A QFT-based Quantum Universe Without Many Worlds

Arnold Neumaier (University of Vienna)

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The Laplacian Quantum Universe

- All physical details in the universe (the only world considered) are uniquely determined by its **universal *-algebra** generated by smeared quantum fields, and its **universal Heisenberg state**.
- The universal Heisenberg state assigns to each X in the universal *-algebra a unique **quantum value** $\langle X\rangle$ (without any a priori statistical connotation).
- The **equations of motion of the universe** are the (nonlinear) **Schwinger–Dyson equations** for the connected N-point functions of the universal Heisenberg state.
- The quantum values of typical **macroscopic quantities** X are directly observable to a good accuracy.
- In particular, this applies to the values of pointer positions in measurements.

$\Rightarrow$ **Measurements have unique outcomes**.

$\Rightarrow$ **Probabilities** and **decoherence** are absent on the level of the universal Heisenberg state, but arise in approximate dynamical models, obtained by the elimination of environmental degrees of freedom.

Approximations

- Models of concrete **physical systems** need approximations by coarse-graining, since the precise state of the universe is unknown.

$\Rightarrow$ **effective equations of motion**

$\Rightarrow$ **Loss of unitarity**, due to simplifying assumptions underlying the models used, which force a reduced description that misses an important part of what happens in a unitary treatment.

Nonlinearities

- Effective equations of motion are often nonlinear (e.g., Hartree-Fock and Gross–Pitaevskii equations) and sensitive to initial conditions.

$\Rightarrow$ **chaos** and effective **randomness**.

Classical Systems

- For common macroscopic matter, the approximation is done by applying the **maximum entropy principle** to the quantum values of densities, currents, and the stress-energy tensor.

$\Rightarrow$ **fluid dynamics**, **elasticity theory**

Nonlocality

- Nonlocality is due to the fact that the N-point functions entering the equations of motion of the universe are nonlocal for $N > 1$.

$\Rightarrow$ **No hidden variables** are needed.

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Classical and Quantum Measurements

- A **classical measurement** at some spacetime point x is the reading of the value of some extensive or intensive field, averaged over a mesoscopic neighborhood of x.
- A **quantum measurement** is the reading of a single detector response to a microscopic system, measured according to the
- **Detector Response Principle (DRP):** *Each detection element responds to an incident stationary source with a nonnegative mean rate depending linearly on the density operator of the source. The mean rates sum to the intensity of the field.*

$\Rightarrow$ **POVM**, **Born rule**

State Determination

- A handful of classical measurements at x reveals the state of a classical system close to x.
- A handful of quantum measurements do not reveal anything about the state of the microscopic system. To determine this state one needs **quantum state tomography**, using a large number of quantum measurements.

Interpretation Issues

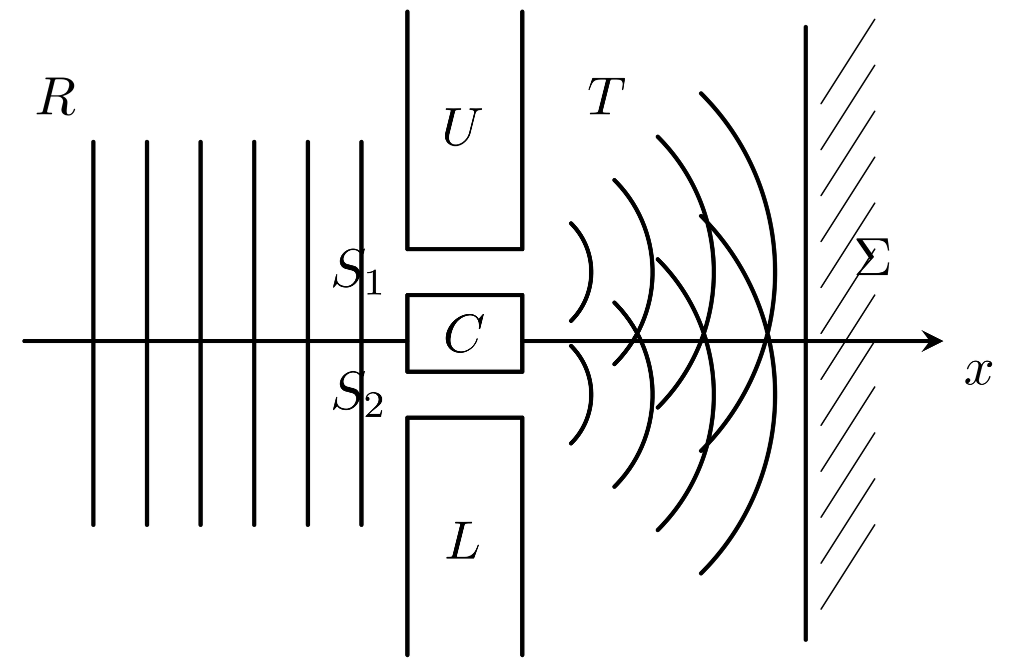
- Every concept is **rigorously defined**, consistent with algebraic QFT.

$\Rightarrow$ Like in geometry, **no further interpretation** is needed.

Further Details

see
`https://arnold-neumaier.at/ms/Laplace.pdf`

The Double Slit Experiment



A Unitary Double Slit Model

In a Laplacian quantum universe, what happens at the screen is adequately handled by the DRP.
But what happens at the barrier?

- We idealize the barrier to be an infinitely extended, infinitesimally thin, and perfectly reflecting polished surface containing a double slit with infinitesimally narrow slits.

$\Rightarrow$ Unitary dynamics for a model universe solely consisting of the free quantum electromagnetic field in the complement of this surface.

$\Rightarrow$ Single photon states satisfy the free Maxwell equations with reflecting boundary conditions.

Mathematical Analysis

- In a 2-dimensional model, a single photon traveling from left to right along a narrow beam of light whose cross section covers the area of the slits is, in the vicinity of the double slit, modeled for $t < 0$ by a traveling wave $F_{\rm in}(x, y, t) = F(x - ct)$ with $F(x) = 0$ for $x > 0$. It arrives at the barrier at time $t = 0$ and is **reflected everywhere except at the slits**, where we get for $t > 0$ and $x > 0$ a superposition $F_{\rm out}(x, y, t)$ of two spherical waves.
- If the cross section has width A and the two slits have total width $D \ll A$, only the fraction $p := D/A \ll 1$ of the total energy E of the incident beam passes through the double slit; thus the total energy of the superposition after passing the barrier is only pE.

$\Rightarrow$ In the unitary description, the total energy E is conserved, but **only the fraction** pE **is available for measurement at the screen**.

Collapse in a Reduced Description

- In the region behind the barrier, the reflected beam projects to the vacuum state $|0\rangle$. After normalization we end up in a superposition $\sqrt{1-p}|0\rangle + \sqrt{p}|1\rangle$ of $|0\rangle$ and the normalized 1-photon state $|1\rangle = F_{\rm out}/\sqrt{p}$.

$\Rightarrow$ The normalized out-state **consists almost only of vacuum**, with only a small admixed fraction of a single photon state, corresponding to the reduced intensity pE of the beam.

- In an ensemble, p can be interpreted as the **Born probability** for finding photons at one of the slits.
- If, as done in textbooks, the vacuum part is ignored, we find a **collapse of the wave function** by projection to the corresponding eigenspace of the position operator, which then propagates further according to the free dynamics with the new initial conditions.

A Single-World Interpretation Suitable for Quantum Cosmology

1. The mathematical formalism of quantum mechanics is sufficient as it stands.
   No metaphysics needs to be added to it.
2. It is unnecessary to introduce external observers or to postulate the existence of a realm
   where the laws of classical physics hold.
3. It makes sense to talk about a state for the whole universe.
4. This state never collapses, and hence the universe as a whole is rigorously deterministic.
5. The ergodic properties of laboratory measuring instruments are inessential to its foundations.
6. The statistical interpretation itself need not be imposed a priori.
7. The symbols of quantum mechanics represent reality just as much as those of classical mechanics.
8. The mathematical formalism of the quantum theory is capable of yielding its own interpretation.

(taken almost verbatim from DeWitt 1971, who had claimed this for Everett's many worlds interpretation)