Nonequilibrium thermodynamics of electromechanical oscillations of membranes

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Abstract

Biological membranes display transitions close to body temperature, in which enthalpy, thickness, and area change significantly. This has a consequence for both, the mechanical and the electrical properties of membranes. They display nonlinear elastic constants because the membrane is very compressible in its transitions. As a consequence, the membrane is also a nonlinear capacitor. Charging the capacitor leads to a change in capacitance and to a compression of the membrane. This makes it possible to propagate electromechanical waves in biomembranes. The theory behind this is of hydrodynamic nature, i.e., it originates from classical mechanic. However, the constants in the theory are of thermodynamic nature, e.g., the elastic constants. It is somewhat disturbing that one has to use two different languages in order to describe such phenomena.

Here, we present a theory which shows that adiabatic propagation phenomena in membranes can also be understood by solely using nonequilibrium thermodynamics. In the simplest approximation, nonequilibrium thermodynamics is described by Onsager's phenomenological equations that successfully describe irreversible thermodynamic processes. They assume a symmetric coupling matrix between thermodynamic fluxes and forces. It is easily shown that the antisymmetric part of a coupling matrix does not contribute to dissipation. Here, we focus on the antisymmetric contributions which describe isentropic oscillations with well-defined equations of motion. The formalism contains variables that are equivalent to momenta and coefficients that are analogous to inertial mass. We apply this formalism to simple problems with known answers such as an oscillating piston containing an ideal gas, and oscillations in an LC-circuit. One can extend this formalism to other pairs of variables, including chemical systems with oscillations. In isentropic thermodynamic systems all extensive and intensive variables including temperature can display oscillations reminiscent of adiabatic waves. We discuss the possibility of electromechanical oscillations in membranes.

We believe that membranes can carry oscillatory phenomena of all variables. Such phenomena are usually not considered.