Redefining Information: A Quantized Approach to Information Flow in Superconductors

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Abstract

This study proposes a novel physical framework for defining information as a quantized field within quantum superconductivity, introducing the concept of “informanons”—discrete matter waves associated with Cooper pairs in superconductors below their critical temperature. A new wave equation is derived to describe the dynamics of this information field in a temperature-entropy space, establishing a paradigm termed “digital quantum mechanics” distinct from conventional “analog quantum mechanics.” This framework reinterprets information flow, challenging traditional probabilistic interpretations of wavefunctions and eliminating wavefunction collapse. An entropic model for quantum memory reveals an inverse-square relationship between memory capacity and stored information, suggesting superconductors enable ultra-high-density storage through quantum information compression. The findings bridge classical information theory and quantum mechanics, offering transformative implications for quantum computing and communication. While theoretical, the framework requires experimental validation to confirm informanon properties and explore applications in quantum systems.

Keywords: Superconductivity, Quantum Information, Informanon, Entropy, Quantum Memory

1 Introduction

Despite the significant advancements in computer science, where information is often defined in terms of storage and processing, a fundamental physical definition of information remains elusive. While Shannon’s groundbreaking work [1] and subsequent mathematical formulations—particularly those related to entropy—provide valuable insights into information from a probabilistic standpoint, they do not offer a direct physical interpretation. A clear physical definition of information, analogous to definitions for other fundamental physical quantities, is crucial, not only for deepening our understanding of the universe but also for potentially revolutionizing information technologies. This gap in understanding motivates the present research.

This paper investigates the nature of information within the framework of quantum mechanics, specifically focusing on its potential as a quantized field. A hypothesis under consideration suggests that quantum-level information is conveyed by discrete entities termed *informanons*. These informanons are theorized to be quantized matter waves linked to Cooper pairs within superconductors operating below their critical temperature. Within this framework, these Cooper pairs are proposed as the physical vehicles for quantum information transfer.

A novel wave equation is introduced to describe the dynamics of this information field. This equation offers a new interpretation of information's behavior, distinct from existing models and requiring a revised perspective within quantum mechanics. To ensure clarity, the term *analog quantum mechanics* is used to refer to conventional, established quantum mechanics. In contrast, the partially developed framework presented here, designed to describe, explain, and interpret information and related phenomena within superconductors at or below critical temperatures, will be termed *digital quantum mechanics*. This framework bridges classical information theory and quantum superconductivity. Applying these concepts to quantum memory, an entropic model reveals a wave-like relationship between memory capacity and stored information. This suggests potential for high-density storage, emphasizing the transformative power of understanding information flow in superconductors.

2 Theoretical and Mathematical Framework and Interpretation

2.1 Superconducting Microstates and the Entropic Basis of Information

Superconducting circuits are a promising platform for quantum information processing, offering potential for both qubit storage and manipulation [2]. While various physical systems are explored for quantum computing, superconductors are attractive due to their ability to form Cooper pairs below a critical temperature [3]. Cooper pairs, which are bound states of two electrons, are central to superconductivity and can be utilized to encode and manipulate quantum information [4]. Furthermore, their formation leads to a rich spectrum of quantum states in superconductors [5]. This rich spectrum of states implies a large number of possible microstates [6]. When a superconductor transitions from its superconducting state to its normal state (above the critical temperature, T_c), the number of accessible microstates changes [7]. Specifically, as established in my previous work on the theoretical analysis of information quantization and reversal in superconducting wires, the change in the number of microstates is given by

$$dW = [ms(T - T_c)] \cdot (W/T_c k), \tag{1}$$

where m is mass of a single superconducting wire, T is room temperature, T_c is critical temperature for a superconductor, W is number of microstates, and

k is Boltzmann constant. This expression, derived from thermodynamic and information-theoretic principles, quantifies the microstate variation associated with the superconducting transition.

In previous work of mine, the factor k multiplying T_c in the denominator of this term was inadvertently omitted. The inclusion of T_c is crucial, as it appropriately scales the change in the number of microstates relative to the characteristic energy scale of the superconducting transition, which is proportional to kT_c.

Another previous work of mine resulted in the derivation of a new formula for the entropy:

$$S = hc/\lambda T, \tag{2}$$

where h is Planck's constant and c is the speed of light. This formula redefines entropy as a measure of the wave-like nature of Cooper pairs in superconductors, with quantized values at or below the critical temperature.

Let us assume that information (I) is flowing through a superconducting wire. From information theory it is known that

$$I = -dS, \tag{3}$$

where dS represents change in entropy. Using equation (2), equation (3) becomes

$$I = -\left(\frac{dS}{dT}\right) dT = \frac{hc(T - T_c)}{\lambda T^2}. \tag{4}$$

Equation (5) is not dimensionally homogeneous. Therefore, it can be restored by defining a constant a and the corrected equation is:

$$I = \frac{hca(T - T_c)}{\lambda T^2}, \tag{5}$$

where

$$a = \frac{T_1}{E}, \tag{6}$$

T_1 is a temperature below T_c, and E is energy required to transmit one qubit of information at T_c or below it. The introduction of a is a theoretical construct to restore dimensional homogeneity, with its form motivated by the physical context of quantum information transmission. Further experimental or theoretical work is needed to determine the precise value of a.

Equation (6) describes the amount of information that can flow at or below the critical temperature (T_c) using Cooper pairs. It indicates that even when sending a large amount of information, upon entering a superconductor at or below its critical temperature, the volume of information will be automatically reduced, allowing for more information transmission within the superconductor. This reduction is inversely proportional to the wave nature; meaning that the shorter the matter wavelength, the more information can be transmitted.

2.1.1 Analysis of Discrepancies and Implications for Information Carriers

At the critical temperature ($T = T_c$), equation (6) yields

$$I = 0. \tag{7}$$

This perfect agreement signifies the certainty of the information. Equation (1) demonstrates that

$$dW = 0 \tag{8}$$

at $T = T_c$, indicating that Cooper pairs cannot occupy multiple quantum states. This transition suggests a shift from particle-like to wave-like behavior. Consequently, information transmitted through a superconductor below T_c must also exhibit wave-like properties. This restriction to a single quantum state implies immunity to noise or interference, as indicated by equation (8). Cooper pairs behave as a single entity with a specific matter wavelength, resulting in the transmitted information possessing only one state at this wavelength. This inherent purity in a pure superconductor eliminates the need for redundant qubits.

2.2 Reflection and the Concept of “Backward Time Travel”

The presence of a wavelength in equation (6) suggests that information encountering an infinite potential barrier undergoes reflection. For a qubit initially in the state $|1, 0\rangle$, this reflection transforms it to the state $|0, 1\rangle$. A subsequent reflection restores the qubit to its original state, $|1, 0\rangle$. This reversible transformation resembles a cyclic operation within the temperature-entropy space, governed by the proposed wave equation. Such behavior is interpreted as state oscillation in the temperature-entropy framework, distinct from conventional spacetime dynamics. This observation provides a novel perspective on information dynamics in superconducting systems, meriting further theoretical and experimental exploration.

2.3 Analogy to Phase Space

Recalling the concept of phase space, wherein position and momentum are analogous to the dimensions, and in special relativity, position and time serve as dimensions. Since momentum reflects the rate of change of velocity, it can be inferred that momentum behaves akin to a temporal dimension in phase space. Considering Heisenberg’s uncertainty principle between position and momentum, as well as energy and time, it becomes evident that momentum essentially acts as a temporal dimension in phase space. Moreover, the existence of Fourier transforms between position space and momentum space, as well as between time domain and frequency domain, corresponding to two distinct formulations of Heisenberg’s uncertainty principle, strongly suggests that the discovery of a new uncertainty principle ($\sigma_{T_c}\sigma_S \leq \hbar/2$) related to entropy and temperature from my same paper cited in equation (2) implies that temperature (specifically, the critical temperature or the temperature at or below it, with an associated uncertainty σ_{T_c}) assumes the role of position space (or time), while entropy (with an associated uncertainty σ_S) behaves akin to time (or frequency).

2.4 A Novel Understanding of Information in Superconductors

Building on the above analogies, a novel understanding of information within superconducting signal transmission is proposed. When information is transmitted by cooling a superconductor below its critical temperature, it behaves as a quantum field with no classical counterpart, with entropy and temperature serving as its background space. The introduction of entropy, with temperature as its conjugate variable, is crucial for understanding how superconductors carry information. Below the critical temperature, the standard space-time description loses relevance, and temperature and entropy become the dominant factors influencing information flow. Therefore, these concepts are essential for understanding information flow in superconducting systems.

Elaborating further, Cooper pairs, despite existing in individual quantum states, exhibit wave-like properties and act as a single entity characterized by a specific matter wavelength. Cooper pairs, when not transmitting information, may exhibit distinct, non-random patterns, but these patterns are not *periodic* and *discrete*. However, during information transmission using Cooper pairs, these pairs exhibit a *periodic* and *discrete* pattern along the non-random pattern. This periodicity and discreteness are directly proportional to the matter wavelength of the Cooper pairs. Without information transmission, regular and distinct patterns of Cooper pairs might still occur, but the wave nature, specifically the periodic and discrete pattern dependent on matter wavelength, is absent in absence of information transmission.

This suggests that information itself is a form of energy arising from the periodic and discrete pattern of Cooper pairs, dependent on their matter wavelength when it is carrying information. Therefore, propose a quantum of information energy, termed an informanon, with energy defined as:

$$E = \frac{hc}{\lambda}, \tag{9}$$

where λ is the matter wavelength of the Cooper pairs when it is carrying information. Notably, the energy of an informanon is independent of frequency. This quantization arises because, during information transmission with Cooper pairs, the matter wavelength λ cannot take on all possible values. λ changes depending on the information being sent—its type, speed, and volume. However, λ maintains its discrete nature. The reason for the discrete, rather than continuous, nature of λ is the inherent periodic and discrete nature of the information itself when transmitted using Cooper pairs. This insight implies that the informanon must possess a wavefunction, which should be a function of temperature and entropy, as discussed in previous sections. Consequently, this necessitates the development of a new wave equation to describe the motion of information.

2.5 Derivation of the Wave Equation for Informanon

Recalling the one-dimensional wave equation replaced $u(x,t)$ by $\psi(x,t)$ we get,

$$\frac{\partial^2\psi(x,t)}{\partial t^2} = v^2\frac{\partial^2\psi(x,t)}{\partial x^2}. \tag{10}$$

Classically,

$$v = \frac{\partial x}{\partial t}. \tag{11}$$

Here, temperature is conceptualized as a spatial component and entropy as a temporal component. Thus, the velocity 'v' is equated to the partial derivative of temperature 'T' with respect to entropy 'S', symbolized as

$$z = \frac{\partial T}{\partial S}. \tag{12}$$

Introducing a novel physical quantity denoted as 'z', it is referred to as 'entropial temperature'. This entity is defined as the change in temperature with respect to change in entropy. Notably, this definition seamlessly conforms to the proposed new uncertainty principle. Now, equation (11) becomes

$$\frac{\partial^2 \psi(T,S)}{\partial S^2} = z^2 \frac{\partial^2 \psi(T,S)}{\partial T^2}. \tag{13}$$

The solution of equation (11) is

$$\psi(x,t) = Ae^{i(kx-\omega t)}. \tag{14}$$

Thus, the solution of equation (14) must be

$$\psi(T,S) = Ae^{i(kT-\omega S)}. \tag{15}$$

But the exponential part of this solution is dimensionally inconsistent. Hence, equation (16) must be

$$\psi(T,S) = Ae^{i\left(\frac{kE}{T}-\omega S\right)}. \tag{16}$$

Now, differentiating equation (16) with respect to 'S' twice, gives

$$\frac{\partial^2 \psi(T,S)}{\partial S^2} = -\omega^2 \psi(T,S). \tag{17}$$

Using (18) in (14), gives,

$$z^2 \frac{\partial^2 \psi(T,S)}{\partial T^2} + \omega^2 \psi(T,S) = 0, \tag{18}$$

or,

$$z^2 \frac{\partial^2 \psi(T,S)}{\partial T^2} + \left(\frac{E}{\hbar}\right)^2 \psi(T,S) = 0, \tag{19}$$

[using $\omega = E/\hbar$ (21) in (19)] or,

$$z^2 \frac{\partial^2 \psi(T,S)}{\partial T^2} + \left(\frac{hc}{\lambda \hbar}\right)^2 \psi(T,S) = 0, \tag{20}$$

[using (15)] or,

$$z^2 \frac{\partial^2 \psi(T,S)}{\partial T^2} + \left(\frac{a}{\lambda}\right)^2 \psi(T,S) = 0. \tag{21}$$

The solution is separable into a product of functions,

$$\psi(T,S) = S(S)\Phi(T), \tag{22}$$

where $\Phi(T)$ depends only on T. Substituting (23) in (22) gives

$$z^2 S(S)\frac{d^2\Phi(T)}{dT^2} + \left(\frac{a^2}{\lambda^2}\right) S(S)\Phi(T) = 0. \tag{23}$$

Factoring out $S(S)$ [assuming $S(S) \neq 0$] gives,

$$z^2 \frac{d^2\Phi(T)}{dT^2} + \left(\frac{a^2}{\lambda^2}\right) \Phi(T) = 0, \tag{24}$$

or,

$$\frac{d^2\Phi(T)}{dT^2} + \left\{\frac{a^2}{z^2\lambda^2}\right\} \Phi(T) = 0. \tag{25}$$

Or,

$$\frac{d^2\Phi(T)}{dT^2} + k^2\Phi(T) = 0, \tag{26}$$

where,

$$k^2 = \frac{a^2}{z^2\lambda^2}. \tag{27}$$

This is a standard second-order linear differential equation with the general solution:

$$\Phi(T) = C_1 e^{ikT} + C_2 e^{-ikT}, \tag{28}$$

where C_1 and C_2 are constants of integration, and

$$k = \frac{a}{z\lambda}. \tag{29}$$

Or,

$$\Phi(T) = C_1 e^{i\left(\frac{aT}{z\lambda}\right)} + C_2 e^{-i\left(\frac{aT}{z\lambda}\right)}. \tag{30}$$

Therefore, the full solution to the original equation is,

$$\psi(T,S) = S(S)\Phi(T) = S(S)\left[C_1 e^{i\left(\frac{aT}{z\lambda}\right)} + C_2 e^{-i\left(\frac{aT}{z\lambda}\right)}\right]. \tag{31}$$

The final solution of equation (32) represents the wave function of 'informanon' in a space defined by temperature and entropy. The solution is a linear combination of two exponential terms with opposite signs in the exponent. This is a characteristic feature of wave solutions, representing a superposition of waves traveling in opposite directions corresponding to electrons of Cooper pairs. The wave function explicitly depends on both temperature (T) and entropy (S). This aligns with the initial hypothesis that these two quantities play analogous roles to position and time in conventional wave mechanics.

Furthermore, this observation suggests that, just as special relativity demonstrates that space and time are not separate entities but rather aspects of a single.coordinate space and time in conventional wave mechanics.

Furthermore, this observation suggests that, just as special relativity demonstrates that space and time are not separate entities but rather aspects of a single entity called spacetime, entropy and temperature might also not be distinct. Instead, they could be considered as different facets of a single quantity, which we could term 'temperature-entropy,' when they function as dimensions. The parameter 'z', defined as the change in temperature with respect to entropy, appears in the exponent. This highlights the crucial role of this derived quantity in determining the wave behavior. The wavelength (λ) also appears in the exponent, indicating that the wavefunction exhibits oscillatory behavior with a characteristic wavelength.

3 A New Paradigm in Digital Quantum Mechanics

3.1 Challenging the Notion of Probability in Digital Quantum Systems

Within the framework of conventional quantum mechanics (analog quantum mechanics), the wavefunction is typically interpreted as a probability amplitude, with its squared modulus representing the probability density of a quantum state within a Hilbert space defined by the spatiotemporal coordinates. However, the wavefunction derived in Equation (32), being a function of entropy and temperature rather than space and time, presents a fundamental challenge to this established interpretation. Postulating that this wavefunction represents a probability amplitude raises the critical question of the probabilistic event to which it corresponds, rendering such an interpretation untenable. Furthermore, while the mathematical operation of squaring this wavefunction is possible, the resulting quantity lacks the physical significance of a probability density as conventionally defined within the spatiotemporal domain of analog quantum mechanics.

In digital quantum mechanics, the conventional interpretation of the squared wavefunction as a probability density is not applicable. Instead, an alternative interpretation is proposed:

The wavefunction (Equation 32) represents the wave-like nature of information, at the quantum level. Furthermore, its complex conjugate, analogous to a "reflection" of the wavefunction, signifies a reversal in the direction of information flow within the temperature-entropy space.

3.2 Beyond Wavefunction Collapse: A Reconceptualization

In conventional quantum mechanics (analog quantum mechanics), the wavefunction is a mathematical object containing information about a particle, such as kinetic energy, potential energy, and momentum. Operators, when applied to the wavefunction, yield corresponding values for these properties. Additionally, the wavefunction undergoes collapse upon measurement. However, in the context being discussed, the wavefunction is a mathematical object that *does not* inherently carry information about momentum, kinetic or potential energy. Operators applied to this wavefunction do not produce corresponding values. This difference arises from a different interpretation, as discussed previously. Similarly, wavefunction collapse, as understood in analog quantum mechanics, does not occur here due to this same difference in interpretation.

4 Applications

4.1 Quantum Information and Memory: An Entropic Perspective

The inextricable link between memory and information is fundamental. Information necessitates a physical storage medium, which constitutes memory. However, a precise physical characterization of memory remains elusive. While we conceptually understand memory as an information repository, a rigorous, quantifiable physical description is lacking.

This paper postulates a direct relationship between changes in memory state and corresponding changes in the entropy of the storage medium. Specifically, it is proposed that modifications to the information stored within a memory device are associated with alterations in its entropy. This entropic change is hypothesized to be particularly pronounced when the memory device stores quantum information.

4.1.1 Entropic Model of Memory

Mathematically, this relationship can be expressed as:

$$dM \propto dS. \tag{32}$$

Introducing a proportionality constant, b, we obtain:

$$dM = b\,dS. \tag{33}$$

Recognizing that the change in entropy (dS) is related to the quantum information (I) as discussed in previous sections, we can rewrite this as:

$$dM = -b\,I. \tag{34}$$

Integrating both sides with respect to I yields:

$$M = -\frac{kI^2}{2} + C, \tag{35}$$

where $k = b$. Applying the boundary condition that $M = 0$ when $I = 0$, we find $C = 0$. Thus,

$$M = -\frac{kI^2}{2}. \tag{36}$$

Further, normalizing such that $M = 1$ bit when $I = 1$ bit, we determine $k = 2/\text{bits}$, leading to:

$$M = -\frac{1}{\text{bit}}I^2. \tag{37}$$

Therefore,

$$M = -eI^2, \tag{38}$$

where $e = \frac{1}{\text{bit}}$ (40) is a constant.

4.1.2 Quantum Information Compression and Wave-like Memory Behavior

The presence of the negative sign in Equation (39) signifies an inverse relationship between memory capacity and the amount of information stored within the device. This observation aligns with classical information theory, where an increase in stored information within a memory device is generally associated with a decrease in the device's remaining storage capacity. Classically, as a memory device approaches its storage limit, its ability to accommodate further information diminishes.

However, while Equation (39) reflects this fundamental principle, its interpretation within the present context offers a significant departure from classical understanding. Equation (39) furnishes strong evidence for interpreting equation (6) as a representation of quantum information reduction. This interpretation posits that, in the quantum regime, not only is the transmission of information in superconducting wires subject to reduction as implied by equation (6), but also the very size of quantum information itself is diminished upon storage in memory devices. This implies that such devices possess a capacity to store information exceeding predictions based on classical models. This enhanced capacity stems from the unique wave-like properties of quantum information, as established and discussed in preceding sections. Consequently, while the inverse relationship between memory and information, as expressed by Equation (39), resonates with classical principles, the magnitude of information storage within this quantum framework surpasses classical expectations, suggesting the potential for unprecedented information storage density. Substituting Equation (6) into Equation (39) yields:

$$M = -e\left[\frac{hca(T-T_c)}{\lambda T^2}\right]^2. \tag{39}$$

Equation (41) reveals a striking wave-like behavior within the memory device during quantum information storage, a phenomenon fundamentally divergent from classical predictions. This observation reinforces the preceding discussion and interpretation, suggesting that memory storage devices can accommodate a significantly greater quantity of quantum information than anticipated by classical information theory and classical memory device limitations. This deviation from classical norms underscores the potential for a deeper understanding of information storage at the quantum level and necessitates further rigorous investigation to fully elucidate the underlying mechanisms and implications. Such research could potentially revolutionize our understanding of quantum memory and its capabilities.

5 Conclusion

Driven by a decade-long curiosity to establish a physically meaningful mathematical foundation for information, this research introduces a novel theoretical framework that redefines information as a fundamental physical entity within quantum superconductivity. This pursuit, born purely from intellectual passion rather than external motives, posits informanons—quantized matter waves tied to Cooper pairs—as a bridge between classical information theory and quantum mechanics. Unlike Planck's introduction of quanta to resolve the black-body radiation problem, the concept of informanons emerged from instinct, shaped by the hypothesis developed in this study. The derived wave equation (Eq. 32) governs informanon dynamics in temperature-entropy space, proposing digital quantum mechanics as a pioneering paradigm where entropy and temperature supplant spacetime. Key findings include:

- **Informanons as Quantum Information Carriers**: Cooper pairs below critical temperatures mediate discrete information units (informanons), providing a physical basis for quantum information. Their dynamics, described by Eq. 32, prioritize temperature-entropy relations over spacetime.
- **Reinterpretation of Quantum Foundations**: The wavefunction's reliance on entropy and temperature eliminates spacetime dependence, challenging traditional probability amplitudes and density. Digital quantum mechanics negates wavefunction collapse and introduces wave-like information flow via reflection operations in a non-spatiotemporal domain. These concepts, while novel, should not be dismissed as merely philosophical or metaphysical, as analogous ideas in established analog quantum mechanics (e.g., many-worlds interpretations) remain debated yet accepted.
- **Quantum Memory Implications**: The entropic model (Eq. 41) reveals an inverse-square relationship between memory capacity and stored information, suggesting superconductors enable ultra-high-density storage through quantum information compression (Eq. 6). This framework, which I believe could revolutionize the IT sector, challenges classical memory limits.

The introduction of informanons and their properties remains in an initial theoretical stage, requiring further development and eventual experimental verification. Similarly, speculative ideas like backward time travel of informanons in temperature-entropy space demand advanced theoretical and mathematical refinement, as they are grounded in a distinct framework from conventional phase space.

6 Limitations and Future Directions

While this framework offers transformative insights, its theoretical nature necessitates rigorous experimental validation. The properties of informanons, currently hypothetical, require further theoretical elaboration before empirical testing in superconducting systems. Experimental efforts should prioritize detecting informanons, validating entropic memory models, and investigating analogous phenomena in topological materials. The concept of digital quantum mechanics, with its non-collapse wavefunction and absence of probability amplitudes and density, is in a pioneering stage and demands substantial theoretical advancement to mature into a robust paradigm.

Additionally, ideas like backward time travel in temperature-entropy space require deeper mathematical grounding due to their unconventional foundation, which diverges from traditional phase space frameworks. Extending this model to other quantum systems, such as photonic or spin-based platforms, could unify diverse quantum information paradigms. By establishing information as a quantum field governed by entropy and temperature, this work lays the foundation for a new understanding of information physics, with profound implications for quantum computing, communication, and the integration of thermodynamics with quantum theory.

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Conflict of Interest

The author declares no conflict of interest.

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