Real Consequences of the Reformulation of Time and Mass in Physics: Beyond the Planck Scale

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March 24, 2025

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1 Introduction

This work examines the real consequences of reformulating fundamental physical concepts, particularly time and mass, as presented in my previous studies: *Complementary Extensions of Physics: Absolute Time and Intrinsic Time* (March 24, 2025), *A Model with Absolute Time and Variable Energy: A Detailed Investigation of the Foundations* (March 24, 2025), and *Extensions of Quantum Mechanics through Intrinsic Time* (March 24, 2025). These papers propose alternative frameworks—absolute time with variable mass and a mass-dependent intrinsic time—that challenge conventional interpretations of special relativity and quantum mechanics. Before exploring the implications, it is important to define the limits within which these models are valid: the speed of light ($c_0 \approx 3 \times 10^8\,\text{m/s}$) and the Planck mass ($m_P = \sqrt{\frac{\hbar c_0}{G}} \approx 2.176 \times 10^{-8}\,\text{kg}$) define the domains where these approaches hold. Nevertheless, the conceptual models extend beyond these limits, opening a speculative but physically significant space between the singularity (Planck scale) and the speed of light, as well as masses smaller than the Planck mass. This document highlights the interpretative and practical consequences of these reformulations and emphasizes their potential to transform our understanding of physical reality.

2 Defining the Limits: Speed of Light and Planck Mass

The speed of light c_0 and the Planck mass m_P serve as fundamental constraints in modern physics, marking the domains where the proposed models unfold their validity. The speed of light represents the upper limit of velocity in both the standard model of special relativity (SRT) and the T_0-model with absolute time, ensuring causality and the consistency of space-time interactions. The Planck mass, derived from the fundamental constants ($\hbar$, c_0, and the gravitational constant G), marks the scale at which quantum gravitational effects become significant, typically associated with the Planck time ($t_P = \sqrt{\frac{\hbar G}{c_0^5}} \approx 5.39 \times 10^{-44}\,\text{s}$) and the Planck length ($l_P = \sqrt{\frac{\hbar G}{c_0^3}} \approx 1.616 \times 10^{-35}\,\text{m}$).

Model Definitions

Standard Model of SRT:

- Time dilation: $t' = \gamma t$
- Rest mass constant: $m_0 = \text{const.}$
- Relativistic mass: $m_{rel} = \gamma m_0$
- Energy: $E = m_{rel} c_0^2$

T_0-Model with Absolute Time:

- Time absolute: $T_0 = \text{const.}$
- Variable mass: $m = \gamma m_0$
- Energy: $E = \frac{\hbar}{T_0}$

Modified Schrödinger Equation:

- Intrinsic time: $T = \frac{\hbar}{mc^2}$
- Time evolution: $i\hbar \frac{\partial \psi}{\partial t} = \frac{t}{T} H \psi$

In standard SRT, time dilation ($t' = \gamma t$) and a constant rest mass (m_0) govern relativistic phenomena, whereas in the T_0-model, time remains absolute (T_0) and mass is variable ($m = \gamma m_0$) with energy ($E = \frac{\hbar}{T_0}$). Similarly, the modified Schrödinger equation introduces an intrinsic time ($T = \frac{\hbar}{mc^2}$) that scales the system's evolution with mass. These reformulations are mathematically consistent within the limits of c_0 and m_P, as they reproduce observable phenomena (e.g., GPS corrections, muon decay) equivalently to the standard model. However, their conceptual reach extends beyond these limits, exploring regions near singularities and masses below the Planck mass, where traditional interpretations fail.

3 Beyond the Limits

Despite the defined limits, the proposed models invite exploration beyond c_0 and m_P, creating a theoretical space between the Planck-scale singularity and the speed of light, as well as masses below m_P. This extension arises from the flexibility of the concepts of absolute time (T_0) and intrinsic time

(T):

- **Near the Singularity**: On the Planck scale, where t_P and m_P dominate, the standard model predicts a collapse of the classical space-time continuum due to infinite densities. In contrast, the T_0-model postulates a constant time, allowing mass and energy to scale ($m = \frac{\hbar}{T_0 c_0^2}$) without assuming a variable time. This suggests a finite, albeit extreme, energy state instead of a singularity. - **Sub-Planck Masses**: For masses $m < m_P$, the intrinsic time $T = \frac{\hbar}{mc^2}$ becomes larger than t_P, implying a slower time evolution for lighter particles. This challenges the notion of a universal minimal timescale and opens possibilities for quantum systems below the Planck threshold. - **Speed of Light**: While c_0 remains inviolable, the reformulations shift the focus from time dilation to mass variation, potentially altering the behavior of systems near this limit.

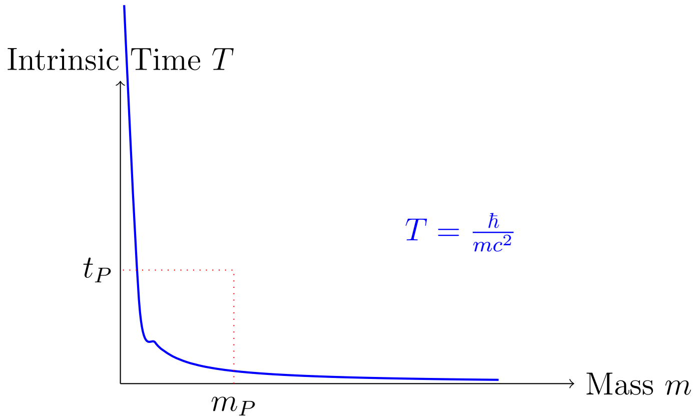

Figure 1: Relationship between mass and intrinsic time. Below the Planck mass (m_P), the intrinsic time (T) becomes larger than the Planck time (t_P).

This speculative domain, though not directly verifiable with current technology, provides a framework to rethink extreme physical conditions.

4 Real Interpretative Consequences

4.1 Cosmological Implications

In cosmology, the standard model interprets redshift as evidence for an expanding universe, driven by time dilation and a fixed rest mass. The T_0-model, however, suggests that redshift could result from energy or mass loss ($E = mc^2$) over a constant time, implying a static or differently evolving universe. For example, the temperature of the cosmic microwave background

(CMB) ($T = 2.725\,\mathrm{K}$) could be viewed as a static field with mass gradients rather than a relic of expansion. This reinterpretation questions the Big Bang singularity, replacing it with a high-energy, massive state at T_0, which could solve problems like the horizon problem without inflation.

Reinterpretation of Cosmological Phenomena

Standard Model:

- Redshift $z = \frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}}$ as a consequence of expansion
- CMB as cooled radiation from the early universe
- Big Bang as initial singularity

T_0-Model:

- Redshift as energy loss $E_2 = E_1(1+z)^{-1}$
- CMB as a static field with mass gradients
- High-energy state instead of a singularity

Testable Predictions:

- Deviations in the redshift-distance relationship
- Anisotropies in the CMB with mass-dependent characteristics
- Altered primordial nucleosynthesis patterns

4.2 Quantum Mechanics and Gravitation

The intrinsic time $T = \frac{\hbar}{mc^2}$ in the modified Schrödinger equation ties quantum evolution to mass, offering a bridge to quantum gravity. For masses near or below m_P, where T exceeds t_P, the slower time evolution could stabilize quantum states and enable coherence in extreme gravitational fields (e.g., near black holes). Conversely, the absolute time of the T_0-model suggests that gravitational effects could arise from energy gradients ($E_{grav} = \sqrt{\frac{\hbar E^5}{G}}$), redefining spacetime curvature as an emergent property of mass variation rather than time distortion.

4.3 Nonlocality in Quantum Physics

A central aspect of quantum physics is nonlocality, as observed in entanglement, often interpreted as "instantaneous" correlations across spatial distances. In the standard model, time is treated relativistically, maintaining the causal structure of light cones, while nonlocality is explained through correlations without signal transmission. True instantaneity would only occur if the Planck mass were zero, which is physically excluded. The T_0-model with absolute time offers an alternative perspective: Since T_0 is constant, entangled states could correlate through mass variation ($m = \gamma m_0$) or energy ($E = \frac{1}{T_0}$) without requiring temporal mediation. The correlations would thus not be "instantaneous" but an expression of mass or energy dynamics.

The modified Schrödinger equation with intrinsic time, in Planck units $T = \frac{1}{m}$ for massive particles, reinforces this view. Since T is mass-dependent, the states of entangled particles evolve at different rates. A particle with smaller mass (larger T) exhibits slower time evolution, implying delays in state changes compared to a heavier partner (smaller T). For example, in an entangled electron-muon pair, the correlation might not be instantaneous but show a measurable delay scaling with $T_e/T_\mu = m_\mu/m_e$. This portrays nonlocality as an emergent property of the mass-time relationship, contradicting the assumption of universal simultaneity. Experimentally, this could be tested through Bell tests with particles of different masses, measuring correlation times to detect mass-dependent delays.

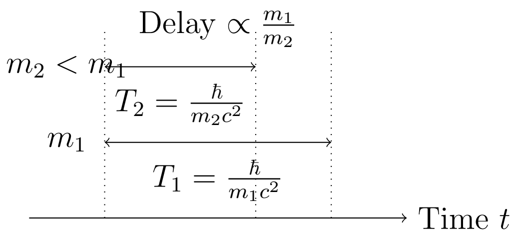

Figure 2: Delayed correlation in entangled particles of different masses. The lighter particle (m_2) evolves more slowly than the heavier one (m_1).

An additional challenge arises for massless particles like the photon ($m = 0$), which only possesses kinetic energy ($E = p$). In the original formulation, $m = 0$ leads to an infinite $T = \frac{1}{m}$, halting time evolution and conflicting with the standard description. Similarly, in the T_0-model, mass variability remains undefined for photons. In Planck units ($\hbar = c_0 = G = 1$), this can be resolved by an extension: $T = \frac{1}{E}$ for massless particles. For a photon with $E = p$, $T = \frac{1}{p}$ corresponds to its wavelength. This simplification eliminates constants, as $T = \frac{\hbar}{mc^2}$ becomes $T = \frac{1}{m}$ and $T = \frac{\hbar}{E}$ becomes $T = \frac{1}{E}$, where $E = m$ for massive and $E = p$ for massless particles. In an entangled system of a photon and a massive particle (e.g., an electron), the correlation depends on $T_{\text{photon}} = \frac{1}{p}$ and $T_e = \frac{1}{m_e}$, implying different delays. A unified time definition $T = \frac{1}{\max(m,E)}$ allows consistent treatment, where m dominates for massive and E for massless particles, and the Schrödinger equation becomes $i\frac{\partial\psi}{\partial(t/T)} = H\psi$, with $H = p$ for photons and $H = -\frac{1}{2m}\nabla^2 + V$ for massive particles. The detailed consequences of this extension for nonlocality in photons, particularly the shift from instantaneous to energy-dependent correlations, are outlined in the separate document *Dynamic Mass of Photons and Its Implications for Nonlocality.*

4.4 Connection to Quantum Field Theory

Quantum field theory (QFT) describes particles as excitations of fields, with time and space as continuous coordinates and the rest mass m_0 remaining invariant. The proposed models have direct implications for this framework. In the T_0-model, time is assumed absolute, and mass varies with energy ($m = \frac{\hbar}{T_0 c_0^2}$). This could mean that field excitations are characterized not by a fixed rest mass but by dynamic energy states scaling with T_0. In QFT, this might require redefining propagators, as the time coordinate no longer varies relativistically, but mass serves as the primary variable. A possible adjustment would be:

$$G(x, T_0) = \int \frac{d^4p}{(2\pi)^4} \frac{e^{-ip\cdot x}}{p^2 - (m(T_0))^2 + i\epsilon},$$

where $m(T_0) = \frac{\hbar}{T_0 c_0^2}$ is a time-independent but energy-dependent mass.

Reformulation of QFT Concepts

Standard QFT:

$$S = \int d^4x \mathcal{L}(\phi, \partial_\mu \phi) \tag{1}$$

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi)(\partial^\mu \phi) - \frac{1}{2}m_0^2\phi^2 - V(\phi) \tag{2}$$

T_0-Model in QFT:

$$S = \int d^3x \int dT_0 \mathcal{L}(\phi, \partial_i \phi, \partial_{T_0}\phi) \tag{3}$$

$$\mathcal{L} = \frac{1}{2}(\partial_i \phi)(\partial^i \phi) - \frac{1}{2}m(T_0)^2\phi^2 - V(\phi) \tag{4}$$

where $m(T_0) = \frac{\hbar}{T_0 c_0^2}$

Modified Feynman Rules:

- Propagator: $G(p) = \frac{i}{p^2 - m(T_0)^2 + i\epsilon}$
- Vertex factor: scales with $m(T_0)$ instead of a constant coupling
- Renormalization: based on mass variation rather than time dilation

The intrinsic time $T = \frac{\hbar}{mc^2}$ of the modified Schrödinger equation implies that each field has its own mass-dependent time evolution. This could extend QFT by assigning a mass-dependent timescale to each field, particularly relevant for describing interactions between particles of different masses. For example, virtual particles in Feynman diagrams might exhibit a T-dependent lifetime, influencing interaction strength and renormalization. This connection to QFT could be tested through simulations or experiments with high-energy particles to identify deviations from standard time dependence.

4.5 Implications for the Big Bang and Black Holes

The reformulations of time and mass have profound implications for interpreting the Big Bang and black holes, two central concepts of modern physics associated with singularities.

Big Bang: In the standard model, the Big Bang is described as a temporal singularity where space, time, and matter emerge from a point of infinite density, followed by rapid expansion (inflation). The T_0-model with absolute time challenges this, as T_0 remains constant and no time dilation occurs. Instead of a temporal singularity, the origin of the universe could be interpreted as a state of extremely high energy and mass ($E = \frac{\hbar}{T_0}$, $m = \frac{\hbar}{T_0 c_0^2}$) evolving over a fixed time. This would weaken the need for expansion, as redshift could be explained as energy loss rather than spatial expansion (see 4.1). The modified Schrödinger equation with $T = \frac{\hbar}{mc^2}$ supports this by introducing mass-dependent time evolution: At extremely high masses near the Planck scale, T would be extremely short, enabling rapid evolution without a classical singularity. This could redefine the Big Bang as a transition from a mass-rich state to a less dense state, verifiable through analyses of the CMB or primordial gravitational waves.

Black Holes: In standard theory, black holes lead to a singularity at the center, where time and space cease to be defined. The T_0-model offers an alternative: Since time remains absolute, the singularity is replaced by a maximal mass and energy concentration ($m = \gamma m_0$) without time collapse. The event horizon could be viewed as the boundary of extreme mass variation, where $E = mc^2$ defines a finite state rather than infinite density. The intrinsic time $T = \frac{\hbar}{mc^2}$ implies that time evolution within a black hole is mass-dependent: At high masses (small T), the dynamics near the center could be extremely fast without requiring a singularity. This might influence the information paradox, as information could be preserved through mass and energy flows rather than lost through time. Experimentally, this could be tested through observations of gravitational waves or Hawking radiation to find evidence of deviations from the standard singularity description.

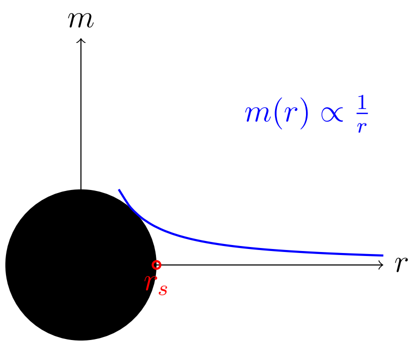

Figure 3: Black hole in the T_0-model: The event horizon (r_s) marks the boundary of extreme mass variation but no singularity at the center.

5 Impact on the Light Cone

The light cone is a central concept of special relativity, defining the causal structure of spacetime, where the speed of light c_0 marks the boundary between reachable (inside the cone) and unreachable (outside the cone) events. The proposed models significantly alter the interpretation and dynamics of the light cone.

In the standard model, the light cone is determined by the Lorentz transformation, where time dilation ($t' = \gamma t$) and length contraction relativistically distort the cone's shape while the rest mass remains constant. The T_0-model with absolute time reverses this: Since T_0 is constant, time dilation is eliminated, and the causal structure is defined by mass and energy variations ($m = \gamma m_0$, $E = \frac{\hbar}{T_0}$). The light cone remains geometrically intact, as c_0 still forms the boundary, but its meaning shifts: Instead of temporal relativity, mass determines the reach of events.

5.1 Reformulation of Causal Structure

In the traditional relativistic interpretation, the light cone defines a boundary between events that can or cannot be causally connected. However, in the T_0-model, this causal structure is no longer manifested through time dilation but through mass variations. For an object with high velocity near c_0, the mass increases ($m = \gamma m_0$), while time remains unchanged, leading to a fundamentally different physical interpretation.

This reinterpretation can be formally expressed through the transformation of the light cone operator:

$$\mathcal{O}_{\text{std}} = c_0^2 t^2 - |\vec{x}|^2 \quad \rightarrow \quad \mathcal{O}_{T_0} = c_0^2 T_0^2 - |\vec{x}|^2 \tag{5}$$

where $\mathcal{O} > 0$ denotes timelike, $\mathcal{O} = 0$ lightlike, and $\mathcal{O} < 0$ spacelike intervals. In the T_0-model, the geometric form of the cone is preserved, but the physical interpretation changes dramatically: The light cone becomes an energy barrier modulated by mass variation.

Concretely, this means that an observer at higher velocity does not experience altered time perception but higher effective mass and energy. This leads to a novel conception of causal connection as a function of energy rather than time, where "future" and "past" are delineated by mass gradients instead of time intervals. In this formulation, causality is determined not by temporal sequences but by energy states, representing a fundamental reversal of the usual relativistic interpretation.

5.2 Dynamic Light Cones in the Intrinsic Time Formulation

The modified Schrödinger equation with intrinsic time $T = \frac{\hbar}{mc^2}$ adds another layer of complexity: Time evolution within the light cone becomes mass-dependent, leading to a dynamic adjustment of the causal structure. This mass dependence can be formally represented by a modified light cone metric:

$$ds^2 = c_0^2 dT^2 - d\vec{x}^2 = c_0^2 \left(\frac{\hbar}{mc^2} \right)^2 dt^2 - d\vec{x}^2 = \frac{\hbar^2}{m^2} dt^2 - d\vec{x}^2 \tag{6}$$

For small masses (large T), the effective time evolution expands, making the light cone appear "wider." This implies that lighter particles could have a more extensive causal reach, while heavier particles exhibit a more compressed causal structure. The mathematical consequence is that the light cone is no longer universal for all particles but is individually scaled:

$$\mathcal{O}_T = \frac{\hbar^2}{m^2} t^2 - |\vec{x}|^2 \tag{7}$$

This mass-dependent scaling leads to several remarkable phenomena:

1. **Mass-Dependent Causality**: Particles of different masses experience different causal structures. Lighter particles could potentially be causally connected to a larger number of events than heavier particles under otherwise identical conditions.

2. **Massless Limit**: For photons ($m = 0$), T formally becomes infinite, conflicting with the standard interpretation of the speed of light as a limit. This requires an extension of the model for massless particles, where $T = \frac{1}{E} = \frac{1}{p}$ can be used for photons, proportional to their wavelength.

3. **Quantum Gravitational Effects**: Near the Planck scale, where $m \approx m_P$, the intrinsic time $T \approx t_P$, hinting at a fundamental entanglement between causal structure and quantum gravitational effects.

5.3 Experimental Consequences

The differing interpretations of the light cone in the proposed models lead to potentially verifiable predictions:

1. **Mass-Dependent Phase Shifts**: In quantum interference experiments, particles of different masses could exhibit different phase shifts due to their varying intrinsic times, measurable through high-precision interferometry.

2. **Mass-Dependent Coherence Times**: The coherence time in quantum systems might scale with $T = \frac{\hbar}{mc^2}$, leading to longer coherence times for lighter particles, verifiable in quantum information experiments.

3. **Gravitational Lensing**: In strong gravitational fields, light deflection might be modified not only by spacetime curvature but also by mass variation, leading to subtle deviations from general relativity.

4. **Novel Causality Effects**: In highly relativistic systems, mass-dependent causal structures could result in unexpected delays or accelerations in signal propagation, measurable through ultra-precise timekeeping.

5.4 Theoretical Extensions

The reformulation of the light cone opens possibilities for theoretical extensions beyond standard relativistic interpretation:

1. **Generalized Lorentz Transformation**: A modified Lorentz transformation accounting for mass variation instead of time dilation could be developed:

$$m' = \gamma m, \quad E' = \gamma E, \quad T_0' = T_0, \quad x' = \gamma(x - vt), \quad t' = t \tag{8}$$

   This would preserve the invariance of the light cone but offer an alternative physical interpretation.

2. **Energy-Dependent Metric**: An energy-dependent metric could be formulated, describing causal structure as a function of local energy gradients rather than spacetime curvature:

$$g_{\mu\nu} = \eta_{\mu\nu} + \kappa \frac{\partial E}{\partial x^\mu} \frac{\partial E}{\partial x^\nu} \tag{9}$$

   where κ is a constant determining the coupling strength.

3. **Extended Causality in Quantum Systems**: The mass-dependent intrinsic time could lead to an extended definition of causality in quantum systems, where causal order is no longer absolute but relative to

the mass of the involved particles. This could be formalized by a generalized operator:

$$\hat{\mathcal{C}} = \mathcal{T} \exp\left(i \int \frac{dt}{T(m)} \hat{H}(t)\right) \tag{10}$$

where $\mathcal{T}$ is the time-ordering operator and $\hat{H}$ is the Hamiltonian.

5.5 Philosophical Reinterpretation of Causality

The reformulation of the light cone leads to profound philosophical implications for our understanding of causality and time:

In the traditional interpretation of special relativity, causal structure is secured by the invariance of the light cone under Lorentz transformations, where time dilation emphasizes the relative nature of time. The T_0-model reverses this perspective by treating time as absolute and mass as variable. This leads to a fundamental reinterpretation of causality, where not temporal sequence but energy states determine causal order.

This energy-based causality suggests that what we perceive as temporal order might be an emergent property of more fundamental energy gradients. In this picture, the "arrow of time" would be given not by the flow of time but by the gradient of mass distribution, consistent with the second law of thermodynamics, as energy dissipation provides a natural direction.

The intrinsic time $T = \frac{\hbar}{mc^2}$ extends this perspective by assigning each particle its own timescale. This leads to a relativized causality, where the causal connection between events is not absolute but relative to the mass of the involved particles. This fragmentation of causal structure challenges the idea of a unified, universal temporal order and suggests a more complex picture where causality is mass-dependent.

Such a reinterpretation could influence our understanding of the arrow of time. While the thermodynamic arrow is given by entropy increase, the causal arrow in this model might be determined by the direction of mass flow or energy dissipation. This would mean that the asymmetry of time is not a fundamental property of spacetime but an emergent property of energy and mass distribution.

Ultimately, this reinterpretation raises a profound question: Is time a fundamental quantity or merely an emergent phenomenon arising from more complex interactions between mass and energy? The proposed models suggest the latter and invite us to rethink our understanding of causality, time, and the fundamental structure of reality.