

Editorial

Rise of the (Molecular) Machines

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The underlying goal of all technological innovation is to address issues relating to complex processes that are inefficient, impractical, or impossible to solve *via* manual methods. From an historical perspective, most of our endeavors to do so have focused on the development of tools and machines that function based on static or equilibrium dynamic properties. However, a quick overview of living systems reveals that biological processes rely upon a host of molecular motors that can overcome most of the limitations associated with those designed from a strictly chemical and/or physical understanding. Fittingly, researchers interested in applying molecular solutions to create novel technologies have been steadily developing the molecular materials and tools necessary for the creation of human-made molecular machines over the past few decades [1]. Their contributions have pushed us to the precipice of applications that will revolutionize the way we will need to think about design and engineering in the future [2]. The contributions of a body of this work was recognized when the 2016 Nobel Prize in Chemistry was awarded to Fraser Stoddart, Jean-Pierre Sauvage, and Ben Feringa for *The Design and Synthesis of Molecular Machines* [3].

Molecular machines are loosely defined as synthesized organic molecules that respond to some physical or chemical input causing a change in the molecule. They are categorized based on their functionality or their resemblance to traditional machine counterparts including: motors (cranks), propellers (gyroscopes), switches, shuttles, tweezers, gates, hinges (brakes), walkers, and more. The types of inputs that have typically been used with a molecular machine include, but are not limited to, heat, light, electric currents, pH changes, and basic chemical reactions. The *de novo* creation of a variety of molecular scale tools with the potential to be combined to make functional molecular machines capable of performing a necessary task opens up a whole new world of applications that are currently unrealized *via* more traditional technologies.

Before we let ourselves get too caught up in the fantastical, it is important to keep in perspective the current limitations and just how far we have yet to go with this technology. For a point of comparison, let us consider the biomolecular motors that served in part as an inspiration to the advent of these molecular machines [1]. Native molecular motors in biological systems are capable of performing all of the varied motility requiring functions that are necessary for life and they do so in a highly coordinated fashion. Basically, they

are an assortment of molecular machines that collectively mediate the spatial-temporal tasks of an incomprehensively complex process. While they collectively employ a variety of structural motifs that utilize different forms of energy to drive their motor mechanisms, they also share a lot of commonalities that are essential to performing work. More specifically, biological molecular motors are able to move processively in a directional manner, progressing in a repetitive fashion that is dependent on a supply of energy, but otherwise autonomous. In the context of a living system, these properties generally play out along a solid support, which serves to limit thermal movement, in turn maximizing work and allowing for efficient transfer of energy that when amplified appropriately is conveyed from the molecular to the macroscopic.

In contrast, the majority of our current repertoire of human-designed molecular machines have been devised to perform single-step, reversible oscillations that require the external administration of two different signals to mediate repetitive, static motion. Because of these current limitations, the most promising, immediate applications for molecular machines reside in the disparate fields of microprocessors and drug delivery systems. What the design of these two technologies have in common is the requirement of a switching system that can be toggled between on/off or open/closed to elicit the desired effect. The obvious benefit for a molecular microprocessor is in the physical dimensions of these molecular switches allowing for greater miniaturization and thus capacity per unit area than what is currently achievable with a silicon based microchip. In fact, it is anticipated that the processing speed of molecular microchips should match and then exceed that of their silicon-based counterparts sometime before 2020. As for drug delivery systems, the ability to package a pharmaceutical in a small vesicle containing “closed” molecular channels that can be switched to “open” upon activation *via* an external signal at a specific location and time has many optimistic about the ability to circumvent several of the issues that currently plague administration and distribution of medications in the body.

Even more exciting than these examples that are quickly approaching practical application is the burgeoning advancement of more complex machines that borrow even further on lessons learned from biological molecular motors. Though mostly a novelty, the creation of a molecular car powered by light that can move processively along a surface by Bernard Feringa’s lab, shows that with the right combination of creativity and materials the ability to produce machines to address some of the most difficult problems we face on the molecular scale is at hand. Most importantly, it illustrates that the development and optimization of molecular tools and machines is coming of age and its promise to address the lapses inherent in our traditional technologies opens up a whole new world of possibilities.

References

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