NEARLY PERPETUAL MOTION MACHINES OF THE THIRD KIND

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EXTENDED ABSTRACT

It has been stated that certain chains of biological reactions can go to near completion in both directions as needed without any exterior driving force. This claim represents a thermodynamic impossibility. Yet, this impossibility is of a new type not covered by the traditional list of impossibility devices known as perpetual motion machines. Rather, it represents a perpetual motion machine of the third kind (PM3) that becomes impossible only in finite time [1]. At non-vanishing rate the chain of biological reactions above would constitute a finite-time perpetual motion machine.

It turns out however that coexistent equilibrium degrees of freedom represent very low dissipation and can come surprisingly close to PM3 operation. Exactly how this fact is exploited in biological systems will be the subject of the talk.

Many biological processes seem to operate near the PM3 limit. In many cases the location where the free energy dissipation occurs is not even clear. Thus claims of the reversibility of such processes are not surprising. Below we present a number of processes for which the energy dissipation is indeed surprisingly low.

- The molecular motor ATP synthase operates very nearly reversibly [2, 3].
- Myriad crista shapes of the inner mitochondrial membrane are isoergic and interconvert freely [4].
- Lipid composition of *E. coli* adjusts to ambient temperature so the sol-gel phase transition temperature is just below ambient [5]. This brings the sol-gel tran- sition within reach of many local fluctuations, e.g. in pressure or charge.
- Twisting and untwisting DNA mediated by DNA-binding proteins that perform extensive DNA remodeling or distortion are frequent processes. The isothermal enthalpy / entropy compensation that keeps these reactions nearly isoergic is well documented [6,7].

In each of these examples a degree of freedom is kept near equilibrium thereby lowering the associated dissipation needed in changing that degree of freedom. Moving along such neutral degrees of freedom is a nice trick for any control minimizing dissipation. As illustrated in Figure 1, to get the rolling pin from one end of the table to the other, we need only lift one end of the table a bit as the table is flat. General bounds on dissipation in finite time relate such dissipation to the thermodynamic distance traversed [8]. This distance is zero along exactly such equilibrium modes! Our list above serves as a partial argument that living systems sometimes exploit these degrees of freedom to achieve their control of the scenarios needed for life.

Figure 1: An illustration of the energetics along a neutral degree of freedom: the horizontal table. Note that only a very small elevation suffices to make the process go in one direction or the other.

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