Cyclic Cosmology and the Thermodynamic Origin of the Arrow of Time

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Abstract

We present a cyclic cosmological model in which space, time, and matter emerge from quantized transitions between discrete vacuum states. The central parameter $\eta = E_{\text{pot}}/E_{\text{kin}}$ governs the causal structure of the universe and defines emergent time directions. The observed matter dominance arises from an asymmetric tunneling process, in which "antimatter" remains in the former vacuum state and destabilizes the Higgs potential. The model connects ideas from quantum cosmology, thermodynamic gravity, and timeless dynamics into a coherent framework.

1 Introduction

Standard cosmology describes the expansion of the universe based on the Friedmann equations and an initial singularity. Open problems such as the nature of the Big Bang, the arrow of time, and the observed matter dominance motivate alternative models.

Cyclic approaches (e.g., [1]) attempt to avoid these issues by attributing a recurrence structure to the universe. We present such a model in which the dynamics is described by discrete transitions between vacuum states U_n. Each state is characterized by a global wavelength λ_{U_n}, associated with a potential energy $E_{\text{pot}} \sim \hbar c/\lambda_{U_n}$.

2 Definitions and Structure

Discrete Vacuum States

The universe undergoes transitions $U_0 \to U_1 \to \cdots \to U_n \to U_{n+1}$, where:

- U_d^n: global wavelength / spatial scale of state U_n
- $\lambda_{U_n} \sim U_d^n$

- $E^n_{\text{pot}} = m_P c^2 = \hbar c/\lambda_{U_n}$
- $E_{\text{kin}} \sim \hbar\omega_{\text{vac}}$: vacuum zero-point fluctuations
- $\eta = E_{\text{pot}}/E_{\text{kin}}$: causal state parameter

A transition $U_n \to U_{n+1}$ increases U_d by l_P, corresponding to a Planck energy step.

3 Dynamics of Cyclic Expansion

In the timeless states U_n ($T = 0$), described by the Wheeler-DeWitt equation $\hat{H}\psi_{U_n} = 0$, vacuum fluctuations dominate. A tunneling process enables the transition to U_{n+1}, in which $E_{\text{pot}} \to E_{\text{kin}}$ is converted and space expands:

$$U_d^{n+1} = U_d^n + l_P \tag{1}$$

$$E_{\text{pot}} = m_P c^2 \sim \hbar c/\lambda_{U_n} \tag{2}$$

4 Asymmetry and Antimatter

In Feynman's interpretation, antimatter can be seen as particles moving backward in time. In our model, such components remain in the former state U_n, while matter tunnels forward to U_{n+1}:

$$\psi_{\text{matter}} \sim e^{i\eta}\psi_{U_n} \tag{3}$$

$$\psi_{\text{antimatter}} \sim e^{-i\eta}\psi_{U_n} \tag{4}$$

The remaining antimatter generates a counter-potential that acts back on the Higgs field, destabilizing it and forcing it into a new metastable minimum:

$$V(\phi_{U_n}) \to V'(\phi_{U_n}) \tag{5}$$

Only after this collapse does spontaneous symmetry breaking occur and massive particles emerge.

5 Emergence of Time and Causality

Time is not a fundamental parameter but emerges from the imbalance $\eta > 0$ in the transition $E_{\text{pot}} \to E_{\text{kin}}$. Once the new vacuum is reached, $\eta = 0$, the time direction vanishes, and the universe becomes causally symmetric:

$$\eta = \frac{E_{\text{pot}}}{E_{\text{kin}}} \to 0 \tag{6}$$

$$i\hbar\partial_t\psi = \hat{H}\psi \quad \text{valid only when } \eta > 0 \tag{7}$$

6 Discussion and Outlook

This model connects aspects of cyclic cosmology, thermodynamic gravity [2,3], and quantum timelessness. It explains the arrow of time as an emergent property and offers a consistent interpretation of matter dominance.

Future work will examine connections to observable cosmology (e.g., CMB, entropy scaling) and explore testable predictions of the model.

References

[1] Penrose, R. (2010). *Cycles of Time*. Bodley Head.

[2] Verlinde, E. (2011). *On the origin of gravity and the laws of Newton*. JHEP, 2011(4), 29.

[3] Jacobson, T. (1995). *Thermodynamics of spacetime: The Einstein equation of state*. Phys. Rev. Lett., 75(7), 1260.