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The Quantum Character of Perception: The Probabilistic and Reversible Thermodynamic Cycle can Produce Spin-like Attitudes, Thinking, and Behavior

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Abstract

One of the most puzzling questions in neuroscience is the nature of emotions and their role in consciousness. The sensory system's energy/information exchange revolves around a stable resting state; therefore, perception represents a closed thermodynamic cycle and can be modeled via the reversible Carnot engine. The brain's significant energy investment in maintaining the resting state indicates its essential role as the ground state of consciousness, the source of our sense of self. Perception forms either an endothermic or exothermic cycle. The first represents high entropy resting state with irreversible activations, generating novelty and intellect; it is energetically analog to the fermionic up-spin. However, exothermic physical processes give rise to time's arrow and loss of work capacity; reversible low entropy activations lead to past focus, regret, and remorse. The energy-weak condition is the psychological spin-down state. The reversible thermodynamic cycle, a classical system, takes on quantum characteristics and gives rise to a psychological spin. The quantum and classical natures represent a particle-like duality between continuous and discrete states explained by the fermionic hypothesis. Therefore, emotions are the brain's homeostatic master regulators. They maintain particle-like stability manifested by cognitive comfort by utilizing physiological and hormonal regulation.

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Highlights

Energy information exchange with the environment is based on the resting-state

Perception is a reversible thermodynamic cycle representing psychological spin

High entropy and irreversible activations form up spin, inspiring future orientation

Low entropy with reversible activations and past focus acts as a down spin

Emotions are cognitive master regulators, the fundamental forces of motivation

Keywords: Quantum cognition, spinor, psychological spin, thermodynamics, positive psychology, emotion regulation.

*Social temperature or arousal:*Like temperature, which indexes internal energy, social temperature measures the intensity of emotions, arousal (Escobar et al., 2021; O'Neill & Schoth, 2022: Deli and Kisvarday, 2020; Deli et al., 2021). For example, low arousal stabilizes focus, but high arousal causes oscillating information processing, leading to erratic and arbitrary behavior. The physiological signals of high social temperature are increased breath, heart rate, skin conductance, hot or cold chills, shouting, aggravation, aggression, and risky behavior.

Introduction

> *"Who would believe that so small a space could contain the images of the whole universe?" — LEONARDO DA VINCI*

The relationship between cognition and physics has deep philosophical and scientific roots. Sensory abilities lend environmental insights even to the most primitive animals. For example, visual projections onto the optic nerve produce a holographic memory representation (Tomasi et al., 2017), which remains stable despite the constantly changing environment (Makey et al., 2019), allowing past experiences to inform present behavior and response. Therefore, memory and learning (Dabaghian, 2019) engender a stable temporal orientation (Fingelkurts & Fingelkurts, 2014; Herzog et al., 2020).

Material systems follow trajectories that have the least action when moving in space. In biological systems, predictive behavior optimizes action performance. For example, a precise computation adjusts muscle strength throughout the execution of the simplest movements, such as negotiating a cup's path to the lips. Because the principle of least action in physics ensures a minimal energy conformation when moving in space, intelligent systems increase future freedom of action (Deli, 2020a; Wissner-Gross/Freer, 2013). Furthermore, spontaneous meaning generation and abstract task structure representations (Witkowski et al., 2022), a fundamental character of intellect, are based on the organizing principle of space (Singer, 2021; Deli et al., 2018; Tsao et al., 2018). Therefore, various physics frameworks can explain enigmas in cognitive sciences (Deli, 2015; Deli, 2020a,b; Goldenberg et al., 2018; Peters & Kashima, 2015; Jiang et al., 2016; Khrennikov, 2015).

Human decision-making and behavior show quantum mechanics. For example, the brain's ability for parallel and ultrafast evaluation of the relations between probabilistic variables resembles quantum systems. Superposition, interference, and entanglement can emerge from the brain's classical sensory cycle; context clues can dramatically modify what we hear, see, or perceive (Xu & Schwarz, 2017). As "quantum" resists classical description, context turns the potentials of the memory and perception into actual properties (Dennett, 2018), discrete thoughts, and decisions. Cognition shows a point-like (discrete) or wavelike character, i.e., complementarity.

In economics, a simple spin model can explain market frictions and herding behavior (Fotouhi & Rabbat, 2013; Kristoufek & Vosvrda, 2018; Krause & Bornholdt, 2013). Moreover, a modification of the above idea, the so-called Ising model, can account for decision-making in social and business situations (Sîrbu et al., 2017; León-Medina, 2019; Li & Dankowicz, 2018; Ishii & Kawahata, 2018; Zha et al., 2021; Vázquez et al., 2020; Salehi & Taghiyareh, 2019).

Nevertheless, the brain is a classical system. Recent investigations have shown that stimulus and its response form a closed and reversible thermodynamic cycle in discrete processing centering on the resting state (Deli and Kisvarday, 2020; Deli et al., 2021, 2022), operating between two information-density reservoirs (Fry, 2017; Deli et al., 2018). Therefore, thermodynamics, which can predict the behavior of systems with large numbers of particles in so many fields, might explain the emergence and nature of intellect. We will investigate how the thermodynamic cycle of perception, a classical system, can give rise to a quantum process.

Mental Homeostasis

The physical world obeys the laws of thermodynamics, but life secures a low entropy internal stability against external conditions. Homeostasis seems to be a fundamental requirement of life from the lowest to the highest level. Cells keep their internal structure, pH, salt concentration, and membrane potential constant. In vertebrates, the heart and the kidneys keep the body's internal parameters within a very tight range. In mammals and birds, the brain is a central regulator responsible for thought, memory, emotion, touch, motor skills, vision, breathing, temperature, hunger, and bodily processes.

Neuronal processes also transpire on many scales, forming power-law distributions (Stringer et al., 2019). For example, functional magnetic resonance imaging reflects microscopic membrane potential and neurotransmitter fluctuations in large-scale signals. Although stimulus rapidly collapses the high-dimensional resting state into a lower-dimensional substrate (Bányai et al., 2019; Singer, 2021), a tightly controlled emotional integration (Rosenzweig et al., 2009; Tomasi, 2013) always restores the resting, neutral position (Northoff, & Tumati, 2019; Schoeller & Perlovsky, 2016).

Therefore, the stability of cognitive function lies in the resting state. First, the resting state's non-computable, subjective, and often ungovernable thought processes enable a subjective, transcendental, and privileged first-person experience (Kolvoort et al., 2020). Second, it personifies the sense of self (Wolff et al., 2019), i.e., a mental comfort point. Third, the cognitive ground state ensures a mental constancy from birth to death. Furthermore, the correlation structure is susceptible to experience and learning-dependent modifications throughout life.

Endothermy is under thermodynamic control (Seebacher, 2020). The deep interconnectivity of emotion and temperature regulatory pathways in the ventral striatum (VS) and middle insula (MI) (Grigg et al., 2021; Kataoka et al., 2020 Inagaki & Eisenberger, 2013; Inagaki et al., 2019) indicates their shared origin in energy regulation (Deli and Kisvarday, 2020). In high-stakes situations and moral dilemmas, emotions may completely rule thinking (Babaev et al., 2018; Bechler et al., 2019).

The autonomic stress pathway connects the corticolimbic stress circuits to the hypothalamus (Kataoka et al., 2020). It activates the sweat glands and controls blood pressure and blood vessel dilation to the muscles, the so-called "fight-or-flight" reaction (Fadok et al., 2017). Physiological changes, such as shivering when stressed, perspiring when afraid, and blushing when confused, often serve emotional purposes. Parental care behaviors are also predicated on thermoregulation (Farmer, 2020).

Cortical fluctuations reflect the priors in the network architecture, stored in the anatomical layout and the synaptic weights of recurrent synaptic connections (Singer, 2021). Like the specific range of endothermic body temperature, emotion regulation keeps cognitive comfort within an individually, culturally prescribed range, immensely influencing our physiology (Ellard et al., 2017). Inversely, our physiology and electric brain stimulation have a remarkable ability to regulate emotions (Caruana et al., 2018), indicating their energy nature. The powerful ability to regulate physiological functions indicates that mental balance, supported by emotions, sits at the top of the homeostatic hierarchy.

Quantum Cognition

Quantum mechanics is the best empirically confirmed scientific theory in human history. Its application in psychology can provide coherent and principled answers to a myriad of puzzling findings and stubborn challenges in decision–making and comparisons (Khrennikov, 2015; Luck et al., 2021; Lubashevsky, 2018). Quantum cognition is based on the idea that chaotic and noisy brain activations give rise to characteristics similar to quantum systems (Table I). For example, complementarity in sequential psychological measures implies that the context generated by the first measure can influence subsequent ones, producing order effects (Hopkins et al., 1997). Furthermore, the superposed psychological states cannot be defined precisely; instead, all possible values within the superposition have some potential for expression (Busemeyer and Wang, 2015).

Analogous to the Born rule, which expresses the probability density of finding a particle at a given point, the medial prefrontal cortex (PFC) efficiently represents hierarchically related choice-outcome associations (Witkowski et al., 2022), corresponding to the "position" of latent association. Cortical fluctuations can anticipate events and the consequences of actions (Hughes et al., 2013; Kok et al., 2017), such as the global coordination of muscle tone by the evoked potential in motor cortices (Uithol and Schurger, 2016). Like waves on a pond, thoughts move with considerable liberty; they are challenging to govern and almost impossible to retrace. They emerge from the brain's wavelike electric activities (Basieva et al., 2019; Chang et al., 2019), representing the neural underpinning of response (Friston et al., 2020). The wavelike, fluctuating mental content formulates a probability function.

Unlike classical systems, quantum systems are probabilistic, lacking the ability to predict the actual outcome of a measurement. Similarly, decision-making and social behaviors are probabilistic, based on the squares of the probability amplitudes (Landé, 1971; Selesnick & Piccinini, 2018). Superposition between network nodes bears similarities to the simultaneous and probabilistic spontaneous activity priors' evaluation (Singer, 2021). Like quantum mechanics, the mental history and current state are just as crucial in determining the quality of neuronal activation as the stimulus itself (Piscopo et al., 2018). Thus, in analogy to the Shannon understanding of entropy, the stimulus's information value and the degree and quality of comprehension depend on the observer (Tomasi et al., 2017).

Quantum mechanics also shows that decoherence changes the wave function, leading to discrete and quantized energy transformations. Similarly, beliefs, decisions, and cognitive change represent discrete conditions (Libet, 1983, 1985; McCraty and Atkinson, 2014) (Table I). Recent work confirms our hypothesis that discrete conscious percepts alternate with substantial periods of continuous unconscious processing (Herzog et al., 2020). Now we turn to the consequences of quantum cognition.

Mental Unity

The mind, representing the smallest unit of intellect, is only meaningful in its unity (Deli, 2020b). Conscious perception is never fractured (Bayne, 2009); ambiguity forces a non-deterministic, quantum-like fluctuation between two possibilities, concepts, or economic decisions (Fioretti et al., 2022). For example, two different images presented to the two eyes (Alais & Blake, 2004; Tong et al., 2006) or two different smells registered by the two nostrils (Zhou & Chen, 2009) do not form averages in perception but trigger a quantum-like fluctuation between the two possibilities.

Stimulus rapidly collapses the high-dimensional resting state into a lower-dimensional one (Bányai et al., 2019; Singer, 2021). Sensory activation evokes involuntary potentials and electric flows in primary sensory regions, forming spatiotemporal symmetry vis-à-vis the brain's resting modules (Bastos et al., 2015), which orients consciousness in time (Huang et al., 2020). Oscillations cross successive regulatory layers on their way to associative regions, but response restores the brain's resting state in a discrete energy processing. The brain's global regulation equilibrates its energy/information balance while gradually evolving personal experiences, memories, and expectations of the moment.

The limited work produced by one cycle turns mental evolution into a stepwise process, giving rise to discrete understanding and beliefs, which supports self-consciousness' "quantized" character. For example, the evoked cycle discretizes the wave function, analogous to the particle's wave function in a “box.”

$$E = \hbar\omega = \frac{\hbar^2 k^2}{2m}$$

where k is the wavenumber and ω is the angular frequency, $\hbar$ is the reduced Planck constant, and m is the mass or emotional weight. The total probability density of finding the meaning during the cycle somewhere between the subsequent resting states (B) is one. Therefore,

$$\int_0^B |\Psi(t)|^2 dx = 1$$

where Ψ is the wave function and is the mental location of a thought

The brain's identification with the body forms the basis of homeostatic self-regulation (Criscuolo et al., 2022; Guterstam, 2015). The sense of self, such as self-identification, self-location, and temporal continuity, feeds on exteroceptive and interoceptive bodily signals (Herzog et al., 2020; Park & Blanke, 2019). Continuous and bidirectional body–brain states with a hierarchical but flexible functional organization formulate a dynamic interactive system that includes perception and response (Criscuolo et al., 2022). The interference between bottom-up and top-down processes (Prentner, 2019) generates unified first-person perception (reviewed by Chen and Spence, 2017) even from diverse, confusing, or chaotic information. The decision turns all other options irrelevant, making unity a fundamental feature of consciousness and intellect (Bayne, 2009; Deli, 2020a,b).

As bodily changes affect the brain and, inversely, emotions impact the body (Nashiro et al., 2022)ą sense of brain-body unity or oneness emerges (Criscuolo et al., 2022). Because emotions are deeply enmeshed in the brain's energy regulation processes, they have immense potential to trigger behavioral, hormonal, and bodily changes to maintain the constancy of the resting state. Emotions ensure self-identification and the constancy of the self, signaling personal guidance. Identification with our emotions can lead to adverse outcomes in interpersonal relationships (e.g., during anger or rage). Therefore, emotions serve as a master regulator, with the ability to adjust physiology and maintain optimal conditions.

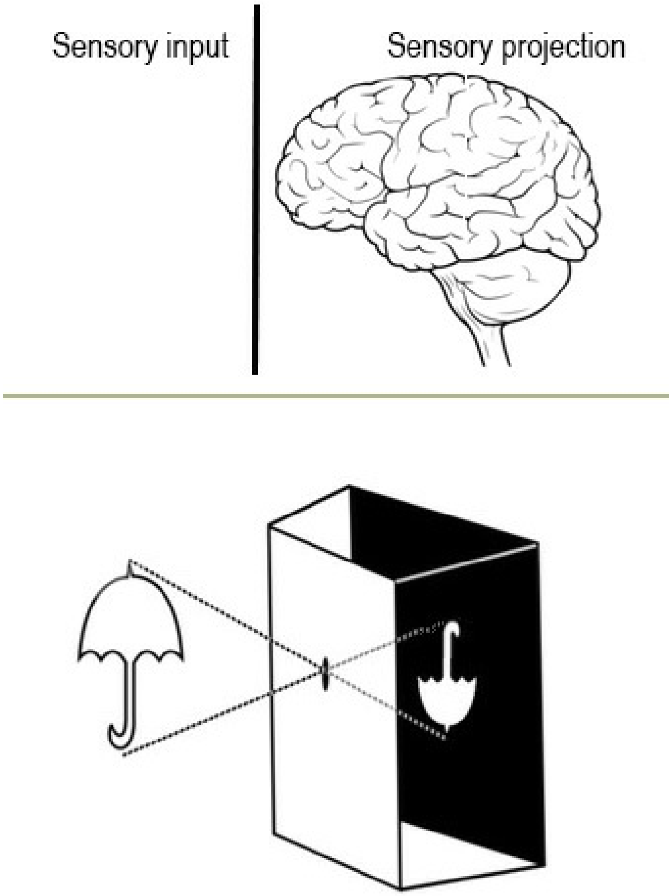

Figure 1. Representation of the brain as a closed system Sensory processing is the basis of intellect. Inputted information generates a representation (top) like a pinhole camera (bottom), e.g., the camera projects a small, upside-down image of a lit scene onto a back wall. Similarly, sensory input is projected upside down onto the cortical surface.

Table I. Analysis of quantum cognition in comparison to fermionic characteristics

Quantum mechanics		**Classical behavior**
Fermions	Quantum cognition	Decisions and beliefs
Wave function	The brain's thermodynamic cycle	The neuronal connection map
Spin (antisymmetric wave functions)	The opposite directions of the Carnot cycle represent spin-like states	Does not apply
Pauli exclusion principle	Stress triggers critical tendency and aggravation, analog to down spin.	Does not apply
Complementarity: the context generated by the first measure can influence responses to the next one	Complementary questions need to be examined sequentially, and the answer to the first question produces a context that changes the response to the next one.	Classical probability
In free regimes, energy is continuous and quantum-like	Thinking is probabilistic, fluid, continuous, and unpredictable	Predictable and well-defined
Reversible	Reversible	Irreversible
The high dimensional wave function, wave-particle duality	High-dimensional activations collapse into discrete decisions	Predictive
Heisenberg uncertainty principle	Individual action is probabilistic	Group behavior is predictable

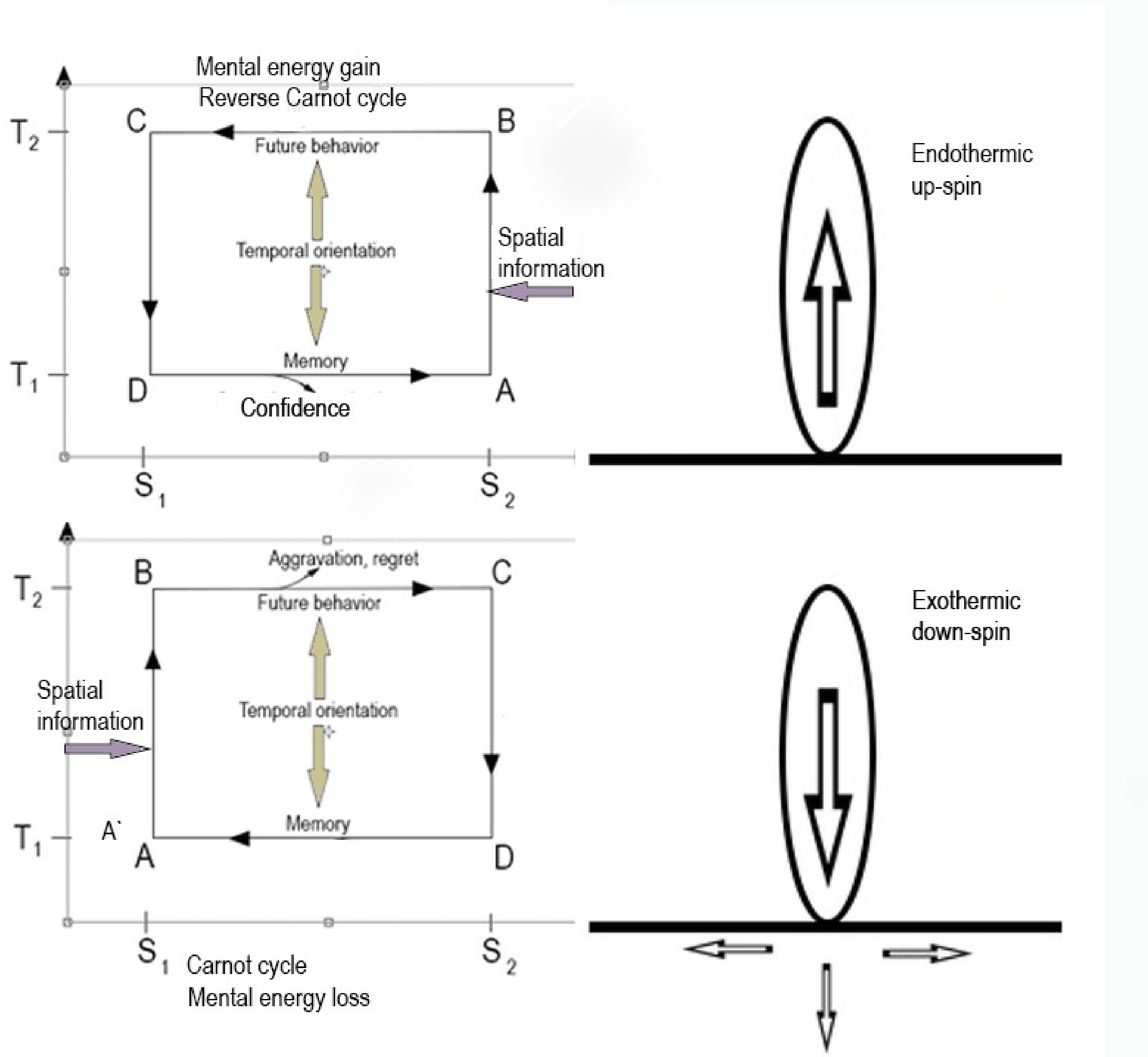

Figure 1. The thermodynamic origin of spin. Sensory interaction with the environment triggers the evoked cycle. Its energy production represents spin (left). The endothermic reversed Carnot cycle absorbs energy from the environment to enhance mental energy. It forms up spin (top), whereas the exothermic (Carnot) cycle parallels down spin (bottom). Conversely, the Carnot cycle degrades mental energy by radiating heat toward the environment (drawn after Deli and Kisvarday, 2020).

Discussion

The thermodynamic foundation of emotion-temperature relation

The brain partakes in the energy/information cycle of the physical world via the sensory system. While exothermic processes dump entropy and energy into the environment, endothermic systems reduce entropy and require energy to operate. An intelligent process acquires information X= {x_1, x_2,..., x_m} and formulates decisions Y= {y_1, y_2, ..., y_q} via complex metabolic feedback networks, which produce endothermic regulation (Seebacher, 2020; Grigg et al., 2021).

The midbrain's temperature regulation is a fundamental homeostatic process that keeps the core body temperature within a narrow range. Centralized primarily in the hypothalamus, it functions at the cellular, tissue, and, ultimately, organism level (Wang et al., 2016). Vasoconstriction, shivering, and non-shivering thermogenesis can elevate body temperature, whereas sweating and vasodilation prevent overheating (Madden & Morrison, 2019; Nowack et al., 2017). Because emotions and temperature share in a thermodynamic control, arousal, the "strength" or intensity of an emotional response, might be analogous to temperature (Escobar et al., 2021). For example, the autonomic nervous system, which encodes the perceived novelty and meaning of the stimulus, involuntarily regulates arousal (O'Neill & Schoth, 2022; Wang et al., 2018).

In addition, body temperature is often used as a proxy for emotional changes (e.g., Nummenmaa et al., 2014). For example, the word "hot" often associate with positively valenced and high-arousal emotions, while "cold" refers to negatively valenced and low-arousal emotions (Escobar et al., 2021). Accordingly, physiological changes can boost motivation (e.g., blushing when confused, shivering or sweating when stressed, or perspiring when afraid).

For example, sentiment contagion transfers information among people based on credibility, self-assertiveness, and other qualities (Goldenberg et al., 2017; Peters and Kashima, 2015). Therefore, a message or social media post's ability to motivate depends on the propagation probability or spontaneous transmission of kinetic or social energy via emotions and related behaviors (Zent and Zhu, 2019). Therefore, emotions, which serve as motivation, are an integral part of the general neural architecture of the brain (Kao et al., 2015).

In the words of Conant and Ashby, "every good regulator of a system must be a model of that system" (1991). The ability to produce an intelligent (i.e., dynamic and responsive) response to a stimulus requires a model of that stimulus (Singer, 2021; Witkowski et al., 2022). Learning is a continuous improvement of the fit between incoming sensory signals and available mental models or predictions (Schoeller & Perlovsky, 2016) through a thermodynamic modification of the functional synaptic connections. For example, increased functional connectivity lowers the resting entropy in the parietal cingulate cortex and amygdala (Rowe and Fitness, 2018). Conversely, information erasure almost always increases synaptic flexibility.

The Thermodynamic Analysis of the Evoked Cycle

Computation theory shows that only two physical processes are possible—dissipative processes reconstruct the past, and intelligent ones control the future (Cox, 1979; Deli et al., 2021; Fry, 2017). The first ones are exothermic processes, which unpack and release accumulated energy and entropy, but endothermic cycles conserve entropy while requiring energy to operate. Therefore, exothermic cycles make endothermic possible. We will compare the entropy generation of the brain with physical systems while studying the evoked activations as exothermic and endothermic cycles.

A closed system exchanges only energy (asheat or work), not matter, with its surroundings. When the cycle repeats with constant parameters, such as entropy and temperature, it forms a Carnot engine. Likewise, the evoked activities operate between resting states with constant parameters; the brain's energetically expensive regulatory function ensures resting stability with constant parameters. Moreover, sensory processing is an energy-information exchange that turns the evoked cycle into a closed thermodynamic cycle (Northoff, 2018).

The prefrontal cortex supports flexible learning and inference by tracking the "position" over the abstracted task space of the stable neuronal map (Witkowski et al., 2022). Cognition alternates between a fluid charge flow versus thermodynamic balance, continuous unconscious processing, versus discrete conscious percepts and beliefs (Herzog et al., 2020), reminiscent of the quantum and classical divide. Therefore, analogous to the wave-particle duality, the brain's probabilistic temporal rhythms (Table I) formulate discrete processing (Herzog et al., 2020).

In information theory, Shannon entropy represents the amount of information needed to represent a random variable, roughly its surprise potential. Although Shannon entropy considers discrete random variables, and the brain's intelligent computation relies on continuous energy flow, brain entropy represents a discretization of a continuous time series. In the maximum entropy situation, the signal-to-energy ratio is very high (Zheng et al., 2022). For example, access to a significant number of neural states affords high degrees of freedom, fluid intelligence (Saxe et al., 2018; Yang et al., 2019), trust, and confidence (Ryan and Deci, 2017; Van Cappellen et al., 2018). Therefore, the brain's thermodynamic cycle is representative of the psychology of motivation.

Psychological Spin

The Stern–Gerlach experiment observes the deflection of a beam of silver atoms traveling in an inhomogeneous magnetic field. The spin-statistics theorem and the Pauli exclusion principle (Peleg et al., 2010) explain the experiment's results as the quantized angular momentum. The particle probabilistic wave function gives rise to discrete angular momentum, forming up or down spin. The half-integer spin, a well-established character of fermions, dictates the atomic structure (only one electron for each possible set of quantum numbers) and the buildup of the periodic table.

Emotions' varied personal histories, cultural, and brain activity profiles (Al-Qazzaz et al., 2019; Glomb et al., 2019; Khan et al., 2017; Lin et al., 2017; Suhaimi et al., 2020; Torres et al., 2020; Zhong et al., 2019) represent only positive or negative motivation (Hesp et al., 2021; Kao et al., 2015). Therefore, emotions are the multi-dimensional representation of attitude, an instant feeling *for* or *against,* with a surprising analogy to spin.

Attitude or disposition represents the direction and magnitude of intention in an abstract vector space (Yih et al., 2018), uncovering *emotions as orientations in a Hilbert space*. Such context-dependence in decision-making contributes to the reproducibility crisis in psychology and social sciences (Basieva et al., 2019; Cervantes et al., 2018; Chang et al., 2019). Moreover, the evoked cycle's thermodynamics (Deli and Kisvarday, 2020; Deli et al., 2021; Chang et al., 2016; Pleeging et al., 2019) permit the spin's psychological interpretation as the cycle's direction.

The spin representation of information processing follows the Born rule (Born, 1926; Don et al., 2020). Let a be an observable vector with eigenvaluefor λ_i an eigenvector $\vec{e_i}$ from an orthonormal basis of eigenvectors$\{\vec{e_i}\}$ If a system such as a brain is in state ψ, then the probability $Pr(a = \lambda_i \mid \psi)$ that λ_i is observed for a equals $|\langle\vec{e_i}, \psi\rangle|^2$ Furthermore, let $B \in 2^{H^4}$ i.e., is a collection of vectors that is a subset of a 4-dimensional Hilbert vector field (each vector in this Hilbert space has coordinates (x,y,z,t),t = instant in time. The Born rule for an observable is

$$\Pr(x \in B \mid \psi) = \int_B |\psi(x)|^2 dx$$

which is the probability that the particle x is found in region B in brain state ψ

The interpretation of spinor psychology

Spin is an intrinsic angular momentum that can change signs. For example, a spinor transforms to its negative when space is rotated through a complete 360° turn. Likewise, partiality (shown by prior stimulus and after-error negativity) inverts the thermodynamic cycle. The reversal is the foundation of psychological spin because it overturns the meaning of the stimulus, turns sincere words and loving caresses into cynicism and abuse (Jiang et al., 2019; Stavrova & Ehlebracht, 2019; Zhang et al., 2019), and tragedy into a farce. Thus the evoked cycle is an abstract, multi-dimensional "spin space," which turns interaction into energy loss (exothermic cycle) or energy accumulation (endothermic cycle).

The energy states of the brain operate behind conscious awareness to modulate what we see, hear and think. The irresistible power of emotions over our behavior gives rise to the belief in free will. Rewards require thalamic neurotensin production and release (Li et al., 2018a). The endothermic cycle requires attentional focus, responsibility, bravery, compassion, altruism, and love (Buckwalter, 2019; Schubert et al., 2019). However, the exothermic cycle does not require initial energy input; it comes for "free" of mental investment, which is the common notion of "free will." Therefore, the above arguments can explain the compounded nature of attitude in long-term well-being (Chang et al., 2016; Moore & Depue, 2016; Pleeging et al., 2019).

A consequence of spinor is that only one electron can exist for each state in an atom, leading to the buildup of the periodic table of the elements. Psychological spinor may originate in the brainstem proximate and distal sensory projections (Festinger, 1954; Peng and Xie, 2016; Van Berkel et al., 2015; Wang et al., 2018). In this framework, social comparisons function as the "inner eye" for reflexive consciousness (Saaty and Vargas, 2017), with higher-power individuals perceiving a more pronounced social distance from others (Magee and Smith, 2013; Maglio et al., 2013). A hierarchic organization often infuses families, social relationships (Wato et al., 2020; van Berkel et al., 2015), career paths, and achievement (Du et al., 2019; Phan et al., 2019).

Therefore, emotions are central to behavior and self-determination (Fang et al., 2018). Even in the non-verbal language of the body, emotional valence and intensity communicate something essential about a person's credibility, popularity, and other qualities. Therefore, although emotions often remain hidden from conscious awareness, they underlie all cognitive processes and decision-making (Beall and Tracy, 2017). The involuntary nature and action-producing power of attitude are perhaps the best indications of the energy nature of emotions. Therefore, emotions represent the fundamental forces of motivation.

The Down Spin Psychology

A Carnot cycle acts as aheat engine. It performs work by transferring entropy from a hot to a cold reservoir during a complete thermodynamic cycle. Similarly, perception forms a thermodynamic cycle, operating between two information reservoirs. Because the information value of incoming stimulus depends on experience, education, and mood, the energetic needs of perception, i.e., resting state recovery, change constantly.

We speculate that the evolutionary purpose of the Carnot cycle has been mitigating mistakes in changing life conditions. Although it is difficult to distinguish particular emotions, the difference between happy and negative emotions (such as fear, sadness, anger, and disgust) is distinct (Esghaei et al., 2022). Frequency-based binary emotion classification (positive and negative) can achieve 96.81% accuracy (Gao et al., 2022). Therefore, based on brain activation profiles, emotional valence is positive during lower frequencies and negative amid information-heavy higher frequencies (Gao et al., 2022; Hesp et al., 2021).

Although rewards require thalamic neurotensin production, punishment learning is free, without energy investment (Li et al., 2018a). However, negative emotions' cumulative effects in the frontal lobe (Gao et al., 2022) lead to remorse, anxiety, guilt, rumination (Lugo et al., 2020), and mind-wandering (Beshai et al., 2018; Laws, 2019; Ruan et al., 2020; Sedighimornani, 2019) (Figure 3). In addition, it takes persistent mental effort to alleviate the cognitive burden of the information-rich self-focus (Bechler et al., 2019; Stringer et al., 2019; Wang et al., 2021).

Likewise, high arousal causes erratic behavior, criticism, verbal attack, aggression, or physical violence due to unstable, high-frequency information processing (Lugo et al., 2020; Laws, 2019; Ruan et al., 2020; Vries, 2017). Even negative facial expressions increase arousal via the hypothalamus (Dureux et al., 2022), narrowing focus and reducing the degrees of freedom (Apazoglou et al., 2019; Rowe and Fitness, 2018; Wang et al., 2019), which corrupts neutral and positive information processing (Flechsenhar et al., 2022). Increased functional connectivity lowers the resting entropy in the parietal cingulate cortex and amygdala (Rowe and Fitness, 2018).

Higher frequencies and accompanying behaviors impose significant energy costs on the neural system (Kao et al., 2015; Saarimäki et al., 2017). As speeding reduces the engine's fuel economy, cognitive information accumulation overwhelms the neural system (Dureux et al., 2022; Gao et al., 2022). For example, glutamate accumulation during long, demanding work corrupts decision control (Wiehler et al., 2022), causing deterministic, compromised post-error behavior (Nuno-Perez et al., 2021; Inzlicht et al., 2015). Energy loss turns the focus on the past (down spin).

The long-term stress-inducing power and feeling of permanence of negative emotions were confirmed recently (Gao et al., 2022; Li et al., 2018b; Yang et al., 2018). Therefore, the exothermic low resting entropy cycle (Table II) can stabilize through a Bayesian process by increasing stress sensitivity (Hollis et al., 2015; Picard & McEwen, 2018; Wiehler et al., 2022). Therefore, the pronounced energy needs of negative emotions turn the evoked cycle into an exothermic energy loss. Therefore, mental diseases might have a thermodynamic origin.

Table II. The thermodynamic and psychological consequences of basic emotions.

The thermodynamic cycle of cognition	Reversed Carnot cycle – Endothermic conditions	Carnot cycle - Exothermic conditions
Entropy	High entropy resting-state	Low entropy resting-state
Mental state	Positive emotions, novelty	Negative emotions, repetitious thinking, aggravation, and violence
Temporal orientation	Future orientation	Past focus
Frequencies	Slow, information-poor oscillations	High, detail-oriented frequencies accumulate information
Future degrees of freedom	Expanding degrees of freedom	Loss of degrees of freedom
Thermodynamic consequences	An endothermic cycle absorbs energy and entropy from the environment.	An exothermic cycle dumps energy and entropy onto the environment.
Consequences for the organism	Mental energy accumulation (intellect)	Mental energy degradation → insecurity, mental and immune problems, depression

The Consequences of the Exothermic Cognition

The typical exothermic mental degradation follows a two-step process: criticism and physical violence, insecurity, and low self-esteem, followed by hormonal disturbances, depression, or disease (Table II). Nevertheless, the trajectory of degradation can show significant individual differences. For example, mental energy loss in introverts might not produce any behavioral symptoms until mental or hormonal disturbances cause psychotic disorders or cancer.

Repeated stress exposure in rodents corrupts connectivity and reduces plasticity within the medial prefrontal cortex (PFC) to drive depressive behavior (Li et al., 2018b; Yang et al., 2018). Increased functional connectivity lowers the resting entropy in the parietal cingulate cortex and amygdala (Rowe and Fitness, 2018) in proportion to the severity of cognitive impairment (Wang, 2020). Cognitive rigidity (putamen and cerebellum) (Hua et al., 2020) corrupts temporal coherence and self-identity (Sugimura et al., 2021).

Anxiety (Stringer et al., 2019; Zanin et al., 2019) and rumination (Lugo et al., 2020) occupy significant attentional resources. For example, depression's excessive energy requirements corrupt energy regulation (Kao et al., 2015; Saarimäki et al., 2016, 2017). Corrupted energy regulation is a precursor of pathologic brain conditions (Contreras et al., 2020; Greene et al., 2019; Rowe and Fitness, 2018), mental and other health problems (Kao et al., 2015; Picard et al., 2018; Trevisiol et al., 2017). Immune dysregulation (reviewed by Morey et al., 2015, 2016) triggers stress hormones (Alhussien & Dang, 2020; Kekic et al., 2020; Koomen et al., 2020).

The Up Spin Psychology

Life has a temporal existence. Because mistakes represent a failure to move forward, corrections require future focus (Deli et al., 2018; Deli, 2020b; Fry, 2017; Cox, 1979). In turn, future orientation is a significant factor in achievement, well-being, health behavior, risk behavior, and retirement planning (Kooij et al., 2018; Li et al., 2019).

Just as a lower rpm engine can produce more significant outputs, intelligent computation or correcting mistakes requires a mental slowing down (Ryan and Deci, 2017). Energy frugal positive emotions leave energy for attention and motivation (Haimovitz et al., 2019). According to Landauer, resetting the system's memory frees memory for new information (Landauer, 1961). Therefore, intelligent processing is analogous to information erasing, which must decrease the temperature (O'Neill and Schoth, 2022) and increase neural flexibility.

The reversed Carnot cycle loops around a high entropy resting state (Gao et al., 2022), increasing the degrees of freedom (Deli and Kisvarday, 2020; Deli et al., 2021; Wissner-Gross and Freer, 2013) through optimism, confidence, and goal-directed and purposeful action (Ryan and Deci, 2017; Van Cappellen et al., 2018). Slow frequencies can access broader cortical areas (microstates), supporting associative representations (Machado & Cantilino, 2016; Tozzi et al., 2017) and adaptive strategies (Brockman et al., 2017; Pavani et al., 2016).

In line with the aforementioned slow oscillations, the resting-state temporal variability, i.e., high entropy, correlates with fluid intelligence (Yang et al., 2019), intellectual humility, and openness (Zmigrod et al., 2019). Slowing down can be an awe moment, but it often takes work, learning, or struggle. For example, acceptance removes the emotional weight of suffering by turning it into confidence and wisdom (Huang et al., 2020b; Jans-Beken et al., 2019; Ng et al., 2020).

Optimism reinforces itself through a Bayesian process (Table II). For example, novelty (high surprise value) inflates reward expectations and dampens uncertainty (Cockburn et al., 2022), predisposing the endothermic cycle through the suitable allocation of attentional resources (Schoeller & Perlovsky, 2016). In addition, positive psychology recognizes the role of a supportive environment or a positive mind in achievement (Buckwalter, 2019; Schubert et al., 2019). The above results confirm positive emotions' pivotal role in meaning-making, social relationships (Du et al., 2019; Phan et al., 2019), self-reliance (Makarevskaya, 2018), and academic performance (Carmona-Halty et al., 2019).

Therefore, mental energy is the brain's structural quality (Dabaghian, 2019; Debatin, 2019; Dupree et al., 2019), ensuring the wisdom of the sage, the expertise of a doctor, a lawyer, or an expert. Thus, the thermodynamics of emotions can explain the compounded nature of attitude in long-term well-being (Chang et al., 2016; Pleeging et al., 2019). Therefore, mental progress and freedom of action might be fundamental psychological requirements for healthy mental function.

The Role of Time in Cognition

The way energy interacts with matter is the basis of the "arrow of time." Its thermodynamic interpretation connects time to entropy production (Gaspard, 2005; Andrieux et al., 2007; Lucia & Grisolia, 2020; Roldán and Parrondo, 2010) and the loss of work potential. The healthy brain's irreversible resting activities' entropy production (Zanin et al., 2019) enhances creativity, novelty, beauty, and work potential (Fitness & Curtis, 2005). Therefore, in contrast to the arrow of time, the brain's irreversible activations (Zanin et al., 2019) "reverse" time's arrow.

Cognitive efficiency is the function of the distribution of brain network dynamics (Tomasi et al., 2017), where endothermic processes differ in their microscopic organization from exothermic ones. Endothermic activity economizes cognitive resources (Poldrack, 2015; Velasco et al., 2019). Better fractal power (the power-law exponent) in diverse cortical areas, such as gamma oscillations in the somatomotor cortex during states of enhanced vigilance, alpha waves in posterior zones with eyes open, and others (Bongers et al., 2020) boost performance (Manohar et al., 2018; Van Cappellen et al., 2018).

Gradually increasing mental energy permits wholesome emotional experiences (Deak et al., 2022), openness, and optimism. Therefore, emotional intelligence, a measure of mental power, is associated with intensive affective experiences. It gives the courage to take hold of opportunities and the capability to take advantage of them. However, happiness is not a state that can be permanently maintained; even occasional adversity, such as seeing a negative face, increases time perception (Gladhill et al., 2020). The physiological signature of the stress response is adaptive insofar as it allows for rapid and flexible action selection (Fadok et al., 2017), leading to a close connection between time perception and emotion. The relativity of time perception introduces an urgency or relaxation that produces powerful motivation and engenders a gradual mental evolution.

In physics, space and time are interconnected flexible fabrics that lead to time dilation via Lorentz's transformation. The spatiotemporal correlations of dynamic brain activities project space into a temporal manifold (Northoff et al., 2019; Tozzi et al., 2017): the temporal projection of a spatially sectioned environment (Tsao et al., 2018; Keppler, 2018). Thus, consciousness emerges from a topologically structured phenomenal space (Prentner 2019). The non-linearly changing biological and psychological needs modulate motivation between urgency and relaxation (Fang et al. 2018).

The present moment is a flexible fabric that stretches or contracts depending on personal psychology (Gladhill et al., 2020). Both awe and mortal danger slow the inner clock (Tozzi et al., 2017) via a subjective, arousal-dependent dilation of the present moment (Lubashevsky, 2018; Tsao et al., 2018; Xu et al., 2018) but parallels contrasting psychological, intellectual, and health consequences. Positive states induce relaxation, wisdom, and generosity due to the wealth of time, whereas the stress of negative emotions leads to impatience and impulsivity.

We have shown that the equivalence principle, that the laws of physics are the same everywhere, also applies to cognition. The universality of physical laws indicates the fundamental coherence of the natural world. The contrasting work production in material systems and the mind indicate their orthogonal relationship, which might provide a possible thermodynamic argument for intellect's evolutionary emergence. Living systems are highly efficient energy and entropy absorbers, an ability exponentially increasing during biological and technological evolution. Therefore, the second law of thermodynamics facilitates complexity, intellect, and social advancement.

By carrying information about past experiences, visceral signals can provide rapid somatic feedback on the proper action selection process in a new situation, thereby acting as a secondary decision inducer (Nashiro et al., 2022). This kind of reinforcement exaggerates the original perception and leads to non-linear emotional regulation, which accelerates the decision process, particularly in stressful environmental conditions (fight, flight, freeze).

Despite a non-linear regulation, emotions oscillate around a neutral position (Northoff & Tumati, 2019), indicating the existence of an emotional set-point. As endothermy keeps body temperature within a specific range, emotion regulation is an individually, culturally prescribed mental optimum cognition. Without the ability to look under the hood, emotions serve mental equilibrium by adjusting neural circuits, including serotonergic circuits, in controlling cognitive function and mood (Lowry et al., 2009).

This way, emotions determine the perception and response. The immense power of emotions to influence physiology underlines the energy nature of emotional states (Ellard et al., 2017) (Figure 2). In this view, blushing, psychogenic shivering, or even perspiration during stress are part of psychological homeostasis. These thermoregulatory pathways release emotional tension to maintain cognitive constancy based on cultural, learned, genetic, and subjective-personal characteristics (Kolvoort et al., 2020; Wolff et al., 2019). Emotions are the fundamental forces of motivation and the master regulators of personal cognitive comfort.

Discussion and Conclusions

Life is a low entropy state maintained by homeostatic regulation occurring on many levels. In endotherms, cognitive self-regulation centered on the resting state sits at the top of this hierarchy, with emotions providing feedback on every aspect of bodily welfare and feedback to the brain's predictions. The emotional master regulation maintains a genetically, culturally, and personally determined cognitive comfort.

According to Conant and Ashby, "every good regulator of a system must be a model of that system" (1991). The ability to produce an intelligent (i.e., dynamic and responsive) response to a stimulus requires modeling the physical environment (Singer, 2021; Witkowski et al., 2022). The sensory system projects the physical laws into the temporal brain, which provides the neural system with a fermionic organization.

Entropy can quantify complexity, a fundamental property of conscious experience. Quantum systems give rise to classical outcomes, but the brain, a classical system, can produce quantum behavior. Perception, a closed, reversible, and probabilistic thermodynamic cycle, is a quantum-like system. This dichotomy may account for many puzzling features of the mind, such as unconscious, vs. conscious states, beliefs and uncertainty, context dependence, and cognitive constancy despite continuous mental evolution.

The varied brain activity profiles and multi-dimensional representations of emotions represent only two energy directions (up and down) of psychological spin. The endothermic cycle parallels up spin, whereas the exothermic cycle corresponds to down spin. The psychological spinor gives rise to hierarchic outcomes. Therefore, psychological spin has real, measurable, long-term consequences.

Nevertheless, the resting state's stability and evolution give rise to classical features. The energy input of attentional focus, arising from a positive environment, learning, or acceptance, ensures an endothermic cycle. In turn, future orientation is a significant factor in achievement, well-being, and intellect, inspiring novelty, future orientation, and creativity. The exothermic cycle disperses energy and entropy onto the environment through criticism, aggravation, or physical violence. Information accumulation lowers entropy and introduces reversible resting activations, which trigger repetitive thinking and remorse. Hormonal problems can cause psychological dysfunction and disease.

The orthogonal transformation of sensory information turns cognitive processes into a holographic, temporal organization based on memories, which helps to anticipate environmental changes. Consciousness is the awareness of being separate from the environment, which defines a separate, inner mental cosmos. The smallest unit of intellect is the first-person conscious experience, which is not available to anyone else.

The mind's self-referential nature (the inside, unique view of the individual) is a particle-like isolation that can explain some of the most intractable aspects of consciousness. The mind is both the observer and observee of the brain (Dennett, 2018). The fermionic mind hypothesis recognizes the temporal mind's separate, first-person view of the conscious experience, which can explain numerous puzzling features of the mind.

Understanding emotions as the fundamental forces of motivation can aid education, psychiatry, animal husbandry, and other fields. In addition, the thermodynamic study of emotions will inspire better AI. Computer simulations, such as the Blue Brain Project and psychological studies, can validate the hypothesis.

Data Availability

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

The authors have no competing interests to declare.

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