The Quantum Handshake Explored

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Outline of Talk

1. Quantum Entanglement and Nonlocality
2. The Transactional Interpretation of Quantum Mechanics
3. Applying the Transactional Interpretation to Quantum Paradoxes
4. The Process of Forming Transactions
5. Conclusions
Part I
Quantum Entanglement and Nonlocality
Newtonian Mechanics vs. Quantum Mechanics

**Newtonian Mechanics:**
When a Newtonian system breaks up, each of its parts has a definite and well-defined energy, momentum, and angular momentum, parceled out at breakup by the system while respecting dynamics and conservation laws. After the component parts are separated, their properties are completely independent and *do not depend on each other*.

**Quantum Mechanics:**
When a quantum system breaks up, its parts may have indefinite values for energy, momentum, and angular momentum, as described by Heisenberg's Uncertainty Principle. After the component parts are separated, their properties are *not* independent and *may depend on each other*. This quantum property is called *nonlocality*, and the interdependent system parts are said to be *entangled*. 

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**Werner Heisenberg**
(1901 – 1976)

**Isaac Newton**
(1642 – 1726)
Why Nonlocality?

Nonlocality comes from two seemingly conflicting and incompatible aspects of the quantum formalism:

(1) Energy, momentum, and angular momentum are conserved in all quantum systems. In the absence of external forces and torques, their net values must remain unchanged as the system evolves.

(2) In the wave functions describing emitted particles in a quantum system, Heisenberg’s Uncertainty Principle allows energy, momentum, and angular momentum to be indefinite, typically spanning a range of values. This non-specificity persists until a measurement collapses the wave function and fixes the measured quantities with specific values.

The EPR Paradox: How can the wave functions describing the separated members of a system of particles, which may be light-years apart, have indefinite values for the conserved quantities, yet respect conservation laws when measurements are made?

Albert Einstein (1879 - 1955)
Why Entanglement?

The conservation laws are respected because the quantum wave functions of particles are entangled, a term coined by Schrödinger, meaning that even when the wave functions describe system parts that are far apart and out of light-speed contact, the separate wave functions continue to depend on each other and cannot be separately specified.

In particular, they depend on each other in such a way that conserved quantities in the parts must add up to the values possessed by the overall quantum system before it separated into parts. Einstein derisively called this nonlocal quantum behavior “spooky actions at a distance.”

How is this behavior possible? The TI provides an answer.
Part II
The Transactional Interpretation of Quantum Mechanics
The Wheeler–Feynman Handshake (1945)
Transactional Interpretation of Quantum Mechanics

See [https://www.amazon.com/dp/3319246402](https://www.amazon.com/dp/3319246402);

Briefly, the Transactional Interpretation applies the logic of Wheeler-Feynman electrodynamics to quantum mechanics. It describes any quantum event as a “handshake” between an offer wave ($\Psi$) generated when a quantum is emitted and a time-reversed confirmation wave ($\Psi^*$) generated when a quantum is absorbed.

The transaction is essentially a standing wave that forms across space-time to transfer the energy, momentum, etc. of a particle from one location to another.
(Step 1) TI Offer Wave
(Step 2) TI Confirmation Wave
(Step 3) TI Completed Transaction
How the TI Explains Quantum Nonlocality in EPR

There is a double handshake between the source and the two detectors. This transaction can only form if the polarizations match, insuring that angular momentum conservation is enforced.
Part III
Applying the Transactional Interpretation to Quantum Paradoxes
Einstein's Bubble (1927)

An isotropic light source emits a single photon as an expanding spherical wave function.

At the 1927 Solvay Conference, Einstein asked: “How do the remote parts of the photon's wave function 'know' that they should disappear when the photon is detected?”
Young's 2-Slit Experiment (1803)

A polarized plane light wave illuminates slit A. The photon wave function passes through both slits at B and produces a 2-slit interference pattern (red) at C.

Placing a half-wave plate over one slit at B converts the 2-slit interference pattern to a 1-slit diffraction pattern (green).
The wave interference pattern can be observed to build up, one photon at a time. Feynman called this behavior “the central mystery of quantum mechanics”.
The TI & Young’s 2-Slit Expt.
Wheeler’s Delayed Choice Experiment (1978)

Choose

Wave-Like Interference Measurement (2 paths)

Particle-Like Which-Way Measurement (1 path)

The observer decides which measurement to do after the photons have already passed through the slit system. Retrocausality?
In a Which-Way setup, we place a set of wires with 6% opacity at the positions of the interference minima that were observed at $\sigma_1$; we place a detector at image focus 2' on plane $\sigma_2$, and the experimenter observes and counts the particle flux passing through slit 2 to Det. 2'.
A Question for the Audience

Q: Will interference be present or not? Which is true?

A. As Bohr taught us, when we do a particle-like Which-Way measurement, all wave properties are absent and no wave interference can be observed. Therefore, the wires will intercept 6% of the flux.

B. Interference is still present. The wires have been placed at the interference minima, where wave cancellation occurs and wave amplitudes are zero. Therefore, the wires will intercept almost no flux.
Afshar Experiment Results

Grid Out & 2 Slits
No Loss

Grid In & 1 Slit
6% Loss

Grid In & 2 Slits
<0.1% Loss
Afshar Experiment Images

One open Wires In

Astra Image Line Plot - Rotate - Row [531]
4/6/2004 6:05:39 AM

Pixel Number

- 1,300
- 1,200
- 1,100
- 1,000
- 900
- 800
- 700
- 600
- 500
- 400
- 300
- 200
- 100

Pixel Value

- 240
- 220
- 200
- 180
- 160
- 140
- 120
- 100
- 80
- 60
- 40
- 20
- 0

Afshar Experiment Images

Both open Wires In

Both open Wires Out
**Afshar Experiment Implications**

**Conclusions:**

- Interference is **still** present, even when an unambiguous Which-Way experimental measurement is performed.

- Measuring particle-like behavior does **not** suppress wave-like behavior, if careful non-interactive wave measurements are made.

- It appears that **simultaneously**, (1) waves pass **both** slits to create interference and (2) a photon passes through **only one slit**.
The Afshar Experiment and Quantum Interpretations

- **The Copenhagen Interpretation** asserts that quantum interference between waves only occurs when the waves are indistinguishable, and that when “Which-Way” measurements are performed, wave interference vanishes. The Afshar experiment *falsifies* this assertion.

- **The Many Worlds Interpretation** asserts that quantum interference between “worlds” cannot occur when the worlds are physically distinguishable. The Afshar experiment *falsifies* this assertion.

- **The Transactional Interpretation** explains the Afshar Expt. as the result of interference between initial offer waves from the two slits. Even in the Which-Way configuration with wires present, destructive offer-wave interference occurs. Therefore, transactions cannot form on the wires because the *offer waves cancel there*. Consequently, the transmission must be nearly 100%, as observed.
Freedman-Clauser Polarization EPR Experiment (1972)

An EPR Experiment Testing QM vs. Bell’s Theorem:
When polarimeters are aligned, only matching (H,H) or (V,V) coincidences are observed.

When polarimeter A is rotated, “noise” coincidences (H,V) and (V,H) grow initially as the square of rotation angle $\theta$. 
The TI’s “V” Handshake Accounts for EPR Correlations

How can the measured polarizations match, no matter what polarization type is measured? How can the noise grow a $\theta^2$?
Interaction-Free Measurement:

With no object in lower beam, all of the photons go to $D_1$.

If an object is placed in the lower beam, photons go to $D_2$ one fourth of the time.

Thus, any photon detection at $D_2$ indicates the presence of an object in the beam, even though no photon has ever interacted with that object.

The TI explains this non-classical behavior as the suppression of an offer wave that would otherwise have canceled the upper-path wave at $D_2$, preventing detection.
The Hardy Boxed-Atom Experiment (1992)

The spin $\frac{1}{2}$ atom is prepared in X-up, Stern-Gerlach split into ±Z projections, then recombined and the X-spin measured.

For photons at D, the atom, prepared in X-up, has a 50% chance of being in X-down, even though it has never interacted with a photon.

The TI explains in the same way as the interaction-free measurement. Detection at D means the offer wave in the lower arm is blocked because the atom is in the Z+ state.
The Quantum Eraser Experiment (1995)

Pump laser beam makes two passes through LiIO$_3$ down-conversion crystal. First-pass photons are reflected to match paths of second-pass photons, and interference is observed by moving mirror $\Phi_p$.

Inserting QWP kills the interference.

Inserting 45° filter near $D_1$ restores interference in $D_1$ and $D_2$, even if this happens far downstream.

The TI explains this behavior in terms of handshakes that include both passes, provided the paths are indistinguishable. Inserting QWP requires separate pass transactions. Inserting the 45° filter project out the same polarization in the two paths, permitting a joint transaction.
Handshakes and Black Holes

The Black Hole Information Paradox:
Hawking radiation makes pairs of entangled photons, one of which disappears behind the event horizon of a Black Hole. Therefore, it is argued, the pair cannot continue to be entangled. How could the entanglement be broken?

Big names have provided absurd explanations:
- **Firewalls??** (Almheiri, Marolf, Polchinski & Sully)
- **Wormholes??** (Maldacena & Susskind)

**Problem:** Nothing can escape from a Black Hole except **advanced waves**, which easily escape and complete a WF Handshake, thereby preserving the entanglement. Therefore, the Black Hole Information Paradox goes away.
Part IV
The Process of Forming Transactions
From Wheeler-Feynman to the Transactional Interpretation

In classical Wheeler-Feynman electrodynamics, it is the advanced-wave responses from all of the absorbers in the future universe, arriving together back at the emitter that cause an emitting object to radiate, lose energy, and recoil during emission. Every future absorber is very slightly perturbed by the arriving retarded wave and generates an advanced-wave responses, which return to perturb the emitter.

In the quantum domain this scenario must be changed to reflect quantization and probabilistic quantum behavior. Due to the inverse-square law, any spherical wave function will become progressively weaker as it propagates for a significant distance before absorption, and cannot deliver a photon’s worth of energy and momentum. Moreover, the absorber cannot accept less than a full quantum of energy, but it may be slightly perturbed by the arriving retarded wave.

In the Transactional Interpretation, the Wheeler-Feynman process is only the initial “perturbative” phase of transaction formation.
A Two-Atom Transaction

Based on Sect. 5.4, Collective Electrodynamics, Carver Mead (2000)

Emitter atom $E$ is in its $1^{-}$ excited state and sends out a retarded “offer” wave $\psi$.

Absorber atom $A$ is in its $0^{+}$ ground state and responds with an advanced “confirmation” wave $\psi^*$. The result is that both atoms are very slightly perturbed by the arriving waves. Both become atoms in mixed states containing a small admixture (green) of an opposite-parity wave function.
Oscillating Dipole

Mixed-State Oscillating Dipole Moment
A Radiating Mixed-State Atom

An atom in the ground state, but with a slight perturbation of an opposite-parity excited-state wave function, or vice versa, develops an oscillating dipole moment that radiates.
A Two-Atom Transaction

Two atomic dipoles oscillating with the same frequency and appropriate phasing dictated by their initial perturbations, transfer energy and momentum, thereby creating a transaction.
The zero crossings of the handshake vector potential at \( t = 0 \). Paths shown through high-amplitude regions have an even number of zero crossings. Thus the potentials traversing these paths all arrive in phase.
Wave Exchange Avalanches to Form a Transaction
Show Movies Now
Part 5 - Conclusions

1. The Transactional Interpretation provides a rational way of visualizing and understanding the mechanisms behind entanglement, nonlocality, and wave function collapse.

2. The plethora of interpretational paradoxes and non-classical quantum-optics experimental results can all be understood by applying the Transactional Interpretation.

3. The process of transaction formation, at least in simple cases, emerges directly from the application of standard quantum mechanics to the advanced-retarded-wave handshake process as it builds and avalanches to completion.

4. As the mattress commercial asks:
   Why buy your Quantum Interpretation anywhere else?
Any Questions?
Extra Slide:
Bohmian Trajectories of Photons in Slits & Crossing Beams

Figure 3.1: Trajectories for two Gaussian slit systems
Extra Slide:
A Gedanken Test of Bohmian Quantum Mechanics