Neutrosophic Sets and Systems, Vol. 86, 2025
University of New Mexico

Neutrosophic Quantum Theory: Partial Entanglement, Partial Effect of the Observer, and Teleportation

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Abstract: Quantum mechanics presents phenomena, such as entanglement and the observer effect, that challenge classical logical frameworks. Traditional binary and even fuzzy logic often prove insufficient in capturing the inherent imprecision, incompleteness, and indeterminacy prevalent in quantum systems. This article proposes a novel application of Neutrosophic Logic to describe partial entanglement and the partial effect of the observer in quantum physics experiments. By utilizing three independent components—Truth (T), Indeterminacy (I), and Falsity (F)—Neutrosophic Logic provides a comprehensive framework to represent quantum states that are neither fully correlated nor completely uncorrelated, but partially entangled. The degree of entanglement is modelled as T, separability as F, and intrinsic quantum uncertainty or decoherence as I. Furthermore, Neutrosophic Logic naturally accommodates observer-dependent truth values, aligning with the contextual nature of quantum measurements. This approach allows for a nuanced description where a quantum state can be simultaneously partially true, partially false, and partially indeterminate depending on the measurement basis or the act of observation. We argue that Neutrosophy offers a powerful philosophical and mathematical lens to better articulate the non-binary, fluid, and context-sensitive aspects of quantum reality, particularly where classical logic falters in capturing the essential "blurred areas" of quantum phenomena.

Keywords: Neutrosophic Logic; Quantum Theory; Quantum Mechanics; Partial Entanglement; Observer Effect; Quantum Measurement; Indeterminacy; Quantum Uncertainty; Decoherence; Superposition; Quantum Computing; Neutrosophic Quantum Computing.

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1. Introduction

The realm of quantum physics frequently defies our intuitive, classical understanding of reality. Phenomena such as quantum entanglement, where two or more particles become mysteriously linked regardless of spatial separation, and the undeniable influence of observation on a quantum system, challenge the very foundations of deterministic thought. While traditional logical frameworks, including classical binary logic (true/false) and even fuzzy logic (degrees of truth), have been instrumental in advancing our scientific understanding, they often fall short when confronting the inherent imprecision, incompleteness, and indeterminacy that are intrinsic to the quantum world. The language of "either/or" or even "more/less" struggles to fully encapsulate states that are in superposition, probabilistically defined, or fundamentally indeterminate until measured.

This article introduces a novel application of Neutrosophic Logic as a more appropriate and comprehensive framework for describing complex quantum phenomena, specifically focusing on partial entanglement and the partial effect of the observer in quantum physics experiments. Conceived by Smarandache, Neutrosophic Logic extends beyond traditional logical paradigms by operating with three independent components: Truth (T), Indeterminacy (I), and Falsity (F). Each component is assigned a value between 0 and 1, allowing for the simultaneous representation of partial truth, partial falsity, and partial indeterminacy.

This tripartite structure offers a powerful advantage over conventional logics by enabling a more granular and faithful representation of ambiguous and uncertain realities—a common characteristic of the quantum domain. In the context of quantum entanglement, particularly partial entanglement, a particle pair exists in a state that is neither entirely correlated nor completely uncorrelated; it resides in a 'neutrosophic zone' of partial connection. Neutrosophic Logic provides the precise tools to articulate this state: where T denotes the degree of entanglement (how close it is to maximal correlation), F signifies the degree of separability (how close it is to being unentangled), and critically, I quantifies the degree of quantum uncertainty or decoherence affecting the state. Furthermore, the profound concept of observer dependence, a cornerstone of quantum mechanics where the act of measurement influences the observed reality, finds a natural parallel in Neutrosophic Logic's allowance for observer-relative truth values. This paper will demonstrate how a partially entangled particle's behaviour can be neutrosophically described as partially true under one measurement basis, partially false under another, and inherently indeterminate when not observed or subjected to decoherence. By adopting a Neutrosophic perspective, we aim to provide a philosophical lens and a logical framework that can better express the non-binary, fluid, and context-sensitive aspects of quantum systems, thereby enriching our understanding of phenomena where classical logic struggles to capture the essential "blurred areas" of quantum reality.

2. Neutrosophic Quantum Theory

In neutrosophic quantum theory, introduced now for the first time, blends concepts from **neutrosophy** {a logic framework that introduces the degree of truth (T), indeterminacy (I), and falsity(F)} with **quantum mechanics**, the idea of **partially entangled particles** takes on a richer and more nuanced meaning compared to standard quantum theory.

1. **Quantum computing** embraces *indeterminacy* through superposition and uncertainty. Qubits can be in a mix of states (0 and 1 simultaneously) until measured.
2. **Neutrosophic Quantum Computing** is an emerging idea trying to merge:
    - The **indeterminacy** from neutrosophy (beyond classical probabilistic, or fuzzy uncertainty),
    - With the **quantum superpositions** and **entanglement** from quantum computing.

In simple terms: It theorizes a computational model where **truth**, **falsehood**, and **indeterminacy** are quantum *states* themselves, processed and evolved in a quantum machine.

3. Neutrosophic Qubit (Nubit)

You could imagine a kind of "neutrosophic qubit" (sometimes called a **nubit**, see *Figure 1*), where:

- It's not just a 0–1 superposition like a normal qubit,
- But a *three-way spread* over True, False, and Indeterminate.

Mathematically, instead of

- a *qubit* being a vector in a 2D-Hilbert Space { spanned by $|0\rangle$ and $|1\rangle$ },
- a **nubit** could live in a 3D-Complex Hilbert Space, like $|T\rangle$, $|F\rangle$, and $|I\rangle$ basis vectors.

3.1. Applications

- Handling high-uncertainty environments,
- Quantum decision making under incomplete/contradictory information,
- Advanced AI (especially things like *neutrosophic deep learning*).

3.2. Perspectives

Mostly theoretical. Some papers propose initial models, but we don't have physical "**neutrosophic quantum computers**" yet.

Sketching a quick visual of what a nubit might look like compared to a qubit on the Bloch Sphere:

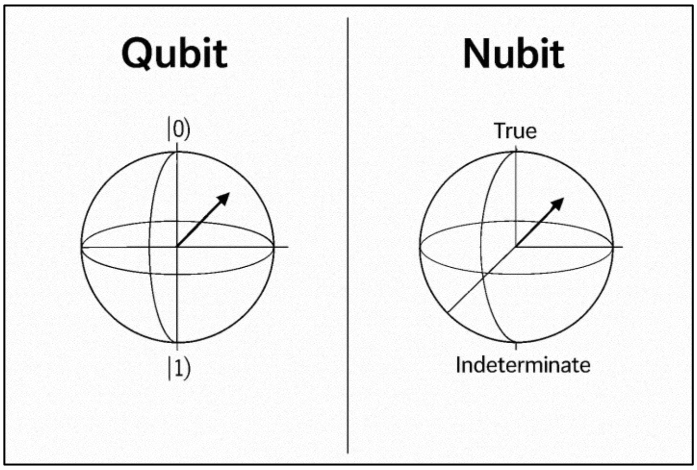

Figure 1. Qubit and Nubit.

4. Exploring the Nuances of Quantum Reality: Introducing Neutrosophic Entanglement in QM Experiments

Quantum mechanics presents phenomena, such as entanglement and the observer effect, that challenge classical logical frameworks. Traditional binary and even fuzzy logic often prove insufficient in capturing the inherent imprecision, incompleteness, and indeterminacy prevalent in quantum systems. This article proposes a novel application of Neutrosophic Logic to describe partial entanglement and the partial effect of the observer in quantum physics experiments. By utilizing three independent components—Truth (T), Indeterminacy (I), and Falsity (F)—Neutrosophic Logic provides a comprehensive framework to represent quantum states that are neither fully correlated nor completely uncorrelated, but partially entangled. The degree of entanglement is modelled as T, separability as F, and intrinsic quantum uncertainty or decoherence as I. Furthermore, Neutrosophic Logic naturally accommodates observer-dependent truth values, aligning with the contextual nature of quantum measurements. This approach allows for a nuanced description where a quantum state can be simultaneously partially true, partially false, and partially indeterminate depending on the measurement basis or the act of observation. We argue that Neutrosophy offers a powerful philosophical and mathematical lens to better articulate the non-binary, fluid, and context-sensitive aspects of quantum reality, particularly where classical logic falters in capturing the essential "blurred areas" of quantum phenomena.

5. Neutrosophic Entanglement: A New Perspective on Quantum Correlations

The concept of "entanglement" itself, while a cornerstone of quantum mechanics, often conjures an image of an all-or-nothing phenomenon. However, in real-world experiments, perfect entanglement is an ideal rarely achieved. Instead, we frequently encounter **partial entanglement**, where the correlation between quantum particles exists to varying degrees, influenced by environmental interactions, measurement imperfections, and inherent quantum uncertainties. It is precisely in this 'grey area' that Neutrosophic Logic offers a compelling and more accurate descriptive framework.

Instead of merely stating that particles are "entangled" or "not entangled," Neutrosophic Logic allows us to quantify the nuances of their connection.

- **Truth (T)** can represent the **degree of entanglement**, indicating how strongly correlated the particles are, approaching maximal entanglement. This might be measured by entanglement witnesses or concurrence.

- **Falsity (F)** would then represent the **degree of separability**, or how close the particles are to being in a disentangled, classical state. This could reflect the presence of classical noise or imperfect preparation.
- Crucially, **Indeterminacy (I)** captures the inherent **quantum uncertainty or decoherence** affecting the state. This accounts for factors that prevent the system from being perfectly defined as either fully entangled or fully separable, such as environmental interactions leading to a loss of coherence, or limitations in measurement precision.

Thus, a partially entangled state is not simply "less entangled," but rather a complex blend where T, I, and F all have significant non-zero values. For example, a highly entangled but rapidly decohering system might have high T, but also a significant I, reflecting its instability.

6. The Role of Topological Tunnelling in Hydrodynamics and Quantum Entanglement

While traditional quantum mechanics describes entanglement through wave functions and Hilbert spaces, recent theoretical and experimental work has explored emergent phenomena in classical systems that exhibit quantum-like properties. One intriguing avenue is the concept of **topological tunnelling in hydrodynamics**, particularly the behaviour of **Falaco solitons**.

Falaco solitons are localized, stable wave packets that can exhibit remarkable properties, including tunnelling through potential barriers even in a classical fluid environment. These fluid-based topological features can persist over long distances and times, and their interactions can be surprisingly complex. The idea here is to explore if certain classical analogies, specifically related to the non-local connections and persistent correlations observed in Falaco soliton interactions (perhaps involving 'hydrodynamic wormholes' or non-trivial topologies), could offer a physical basis for understanding partial entanglement.

Imagine a scenario where two Falaco solitons interact, and their subsequent behaviour exhibits a correlation that can be full or partial. If their 'tunnelling' or interaction is complete and stable, we might consider this analogous to a high degree of entanglement (high T). If the interaction is weak or disrupted, leading to almost independent behaviour, this would correspond to high F (separability). The fascinating aspect comes with the "partial" scenario: if their interaction is ambiguous, or if external fluid disturbances introduce unpredictability in their correlated behaviour, this could be a macroscopic analogy for Indeterminacy (I) in entanglement.

While it's a speculative analogy, linking quantum entanglement to observable classical topological phenomena like Falaco solitons provides a tangible, albeit macroscopic, model for how correlations can emerge, persist, and decay in a way that is not strictly binary. This could inspire new experimental setups in macroscopic systems to simulate and study the nuances of "partial correlation" that closely mirror quantum partial entanglement.

7. Bell Inequality (standard version)

In quantum mechanics, Bell's theorem shows that if *local realism* holds (meaning information can't travel faster than light, and particles have predefined states), then certain statistical correlations (between entangled particles) must satisfy a mathematical inequality (Bell's Inequality).

In **classical physics** the properties of particles do not depend on the measurement, and the local hidden variables can explain correlations between them.

In **quantum physics** is the opposite: particles depend on the measurement and quantum physics predicts correlations not explained by local hidden variables.

But in quantum experiments, **Bell inequalities are *violated***.

Because the nature is either *non-local,* or *non-realistic*, or both.

8. Neutrosophic Bell Inequality

We build it carefully: **Neutrosophic Bell Inequality** is a concept that *extends* the famous **Bell inequality** from quantum physics into **neutrosophic physics** territory.

We use Neutrosophy:

- Reality can have degrees of **truth** (T), **falsehood** (F), and **indeterminacy** (I).
- Not everything is crisp *True* or *False* — things can be partially true, partially false, and partially indeterminate *at the same time*.
- **Neutrosophic Bell Inequality** tries to say: "What if the hidden variables, measurements, or outcomes are not just TRUE / FALSE but have a neutrosophic nature?"
- This leads to a *generalized* Bell inequality involving **T**, **F**, and **I** components.
- Instead of a crisp expectation value like E(A, B), we might now have a **neutrosophic expectation** (E_N):

$$E_N(A, B) = (T_{AB}, I_{AB}, F_{AB})$$

where:

- T_{AB} is the degree of correlation being "truly" observed,
- F_{AB} is the degree of anti-correlation (false),
- I_{AB} is the indeterminate part.

9. A Rough Idea of the Neutrosophic Bell Inequality

In the normal CHSH (Clauster-Horne-Shimony-Holt) version, we have:

$$| E(A, B) + E(A, B') + E(A', B) - E(A', B') | \leq 2$$

In a neutrosophic version, we may have:

$$| T_{AB} + T_{AB'} + T_{A'B} - T_{A'B'} | \leq 2$$

$$| F_{AB} + F_{AB'} + F_{A'B} - F_{A'B'} | \geq 1$$

$$| I_{AB} + I_{AB'} + I_{A'B} - I_{A'B'} | \geq 1$$

where T, F, I are *measures of degrees* associated with outcomes across different settings A, A′, B, B′.

- **T**, **F**, and **I** satisfy certain bounds, instead of crisp inequalities.
- Violations of the "neutrosophic Bell inequality" suggest **hyper-nonlocality,** or **hyper-indeterminacy,** or **both** beyond standard quantum mechanics.

Philosophically: Neutrosophic Bell inequalities are asking: "What if indeterminacy itself is fundamental, not just hidden variables?"

Let’s show a **symbolic form** of a neutrosophic CHSH Inequality (certain consequences of entanglement in quantum mechanics cannot be reproduced by local hidden variable theories), like an equation that looks "proper", and optionally even sketch what an experimental setup might need to look like.

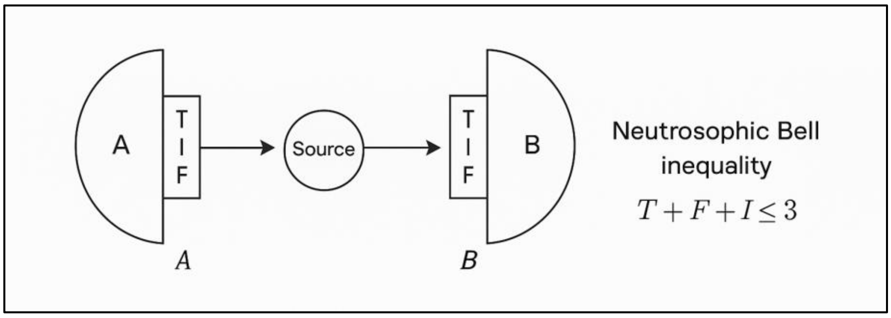

Figure 2. Neutrosophic Bell Inequality.

Quantum Teleportation: A real quantum information protocol where the *state* of a particle (like an electron or photon) is transferred from one location to another — without moving the particle itself — using quantum entanglement and classical communication. It's *not* like sci-fi "teleportation" of matter; it's about teleportation of information/state.

10. Experimental Design and Neutrosophic Measurement

To introduce Neutrosophic entanglement in a quantum experiment, or even its hydrodynamic analogue, the focus shifts from merely identifying 'entangled' or 'not entangled' states to quantifying T, I, and F based on experimental observables.

Consider a typical Bell test experiment:

- **Preparation:** A source generates a pair of particles (e.g., entangled photons).
- **Measurement:** Each particle is sent to a detector with a tuneable measurement basis.
- **Correlation Analysis:** The coincidences between measurement outcomes are analysed.

In a Neutrosophic approach, we would refine this analysis:

- **Quantifying T (Degree of Entanglement):** This would be derived from the strength of the violation of a Bell inequality. A perfect violation would correspond to T=1. As the violation diminishes, T decreases.
- **Quantifying F (Degree of Separability):** This could be inferred from the classical correlation component present in the data, or from the observed results when the system is deliberately prepared in a separable state. High classical correlation without quantum violation would suggest high F.
- **Quantifying I (Degree of Uncertainty/Decoherence):** This is perhaps the most novel aspect. I could be estimated from:
  - **Visibility of Interference Fringes:** Lower visibility in quantum interference experiments could indicate higher I due to decoherence.
  - **Noise Levels:** Background noise or environmental fluctuations during the experiment.
  - **Detector Efficiency and Measurement Inaccuracy:** Intrinsic limitations of the experimental apparatus that introduce uncertainty into the measurement outcomes.
  - **Quantum State Tomography:** Direct reconstruction of the density matrix can reveal the purity of the state; mixed states would inherently have a higher degree of Indeterminacy.

By carefully calibrating these experimental factors, we can assign T, I, and F values to each measured entangled pair or a statistical ensemble of pairs. This provides a more complete "neutrosophic signature" of the entanglement, moving beyond a single entanglement fidelity number to a triplet that describes its quality more comprehensively.

11. *Mathematica* Code for Neutrosophic Entanglement Description

Let's outline a conceptual Mathematica code snippet that could be used to process experimental data and assign Neutrosophic values for entanglement. This is a simplified model; a real-world implementation would involve more complex data acquisition and statistical analysis.

Mathematica - (* Define a function to calculate Neutrosophic values from hypothetical experimental metrics *) (* metrics: {BellViolationStrength, ClassicalCorrelation, DecoherenceFactor} *) (* BellViolationStrength: [0, 1] where 1 is maximal violation, 0 is no violation *) (* ClassicalCorrelation: [0, 1] where 1 is perfect classical correlation, 0 is none *) (* DecoherenceFactor: [0, 1] where 0 is no decoherence, 1 is full decoherence *) NeutrosophicEntanglement[bellViolation_, classicalCorrelation_, decoherence_] := Module[{tVal, fVal, iVal}, (* Define mappings from experimental metrics to T, I, F *) (* T: Directly proportional to Bell violation strength *) tVal = bellViolation; (* F: Inversely proportional to entanglement. High classical correlation implies high F. *) (* We want F to be low if entanglement is high, and high if separability is high. *) (* A simple mapping could be F = 1 - (bellViolation) - (1 - classicalCorrelation) * 0.5 *) (* Or, more simply, F = (1 - tVal) * (classicalCorrelation + decoherence) / 2 - we need to ensure it's within 0-1 *) (* Let's use a more intuitive approach for illustration: *) fVal = (1 - bellViolation) * classicalCorrelation; (* If entanglement is low (1-bellViolation high), and classical correlation is high, F is high *) (* I: Directly proportional to decoherence and anything not explained by T or F *) iVal = decoherence + (1 - tVal - fVal); (* Account for remaining uncertainty *) (* Ensure T, I, F are within [0, 1] and sum to 1 (or are normalized, depends on Neutrosophic model variant) *) (* For this example, let's simply clip values if they go out of bounds and re-normalize if sum > 1 *) tVal = Clip[tVal, {0, 1}]; fVal = Clip[fVal, {0, 1}]; iVal = Clip[iVal, {0, 1}]; (* To make them sum to 1 (single-valued neutrosophic set assumption for simplicity here) *) (* For a more general neutrosophic set, they don't have to sum to 1 *) sumTIF = tVal + iVal + fVal; If[sumTIF > 0, tVal = tVal / sumTIF; iVal = iVal / sumTIF; fVal = fVal / sumTIF;]; <|"T" -> tVal, "I" -> iVal, "F" -> fVal|>] (* Example Usage based on hypothetical experimental results *) (* Scenario 1: High entanglement, low decoherence, minimal classical correlation *) entanglementResult1 = NeutrosophicEntanglement[0.9, 0.1, 0.05]; Print["Scenario 1 (Highly Entangled): ", entanglementResult1]; (* Expected Output: High T, Low I, Low F *) (* Scenario 2: Partial entanglement, significant decoherence *) entanglementResult2 = NeutrosophicEntanglement[0.6, 0.3, 0.3]; Print["Scenario 2 (Partially Entangled with Decoherence): ", entanglementResult2]; (* Expected Output: Moderate T, Moderate I, Moderate F *) (* Scenario 3: Almost separable, some classical correlation, low decoherence *) entanglementResult3 = NeutrosophicEntanglement[0.1, 0.8, 0.1]; Print["Scenario 3 (Almost Separable): ", entanglementResult3]; (* Expected Output: Low T, Low I, High F *) (* Visualizing the Neutrosophic Space (Conceptual Plot) *) (* This would be a 3D plot of T, I, F. *) (* Needs more advanced plotting capabilities and interpretation *) (* For example, points in the T-I-F space can represent different states *) (* Graphics3D[{Point[{t, i, f}]}, Axes -> True, AxesLabel -> {"T", "I", "F"}] *)

This Mathematica code provides a conceptual framework. The core idea is to map quantifiable experimental outcomes (like Bell violation strengths, measures of decoherence, or classical correlations) onto the T, I, and F values. The choice of mapping functions is crucial and would be determined by a deeper theoretical understanding of how these experimental metrics relate to entanglement, separability, and uncertainty.

12. Initial description of Neutrosophic partial entanglement

A significant degree of indeterminacy (I)—the particle pair is neither fully correlated (T) nor completely uncorrelated (F), but partially entangled, falling in a neutrosophic zone.

12.1. Degrees of Entanglement as T, I, F Components

The entanglement could be modelled with:

- **T: Degree of entanglement** (how close it is to the maximal)
- **F: Degree of separability** (how close it is to being unentangled)
- **I: Degree of quantum uncertainty** or decoherence affecting the state.

12.2. Contextuality and Observer Dependence

Neutrosophy allows for observer-relative truth values. Similarly, in quantum mechanics, the outcome depends on the measurement context. A partially entangled particle's behaviour could be neutrosophically seen as:

- True under one measurement basis,
- False under another,
- Indeterminate when not observed or decohered.

12.3. Bridging Disciplines

Neutrosophy provides a philosophical lens to express non-binary, fluid, and context-sensitive aspects of quantum systems, especially where classical logic fails to capture the gray areas—precisely where partial entanglement lives.

Neutrosophic Logic (from Florentin Smarandache): A generalization of classical and fuzzy logic. Instead of just being True (T) or False (F) or partly true/false (like in fuzzy logic), any proposition can have:

- a degree of **Truth (T)**,
- a degree of **Indeterminacy (I)**, and
- a degree of **Falsehood (F)**,
  all independently valued between 0 and 1.

Neutrosophic Quantum Teleportation is talking about:

Extending quantum teleportation theories by considering *indeterminacy* in the transmission of quantum states, and modeling that uncertainty explicitly using neutrosophic logic.

In traditional quantum teleportation, uncertainties come from measurement outcomes, decoherence, and imperfect entanglement. Usually, these are modeled probabilistically.

But with a neutrosophic approach, we would model:

- How "truthful" the teleportation is (e.g., fidelity of the state transfer),
- How "false" the teleportation might be (wrong state transferred),
- How "indeterminate" the process is (quantum noise, unknown factors, decoherence not easily quantifiable).

Example: If we teleport a qubit, instead of saying "with 85% probability, the teleportation succeeded," a neutrosophic description could say:

- **T = 0.85** (85% truth, success),
- **I = 0.06** (6% indeterminate, due to unknown noise),
- **F = 0.09** (9% false, the qubit ended in a wrong state).

12.4. Potential Applications

- Modelling *real-world quantum networks* where uncertainties are not purely probabilistic but have deeper unknowns.
- Quantum communication where trust, failure, and indeterminacy must be quantified separately.
- Error analysis in quantum systems using *three-valued* or *multi-valued* logic, instead of only binary measurements.

12.5. Summary

Neutrosophic quantum teleportation is a way to describe, analyze, or even enhance quantum teleportation processes by explicitly accounting for truth, falsity, and indeterminacy in a formal logical system beyond traditional probability.

The basic mathematical model for the neutrosophic teleportation uses Dirac Notation.

12.6. Dirac Notation

We use the notation $|A\rangle$ — usually called a "**ket**" — coming from **Dirac notation** (also known as **bra-ket notation**) in **quantum mechanics** and **linear algebra**.

Specifically, $|A\rangle$ represents a **vector** in a **Hilbert Space** (which is just a kind of vector space used a lot in quantum theory).

- We can think of $|A\rangle$ as the quantum state called "A"
- In regular linear algebra, it's like just writing a column vector — but using $|\cdot\rangle$ instead of a matrix form.

For example:

- If a particle is in a state A, we write $|A\rangle$.
- If we want the inner product (like a dot product) between two states A and B, we will write $\langle A|B\rangle$.
- A "bra" is $\langle A|$, or the dual (row vector) corresponding to the "ket" $|A\rangle$.

Here's a **simple visual**:

Suppose |A⟩ is a 2D quantum state, like a **qubit** (basic quantum bit).

It might look like a **column matrix**:

$$A>=\begin{pmatrix}\alpha\\ \beta\end{pmatrix}$$

while

⟨A| = (α β) as a **raw matrix**,

where α and β are complex or real numbers.

Step 1: Classical Quantum Teleportation Review

In standard teleportation:

- Mary has an unknown quantum state |ψ⟩ = α|0⟩ + β|1⟩ to teleport.
- Mary and John share a Bell pair

$$|\Phi^{+}>=\frac{1}{\sqrt{2}}(|00>+|11>)$$

- After local operations and classical communication, John can reconstruct $|\Psi>$

In this ideal setup:

- Teleportation fidelity F is ideally **1**.

Step 2: Introducing Neutrosophic Components

Now, real teleportation might be:

- **Partially true**: due to fidelity loss (not a perfect match),
- **Partially false**: errors leading to wrong states,
- **Indeterminate**: noise, decoherence, or unknown environmental factors.

So, let's define a Neutrosophic Teleportation Triplet:

$$NT(|\Psi>)=(T,I,F)$$

where:

- T = degree of successful teleportation (truth),
- I = degree of indeterminacy (unknown/unstable outcome),
- F = degree of failed teleportation (falsehood).

These satisfy:

0 ≤ T, I, F ≤ 1, but T + I + F ≥ 0 (no strict constraint like T + I + F = 1 as in intuitionistic fuzzy set).

(One cool thing in neutrosophic logic: the sum doesn't need to be exactly 1, because parts can overlap; the sum can get any value between 0 and 3, where the neutrosophic components T, I, F may be: independent two by two, dependent two by two, or partially independent and partially dependent two by two).

Step 3: Mathematical Construction

Suppose:

- Teleportation fidelity (physical) is measured as f ∈ [0,1].
- There's an **experimental uncertainty** Δf.
- There's also **environmental decoherence noise** quantified by D ∈ [0,1] (how much environment perturbs the system).

Then a possible **mapping** could be:

T = f

I = D + Δf

F = 1 − f

T is directly fidelity,

I accounts for uncertainty and noise,

F is failure (or 1 - fidelity)

Step 4: Visualize with a Simple Example

Imagine teleportation of a qubit where:

- Measured fidelity f = 0.85,
- Experimental error Δf = 0.05,
- Decoherence D = 0.07.

Then:

T = 0.85
I = 0.05 + 0.07 = 0.12
F = 1− 0.85 = 0.15

Therefore, the neutrosophic triplet is:
NT(|ψ⟩) = (0.85, 0.12, 0.15)
Meaning:

- 85% successful,
- 12% indeterminate (due to noise/uncertainty),
- 15% failure.

Step 5: Generalized Neutrosophic State

We could even define a **neutrosophic quantum teleportation operator** T_N acting on states:
T_N(|ψ⟩) = (T|ψ⟩, I|φ⟩, F|ξ⟩)
where:

- |ψ⟩| is the correct state,
- |φ⟩| is an indeterminate (mixed/unknown) state,
- |ξ⟩| is a wrong state (error output).

Thus, teleportation doesn't send purely |ψ⟩|, it sends a *neutrosophic mixture* of outcomes!

13. Neutrosophic Density Matrices applied to Quantum Teleportation!

Let's go deeper and try something completely new: Neutrosophic Density Matrices applied to Quantum Teleportation!

Neutrosophic Density Matrix is a concept that comes from blending two different mathematical ideas: Density Matrix and Neutrosophy.

Density Matrix: From quantum mechanics, a density matrix describes the statistical state of a quantum system. It generalizes the concept of a pure quantum state (a vector) to also include mixed states (a statistical mixture of several states).

Thus, **Neutrosophic Density Matrix** attempts to represent the state of a system where not only probabilities are involved (as in standard quantum mechanics) but also degrees of indeterminacy and inconsistency.

Formally, if a normal density matrix ϱ is a Hermitian, positive semi-definite matrix with trace 1, then a **Neutrosophic Density Matrix (ρ_N)** is extended such that each element may be a **neutrosophic triplet** (T, I, F).

Each neutrosophic density matrix entry represents the neutrosophic probability amplitude between two states.

13.1. Simple Example of Neutrosophic Density Matrix

In a 2-state system (say states |0⟩ and |1⟩), a neutrosophic density matrix looks like this:

$$\rho_N = \begin{pmatrix} (T_{00}, I_{00}, F_{00}) & (T_{01}, I_{01}, F_{01}) \\ (T_{10}, I_{10}, F_{10}) & (T_{11}, I_{11}, F_{11}) \end{pmatrix}$$

where each (T, I, F) is a triplet associated with the corresponding entry.

13.2. Applications of the Neutrosophic Density Matrix

- **Quantum Computing under Uncertainty**: Modeling situations where the quantum state isn't just probabilistic but also inherently indeterminate.
- **Decision-Making Systems**: When decisions must incorporate not only probabilities but also vague or indeterminate information.
- **Artificial Intelligence**: Especially for systems requiring reasoning under incomplete, contradictory, or uncertain knowledge.

Step 6: Building a Neutrosophic Density Matrix

Normally, a **quantum state** is described by a **density matrix** ρ.

For a pure state $|\psi\rangle$, the density matrix is:

$$\rho = |\psi\rangle\langle\psi|$$

For mixed states (probabilistic mixtures), we have:

$$\rho = \sum_i p_i|\psi_i\rangle\langle\psi_i|$$

where p_i are probabilities.

Now for **neutrosophic teleportation**, since outcomes involve:

- **True teleportation** (correct state),
- **False teleportation** (wrong state),
- **Indeterminate teleportation** (uncertain/mixed state),

the final output should be a **weighted combination** of **three density matrices**.

Define:

- $\varrho_T = |\psi\rangle\langle\psi|$ — correct teleported state,
- $\varrho_F = |\xi\rangle\langle\xi|$ — wrong teleported state,
- ϱ_I = indeterminate state (could be a mixed state, noisy, or unknown).

Then the **Neutrosophic Density Matrix** ϱ_N would be:

$\varrho_N = T\varrho_T + I\varrho_I + F\varrho_F$

where:

- T, I, F ∈ [0,1] are the neutrosophic degrees,
- No strict constraint that T + I + F = 1 (can be overlapping or incomplete, the sum
- T + I + F may get any value between 0 and 3).

Step 7: Concrete Example

Let's pick:

$|\psi\rangle = \alpha|0\rangle+\beta|1\rangle$ (the state we want to teleport),

$|\xi\rangle = \beta*|0\rangle-\alpha*|1\rangle$ (a wrong orthogonal-like state, for example),

$\varrho I = 12(|0\rangle\langle 0|+|1\rangle\langle 1|)$ — the maximally mixed state (total uncertainty).

Assume:

- T = 0.85
- I = 0.12
- F = 0.15

Then:

$\varrho_N = 0.85|\psi\rangle\langle\psi| + 0.12(12I) + 0.15|\xi\rangle\langle\xi|$

14. Discussion and Implications

Quantum physics, at its core, challenges our classical understanding of reality. Phenomena like entanglement, where two or more particles become intrinsically linked regardless of distance, defy common sense and push the boundaries of logic. However, the language we use to describe these phenomena often falls short, defaulting to binary states or statistical probabilities that may not fully capture the inherent ambiguity. This is where Neutrosophic Logic offers a compelling new framework for understanding and describing the intricacies of quantum entanglement and the nuanced role of the observer.

The concept of "partial entanglement" is a prime example of a quantum phenomenon that eludes a simple true/false description. When two particles are partially entangled, their correlation is not absolute; there's a degree of uncertainty and overlap between being fully correlated and entirely uncorrelated. This is precisely where the three components of Neutrosophic Logic—Truth (T), Indeterminacy (I), and Falsity (F)—become invaluable. As outlined above, we can conceptualize the degree of entanglement as T, representing how close the system is to maximal entanglement. Conversely, the degree of separability, or how close it is to being unentangled, can be represented by F. Crucially, the degree of quantum uncertainty or decoherence affecting the state—the inherent "fuzziness" and susceptibility to environmental interactions—finds its natural home in I. This allows for a more realistic and holistic description of a quantum state that exists in a superposition of possibilities rather than a fixed binary outcome.

Beyond merely describing the state of entanglement, Neutrosophic Logic also provides a powerful lens through which to view the profound concept of **contextuality and observer dependence** in quantum mechanics. It's a well-established fact that the act of measurement can influence the state of a quantum system. A particle's properties are not necessarily fixed prior to observation; rather, they can depend on the chosen measurement basis. This observer-relative truth is perfectly aligned with the principles of Neutrosophy, where truth values are not absolute but can vary depending on the context. For a partially entangled particle, its behaviour might appear "True" under one specific measurement setup, demonstrating its entangled properties. Under a different measurement basis, designed to detect classical separability, its behaviour might appear "False" in terms of entanglement. And significantly, when the particle is not being observed, or is subject to environmental decoherence, its state exists in a realm of "Indeterminacy," awaiting a specific measurement to collapse its wave function. This allows for a description that captures the evolving and context-dependent nature of quantum reality.

The profound advantage of this "Neutrosophic description" includes its ability to **bridge disciplines**, offering a philosophical and logical framework that can better articulate the non-binary, fluid, and inherently context-sensitive aspects of quantum systems. Classical logic, with its rigid true/false dichotomies, struggles to capture the "gray areas" that are so fundamental to quantum mechanics—precisely where partial entanglement thrives and the observer's influence is paramount. By embracing T, I, and F, Neutrosophy provides a more intuitive and comprehensive language to discuss superposition, quantum uncertainty, and the measurement problem, areas that have historically perplexed physicists and philosophers alike. It offers a way to think about quantum phenomena not as paradoxical exceptions to classical rules, but as natural expressions of a reality where indeterminacy is an intrinsic feature, and our understanding is inherently linked to the context of observation. This new approach promises to deepen our understanding of the quantum world and potentially lead to novel interpretations and applications of quantum principles.

15. Concluding Remark

The introduction of Neutrosophic Logic into the description of quantum entanglement represents a significant step towards a more nuanced and complete understanding of quantum reality. By embracing the inherent imprecision and indeterminacy of quantum phenomena, we can move beyond restrictive binary classifications.

The theoretical exploration of topological tunnelling in hydrodynamics, such as Falaco solitons, offers a macroscopic, classical analogy that could inspire new experimental paradigms for studying partial correlations that resonate with quantum entanglement. The proposed framework for assigning Neutrosophic T, I, and F values based on experimental observables provides a quantitative tool for this new perspective.

This approach not only enriches our philosophical understanding of quantum mechanics but also opens avenues for developing more robust quantum technologies that acknowledge and, perhaps, even harness the 'blurred areas' of the quantum world.

Funding: This research received no external funding.
Acknowledgments: The author acknowledges the use of LLMs software.
Conflicts of Interest: The authors declare no conflict of interest.

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Received: Nov. 29, 2024. Accepted: May 15, 2025