Beyond Wave-Particle Duality: The Wave Energy Exchange (WEX) Principle and the Intrinsic Wave Nature of Matter

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Abstract

Classical physics was built on a ‘particle view’ of matter where fundamental entities were assumed to be tiny indivisible structures with objective properties and permanent existence. This view was held from the earliest days of scientific thought until the 1920s when experiments and theories began exposing a wave aspect of matter. This led to ‘wave-particle duality’ where fundamental entities exhibited both wave-like and particle-like behaviors, a view that remains the default assumption to this day. Yet numerous mysteries and paradoxes remain unresolved under the wave-particle view despite a century of investigation into quantum phenomena, suggesting it may not be the correct lens to view fundamental entities.

This paper argues that quantum mysteries and paradoxes arise from mathematics, interpretations, and terminology that remain primarily grounded in the assumption that particles are fundamental constituents of reality while attributing little-to-no ontological status to the wave aspect of matter. Physicists speak of particles in superposition existing in multiple places simultaneously, particles having hidden properties when not being measured, wave functions collapsing from many possible particles in superposition to one actual particle upon measurement, entangled particles influencing one another at a distance, and so on. This particle-centric perspective and terminology was useful in the 1920s as physicists grappled with fitting the newly discovered wave behaviors into their existing particle physics framework, but they have become an obstacle to understanding what quantum physics is telling us about the intrinsic nature of matter. It is time to consider a third possibility where the intrinsic nature of matter is not particle-like, not wave-particle-like, but purely wave-like. This paper explores the wave nature of matter as an ontological position and traces its consequences through an array of quantum mysteries.

Eleven quantum formalisms are explored which differ significantly in their mathematical structures, objects they treat as fundamental entities, and the higher dimensional abstract mathematics used to make predictions. Yet each directly represents or predicts that fundamental entities evolve continuously, exchange energy in discrete amounts, have extended structures that exhibit wave-like interference and non-local entanglement, and produce precise values only when they are measured. In short, they describe wave behaviors more than particle behaviors. These shared features across formalisms logically provide a more reliable guide to the intrinsic nature of fundamental entities than any single formalism can provide from its unique and abstract mathematical vantage point. These shared features are embedded into a wave realism claim whose consequences will be traced throughout the mysteries and paradoxes of quantum physics:

> **The Wave Energy Exchange (WEX) Principle:** The sole persistent constituents of physical reality are energy waves that have spatial extent, dynamical structures, and exchange energy in discrete quanta. Particles with precise properties are point-in-time energy signatures of quanta absorbed by measurement devices.

Energy waves have extended dynamical structures that evolve over time and carry no precise values of any kind. Precise values only appear in the 'energy signature' of a quantum absorbed by a measurement device. Measurement devices essentially take a 'snapshot' of the absorbed energy at a specific point in space and time, translate it into the variables used in physics equations, and store the values of the variables as property values in memory and display them on screens. In short, the WEX principle asserts that particles are illusions and energy waves are the sole ontological primitive. Twelve precise definitions are offered for currently undefined terms in standard quantum theory which remove ambiguities and allow the WEX principle to naturally resolve numerous quantum mysteries and paradoxes.

1. Introduction

The 'particle view' of matter was first proposed by Greek philosopher Democritus around 400 BCE and persisted for millennia until quantum theory uncovered a wave aspect of matter. [1,2] The 'wave-particle duality' view quickly replaced the particle view as this hybrid framing allowed for both wave and particle aspects of fundamental entities, depending on context.

The paper argues that quantum mysteries and paradoxes arise from mathematics, interpretations, and terminology that remain grounded in the assumption that particles are fundamental constituents of reality while attributing little-to-no ontological status to the wave aspect of matter. Physicists speak of particles in superposition existing in multiple places simultaneously in an abstract higher-dimensional mathematical space, rather than considering the possibility the quantum formalisms are describing physically real wave energy patterns in our physical universe. Elementary particles are viewed as possessing hidden properties when they are not being measured, whereas the wave energy patterns described by quantum formalisms have spatial extent that span many points in space and have dynamical properties that evolve over time. Wave functions are viewed as collapsing from many possible particles in superposition to one actual particle upon measurement, instead of viewing measurement as an extended wave energy pattern that exchanges energy with a measurement device at a specific point in space and time. Entangled particles influence each other at a distance, yet wave functions of entangled pairs describe only a single inseparable wave-like entity. These particle-centric perspectives and terminology were useful in the 1920s as physicists grappled with fitting the newly discovered wave behaviors into their existing particle physics framework, but they have since become an obstacle to understanding what quantum physics is telling us about the intrinsic nature of matter.

The wave-particle duality view was developed to integrate the particle and wave aspects of matter into a coherent physics framework. But in practice quantum physics has remained overly committed to the particle aspect of matter while treating the wave aspect of matter as an experimental artifact that must be addressed but is not generally viewed as having equal ontological status as particles. Since the particle view and the wave-particle view have been unable to resolve the mysteries and paradoxes that pervade quantum theory, this paper will explore an adjacent ontology, that the intrinsic nature of matter is not particle-like, not wave-particle-like, but purely wave-like. The paper is not offering a wave function realism view, but a wave realism view. Wave function realism has been extensively explored in higher dimensional spaces and in the many-worlds interpretation. The present claim is that physically real energy waves are the sole ontological primitives existing within the space and time dimensions of our physical universe, not in an abstract higher dimensional mathematic space.

The mysteries of quantum physics are further compounded by the lack of precise definitions for many important terms used in the field. For instance, there is no definition for what constitutes a measurement nor a measurement device, which leads directly to the ambiguities surrounding the measurement problem, the central mystery of quantum physics. There is no guidance nor set of rules to define the proper scope for modeling quantum systems with wave functions, creating ambiguity for locating Heisenberg cuts for any given quantum system, which directly leads to paradoxes such as Schrodinger's Cat, Wigner's Friend, and Frauchiger-Renner. The paper aims to resolve these ambiguities and confusion by stripping away ill-defined particle-centric language and replacing it with 12 precisely defined wave-native terms (§3).

Eleven quantum formalisms are compared (§2). They predict the same measurement outcomes using radically different assumptions for their mathematical constructions, the central objects they treat as fundamental, and the abstract mathematical techniques used to make predictions. Extrapolating each of their unique architectures and assumptions leads to widely divergent and conflicting ontologies, hence they cannot all be accurate in their depictions of fundamental entities. Which formalism ontology is correct is left to personal preference as opposed to science and logic. The paper argues that the most accurate ontological insight is based on the common features that all formalisms share because their overlap is more likely to depict fundamental entities more accurately than any one formalism can in isolation. The eleven formalisms all directly represent or predict six shared features of fundamental entities: continuous evolution when not being measured, discrete energy exchange when being measured, extended structures, wave-like interference, non-local entanglement, and definite property values appearing when fundamental entities are measured in the physical universe.

The paper offers no new mathematics but instead an ontological reading of the common features from a wave realism perspective. This view suggests the fundamental constituents of matter are physically real spatially extended energy patterns, which exhibit wave interference and non-local entanglement effects, that dynamically evolve as they propagate through our physical universe and only produce defined property values when they exchange energy in discrete amounts with measurement devices. 'Wave packet' is the term used in standard quantum theory to describe the wave-like energy patterns whose behaviors are modeled by wave functions, so wave packet will be used throughout the paper to refer to these fundamental entities and precisely defined in §3.1.

The 12 precise definitions combined with a wave realism ontology grounded in shared formalism features together resolve longstanding mysteries and paradoxes that remain unresolved under the wave-particle view of fundamental entities. The paper embraces this perspective in a single claim called the Wave Energy Exchange (WEX) Principle, and will trace its consequences throughout the mysteries and paradoxes of quantum physics, yielding the following insights:

- The collapse postulate is replaced with quantized energy exchange, a physical mechanism integrating the Standard Model with the formalisms. Measurement outcomes are definite and localized because quantized energy exchange is discrete and positioned. (§4)

- Entanglement becomes wave packet unification, a merging of physically real wave packets that combine their energy structures to form a single unified wave packet with the aggregate energy structure of the merged wave packets. Nothing is correlated in this view because there is only one wave packet and wave packets carry no values to correlate. (§5)

- Bell's theorem assumes entangled systems are separable and carry pre-existing values that can be correlated. WEX evades Bell because a unified wave packet is a single non-separable object and carries no pre-existing values to correlate, consistent with the non-separable wave function of entangled systems evolving as single unified objects. Conservation laws acting on a single extended structure give a physical account of the complementarity underlying EPR correlations. WEX does not claim locality pervades physics but confines it to energy redistribution within individual wave packets. (§6)
- Weak measurement defines no value during the weak interaction because the coupling does not produce a quantized energy exchange, accounting for the system's minimal disturbance and offering a straightforward reading of anomalous weak values. (§7)
- Delayed choice experiments require no retro-causality because no which-path value exists before an energy exchange defines one, and wave packets always go through both slits. Double-slit, delayed-choice, entangled-pair, and Bose-Einstein condensate experiments share one physical description: a single extended wave packet undergoes a localized energy exchange that constrains the remainder through conservation laws. (§8)
- Energy exchange alters the physical structure of the wave packets involved, requiring wave function reconstruction after each exchange to accurately model the updated state of the system. Observer paradoxes are resolved by removing observers and other objects not involved in the next energy exchange that triggers wave function reconstruction. (§9)
- There is no boundary between the quantum and classical worlds where quantum dynamics cease to exist. Wave packet energy exchange dynamics apply at all scales of the universe from organic molecules, to living organisms, to the plasma that forms stars and the solar wind, to the dynamics of event horizons surrounding black holes. (§10)
- Quantum Information Theory (QIT) becomes the study of how wave packet structure constrains energy exchange, determining which measurement outcomes are possible. What changes is the context, not the experimental results. QIT is the study of information production, not information discovery. (§11)
- Quantum computing exploits two complementary resources: wave packet geometry (hardware) contains infinite structural degrees of freedom, and quantum algorithms (software) manipulate this geometry through controlled sub-quantum energy exchange. The result is a geometrically optimized answer defined at measurement, a form of geometric computing that is far more powerful than binary computing. (§12)
- WEX is scale-independent, formalism-agnostic, and geometry-independent. It applies equally to non-relativistic and relativistic systems, in Euclidean or curved geometries, across any number of dimensions, and is independent of mathematical frameworks describing wave packet dynamics. (§13)

2. Common Features of Quantum Formalisms

There are many quantum formalisms that predict, within their domains, the same set of empirically validated results gathered over a century of quantum experiments. Table 1 provides a high-level overview of the mathematical constructions of eleven formalisms.

Table 1. High-Level Mathematical Construction of Quantum Formalisms

Formalism	Central Object	Localization	Required Dimensions	Relativistic
Wave Mechanics [1]	Wave Function	Collapse Postulate	3N plus Time (N = Number of Particles)	With Modification
Matrix Mechanics [3]	Observable Matrices	Collapse Postulate	Infinite Dimensional Matrices	Adapts Naturally
Phase-Space [4,5]	Quasi-Probability Distribution	Collapse Postulate	6N plus Time (N = Number of Particles)	With Modification
Density-Matrix [6]	Density Matrix	Collapse Postulate	Operators on Infinite Dimensional Space	Adapts Naturally
Second Quantization [7]	Occupation Number of Field Modes	Collapse Postulate	Infinite Dimensional Space of Occupation Numbers	Adapts Naturally
Path Integral [8]	Sum over Histories	Not Addressed	Infinite Dimensional Space of Paths Through 4D Spacetime	Adapts Naturally
Action Principle [9]	Quantum Action Principle	Collapse Postulate	Fields over 4D Spacetime in Infinite Dimensional Space	Adapts Naturally
Algebraic QFT [10]	Algebras of Local Observables	Not Addressed	Regions of 4D Spacetime with Infinite Dimensional Representations	By Construction
Hamilton–Jacobi [11]	A Complex Action	Collapse Postulate	3N plus Time (N = Number of Particles)	With Modification
Pilot Wave [12]	Wave Function plus Hidden Particles	Not Needed	3N plus Time (N = Number of Particles)	With Modification
Direct-Action [13,14,15]	Direct Interactions Between Charges	Energy Absorption	4D Spacetime plus Infinite Dimensional State Space	By Construction

Wave mechanics became the standard framework in the 1920s for practical reasons. Its differential equations used mathematics that physicists were already familiar with from modeling the wave behavior of sound, light, and vibrating structures. It made models of the hydrogen atom far easier to solve than matrix mechanics (its main competitor in the 1920s) and its wave concepts were much easier to visualize than abstract matrices.

While wave mechanics remains the dominant formalism, other formalisms are routinely used for applications where their unique mathematical structures simplify certain types of calculations. Matrix methods are preferred for quantum circuits, second quantization for many-particle systems, path integrals for particle collisions, and phase-space methods for quantum optics. Since all formalisms yield the same predictions where their domains overlap, physicists can use them as interchangeable models of the behavior of quantum systems, with the nature of the problem at hand driving the choice of formalism used to model any given system.

Some formalisms are relativistic by construction, some adapt naturally, and others require modifying or replacing their core equation. The 4D spacetime manifold of relativity theory is the conventional mathematical model used to describe the physical universe, a model that WEX accepts as a mathematical tool but not as an ontologically real object. The universe itself is physically real in WEX, not its spacetime model.

Relativistic quantum field theory (QFT), including the Standard Model, is not a separate formalism but is expressed through second quantization, path integral, and algebraic formulations. QFT is commonly read as treating elementary particles as excitations of underlying quantum fields, making quantum fields more fundamental than particles. WEX treats quantum fields as part of QFT's abstract mathematical model that requires infinite mathematical dimensions to model a quantum system's degrees of freedom. Neither WEX nor the mathematics of QFT requires treating quantum fields as physically real substances existing in the physical universe. Quantum direct-action electrodynamics shows that electromagnetic fields can be removed from the mathematics altogether without changing its predictions for the scattering processes analyzed, provided all emitted energy is eventually absorbed. [14] The concept of quantum fields is a useful mathematical tool for modeling purposes but need not be ontologically real and is not a shared feature across formalisms. Under WEX, wave packets (defined in §3.1), not fields, are the sole fundamental physical entities that QFT describes. This is consistent with WEX's treatment of wave packets as spatially extended, since the sharpest objections to the particle ontology of QFT concern strictly localized, point-like particles.

Each formalism relies on add-on frameworks to handle different kinds of problems such as perturbation theory for systems too complex to solve exactly, the Pauli equation for spin, and the Dirac equation for relativistic particles. Each formalism also requires additional mathematical adjustments to ensure it produces accurate predictions, such as boundary conditions, absorber conditions, normalization, renormalization, ordering rules, regularization, gauge fixing, and/or rotation to imaginary time.

Seven formalisms do not address the measurement problem and instead add an ad hoc collapse postulate from outside the mathematics as a proxy for localization physics. Two do not address localization at all, and pilot-wave theory evades it by assuming particles exist with definite positions both pre- and post-measurement. Direct-action theory as further developed in the transactional framework addresses localization with physics attributing it to energy absorption [15], a view that is consistent with WEX.

The formalisms have radically different mathematical objects at their core: wave functions, observable matrices, quasi-probability distributions, density matrices, occupation numbers of field modes, histories, action principles, a complex action, algebras of local observables, a wave function guiding hidden particles, and direct interactions between charges without an associated field. The formalisms all rely on higher-dimensional mathematical spaces to model the properties and behaviors of their core mathematical objects and to predict the range of possible outcomes of measurements of quantum systems.

Since all eleven formalisms predict the same results within their domains using vastly different frameworks, the paper views them as valid mathematical models to predict the behavior of fundamental entities and refers to 'formalisms' in the plural sense throughout the paper. What is rejected is that their abstract mathematical models accurately describe the intrinsic nature of the fundamental entities whose behaviors they describe.

The significant diversity in core mathematical objects, add-on frameworks, procedural adjustments, and the reliance of all formalisms on abstract mathematical spaces with many more

dimensions than our physical universe suggest that no single formalism should be taken literally as an accurate depiction of the fundamental entities as they truly exist. Extrapolating the mathematics of any single formalism to make ontological claims about the intrinsic nature of reality yields vastly different ontologies based on the formalism chosen, many of which are incompatible with one another. This approach would confuse a mathematical model with the fundamental entities the models collectively describe. It would be akin to confusing a map with the territory the map describes. The paper argues that any ontological speculation should be grounded only in the common set of features that all formalisms share, which is logically more likely to accurately describe quantum reality than any one formalism can in isolation. The most sure-footed ontological claims are grounded in the overlap of shared features across formalisms.

Table 2 identifies six shared features that are either represented in each formalism's central mathematical object or predicted in its results. A seventh column denoting how each formalism handles 'values pre-measurement' has been included for additional context since many quantum mysteries revolve around the assumption that particle-like properties exist and have values pre-measurement, yet the column contents illustrate this is not a shared feature.

Table 2. Common Features Across Formalisms

Formalism	Continuous Evolution	Discrete Energy Exchange	Extended Structure	Wave-Like Interference	Entangled Structures	Values At Measurement	Values Pre-Measurement
Wave Mechanics	Represented	Predicted	Represented	Represented	Represented	In Space & Time	Only in Abstract Mathematical Space
Matrix Mechanics	Represented	Represented	Predicted	Predicted	Represented	In Space & Time	Only in Abstract Mathematical Space
Phase-Space	Represented	Predicted	Represented	Represented	Represented	In Space & Time	None
Density-Matrix	Represented	Predicted	Represented	Represented	Represented	In Space & Time	Only in Abstract Mathematical Space
Second Quantization	Represented	Represented	Represented	Represented	Represented	In Space & Time	Only in Abstract Mathematical Space
Path Integral	Represented	Predicted	Represented	Represented	Predicted	In Space & Time	None
Action Principle	Represented	Predicted	Represented	Represented	Predicted	In Space & Time	Only in Abstract Mathematical Space
Algebraic QFT	Represented	Predicted	Indirectly Represented	Predicted	Represented	In Spacetime Regions	Only in Abstract Mathematical Space
Hamilton–Jacobi	Represented	Predicted	Represented	Indirectly Represented	Indirectly Represented	In Space & Time	None
Pilot Wave	Represented	Predicted	Represented	Represented	Represented	In Space & Time	Position in Spacet & Time (Others in Abstract Mathematical Space)
Direct-Action	Predicted	Represented	Predicted	Represented	Predicted	In Space & Time	Only in Abstract Mathematical Space

Every formalism either represents or predicts that fundamental entities evolve continuously, exchange energy in discrete amounts, have extended structures, exhibit wave-like interference, exhibit non-local entanglement effects, and produce definite property values when measured in the space and time of our physical universe where physicists and measurement devices exist.

The pre-measurement column shows that ten formalisms assign no definite values prior to measurement in our physical universe. Seven assign pre-measurement values only in the higher dimensional abstract mathematical space in which the formalism is built, and three assign no pre-measurement values at all. Pilot-wave theory encodes positions in space and time by design but encodes other properties in the wave function which lives in an abstract higher-dimensional mathematical space. Note that the Hamilton-Jacobi formulation uses mathematics closely related to that of pilot-wave theory without assuming that particles have definite positions pre-measurement, thus the particle position assumption of pilot-wave theory can be viewed as an optional claim added to its mathematics upon construction as opposed to a claim required by its mathematics.

The first six columns of Table 2 define the six shared features across formalisms in which ontological claims can be reasonably grounded. The introduction made the case that it is time to seriously consider the wave nature of matter as an ontology, and the remainder of the paper will incorporate these six shared features into a wave realism ontology. The ontological commitment is that the only fundamental entities that exist are physically real energy patterns, that continuously evolve as they propagate through our physical universe, have spatially extended dynamical energy structures that exhibit both wave-like interference and non-local entanglement effects, and produce definite property values only when they exchange a quantum of energy with a measurement device at a specific point in space and time. This ontology is captured in the Wave Energy Exchange (WEX) Principle.

3. The Wave Energy Exchange (WEX) Principle

The WEX Principle is a two-sentence claim that elevates the ontological status of the wave nature of matter while denying an ontological status to particles:

> **The WEX Principle:** The sole persistent constituents of physical reality are energy waves that have spatial extent, dynamical structures, and exchange energy in discrete quanta. Particles with precise properties are point-in-time energy signatures of quanta absorbed by measurement devices.

Twelve precise definitions are provided below which attempt to remove all ambiguities and unlock the power of the WEX principle to resolve quantum mysteries and paradoxes.

3.1 Wave Packets

The WEX principle is a claim about energy exchange, so it requires an account of what exchanges energy, which in standard quantum theory are called wave packets. Wave packets are not mathematical concepts nor a wave aspect of physically real particles. They are the only physically real entities that exist in nature.

> **Wave Packet.** A physically real pattern of energy that oscillates as it propagates through the physical universe, exchanges energy, unifies (i.e. entangles) with other wave packets, and exists independent of measurement or observation. A wave packet has ‘structural features’ that include fixed *identity features* that define its species in the Standard Model and *dynamical features* that change and evolve over time. A wave packet’s structural features determine its energy exchange possibilities.

Identity Features. Intrinsic properties that define a wave packet's species in the Standard Model, including mass (i.e., rest energy), charge, and intrinsic angular momentum (i.e. spin quantum number). This category of structural features is identical for every wave packet of the same species and requires no quantum energy exchange to become defined. Inherited from the Standard Model.

Dynamical Features. Structural properties that can vary within a wave packet, including spatial extent, geometry, momentum, axis of energy rotation, handedness, frequency, wavelength, relative phase, polarization, energy distribution, and degree of unification with other wave packets. Dynamical features constrain what outcome values measurement devices can read during a quantum energy exchange.

In standard quantum theory, energy is treated as an observable, undefined until measurement, with systems permitted to exist in superpositions of energy eigenstates. Under WEX, a wave packet's energy pattern is what physically exists and it exists independent of measurement. This is no different from a radio tower emitting physically real electromagnetic energy that is absorbed by radio receivers and exists independent of whether any radio receiver is turned on. The energy a star emits likewise exists regardless of whether anyone observes it. WEX accepts energy as a physically real phenomenon at every scale of the universe that exists independent of observation.

A wave packet's dynamical features evolve over time and are altered by any form of energy exchange or coupling to a field. [16] What wave function evolution accurately tracks is the evolution of a wave packet's dynamical features in physical reality, not a superposition of observable state vectors in abstract Hilbert space. This is consistent with ordinary wave packet dynamics: a free wave packet's spatial extent evolves over time under the Schrödinger equation, a textbook result usually described as wave packet spreading. WEX takes this spreading, and structural changes generally, as evidence of a physically real, continuously evolving energy pattern, not the evolution of a probability distribution over a hypothetical future measurement outcome.

Not every mathematical feature of a wave function corresponds to a wave packet structural feature. For example, global phase has no observable consequence and reflects the abstract character of Hilbert space rather than a change in wave packet structure. Contrast that with the relative phase across a wave packet's extent, which is physically meaningful and constrains interference and energy exchange outcomes (§8). Section 3.2 defines structural evolution as energy redistribution.

Structural features are not a second kind of information. They are properties that describe the physical attributes of a wave packet as it exists in physical reality. We assign numbers to these properties (e.g., charge −e, spin quantum number ½) as tools for categorizing and analyzing wave packet structure, but wave packets carry properties, not numbers. Measurement outcome values (defined as classical information in §3.4) are different in kind: they describe attributes of an energy exchange defined at measurement, not a property the wave packet possessed before measurement.

Consider a coastline as an analogy: it has a shape, the shape is real, it consists of various materials and elevations that vary along its length, and it changes over time due to erosion, human and animal activity, and other environmental factors. These features are not information

about the coastline; they are properties the coastline 'has' in physical reality. These features exist prior to any survey, and they constrain what any survey could find. The survey records measurement outcomes with definite values and units at specific points in space and time. Wave packets and coastlines are what physically exist, while the quantitative measurement outcomes for both are informational snapshots taken at a point in space and time. The analogy has limits. A survey instrument absorbs light the coastline scatters rather than energy from the coastline itself, so it records the coastline's current state without altering it. A quantum measurement device absorbs a wave packet's energy, so the exchange both defines outcome values and alters the wave packet it measures.

Two scope notes on the definition of wave packets. First, extension and propagation are asserted as spatiotemporal. Wave packets are extended in and propagate through the physical reality we inhabit, and the arguments of Sections 6 and 8 depend on this. Second, this paper deliberately leaves open whether wave packet structure is limited to the four dimensions of space and time that we directly experience given recent research suggesting spacetime may be emergent rather than fundamental. [17,18] Whether wave packet structures are confined to 4 dimensions of space and time, extend into additional dimensions, and/or extend into a quantum substratum beneath spacetime, does not affect the WEX principle or any of its consequences. Section 13 states this position positively rather than as a hedge when it argues the WEX principle is scale, formalism, and geometry independent.

3.2 Wave Packet Energy Dynamics

Several terms related to energy exchange require precise definitions.

> **Energy Exchange.** Any transfer of energy between two independent quantum systems. Energy exchange alters the dynamical features of both systems, requiring wave function reconstruction to describe the updated structures.
>
> **Quantum Energy Exchange.** The minimal amount of energy that can be exchanged between two independent wave packets which allows them to remain independent. This threshold is interaction-relative, determined by Planck’s constant and the structural and coupling properties of the wave packets exchanging energy. Precise values are defined when a quantum of energy is emitted from a wave packet and absorbed by a measurement device. Inherited from quantum theory.
>
> **Wave Packet Unification.** An energy coupling between independent wave packets where total energy is retained within a single unified wave packet, thus independence is lost. No energy is emitted from the unified wave packet thus no point-in-time values are measured. This is the WEX definition of entanglement.
>
> **Energy Redistribution.** The movement of energy within a wave packet defines its evolving structure over time. Energy can concentrate in regions and deplete in others, dynamically changing the wave packet's geometry and coupling possibilities over time. Energy redistribution occurs independent of measurement and represents the temporal evolution of physically real energy patterns whose behavior is accurately modeled by wave function evolution.

Wave packet energy dynamics are not additional commitments but logical consequences of WEX's core ontology: wave packets are physically real energy patterns with dynamic structures

that evolve over time, are subject to conservation laws, and exchange energy. Quantum mechanics works because it accurately models the dynamics and evolution of physically real energy patterns, not because its abstract mathematics represents underlying reality. Standard quantum mechanics leaves internal wave packet energy redistribution undefined while WEX defines it as a natural feature of the energy dynamics of wave packets.

These distinctions are foundational to understanding the energy dynamics of wave packets under WEX, how measurement produces definite values (§4), how entanglement creates unified wave packets without defining values (§5), and how quantum information theory studies structural constraints rather than latent values (§11).

The compatibility of structural features between a wave packet and measurement device determines whether they can couple and exchange energy. For example, an ultraviolet light detector will not couple with light at infrared frequencies. Engineered measurement devices are designed to couple with and absorb wave packets with specific structures, capture and store attributes of the energy absorbed, and display the attributes on a screen or printout, creating the illusion that a particle with properties exists when in fact what was captured by the instrument was the energy 'signature' of an absorbed wave packet.

The structural and coupling properties of interacting wave packets determine the magnitude of energy exchanged, not only whether one can occur. In a two-dimensional electron gas subjected to a strong magnetic field, the structural and coupling properties of the electrons and the field allow current to be carried by quasiparticles with one-third the charge of an electron.[19] The structural and coupling properties of interacting wave packets therefore determine both whether a quantum of energy will be exchanged *and* the quantum of charge and energy exchanged, a point developed further in the discussion of condensed matter physics (§10).

3.3 Measurement

The lack of definitions for the terms related to wave packet localization leads directly to the ambiguities of the measurement problem and resulting paradoxes that surround it. WEX offers precise definitions for two undefined terms in standard quantum physics:

> **Measurement.** A physical process where a quantum of energy is exchanged between two systems while maintaining system independence. Measurement produces outcomes with defined values. Observation of a quantum system that does not involve direct physical interaction with the energy being exchanged does not qualify as a measurement.
>
> **Measurement Device.** Any system with the ability to absorb a quantum of energy emitted from another system while maintaining system independence. The structural and coupling properties of both systems determine the timing and type of quantum energy exchanged.

Along with the definition of quantum energy exchange in §3.2, WEX grounds measurement entirely in operational definitions connected to the formalisms, the Standard Model, and two indisputable facts about the natural world.

- Energy exchange occurs at all scales of the universe
- Both natural and engineered systems can emit and/or absorb energy

Quantized energy exchange between independent natural systems qualifies as a measurement. An example is a photon emitted by the sun and absorbed by a photoreceptor neuron in the human eye. The structural properties of the human eye and coupling of its photoreceptor neurons to photons in the visible light spectrum form a natural measurement device that produces visual information about the external world encoded in synapses for the brain to interpret.

Engineered measurement devices are designed with specific coupling mechanisms to absorb targeted energy quanta emitted by quantum systems and to produce specific types of classical information. A photographic plate is engineered with materials and couplings designed to capture location information. A Geiger counter is engineered with ionization chambers that register radiation emitted by atomic decay. A Stern-Gerlach apparatus is engineered to capture spin and location information. All scientific instruments engineered to measure quantum systems are specifically designed to couple with and absorb a specific quantum of energy emitted from a system while maintaining independence to ensure a particle signature appears and produces the targeted classical information.

A weak probe does not qualify as a measurement device because it does not maintain system independence with the system being studied, thus does not produce a particle signature so no outcome values are produced (§7). More generally, a wave packet that exchanges a sub-quantum amount of energy with any object unifies with that object, altering the packet's structure without producing a particle signature. Classical information is defined only where a quantum energy exchange occurs, so no classical information is carried in any wave packet, unified or not.

The third sentence in the measurement definition guards against conceptual confusion about a possible role for human consciousness in measurement. A photoreceptor neuron in the human eye that absorbs a photon directly from a quantum system qualifies as a measurement device, however a photoreceptor neuron absorbing a photon emitted from the display on a scientific instrument has no direct physical interaction with the energy exchange registered by the instrument, thus does not qualify as a measurement device in this context. This distinction is essential to resolving paradoxes in §9.

3.4 Outcome Values

Since wave packets contain no form of value in WEX, outcome values are defined by the measurement devices that capture and analyze the attributes of quantum energy exchanges, leading to two more definitions:

> **Particle Signature.** The point-in-time snapshot of the attributes of a quantum of energy emitted by a wave packet and absorbed by a measurement device. Particle signatures are evidence of an energy exchange event, not physical entities that exist in nature.
>
> **Classical Information.** Defined values produced when a measurement device registers a quantum energy exchange and represents it in terms of the variables used in physics models (e.g., position, momentum, spin, and polarization). The device's structure and those variables determine how the absorbed energy is represented as defined values contained in a particle signature.

‘Classical Information' is equivalent to 'Observable Values' as a description of measurement outcomes, but the two terms carry different ontological commitments. Observable values are derived from observables, mathematical operators with eigenvalue spectra in the formalism. Classical information is produced by scientific instruments that read particle signatures and report their attributes in quantities defined by the variables used in physics. WEX prefers the term ‘classical information’ because its meaning is clear and unambiguous. Observable Value is so deeply connected to Observables in quantum physics that using the term might mislead readers to think some form of value exists in wave packets prior to measurement, which WEX rules out. Meanwhile no reader will think anything defined as ‘classical’ exists in wave packets prior to measurement.

Energy and angular momentum illustrate how structural features constrain what classical information is defined in a particle signature. A wave packet's rest energy, equivalent to its mass, is an identity feature shared by every wave packet of its species. Its total energy pattern includes dynamical features that evolve between energy exchanges, such as when a wave packet’s axis of energy rotation precesses in a magnetic field. [16] Measured energy and spin values are classical information defined by a measurement device and contained in a particle signature. The signature contains the amount of energy exchanged and the spin value along the device's measurement axis as a point-in-time snapshot of the exchange, not values the wave packet held before measurement. Spin values along different measurement axes cannot be defined simultaneously, since each requires its own exchange with a device configured for that axis.

Particle signature is identical to ‘energy signature’ mentioned earlier. The use of the word 'particle' here is the one remnant of particle language that WEX intentionally retains for clarity purposes only. Particle signature corresponds precisely to the detection events the Standard Model attributes to elementary particles, but with a different ontological commitment. The name 'Standard Model of Elementary Particles' suggests that elementary particles physically exist, while under WEX, a particle signature is simply a record of a quantum energy exchange event, not a physical entity that exists in nature. The term ‘particle signature’ therefore provides a natural reminder throughout the paper that what the Standard Model calls an elementary particle is the fleeting signature of a quantum energy exchange in WEX that creates the illusion that a particle exists. Particle signatures are empirical evidence of energy exchange events, not evidence of objects with measurable properties that exist before, during, or after measurement.

Wave packet unification produces no particle signature thus produces no classical information. Sections 5 through 8 elaborate on this in the WEX treatment of entanglement, EPR correlations, weak measurement, double-slit, and delayed choice experiments.

Particles with precise values do not exist in WEX. The intrinsic wave nature of matter embedded in the WEX principle suggests that what we think of as elementary particles are illusions. The Standard Model inventories and organizes the empirical particle signatures of quantized energy exchanges that occur between independent quantum systems.

3.5 Wave Function Scope

Wave functions are abstract mathematical models that describe physically real wave packet behavior individually or as part of a quantum system. Energy exchange between wave packets will alter the structural features of the interacting wave packets, thus requires wave function reconstruction post-exchange to accurately describe the updated state of the system.

> **Wave Function Scope.** A wave function should model the components of a quantum system involved in energy exchange up to the moment the exchange begins. Wave functions must be reconstructed after any form of energy exchange because the exchange alters the dynamical features of the wave packets involved. Including entities that play no role in that exchange adds unnecessary complexity to a wave function.

Including observers and other objects that play no role in an energy exchange adds complexity without adding physics. Measurement devices are excluded because wave functions model the system only up to the moment it starts exchanging energy with a measurement device, so measurement devices lie at the boundary of a wave function's scope rather than within it. After the exchange, the wave function must be reconstructed to describe the updated system. Scoping wave functions around energy exchange in this way is the central argument resolving Schrödinger's Cat and nested observer paradoxes (§9).

3.6 Comments on the WEX Principle and Definitions

WEX is a claim about definition, not discovery. Observables, what the standard formalism represents as operators with eigenvalue spectra (e.g., position, momentum, spin, polarization), have no value whatsoever until an energy exchange with a measurement device defines one. This energy exchange does not reveal values that were already there in some form, rather they are produced by measurement devices. When a scientific instrument absorbs a quantum of energy, it analyzes the properties of the energy pattern at a specific point in time and space. It essentially takes a point-in-time ‘snapshot’ of the absorbed energy pattern and converts its attributes into specific values for position, energy, momentum, spin, and polarization. Particles with defined property values are extracted from the point-in-time ‘energy signatures’ of absorption events, thus are evidence of quantized energy exchange rather than evidence of a particle with defined properties that existed before the measurement. This is the sense in which WEX views particles as illusions rather than fundamental entities existing in nature.

WEX explicitly rejects hidden and partial values. There is no value that is fractionally defined, no state in which a wave packet partly has a value, no form of value ever exists in a wave packet. WEX explicitly rejects the vocabulary of intermediate and partial values entirely, on the grounds that such language smuggles in the idea that a fraction of a value, a hidden value, or a hidden particle with any properties whatsoever can exist. It does not. Section 7 shows that this absolute strictness in definition is what allows weak measurement to be understood cleanly rather than being a challenge to the WEX principle.

Measurement devices define property values. Scientific instruments that function as measurement devices are designed to couple with wave packets, absorb specific quanta of energy from them, analyze the various attributes of the absorbed energy, correlate the attributes to variables used in physics as property values, record the magnitudes of the property values and store them in device memory, and present the values on an output display or printout. This process creates the illusion that a particle with defined properties existed before measurement and was absorbed by the measurement device. Under WEX, a measurement device absorbs a quantum of energy and produces a particle signature with assigned property values that reflect the attributes of the absorbed energy.

WEX ‘partially’ resolves the measurement problem. Standard quantum theory lacks an account of the instant its indeterminate equations produce outcomes with precisely defined

values at precise locations in space, the central mystery in quantum physics known as the measurement problem. [20,21] That values are 'precisely defined by' quantized energy exchange addresses part of the measurement problem but does not explain where one of the probabilistic locations defined by the Born rule will host an energy exchange event.

WEX is formalism agnostic. It is independent of mathematical language because it focuses on the shared features across quantum formalisms. This is no different from the earth's surface being independent of whether it is mapped with a Mercator or a polar projection, or whether its features are measured using imperial or metric units. Since WEX is formalism agnostic, it adds nothing mathematical to quantum theory: no new equations, constants, dimensions, variables, or modifications to the Born rule. Every empirical prediction of quantum theory is therefore a prediction of WEX, and any experiment falsifying standard quantum mechanics would falsify WEX. Its claims concern the fundamental entities the formalisms model, not the mathematical descriptions of their behavior. The paper contains no mathematics as prose alone is sufficient to define WEX and trace its consequences.

WEX rejects wave-particle duality. Every formalism predicts the wave-like behavior of fundamental entities with discrete, localized outcomes resulting from energy exchanges in the physical universe. What appears as a particle during measurement is not described by ten of the eleven formalisms as having any defined values in the physical universe before measurement. Pilot-wave theory is the sole exception, but only for particle positions by design of the formalism.

WEX rejects superposition as a physical state of particles or properties existing before measurement. It retains only the linear combination of superposed waves, the adding of wave amplitudes that produces interference, which every formalism predicts and which WEX relies upon. Wave packets are singular extended entities that cannot exist in multiple places simultaneously. Neither particles nor the properties defined in particle signatures exist before measurement, so no superposition of any particle or property can exist. Superposition in this sense is an artifact of the wave-particle duality view and thus is rejected as incoherent in WEX.

4. First Consequence: No Collapse Postulate Needed

Most formalisms require a collapse postulate because they lack a physical mechanism for wave packet localization. The collapse postulate asserts that measurement causes wave functions (or other core mathematical objects) to collapse instantaneously to a single state with a defined property value. This postulate is "ad hoc" in the strictest sense: it introduces an undefined process with no connection to the formalisms, contradicts unitary evolution, and serves no role except to make predictions agree with observation. It is imposed from outside the theoretical framework, not derived from it.

4.1 Why Standard Quantum Theory Needs a Collapse Postulate

Standard quantum mechanics describes wave function evolution through the Schrödinger equation, which is linear and unitary. Unitary evolution preserves superposition: a wave packet described by a linear combination of eigenstates will remain in superposition indefinitely. Yet

measurement produces definite outcomes at specific locations in physical reality. How superposed eigenstates collapse into a single definite outcome remains unexplained in quantum theory.

The collapse postulate fills this gap by stipulating that 'measurement' causes the instantaneous collapse from the superposition produced by unitary evolution to a single definite result. But this postulate simply introduces an ad hoc mechanism which:

- Is not derivable from any formalism's core equations
- Ends unitary evolution without providing explanatory physics
- Fails to define what constitutes a measurement
- Fails to define what constitutes a measurement device that can trigger collapse
- Leaves open the possibility that merely observing a quantum system can trigger collapse without any physical interaction

The postulate is necessary precisely because quantum mechanics has no physical mechanism to explain localization. Without it, unitary evolution can never yield localized results with defined values.

4.2 Energy Exchange Physics Makes the Collapse Postulate Unnecessary

WEX does not require a collapse postulate because it grounds localization in the physics of energy exchange and the definitions supplied in §3 for energy exchange and wave function scope. Since wave function reconstruction is required after each energy exchange, wave function collapse can best be understood by flipping the conventional view on its head. Collapse is not an externally imposed process that causes definite results to appear. Energy exchange causes wave functions to 'collapse in their usefulness' in describing the post-exchange state of the system. A measurement device couples to a quantum system and absorbs a quantum of its energy, after which the wave function model must be reconstructed to represent the updated state of the system. No additional postulate is needed to describe localization events. This does not mean that WEX fully explains localization as it only explains parts of it. Consider the What, When, Where, Why and How of localization:

- **What** we are attempting to explain is localization.
- **When** localization occurs is determined by the interaction between a quantum system and a measurement device whose structures are sufficiently compatible to couple and exchange a quantum of energy.
- **Where** localization is likely to occur is defined by the Born rule.
- **Why** localization is quantized is inherited from quantum theory, which rests on Planck's constant h.
- **How** a wave packet exchanges a quantum of energy with a measurement device at the specific location is described in §6.4.

WEX is not alone in attempting to explain various aspects of localization. Other approaches attempt to supply the missing physics through spontaneous collapse, gravitational thresholds, or exchanges between emitters and absorbers.[22,23,24,25] The transactional extension of quantum

direct-action electrodynamics offers a physical account of the Born rule's squaring as the product of emission and absorption amplitudes.[15] WEX shares this view of energy exchange as two-sided but remains agnostic on the mechanism involving advanced waves propagating through a quantum substratum on which that account relies.

4.3 Lightning as an Energy Exchange Analogy

Consider the analogy of a lightning bolt as an energy exchange event. Before lightning appears, there are only the voltage differentials between various points in the cloud and earth below. These differentials vary between trillions of points in the cloud and earth where the lightning bolt may appear and exchange energy. A mathematical model could be built that treats the lightning bolt as existing in superposition of many states in infinite dimensional configuration space that describes every possible path the bolt could travel between the cloud and earth. When the coupling conditions between the cloud and earth align (e.g., the voltage differential of one of these paths exceeds the dielectric insulation strength of the atmosphere) energy is exchanged between the earth and cloud in the form of a lightning bolt. The bolt exchanges an amount of energy that can be precisely measured, it travels between two points in the cloud and earth that can be precisely measured, takes a zig-zag path through the atmosphere that can be precisely measured, and quickly disappears once the energy exchange is completed. Lightning bolts are evidence of energy exchange between the cloud and earth that contain precisely defined values in their energy exchange signatures.

The analogy has limits in that a lightning bolt's end points, path, and amount of energy exchanged are in principle determined by atmospheric conditions while WEX leaves where a quantum energy exchange occurs to Born statistics. The energy differential between the earth and cloud existed before the bolt appeared, but neither the lightning bolt, its end points, its path, nor the amount of energy transferred existed before the discharge nor did they persist afterwards. The classical information that quantitatively describes a lightning bolt is defined only when measurement devices register the energy exchange and record its property values as a lightning bolt energy signature.

The lightning bolt did not exist in superposition and contained no hidden values awaiting discovery. A “lightning postulate” is not required to explain the appearance of a lightning bolt with defined property values as energy exchange physics is all that is needed. Similarly, quantum energy exchange physics is all that is needed to explain the appearance of particle signatures containing defined values at measurement. No additional postulate beyond energy exchange physics is required in either case. The mathematical model that treated lightning bolts in superposition of many possible lightning bolts collapsed in its usefulness once the lightning bolt appeared, no different from the way a quantum wave function collapses in its usefulness once a wave packet exchanges energy. Localization is evidence of quantum energy exchange events and mathematical models of energetic systems at all scales of the universe collapse in their usefulness after energy exchange.

5. Second Consequence: Unified Wave Packets Contain No Values

Wave packet unification is the WEX term for entanglement (§3.2). The standard view of entanglement treats entangled systems as separate particles with some degree of independence

and some degree of dependence that enables them to have correlated property values. WEX rejects this view on two points: energy coupling that results in unification involves a complete loss of independence, and no values ever exist in wave packets to correlate. Most formalisms model entangled wave packets as a single unified wave function, which WEX takes literally as meaning the predecessor wave packets have no degree of independence once they merge to form a single unified wave packet. Unification is simply a more precise term for entanglement that avoids the trap of thinking that merged wave packets have any degree of independence. Sub-quantum energy exchange is the usual route to unification, but any coupling that retains energy within the combined system produces it.

Unification carries no correlated values. The correlations observed in measurement outcomes are correlations between particle signatures, never values carried by a unified wave packet. To say that entanglement "correlates the spin of A with the spin of B" implies that A and B retain some degree of independence and carry correlated spin values. They have neither under WEX.

Unification transfers no classical information. No form of classical information exists until it is defined by a measurement device that produces a particle signature which contains classical information.

Unification produces no partial values. This follows immediately from the principle's rejection of fractional values, and it is the commitment Section 7 turns on.

The unified packet is the whole of what exists. There is no "joint state." There is only the "unified state."

Degree of unification is continuous. The degree of unification is continuous and a function of coupling strength. The formalisms compute it routinely as entanglement entropy (§11) and a weak-measurement probe (§7) is deliberately engineered to sit near the low end of that range.

Degree of unification is independent of separation. A unified extended bimodal wave packet whose modes are separated by a billion light years may be maximally unified, which is why EPR correlations can survive arbitrary distances (§6). Under WEX the modes are part of a single unified wave packet so there are no separate parts to be far apart.

Unification can be reduced but never reversed. Further energy exchange, whether a quantum exchange that produces a particle signature (§6) or a controlled sub-quantum exchange such as those used in quantum computing (§12), can reduce the degree of unification. Each is a new exchange not a reversal of the one that produced the unification. Restored wave packets have different physical histories than packets that unified with no observable consequence. Wave packet histories cannot be erased (§11).

Unification requires no mechanism beyond energy exchange that results in loss of independence. The mystery of entanglement is largely an artifact of assuming property values existed in the predecessor wave packets, were correlated at unification, and maintain some degree of independence from one another after unification. WEX rejects all three of these assumptions.

6. Third Consequence: Non-Locality Confined to Energy Redistribution

Einstein, Podolsky, and Rosen (EPR) argued in 1935 that quantum theory must be incomplete, because otherwise two particles could act on each other at a distance, violating the local causality embedded in classical theories. [26] Bell's 1964 theorem made the question experimentally testable. [27, 28] Experiments reported violations of Bell's inequalities in 1982 [29] and later experiments closed remaining loopholes. [30] Einstein's hope of explaining the behavior with local hidden variables was ruled out by Bell's theorem and these experiments. The 2022 Nobel Prize in Physics recognized this work.

Bell's theorem is a mathematical test of assumptions about how correlated measurement outcomes can arise at two spacelike separated locations. Bell's argument rests on four core assumptions: [31]

1. **Separability:** Two entangled quantum systems can be treated as separate systems.
2. **Locality:** A measurement on one quantum system cannot influence another quantum system faster than light.
3. **Realism:** Quantum systems carry definite values before measurement that determine outcomes. Bell's 1964 argument assumed these values fix outcomes, while his later formulations replaced determinism with local causality. [32,33]
4. **Measurement Independence:** Experimenter choices of what to measure are uncorrelated with the properties of the systems.

The separability assumption does not apply to WEX because unifying wave packets lose their independence and cannot be treated as separate systems (§6.1). The locality assumption does not apply to WEX because there is only one unified wave packet at initial measurement, which fractures the unified packet and constrains its remainder (§6.2). The realism assumption does not apply to WEX because wave packets carry no values prior to measurement (§3.4). WEX retains the fourth assumption and does not require a measurement loophole to evade Bell's argument. A theorem designed to test for a non-local connection between two systems simply does not apply to the single system described by WEX. The relevant non-locality test for WEX is whether it can explain EPR correlations from an extended unified wave packet perspective without invoking non-local influences. It cannot do so entirely, because WEX retains non-local energy redistribution within a single wave packet. The remainder of this section shows that WEX is consistent with the observed Bell violations and confines non-local effects to energy redistribution dynamics within individual wave packets.

6.1 Unified Wave Packets Are Non-Separable

When two wave packets form an entangled system, their energy structures unify to become a single extended wave packet whose structural properties must be derived from the combined structural properties of the predecessor wave packets according to universal conservation laws. The resulting unified wave packet is a single energy pattern that has one geometry, one oscillatory structure, and one angular momentum. It has one set of structural properties and contains no defined values since it is an extended energy pattern that is dynamically evolving in space and time. Any net rotation of its energy pattern has a single axis and handedness,

dynamical features of how energy rotates in any wave packet. Conventional EPR pairs are a special case where the unified wave packet has zero net angular momentum, is rotationally symmetric, and its measurement axis is only determined by the detection geometry of the first measurement device it encounters. The structural features of a unified wave packet no longer belong to the predecessor wave packets individually because they completely lose their independence as separate entities when they unify, and neither can recover its former identity when the unified wave packet is measured.

6.2 Fracture and Conservation

Figure 1 is a schematic representation of a unified wave packet extending in space and approaching a measurement device in the top half of the figure. In the bottom half, a quantum energy exchange with a measurement device fractures the unified wave packet into a particle signature and residual wave packet. The particle signature is shown with a dotted line to illustrate that it is not an entity that has physical existence, but an instantaneous record of the energy exchange event.

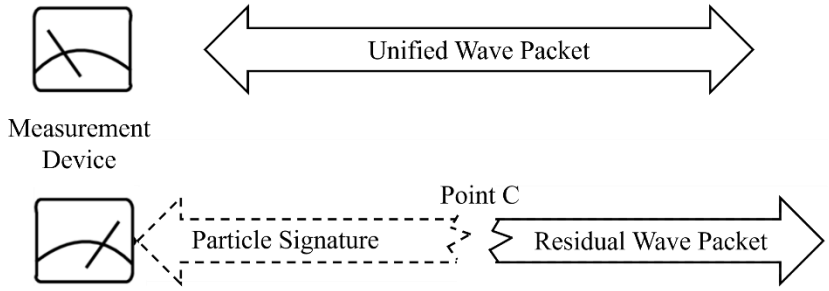


Figure 1: Fracture of a Unified Wave Packet Constrained by Conservation Laws

The signature and residual have complementary dynamical features that together account for the dynamical features of the unified wave packet, just as the pieces of any fractured physical object (e.g., a dinner plate dropped on the floor that breaks into two pieces) will have complementary physical structures that together account for the original unfractured whole. In both cases the possible structures of the broken parts are constrained by the original structure and conservation laws applied at the point of fracture (point C in Figure 1). This is conceptually represented in the figure by the geometry of the signature and residual having complementary jagged edges.

6.3 Why Bell Violations Are Consistent with WEX

Bell's inequalities limit how strongly two outcomes can be correlated when each is determined only by properties on its own side of the experiment and by its own detector setting. WEX outcomes are not determined in this manner. The first quantum energy exchange fractures the unified wave packet in Figure 1 and defines the first outcome through the interaction between the unified packet's structural features and the detection geometry of the measurement device. Conservation laws leave the residual wave packet with complementary dynamical features to the particle signature because the structural features of the parts must account for the structural features of the whole. A subsequent measurement of the residual is defined by the residual's structural features and the second measurement device's detection geometry.

The observed spin or polarization correlations between two measurements depend on the relative orientation of the two detection geometries, a relational fact about the unified wave packet's structure constrained by conservation at fracture, not a product of pre-existing values each fractured part carries independently. The correlations are observed because the rotational structures of the energy patterns that were absorbed by the two measurement devices were complementary due to the conservation of energy, momentum, and angular momentum applied at the point of fracture. The particle signature and residual wave packet will have complementary angular momentum and axes of rotation because they are fractured parts of a single physically real object whose properties were constrained by universal conservation laws at the fracture event. Measurements along any common axis yield complementary values because the wave packets being measured have complementary angular momentum and axes of rotation. They have complementary dynamical features, not complementary values.

Bell's bound follows from independent outcome determination which is not the case under WEX. Correlations that exceed the bound are consistent with WEX because the particle signature and residual wave packet are complementary parts fractured from a unified whole. Conservation at fracture accounts for complementary outcomes when the two detection geometries are aligned. At other settings, the wave function model supplies the quantitative dependence on detector angle, including the quantum limit on the strength of correlations, and WEX supplies the physical reading.

6.4 Where the Non-Locality Resides

Prior to the first quantum energy exchange, the unified wave packet carries energy equal to two photon quanta. A full quantum of energy is unlikely to be concentrated at the precise location of any quantum energy exchange. A wave packet is made solely of energy and that energy is spread across its extent to give the wave packet a physical structure. Thus, in order to exchange one quantum of energy with the first measurement device, the unified packet must redistribute its internal energy to concentrate a full quantum at the exchange location. The location inside its extended structure where the last bit of sub-quantum energy is gathered to produce a full quantum is denoted as point C in Figure 1. Point C is where the unified packet fractures and conservation laws apply to the fractured parts. Because the energy available to complete the quantum energy exchange depends on how energy is spread across the packet, the precise location of point C varies with the unified packet's internal energy pattern at the exact moment of the energy exchange.

The energy exchange with the measurement device and the application of conservation laws at C are both local events. The non-local aspect of WEX is the instantaneous redistribution of sub-quantum energy from within the unified packet’s extent to concentrate a full quantum at the energy exchange location. This non-local redistribution is an internal process occurring within a single extended entity, confining WEX non-locality to the internal energy dynamics within individual wave packets. This redistribution cannot carry a message because no values exist in wave packets that could encode a message, nor does it affect the probability distributions of subsequent energy exchange events, consistent with the no-signaling theorem (§6.6).

6.5 Relativity

A residual wave packet exists only after a fracture, so a fracture always precedes any measurement of the residual. If two quantum energy exchanges on the same unified wave packet

are spacelike separated, observers in different frames may disagree about which one fractures the packet. In every reference frame the earlier exchange fractures the packet and the later one measures the residual, with the ordering relative to each frame and no preferred frame, consistent with special relativity. The correlation described in §6.3 is a relational fact about the unified wave packet that depends only on the relative orientation of the two detection geometries. It is therefore symmetric between the devices and is the same whichever exchange is assigned to be first. The redistribution of energy and the conservation constraint are conditions on a single object, so no speed attaches to either. The description of which exchange fractures the packet depends on the frame, but the measured outcomes and their correlations do not.

6.6 Summary

Bell's separability, locality, and realism assumptions do not apply to a single unified wave packet, thus Bell's theorem does not apply to WEX. EPR correlations are consistent with conservation laws constraining the structural features of physically real wave packets upon fracture. Local causality between independent objects is maintained under WEX while non-local influences are confined to the internal energy dynamics within individual wave packets. Observers in different reference frames may disagree about which exchange fractures the unified packet, but not about the outcomes and their correlations. Wave packets carry no values that could encode a message, consistent with the no-signaling theorem.

7. Fourth Consequence: Weak Measurement Defines No Values

Weak measurement may be the sharpest test of the WEX principle, and it is worth stating the challenge at full strength before answering it. The conventional view is that weak measurement couples a probe to a system with arbitrarily small interaction strength, yielding classical information about the system while leaving the system largely undisturbed. If classical information is truly obtained by weak measurement, then a value would be defined without a quantum energy exchange that produces a particle signature, which would falsify the WEX principle. [34,35]

The WEX response is that the probe acquires no value during the weak interaction. Not a partial value. Not a degraded value. Not a hidden value. No value whatsoever. What occurs during the weak interaction is minimal unification at the low end of the continuous range described in §5.

Consider probe X and system Y which exchange a sub-quantum amount of energy, forming unified wave packet XY. Energy redistributes within the unified wave packet as it does within any wave packet as it evolves through time. This internal redistribution does not result in quantum energy being emitted by unified packet XY, so no particle signature is produced and no values are defined. The probe's values are only defined when it subsequently undergoes a quantum energy exchange with a measurement device that produces a particle signature. Measurement of probe X accomplishes two things simultaneously: it defines classical information in X's particle signature AND constrains the residual wave packet through conservation laws to be complementary to X's particle signature, no different from the discussion on fractured unified wave packets in §6.2.

A concrete example may be helpful. A weak photon probe couples to an electron being studied, forming a minimally unified wave packet. When the weak probe photon subsequently strikes a detector, the particle signature defines the photon's values (location, energy, polarization).

Simultaneously, the fractured unified packet constrains the residual electron wave packet structure through conservation of momentum, energy, and angular momentum to produce values correlated with the probe's particle signature to a degree set by the degree of unification (weak when the coupling is weak) when the electron is subsequently measured. The values were not extracted from the electron by the weak probe but were defined when the probe was measured and constrained what future measurements of the electron will reveal. Under WEX, weak measurement does not capture classical information about a quantum system being studied, it changes and constrains the system being studied.

This account of weak measurement is consistent with empirical results and is where the strictness of WEX rejecting any form or degree of value existing in wave packets earns its keep. A weaker position that concedes any form of value exists in wave packets before measurement would falsify the WEX principle thus the strict position is more defensible, not less.

Minimal disturbance. The system is minimally disturbed because the sub-quantum energy exchange is minimal, resulting in probe and system forming a minimally unified wave packet. Minimally unified does not imply there is any degree of independence. It simply means unified wave packet XY has minimal entanglement entropy.

Anomalous weak values. Weak values lying outside the eigenvalue spectrum of the measured values are often treated as puzzling in the conventional view but are unproblematic under WEX. They are not values of anything during the weak interaction but result from computing the statistics of particle signatures over an ensemble with post-selection, a computational artifact under WEX that describes no aspect of unified or residual wave packets. [36]

Post-selection. Post-selection requires only that the system eventually undergoes a measurement that yields a definite outcome, which it does under WEX. Conditioning an ensemble on a later outcome is a procedure for selecting a subset of runs. WEX does not allow an outcome value to exist before an energy exchange defines one, hence there is no pre-existing outcome to select from. This is a variation of no retro-causation in the delayed-choice experiments in §8.2.

The calculation mechanism of weak measurement is untouched. Under WEX it describes structural features of the unified wave packet that constrain the particle signatures of probe and system to be complementary when measured. WEX does not need to address partial values because there are none.

8. Fifth Consequence: One Description of Extended Structures

The WEX principle describes all forms of spatially extended wave packets similarly, independent of their total energy.

8.1 The double-slit experiment

A photon wave packet emitted from a source will spread out over the region between source and the double slit barrier, pass through both slits, and emerge as a bimodal wave packet that interferes with itself as it approaches the screen. On reaching the screen the packet undergoes a quantum energy exchange with the screen and produces a particle signature somewhere on the screen. The screen functions as a measurement device (§3.3) and successive wave packets produce particle signatures distributed on the screen according to Born statistics for a single self-

interfering wave packet, yielding the classic interference pattern. [37] The screen is engineered with structural and coupling properties designed to absorb photons and produce particle signatures anywhere on the screen, resulting in classical information on energy exchange locations for successive energy exchanges.

If absorptive photon detectors are placed at the slits, they will function as additional measurement devices that absorb the photon's energy at one or the other slit, thus no interference pattern appears on the screen. Traditionally this is viewed as revealing the particle nature of reality while WEX views it as evidence of an energy exchange that produced a particle signature at one of the slits. Either slit detector will fully absorb the photon's quantum of energy, leaving no residual energy to exchange with the other slit detector or the screen, thus no impacts appear on the screen, and no interference pattern builds up. The wave packet has some probability of undergoing an energy exchange at each detector, defined by the Born rule applied to the amplitude of the wave packet at each slit.

If one slit is blocked the wave packets pass through the unblocked slit, spread out as they emerge from the slit, impact the screen and the screen does not build up a two-slit interference pattern because the wave packets were not bimodal thus could not interfere with themselves. WEX accounts for the standard double slit results in a straightforward manner where a single extended wave packet passes through both slits and exchanges its energy with the first measurement device it encounters.

8.2 Wheeler's delayed-choice double-slit experiment

In Wheeler's thought experiment, the choice of how to detect a photon is made after the photon has passed the point where it seems to have committed to one path or both. A stream of photons passes through a double slit apparatus and builds up an interference pattern on a screen, suggesting each photon travels through both slits. If the screen is removed, each photon is instead absorbed by one of two telescopes aimed at different slits, resulting in 'which-slit' information about the slit each photon traveled through. Quantum theory predicts that the screen can be randomly removed after each photon has passed the slits, and the results will still produce interference if the screen is not removed and which-slit information when it is removed. The question is how a later choice could determine whether the photon behaves as a wave or a particle, a scenario often viewed as possible evidence of retro-causality.

Under WEX, each photon is a single coherent wave packet that always passes through both slits and forms an extended bi-modal wave packet on the other side of the double slit barrier. The only question is whether the wave packet encounters a measurement device that absorbs its quantum with or without sorting its energy by slit.

The two modes begin to overlap after the wave packet passes through the slits, and the overlapping region carries an interference pattern created as the energy patterns in each mode constructively and destructively interfere with each other. The screen absorbs a steady stream of quanta at locations predicted by Born rule statistics, and the particle signatures accumulate into an interference pattern. Additional screens placed anywhere the modes overlap would record the same pattern, including if two screens were to replace the two telescopes.

Each telescope lens focuses light arriving from the slit it is aimed at onto its detector while focusing light from other directions away from its detector. Each telescope detector can therefore only absorb energy from the portion of the wave packet arriving directly from its slit. As discussed in §6.4, a quantum energy exchange draws a full quantum from the extended packet and concentrates it at the point of exchange. Every particle signature the telescopes record is thus a which-slit result that can never contribute to an interference pattern. Which-slit information does not exist because the photon always travels through both slits. The which-slit information that appears in the experiment is a function of the detection geometry of the telescopes, not evidence that the wave packet passed through one or the other slit. Each measurement device produces the classical information its detection geometry was designed to capture.

The delayed choice prediction was later confirmed with single photons traveling through a two-arm interferometer. [38] Each photon is split into two beams with perpendicular polarizations traveling separate paths. Mirrors bring the beams back to a common point, and two detectors sit just past the convergence point. After each photon enters the interferometer, a quantum random number generator decides whether to bring the two beams back into the same polarization before they reach the detectors. Interference appears when the polarizations match, and 'which-path' information appears when the polarizations are perpendicular.

Under WEX, each photon is a single bi-modal wave packet that always travels both paths. If the modes have perpendicular polarization at measurement, they will not interfere and 'which-path' information results. If the modes have the same polarization at measurement, interference will appear. The random number generator determines which result appears at measurement.

In both experiments there is only one extended bi-modal wave packet, one energy exchange, and one particle signature which defines one value in each trial. There is never an earlier fact for a later choice to overturn so the predicted results are consistent with WEX without retro-causality. Variants in which the choice is made on an entangled partner, as in the delayed-choice quantum eraser experiment, [39] simply apply the same reasoning to unified wave packets rather than individual photon wave packets. The correlations appear only when outcomes are sorted by a later measurement, as described in §7 and §11.

8.3 The common structure of extended wave packets

The single-photon double-slit, delayed choice double-slit, and unified wave packet (§6) can be understood using the same structural dynamics of extended wave packets at measurement. In all three, a quantum energy exchange occurring anywhere within a wave packet's extended bimodal structure exchanges a single quantum of energy at the location of measurement, constraining the remainder through conservation laws. There is no residual energy left after the energy exchange in the single-photon double slit and delayed choice variant, while a residual quantum of energy remains in the unified two-photon case. This reflects a difference in total energy of the wave packets, not difference in principle. A photon passing through a double-slit apparatus carries one photon quantum of energy while the unified packet carries two photon quanta of energy, both having their energy concentrated in the modes of a single coherent extended bimodal structure. The same rule governs both: a single coherent, spatially extended wave packet undergoes a localized energy exchange of a single photon quantum with its total energy conserved. Standard

quantum mechanics treats double-slit wave packets and entangled pairs as distinct phenomena while WEX offers a single description of both.

What differs is how the structure became extended. In the single photon double-slit case, the extension is self-coherent, the two modes remaining one structure throughout the apparatus. In the unified two-photon case the connection is a structural feature of the unified packet fixed at pair creation, consistent with EPR correlations surviving distances far exceeding any realistic coherence length. Despite becoming extended via different mechanisms, all extended packets share similar structural dynamics.

9. Sixth Consequence: Observer Paradoxes Dissolve

The paradoxes of Schrödinger's Cat, Wigner's Friend, and Frauchiger-Renner arise from a common source: the absence of a rule specifying what belongs inside a quantum system when constructing a wave function to model the system. WEX defines such a rule around energy exchange and repeats it here for convenience as it is central to resolving observer paradoxes.

> **Wave Function Scope (§3.5).** A wave function should model the components of a quantum system involved in energy exchange up to the moment the exchange begins. Wave functions must be reconstructed after any form of energy exchange because the exchange alters the dynamical features of the wave packets involved. Including entities that play no role in that exchange adds unnecessary complexity to a wave function.

Schrödinger's Cat. The setup places a cat inside a box with a radioactive atom, a Geiger counter, and a vial of poison. If the Geiger counter detects the atom's decay, it triggers a mechanism that breaks the vial, releases the poison, and kills the cat. [40] Standard quantum theory leaves unclear whether the cat qualifies as an 'observer' (i.e. measurement device) and offers no guidance on which side of an undefined quantum-classical boundary the cat lies. The paradox emerges when the cat is included in a wave function modeling the system, leading to the cat being in "superposition" of alive and dead simultaneously until the box is opened.

WEX notes that the undefined terms traditionally used in these paradoxes (observer, measurement device, and wave function scope) lead directly to the paradox. WEX retires 'observer' and provides precise definitions for measurement device and wave function scope, which together offer a resolution of this paradox.

Only the atom should be included in a wave function describing the system because it is the only entity in the box *involved in energy exchange up to the moment the exchange begins*. The atom's decay is driven solely by its own internal energy dynamics. The Geiger counter, cat, vial, and mechanism to release the poison should be excluded from the system wave function because the wave function must be reconstructed once the atom begins to emit energy as it decays. From a practical standpoint wave function reconstruction should occur as soon as the Geiger counter begins registering the decay event. Everything that occurs after this point is no longer described by the original system wave function which has collapsed in its usefulness.

Under WEX the cat is always alive or dead, never in superposition of both. The atom's wave function describes the only relevant energy exchange that determines the fate of the cat, decaying according to Born rule statistics. Constructing a wave function that includes anything more than

the atom adds unnecessary complexity because once the atom begins to decay the wave function must be reconstructed.

Nested observers. Wigner's Friend and Frauchiger-Renner extend the Schrödinger Cat paradox by nesting observers which creates even more complex paradoxes. Most analyses of the Frauchiger-Renner thought experiment conclude that one of the following three core assumptions underpinning the foundations of quantum theory must be incorrect. [41]

- **Universality.** Quantum theory can be applied to everything, including observers and measurement devices.
- **Consistency.** Two physicists performing the same calculations on a system agree on the resulting statistical predictions.
- **Single Outcomes.** Each physicist who performs a measurement obtains a single definite result.

The WEX wave function scope argument offered for Schrödinger's Cat applies equally to any paradox that includes nested observers and/or nested measurement devices in a system's wave function, including Wigner's Friend and Frauchiger-Renner. WEX narrows the Universality assumption in quantum foundations by explicitly excluding measurement devices (and by extension, observers) from wave functions while its wave packet realism vantage point affirms the Consistency and Single Outcome assumptions.

10. Seventh Consequence: No Quantum Boundary

If the intrinsic nature of reality is wave-like as asserted in WEX, then there is no need for a boundary at which quantum dynamics cease to apply. The exclusion of measurement devices from wave functions does not imply that a boundary exists between a hypothetical quantum and classical world at measurement. It is simply a wave function scope rule to efficiently define what a wave function can coherently describe before requiring reconstruction.

Experimental work supports the absence of a boundary. Organic molecules with thousands of atoms have illustrated the intrinsic wave nature of reality at the molecular scale. [42,43] Micro-mechanical resonators of trillions of atoms have shown collective vibrational states at scales visible under a microscope. [44] Quantum biology has reported possible evidence of quantum effects at molecular and cellular scales in living organisms, including coherent energy transfer in photosynthesis [45] and in retinal proteins that migratory birds appear to use for magnetic navigation. [46]

Standard physics models a Bose-Einstein condensate as a single macroscopic wave function, which WEX views as a macroscopic wave packet. Two condensates formed in separate wells that are allowed to overlap will produce high-contrast interference fringes in the overlap region. [47] Under WEX, the overlap region is where the two condensate wave packets unify, and the interference pattern is carried in that unified region. This is consistent with wave behavior and unification in macroscopic matter.

Environmental energy exchanges in macroscopic systems make it difficult for measurement apparatus to discriminate and absorb the specific energy quanta being investigated. But environmental noise does not imply the cessation of wave packet energy exchange dynamics at any scale. [21,48,49] Organized electromagnetic fields (such as those surrounding cells and neural

tissue) may constrain and channel energy exchange patterns inside large matter structures, preserving internal quantum dynamics beyond what conventional measurement devices can resolve. Standard quantum physics, condensed matter physics, plasma physics, classical physics, chemistry, and biology are all powered by wave packet energy exchange between subatomic particles, quasiparticles, atoms, molecules, cells, brains, and stars. The WEX principle asserts there is no scale boundary where quantum dynamics cease. Wave packet energy exchange occurs constantly in all matter structures at all scales. The only limitation in demonstrating the intrinsic wave nature of reality in larger structures is the measurement apparatus's ability to discriminate quantum energy exchanges against the backdrop of increasing environmental noise as matter structures increase in scale.

Plasma physics extends the same point to astronomical scales. Stars and the solar wind are plasmas, described by collective waves such as plasma oscillations and Alfvén waves, and by resonant energy exchange between those waves and the electron and ion wave packets of the plasma. Landau damping is the standard example: it was predicted in 1946 and directly measured in laboratory plasma waves in 1964. [50] WEX reads this as ordinary wave packet energy exchange at a scale where individual quantum exchanges cannot be resolved against the backdrop of environmental noise. The WEX principle does not depend on resolving them, but the same limitation means plasma physics can illustrate wave packet energy exchange dynamics at large scales without distinguishing WEX from standard interpretations. Stellar interiors offer indirect evidence of quantum dynamics at extreme scales since fusion in stellar cores depends on quantum tunneling despite intense heat and density. Quantum dynamics are therefore not extinguished by extreme conditions, which raises questions regarding the blanket assumption that the wet, warm, and electromagnetically noisy environments of biological tissues cannot support quantum effects. WEX holds that the sole fundamental constituents of physical reality are physically real wave packets whose energy exchange dynamics are not bounded by scale. That these dynamics have not yet been demonstrated at any given scale does not mean they do not exist there.

Condensed matter physics offers a further illustration. Dense phases of matter are described through quantized collective excitations, conventionally called quasiparticles, whose properties are fixed by the collective structure of the system rather than by any single constituent. Semiclassical theories even treat electrons in crystals as wave packets with structure-derived properties such as Berry curvature and orbital magnetic moment. [51,52] Standard physics treats these as effective descriptions emerging from interacting atoms and electrons. WEX views them as quantized excitations of complex unified wave packet structures. A guitar string offers a useful comparison. The string is a single physical structure with natural modes of vibration. Plucking or damping the string moves energy into or out of its harmonic modes. A crystal lattice is likewise a single unified structure, and a phonon is not a particle traveling through it but a unit of energy in one of its resonant vibrational modes. The quantum version adds that energy can enter or leave each mode only in discrete units set by the mode itself, so every energy exchange with a probe or detector transfers discrete quanta. The particle-like appearance of quasiparticles is therefore the same as that of elementary particles: a particle signature recording a quantized energy exchange. As with the fractional charges discussed in §3.2, the structural features and coupling properties of interacting systems determine the quanta that can be exchanged. Standard descriptions already account for the data, so the WEX reading is consistent with condensed

matter physics rather than evidence for WEX, but it extends its no-boundary argument to some of the most complex collective quantum systems known to science.

A final argument for scale independence comes from black holes. Quantum field theory in curved spacetime predicts the horizons of black holes will emit thermal radiation, suggesting quantum dynamics are even predicted in the most massive objects in the known universe. [53]

11. Eighth Consequence: Quantum Information Theory is the Study of Classical Information Production, Not Quantum Information Discovery

Quantum Information Theory (QIT) studies how quantum systems encode, process, and transmit information. The field treats 'quantum information' as encoded in quantum states, conventionally defined abstractly in Hilbert space independent of how a system is physically implemented. It treats wave functions as mathematical representations of a system's quantum information, the state that quantum operations process. QIT therefore offers no definition of quantum information independent of the abstract mathematics of the formalisms, as it is identified only with a mathematical state and its transformations.

A theorem on the reality of the quantum state shows that any model in which quantum states represent mere information about an underlying reality contradicts the predictions of quantum theory, provided the model satisfies preparation independence. [54] If preparation independence holds, quantum states cannot be mere information but must correspond to something physically real. The abstract mathematics of Hilbert space models wave packet behavior with remarkable accuracy, which is why every result of QIT holds, but it is not an accurate depiction of wave packets in physical reality (§2). What physical reality quantum states refer to in QIT remains an open question, and WEX provides an answer: Quantum states are mathematical representations of physically real wave packets.

WEX rejects the idea that quantum information exists in wave packets because no values of any form exist in wave packets. Information is neither fundamental nor a feature of wave packets. Information is expressed in the variables defined by physics models and produced by measurement devices which map the properties of energy exchange signatures to these variables. What changes is QIT's subject matter, not its results. QIT describes how wave packet structure constrains energy exchange to determine which measurement outcomes are possible. It is the science of controlled classical information production, not quantum information discovery.

Entanglement entropy is a number assigned to degree of unification, a dynamical feature of wave packets in the sense described in §3.1. It is a tool for analyzing unified wave packet structure, not a value the wave packet carries nor a measure of latent correlations since no values exist in wave packets to correlate. Degree of unification is continuous and independent of spatial separation. No single energy exchange defines it, rather it is inferred from the statistics of many exchanges with identically prepared wave packets and persists until a further exchange alters it. Exchanges can reduce the degree of unification (e.g., when quantum algorithms disentangle qubits), but they cannot undo the energy exchanges that unified the packet. Every energy exchange alters the exchange partners that drive it, such as the control fields that operate on qubits, and that history persists even when the qubits themselves are restored to an unentangled state.

Holevo's theorem states that n qubits yield at most n classical bits of information. One common reading treats this as a limit on how many classical bits can be extracted from a vast array of

hidden quantum information. Under WEX, a wave packet's structural features constrain the maximum number of quantum energy exchanges that are possible, thus the maximum number of particle signatures that can be produced containing classical bits of information. The Holevo bound relates to how many classical bits can be extracted from a given wave packet's energy pattern, making it a physically intuitive metric rather than a mysterious one. [55]

Teleportation transfers the structural features of one wave packet to another without either one traveling between sender and receiver. The sender and receiver share a unified bi-modal wave packet, and the sender brings the packet to be teleported into coherent overlap with the sender's mode, unifying all three. The sender performs a joint measurement which fractures the tri-modal packet. The detection geometry of the sender's device registers the relative polarization and phase between the two measured modes, and the resulting pair of particle signatures encode that relation as two classical bits which carry no information about the teleported structure. Because conservation at fracture ties the receiver's residual mode to that same relation (§6.2), the bits, sent at light speed, tell the receiver which of four controlled energy exchanges to apply, after which the residual takes on the structure of the teleported packet. [56] The structure moves through the unified packet, never through the classical channel, and the teleported packet's features do not survive the joint measurement, so the structure is transferred, never copied.

Entanglement swapping applies the same logic to two unified wave packets. [57] Wave packets A and B unify to form bi-modal wave packet AB, and C and D unify to form CD. The B and C modes travel to a joint measurement apparatus while the A and D modes head elsewhere. At the apparatus, the B and C modes coherently overlap, and a sub-quantum energy exchange unifies all four modes into a single wave packet, ABCD. A joint measurement of the B and C modes then fractures ABCD, and, as in teleportation, the detection geometry registers the relative polarization and phase between them as two classical bits. The fracture leaves a residual unified bi-modal wave packet spanning the regions where A and D were headed, even though A and D never interacted, and the two bits identify which of four relations its modes bear to each other. That residual cannot be said to carry the identities of A and D, because predecessor identities are lost in unification. If the A or D mode is measured first, that measurement fractures AB or CD before ABCD can form, so no unified packet ever spans those regions. The B and C residuals then carry structures complementary to the earlier signatures, and the joint measurement registers the relation between them. In both cases, correlations between the A and D outcomes appear only when those outcomes are sorted by the result of the joint measurement, the same post-selection described in §8, so no signal passes between them (§6.6).

The no-cloning theorem states that no quantum operation can create an identical copy of an unknown quantum state while leaving the original intact, a theorem that follows directly from the linearity of quantum theory. [58] WEX offers a physical reading of why wave packets cannot be cloned. Copying a wave packet's structure requires first defining its dynamical features, but dynamical features are properties rather than values (§3.1). The only way to define a value is a quantum energy exchange, which defines a single outcome and alters the wave packet in the process. Any attempt to copy without measurement through sub-quantum coupling fares no better as it unifies the original and the blank into a single wave packet rather than producing two independent copies, exactly as the formalisms all predict. An unknown structure can be transferred, as in teleportation, but never duplicated.

12. Ninth Consequence: Quantum Computers Leverage Geometric Computing, not Superposition of States

WEX views quantum algorithms (the software of quantum computers) as manipulating wave packet structure (the hardware of quantum computers) to compute, much like classical software algorithms manipulating transistor gate hardware to compute. The difference lies in the hardware. Transistor gates are binary while wave packet structure has infinite geometric degrees of freedom. N unified wave packets form a single non-separable structure which requires 2^N complex amplitudes to model the range of possible outcomes. Quantum algorithms exploit this structural flexibility by manipulating wave packet geometry through precisely controlled sub-quantum energy exchange, navigating a computational path through infinite geometric possibilities. [59]

Each quantum gate operation unifies with the computational packet via sub-quantum coupling, progressively reshaping its structure while maintaining the computational wave packet's unity. The algorithm imposes sequential constraints on the unified packet's physical structure, altering its geometry as it navigates a computational path through the infinite possibilities of wave packet geometry, incorporating all of the algorithmic constraints in the computational packet's final structure. A subsequent measurement of the final packet reveals a geometrically optimized answer in the particle signature as classical information.

Viewed through WEX, quantum algorithms execute 'geometric computing' on a unified wave packet substrate, manipulating its geometry through controlled sub-quantum energy exchanges that impose constraints on the unified computational packet. Under WEX, the computational power is understood not as processing multiple superposed states simultaneously, but as manipulating continuous geometric structure in ways discrete bit states cannot access.

13. Tenth Consequence: Universality Across Scale, Formalism, and Geometry

WEX asserts universality along three dimensions: formalism, scale, and geometry. Section 2 made the formalism independence argument by showing that eleven formalisms with vastly different mathematical structures and assumptions all predict the same physics. Every formalism either represents or predicts that fundamental entities evolve continuously between discrete energy exchange events, have extended structures that exhibit wave-like interference and entanglement, and that definite property values appear in space and time at measurement. Each formalism can be viewed as modeling the intrinsic wave behavior of matter advocated by WEX using different abstract mathematical models.

Section 10 made the WEX scale independence argument by showing there is no scale at which physics predicts wave packet dynamics will cease. The evidence of atoms, molecules, condensed matter structures, biological organisms, and stars exhibiting quantum effects, together with the quantum effects predicted for black holes, is supported by a wide range of sub-disciplines at different scales within physics.

The remaining universality claim is that WEX is independent of geometry. The WEX principle was developed, and its consequences traced within our 3D universe using standard non-relativistic quantum mechanics frameworks for clarity. But WEX's core ontological claim

transcends this context as the extension to 4D spacetime using relativistic principles is consistent with WEX as discussed in §3.1, §6.5 and §10. Relativistic quantum theory predicts that whether a detector registers particles depends on the detector's own motion, as when an accelerating detector registers particles in a vacuum where an inertial detector registers none. [60] Under a particle ontology this is puzzling, but under WEX it is expected since particle signatures are records of energy exchange with a detector, not objects that exist independent of one.

The amplituhedron computes particle interactions in a model quantum field theory as the volume of a geometric object that lies beyond 4D spacetime, with locality and unitarity emerging from geometry rather than being assumed. [18] This focus on the importance of geometry echoes WEX's emphasis on wave packet geometry as a dynamical feature and quantum computing as geometric computing. And its treatment of spacetime locality as emerging from a more fundamental geometry is consistent with this paper's openness to structure beneath spacetime (§3.1). Along these same lines the relativistic transactional interpretation's explanation of the Born rule requires a 'substratum' beneath 4D spacetime. [17,25] WEX views these innovative approaches as pushing the boundaries of conventional thinking, an approach that may one day lead to a more fundamental branch of physics operating beneath the Planck scale.

The WEX explanation of EPR correlations suggested that local causality exists between independent entities while confining non-local influences to energy dynamics within individual wave packets. Whether these non-local influences will one day be explained by causal connections in higher dimensions such as ten-dimensional string theory geometry [61] or by causal connections through a substratum remains an open question. The WEX principle should apply equally whether physically real wave packets are limited to the space and time dimensions of physical reality or extend into higher dimensions or a substratum, provided these extensions continue to represent or predict the six shared formalism features discussed in §2 which support WEX's wave realism ontology.

This universality across scale, formalism, and geometry suggests that WEX identifies something deeper about underlying reality: the relationship between physically real fundamental energy patterns, their structural properties, energy exchange dynamics, and measurement device interactions. The core insight is not technical but metaphysical: Our physical reality is solely constituted of physically real energy patterns that propagate and exchange energy while particles as conventionally thought of in physics simply do not exist.

14. Conclusion

The paper identified the common features across quantum formalisms, interpreted them using a wave realism ontology, precisely defined a number of ambiguous terms in standard quantum theory, and encapsulated these aspects into a two-sentence claim and traced its consequences.

> **The Wave Energy Exchange (WEX) Principle:** The sole persistent constituents of physical reality are energy waves that have spatial extent, dynamical structures, and exchange energy in discrete quanta. Particles with precise properties are the point-in-time energy signatures of quanta absorbed by measurement devices.

Wave packets are physically real energy patterns. Particle signatures are evidence of energy exchange, not physical objects that exist. Wave packet structure is the currency of quantum physics, not hidden variables, not quantum information, not superposed particles. The wave-

particle duality perspective should be replaced with the intrinsic wave nature of reality perspective and particle-centric terminology replaced with wave-native terminology.

The ten consequences traced in this paper illustrate the efficacy and economy of the WEX principle, suggesting that seemingly disparate phenomena can all be understood through a single ontological lens. Open questions remain including the measurement problem (which WEX partially addresses) and why energy is exchanged in quantized amounts (an empirical versus theoretical aspect of quantum theory). While WEX does not fully resolve these problems, a potentially fruitful path forward involves embracing the intrinsic wave nature of matter and structuring research programs and experiments to further explore this perspective.

More broadly, WEX reframes quantum reality ontologically: Every star, planet, organism, cell, molecule, atom, subatomic particle, elementary particle, and every force of nature consists of physically real, spatially extended, interacting wave energy patterns that are the sole fundamental constituents of physical reality. This perspective could help shift quantum foundations from a primarily abstract mathematical discipline toward one grounded in the physical mechanism of energy exchange. It opens research pathways across multiple domains: quantum information theory as structural constraint theory, quantum computing as geometric computing exploiting wave packet structure, optimizing measurement device design around wave packet structural properties, etc. Embracing the intrinsic wave nature of matter as an ontology can become an organizing principle for better understanding quantum phenomena at all scales of the universe and across all mathematical frameworks.

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Each entry links to the publisher's record or to an open-access preprint where one exists.

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