Aesthetics in quantum physics: Motivation, Meaning and Education

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What is aesthetics (in science)?

Narrow conception: The study of beauty, or the philosophy of art.

In science: Beauty related to symmetry, order, simplicity and unity.

Though aesthetics also includes the sublime – relating to awe and wonder.

Broad conception: Aesthetics derives from *aisthesis* (pertaining to the senses).

The opposite: An-*aisthesis* or anesthesia, that which numbs or puts us to sleep…

→ Aesthetics can be understood as what captures our attention and wakes us up.

Theoretically, it has been defined as sensitive cognition which involves a combined activity of our intellect, our senses and our emotions.

→ Aesthetics in science is not just about beauty, and it can be related to, e.g., motivation, heuristic guidance, theory evaluation and interpretation in science.

A key role of aesthetics in physics: Motivation

"Science is beautiful, and it is because of that beauty that we must work on it, and then there is always the chance that a scientific discovery may become, like the radium, a benefit for humanity."

"A scientist in his laboratory is not only a technician: he is also a child placed before natural phenomena which impress him like a fairy tale."

Marie Curie (1921 and 1933)

Still: Is aesthetics not just a question of personal or subjective taste?

A shared notion of beauty in physics

Historically, a persistent notion of beauty has been that of unity or connection between different natural phenomena, and between the theories describing these.

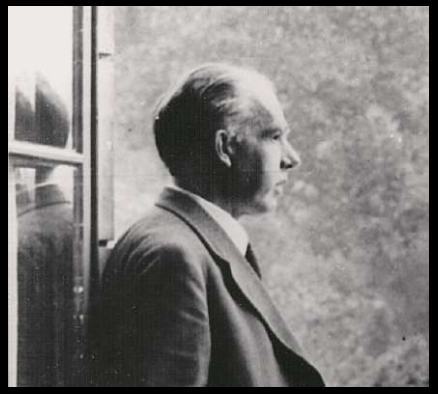
Many, if not all, of the quantum pioneers would have agreed (Heisenberg 1971):

"Beauty is the proper conformity of the parts to one another and to the whole."

This notion of beauty is *also* a common conception of scientific understanding:

"Understanding' probably means nothing more than having whatever ideas and concepts are needed to recognize that a great many different phenomena are part of a coherent whole."

W. Pauli in the early twenties (according to Heisenberg 1971)



"To take part in lifting only a corner of the veil under which truth is hiding and perhaps thereby getting on the track of deeper connections than those immediately apparent, is all the happiness that a researcher can be given."

N. Bohr (1945)

But *which* connections? (a more subjective matter)

"If I have understood correctly your point of view, then you would gladly sacrifice the simplicity [of quantum mechanics] to the principle of [classical] causality. Perhaps we could comfort ourselves [with the idea that] the dear Lord could go beyond [quantum mechanics] and maintain causality. I do not really find it beautiful, however, to demand more than a physical description of the connection between experiments."

Heisenberg to Einstein, 10 June 1927

But Einstein was not alone in his demand for beauty beyond connections between experimental results…

The request for a causal description of quantum processes is closely related to one that is visualizable, and it appears that the *absence* of beauty in this sense may have formed part of Schrödinger's motivation for developing wave mechanics…

Early interpretative question: Is visualizability beautiful and is it needed for understanding?

"I naturally knew about his [Heisenberg's] theory, but because of the to me very difficult-appearing methods of transcendental algebra and because of the lack of *Anschaulichkeit* [visualizability], I felt deterred by it, if not to say repelled.

E. Schrödinger (paper on wave- vs matrix mechanics) May 1926

"The more I think of the physical part of Schrödinger's theory, the more abominable I find it. What Schrödinger writes about *Anschaulichkeit* makes scarcely any sense, in other words I think it is crap."

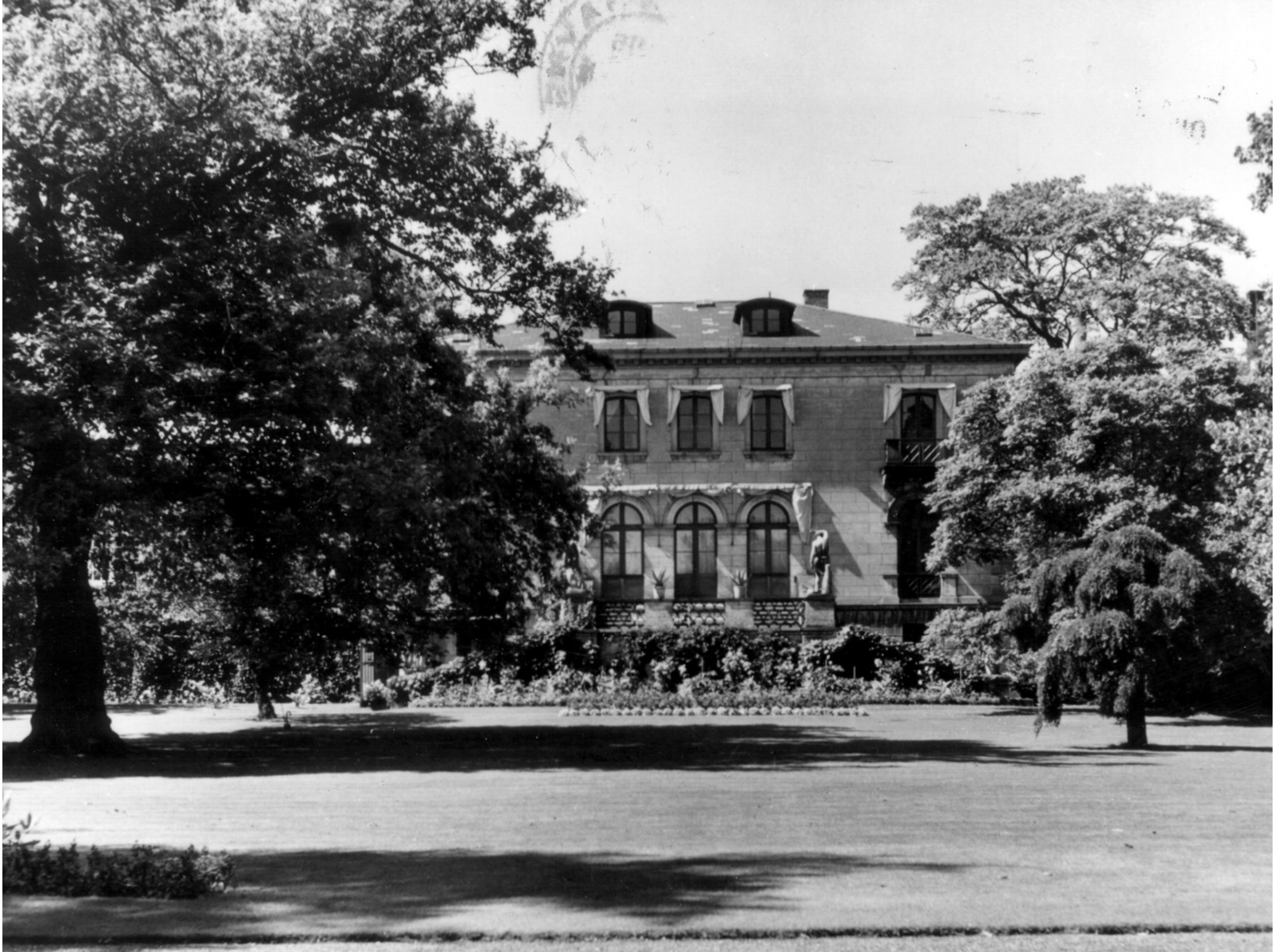
W. Heisenberg to W. Pauli, 6 June 1926

What about Niels Bohr and pictures?

"One must in general and especially in new fields of work constantly be aware of the apparent or possible inadequacy of pictures […] my personal viewpoint is that these difficulties are of a kind that hardly leaves room for the hope of accomplishing a spatial and temporal description of them that corresponds to our usual sense-impressions."

Bohr (1922)

Bohr would maintain this view also later on…



La Femme au Cheval (Woman with a Horse), 1911/12
Jean Metzinger

Metzinger in *On Cubism* (1912):
"An object has not one absolute form; it has many."

On particle-wave duality:
"We must, in general, be prepared to accept the fact that a complete elucidation of one and the same object may require diverse points of view which defy a unique description."

Bohr (1929)

Complementarity puts further constraints on pictures…

Elements of Bohr's view: Complementarity

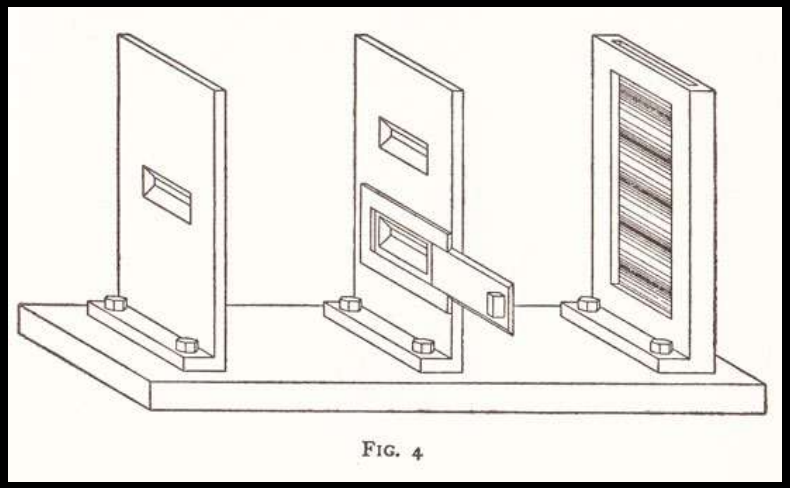


FIG. 4

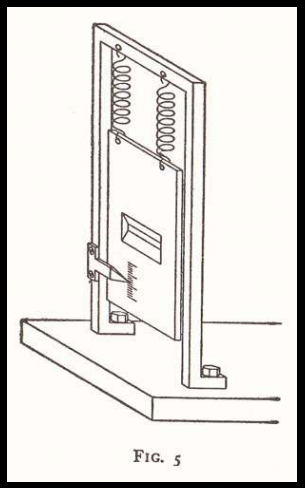


FIG. 5

Bohr (1949): "[W]e are presented with a choice of *either* tracing the path of a particle *or* observing interference effects … [This is] a typical example of how the complementary phenomena appear under mutually exclusive experimental arrangements... and [we] are just faced with the impossibility … of drawing any sharp separation between an independent behaviour of atomic objects and their interaction with the measuring instruments."

The object and apparatus are dynamically inseparable (until a result is obtained):

Un-analyzability of the measurement process (by which, somehow, a quantum object interacts with an instrument to produce a permanent mark in the latter).

→ A causal space-time picture of this process will forever remain elusive.

The sublime

In a scientific context: The sublime relates e.g. to awe, wonder, and the exploration of that which may be on the *limit* of (or beyond) scientific understanding.

"The universe therefore is not wide enough for the range of human speculation and intellect. Our thoughts often travel beyond the boundaries of our surroundings. If anyone wants to know what we were born for, let him look round at life and contemplate the splendour, grandeur, and beauty in which it everywhere abounds."

Longinus, *On the Sublime*, 1th century.

"Margrethe and I thank you many times for your great kindness in sending us your beautiful edition of Longinus, which it has been a great experience to get to know for both of us. Seldom have I read anything that from first to last has been more instructive and enchanting than this old text, which with all its soberness is so full of spirit and enthusiasm."

N. Bohr to N. Møller, 11 March 1934

Sublimity and the exploration of the unknown

"…particularly stimulated by discussions with Pauli, I am these days working slavishly to the best of my power to accustom myself to the mysteries of nature and to attempt to prepare myself for all eventualities."

N. Bohr to W. Heisenberg, 18 april 1925

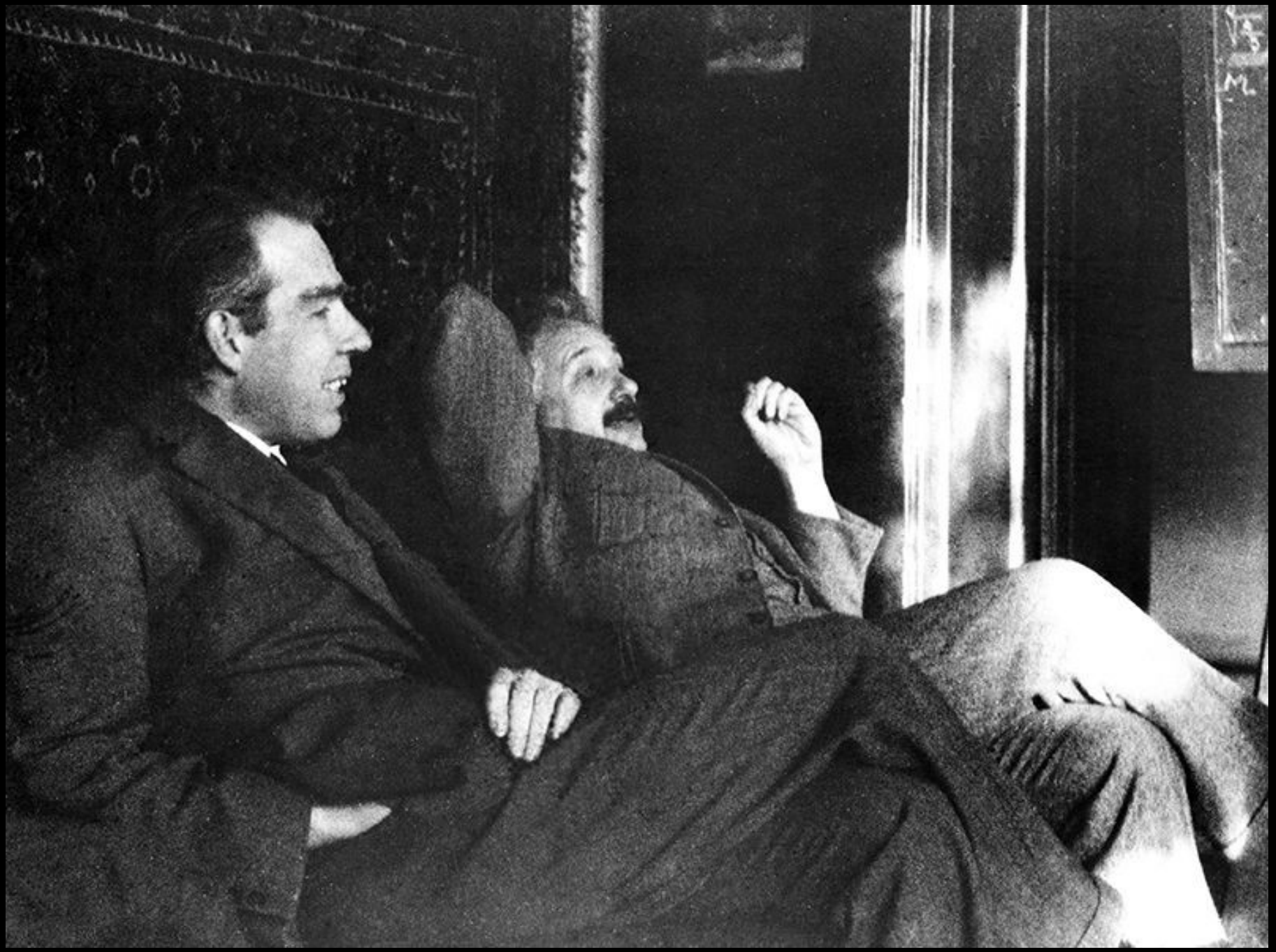
"When the first terms seemed to accord with the energy principle, I became rather excited, and I began to make countless arithmetical errors. As a result, it was almost three o'clock in the morning before the final result of my computations lay before me … At first, I was deeply alarmed. I had the feeling that, through the surface of atomic phenomena, I was looking at a strangely beautiful interior, and felt almost giddy at the thought that I now had to probe this wealth of mathematical structures nature had so generously spread out before me…"

W. Heisenberg on the 1925 event (1971)

"Our penetration into the world of atoms, hitherto hidden from the eyes of man, is truly an adventure comparable to the great voyages of discovery of the circumnavigators and the bold explorations of astronomers into the depths of celestial space."

N. Bohr (1938)

More on how aesthetics influences interpretation



Indeterminacy of measurement outcomes

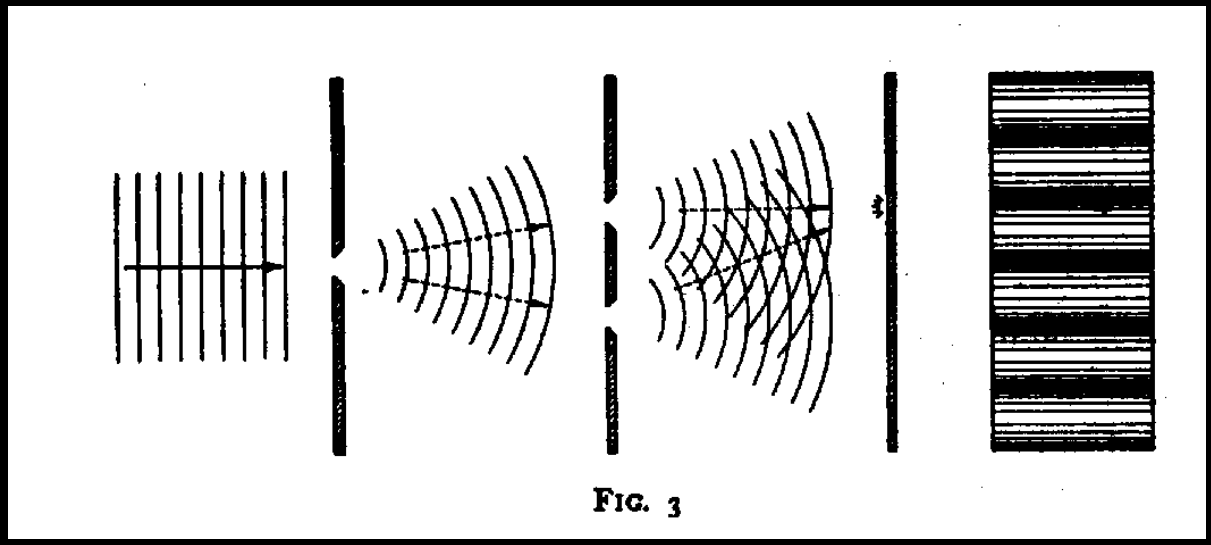


FIG. 3

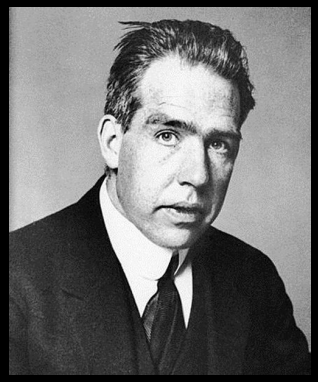
"Quantum theory yields much, but it hardly brings us close to the Old One's secrets. I, in any case, am convinced He does not play dice with the universe…You believe in a God who plays dice, and I in *complete law and order* in a world which objectively exists, and which I in a wildly speculative way, am trying to capture.

A. Einstein to M. Born, 4 December 1926.

Meaning and the limits of beauty and understanding

"I believe that there is a meaning in the world, a meaning that human beings cannot understand, but only can sense. And that does not make life poorer to me, on the contrary it would be so infinitely trivial if I thought that I could understand it."

N. Bohr to Sophie Nørlund (1 May 1912)



"It is not the recognition of our human limitations, but the striving to investigate the nature of these limitations, which marks our time. […] We are subject to a constantly growing impression of an eternal, infinite harmony; the harmony itself can, of course, only be dimly perceived, never grasped; at any attempt to do so, it slips according to its very nature through our fingers".

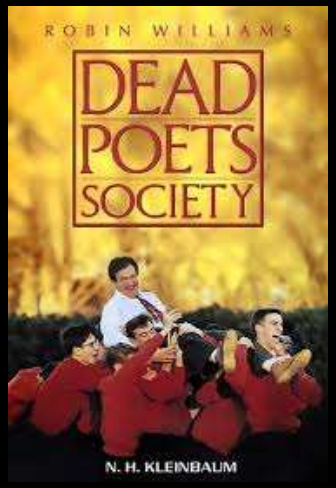
N. Bohr (1928)

Aesthetics of science in an educational context

The aesthetics of science seems to be motivating not only for scientists but also for students in science education. Psychologists Deci and Ryan (2000):

"People will be intrinsically motivated only for activities that hold intrinsic interest for them, activities that have the appeal of novelty, challenge, or *aesthetic value*."

Moreover, aesthetic values like beauty and wonder can be *shared*, and may get even more meaningful when shared → This can strengthen a sense of community.



"We don't read and write poetry because it's cute. We read and write poetry because we are members of the human race. And the human race is filled with passion. And medicine, law, business, engineering, these are noble pursuits and necessary to sustain life. But poetry, beauty, romance, love, these are what we stay alive for."

Keating in *Dead Poets Society*

Most likely, Mr. Keating would not object if we were to extend the reference to poetry also to the poetic and aesthetic aspects of science…

Conclusions

- Aesthetics in broad terms includes not only beauty but also awe and wonder (the sublime). It relates to motivation, heuristic guidance and meaning in science.

- Beauty can be an indication of understanding, whereas sublimity may track lack of, or limits to, understanding (motivation for exploration).

- Aesthetic considerations – e.g., in relation to visualization, determinism, and the limitations of quantum theory – played an important role in the history of quantum physics.

- The aesthetics of science can have important consequences also for science education, both as motivation and as meaning making.

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