Molecular machines

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Molecular machines are molecules with moving parts that allow them to undergo a mechanical cycle. The smallest of these, which consist of just a few atoms, can be driven to execute directional mechanical cycles by adding or withdrawing components of the bathing solution or by using alternating laser illumination. For these human-designed molecular machines, the key problem currently under study is how to amplify and synchronise their molecular-scale mechanical cycles so that teams of machines can be made to do useful work (Ke 2017).

Living systems, by contrast, have already solved this key engineering problem many times, through relentless natural selection over billions of years. The molecular machines found in living systems still consist of only a few thousand atoms, yet these are able to do useful work, sum up the work-contributions produced by teams of multiple molecular machines and respond predictably to control signals. Excitingly, there is evidently much still to be discovered about their mechanisms and capabilities.

This *Molecular Machines* session in the 2017 IUPAB meeting, and the associated collection of reviews in this Special Issue, showcases some of the best current work on the mechanisms of natural molecular machines, on

engineering and controlling their mechanisms and on molecular teamwork.

Andreas Bausch describes his work on the entrainment of actin filaments in the sliding filament assay and on active remodelling of membranous vesicles by teams of microtubules and motors (Suzuki and Bausch 2017). Zev Bryant is doing spectacular work on re-designing and re-engineering natural molecular motors, opening up new technical possibilities whilst at the same time testing our current understanding of motor mechanism to its limits (Nakamura et al. 2014). The ribosome is a protein machine that makes other protein machines and is arguably the most sophisticated molecular device in the cellular universe. Sarah Adio tracks its mechanical cycle at the single-residue scale (Sharma et al. 2016). Living cells are societies of molecular machines. Lukas Kapitein is seeking to understand and steer inter-machine interactions that control intracellular transport, and he discusses how kinesin motors are sorted into the axons and dendrites of neurons (Franker et al. 2016). Ryota Iino is currently analysing the mechanical cycle of chitinase, a processive molecular machine that moves unidirectionally along crystalline chitin. Finally, Arne Gennerich is doing some of the best current work on the stepping mechanism of cytoplasmic dynein, which hauls cargo rapidly towards the minus ends of microtubules in cells (Nicholas et al. 2015).

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References

- Franker MA, Esteves da Silva M, Tas RP, Tortosa E, Cao Y, Frias CP et al (2016) Three-step model for polarized sorting of KIF17 into dendrites. *Current Biology* : CB 26(13):1705–1712. doi:10.1016/j.cub.2016.04.057

- Ke C (2017) Nanomachines: a light-powered clockwork. *Nat Nanotechnol* 12(6):504–506. doi:[10.1038/nnano.2017.44](https://doi.org/10.1038/nnano.2017.44)
- Nakamura M, Chen L, Howes SC, Schindler TD, Nogales E, Bryant Z (2014) Remote control of myosin and kinesin motors using light-activated gearshifting. *Nat Nanotechnol* 9(9):693–697. doi:[10.1038/nnano.2014.147](https://doi.org/10.1038/nnano.2014.147)
- Nicholas MP, Berger F, Rao L, Brenner S, Cho C, Gennerich A (2015) Cytoplasmic dynein regulates its attachment to microtubules via nucleotide state-switched mechanosensing at multiple AAA domains. *Proc Natl Acad Sci USA* 12:6371–6376
- Sharma H, Adio S, Senyushkina T, Belardinelli R, Peske F, Rodnina MV (2016) Kinetics of spontaneous and EF-G-accelerated rotation of ribosomal subunits. *Cell Rep* 16(8):2187–2196. doi:[10.1016/j.celrep.2016.07.051](https://doi.org/10.1016/j.celrep.2016.07.051)
- Suzuki R, Bausch AR (2017) The emergence and transient behaviour of collective motion in active filament systems. *Nat Commun* 8(1):41. doi:[10.1038/s41467-017-00035-3](https://doi.org/10.1038/s41467-017-00035-3)