

Peer Review

Review of: "What Is Life: A Biochemist's View"

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We live at a problematic time in the history of the study of life. This is because advances in artificial intelligence (AI) and robotics have made possible the manufacture of physically adept and intelligently behaving non-organic individuals that have nearly all the superficial characteristics of organic beings. Only the inability thus far to reproduce (by manufacture or otherwise) replicas of themselves – an element of nearly all contemporary definitions of life – prevents us from distinguishing intelligent-behaving humanoids from organic humans.

This leaves the author of this brief essay in a quandary. As a biochemist, and as use of terms like “chemical entities,” a living entity “based on carbon chemistry,” “organic life,” and “entities in the metabolic sense,” he clearly signals that his focus is actually restricted to defining the living state as a metabolic state. Yet much of the essay is devoted to describing the capabilities of robots and arguing ultimately how they fail to fulfill the characteristics of the living state in a metabolic sense. This is not necessary once we have accepted his focus as not just on chemistry, but on a specific form of chemistry – namely organic chemistry that extracts and stores energy for organismic maintenance and biosynthesis through stepwise metabolic reactions.

The question then becomes whether, once the arguments about robots, viruses, and sterile animals are removed, there is much substance left. While the essay is minimal and underdeveloped, it does advance a significant idea, and one that is seldom emphasized in the extensive literature on the definition of life: the fact that the living state requires the continual operation of metabolic pathways not far from thermodynamic equilibrium locally but in significant disequilibrium with its external environment, and that this continuity stretches back through the evolutionary history of the living entity's antecedents. The author further elaborates on the open thermodynamic nature of a living (metabolic) system by

pointing out its capacity for self-perpetuation through an ongoing intake of materials and energy which are converted to work, waste, and an increase in entropy, as Figure 1 illustrates. This part of the argument could be strengthened by reference to the Principle of Least Action (Kaila and Annala, 2008) or the related Maximum Entropy Production Principle (Martyushev, 2021). A detailed explanation of how the Second Law of Thermodynamics works in conjunction with these principles of entropy production for the perpetuation of living systems has recently been published (Irwin, 2026).

This is not to say that the need for a definition of the living state (as opposed to “life,” which is simply too all-encompassing) will become increasingly urgent as the distinction between organic organisms and their mechanical analogs becomes indistinguishable. That is a topic that the author of this essay is obviously capable of addressing if the entities under discussion are not restricted to metabolically dependent forms of life. Were he to advocate that metabolism is a *necessary* feature of any concept of a living entity, as he seems to imply here, that would be an interesting argument to make, but he would need to do so in greater depth to counter the alternative definitions that he cites.

Irwin, L.N. 2026. The energy dissipation model of the evolutionary imperative. *Entropy* 28: 948. doi:10.3390/e28090948

Kaila, V.R.I. and A. Annala. 2008. Natural selection for least action. *Proc Royal Soc A* 464: 3055–3070. doi:10.1098/rspa.2008.0178.

Martyushev, L.M. 2021. Maximum entropy production principle: history and current status. *Physics-Uspekhi* 64: 558. [10.3367/UFNe.2020.08.038819](https://doi.org/10.3367/UFNe.2020.08.038819).

Declarations

Potential competing interests: No potential competing interests to declare.