

# Philosophical Considerations on Quantum Physics

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# Wavefunction and Reality

$$\hat{H} |\Psi\rangle = i\hbar \frac{\partial}{\partial t} |\Psi\rangle$$

only quantum formalism      or      „real“ quantum world ?

→ Interpretations of the quantum wave function  $\psi$

- Copenhagen Interpretation
- Many worlds theory
- De Broglie-Bohm Interpretation
- Decoherence

# Copenhagen Interpretation

- **Pioneer** of the interpretations
- Origin: Discussions at the institute of theoretical physics in **Copenhagen** between 1925 and 1927
- Intellectual fathers: Niels **Bohr**, Werner **Heisenberg**, Wolfgang **Pauli**
- Postulate: **Collaps of the wave-function** through measurement
- **Wave-function  $\psi$**  is no real physical entity, but an abstract mathematical tool

# Copenhagen Interpretation

micro world  
quantum state

$$|\psi\rangle = \sum_n c_n |n\rangle$$



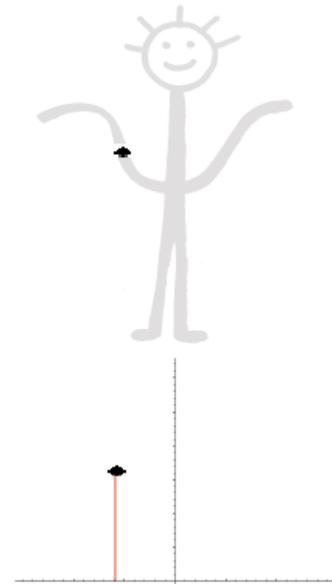
measurement > collapse

$$|n\rangle\langle n|$$



macro world  
observed state

$$|n\rangle$$



*Credit: Reinhold A. Bertlmann and Tanja Traxler*

# Copenhagen Interpretation

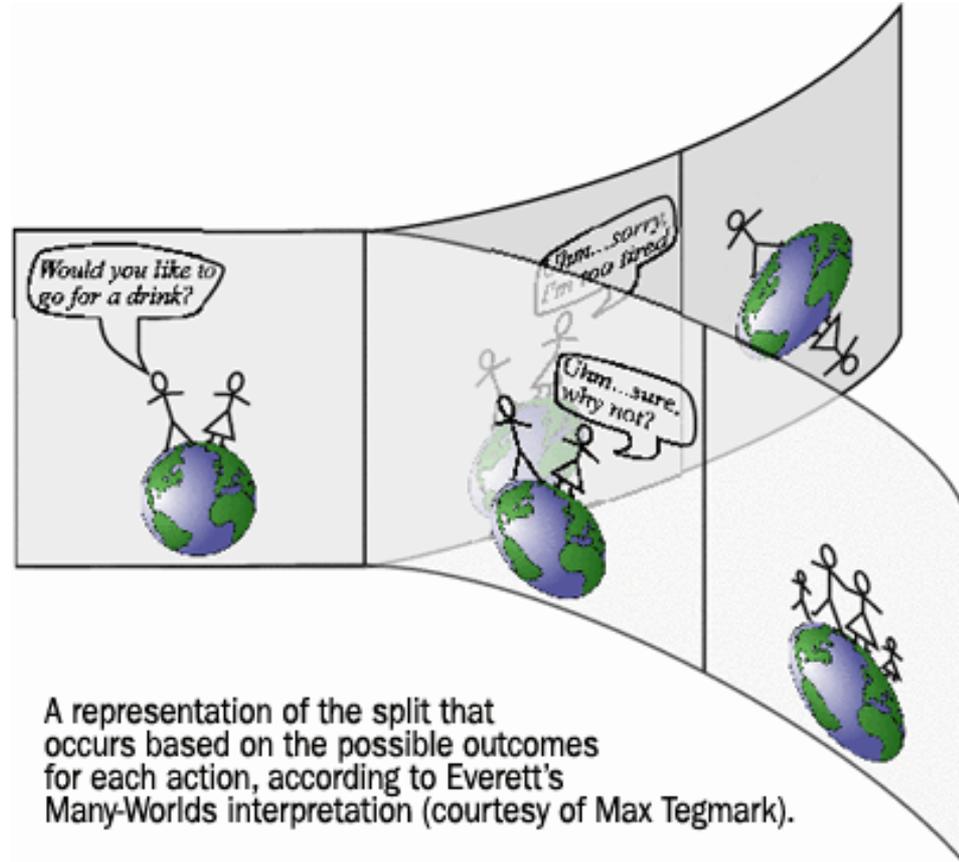
- Interesting: no fixed definition

Claus Kiefer (2002): *„There has never been complete agreement about the actual meaning, or even definition, of this interpretation even among its main contributors. In fact, the Copenhagen interpretation has remained until today an amalgamation of different views.“*

- Open question: Why collapse?

# Many worlds theory

- Postulate: Collaps is just illusion
- Mathematical formalism obtains **real meaning**
- Measurement: **universe splits** into parallel worlds

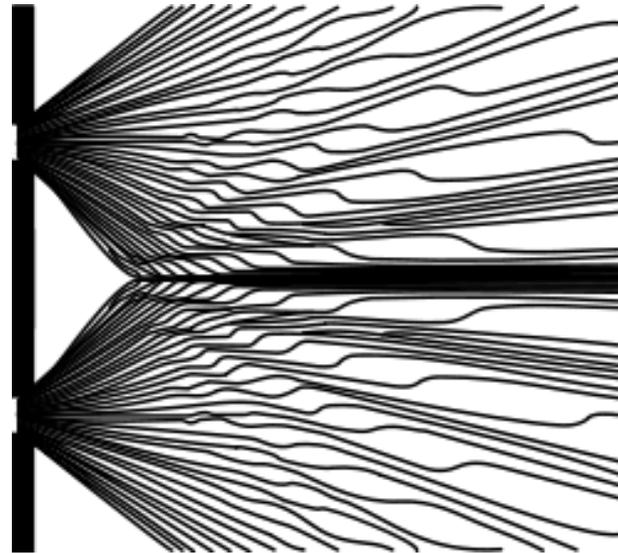


*Credit: Max Tegmark*

# De Broglie – Bohm Interpretation

- Developed by **Louis de Broglie** (1920ies) and **David Bohm** (1950ies)
- Wave-function  $\psi$  is **real** physical entity
- **Deterministic theory**, measurement not unique process
- Basic idea: quantum mechanical system not only described by the wave-function, but mainly by the **trajectories** of the system. The trajectories themselves are **hidden parameters** since the position of the system is not determined precisely as long as it is not measured.

# De Broglie – Bohm Interpretation



Simulation of a **Bohmian trajectory at the double slit**: particles are governed by the wave-function, which interferes at the double slit  
→ **interference pattern** even though the trajectories are being described.

*Source: Wikipedia*

# Decoherence

- Basic idea: no quantum system is completely isolated, but every system is in **interaction** with its **environment**
- Interaction with its environment destroys quantum phenomena like entanglement or superposition
- **Collaps** of the wave-function is replaced by **decoherence process**

*Next slide- Credit: W. Zurek*

# THE BORDER TERRITORY

QUANTUM DOMAIN

CLASSICAL DOMAIN

PHOTONS  
ELECTRONS  
ATOMS

SUN  
PLANETS



GRAVITY WAVE DETECTOR

QUANTUM FLUIDS



QUANTUM BILL OF RIGHTS  
INTERFERE IF YOU CAN!!!  
SCHRÖDINGER'S EQUATION\*

CLASSICAL LAW AND ORDER  
DO NOT INTERFERE!!!  
NEWTON'S EQUATIONS  
SECOND LAW OF THERMODYNAMICS

1

SIZE (# OF ATOMS)

$10^{23}$

# Quantum physics and philosophy

Main philosophical questions in physics

- Reality
- Matter
- Determinism/Causality
- Subject/Object – Observer/Observation

„ It has often been said, and certainly not without justification, that the man of science is a poor philosopher. Why then should it not be the right thing for the physicist to let the philosopher do the philosophizing? Such might indeed be the right thing at a time when the physicist believes he has at his disposal a rigid system of fundamental concepts and fundamental laws which are so well established that waves of doubt can not reach them; but it can not be right at a time when the very foundations of physics itself have become problematic as they are now. At a time like the present, when experience forces us to seek a newer and more solid foundation, the physicist cannot simply surrender to the philosopher the critical contemplation of the theoretical foundations; for, he himself knows best, and feels more surely where the shoe pinches. In looking for a new foundation, he must try to make clear in his own mind just how far the concepts which he uses are justified, and are necessities.”

*Albert Einstein: Physics and Reality (1936)*

## What is matter?

**Classical conception:** important in the classical conception is that **matter** is considered as **fundamentally different from forces and fields**

**Modern physics:** concepts of matter and fields are melting  
(*Erwin Schrödinger: Was ist Materie?, 1952*)

*What is matter?*



*What is a particle?*



$$\mathcal{L} = \bar{\psi} i \gamma^\mu D_\mu \psi - \frac{i}{2} g \bar{\psi} \gamma^\mu (\vec{\tau} \cdot \vec{A}_\mu) \psi - m \bar{\psi} \psi + \frac{1}{16\pi^2} \text{Tr} (D^\mu U D_\mu U^\dagger)$$

$$= \bar{N} i \gamma^\mu (D_\mu + M_\mu) N - m \bar{N} N + \frac{1}{16\pi^2} \text{Tr} (D^\mu U D_\mu U^\dagger)$$

$$N = U^{1/2} \psi$$

$$D_\mu U = \partial_\mu U - 2igf_{\alpha\beta\gamma} \vec{e}(\vec{\tau} \times \vec{A}_\mu) + igf_{\alpha\beta\gamma} \vec{e} \vec{a}_\mu - 2gf_{\alpha\beta\gamma} \vec{a}_\mu \vec{e}$$

$$D_\mu N = \partial_\mu N - ig \left[ \sigma \frac{\vec{\tau}}{2} - (1+g') f_{\alpha\beta\gamma} (\vec{e} \times \vec{e}) + \frac{2f'_{\alpha\beta\gamma}}{1+g'} (\vec{e} \vec{e}) \vec{e} \right] N \vec{e}_\mu$$

$$- ig \left[ (1+g') f_{\alpha\beta\gamma} \frac{\vec{\tau}}{2} - f_{\alpha\beta\gamma} (\vec{e} \times \vec{e}) + (1+g') f_{\alpha\beta\gamma} \frac{2f'_{\alpha\beta\gamma}}{1+g'} (\vec{e} \vec{e}) \vec{e} \right] N \vec{a}_\mu$$

$$M_\mu = U^{1/2} \partial_\mu U^{1/2} + \frac{g'}{2} (U^{1/2} \partial_\mu U^\dagger) U^{1/2}$$

$$U = \sigma(f'_{\alpha\beta\gamma}) + 2if_{\alpha\beta\gamma} (f'_{\alpha\beta\gamma}) \vec{e} \vec{e}$$

$$\mathcal{L} = \bar{N} i \gamma^\mu (D_\mu + M_\mu) N - m \bar{N} N + \frac{1}{16\pi^2} \text{Tr} (D^\mu U D_\mu U^\dagger)$$

$$- \frac{1}{4} \vec{R}_{\mu\nu} \vec{R}_{\mu\nu} - \frac{1}{4} \vec{A}_{\mu\nu} \vec{A}_{\mu\nu} + \frac{1}{2} m_f^2 (\vec{e}^{\mu\nu} \vec{e}_\mu + \vec{a}^{\mu\nu} \vec{a}_\mu)$$

$$\vec{R}_{\mu\nu} = \partial_\mu \vec{e}_\nu - \partial_\nu \vec{e}_\mu + g(\vec{e}_\mu \times \vec{e}_\nu) + g(\vec{a}_\mu \times \vec{a}_\nu)$$

$$\vec{A}_{\mu\nu} = \partial_\mu \vec{a}_\nu - \partial_\nu \vec{a}_\mu + g(\vec{a}_\mu \times \vec{e}_\nu) + g(\vec{e}_\mu \times \vec{a}_\nu)$$

$$\partial^\mu \vec{R}_{\mu\nu} = -g \vec{V}'_\nu + m_f \vec{e}_\nu; \quad \vec{V}'_\nu = \vec{V}'_\nu + \frac{1}{g} \partial^\mu \vec{R}_{\mu\nu}$$

$$\partial^\mu \vec{A}_{\mu\nu} = -g \vec{A}'_\nu + m_f \vec{a}_\nu; \quad \vec{A}'_\nu = \vec{A}'_\nu + \frac{1}{g} \partial^\mu \vec{A}_{\mu\nu}$$

$$[V_\alpha^a(\vec{x}, t), V_\beta^b(\vec{y}, t)] = [A_\alpha^a(\vec{x}, t), A_\beta^b(\vec{y}, t)] = i \epsilon^{abc} V_\alpha^c(\vec{x}, t) \delta^3(\vec{x} - \vec{y})$$

$$[V_\alpha^a(\vec{x}, t), A_\beta^b(\vec{y}, t)] = [A_\alpha^a(\vec{x}, t), V_\beta^b(\vec{y}, t)] = i \epsilon^{abc} A_\alpha^c(\vec{x}, t) \delta^3(\vec{x} - \vec{y})$$

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### III Die Parallelen

अञ्जतिः प्रसाधनकर्मा । इन्धानः । मस्यगदौष्यमानः । अक्रः ।  
ज्वालाममिदादिभिराक्रान्तः । अन्यैरनाक्रान्तो वा । क्रमेश्चान्दमो  
डः । विदथेषु । यज्ञेषु वेदयत्सु स्तोत्रेषु निमित्तभूतेषु दौघत्  
स्वयं दौष्यमानोऽस्मदीयां धियं प्रजां यागादिविषयां शुक्रवर्णां  
शुभ्रवर्णां निर्मलां ज्योतिष्टोमादि कर्म वा उद् यंमते । उद्योतय-  
त्येव । यमेर्लथ्यडागमः । मिप् । उग्रब्दोऽवधारणे । धीरिति कर्म-  
नाम । धीः शमोति तन्नामसु पाठात् ॥

मन्त्रः ।

अप्रयुच्छन्नप्रयुच्छद्विरग्ने

शिवेभिर्नः पायुभिः पाहि शग्मैः ।

अदब्धेभिरहपितेभिरिष्टेऽ-

निमिषद्भिः परि पाहि नो जाः ॥ ८ ॥

पदपाठः ।

अप्रयुच्छन् । अप्रयुच्छत्सुभिः । अग्ने । शिवेभिः ।  
नः । पायुसुभिः । पाहि । शग्मैः । अदब्धेभिः ।

## Unity of Matter:

Quantum physics: basic elements of matter and phenomena are connected, no isolated entities but part of an environment

*„The world thus appears as a complicated tissue of events, in which connections of different kinds alternate or overlap or combine and thereby determine the texture of the whole.“*  
(Werner Heisenberg)

*“The material object becomes . . . something different from what we now see, not a separate object on the background or in the environment of the rest of nature but an indivisible part and even in a subtle way an expression of the unity of all that we see.”*  
(Sri Aurobindo)

**Fritjof Capra: Tao of Physics (1975)**

## Beyond classical opposites:

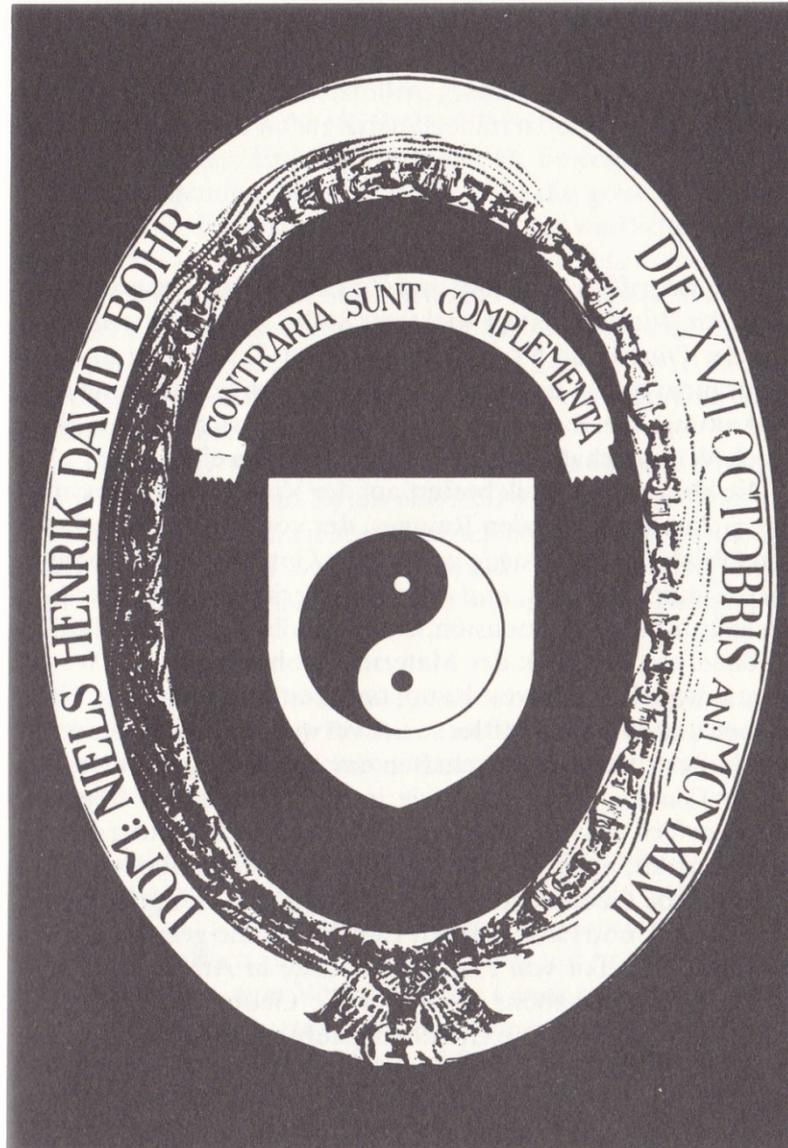
Quantum physics: wave-particle duality, uncertainty relation, complementarity, superposition, etc.

*“If we ask, for instance, whether the position of the electron remains the same, we must say ‘no’; if we ask whether the electron’s position changes with time, we must say no’; if we ask whether the electron is at rest, we must say no’; if we ask whether it is in motion, we must say ‘no’.”*

*(J. P. Oppenheimer)*

*“It moves. It moves not.  
It is far, and It is near.  
It is within all this,  
And It is outside of all this.”*

*(Upanishads)*



*Niels Bohrs Wappen*

*Aus dem Gedenkbuch Niels Bohr, hrsg. von S. Rozental (North-Holland  
Publishing Company, Amsterdam 1967)*