gravity in vacuum to a discussion of the same motion in a viscous medium can be made simply by the inclusion of additional terms in the equation of motion. We recognize, of course, that the mechanical energy of the particle is no longer conserved, but continually decreases as it is degraded to heat, and that the degraded energy plays no further role in the mechanical problem. We also recognize that in a closed dissipative system, with no external force-fields or sources of mechanical energy, all mechanical motion will eventually cease and the coordinates of all the particles take fixed values, their momenta taking zero values.

The situation is quite different in quantum mechanics. If we attempt to construct a dissipative equation of motion, the final state of the system eventually will violate the uncertainty principle. Dissipation is not a process, or concept, which plays any role in the microscopic quantum-mechanical description of a physical system. It is an entirely macroscopic concept, and its relation to quantum mechanics is a statistical relation. If we have, for example, a tuned circuit containing a resistance, the charge q on the capacitor is a perfectly legitimate quantity to use both as a dynamical variable and as one of a pair of canonically conjugate variables associated with the system. We might also regard q as the one interesting observable associated with the system. There are, however, many other pairs of conjugate variables associated with the system, amongst these we may mention the mechanical variables describing the charge carriers and, especially, the variables describing the state of excitation of the lattice modes of the resistive material in the circuit. Collisions couple the one interesting observable to these uninteresting and very numerous lattice variables. The system as a whole possesses a Hamiltonian which is constant in time, and this can be used to obtain the equation of motion for any variable of interest. The motion of the system will consist of a transfer of energy from mode to mode within the system. Energy transferred from the macroscopic, electric mode to the lattice modes is transferred from a single mode to upwards of 10^{20} modes. The probability that this energy will reappear in coherent form in the electric mode is nil in any finite time; the energy is dissipated. The 10^{20} lattice modes supply energy to the electric mode. The probability that this will result in a macroscopic oscillation which can be recognized as such, from the moment of its onset to its final decay, is also nil. This energy transfer is random and unpredictable and leads to noise.

Because the same fundamental microscopic collision processes mediate both the dissipation and the generation of noise, there is a direct connection between the two processes. In the classical limit this leads to Nyquist's Johnson-noise formulae.