Reductionism, Holism and Emergence

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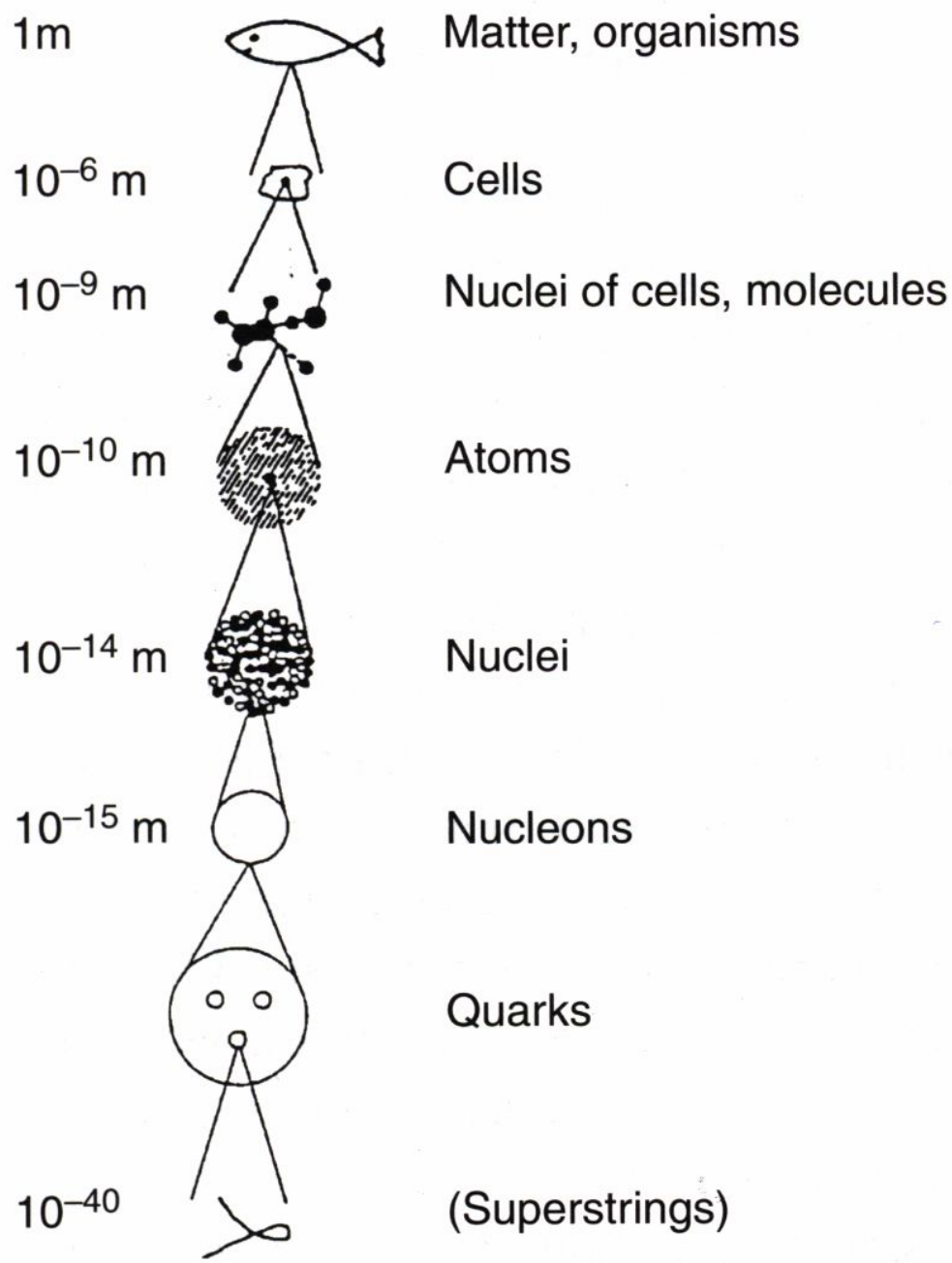


The problem of reductionism

- Can one level be completely reduced to a lower level? ("ontological reductionism")
- (For example, cells are “nothing but” molecules.)

“The reductionist hypothesis may still be a topic for controversy among philosophers, but among the great majority of active scientists I think it is accepted without question.The workings of our minds and bodies, and of all the animate or inanimate matter of which we have any detailed knowledge, are assumed to be controlled by the same set of fundamental laws, which except under certain extreme conditions we feel we know pretty well.” (P. W. Anderson: "More is Different", *Science*, 4. August 1972, Vol 177, No 4047)

“...if everything obeys the same fundamental laws, then the only scientists who are studying anything really fundamental are those who are working on those laws.” (Anderson: "More is Different")

... and Steven Weinberg twenty years later:

"This book is about a great intellectual adventure, the search for the final laws of nature. The dream of a final theory inspires much of today's work in high energy physics, and though we do not know what the final laws might be or how many years will pass before they are discovered, already in today's theories we think we are beginning to catch glimpses of the outlines of a final theory."
(Steven Weinberg: *Dreams of a Final Theory* (1993), Preface)

"However, if we do discover a complete theory [.....] it would be the ultimate triumph of human reason – for then we would know the mind of God."
(Stephen Hawking: *A Brief History of Time* (1988), Conclusion)

Gerard t' Hooft on a “Theory of Everything”

"The laws will determine with infinite accuracy the evolution of all physical dynamical variables at a local level, and should also include a description of the 'boundary' of the universe, as well as its initial state.

There exists no closely resembling alternative theory. This means that any slight change brought about in the rules would make the theory unlikely or inelegant. The theory will be a 'package deal': take it, or leave it. This should hold both for the local laws and for the boundary conditions."

"Evolution according to these laws will give rise to a nearly infinite complexity, a complexity sufficiently extensive to include the marvelously perplexing wonders abounding in our universe – the emergence of life and intelligence being only a few of these."

(Gerard 't Hooft: “Questioning the answers or Stumbling upon good and bad Theories of Everytning”, J. Hilgevoord (ed): *Physics and our View of the World,*1994).

The principal candidate for a theory of everything was (and is?) string theory.

Lee Smolin has given substantial contributions to the theory. However .....

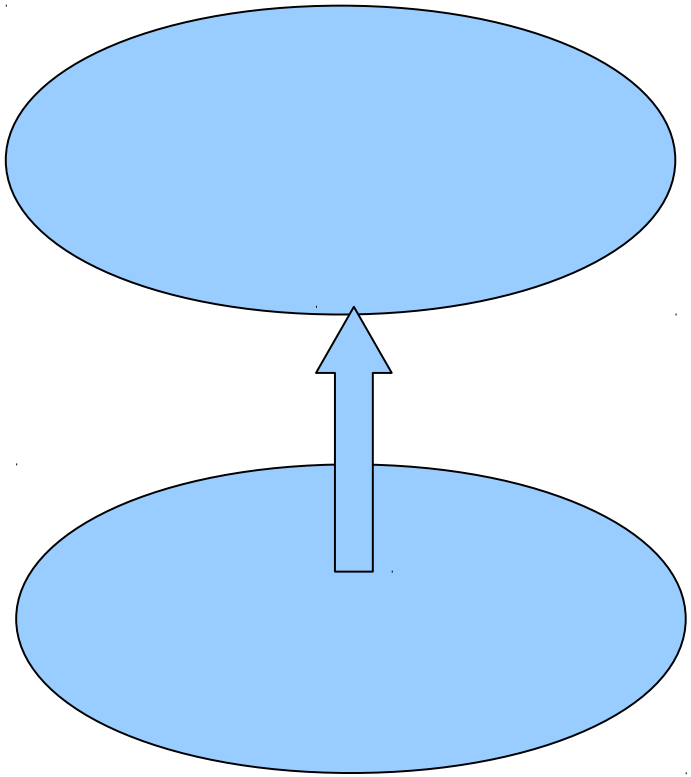
"There appears to be no precedent for a gap between theory and experiment lasting decades. It is something we theorists talk about often. Some see it as a temporary lull and look forward to new experiments now in preparation. Others speak of a new era in science in which mathematical consistency has replaced experiment as the final arbiter of a theory's correctness. A growing number of theoretical physicists, myself among them, see the present situation as a crisis that requires us to reexamine the assumptions behind our so-far unsuccessful theories."
(Lee Smolin: "A Crisis in Fundamental Physics", New York Academy of Science, January/February 2006)

Almost twenty-five years after *A Brief History of Time* it looks as if Hawking has also given up the search for a final theory:

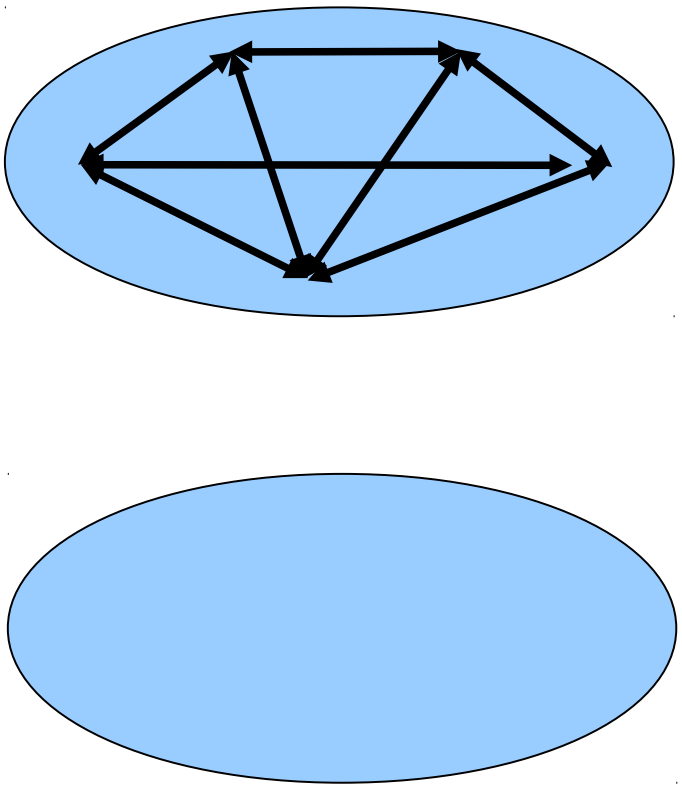
"Physicists have long sought to find one final theory that would unify all of physics. Instead they may have to settle for several."
(Stephen Hawking and Leonard Mlodinow: "The (Elusive) Theory of Everyting", *Scientific American*, Special issue on extreme physics, summer 2013.)

The problem is that the world is in general not simple, but complex. The whole cannot in general be reduced to its parts. At each level of organization there are emergent properties that cannot be explained as just an interaction of the parts at the lower level.

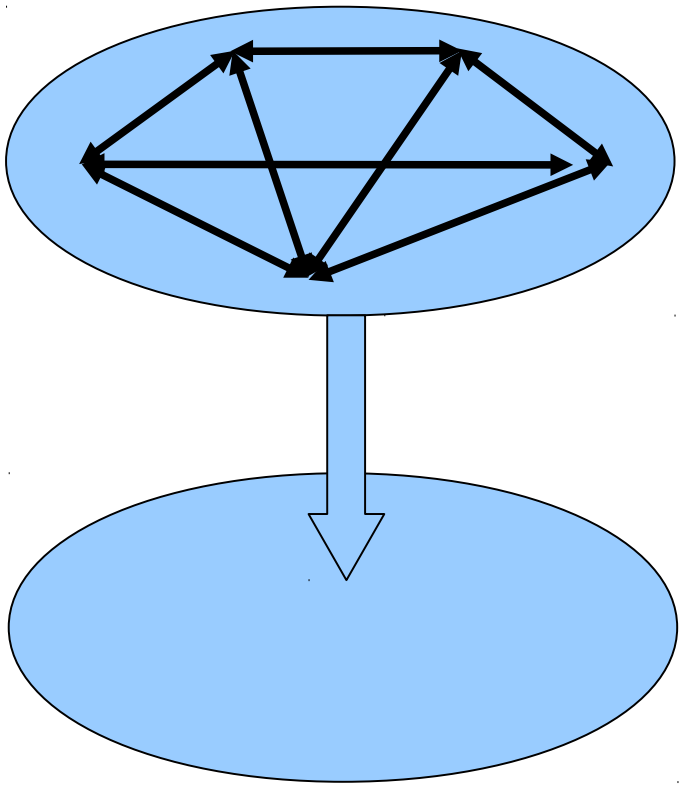
Not this



But this



Or even this



Emergence

“At each stage entirely new laws, concepts, and generalizations are necessary, requiring inspiration and creativity to just as great a degree as in the previous one. Psychology is not applied biology, nor is biology applied chemistry.” (Anderson: "More is Different",1972)

Emergence

"I heard the great evolutionist Ernst Mayr claiming 30 or 40 years ago, when he described emergence to Niels Bohr, Bohr said: "but we have that in physics as well! - physics is all emergent", but at the time, as usual, only Bohr knew what he meant.

In fact, the story of physics in the last half of the 20th century has been one of emergence – Bohr was also, as usual, basically right."

(Anderson: "What Is a Condensed Matter Theorist?", in *More and Different*, 2011)

Examples of emergent physical properties:

- A simple atom of gold cannot be yellow and shiny and conduct electricity. Properties of gold metal have only meaning at a macroscopic scale.
- A molecule of salt is not a cube. Only a salt crystal can have cubic symmetry.
- Anderson's key-word is "broken symmetry"

(Anderson: "Emergence vs Reductionism", in *More and Different*, 2011)

A semi-formal definition of complexity

"Loosely speaking, the complexity of a system is the amount of information needed in order to describe it."
Yaneer Bar-Yam: *Dynamics of Complex Systems* (1997)

A less formal (but perhaps more useful) characterization of complexity

"To investigate many-body systems, scientists construct simplified models that capture various important aspects of a larger picture from various perspectives. Consequently economics, evolutionary biology, and statistical physics all branch into a multitude of models, each of which addresses a particular process or a specific aspect of composition. Various models employ various approaches and approximations as befits their specific topics." (Sunny Y. Auyang: *Foundations of Complex-System Theories* (1998)

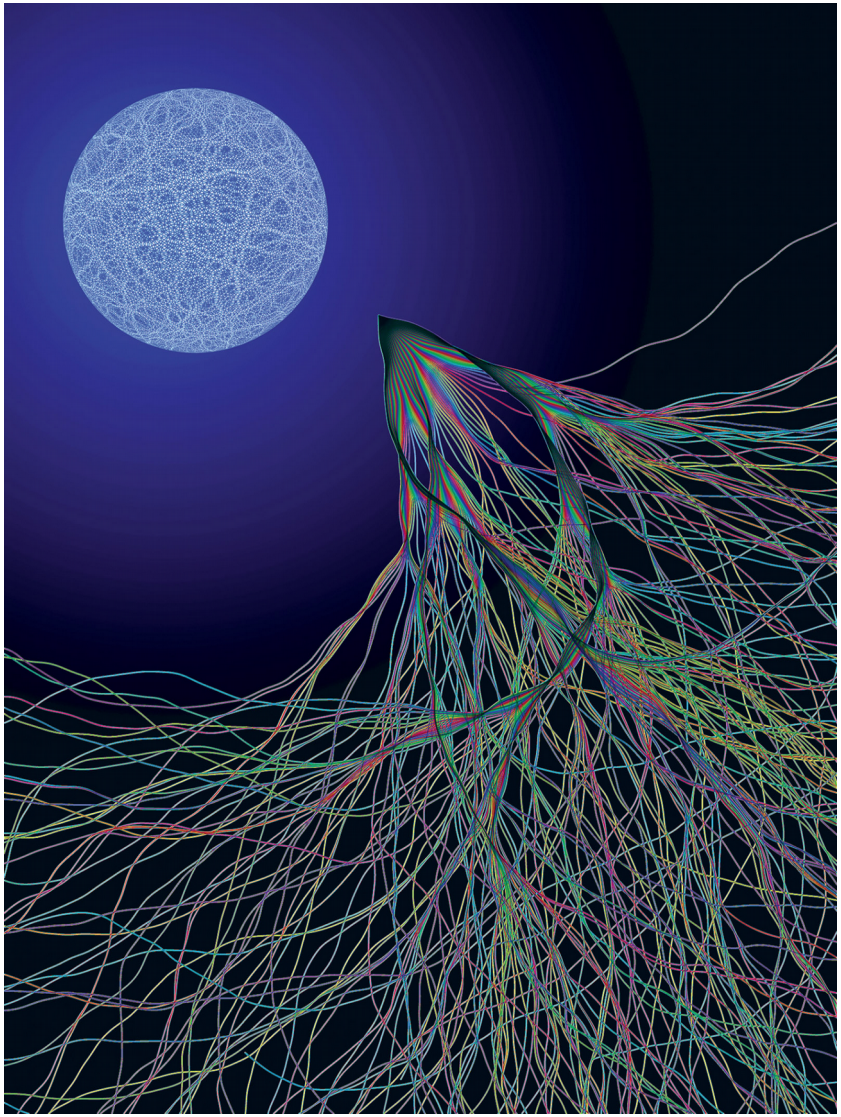
Back to Smolin:

"The great physicists of the beginning of the 20th century—Einstein, Bohr, Mach, Boltzmann, Poincare, Schrodinger, Heisenberg—thought of theoretical physics as a philosophical endeavor. They were motivated by philosophical problems, and they often discussed their scientific problems in the light of a philosophical tradition in which they were at home.
[...]
Thus, I suspect that the crisis is a result of having ignored foundational issues. If this is true, the problems of quantum gravity and unification can only be solved by returning to the older style of research."
Lee Smolin: "A Crisis in Fundamental Physics"

It looks as if Steven Weinberg agrees:

"Even the most adventurous modern speculations, such as string theory, are based on the principles of quantum mechanics."

The New York Review of Books



Steven Weinberg:

The Trouble with Quantum Mechanics

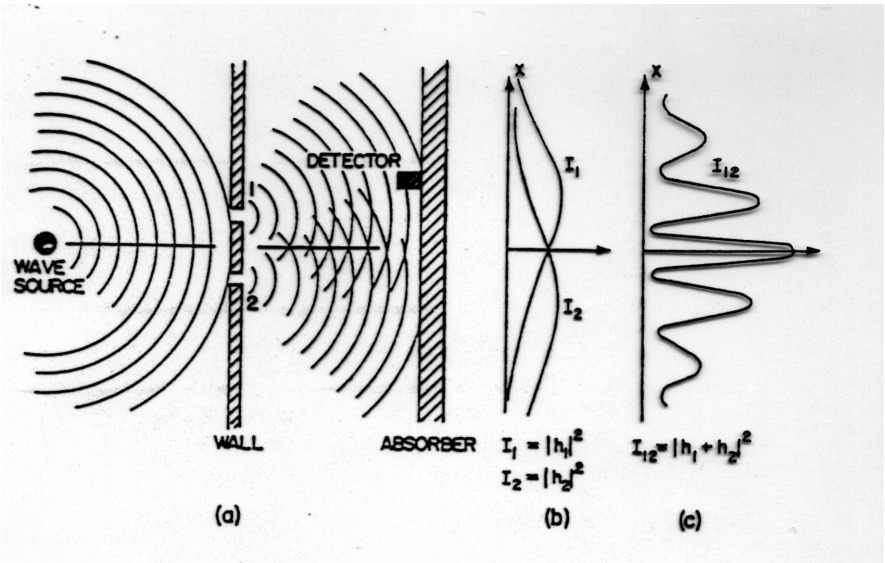
January 19, 2017 Issue

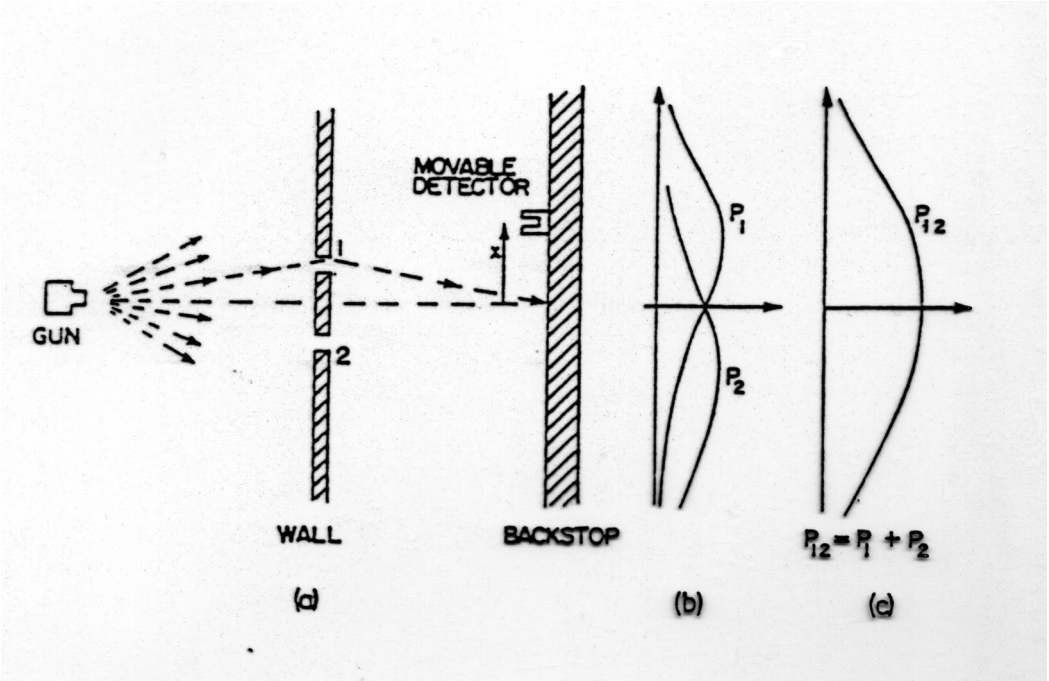
"I’m not as sure as I once was about the future of quantum mechanics. It is a bad sign that those physicists today who are most comfortable with quantum mechanics do not agree with one another about what it all means. The dispute arises chiefly regarding the nature of measurement in quantum mechanics."
(Steven Weinberg: The Trouble with Quantum Mechanics)

"According to Bohr, in a measurement the state of a system such as a spin collapses to one result or another in a way that cannot itself be described by quantum mechanics, and is truly unpredictable. This answer is now widely felt to be unacceptable." (Steven Weinberg: The Trouble with Quantum Mechanics)

I disagree with Weinberg, and shall argue that any solution to the problem must incorporate Bohr's insights.

The double-slit experiment





From Richard Feynman: Lectures on Physics, vol 3.

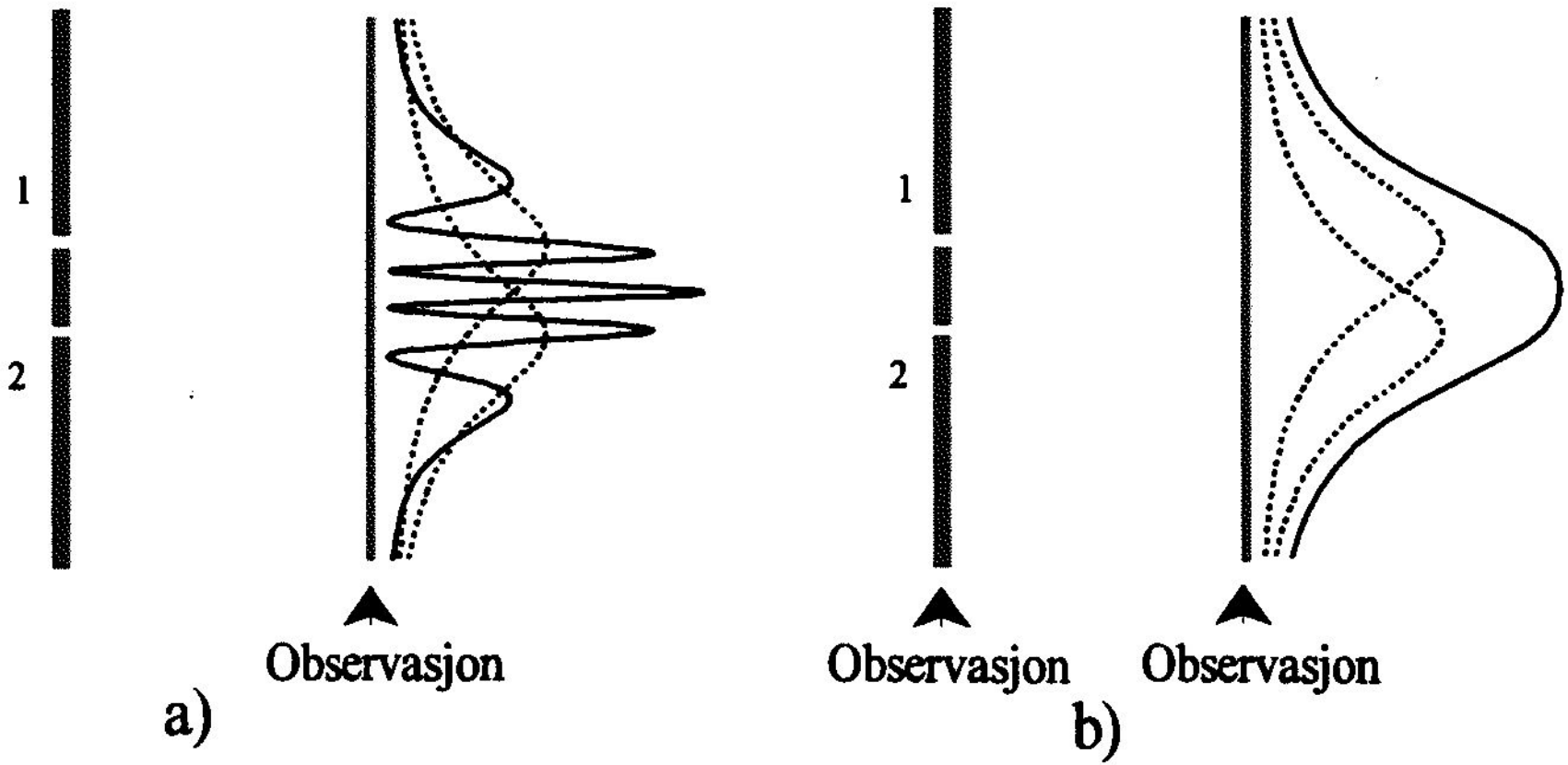
The paradox

When we don't know which slit the electron passes through, then it behaves like a wave

When we know which slit the electron passes through, then it behaves like a particle

Indeed, the finite interaction between object and measuring agencies [...] entails the necessity of a final renunciation of the classical ideal [...] and a radical revision of our attitude towards the problem of physical reality. (Bohr 1949: 697)

Crucial point:
The observer cannot be abstracted away



Einstein, Podolsky and Rosen on "physical reality"

"If, without in any way disturbing a system, we can predict with certainty (i.e. with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity. (criterion of physical reality)"
(Einstein, Podolsky and Rosen: "Can Quantum-Mechanical Description of Reality Be Consisered Complete? *Physical Review*, May 15, 1935)

This is the idea of "physical reality" that we have inherited from Galileo and Descartes. Objectivity in science is depicting a reality that exists independently of man.

Sometimes it is referred to as "the view from nowhere" or "God's Eye View".

Einstein:
"Is the moon there when nobody looks?"
(Story referred in N.D. Mermin: "Is the Moon there When Nobody Looks?", *Physics Today*, April 1985.)

God in the Quad

There was a young man who said "God
Must find it exceedingly odd
To think that the tree
Should continue to be
When there's no one about in the quad."

Reply:
"Dear Sir: Your astonishment's odd;
I am always about in the quad.
And that's why the tree
Will continue to be
Since observed by, Yours faithfully, God."

Bohr: There is no "God's Eye View"

Bohr on “physical reality”

“But even at this stage there is essentially the question of *an influence on the very conditions which define the possible types of predictions regarding the future behavior of the system.* Since these conditions constitute an inherent element of the description of any phenomenon to which the term “physical reality” can be properly attached, we see that the argumentation of the mentioned authors does not justify their conclusion that quantum-mechanical description is essentially incomplete.”

(Niels Bohr: "Discussions with Einstein on Epistemological Problems in Atomic Physics", in *Albert Einstein: Philosopher-Scientist* 1949.)

Question: Are electrons particles or waves?

Bohr's answer: This question cannot be asked in quantum mechanics. We should rather ask the question: Do electrons behave like particles or waves? In answering that question we should specify under what experimental conditions they behave as particles or waves.

Summary of Bohr's philosophy of physics:

- The “observer” cannot be eliminated
- There is no “God's Eye View” (or no view from nowhere)
- Some perspectives are mutually exclusive (Bohr's idea of complementarity)
- The everyday world perspective is prior to a theoretical perspective

"In physics we learn [...] time and again that our task is not to penetrate into the essence of things, the meaning of which we don’t know anyway, but rather to develop concepts which allow us to talk in a productive way about phenomena in nature."
(Letter to the Danish author HPE Hansen, dated 20.7.1935, Engl. transl. quoted from Abraham Pais: *Subtle is the Lord*, 1991)