Ratchets: Rectifying Brownian motion for transport

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A major reason for the great resurgence of interest in ratchets – broadly, systems capable of rectifying unbiased fluctuations into directed transport – about 10 years ago was for their possible role in explaining the operation of molecular motors such as kinesin. Kinesin contrives to 'walk' along the cytoskeleton, without any external force to bias its motion. A number of 'Brownian motor' ratchet models were proposed to explain how kinesin and other molecular motors such as myosin and the rotary F1-ATPsynthase achieve this transport. Some of these models were of an appealing but speculative nature (Menche & Schimansky-Geier, 2006), others general in scope (Reimann, 2002; Ait-Haddou & Herzog, 2003), while some claimed to reproduce specific experimental results (Derényi & Vicsek, 1998). The lack of detailed information about the motors' conformations and dynamics, however, mean that current efforts to explain their motion are returning to conventional discrete chemical models (Kolomeisky & Fisher, 2007).

The generality of the ratchet concept, however, suggests potential applications in biophysics beyond just molecular motors. A primary task of this poster is to provide a review of general ratchet types and properties. From a theoretical viewpoint, there are two basic classes of ratchets: rocking and flashing. In the rocking ratchet, a periodic zero-mean force is applied to the particle (or variable being modeled as a particle), which in turn is moving in a periodic potential 'landscape'. A flashing, or pulsating, ratchet has no external force but has the potential landscape depending on time. This time dependence could be deterministic or stochastic. Rocking ratchets are the most straightforward to implement in nanotechnology, while pulsating ratchet models are often more suitable for biophysics, being able, for example, to model stochastic switching between chemical states (Reimann, 2002), and are the form most commonly employed in modeling molecular motors. If the particle is moving in a two-dimensional asymmetric potential, like the 'Christmas tree' potential, it is known as a geometric ratchet. Such models beckon comparison with transport in ion channels; this is reinforced by geometric ratchet-like models showing negative resistance in response to an applied force (Cecchi & Magnasco, 1996), an important feature of some ion channels.

All ratchets share the capability of rectifying unbiased fluctuations into directed transport through a breaking of symmetry. This is most commonly the spatial symmetry of the potential, but transport is also achievable by breaking of temporal symmetry. Despite that at a coarse-grained level, the potential is completely flat, particle transport will occur. The direction of transport, however, is often not obvious; indeed, in many ratchets the current direction may completely reverse on the variation of some system parameter. Ratchet models, particularly pulsating models, may also have the particle undergoing Brownian motion; the ratchet may then be called a 'Brownian ratchet' or 'Brownian motor'.

This ratchet phenomenon is sufficiently general and appealing – this directed transport where one might expect none – that it has found, and one might reasonably expect it to find, application in varied areas of biophysics and physics and general. It is hoped that the concepts presented in this review will allow the biophysicist to see phenomena from their own study in this new framework and possibly apply results and ideas from this emerging field.

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