New thermodynamic framework for cells

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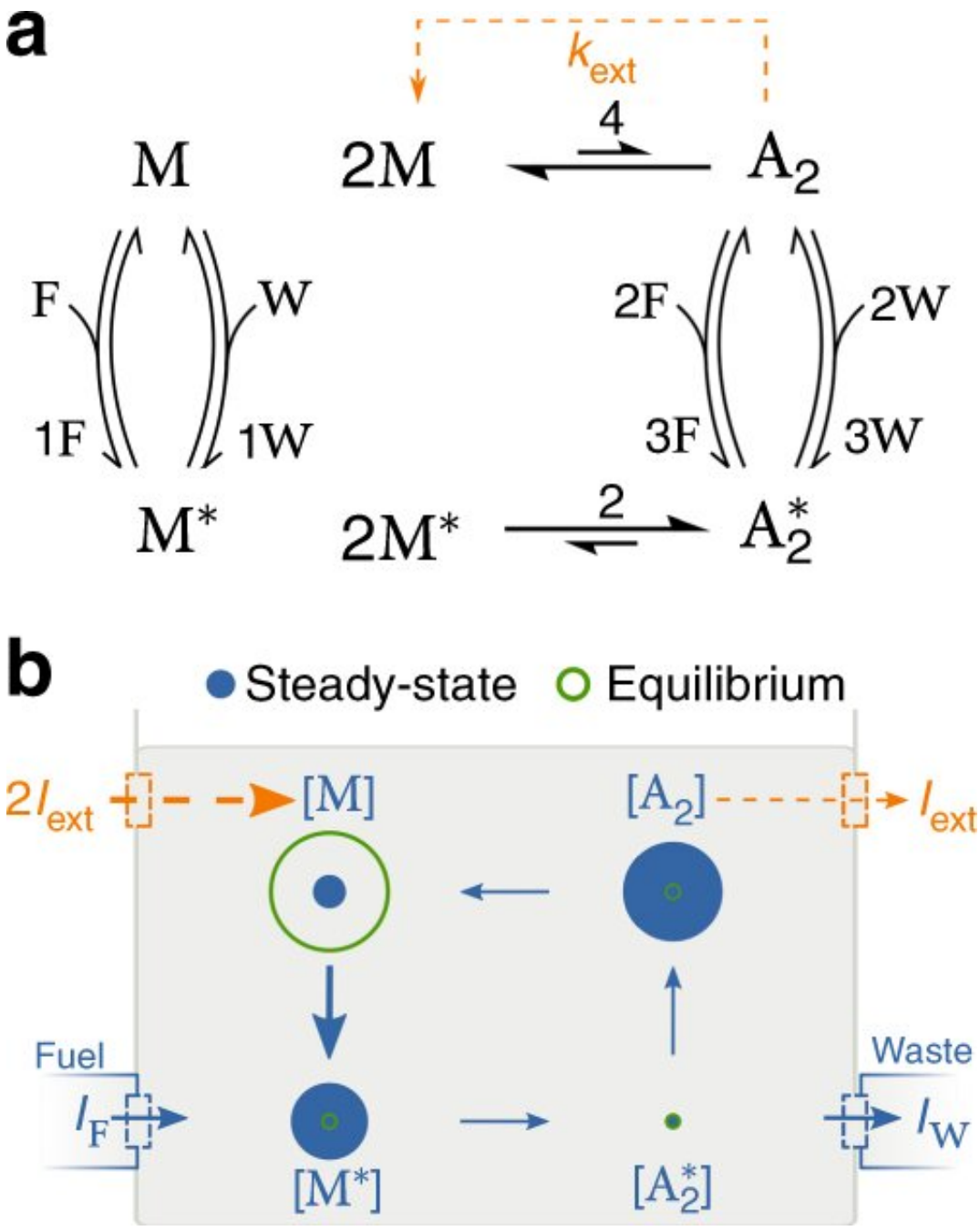

Model for energy storage and driven synthesis. Without (resp. with) the orange dashed transition, the chemical reaction network models energy storage (resp. driven synthesis). The high-energy species A2A2 is at low concentration at equilibrium. Powering the system by chemostatting fuel (FF) and waste (WW) species boosts the formation of A2A2 out of the monomer MM via the activated species M2M2 and A∗2A2∗. a The chemical reaction network (forward fluxes are defined counter-clockwise). Credit: *Nature Communications* (2019). DOI: 10.1038/s41467-019-11676-x

Physicists at the University of Luxembourg have developed theoretical tools to analyze and optimize chemical engines ranging from simple chemical reaction networks to complex metabolic pathways.

The paper, "Thermodynamic efficiency in dissipative chemistry," reports the results of the research conducted by Prof. Massimiliano Esposito, Dr. Riccardo Rao and Ph.D. student Emanuele Penocchio from the Faculty of Science, Technology and Communication at the University of Luxembourg. It was published in *Nature Communications*.

Thermodynamics, the branch of physics dealing with energy conversion and its limitations, originated in an effort to improve the efficiency of mechanical engines such as steam or combustion engines. In standard theory, thermodynamic laws were never applicable to characterizing the performance of small chemical engines such as living cells.

In mechanical engines, maximum efficiency never coincides with maximum power. A car's efficiency varies depending on the speed. If driven fast at full horsepower, the efficiency at maximum power is usually very low.

Things are different in the world of molecules, as Prof. Esposito, Dr. Rao and Mr. Penocchio have discovered. The researchers have

developed a new method to apply principles of thermodynamics to chemical systems. These findings may prove to be helpful in bioengineering or nanotechnology in the future.

The research has taken a step toward evaluating the thermodynamic cost to build and keep a cell working. For example: How much energy in the food consumed by a cell is wasted, and how much is used at the chemical level? The results record conditions in which systems work at maximum efficiency and maximum power simultaneously.

"We usually assume that nature is very efficient thanks to ages of evolution. By quantifying the efficiencies of various chemical operations in different organisms, we may be able to put those kinds of ideas on more solid ground one day, thus contributing to a better understanding of biological systems. This study provides the basis for future performance studies and optimal design in chemistry. We can now answer questions about the efficiency of any operation done by an open chemical system," Prof. Esposito says.

More information: Emanuele Penocchio et al. Thermodynamic efficiency in dissipative chemistry, *Nature Communications* (2019). DOI: 10.1038/s41467-019-11676-x

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