



# In Search of Time Lost: Asymmetry of Time and Irreversibility in Natural Processes

A. L. Kuzemsky<sup>1</sup>

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## Abstract

In this survey, we discuss and analyze foundational issues of the problem of time and its asymmetry from a unified standpoint. Our aim is to discuss concisely the current theories and underlying notions, including interdisciplinary aspects, such as the role of time and temporality in quantum and statistical physics, biology, and cosmology. We compare some sophisticated ideas and approaches for the treatment of the problem of time and its asymmetry by thoroughly considering various aspects of the second law of thermodynamics, nonequilibrium entropy, entropy production, and irreversibility. The concept of irreversibility is discussed carefully and reanalyzed in this connection to clarify the concept of entropy production, which is a marked characteristic of irreversibility. The role of boundary conditions in the distinction between past and future is discussed with attention in this context. The paper also includes a synthesis of past and present research and a survey of methodology. It also analyzes some open questions in the field from a critical perspective.

**Keywords** Asymmetry of time · Irreversibility · Arrow of time · Second law of thermodynamics · Quantum mechanics · Quantum entropy · Entropy production

## 1 Introduction

“The physical world is constituted by changing things” (Bunge and Maynez 1976). Paradoxically, this conclusion follows from an analysis of physical space: “...construction of space involves the notions of event and event composition, and the latter allows one to define a time order of events” (Bunge and Maynez 1976).

The problem of time (Denbigh 1981; Landsberg 1984; ’t Hooft and Vandoren 2015; Anderson 2012, 2017, 2010) is a complicated conceptual problem in various branches of science, and in physics and cosmology in particular. Like the universe, which has many faces (or facets) (Hoyle 1977), time is a many-faceted notion (Denbigh 1981; Horwitz et al. 1988). Entropy, like time, is also a many-faceted concept (Grad 1961). There is an apparent

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**Key words:** Nonequilibrium statistical physics, irreversible processes, method of nonequilibrium statistical operator, equation of evolution, open systems, kinetic equations.  
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