Thermodynamics of metabolic energy conversion under muscle load

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The complexity of the metabolic processes at the heart of energy conversion in living organisms is a great obstacle to the development of tractable thermodynamic models of metabolism, which would be based on the definition of a small set of physical parameters. In this talk, we construct such a thermodynamic model and show how it can apply in biomechanics by considering the case of muscle load. We assume that living organisms are dynamical systems experiencing a feedback loop, in the sense that they can be considered as thermodynamic systems subjected to mixed (coupled potentials and fluxes) boundary conditions. These feedback effects give rise to homeostatic mechanisms keeping key physiological parameters such as, e.g., body temperature and osmotic pressure, within specific and narrow ranges. The complex nature of such a kind of systems may be dealt with at the cost of raising the abstract analysis to a higher level, but with the advantage of offering a compact approach that relies on a few generic parameters only. To this purpose, we consider a conversion zone as an equivalent thermodynamic working fluid under mixed boundary conditions. The energy conversion process becomes a combination of "one-to-many" (entropy generating) and "many-to-one" (work producing) processes. We introduce and derive the generalized thermoelastic coefficients of the working fluid equivalent, as well as the metabolic transport coefficients from which we define the metabolic figure of merit. Intrinsic muscle friction dissipates the converted energy during muscle mechanical activity, but the chemical-mechanical coupling also causes a dissipative mechanism, which we call the feedback resistance. We discuss the impact of the feedback resistance on the metabolic energy conversion under muscle load. Finally, our approach allows to give a thermodynamic ground to Hill's widely used muscular operational response theory.

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