Quantum Physics not understandable? Surely You're Joking, Mr. Feynman!

Detlef Dürr

Mathematisches Institut
LMU München

for a good old friend: Gianfausto Dell'Antonio

Gianfausto described me once as a member of a sect (and maybe he still does); the sect of the understanders - the holders of the truth

sect of the understanders? Nobody understands quantum mechanics

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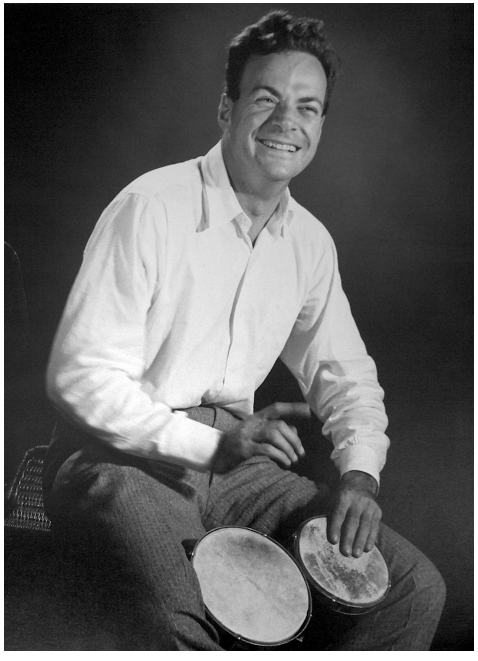

Richard P. Feynman (1965) The Character of Physical Law

There was a time when the newspapers said that only twelve men understood the theory of relativity. I do not believe there ever was such a time. There might have been a time when only one man did, because he was the only guy who caught on, before he wrote his paper. But after people read the paper, a lot of people understood the theory of relativity in some way or other, certainly more than twelve. On the other hand, I think I can safely say that nobody understands quantum mechanics.

Why would he say that? Because of

the mad hatter?

The inventor of observables: Matrix Mechanics - physical quantities become operator observables

Werner Heisenberg (1901-1976)

How?

by putting hats on $x \rightarrow \hat{X}; p \rightarrow \hat{P}; \hat{X}\hat{P} \neq \hat{P}\hat{X} \Rightarrow$ non commutative algebra

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How can putting hats achieve a description of the real world?

No problem says W. Heisenberg, there is no real world

...the idea of an objective real world whose smallest parts exist objectively in the same sense as stones or trees exist, independently of whether or not we observe them... is impossible....

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He did not walk alone. There was also the quantum philosopher

Niels Bohr 1885-1962

Complementarity, the new philosophy of nature

A complete elucidation of one and the same object may require diverse points of view which defy a unique description. Indeed, strictly speaking, the conscious analysis of any concept stands in a relation of exclusion to its immediate application

Bohr quoted in M. Jammer, *The Philosophy of Quantum Mechanics*. Wiley, New York, page 102, (1974) introducing "complementarity"

Applied Quantum Philosophy

The thesis ‘light consists of particles’ and the antithesis ‘light consists of waves’ fought with one another until they were united in the synthesis of quantum mechanics. ...Only why not apply it to the thesis Liberalism (or Capitalism), the antithesis Communism, and expect a synthesis, instead of a complete and permanent victory for the antithesis? There seems to be some inconsistency. But the idea of complementarity goes deeper. In fact, this thesis and antithesis represent two psychological motives and economic forces, both justified in themselves, but, in their extremes, mutually exclusive. ...there must exist a relation between the latitudes of freedom df and of regulation dr, of the type df dr=p. ...But what is the ‘political constant’ p? I must leave this to a future quantum theory of human affairs.

Max Born: Physics and Politics

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Neither did he fall for that

He did worry about real physics

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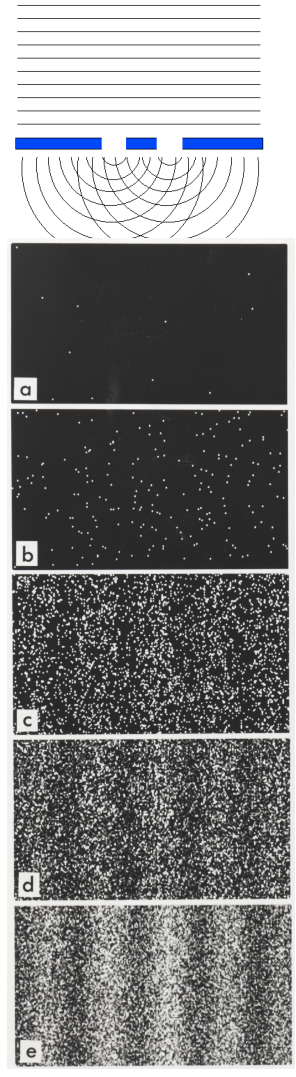
the double slit experiment

A phenomenon which is impossible to explain in any classical way and which has in it the heart of quantum mechanics. In reality it contains the only mystery of quantum mechancis

Richard Feynman



Landau and Lifshitz about the double slit experiment

It is clear that this result can in no way be reconciled with the idea that electrons move in paths.... In quantum mechanics there is no such concept as the path of a particle

What is mysterious about that experiment? What is the source of all evil?

A particle can only go through one of the slits, a wave can go through both, but on the screen only localized dots appear, as if particles arrived, but the ensemble of dots make up a pattern which looks like an interference pattern of a wave

So? Where's the problem?

No problem as this man suggested in 1927

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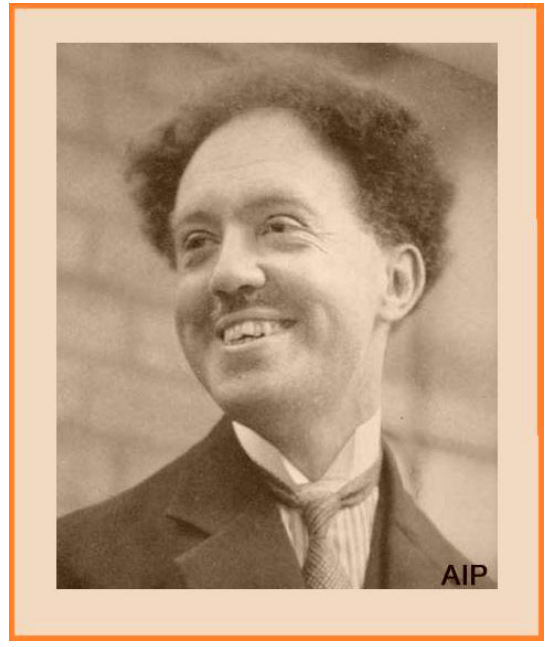

de Broglie 1892- 1987: wave and particle

de Broglie proposed that the wave guides the particles: (Q, ψ)

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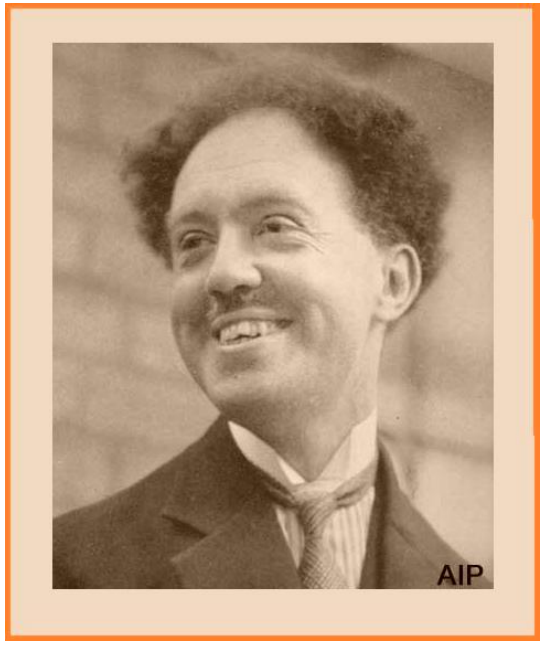

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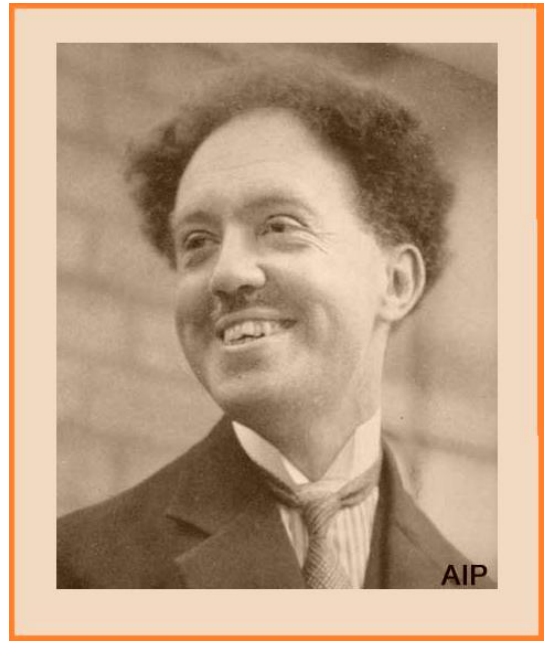

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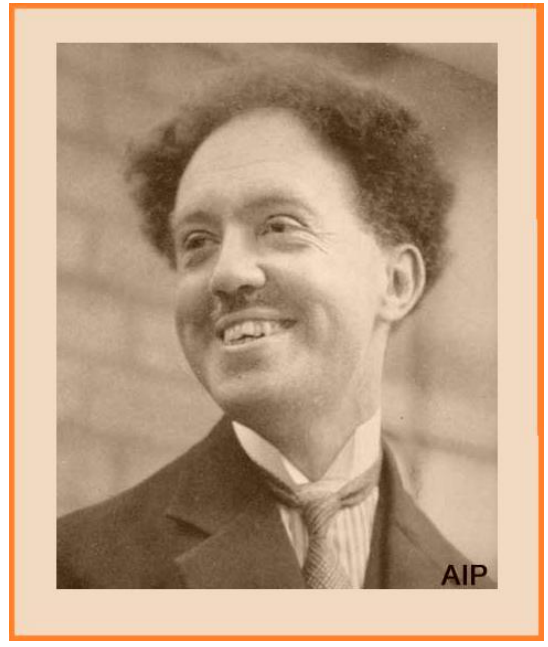

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The endless agony revisited

ψ the "unphysical" wave function

Erwin Schrödinger 1887-1961

ψ and the high dimensional unphysical configuration space

- Wave function ψ of n "particles" is a function of n position variables $\psi(x_1, x_2, ..., x_n)$! It is not a function on physical space!
- This is called *entanglement and is the source of decoherence*
- it is governed by a linear equation
- It changes continuously, no jumps

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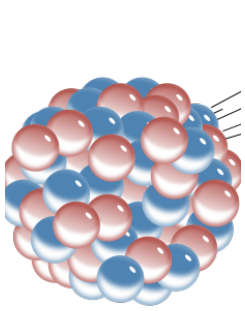
ψ and measurement problem

One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The psi-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts. It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be resolved by direct observation. That prevents us from so naively accepting as valid a "blurred model" for representing reality. In itself it would not embody anything unclear or contradictory. **There is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks.**

Clearly, the cat decoheres the atomic wave function and Alice decoheres the cat, but who or what creates the facts?

the cat waits for the α particle, she wants to catch it

and then



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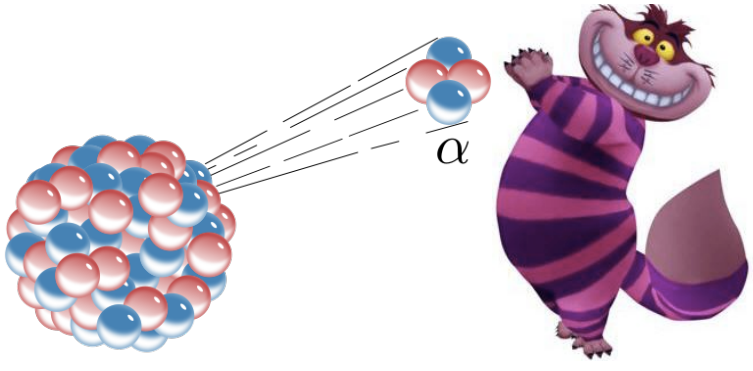

and then Alice looks

and then? Don't worry says

the mad hatter

...the idea of an objective real world whose smallest parts exist objectively in the same sense as stones or trees exist, independently of whether or not we observe them... is impossible...

we observe and creates facts? who are we? is Alice a we?

Feynman wouldn't buy that. He says:

Does this mean that my observations become real only when I observe an observer observing something as it happens? This is a horrible viewpoint. Do you seriously entertain the thought that without observer there is no reality? Which observer? Any observer? Is a fly an observer? Is a star an observer? Was there no reality before 10^9 B.C. before life began? Or are you the observer? Then there is no reality to the world after you are dead? I know a number of otherwise respectable physicists who have bought life insurance.

Some still think that this man (and perhaps this man thinks so himself) can help us to exist! He is an observer, presumably with life insurance

Mermin, in Physics Today on Quantum Baysianism, says no, we don't need him:

Albert Einstein famously asked whether a wavefunction could be collapsed by the observations of a mouse. Bell expanded on that, asking whether the wavefunction of the world awaited the appearance of a physicist with a PhD before collapsing. The QBist answers both questions with "no." A mouse lacks the mental facility to use quantum mechanics to update its state assignments on the basis of its subsequent experience, but these days even an undergraduate can easily learn enough quantum mechanics to do just that.

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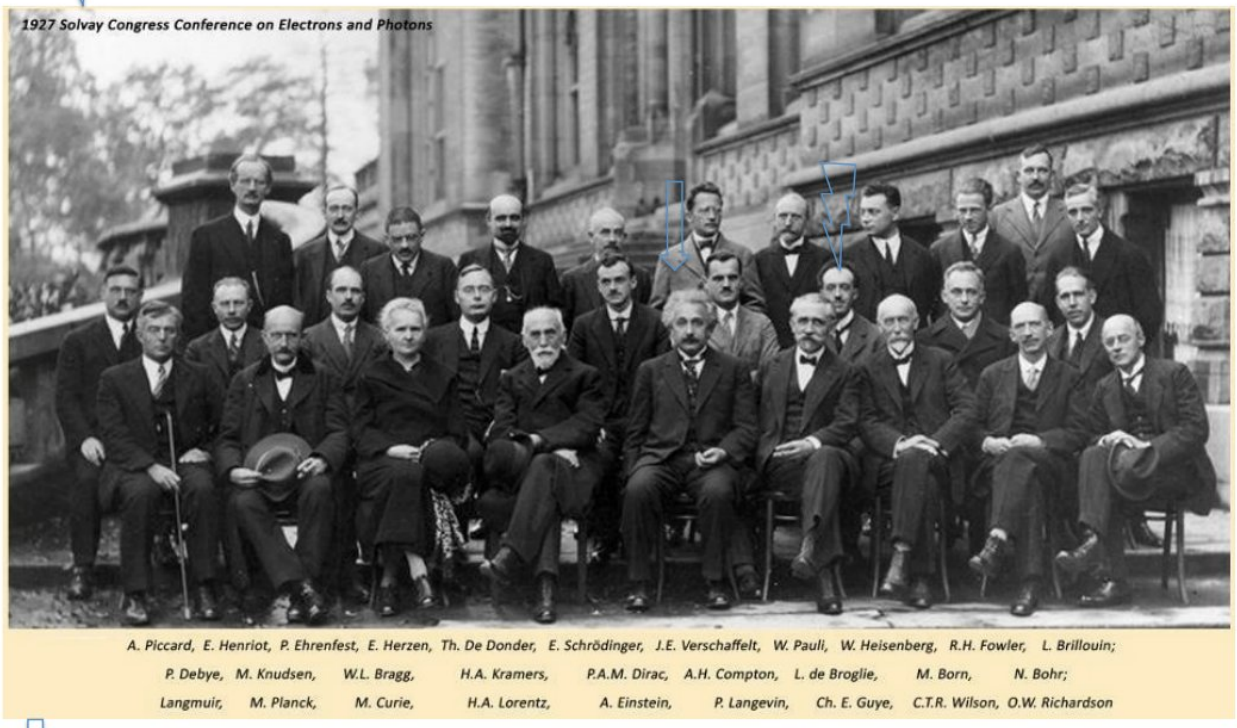
Why comes a dot at the screen, that is the question!

No said this man

To be, or not to be: that is the question: Whether 'tis nobler in the mind to suffer The slings and arrows of outrageous fortune, Or to take arms against a sea of troubles...

de Broglie took arms against a sea of troubles and suggested that the wave on configuration space guides the particles in physical space $((Q_1, Q_2, ..., Q_n), \psi)$

de Broglie proposed that the wave function guides the particles



De Broglie's idea was in spirit against Einstein's locality idea on which he based relativity

Because the wave function lives on configuration space and not physical space

but one man understood it all in 1952: (Q, ψ) is indeed the trivial solution to all the mysteries of quantum mechanics.

David Bohm (1917-1992)

Bohmian Mechanics (Q, Ψ)

Ψ is a solution of the Schrödinger equation

$Q = (Q_1, \ldots Q_N)$ positions of N particles. $Q(t)$ solves the guiding equation

$$\frac{d}{dt} Q \sim \nabla \ln \Psi$$

Analyze this in Quantum Equilibrium (Boltzmannian statistical analysis of BM)

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theorems about (Q, ψ) instead of axioms

- a subsystem X of a big system $Q = (X, Y), \Psi(x, y)$ has the conditional wave function $\varphi(x) = \Psi(x, Y)$ guiding the particles of the subsystem and which sometimes is the effective wave function observing an autonomous Schrödinger equation for the subsystem.
- Quantum equilibrium (DGZ): $\rho = |\varphi|^2$ is the typical empirical distribution for X in the sense of Boltzmann in an ensemble of subsystems having wave function φ
- Heisenberg's uncertainty principle holds (of course)
- POVMs appear naturally as book keeper of statistics in measurement situations, sometimes POVMs are PVs and the book keepers define (via the spectral measure) observables $\hat{A}$
- precise description of the effective collapse of the wave function and emergence of classical behavior
- Alice stays completely sane, never mind the grinning cat
- arrival times of particles are well defined
- wave function must be either fermionic or bosonic

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- little mystery: Why does the interference pattern vanish if one looks through which slit the particle goes?
- Answer: Because the wave function of system and apparatus lives on the configuration space of system and apparatus, and the wave parts in configuration space don't meet anymore: Decoherence!
- huge mystery: What is the role of the wave, what describes the factual state of affairs? What is really going on?
- Answer: ψ guides Q and Q is what there is. Just like ordinary physics ought to be

all mysteries (the tiny, the big and the huge) are gone

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It is all so easy when local “beables” (like particle positions) exist

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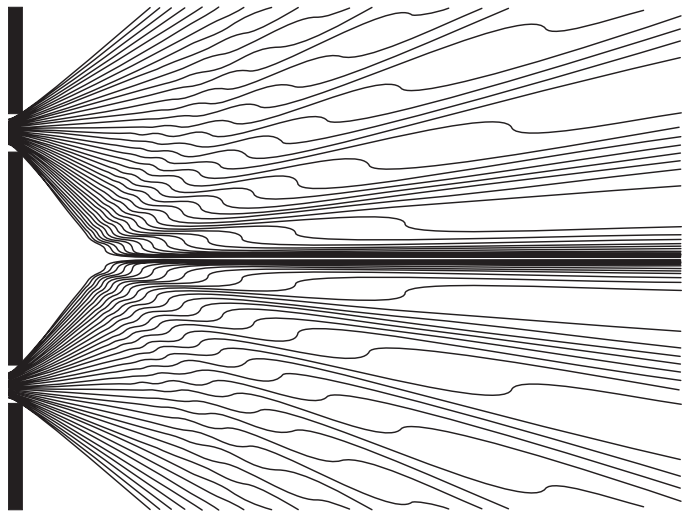

computer simulation of Bohmian trajectories by Chris Dewdney

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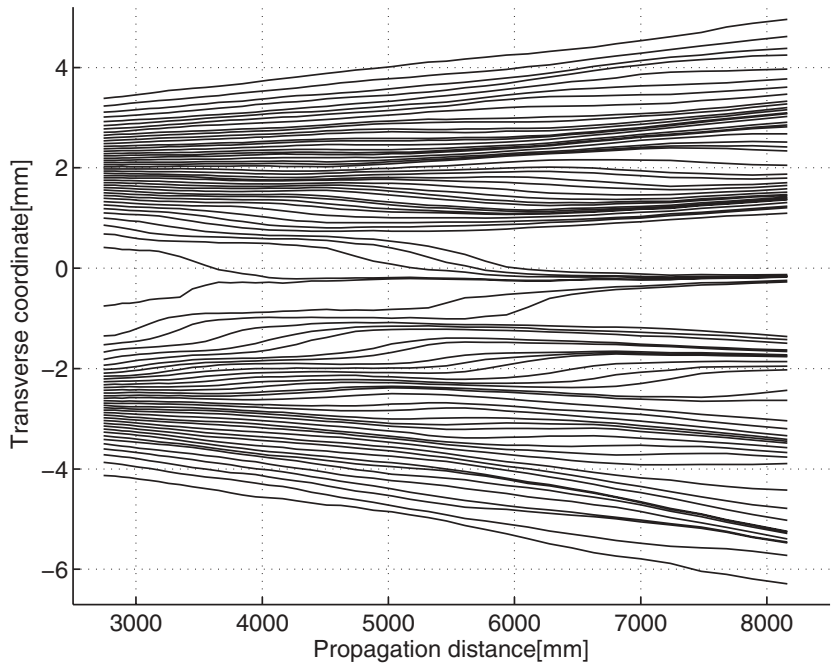

Exeperiment: S.Kocsis et al: Observing the Average Trajectories of Single Photons in a Two-Slit Interferometer. Science 2011

But hold on! Bohm's papers were read and readily dismissed! Why? Because all the romantics of mysticism was gone? Because the swamp was laid dry? How did he overcome the problem de Broglie faced in the Solvay conference. Isn't it a sin to have a physical field, Ψ, is on configuration space? He did not overcome that! Quite the contrary!

Exactly, says this man, nature is like that, there is no better way

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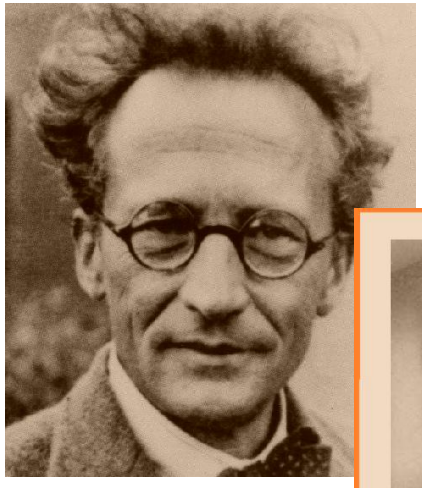
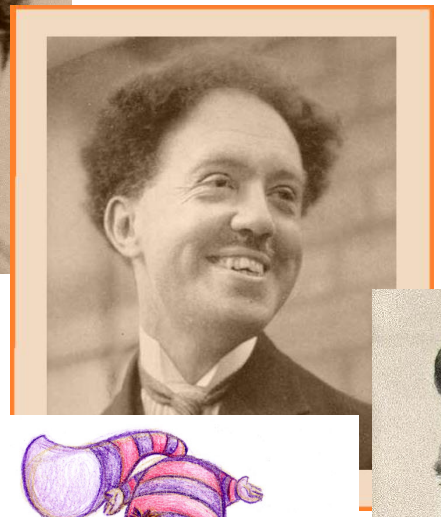
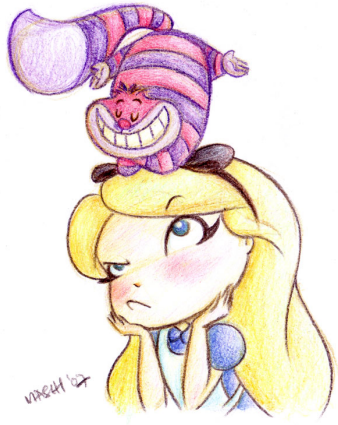
Bohmian mechanics is just what the doctor ordered



They all can be happy!





And Gianfausto should be too! Welcome to the sect! But-and there is always a but-: Why isn't Bohmian mechanics taught?

Possible answers:

- since it isn't taught there must be something wrong with it
- since your admired authority does not like it, there must be something wrong with it
- Heisenberg or Bohr (or the pope) forbids it, because it is bad for your mind (or for your well being after death)
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Facts can't be impossible or can they?

The Impossible Fact
Palmstroem, old, an aimless rover, walking in the wrong direction
at a busy intersection is run over.
"How", he says, his life restoring and with pluck his death ignoring,
"can an accident like this ever happen? What's amiss?" "Did the state
administration fail in motor transportation?
Did police ignore the need for reducing driving speed?"
"Isn't there a prohibition, barring motorized transmission
of the living to the dead? Was the driver right who sped ... ?"
Tightly swathed in dampened tissues he explores the legal issues,
and it soon is clear as air: Cars were not permitted there!
And he comes to the conclusion: His mishap was an illusion,
for, he reasons pointedly, **that which must not, can not be**.

Ch. Morgenstern, *Die unmögliche Tatsache*, taken from *Palmström und anderen Galgenliedern* translated by M. Knight

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