

Speculation on the Origin of Dark Energy Based on Thermomass Theory

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How to cite this paper: Wu, Z.W., Zhu, H.X., Guo, Z.Y. and Wang, H.D. (2026) Speculation on the Origin of Dark Energy Based on Thermomass Theory. *Journal of Modern Physics*, 17, 755-769.
<https://doi.org/10.4236/jmp.2026.177034>

Received: April 1, 2026

Accepted: July 6, 2026

Published: July 9, 2026

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Abstract

Dark energy accounts for approximately 68% of the total matter-energy content of the known universe and, within the standard cosmological model, is successfully invoked to explain the observed accelerated expansion. Nevertheless, the academic community remains deeply divided regarding the fundamental issue of dark energy's origin, which stands as one of the most significant unresolved problems in cosmology. This paper investigates the origin of dark energy from the perspective of thermomass theory, grounded in the principle of energy conservation. Thermomass theory is an emerging framework in heat transfer that introduces novel physical quantities, including thermomass, thermomass velocity, and thermomass energy. In this framework, thermomass is defined as the mass equivalent associated with the internal energy of a material system, rather than as the relativistic mass increment caused by macroscopic motion. Under terrestrial conditions of temperature, the magnitudes of thermomass and thermomass energy are far smaller than those of rest mass and rest energy. However, in the early universe following the Big Bang, temperatures are thought to have exceeded 1032 K—a regime in which thermomass energy could be comparable to, or even exceeded, rest energy. High-grade forms of energy, such as electrical, optical, and mechanical energy, tend to dissipate into low-grade thermal energy during transfer. Consequently, in the process of heat (thermomass) transfer, the heat (thermomass) is conserved, whereas thermomass energy dissipates into a lower-grade, invisible form of energy. The resulting energy exhibits four characteristics: it permeates the entire universe, possesses extremely low energy density, exerts negative pressure, and accumulates gradually over time. These properties align closely with those attributed to dark energy. Accordingly, we conjecture that the thermomass energy dissipation product may provide a possible thermophysical origin of dark energy. This conjecture offers a new perspective on the connection between irreversible energy-transfer processes and cosmic acceleration.

Keywords

Dark Energy, Thermomass, Thermal Energy, Conservation of Energy

1. Introduction

Throughout history, humanity has maintained a profound interest in the universe, and the exploration of it has never ceased. With the continuous advancement of astronomical observation techniques, our understanding of the universe has deepened considerably. In 1916, Einstein established the theory of general relativity, marking the beginning of a new era in modern cosmology. However, to ensure that the field equations of general relativity described a static universe, Einstein artificially introduced the cosmological constant term on the left-hand side of the equations to counterbalance the tendency for gravitational contraction, thereby formulating a “finite yet boundless static universe model”, in which the universe has a finite volume but lacks a definite boundary due to the curvature of space. In 1929, Hubble determined the relationship between the distances and redshifts of extragalactic nebulae, concluding that the velocity is proportional to the distance, a relation now known as Hubble’s law [1]. This law implies that galaxies farther away from us are receding at faster speeds, a finding clearly inconsistent with the static universe model. After reflection, Einstein consequently abandoned the cosmological constant term. At the end of the 20th century, new insights into the expansion of the universe emerged. Three independent astronomical teams observed the brightness of Type Ia supernovae, which serve as standard candles. Their results showed that these supernovae were dimmer than predicted by a uniformly expanding universe, leading to the proposal that the universe is undergoing accelerated expansion [2]. To corroborate this conclusion, subsequent extensive astronomical observations were conducted, including measurements of the cosmic microwave background (CMB) [3] and large-scale structure (LSS) [4] [5]. Regarding the question of why the universe is accelerating, the prevailing view in the academic community is that the universe contains an additional special component that cannot be directly observed. This component possesses negative pressure and provides a repulsive force that counteracts gravity, and it is termed dark energy. In 2013, the Planck satellite, launched by the European Space Agency to measure the cosmic microwave background, provided precise estimates of the universe’s composition: 4.9% visible matter, 26.8% dark matter, and 68.3% dark energy. Dark energy is not only the primary driver of cosmic acceleration but also plays a decisive role in the future evolution and development of the universe. It is noteworthy, however, that the significance of dark energy becomes apparent only on cosmological scales. Modern physical cosmology calculates the critical density of dark energy required to sustain the accelerated expansion of the universe to be $\rho_c \sim 10^{-29} \text{ g/cm}^3$. Dark matter and dark energy constitute the major components of the universe, yet their energy densities are far lower than those of the familiar

forms of energy we encounter. Current large experimental facilities designed to observe large-scale structure, the cosmic microwave background, and gravitational lensing have not been able to directly uncover evidence for dark energy. Despite the lack of experimental data, modern cosmological models have summarized the fundamental properties of dark energy: it pervades the entire universe, exhibits extremely low energy density, possesses negative pressure, and accumulates gradually over time.

Currently, researchers lack a unified understanding of the origin of dark energy. Among the proposed explanations, the simplest theoretical model is the cosmological constant model [6]. The dark energy equation of state parameter corresponding to the cosmological constant is $w = -1$, which is consistent with current cosmological observations. However, this model also encounters several theoretical challenges, including the fine-tuning problem [7] and the coincidence problem [8]. Vacuum energy is another candidate for explaining the nature of dark energy [9]. This theory posits the existence of a constant energy density in vacuum that pervades the entire universe and becomes dominant. Vacuum energy is physically equivalent to the cosmological constant. In addition, some researchers have proposed introducing a scalar field into the cosmological equation of state to account for the accelerated expansion of the universe [10]. Scalar field theories allow for inhomogeneities in dark energy. When the radiation energy density in the early universe drops below a certain critical value, the scalar field is activated, driving the universe into a phase of accelerated expansion. Another proposal identifies radiation pressure as a potential candidate for dark energy. The radiation pressure equation indicates that the magnitude of radiation pressure is proportional to the fourth power of acceleration, implying that the radiation pressure reaching the edge of the universe could drive its accelerated expansion, thereby aligning with current experimental observations. Beyond these, other hypotheses have emerged in the academic community, such as holographic dark energy and entropic force. Nevertheless, it is evident that none of the current theories of dark energy is fully mature. Some scientists even question whether dark matter and dark energy truly exist, suggesting that they might merely represent contradictions arising from the unconstrained extrapolation of relativistic principles to cosmological scales [11].

Faced with the aforementioned challenges, seeking breakthroughs within the traditional frameworks of particle physics and gravitational theory appears to have reached an impasse. Therefore, exploring interdisciplinary perspectives grounded in different physical principles has become essential. Current mainstream theories predominantly focus on microscopic quantum fields or modifications to gravity at macroscopic scales, potentially overlooking the influence of energy transfer and its dissipation, a ubiquitous physical process, on cosmological scales. In this study, starting from natural phenomena on Earth, we identified a new form of energy based on further exploration of the essence of heat. By connecting this with the evolutionary process of the Big Bang, we propose a conjecture regarding the origin of dark energy. Specifically, through an analogy between heat conduction and elec-

tric conduction, and based on Einstein's mass-energy equivalence, this study introduces the concepts of thermomass and thermomass energy. The former represents relativistic mass, while the latter represents relativistic energy, constituting a new form of energy. This reveals the energy-mass duality of heat, establishes a series of new physical quantities in heat transfer, and develops corresponding analytical principles [12]-[16]. In irreversible heat transfer processes, heat (thermomass) is conserved, whereas thermomass energy is not conserved due to dissipation [17] [18]. Different forms of energy may be characterized by different energy grades. During irreversible transfer processes, higher-grade energy may be degraded into lower-grade and less recoverable forms. Within the framework of thermomass theory, thermomass energy is therefore expected to dissipate into a lower-grade form of energy during irreversible heat transfer. Hereafter, this hypothetical low-grade and diffuse energy form is referred to as the "thermomass energy dissipation product". We further conjecture that, on cosmological scales, this thermomass energy dissipation product may be physically associated with dark energy and may provide a possible thermophysical perspective for understanding its origin.

2. Thermomass and Thermomass Energy

Einstein gave the famous mass-energy relationship in his theory of relativity:

$$E = Mc^2 = \frac{M_0 c^2}{\sqrt{1-u^2/c^2}} \approx M_0 c^2 + \frac{1}{2} M_0 u^2, (u \ll c). \quad (1)$$

In this framework, E , M , and c denote energy, mass, and the speed of light in vacuum, respectively, while M_0 and u represent the rest mass of a substance and its velocity. The total mass of an object is the sum of its rest mass and its relativistic mass, and the total energy of the substance is the sum of the energy associated with its rest mass and its relativistic energy. Similarly, in addition to the macroscopic motion of objects, the total mechanical energy of the irregular thermal motion of a large number of particles that make up the material (*i.e.*, the internal energy of the material) also corresponds to a certain relative mass. Therefore, M_h is defined as the equivalent mass of material internal energy (referred to as thermomass):

$$M_h = \frac{E_h}{c^2}. \quad (2)$$

Here, E_h represents the thermal energy of the substance. The thermomass M_h is the relativistic mass corresponding to the internal energy and has the unit of mass (kg). Because internal energy possesses relativistic mass, an increase in the temperature of an object leads to a slight increase in its mass (weight) [19]. The thermomass is attached to rest mass material, the thermomass gas can be considered as the main carrier of heat conduction and the carrier of heat transfer [20]. Similar to phonons defined by the quantization of lattice vibration energy in dielectric materials, a large number of phonons form a phonon gas. In gases and metals,

thermions can be defined based on the energy of irregularly moving molecules and electrons, and a large number of irregularly moving thermions form a thermon gas. In heat conduction, the rest mass material can be considered the skeleton, within which the thermodynamic gas undergoes directional motion, thereby forming heat flow. Different materials, such as gases, metals, and dielectrics, exhibit distinct relationships between the pressure of the thermon gas and temperature, known as the equation of state for the thermon gas. In dielectric materials, the equation of state for the thermon gas in solids can be derived from the Debye model as follows:

$$P_h = \gamma \frac{\partial E_{D0}}{\partial V} = \gamma \rho_h CT = \frac{\gamma \rho}{c^2} C^2 T^2. \quad (3)$$

In this equation, P_h denotes the pressure of the thermomass, with units of Pa. $\rho_h = \rho CT / c^2$ is the density of the thermomass, with units of kg/m³. C , ρ , and T represent the specific heat, density, and temperature of the rest mass material, respectively. And γ is the Grüneisen parameter of the material.

During heat transfer, when the heat flux is extremely high or the heating pulse is extremely short, the inertial effect of thermomass becomes nonnegligible, leading to non-Fourier heat conduction phenomena. The conservation of heat and the occurrence of non-Fourier heat conduction during the transfer process reveal the energy-mass duality of heat: heat exhibits energy characteristics during conversion into other forms of energy, while it exhibits mass characteristics during the transfer process. The thermomass theory equates the heat conduction process to the motion of thermomass, allowing the application of fluid mechanics to describe the laws of heat transfer (the motion of thermomass) and to derive a general heat conduction equation. From Equation (3), it can be observed that the pressure of the thermomass is proportional to the square of the temperature; thus, a temperature difference gives rise to a pressure gradient of the thermomass, which drives the motion of the thermon gas in porous media, forming heat flow. Compared with the rest mass of an object, the thermomass is extremely small, and both the thermomass pressure and its gradient are correspondingly minute, making their effects typically difficult to detect. The pressure gradient of the thermomass serves as the driving force for heat transfer:

$$\frac{q}{c^2} = \rho_h u_h = \frac{\rho CT}{c^2} u_h. \quad (4)$$

Here, u_h denotes the migration velocity of the thermon gas, with units of m/s. The heat flux q is essentially the thermomass flow rate of the thermon gas, meaning that the nature of heat flow can be understood as the directional motion of the thermon gas. By employing the analytical methods of fluid mechanics, the mass and momentum conservation equations for the thermodynamic gas can be formulated as follows:

$$\frac{\partial \rho_h}{\partial t} + \nabla \cdot (\rho_h u_h) = 0. \quad (5)$$

$$\rho_h \frac{d}{dt}(\rho_h u_h) + \nabla P_h + f_h = 0. \quad (6)$$

In this equation, f_h represents the resistance term for thermomass motion. The expression for this resistance can be derived from Darcy's law for fluid flow in porous media, yielding $f_h = u_h 2\gamma c^2 \rho_h^2 C / \lambda$. Under one-dimensional conditions, the momentum conservation equation for the thermomass gas reduces to the following form:

$$\tau_h \left(\frac{\partial q}{\partial t} - \frac{q}{T} \frac{\partial T}{\partial t} + \frac{q}{\rho C T} \frac{\partial q}{\partial x} - \frac{q^2}{\rho C T^2} \frac{\partial T}{\partial x} \right) + \lambda \frac{\partial T}{\partial x} + q = 0. \quad (7)$$

Here, λ is the thermal conductivity of the material, and $\tau_h = \lambda / 2\gamma \rho C^2 T$ is the relaxation time for thermomass motion, with units of time (s). Equation (7) is also referred to as the general heat conduction equation [21]. The mass-energy relation and the analytical methods of fluid mechanics are not constrained by the specific form of energy or the transfer process. Consequently, the general heat conduction equation established on this foundation differs markedly from heat conduction theories based on empirical approaches such as Fourier's law, avoiding physical paradoxes such as negative temperatures or infinite thermal disturbance velocities. It is applicable to thermal analysis and design under various extreme heat conduction conditions, including nanomaterials, ultrafast heating, and extremely high heat flux densities.

In Equation (7), the first two terms inside the parentheses on the left-hand side are referred to as the temporal inertial terms, while the latter two terms are called the spatial inertial terms. If both the temporal and spatial inertial terms in Equation (7) are neglected, it reduces to the classical Fourier heat conduction equation:

$$\lambda \frac{dT}{dx} + q = 0. \quad (8)$$

This also demonstrates that the thermal mass theory is compatible with existing thermal wave models and the Fourier heat conduction model, revealing that the physical essence of the Fourier heat conduction equation is a balance equation between the driving force and the resistance of thermal gas under the condition where the inertial effect of thermal mass is neglected.

Because temperatures achievable on Earth are not extremely high, the thermomass within an object is very small, making it impossible to verify the existence of thermomass through direct measurement. However, under conditions of extremely high heat flux density in nanomaterials, non-Fourier heat conduction arises due to the inertial effect of thermomass. Thus, the presence of thermomass can be indirectly demonstrated by measuring non-Fourier heat conduction effects. We fabricated gold nanowires with a thickness of 76 nm, a width of 300 nm, and a length of 10 μm , and placed them in a cryogenic environment at 3 K with an applied electric current, achieving a maximum heat flux density of 1.83×10^{10} W/m². The measured average temperature of the gold nanowires was approximately 20 K higher than the value predicted by Fourier's law, indicating a clear non-Fourier heat conduction phenomenon. This effect, attributed to the spatial

inertial effect of the thermomass gas, provides indirect evidence for the validity of the thermomass theory [22].

As a form of relativistic mass, thermomass possesses potential energy when placed in a field and kinetic energy when in motion, analogous to rest mass. For a substance at temperature T with specific heat C and rest mass M_0 , the thermomass is given by $M_h = M_0 CT / 2c^2$. Similar to rest mass M_0 , the potential energy of the relativistic mass M_h in a temperature field can be calculated as follows.

$$E_{hp} = M_h CT = \frac{E_{D0}}{2c^2} CT = \frac{M_h CT}{2c^2} CT. \quad (9)$$

where the subscript p denotes potential energy. Similarly, the kinetic energy of the relativistic mass M_h is given by:

$$E_{hk} = \frac{M_h u_h^2}{2} = \frac{E_{D0} u_h^2}{2c^2} = \frac{M_0 CT u_h^2}{2c^2}. \quad (10)$$

where the subscript k denotes kinetic energy, and E_h has units of energy (J). Both E_{hp} and E_{hk} are relativistic energies and can be converted into each other. This is entirely analogous to water flow in a gravitational field: as water flows from a higher elevation to a lower one, its potential energy decreases while its kinetic energy increases, and the total energy of the water remains conserved. When thermomass moves in a thermal field with a temperature gradient, its potential energy decreases and its kinetic energy increases; under reversible conditions, the total thermomass energy remains conserved.

According to the principle of energy conservation, the following analogy can be drawn. Electric charge transport is accompanied by electrical energy transport, during which the electric charge is conserved, while the electrical energy is not conserved, but dissipated into heat. Mass transport is accompanied by mechanical energy transport, during which mass is conserved while mechanical energy is not conserved, but dissipated into heat. By analogy, during heat transfer, thermomass is conserved while thermomass energy is not; the dissipation of thermomass energy inevitably gives rise to another new form of energy with a lower grade than thermomass energy. On Earth, the absolute magnitude of thermomass energy is extremely small, and the corresponding dissipation product is therefore difficult to identify or measure directly. However, on cosmological scales, especially during the high-temperature and highly nonequilibrium stages of cosmic evolution, heat transfer and energy conversion processes driven by temperature nonuniformities may have generated a much larger cumulative amount of such dissipation products. We therefore conjecture that the thermomass energy dissipation product may be physically associated with cosmological dark energy.

3. The Big Bang Theory and Thermomass Energy Dissipation

Although the thermomass and thermomass energy on Earth's surface are orders of magnitude smaller than their rest mass and rest energy counterparts, when we shift our focus to the cosmic scale, during the early stages of the universe's for-

mation, the thermomass and thermomass energy could have been comparable to, or even exceeded, the rest mass and rest energy. This observation motivates a cross-scale analogical inquiry: if, at the nanometer scale in terrestrial laboratories, the dissipation of thermomass energy during heat transfer produces observable physical phenomenon such as variations in apparent thermal conductivity, then in the early universe, under conditions of extremely high temperature and density, could the pervasive heat transfer and conversion processes, accompanied by the dissipation of thermomass energy, accumulate and yield significant macroscopic effects on the cosmic scale? Furthermore, could such effects possess a series of characteristics consistent with dark energy? Extrapolating the fundamental concepts and logical framework of the thermomass theory from the engineering thermophysics scale to the early cosmological scale may offer a new conjecture concerning the origin of dark energy, one that is distinct from mainstream approaches and grounded in the physical mechanism of energy dissipation.

Before applying the concept of thermomass energy dissipation to cosmic evolution, it is necessary to clarify how energy conservation is used in this paper. In an expanding relativistic universe, energy conservation is not equivalent to a simple global conservation law as in a laboratory closed system. Therefore, the energy-conservation argument used here should be understood as a local thermophysical statement: during irreversible heat-transfer and energy-conversion processes, thermomass energy is not assumed to vanish, but to be transformed into a lower-grade dissipation product. The present work does not claim to establish a global conservation law for the universe as a whole. Rather, it proposes that such local dissipative processes, accumulated over cosmological time and space, may provide a possible thermophysical source for a dark-energy-like component. A complete treatment would require incorporating this dissipation product into an effective stress-energy tensor and connecting it quantitatively with cosmological evolution equations.

The Big Bang theory is a widely accepted cosmological model, supported by the most extensive and precise scientific observations. The phenomena discussed in the first part of this paper, such as redshift, cosmic microwave background radiation, and dark energy, are all closely associated with the Big Bang cosmological model. According to this view, the universe originated from a singularity of extremely high density and temperature, expanding and evolving from that state over a finite time in the past. Current precise measurements from the Planck satellite indicate that the Big Bang occurred approximately 13.8 billion years ago, and the universe has been expanding and evolving ever since. **Figure 1** illustrates the evolution of time, temperature, and energy after the Big Bang. In the very early universe, the temperature at the central singularity was extremely high, reaching 10^{32} K. At this stage, the universe existed in a phase of exceptionally high density and temperature, with an enormous energy density, while fundamental particles such as atoms and electrons had not yet formed. During this period, the thermomass energy is very large. Subsequently, the universe underwent exponential

expansion within an extremely short time, leading to a rapid decline in temperature and density. By this stage, fundamental particles had already formed, undergoing high-speed random motion and collisions. As the temperature continued to decrease, the overall energy level of the universe further declined, enabling the formation of heavier particles. Through a prolonged evolutionary process, these eventually gave rise to observable cosmic structures, including gas clouds, stars, and galaxies. Throughout the evolution following the Big Bang, heat transfer and energy conversion inevitably occurred among various high-energy substances and particles. During these heat transfer processes, thermomass energy would have been unavoidably dissipated into other new forms of energy with a lower grade. The energy generated from the dissipation of thermomass energy should exhibit the following characteristics: it may be distributed over cosmological scales, have an extremely low effective energy density but a large total amount, be associated with a possible negative-pressure effect, and increase in total amount through long-term irreversible energy-transfer processes. Here, the term “accumulation” refers to the increase in the total amount or total cosmological contribution of the dissipation product, rather than to a rapid growth of its effective energy density. The latter may remain approximately constant, or vary only slowly, in the late universe. Therefore, we hypothesize that the thermomass energy dissipation product may be physically associated with cosmological dark energy and may provide a possible thermophysical explanation for its origin.

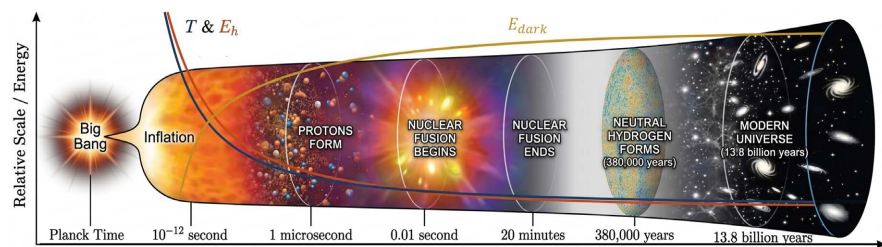


Figure 1. The evolution process of temperature, thermomass energy, and dark energy over time within the framework of thermomass theory.

We now elaborate on the four core characteristics of the product of thermomass energy dissipation and compare each with the properties of dark energy as described by traditional models. The first characteristic is that this energy permeates the entire universe. According to observations of the cosmic microwave background, the early universe was not perfectly homogeneous but exhibited minute fluctuations in temperature and density. The existence of such temperature gradients on cosmological scales provides the driving force for the directional motion of thermomass. During heat transfer, thermomass itself is conserved, analogous to the conservation of mass. However, thermomass energy, being the relativistic energy carried by thermomass, is not conserved due to the dissipative effects inherent in irreversible heat transfer processes. This dissipated thermomass energy can no longer be fully recovered in its original form but instead transforms into a

more diffuse, lower-grade form of energy. According to the principle of energy conservation, this transformation product can neither vanish nor be fully recovered in its original form. It must exist in some new form in the vacuum of the universe, becoming a vacuum zero-point energy in a sense. Dark energy, as a form of energy of such low grade that it cannot be directly observed, may well represent the inevitable destination of this irreversible process.

The second characteristic of the product of thermomass energy dissipation is its extremely low energy density coupled with an enormous total amount. Although the thermomass energy dissipated in a single heat transfer event is exceedingly small, the cumulative effect over approximately 13.8 billion years of cosmic evolution, involving countless such events, can reach a magnitude sufficient to dominate the energy density of the universe. To further examine the self-consistency of this conjecture, it is necessary to perform a preliminary order-of-magnitude estimate of the cumulative dissipation of thermomass energy across different stages of cosmic evolution. It should be emphasized that the following estimation aims to demonstrate the plausibility of this conjecture in terms of order of magnitude rather than to provide a precise theoretical prediction. Consider a material system with temperature T and mass M ; the total thermomass energy can be approximated as follows:

$$E_h \sim \frac{M_0 C^2 T^2}{c^2}. \quad (11)$$

In the very early universe, when the temperature was as high as $T \sim 10^{32}$ K, the behavior of matter at the Planck energy density remains difficult to describe using classical thermodynamics. However, qualitatively speaking, the ratio of thermomass energy to rest mass energy at this stage is given by:

$$\frac{E_h}{E_0} \sim \frac{C^2 T^2}{c^4}. \quad (12)$$

Substituting typical values reveals that this ratio can reach approximately 10^{18} in the very early universe, indicating that thermomass energy dominated the energy composition of the universe during that epoch.

As the universe expanded, its temperature gradually decreased. In the very early and radiation-dominated stages, energy transport was mainly governed by radiation diffusion, particle scattering, and plasma interactions, rather than by conduction in the classical solid-state sense. After matter-radiation decoupling, free streaming of photons and other weakly interacting particles also became important. Therefore, the proposed thermomass energy dissipation channel is expected to operate in physical particle regions where a local thermodynamic description is meaningful: a local temperature can be defined, temperature nonuniformities exist, and microscopic interactions are sufficiently frequent to support effective transport coefficients. Such conditions may occur in locally thermalized plasma, gas clouds during structure formation, interstellar and intergalactic media, and the interiors of astrophysical objects. In these regimes, conduction-like thermomass transport may coexist with radiation transport, and both may contribute to irre-

versible energy dissipation. Based on the universal principle of energy conservation underlying thermomass theory, the dissipation rate of thermomass energy per unit volume can be approximately expressed as follows:

$$\dot{e} = \dot{e}_{\text{cond}} + \dot{e}_{\text{rad}} \sim (\kappa_{\text{cond}} + \kappa_{\text{rad}}) \cdot \frac{(\nabla T)^2}{c^2} \cdot \tau_{\text{relax}}. \quad (13)$$

where κ_{cond} and κ_{rad} denote effective transport coefficients for conduction-like thermomass transport and radiation-like diffusion, respectively; ∇T is the temperature gradient, and τ_{relax} is the relaxation time of thermomass motion. These quantities are introduced as effective parameters for an order-of-magnitude estimate and may vary significantly across different cosmic epochs and physical environments. Integrating this dissipation rate over the age of the universe gives the cumulative energy density of the thermomass energy dissipation product:

$$\rho \sim \int_0^{t_0} \dot{e}(t) dt. \quad (14)$$

Although precise calculation of this integral requires a detailed model of the universe's thermal history, order-of-magnitude estimation suggests that the cumulative effect of continuous thermomass energy dissipation over cosmic time scales ($t_0 \sim 10^{17}$ s) can indeed reach the order of $\rho \sim 10^{-29}$ g/cm³. This estimation is compatible in order of magnitude with the dark energy density observed by the Planck satellite, providing preliminary support for the self-consistency of this hypothesis.

The third characteristic concerns negative pressure. Within the thermomass theory, the thermomass itself possesses a thermomass pressure: $P_h = \gamma \rho_h CT$. When thermomass energy dissipates out of a system, its product may inherit and transform into a repulsive negative pressure. In the context of gravitational theory, negative pressure serves as the driving force behind the accelerated expansion of the universe. Within the framework of general relativity, the form of the energy-momentum tensor governs the evolution of spacetime. At the present stage, this paper does not derive a complete covariant stress-energy tensor for the thermomass energy dissipation product. Instead, we argue that irreversible thermomass energy dissipation may provide a possible physical source for such an effective component. The thermomass itself possesses a thermomass pressure in the heat-transfer description, and irreversible dissipation converts ordered thermomass energy into a more diffuse and lower-grade form. This process suggests a possible route by which the dissipation product may acquire an effective pressure different from that of ordinary matter or radiation. However, the exact mechanism by which this pressure becomes negative remains to be established. A rigorous verification requires constructing an effective stress-energy tensor for the dissipation product and coupling it quantitatively to the Einstein-Friedmann equations. This remains an important direction for future research.

The final characteristic of the product of thermomass energy dissipation lies in its gradual accumulation over time. As the universe continues to expand and evolve, heat transfer processes between matter proceed incessantly, leading to a continuous dissipation of thermomass energy. The cumulative effect of the energy density of

the dissipation product over the vast timescale of the universe may correspond precisely to the currently observed dark energy density. This evolutionary characteristic may explain why dark energy dominates the current cosmic energy composition, accounting for approximately 68%, and will increasingly determine the fate of the universe in the future. In contrast, the density of matter decays as a^{-3} with cosmic expansion, while radiation density decays as a^{-4} . If dark energy density originates from a persistent dissipation process, its evolutionary behavior would differ from that of matter and radiation, enabling it to become dominant in the late universe.

Furthermore, the conjecture that dark energy originates from the dissipation of thermomass energy is not isolated from existing physical theories; rather, it can be connected to several well-established theoretical frameworks. First, from the perspectives of nonequilibrium thermodynamics and dissipative structure theory, the universe as a whole can be regarded as a vast open system, with its expansion itself representing a nonequilibrium process far from equilibrium. Within this framework, the continuous dissipation of thermomass energy corresponds to the entropy increase required for the universe to maintain its ordered evolution as a dissipative structure, while dark energy can be understood as the imprint or residue of this macroscopic dissipative process. Second, situating the thermomass energy dissipation model within the spectrum of existing dark energy theories allows for a clearer appreciation of its distinct value and theoretical position. Vacuum energy, as the most natural candidate for dark energy, arises directly from the zero-point energy in quantum field theory. However, the central difficulty confronting this theory lies in the immense discrepancy between theoretical predictions and observational values: the vacuum energy density estimated by quantum field theory reaches as high as 10^{92} g/cm³, whereas the observed value is merely 10^{29} g/cm³, a difference of approximately 121 orders of magnitude. This vacuum catastrophe severely undermines the viability of vacuum energy as an explanation. In contrast, the thermomass energy dissipation model does not presuppose a vast background energy; instead, it interprets dark energy as the cumulative product of dissipation throughout the universe's evolutionary history, thereby naturally circumventing this order-of-magnitude dilemma.

Synthesizing the discussion above, the dissipation of thermomass energy provides a plausible basis for the origin of dark energy and successfully accounts for the destination of the dissipated thermomass energy, achieving theoretical self-consistency. Compared with existing explanations for the origin of dark energy, such as vacuum energy, scalar field theories, and radiation pressure, which are rooted in microscopic particle physics, the thermomass potential energy dissipation model is a macroscopic theory grounded in a universal yet previously overlooked process in the universe, namely heat transfer, and thus carries more explicit physical significance. This is because the thermomass theory has been validated and applied in engineering domains such as non-Fourier heat conduction experiments, heat exchanger structural design, and heat transfer process optimization, resting on a solid foundation of experimental evidence.

4. Limitations and Future Work

It is worth noting that the present work should be understood as a first-step thermophysical conjecture concerning the possible origin of dark energy. The thermomass theory reviewed in Section 2 has been developed for heat-transfer processes and has been used to describe non-Fourier heat conduction and related transport phenomena. These results constitute the thermophysical basis of the present discussion. However, in subsequent chapters, extending thermomass energy dissipation from local heat-transfer processes to cosmological evolution necessarily involves an extrapolation across physical scales. Therefore, several limitations should be noted. First, the proposed association between the thermomass energy dissipation product and dark energy remains a conjecture. Although the dissipation product is argued to possess several dark-energy-like phenomenological features, including cosmic ubiquity, extremely low effective energy density, possible negative-pressure behavior, and long-term accumulation in total amount, these similarities do not by themselves constitute a complete cosmological proof. Second, the thermomass transport equations used in heat-transfer theory are not covariant field equations in the sense of general relativity and cannot be directly used to determine spacetime curvature. Third, the thermomass energy dissipation product has not yet been formulated as an effective stress-energy tensor, and its quantitative coupling to the Einstein field equations or the Friedmann equations remains to be established. In particular, the effective equation of state of this component and the mechanism by which it may produce negative pressure require further theoretical investigation.

Accordingly, future work should therefore focus on developing a covariant formulation of the thermomass energy dissipation product, deriving its effective stress-energy tensor, and examining whether the resulting effective energy density and pressure can satisfy the conditions required for cosmic acceleration. Quantitative comparison with cosmological observations will also be necessary to evaluate whether this thermophysical conjecture can be developed into a viable dark-energy model.

5. Conclusions

Based on the thermomass theory, this paper presents a new perspective on the origin of dark energy from the viewpoint of energy transfer processes. The conclusions are summarized as follows.

- 1) Research on the dark energy problem has become a key issue in exploring the origin of the universe and understanding its structure and nature. However, neither astronomical observations nor theoretical studies have yet reached a broad consensus on the origin and properties of dark energy.
- 2) Further investigation into the essence of heat reveals that heat possesses an energy-mass duality: it exhibits energy characteristics when converted into other forms of energy, while it exhibits mass characteristics during transfer. The thermomass possesses potential energy in a thermal field and kinetic energy during

motion; both are forms of relativistic energy.

3) In irreversible heat transfer processes, thermomass is conserved, whereas thermomass energy is not conserved due to its dissipation. According to the principle of energy conservation, thermomass energy inevitably dissipates into a lower-grade, invisible form of energy that is difficult to measure directly because of its extremely small magnitude; under terrestrial conditions, this may be referred to as dark energy. In contrast, during the early stages of the Big Bang, the magnitude of thermomass energy was substantial.

4) Existing theories of cosmic evolution primarily address the gradual transformation of radiation into material particles, gases, and celestial bodies, but they do not explicitly account for heat transfer processes. Nevertheless, temperature non-uniformities inevitably exist both among different forms of matter and within matter itself throughout the evolution of the universe, leading to unavoidable heat transfer and consequently to the dissipation of thermomass energy.

5) On cosmological scales, thermomass energy may dissipate and transform into a lower-grade energy form during irreversible heat-transfer and energy-conversion processes. The resulting thermomass energy dissipation product is expected to exhibit several dark-energy-like characteristics: it pervades the entire universe, possesses an extremely low energy density, exerts negative pressure, and accumulates gradually over time. Accordingly, we conjecture that the thermomass energy dissipation product may provide a possible thermophysical origin of dark energy. This conjecture still requires further development through covariant formulation, effective stress-energy modeling, quantitative coupling to the Friedmann equations, and comparison with cosmological observations.

Funding

This research was supported by the Original Exploration Program of the National Natural Science Foundation of China (No. 52250273).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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