Does the reality of the wave function follow from the possibility of its manipulation?

Vladislav Terekhovich

Institute of Philosophy, Saint Petersburg University, Saint Petersburg

The issue

Three aims of the physical theory:

➤ to describe and unify phenomena (integration);
➤ to predict phenomena (computation);
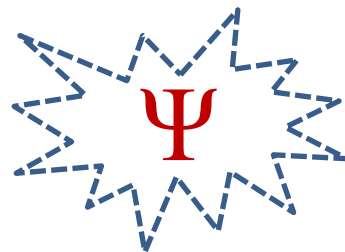➤ to explain phenomena, giving meaning to formulas (interpretation).

in science:

does everyone unobserved theoretical objects exist or not?

in quantum theory:

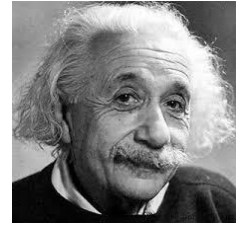does a wave function (a state vector) exist or not?

exist? how?   Ψ   not exist?

# Is Ψ a subjective fiction, real or objective?

A. Einstein: "Any serious consideration of a physical theory must take into account the distinction between the **objective reality**, which is independent of any theory, and the **physical concepts** with which the theory operates" (*EPR paper, 1935*).

V. Heisenberg : "The probability function **combines objective and subjective elements**. It contains statements about possibilities or better tendencies ("potentia" in Aristotelian philosophy), and these statements are completely **objective** …; and it contains statements about our **knowledge** of the system" (*Physics and Philosophy: The Revolution in Modern Science. 1958*).
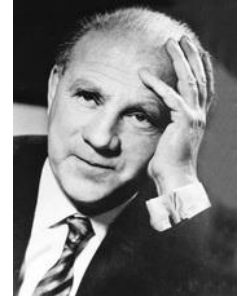
V.A. Fock: «Bohr […] resolutely expresses his disagreement with the positivist point of view and fully recognizes the **objectivity** of the properties of atomic objects».
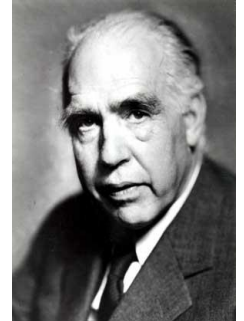
«The state described by the wave function […] represents an **objective** (independent of the observer) characteristic of the **potential possibilities** of one or another result of the interaction of the atomic object with the device. … But this objective state is **not yet actual**» (*On the interpretation of quantum mechanics. UFN, 62(4), 1957.*)

The approaches to the reality of the wave function

| "Classical realism"	"Quantum dualism"	"Quantum realism"
ψ (psi)-epistemic		**ψ (psi)-ontic**
Statistical Ψ is our incomplete knowledge of the real state before observation. **Quantum objects exist in the same way as classical ones.** **Local hidden variables.** **Analogy – statistical distribution of probabilities.**	**Subjective Ψ is our knowledge (or belief) of all possible outcomes of experience in the future.** **Before observation quantum state does not exist (but quantum objects somehow exist).** **Classical reality arises as a result of measurement ("collapse").**	**Ψ exists objectively as a superposition of some entities:** ■ many worlds ■ non-local potentials ■ relations (structures) ■ dispositions ■ coherent histories ■ laws of nature ■ information (qbits), etc. **Classical reality arises due to decoherence with the environment.**

"Participatory realism"

**Qbism; Heisenberg, Fock, Wheeler; Zeilinger; Rovelli**

Ψ is not a statistical probability distribution.
# Ψ is unlikely a wave of matter or some field.

✓ In the experiment, quantum objects are detected <u>only as particles</u>.

✓ <u>No waves interfere</u>; all possible outcomes of the experiment interfere. The wave of the electromagnetic field is a statistical averaging.

✓ In the Feynman path integral formalism <u>no need for a wave analogy</u>. Instead, the particle moves right along all possible paths (the analogy with the principle of least action).
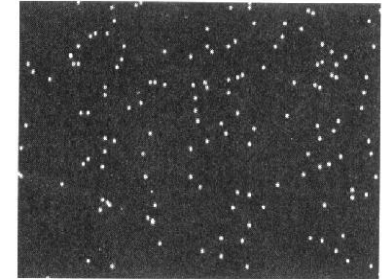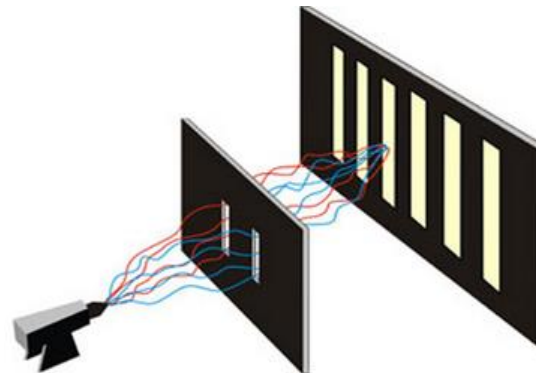
(b) After 100 electrons
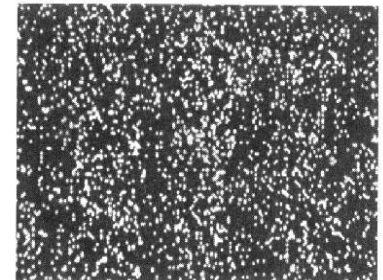
(c) After 3000 electrons
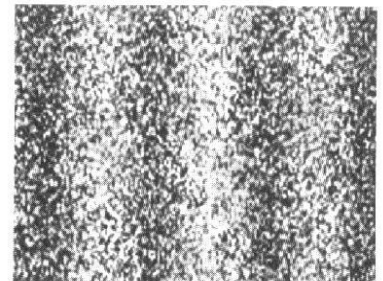
(d) After 70 000 electrons

Manipulative criterion for the existence

Scientific realism:

Welltested theory ➔ theoretical entities exist.

Instrumentalism:

Welltested theory ➔ be agnostic about existence of theoretical entities.

Entity realism (I. Hacking, N. Cartwright):

Experimental entities that scientists manipulate to study other phenomena ➔ entities can exist ➔ theory can be true (or not).

I. Hacking: "Experimenting on an entity does not commit you to believing that it exist. Only manipulating an entity, in order to experiment on something else, need do that" (*Representing and Intervening. 1983, p. 263*).

"Reality has to do with causation and our notions of reality are formed from our abilities to change the world" (*Ibid, p.146*).

Manipulative criterion for the wave function

If one can use Ψ to intervene in the world to affect something else,
if Ψ takes part in a causal influence,
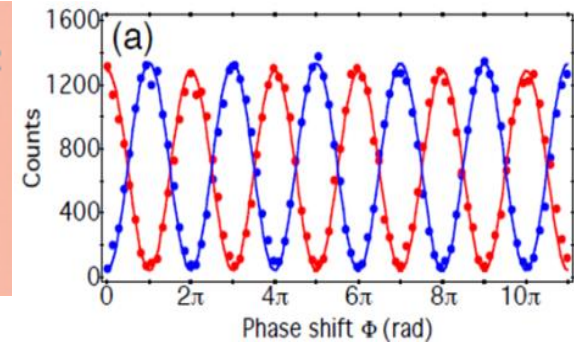does it mean that it exists?

Experiment preparation
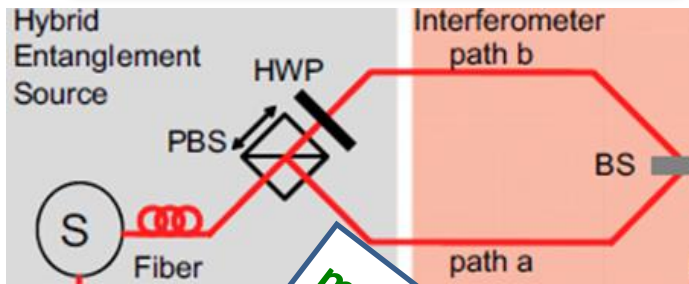
Real objects

Observable change

manipulation
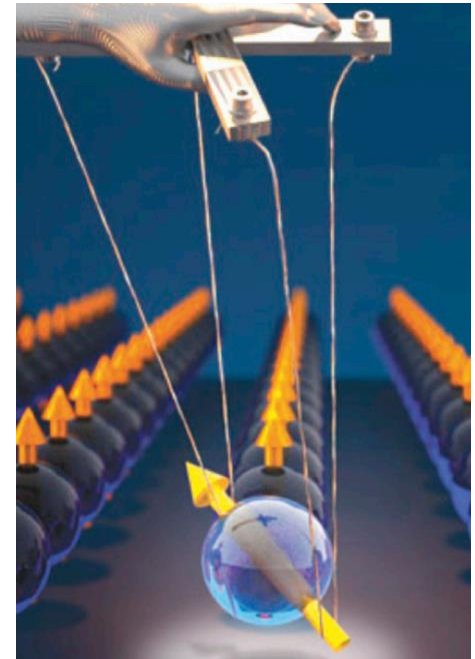
causality

Ψ

Unobservable entity

$$|\psi\rangle = c_a|\psi_a\rangle + c_b|\psi_b\rangle$$

Two quantum revolutions

The first quantum revolution: nuclear weapons; nuclear energy; superconductors; lasers; semiconductors, computers, Internet, mobile communications, medicine, etc.
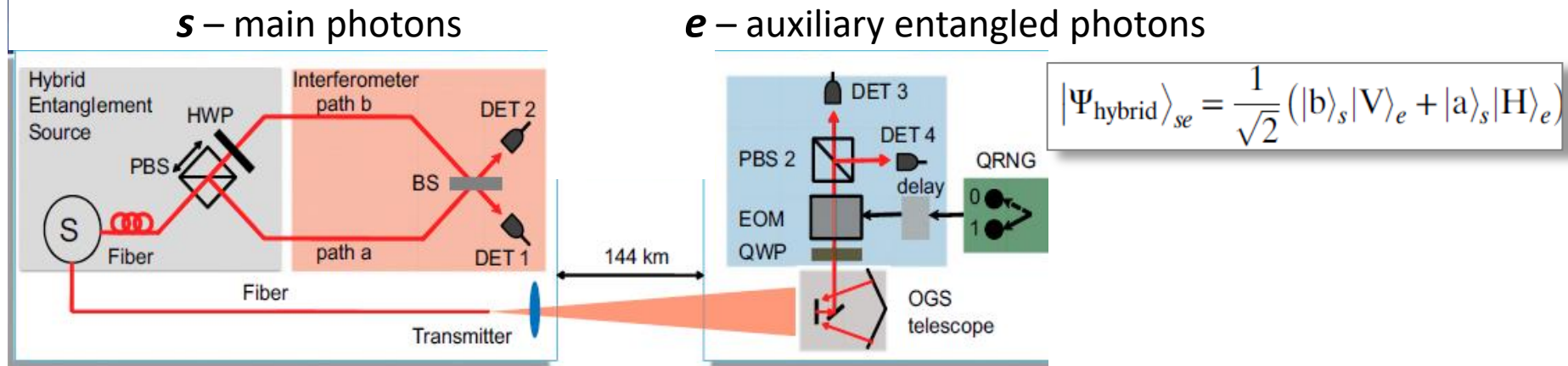
The second quantum revolution:

Manipulation with single quantum objects (photons, ions, atoms, ...) in a state of superposition and complex entangled systems.

Experiments with the "quantum eraser"

The manipulation with Ψ of main photons (*s*) is made by informing "labeling" of the possible ways using auxiliary entangled photons (*e*).

s – main photons   *e* – auxiliary entangled photons

$$\left|\Psi_{\text{hybrid}}\right\rangle_{se} = \frac{1}{\sqrt{2}}\left(|b\rangle_s|V\rangle_e + |a\rangle_s|H\rangle_e\right)$$

➢ If the main photons are "labeled", the interference **disappears**.

➢ If then which-way **information is erased**, the interference appear.

➢ Ψ can be manipulated even when the measurement has **occurred**.

*Ma X. et al. Quantum erasure with causally disconnected choice // Proceedings of the National Academy of Sciences. 2013. Vol. 110(4), P. 1221-1226.*

# Quantum communications and cryptography
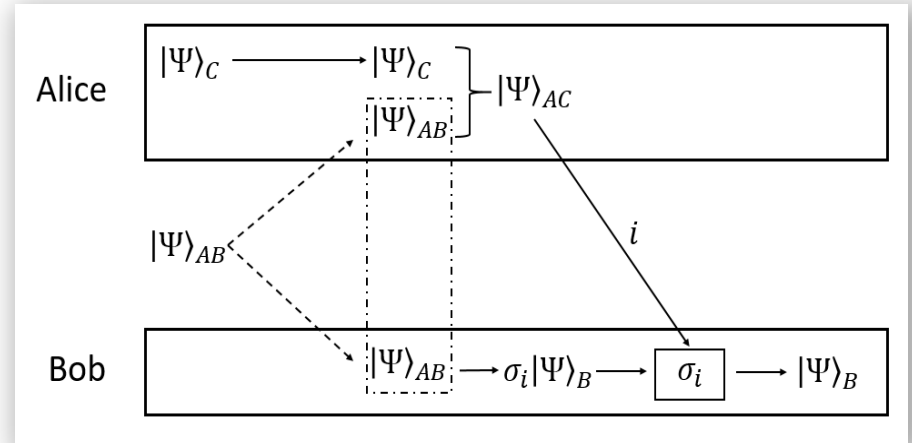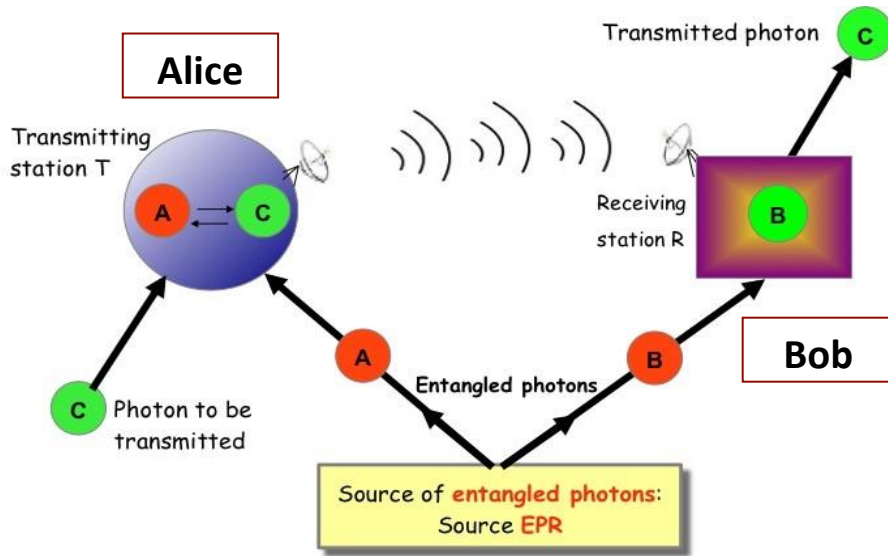
"Quantum teleportation": as a result of the manipulation with Ψ of the objects at the point of departure (Alice), its state is destroyed and recreated for the second object at the point of reception (Bob).

Quantum computer
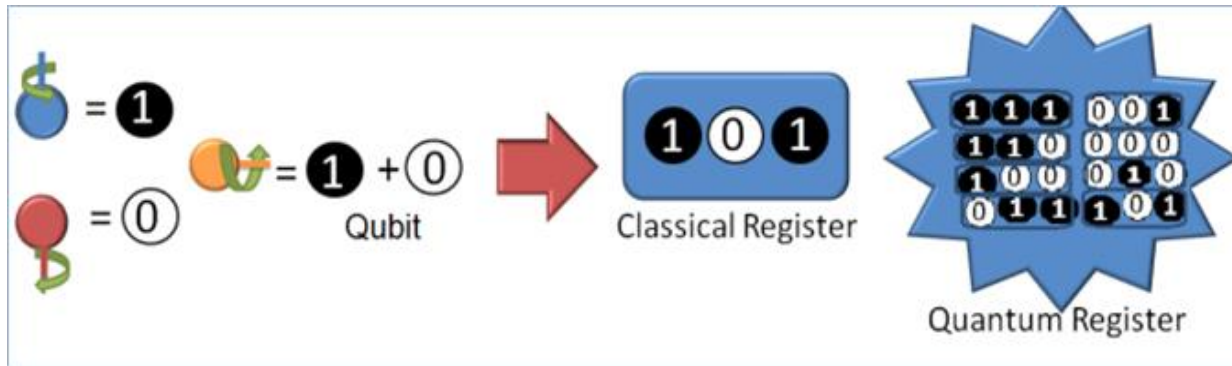
Quantum Register (101):

$2^3 = 8$ combinations that are processed at once

- ❖ By manipulating entangled qubits, one can make them perform calculations.

- ❖ We cannot observe the process itself, but we know its result.

- ❖ The parts of the superposition have some degree of existence.
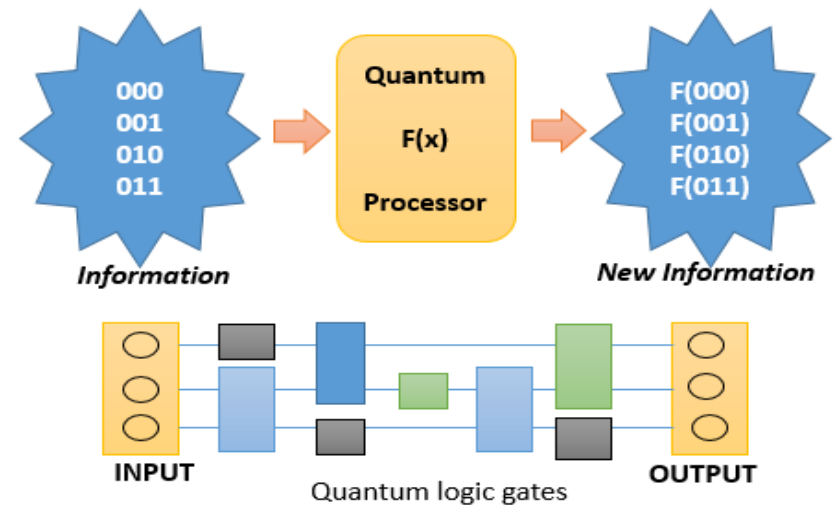
Where does this result of calculation come from?

Against the manipulative criterion of existence

Objection №1. **The scope of entity realism is too narrow.**

        (black holes, neutrino, quarks and gluons, bosons, etc.)

❑ **Hacking's reply**: "Engineering is only the best proof of scientific realism about entities"

(Comments on Zeidler & Sobczynska's Paper. Foundations of Science 4, 1995/96).

❑ **Hypothesis**: manipulability is neither the necessary nor sufficient criterion of existence.
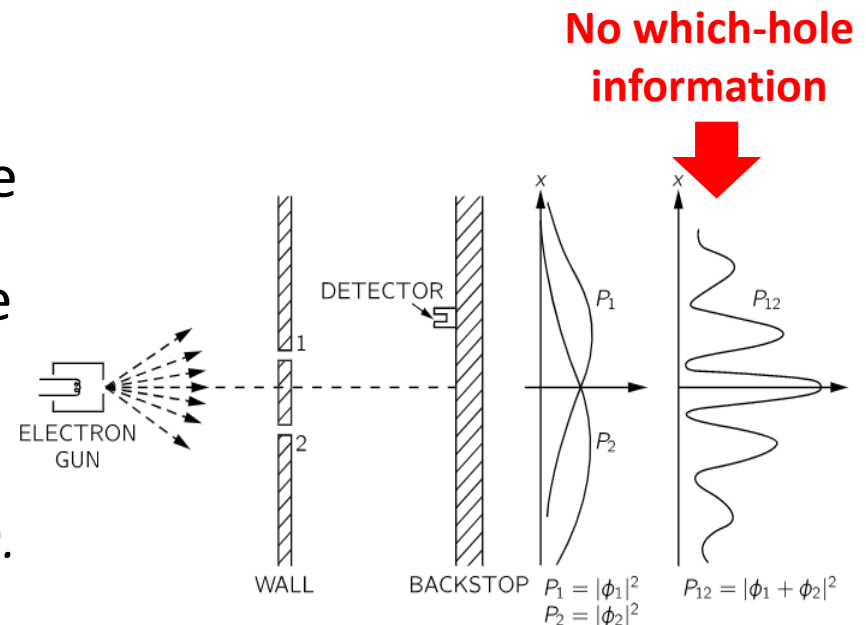
Against the manipulative criterion of existence

Objection №2. **Anthropomorphic content of "manipulation".**

❑ **Hypothesis**: the role of human being in manipulation is not so important. Instead, impact on the information contained within a system "object-device-environment" plays a key role.

See the "delayed choice" experiment.

No which-hole information

R. Feynman: "It is impossible to design an apparatus to determine which hole the electron passes through, that will not at the same time disturb the electrons enough to destroy the interference pattern"
(Feynman, Leighton, Sands, Vol. III, 1-6.).

Against the manipulative criterion of existence

*Objection №3.* **"Theoretical loading" of unobservable entities.**

❑ **Hacking's reply**: Experiment – it's action, not words. A theoretical model can be replaced by a family of causal properties of an object (*Representing and Intervening. 1983*).

❑ **Cartwright's reply***:* The causes are specific active objects, even unobservable *(How the laws of physics lie. 1983).*

❑ **OSR.** There are no individuals, there are only relational modal mindindependent structures. Objects used by agents to construct approximate representations of the world (S. French, J. Ladyman).

❑ **Semirealism** or **dispositional realism**. ER and SR contain one another. Dispositions are causal modal properties of objects. Their relations compose the ontic structures (A. Chakravartty).

❑ Both structures and individual entities are real. The holistic structures constitute of the individuality of its components (T. Cao).

Hypothesis: Ψ represents a derivative structure

Objection №3. **"Theoretical loading" of unobservable entities.**

- ✓ **Ψ is one of the mathematical structures that represent the existing modal structure of alternative possibilities.**

- ✓ Neither the modal structure nor its components are ontologically primacy. Both of them are derivative from some fundamental modal entities and structures.

- ✓ **When manipulating with quantum object, we change the structure of possibilities (described by Ψ).** Due to decoherence, the changing modal structure turns into a new statistical structure of probability distribution observed in experiments.
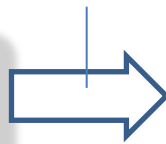
manipulation   **decoherence**   **experiment**
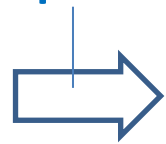
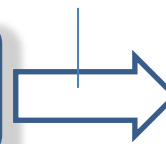→ | Structure of possibilities | → | Structure of probabilities | → | Statistical structure of observable events |

Ψ   mixture   probability distribution

Against the manipulative criterion of existence

Objection №4. **The difficulties of causality.**

❖ Many philosophers deny causality as a metaphysical concept.

❖ The principle of causality faces a number of difficulties for quantum phenomena (uncertainty principle, Born's rule, non-locality).

❑ Dispositional essentialism and causal structuralism (S. Shoemaker, A. Bird, M. Dorato, A. Chakravartty).

"... it is not relations per se that determine the identities of properties, but rather the generally intrinsic potential for relations" (Chakravartty, A. Ontological priority: The conceptual basis of non-eliminative, ontic structural realism. 2012).

❑ **Hypothesis**: the relations between observable events are not primary. Only change of the structure of possibilities affects the observation. The source of any influence is within some modal structures.

Summary

❖ **Ψ** is one of the mathematical ways to represent a modal quantum structure that obtains its own existence from some unknown fundamental entities or structures.

❖ Manipulations change the structure of possibilities (information and our knowledge) and then change the structure of observable states.

❖ Manipulability is neither the necessary nor sufficient for existence, but it says in favor ψ-ontic approach and "participatory realism".

❖ Both manipulation and asymmetry of causation can be explained through the changing of the structure of possibilities.
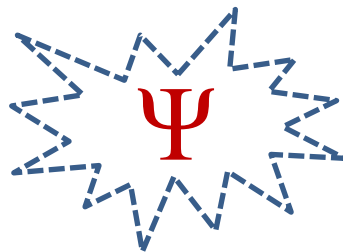
exists? how?   Ψ   exists as a modal
                                 derivative structure (?)