|INDETERMINATE⟩⟨APPARATUS|

Civa – Contemporary Immersive Virtual Art

GLOSSARY

Agential realism
Quantum physics has fundamentally changed our understanding of reality. It offers no universally valid answers to basic questions about the essence of space, time, matter, or reality but rather opens different interpretive possibilities. The approach of agential realism proposed by Karen Barad assumes that reality is not independent of the practices that produce it.[i] Matter and meaning are inseparably connected.

Black holes
According to Einstein's general theory of relativity, space is not static and immutable but is rather bent by massive objects, with the curve being greater the larger the mass. When a mass is extremely concentrated in a very small space, a black hole may form. Its gravitation is so massive that nothing within a certain radius can escape it, not even light.

Bra-ket notation
The astonishing processes that occur in quantum systems often defy our everyday language but can be described very precisely with mathematics. Probably the most popular mathematical notation for quantum physics, created by Paul Dirac, is known as "bra-ket notation": he used specific brackets to express the states of quantum systems and their relationships.[ii] The main elements are the ket vector, written $|\psi\rangle$, and the dually conjugate vector bra $\langle\varphi|$—that is to say, a mathematical object and a mathematical object associated with it.

Determinism
According to determinism, everything that happens is completely determined by past causes and therefore with sufficient knowledge could be predicted exactly. Because quantum physics predicts only static probabilities for events but can never forecast specific results of measurements with certainty, it contradicts strict determinism. Chance also plays a fundamental role in the spontaneous behavior of quantum systems. The fact that the observer influences states by measuring them is also incompatible with strict determinism.

Entanglement
Entanglement: Entanglement and superposition are considered the core of quantum physics. Two or more quantum objects in states of superposition are connected such that the state of each cannot be described independently of the others. A change in one part therefore leads to an immediate change in the state of the entangled partners—even across large distances. The basic idea came from Einstein and his colleagues, but Erwin Schrödinger coined the term *Verschränkung* (entanglement).

Free will
Once determinism is overturned, other questions arise, such as whether there is free will. Quantum physicists have long been preoccupied with this; John Conway and Simon Kochen made a famous foray in the direction of the free will of both experimenters and of elementary particles.[iii] There is no final answer yet to the question of whether free will exists—the processes of quantum physics in the brain remain a mystery today.

Indeterminacy
Although it may conflict with our intuition, the properties of quantum systems are indeterminate as long as they are not measured. This indeterminacy not only refers to what we know about quantum systems but also does not determine them in an objective sense.

Intra-action
Interactions play an important role in particle physics: naturally it is assumed when describing such interactions that the particles already exist before they interact with one another. The concept of intra-action that Karen Barad introduced, by contrast, emphasizes that the reality of particles or other entities is only determined when they enter into relationship.iv

Matter
Although matter is elementary and omnipresent, science has difficulties describing what exactly it is. In classical physics, matter was thought of as a substance—that is, everything material that possess mass and occupies space. According to modern physics, all material is composed of elementary particles, which are understood in turn as excited states of quantum fields that as fundamental entities distributed spatially in the universe describe not only matter and energy but also forces and interactions. For philosophers such as Karen Barad, it is central that matter is not passive but rather active and relational.

Objectivity
Is the moon there when no one is looking at it? Yes, one would argue from a traditional, classical perspective in which it makes sense to distinguish between subjective observation and objective reality. However, because observation is not a neutral process in quantum physics but is rather influenced by the state of the system measured, a classical understanding of objectivity is no longer tenable in light of quantum physics.

Observation
What exactly happens during observation is one of the great mysteries of quantum physics. Mathematical formalism offers us a precise description of quantum systems and makes it possible to predict probabilities. But what happens during observation, why one specific state is observed and not a different one, remains a mystery.

Observer
Unlike in classical physics, the observer plays a special role in quantum physics. While in classical physics one can assume that physical states actually exist independently of observation, that is no

longer clear in quantum physics. The observer no longer stands outside uninvolved but instead contributes actively to the observation in question.

Particle

In classical physics, a particle was imagined as a solid sphere with a specific location. From the perspective of quantum physics, the description of a particle is considerably more complex. In quantum field theory, it is the quantized excited state of a field. Before it is measured, its location can be determined only by probabilities, and other properties of the particle can also be clearly determined only by measurement.

Potentiality

Because quantum physics operates with statistical probabilities and does not permit definitive predictions for single events, the possibility or potentiality remains the focus of quantum mechanical description: As long as a system is not measured, it develops in accordance with all its possibilities. Only when measured does it take on a specific state.

Quantum

The name quantum physics derives from Max Planck's insight that energy is transmitted in quantized form—that is to say, in discrete packets.[v] A quantum is therefore the smallest possible unit of any physical entity such as energy. Quantization sounds like a truly marginal idea. As it turns out, however, it results in astonishing consequences that are described in quantum physics.

Quantum computer

Unlike classical computers, which work with bits (0 or 1), quantum computers use qubits, which can be simultaneously 0, 1, or a superpositions of both states. The particular effects of quantum physics that make superposition and entanglement possible can solve more complex computing problems. Quantum computers do not work with a binary yes-no logic but can use nonbinary, multidimensional, quantum physical states.

Quantum physics

Along with the theory of relativity, quantum physics is one of two great theories of modern physics. It was developed from 1900 onward and is the umbrella term for all physical theories and concepts based on the principle of quantization. That includes quantum mechanics and quantum field theory as well as quantum information theory, which has diverse possibilities of application.

Quantum technologies

When the principles of quantum physics are applied to solve specific technical problems, one speaks of quantum technologies. A distinction is usually made between two generations: Lasers, transistors, and semiconductor elements are considered early quantum technologies, which is why traditional computers and smartphones are also considered quantum technologies. Nevertheless, they are not called quantum computers. The latter belong to a second generation of quantum technologies that make use of the specific effects of quantum physics such as superposition and entanglement.

Reality
Quantum physics makes the idea of an objective world that exists independently of observation seem dubious. Different interpretations of quantum physics offer different explanations for what is real. They range from relational ontology, in which the fundamental building blocks of reality are not things but rather relationships,[vi] to many-worlds theory, in which infinitely many universes exist in parallel.[vii]

Schrödinger's cat
To show how absurd quantum physics is, Erwin Schrödinger came up with a thought experiment that applied quantum phenomena to a living creature: If a cat is placed in a box with a radioactive substance, its existence depends on the behavior of the radioactive atom. As long as the box remains closed, quantum physics permits statements about probability. The cat is therefore in a state of superposition of being dead and alive. Only opening the box permits a definitive statement.[viii]

Spooky action at a distance
Although he made an essential contribution to its development,[ix] Albert Einstein had all sorts of objections to quantum physics: First, he objected to chance seeming to play a fundamental role. In addition, he recognized that quantum systems can be correlated in a way that does not exist in classical systems. He dismissively called such entanglement "spooky actions at a distance."[x]

Superposition
The idea that a particle can be located in several places at once is one of the most fascinating and most astonishing insights of quantum physics. This principle is called superposition. According to quantum physics, a quantum object can be in several states simultaneously as long as it is not measured. Only when it is measured does a specific state result, and the state of superposition "collapses."

Wave function
Wave function is the mathematical object with which a quantum state is described. It is usually represented by the Greek letter psi (ψ). Because wave function cannot be observed directly, opinions differ about whether it has a real meaning beyond its mathematical function and, if it does, what that might be. In any case, from the wave function one can determine the probability that a particle will be detected in a specific place when measured.

---

[i] Karen Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (Durham, NC, 2007).
[ii] P. A. M. Dirac, *The Principles of Quantum Mechanics*, 4th rev. ed. (Oxford, 1958).
[iii] John Conway and Simon Kochen, "The Free Will Theorem," *Foundations of Physics* yr. 36, no. 10 (2006), pp. 1441–73.
[iv] Barad 2007 (see note 1).
[v] Max Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum" (1900), trans. D. ter Haar, in *The Old Quantum Theory*, ed. D. ter Haar (Oxford, 1967), pp. 82–90.

[vi] Carlo Rovelli, "Relational Quantum Mechanics," *International Journal of Theoretical Physics* yr. 35, no. 8 (1996), pp. 1637–78.
[vii] Hugh Everett, "'Relative State' Formulation of Quantum Mechanics," *Reviews of Modern Physics* yr. 29, no. 3 (1957), pp. 454–62.
[viii] Schrödinger 1983 (see note 4).
[ix] Albert Einstein, "On a Heuristic Point of View about the Creation and Conversion of Light" (1905), trans. D. ter Haar, in ter Haar 1967 (see note 7), pp. 91–107.
[x] Albert Einstein, Max Born, and Hedwig Born, *The Born-Einstein Letters: Friendship, Politics, and Physics in Uncertain Times; Correspondence Between Albert Einstein and Max and Hedwig Born from 1916 to 1955 with Commentaries by Max Born*, trans. Irene Born (New York, 1971), p. 158.