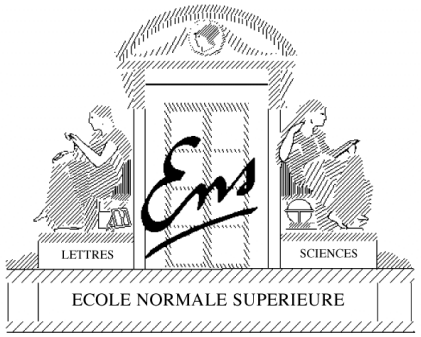

Bohr's Complementarity and Kant's Epistemology

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Roadmap

- *Introduction:* Bohr and Philosophy

1. A forerunner: Bohr's apparently "conservative" attitude towards classical physics

2. Kant's theory of knowledge and Bohr's Kant-like epistemology

3. Bohr's complementarity as a (wild) stretching of Kant's requirements for knowledge

4. Naturalized and transcendental readings of the measurement problem of quantum mechanics

- *Conclusion*

Bohr and philosophy

Harald Høffding
(1843-1931)

- The so-called "Copenhagen" and "Orthodox" interpretations of quantum mechanics combine elements borrowed from Heisenberg, Dirac, and Von Neumann… with *some* inspiration from Bohr.
- **Bohr** perceived as **"too philosophical"** (E. Fermi)
- What **is** Bohr's philosophy? Pragmatism, operationalism, positivism, idealism … Or something else?
- **Harald Høffding:** Bohr's professor of philosophy, and later his friend. Lectures on Kierkegaard and Logic (c. 1905)

Modern Physics: The collapse of Kantianism?

- *"Unless one is ready to declare that relativity theory is averse to reason,* ***one cannot stick any longer to Kant's system of a priori concepts and norms"*** A. Einstein, 1924
- *"Kant's arguments for the a priori character of the law of causality no longer apply. A similar could be given on the a priori character of space and time as forms of intuition.* ***The a priori concepts which Kant considered as undisputable truth are no longer contained in the scientific system of modern physics"*** W. Heisenberg, 1958

Space
Time

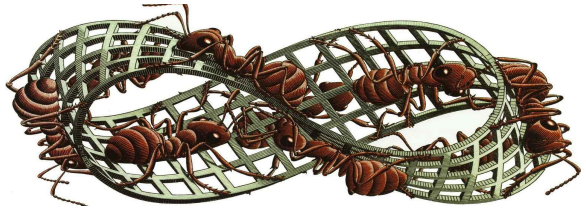
(General Relativity)

Substance
Causality
Reciprocity

(Quantum Physics)

- BUT **Ernst Cassirer** (1936), **Grete Hermann** (1935) etc. advocated a Kantian reading of quantum physics. **What's the problem?**

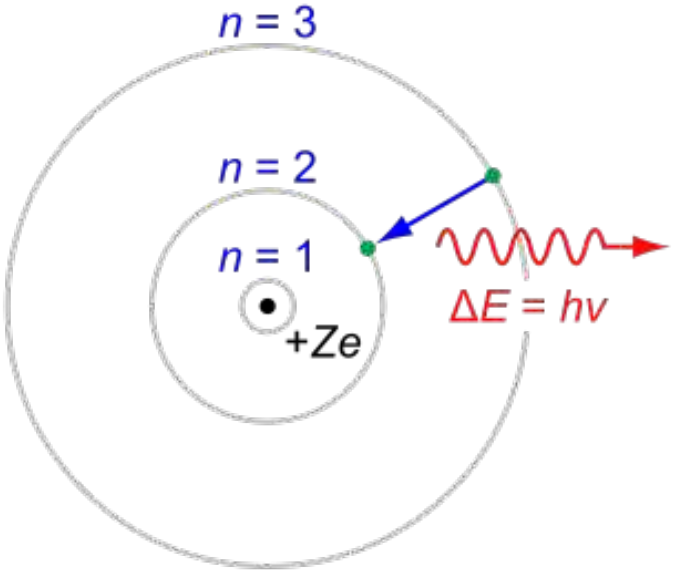
1. A forerunner: Bohr's apparently "conservative" attitude towards classical physics



The “horrid assumptions” of 1913

	Classical mechanics	Classical electrodynamics	“Quantum rules”
Electron on orbit	YES	NO	NO
Transition between orbits	NO	NO (But **Correspondence**)	YES

- No inconsistency, but lack of unity. Patchwork-like rules…
- Provisional compromise?



From 1913 to 1925, Bohr varied the articulation of classical physics with quantum postulates, rather than eliminating classical features

The correspondence principle: *"Although the process of radiation cannot be described on the basis of the ordinary theory of electrodynamics ... there is found, nevertheless, to exist a far-reaching* ***correspondence.*** *... The present theory of spectra is in a certain sense to be regarded as a* ***rational generalization*** *of the ordinary theory of radiation."* **Bohr 1922**

Continuity AND Gap: *"In the limiting region of large quantum numbers, there is ... no gradual diminution of the difference between the quantum theory of radiation and classical electrodynamics, but only an asymptotic agreement of the statistical results"* **Bohr 1924**

Bad compromise: Bohr Kramers Slater 1924.

Orbits and virtual radiation fields (semi-classical) + stochastic transition (with no conservation of energy for individual processes, but only statistically)

"Quantenmechanik"!

(1924-1925)

M. Born, "Über Quantenmechanik", 1924

W. Heisenberg, "Über die Quantentheoretische Umdeutung kinematischer und mechanischer Beziehungen", 1925

- Form of Hamilton's classical equations, but on non-commutative q-numbers rather than commutative c-numbers

- "A … precise formulation of the tendencies embodied in the correspondence principle" **Bohr 1925**

- "a quantitative formulation of the correspondence principle" **Heisenberg 1925**

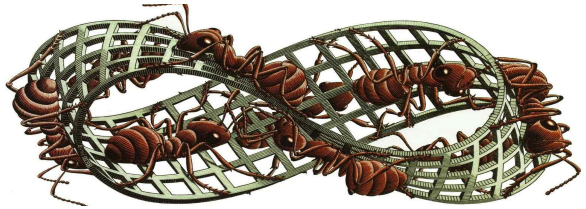
WHY this persistence of classical concepts and forms?

- Bohr's Kantian style: Epistemology rather than Ontology
- Classicity: not in micro-objects; **condition of possibility for knowing them**
- *"No more is it likely that the fundamental concepts of the classical theories will ever become superfluous for the description of physical experience. ... **It continues to be the application of these concepts alone that makes it possible to relate the symbolism of the quantum theory to the data of experience**"* Bohr, 1929

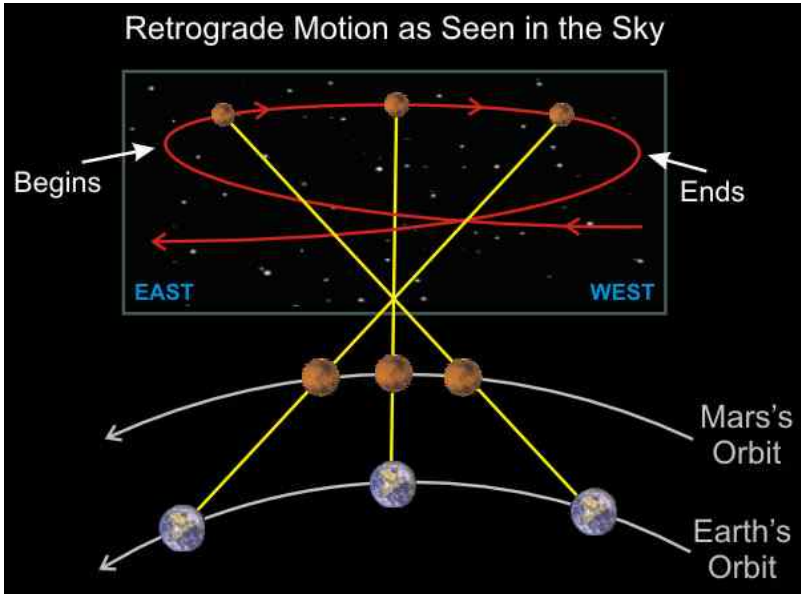
- **NO** MACRO-REALISM
- **NO** ONTOLOGICAL DIVIDE between the quantum and the classical domain
- Only an epistemological divide between (a) quantum objects, and (b) the logico-linguistic tools implemented in classical physics.

"Quantum mechanics holds a special position among physical theories. It contains classical mechanics as a limiting case and it needs it as a foundation"
Landau & Lifschitz, 1967

2. Kant's theory of knowledge and Bohr's Kant-like epistemology



Kant's "**Copernican revolution**"



- Two meanings of "Copernican":

1. **Decentration** of Human Beings

2. **Relativity** of spatio-temporal attributes, such as apparent trajectories on the celestial vault

- Kant retains the **second** meaning:

"Thus far it has been assumed that all our cognition must conform to objects ... Let us try to find out by experiment whether we shall not make better progress ... if we assume that objects must conform to our cognition" Kant, 1781

- **The form of objects is predetermined by a set of cognitive conditions**

- **"Object" is the name of experiential invariants, not of something beyond experience**

***A priori* forms ... again**

Sensibility { Space, Time

Understanding { Substance, Causality, Reciprocity

Bohr's Copernican revolution

- Remember: **epistemological** rather than ontological status of classical concepts
- In a scientific revolution, old ontologies are questioned and the only firm ground is seen to be ***experience***
- *"The task of science is both to extend the range of our experience and to reduce it to order"* Bohr, 1929
- **Reflective analysis of cognition:**
  - ✓ *"The boundary of our concepts"* is *"exactly congruent with the boundary to our possibilities of observation"* 1927
  - ✓ *"All knowledge presents itself within a conceptual framework"* 1934
  - ✓ *"... In spite of their limitations, we can by no means dispense with those forms of perception which colour our whole language and in terms of which all experience must ultimately be expressed"* 1929

Yet here Concepts no longer apply to spatio-temporal pictures

•**Prediction of phenomena:** not with spatio-temporal representations, but by using *"... a purely **symbolic scheme** permitting only predictions ... as to results obtainable under conditions specified by means of classical concepts"* 1936

•*"... We must always be prepared ... to expect **alterations** in the points of views best suited for the ordering of our experiments"*. 1929

Is this a serious divergence?

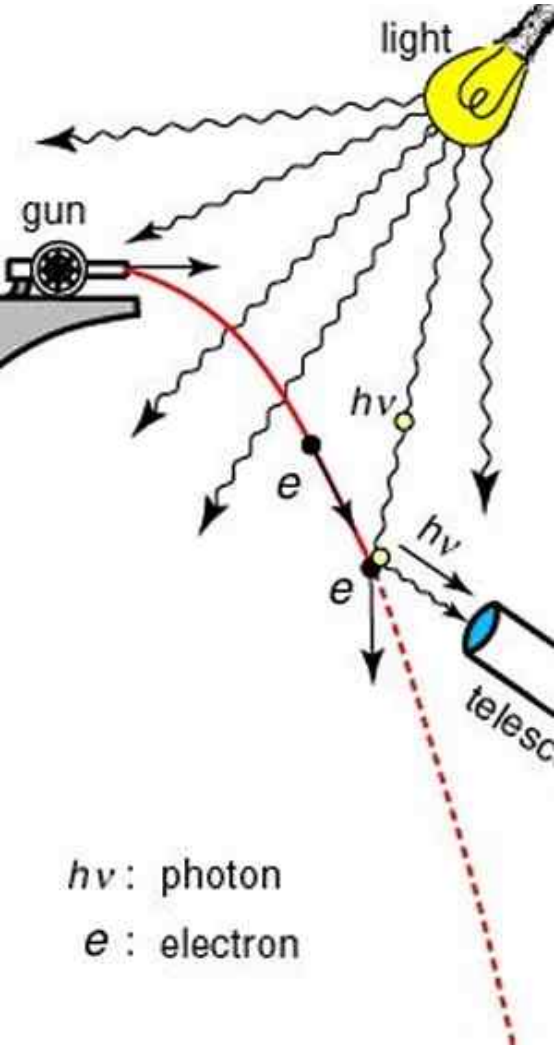
•**Modifying *a priori*** forms? Sounds like a contradiction…

•**No!**

- Kant's epistemology = **a research program** (Cassirer and "symbolic forms", Reichenbach and "relative *a priori*")
- Bohr's **anthropological** condition of possibility of microphysical knowledge
- *"What Kant had not foreseen was that these a priori concepts can be the conditions for science and at the same time have a limited range of applicability"*. Heisenberg, 1958

Ernst Cassirer
1874-1945

Hans Reichenbach
1891-1953



The image of "disturbance"

The relational status of attributes

- "*Whatever [characteristics] we are acquainted with in matter are* ***nothing but relations*** *(what we call its intrinsic determinations is intrinsic only comparatively) ; among these relations there are independent and permanent ones, through which a determinate object is given to us*" **Kant, 1781**

- "**Thing-in-itself**" is a **word** for the **impossibility to substract the contribution of the knower from what is known**.

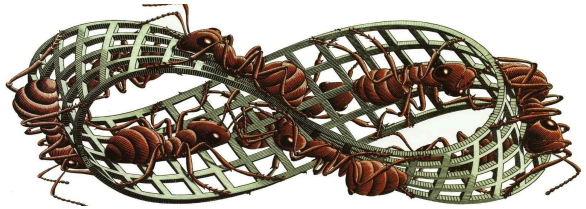
➢ *"The properties of atoms are always obtained by observing their reactions under collisions or under the influence of radiation"*. **Bohr 1929**

➢ No "Disturbance"

➢ *"Impossibility of a strict separation of phenomena and means of observation"* **Bohr 1929**

➢ *"... Interaction forms an inseparable part of the phenomena"* **Bohr 1958**

3. Bohr's complementarity as a (wild) stretching of Kant's requirements for knowledge



Relational attributes and complementarity

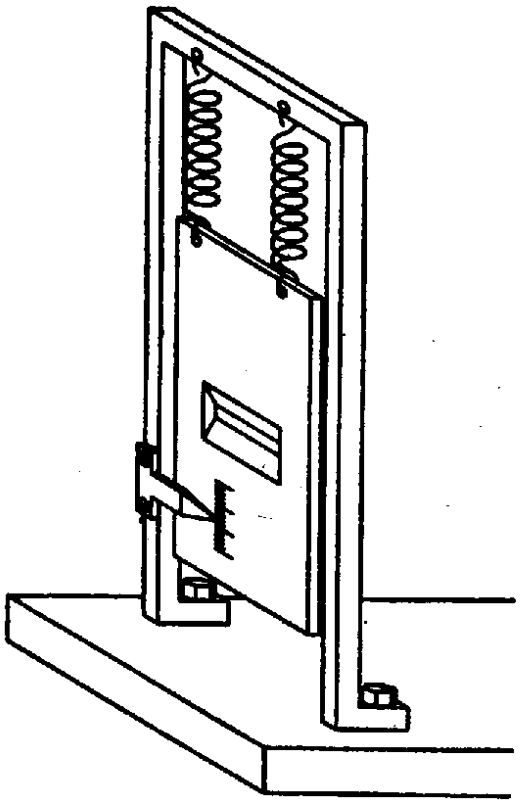


FIG. 5

- In **classical physics,** where the influence of the measurement can be substracted, data *"supplement each other and **can be combined into a consistent picture** of the behaviour of the object under consideration"*. Bohr 1958

- In **quantum physics,** *"... evidence obtained under different experimental conditions **cannot be comprehended within a single picture**, but must be regarded as **complementary** in the sense that only the totality of the phenomena exhausts the possible information about the objects"*. Bohr, 1935

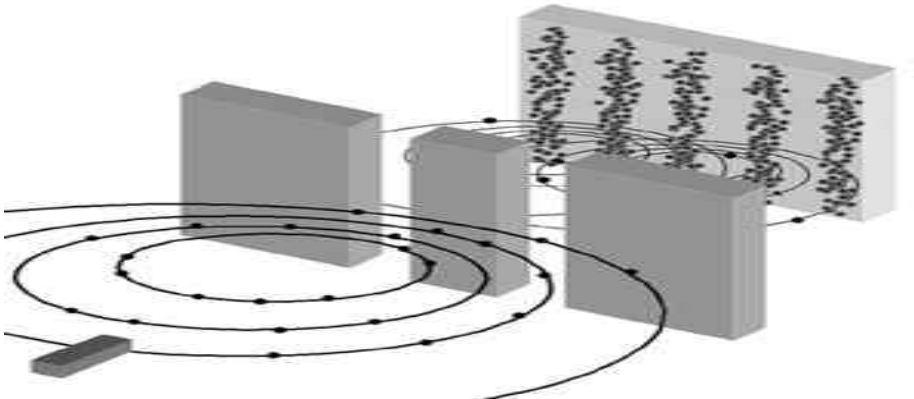
  - Afshar's 2004 claim and disclaim
  - Quantitative which-way experiments etc.

Three complementarities

1. **Between incompatible / conjugate variables.** *"In quantum physics ... evidence about atomic objects obtained by **different experimental arrangements** exhibits a novel kind of **complementary** relationship"*

2. **Between causation and spatiotemporal location of phenomena.** *"The very nature of quantum theory (...) forces us to regard the **space-time coordination** and the claim of **causality**, the union of which characterizes the classical theories, as **complementary** features of the description, symbolizing the idealization of observation and definition respectively".*

3. **Between wave and particle pictures.** *"The **individuality** of the elementary electrical **corpuscles** is forced upon us by general evidence. Nevertheless, recent experience, above all the discovery of the selective reflection of electrons from metal crystals, requires the use of the **wave** theory"*



Two problems of complementarities (1)

- Why should conjugate variables be ***jointly indispensible?***
- *"(...) evidence obtained under different experimental conditions (...) must be regarded as* ***complementary*** *in the sense that only the totality of the phenomena exhausts the possible information* ***about*** *the objects"* Bohr 1935
- ABOUTNESS…
- Is it still possible to ***refer*** to some **"micro-object in itself"** characterized by mutually incompatible probings ?
- … Or should we look for a **new** mode of **objectification** that retains *nothing* of the classical corpuscularian concept ?

Erwin Schrödinger
1887-1961

Bohr vs. **Schrödinger**

Old visualizable concepts vs. **"New concepts"**

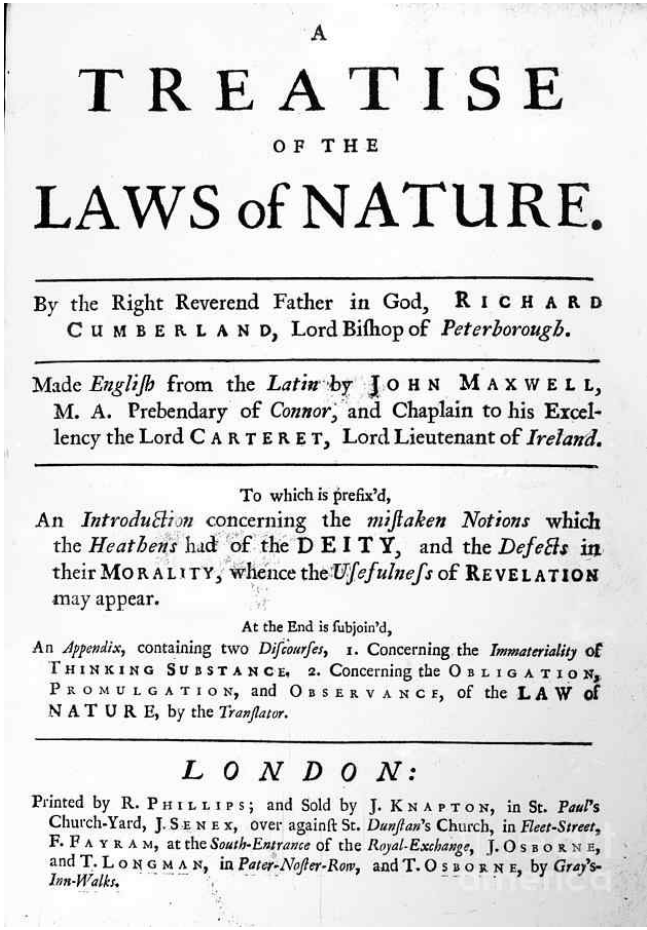
Two problems of complementarities (2)

- *"The very nature of the quantum theory forces us to regard **the space-time co-ordination** and the **claim of causality** as **complementary** features of the description"* Bohr, 1929

How can we compensate for the dismantling of Kant's connection between the category of causality and spatiotemporally-shaped sensory experience?

- Quantum physics *"forces us to **replace** the ideal of **causality** **by** a more general viewpoint called '**complementarity**'"*. Bohr, 1937

- *"**Complementarity** is called for to provide a frame wide enough to embrace the account of **fundamental regularities** of nature **which cannot be comprehended within a single picture**"*. Bohr, 1958



A

TREATISE

OF THE

LAWS of NATURE.

By the Right Reverend Father in God, RICHARD CUMBERLAND, Lord Bishop of *Peterborough*.

Made *English* from the *Latin* by JOHN MAXWELL, M. A. Prebendary of *Connor*, and Chaplain to his Excellency the Lord CARTERET, Lord Lieutenant of *Ireland*.

To which is prefix'd,

An *Introduction* concerning the *mistaken Notions* which the *Heathens* had of the DEITY, and the *Defects* in their MORALITY, whence the *Usefulness* of REVELATION may appear.

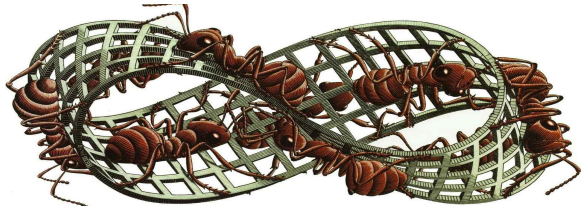
At the End is subjoin'd,

An *Appendix*, containing two *Discourses*, 1. Concerning the *Immateriality* of THINKING SUBSTANCE. 2. Concerning the OBLIGATION, PROMULGATION, and OBSERVANCE, of the LAW of NATURE, by the *Translator*.

LONDON:

Printed by R. PHILLIPS; and Sold by J. KNAPTON, in St. *Paul's* Church-Yard, J. SENEX, over against St. *Dunstan's* Church, in *Fleet-Street*, F. FAYRAM, at the *South-Entrance* of the *Royal-Exchange*, J. OSBORNE, and T. LONGMAN, in *Pater-Noster-Row*, and T. OSBORNE, by *Gray's-Inn-Walks*.

4. *Naturalized and transcendental readings of the measurement problem of quantum mechanics*



On the transcendental status of measuring instruments

Transcendental ≠ Transcendent

•Nucleus of meaning: **"Exceeds experience"**

Precondition of experience ≠ Existing beyond experience

•A *precondition* of experience **shapes up** experience without being **part of** experience.

- ✓ The knower is not known in the act of knowing (**Kant**)
- ✓ The instrumental preconditions of a quantum description cannot be described quantum-mechanically (**Bohr**)

- **Extra-Territoriality of measuring device in Bohr's thought:**

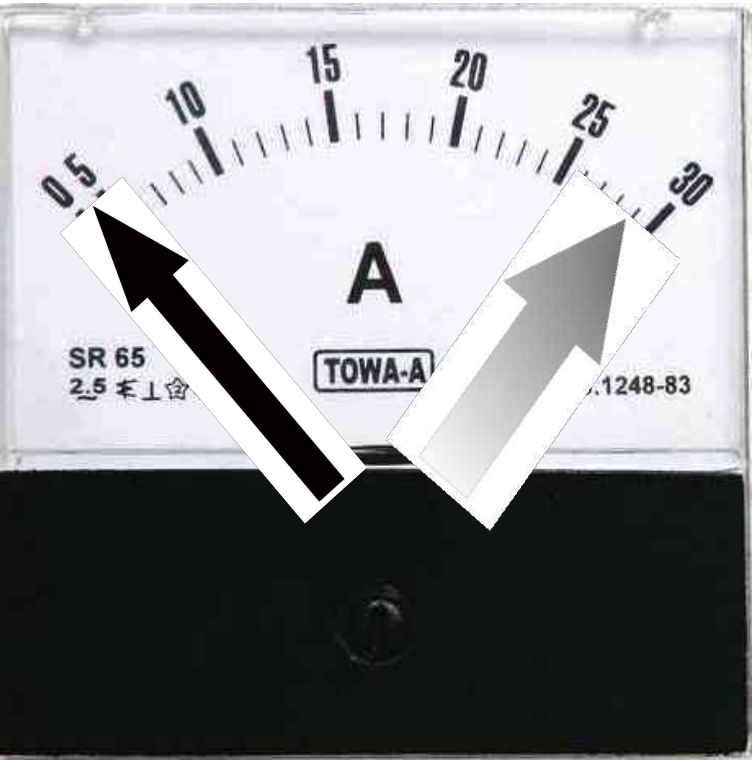
✓No special **nature** of measuring instruments

✓Just special **function**: condition of possibility of intersubjective agreement about experimental results

•We have **"free choice"** of the location of the object/precondition transition. Bohr 1935

Advantage of transcendental status of measurement devices

Immanuel Kant
1724-1804

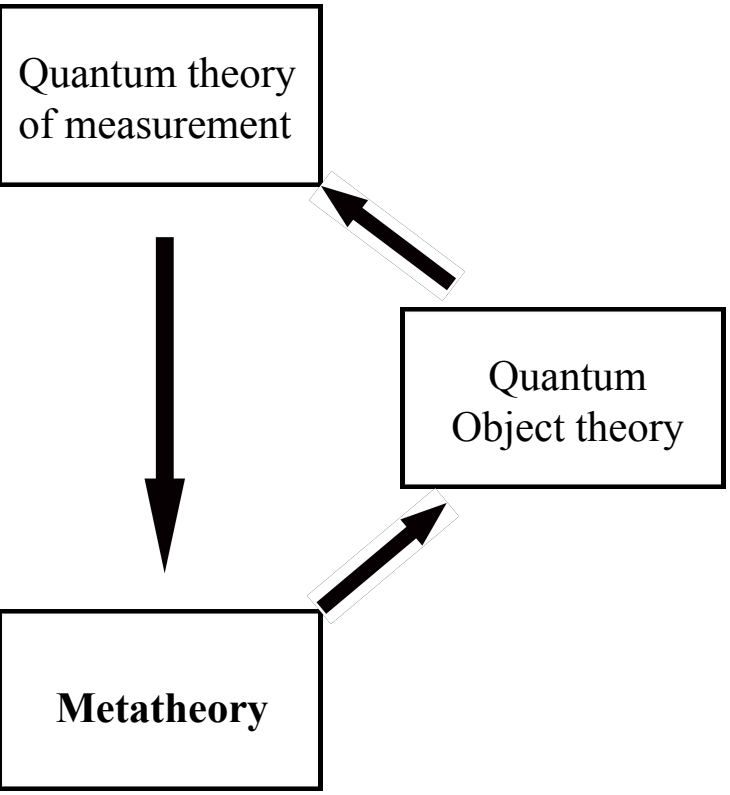


It dissolves the measurement problem from the outset

✓Since a classic-like **actualistic** description of measuring instruments is taken as a **presupposition** of quantum account of phenomena, there is **no need for a mechanism of transition between potentialities and actuality**

✓Since the quantum description is prevented from extending to the totality of the measurement chain, there is **no such thing as a superposition of pointer macrostates**

"The measuring process plays a twofold role: a means to interpret the quantum object theory, and a real physical process described by the object theory" P. Mittelstaedt, 1998



Should we criticize this bohrian strategy?

- John Bell (1990): "Against measurement"
  - ✓ Do not stick to propositions that are valid only "for all practical purposes (FAPP)"
  - ✓ Do not accept Bohr's "shifty split"
- Project of a **naturalized theory of knowledge:** cognitive apparatus part of described nature, not precondition for describing.
  - ✓ " The measurement process should be understood as a special case of the general laws applying to the entire universe" Bohm 1993
- **Counter-objection:** "Quantum theory can describe ***anything***, but not ***everything***" Peres & Zurek 1982, Fuchs & Peres 2000
- The **metatheory** (or the **pre-theory**) can be restricted, expelled outside the domain of description of a theory, but **not eliminated ...**

Conclusion

- Bohr's Kant-like interpretation of quantum theory is not outmoded
- Instead, it might well represent a general Framework for Any future Philosophy of Physics (FAfPP) ...