Niels Bohr: Physicist-Philosopher in Action*

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December 26, 2025

Abstract

Niels Bohr was one of the central figures in the emergence of quantum mechanics and a paradigmatic example of a scientist who engaged reflectively with his own practice. For several decades, he was also a leading voice in the philosophical interpretation of the theory. Yet toward the end of the twentieth century his influence declined sharply, and his views came to be widely dismissed as obscure or irrelevant. To evaluate Bohr's contributions, we need to resist the analytic philosopher's urge to separate ontology from action—to treat questions about what there is as detachable from the concrete practices through which physical descriptions are articulated and assessed. That ontology-first stance fits uneasily with Bohr's philosophical sensibility, shaped by a Danish tradition that emphasized reflection on meaning, practice, and responsibility rather than the construction of autonomous metaphysical systems. Seen from this perspective, Bohr's philosophical project comes into focus: his central concern was not the limits of knowledge, but with how our concepts can be extended unambiguously into new domains.

1 Introduction

Niels Bohr was one of the central figures in the emergence of quantum mechanics between 1913 and 1927. In the decades that followed, he led the Institute for Physics in Copenhagen, which became a remarkable incubator of new ideas and a formative training ground for many of the minds who would go on to shape twentieth-century

*Forthcoming in F. Laguens, *La philosophie des physiciens, XXe–XXIe siècles.* Much of this work was done in collaboration with Anja Skaar Jacobsen, but any infelicities in the current essay are solely my responsibility.

physics. Between the mid-1920s and the postwar period, work carried out at Bohr's institute contributed decisively to the development of quantum mechanics, atomic and nuclear structure, quantum electrodynamics, and the conceptual analysis of measurement and complementarity.

Bohr was an internationally recognized leader not only in scientific research, but also in the philosophical interpretation of science and in shaping its cultural significance. Nonetheless, after the war, Bohr's influence began to taper off dramatically. When he died in 1962, something like a backlash began. By the end of the twentieth century, Bohr's philosophical views were essentially unknown among physicists, and were regularly attacked by philosophers, even when they claimed not to know what his views were. There were complex sociological factors at play in this change of sentiment towards Bohr, but I will not delve further into them. I will restrict myself to describing the fate of Bohr's ideas.

Beginning in the 1920s, Bohr and Einstein were frequently in contact, discussing physics, and sometimes disagreeing about how to move forward. It is misleading to describe them as "opponents," despite a persistent tendency in the secondary literature — especially in popular treatments — to sensationalize their exchanges as a dramatic clash between determinism and indeterminism or realism and anti-realism. Their relationship was warm, and Einstein clearly valued Bohr as a partner in dialogue. In a handwritten letter from 1922, Einstein told Bohr: "Your new analysis on the atom accompanied me on my journey and my love for your mind has grown even more."[1] It would be even less accurate to portray Bohr as an opponent of Erwin Schrödinger. In fact, Bohr was a great champion of Schrödinger's wave mechanics over and against Heisenberg's protests. The relationship between Bohr and Heisenberg's views is difficult to disentangle. Heisenberg was often quick to claim agreement with Bohr where none existed, and historians agree that he was more inclined than Bohr to adopt extreme empiricist positions.

Einstein emigrated to the United States in 1933, at a time when American physics was rapidly expanding in institutional strength and international influence. Already famous from the 1920s, Einstein soon came to occupy a unique place in American public culture, acquiring the image of a solitary scientific genius whose authority extended far beyond physics itself. By contrast, although Bohr spent a period in the United States during the Second World War and maintained professional ties with American institutions, he returned to Denmark after the war and never achieved

[1]Einstein to Bohr, 1922, quoted in Vilhelm Bohr, "Niels Bohr: Life Behind the Physics," lecture at the Perimeter Institute for Theoretical Physics, June 3, 2015.

comparable public visibility. Bohr was respected among physicists who had direct contact with the Copenhagen institute or with his immediate circle — figures such as John Wheeler — but he was never assimilated into American scientific culture in the same iconic way as Einstein, nor did his philosophical views circulate widely beyond those personal and institutional networks.

Bohr's philosophical views about physics, and about science more generally, were not transmitted with the same force or clarity to physicists trained in the postwar period. Much of Bohr's influence had been conveyed through personal interaction, institutional practice, and shared assumptions rather than through systematic textual study, and this mode of transmission proved fragile once those personal and institutional links weakened. Even when Bohr's writings were read, their aims were often obscured by a prose style shaped by an earlier philosophical tradition, one that did not align easily with the increasingly technical and formal idioms of postwar theoretical physics. As a result, many of Bohr's central philosophical commitments were absorbed only in partial or simplified form, if at all.

A further factor was the emergence, in the postwar period, of alternative programs that presented themselves explicitly as corrections to Bohr's standpoint. Karl Popper's influential critique of the "Copenhagen interpretation" portrayed Bohr as retreating from realism and causal explanation, and Popper's clear, polemical style proved far more accessible than Bohr's own writings (Popper, 1959). David Bohm's revival of a deterministic hidden-variable theory in 1952 gave concrete form to the idea that Bohr had prematurely foreclosed viable research directions (Bohm, 1952a; Bohm, 1952b), while Hugh Everett's relative-state formulation suggested that the conceptual difficulties Bohr emphasized might be avoided altogether by a sufficiently bold rethinking of quantum theory (Everett, 2012). These proposals did not merely compete with Bohr's views; they reshaped the terms in which foundational questions were posed.

The decisive turning point, however, came with John Bell's work in the 1960s. Bell recast the Bohr–Einstein debate in sharply ontological terms, framing the central issue as a choice between locality and realism, and treating Bohr's writings as evasive responses to questions that Bell regarded as both clear and unavoidable. Bell's criticisms, expressed with unusual rhetorical force, became canonical for later generations of physicists and philosophers, many of whom encountered Bohr primarily through Bell's lens. By the end of the twentieth century, Bohr's philosophy was widely regarded not as a serious alternative framework, but as a historically important stage that had been superseded by clearer and more technically articulated approaches.

This reframing of Bohr's views had become entrenched, especially in the United States. Prominent American physicists increasingly spoke as if their forebears had never really understood what quantum physics means. Murray Gell-Mann famously remarked that "Niels Bohr brainwashed a whole generation of theorists into thinking that the job [of interpreting quantum theory] was done 50 years ago" (Gell-Mann, 1979) a complaint that captures both a sense of intellectual frustration and a conviction that Bohr's influence had actively impeded progress. Steven Weinberg expressed a similar sentiment, portraying Bohr's response to the appearance of probabilities in quantum mechanics as a stopgap that is now "widely felt to be unacceptable" (Weinberg, 2017). Such remarks suggest not merely disagreement with Bohr, but a shared narrative according to which his philosophical reflections failed to yield enduring insight.

What is striking about these criticisms is that they are typically framed as objections to a theory or answer that Bohr never claimed to provide. Weinberg, for example, treats Bohr as offering a specific account of state collapse — one that should be evaluated alongside competing dynamical proposals — rather than as articulating constraints on the very form that physical description can take. The irony is that Weinberg, who elsewhere expressed skepticism about the relevance of philosophy to physics (Weinberg, 1992), here diagnoses a philosophical deficiency in quantum theory, without acknowledging that Bohr's project was precisely to clarify the philosophical conditions under which quantum theory can function as a physical theory at all. This tension already points to a deeper confusion about what kind of problem the foundations of quantum mechanics present.

That confusion has been inherited, and in some respects intensified, by more recent philosophers of physics. Figures such as Tim Maudlin and David Albert have taken Bell's framing of the issues as their point of departure, treating the foundational problem of quantum mechanics as a choice among sharply defined ontological options. Within this framework, Bohr's writings are often dismissed as obscure, evasive, or simply irrelevant, since they do not offer the sort of microphysical ontology or dynamical story that these philosophers take to be mandatory. The eclipse of Bohr's influence is thus not merely a matter of historical neglect; it reflects a profound shift in what physicists and philosophers alike expect an interpretation of quantum mechanics to deliver.

To assess this situation fairly, however, it is not enough to continue the debate on the terms in which it is now usually conducted. The eclipse of Bohr's influence was accompanied by a profound shift in the questions that physicists and philosophers took to be fundamental, and it is precisely those shifts that must be set aside if Bohr's views are to be understood on their own terms. For that reason, the remainder of this chapter returns to the beginning of Bohr's career, before the later dichotomies between realism and anti-realism, ontology and epistemology, or locality and nonlocality had come to dominate foundational discussion. Only by reconstructing the original problems Bohr was addressing can we properly evaluate both the ambitions and the limitations of his philosophy of physics.

Bohr's philosophical writings have often been read either as expressions of epistemic caution or as signs of a retreat from the classical ideal of physical explanation. On both readings, complementarity appears as a kind of limitation: a reminder of how little can be known about the quantum world, or of how far physics has drifted from its earlier ambitions. The perspective developed in this essay is different. Bohr's concern was not primarily with the limits of knowledge, but with the conditions under which physical descriptions can be given unambiguous meaning. Complementarity, as he understood it, was not a concession to subjectivity, but an attempt to preserve objectivity in a situation where familiar classical concepts could no longer be jointly applied.

2 Bohr's life and times

Niels Bohr was born in 1885 in Copenhagen, Denmark, at the height of what later came to be called the Modern Breakthrough in Scandinavian culture. Denmark was still formally a Lutheran country, but its intellectual life was undergoing rapid secularization. New universities, laboratories, and research traditions were taking shape, even if Danish science remained smaller in scale and less continuous than that of its larger European neighbors. Bohr grew up in a culture that combined scientific ambition with a strong tradition of philosophical reflection[2] — an inheritance that would shape his entire career.

Bohr's doctoral dissertation on the electronic theory of metals was technically competent but gave little hint of what was to come.[3] The decisive turn occurred in

[2]The Danish philosopher Rasmus Nielsen (1809-1884) had an elaborate philosophy of science that engaged in detail with mathematics, physics, chemistry, biology, and psychology. He was the teacher of both Bohr's father, Christian, and of Bohr's philosophy teacher, Harald Høffding (see Halvorson, 2026).

[3]Bohr's writings have been collected in *Niels Bohr: Collected Works*, 13 vols. (Amsterdam: North-Holland/Elsevier, 1972–2008). His philosophical essays appear, in English translation, in

Manchester, where he worked with Ernest Rutherford. There, in 1913, Bohr proposed a bold theory of atomic structure: atoms do not obey the laws of classical mechanics and electromagnetism in all circumstances, but are governed by discrete quantum conditions that sharply limit what can be said about their motion. With this proposal, Bohr placed a question mark over the classical ideal of a fully picturable, continuously evolving physical world.

Bohr's theory, first published in 1913, attracted immediate attention. Some physicists regarded it as ingenious but ad hoc, while others saw in it the beginnings of a deeper transformation. Over the next decade, researchers across Europe attempted to refine, extend, or replace Bohr's model. Only in the period from roughly 1925 to 1927 did these efforts coalesce into what we now call quantum mechanics. During those years, Bohr's institute in Copenhagen became a focal point for the emerging field. Young physicists such as Werner Heisenberg and Wolfgang Pauli passed through its doors, drawn not only by technical problems but by Bohr's distinctive way of thinking and talking about them.

As quantum mechanics matured, it became an extraordinarily effective formalism — one that could be used to generate precise predictions without much understanding of the underlying processes. Bohr, however, never believed that the theory merely added new tools to physics. He was convinced that it forced a fundamental rethinking of what it means to describe nature at all. He often spoke of "the epistemological lesson of quantum mechanics," and he introduced the term "complementarity" to express the idea that mutually exclusive modes of description may each be necessary for a full account of physical phenomena. For Bohr, this was not a technical slogan but a general insight into the structure of scientific knowledge.

The roots of this outlook lay not only in physics, but in Bohr's upbringing. He was raised in a deeply intellectual household that served as a gathering place for conversation across disciplinary and cultural lines. His father, Christian Bohr, was a distinguished physiologist; his mother, Ellen Adler Bohr, came from a prominent Jewish family with strong ties to scholarship, philanthropy, and civic life. Although Bohr was raised in a largely secular environment, this background placed him at the intersection of different intellectual traditions and social worlds. Visitors to the Bohr home included figures such as the philosopher Harald Høffding and the physicist Christian Christiansen, and discussion there was marked by openness,

four volumes: *Atomic Theory and the Description of Nature* (1934), *Atomic Physics and Human Knowledge* (1958), *Essays 1958–1962 on Atomic Physics and Human Knowledge* (1963), and *The Philosophical Writings of Niels Bohr*, vol. IV, ed. J. Faye and H. Folse (1998).

seriousness, and a willingness to entertain competing viewpoints — traits that would later become hallmarks of Bohr's scientific style.

In Denmark today, Bohr remains a towering cultural figure. His bust stands outside the main building of the University of Copenhagen, and its most modern scientific complex bears his name. The question for us, however, is whether Bohr sets an example that we might want to follow.

§§

There are enormously many relevant factors in the background to Bohr's development of his philosophical views about physics. His family background, education, and cultural environment are all relevant, as are the developments that occurred in physics in the years that Bohr was active. It won't be useful to debate about which influences were most important — which would be just a specific version of the "nature versus nurture" debate. My goal here is just to help the reader form an accurate picture of Bohr's way of thinking.

One key development that should be named here is the back-and-forth between wave and particle theories that occurred between 1900 and 1927. Advances in experimental techniques brought it about that physicists had an enormous amount of new phenomena that needed to be understood; and some of it seemed best understood as the result of particles moving and banging into each other, while other experimental evidence seemed best understood as the result of waves being superposed on top of each other. The quantum hypothesis introduced by Max Planck and sharpened by Albert Einstein showed that light sometimes behaves as if it consists of localized quanta, while the continued success of wave optics in explaining interference and diffraction made it equally clear that a purely particle-based description was inadequate. Rather than resolving this tension, subsequent developments made it unavoidable: experiments and theoretical analyses increasingly demonstrated that the applicability of wave or particle concepts depended on the conditions under which phenomena were observed.

This lesson became decisive when the same duality was extended to matter itself. Following Louis de Broglie's proposal that material particles possess wave-like properties, quantum theory developed into distinct but formally equivalent frameworks — most notably Werner Heisenberg's matrix mechanics and Erwin Schrödinger's wave mechanics — each of which made essential use of different classical concepts. By 1927, it was no longer plausible to regard either waves or particles as merely provisional models awaiting replacement by a single, more complete picture. It was this situation that led Niels Bohr to his doctrine of complementarity: the claim that mutually exclusive descriptions are not signs of theoretical failure, but reflect the conditions under which classical concepts can be unambiguously applied in quantum physics.

In his 1913 papers, Bohr explained the stability of atoms by assuming that transitions between physical states are not continuous, but occur in discrete "leaps." At the time, he does not seem to have fully appreciated how deeply this assumption conflicted with the classical ideal of causal description. Over the following years, however, Bohr came to see that quantum jumps resist any account in which individual physical processes are represented as localized events in spacetime, governed by strict conservation of energy and momentum in each transition. Bohr's response to this tension was the correspondence principle: quantum theory must be constrained so that its predictions converge with classical physics in the limit of large quantum numbers (Bohr, 1918). The principle did not resolve the conflict between continuity and discontinuity, but it expressed Bohr's conviction that classical concepts — including causal ones — could not simply be discarded.[4]

The Bohr–Kramers–Slater (BKS) theory of 1924 brought this tension to a head (Bohr, Kramers, and Slater, 1924). Bohr and his collaborators sought to retain a wave-based picture of radiation while avoiding Einstein's suggestion that light consists of localized particles. The price was the abandonment of strict conservation of momentum and energy in individual processes. The BKS theory was quickly disconfirmed by the Bothe-Geiger experiment, but it played an important role in Bohr's thinking nonetheless. It convinced him that neither classical waves nor classical causality could simply be carried over into the quantum domain. Classical causality could be maintained — but only at the cost of renouncing any unambiguous spatiotemporal description of individual atomic processes.

The failure of the BKS theory in 1924 marked Bohr's last personal attempt to unify the diverse strands of the "old" quantum theory. In the period that followed, he would increasingly occupy a conceptually guiding and supervisory, rather than

[4]For interpretations emphasizing the continuity of Bohr's views on causality through the correspondence principle, see (Folse, 1985; Faye, 1991). Folse in particular argues that Bohr never abandoned causality tout court, but sought to reformulate it as a methodological constraint compatible with quantum discontinuities. Howard develops a closely related reading on which Bohr's appeal to classical causal concepts reflects constraints on description rather than ontological commitments (Howard, 1994).

visionary, role. The visionaries were Schrödinger and Heisenberg. The latter began his postdoctoral work in Copenhagen in 1924, and already in the summer of 1925, he came upon the idea of representing "observable quantities" via the new device of matrices — thus the theory of matrix mechanics.

Heisenberg's radical new idea of a predictive algorithm without an underlying description of reality was not universally welcomed. Schrödinger, for one, found himself "repelled" by the lack of visualizability in Heisenberg's matrix mechanics.[5] With a completely different vision for the future of physics, he introduced wave mechanics, offering a formally distinct but (empirically) equivalent framework that posed new questions about the interpretation of the quantum formalism and the relations between competing representations. Heisenberg, in turn, was dismissive: "The more I think about the physical part of Schrödinger's theory, the more disgusting I find it," he wrote to Pauli, calling Schrödinger's claims to physical insight *Mist*.[6] The visions of Heisenberg and Schrödinger came to a direct clash in the fall of 1926 when the latter delivered a series of lectures in Copenhagen — an event that Heisenberg recollects in detail (albeit with some partiality) in his book *Der Teil und das Ganze* (Heisenberg, 1969).

The winter of 1926–27 marks the turning point, though the historical record is hazy, as Bohr and Heisenberg carried on their discussions face-to-face rather than through recorded correspondence. In early 1927, Heisenberg began working out what would become the uncertainty relations. Through a thought experiment involving a hypothetical gamma-ray microscope, he argued that any attempt to measure an electron's position with greater precision would necessarily disturb its momentum, and vice versa. At the crucial moment when Heisenberg was developing these ideas, Bohr was away on a skiing holiday in Norway; it was during this break that Heisenberg sent a fourteen-page letter outlining his new principle to Pauli, then a lecturer at Hamburg (Heisenberg, 1979; Cassidy, 1992).

When Bohr returned and read Heisenberg's manuscript, he reacted with marked intensity. Although he accepted the formal relations themselves, he strongly objected to Heisenberg's interpretation of them as expressing simple limitations on what can be known about a quantum system due to measurement disturbance (see Pais, 1991, 303ff). For Bohr, Heisenberg's uncertainty relations were a special case of something more fundamental: an indeterminacy built into the very framework of quantum mechanics (Jammer, 1974, ch. 3). The issue was not merely that measurement

[5]Schrödinger to Wilhelm Wien, October 21, 1926. See Cassidy (1992, p. 228).
[6]Heisenberg to Pauli, June 8, 1926, in Hermann, Meyenn, and Weisskopf (1979, p. 328).

disturbs a pre-existing value, but that certain pairs of physical quantities — position and momentum, energy and time — cannot be simultaneously well-defined at all (Hilgevoord and Uffink, 2024). On Bohr's view, the experimental arrangement does not just limit our knowledge; it determines which concepts are applicable in the first place (Cassidy, 1992, pp. 226–236). What followed was a series of unusually tense discussions between the two, in which Bohr pressed Heisenberg to reconsider the role of the experimental arrangement and the conditions under which physical quantities can be meaningfully defined. This episode marks one of the clearest early points of divergence between Bohr and Heisenberg over the interpretation of quantum mechanics.

A close study of Bohr's manuscripts from the summer of 1927 shows the idea of complementarity beginning to take shape.[7] Given the apparently dramatic implications of the idea — an impression later reinforced by Bohr's own choice of the yin-yang symbol for his coat of arms — there has been considerable scholarly effort devoted to tracing its origins. Some have sought its roots deep in Immanuel Kant's philosophy (see Kaiser, 1992; Cuffaro, 2010); others have portrayed it as a strategic rhetorical move designed to consolidate Copenhagen orthodoxy (see Beller, 1999, ch. 11–12).

But there is a simpler reading: ideas closely related to complementarity were, so to speak, already in the air in Copenhagen, and they came to function less as a doctrine than as a lens through which Bohr interpreted phenomena — both the first-order experimental phenomena themselves and the second-order phenomenon of how other physicists were understanding them. Already in 1910, while writing his PhD thesis, Bohr experimented with the idea of representing distinct "planes of objectivity" by means of Riemann surfaces.[8] Long before 1927, then, Bohr was already receptive to the thought that certain domains of experience resist integration into a single, unified description. The broader idea that objectivity requires contextually anchored forms of description is also clearly present in the work of Harald Høffding, and earlier still in that of Rasmus Nielsen.

[7]The first dated manuscript using the language of "complementary aspects" is from July 10, 1927; see De Gregorio (2014).

[8]Niels to his brother Harald: "emotions, like cognition, must be arranged in planes that cannot be compared." June 26, 1910. The remark is cited in David Favrholdt, "General Introduction: Complementarity beyond Physics," BCW vol. 10 (1999), p. xxix. See also (Petersen, 1963).

3 Complementarity

3.1 The basic idea

The idea behind complementarity codifies a fact of life that we are all familiar with.

1. What you can see (or know) depends on where you are.
2. Human beings have some range of freedom to move from place to place.
3. Nobody can be in every place at one time.

These three facts together have two simple epistemological consequences. First, a person's knowledge is, at any given time, limited. Second, a person can always gain more knowledge.

The formulation just given is mine, but I believe it faithfully captures the outlines of Bohr's thought. And Bohr himself did not present complementarity as a novel idea, or as a sort of Copernican revolution. In fact, he presented it as a natural generalization of the thought process that began in early modern physics, and that had reached its highest point so far in Einstein's theory of relativity. What's more, Bohr believed that complementarity, as a general fact of our epistemic situation, was already familiar from the phenomena of introspection.

> While in the early stages of physical science one could directly refer to such features of daily life events which permitted simple causal account, an essentially complementary description of the states of our mind has been used since the origin of language. In fact, the rich terminology adapted to this purpose does not point to an unbroken course of events, but rather to separate mutually exclusive experiences reminding of the complementary phenomena in atomic physics. Just as these phenomena for their definition demand different experimental arrangements, the various psychological experiences are characterized by different placings of the separation between the content on which attention is focused and the background indicated by the word 'ourselves'. (Bohr, 1955a, p. 813)

The point is easier to grasp with concrete examples. Consider deliberation and decision: as long as one is weighing alternatives, one has not yet decided; but in the moment of decision, the deliberation is over — not because it has become unnecessary, but because the act of deciding forecloses the stance of weighing.[9] Or consider the attempt to catch oneself in the act of thinking. William James — whose work Bohr knew through Høffding — compared introspective analysis to "seizing a spinning top to catch its motion, or trying to turn up the gas quickly enough to see how the darkness looks" (James, 1910, pp. 243–244).[10]

What was new, in Bohr's view, was the discovery that complementarity is relevant even in physics — a domain where it had long been assumed that the subject-object line could be fixed once and for all.[11] Many philosophers had taken physics to aim at a description of how things are "in themselves," independently of any particular standpoint or conditions of observation. Bohr himself emphasized that this aspiration had functioned as a guiding presupposition of classical physics:

> The feature which characterizes the so-called exact sciences is, in general, the attempt to attain to uniqueness [Eindeutigkeit] by avoiding all reference to the perceiving subject. (Bohr, 1934b, pp. 96–97)

Faced with the apparent paradoxes of quantum physics, Bohr arrived at the conclusion that Eindeutigkeit could be saved by taking explicit account of the "conditions of description," e.g. of whether the described system was taken to be isolated or not. The goal of complementarity was precisely to eliminate reference to the perceiving subject.

3.2 Causality and conservation

For Bohr, causality was not primarily a metaphysical thesis about how the world must unfold, but a methodological ideal rooted in classical physics itself. It was expressed most clearly in the strict application of conservation laws to isolated systems, and it presupposed a form of spacetime description in which individual physical processes could be sharply delineated. It was precisely this conjunction — of causal conservation and spacetime picturability — that quantum theory would eventually force apart.

In this sense, Bohr used the term "causality" in a precise and somewhat idiosyncratic way. He took the "law of causality" to be paradigmatically expressed by the

[9]Favrholdt (2015) presents the point in greater detail. Remarkably, Søren Kierkegaard treats deliberation and decision as mutually exclusive states of mind (see Halvorson, 2023), and his views exercised enormous influence on Høffding.

[10]For more on Bohr's use of analogies from psychology, see (Jacobsen, 2025).

[11]"In the mechanical conception of nature the subject-object distinction was fixed." (Bohr, 1958, p. 173)

conservation of momentum: in any closed system, the total momentum remains constant over time. This principle underwrites the most familiar forms of causal reasoning in physics. In the case of an ordinary collision, for example, knowledge of the initial momenta allows one to infer the final momenta of the colliding bodies, even when some aspects of the interaction are not directly observed. The same style of reasoning lay behind early twentieth-century successes such as Rutherford's analysis of scattering experiments, where conservation of momentum made it possible to draw conclusions about unseen atomic nuclei, and later Compton's explanation of photon-electron collisions.

The principle also has a negative application: if, at the end of a process, the sum of the momenta of the observed parts fails to equal the total momentum at the start, then something has been left out of the description. Even before Pauli's famous proposal of the neutrino in late 1930, this form of reasoning was a standard tool of causal explanation in physics. For Bohr, it was precisely this tightly constrained use of conservation laws — applied to isolated systems and individual processes — that defined what it meant to give a causal account.[12]

Bohr's considered opinion was that the law of causality is not violated in the quantum domain, and that it falls under the more general principle of complementarity. But it took him more than a decade to get clear on this issue.

3.3 Position and momentum

Position and momentum are typically taken to be the quantities that are individually necessary and jointly sufficient to determine the state of a physical system. Bohr argued, however, that no system can really have both a precise position and a precise momentum at the same time. His explanation for why these quantities are complementary was not, however, based on reasoning about what can be measured, or verified, or known. Rather, Bohr claimed that the conditions necessary for defining location are mutually exclusive with the conditions necessary for defining momentum.

> We have in each experimental arrangement suited for the study of proper

[12]Advocates of Bohmian mechanics will object that their theory restores a spacetime picture with definite particle trajectories. Bohr would have replied that trajectories alone do not suffice for causality: what is required is the possibility of isolating a system so that momentum can be meaningfully attributed and conservation laws applied to individual processes. Since Bohmian trajectories are inseparable from a nonlocal guiding wave tied to the entire experimental context, Bohr would not have regarded this as meeting the traditional conditions for causal description.

quantum phenomena not merely to do with an ignorance of the value of certain physical quantities, but with the impossibility of defining these quantities in an unambiguous way. (Bohr, 1935, p. 699).

The whole situation in atomic physics deprives of all meaning such inherent attributes as the idealizations of classical physics would ascribe to the object. On the contrary, the proper role of the indeterminacy relations consists in assuring quantitatively the logical compatibility of apparently contradictory laws which appear when we use two different experimental arrangements, of which only one permits an unambiguous use of the concept of position, while only the other permits the application of the concept of momentum defined as it is, solely by the law of conservation. (Bohr, 1937, p. 293)

Here Bohr is making several philosophical moves at once. First, he is assuming that certain contingent physical conditions must hold for human beings to use phrases like "the location of x is y" in a well-defined fashion. In particular, he assumes that "the location of x is y" is defined in a context of communication only if the speaker and listener agree on an implicit frame of reference. If one person says "the electron is located at q", while the second person doesn't know how to relate q to her own situation, then no communication between them has occurred.

Bohr similarly believes that the definition of the concept of momentum depends on certain physical conditions holding. Here we must note that Bohr does not think that momentum is nothing more than $m\dot{\mathbf{x}}$, mass times the first derivative of position, as that would trivially falsify his claim. Instead, Bohr thinks that the concept of momentum is defined by the role it plays in the law of conservation of momentum:

If a system S is isolated, then its momentum is conserved.

If a system is essentially open to its environment — as would be the case with an entangled system — then the concept of momentum cannot be defined.

Bohr's reasoning for the complementarity of position and momentum can be schematically reconstructed as follows:

1. A spacetime description employing the concept of position presupposes the existence of a fixed reference frame.

2. In such a description, the object system cannot be sharply separated from the physical reference frame; together they form an indivisible whole for the purposes of the phenomenon under investigation.
3. By treating the reference frame as fixed, any exchange of momentum between the object and the frame is deliberately excluded from the description.
4. As a result, the conservation of momentum cannot be unambiguously applied to the object system alone.

The argument depends not only on special features of position and momentum, but on Bohr's more general insistence that, in quantum phenomena, the object and the measuring arrangement together constitute a single physical situation. In more contemporary parlance, the key issue here is that the object system is entangled with the agencies of observation.[13]

Even if one finds Bohr's argument here plausible, it only establishes the complementarity of position and momentum. It wouldn't directly explain why other quantities, such as time and energy, or spin-y and spin-z, that are complementary to each other. In contemporary presentations of QM, one doesn't need to guess at which quantities are complementary to each other, because it's built into the formalism of non-commuting matrices. Of course, physicists have to decide which matrices represent which quantities, so they are still making substantive judgments about which quantities are complementary to each other.

Bohr's complementarity amounts to the claim that modern physics' ideal for explanation consists of two components that can fall apart from each other. The first component is localizability in space and time, and the second component is causal explanation. It shouldn't be too surprising that we can have the latter without the former. For example, human beings apply cause-effect reasoning to understanding each other, without much interest in spatial location. I might say that Adam went to the store because he was hungry, but I don't have much of a stake in where his hunger is located. It is perhaps more surprising that objects can exist in space and time without standing in causal relations. But here we should remember what happened to causality in the wake of Descartes' proposal to explain everything in terms of the motion of matter. I will not argue here that these developments were logically inevitable, but recall that Descartes himself believed that causal relations

[13]For Bohr's explicit arguments connecting spacetime description with the exclusion of momentum exchange, see Bohr (1937, pp. 291–292) and Bohr (1948). On the interpretation of Bohr's "wholeness" as a form of entanglement, see Howard (2007).

between mind and matter were a mystery; and his reasoning was extended by Hume and Malebranche to causal relations between physical objects. The history of modern natural philosophy gives ample reason to think that the reductionistic "matter in motion" picture does not sit comfortably with causality.

3.4 Einstein's arguments against complementarity

Einstein had been involved with "the quantum hypothesis" from its very beginning. By the 1920s, however, he was mostly playing the role of a critical bystander, who would occasionally try to move the discussion in a new direction. For example, in 1930, at the Sixth Solvay Conference, Einstein proposed the famous "photon box," which was intended to show that the time-energy uncertainty relation could be bypassed. Bohr famously replied that Einstein had failed to take into account general-relativistic time dilation—a response that experts still regard as controversial.[14]

Einstein's most famous contribution to the debates about the foundations of quantum mechanics is his 1935 paper with Podolsky and Rosen (Einstein, Podolsky, and Rosen, 1935). In this paper, EPR describe a pair of quantum systems that are spatially separated but strictly correlated in both position and momentum. They show that a position measurement on the first system allows one to predict the position of the second system with certainty, and similarly for momentum. They conclude that, since distant measurements cannot change the state of affairs, the second system already had a definite position and momentum — a fact not captured by the quantum state. Therefore, they argue, quantum mechanics is incomplete.

Bohr hastily replied to the EPR paper, producing a response that was later criticized in the harshest of tones by John Bell. Bell focused in particular on Bohr's claim that a measurement on one system involves "an influence on the very conditions which define the possible types of predictions regarding the future behaviour of the system" (Bohr, 1935). Bell complained that this talk of an "influence" was obscure, and that it appeared to substitute an epistemological shift — an influence on what can be predicted — for the sort of physical influence at a distance that EPR had argued must exist (see Bell, 1981). In Bell's view, Bohr was not so much answering the EPR argument as changing the subject.

But this diagnosis risks missing what Bohr took himself to be saying. When Bohr speaks of an "influence on the very conditions," he does not mean a causal

[14] See (Bohr, 1949) for his account of the debate. For critical discussion of this exchange, see (Dieks, 1999; Howard, 2007; Rovelli, 2021).

disturbance propagating to the distant system. Rather, he means that the context of description has changed. More concretely, the measuring apparatus has become entangled with the system in a different way, and this alters which correlations can be meaningfully attributed to it. The point is not that something has happened to the distant system, but that the joint system — object plus measuring context — now admits of a different articulation. On this reading, Bohr's reply is not an evasion of the locality issue, but a rejection of the assumption that physical properties can be specified independently of the experimental situation in which they are defined.

3.5 Complementarity beyond physics

In his later career, Bohr showed an increasing willingness to see complementary structures far beyond their original physical home. He explored their relevance to biological phenomena (Bohr, 1933), and he invoked complementarity in discussions of culture, religion, and politics (see Bohr, 1939; Bohr, 1953; Favrholdt, 1999). By this point, however, he was speaking to a dwindling audience. Younger physicists were preoccupied with the technical consolidation of quantum theory, while philosophers — especially in the United States — were increasingly absorbed by developments in formal logic and semantics. In retrospect, this divergence looks less like a failure of Bohr's ideas than a missed opportunity for dialogue: few were in a position to recognize the philosophical lineage Bohr was drawing on — shaped above all by Høffding and, more distantly, by Nielsen — or to engage seriously with his attempt to rethink the conditions of objectivity in physics from within that tradition.

Bohr's broader applications of complementarity are often dismissed as speculative overreach. But the rebuttals are rarely based on close engagement with what Bohr wrote about these issues, nor are they sensitive to the historical context in which he was working.

Since the seventeenth century, physical science had been guided by an ideal of mechanistic explanation: a phenomenon is explained by specifying the configurations of particles (or fields) at earlier times together with the laws governing their evolution. Within this framework there is no place for Aristotelian teleological explanations, according to which a phenomenon occurs *because* some outcome is intended or aimed at. Yet there were phenomena — most prominently those associated with biological life — that seemed resistant to purely mechanical treatment. Some scientists and philosophers concluded that living systems must involve additional elements of reality, often described as "vital forces."

This debate had deep roots in Danish intellectual life. Rasmus Nielsen lectured on mechanism and vitalism, and among his students were both Harald Høffding and Niels Bohr's father, the physiologist Christian Bohr (see Halvorson, 2026). The elder Bohr took a mediating position: physico-chemical analysis could go far, but the organism's purposiveness — its self-regulation, its development toward ends — required a vocabulary that mechanism could not supply. He did not infer vital forces, but he insisted that teleological description was indispensable. Høffding took a similar line, seeking to clarify the limits of mechanistic explanation without abandoning its scientific credentials.[15] Niels Bohr inherited this stance from both sides of his upbringing: the opposition between mechanism and vitalism is a false dichotomy. When mechanistic description breaks down, the answer is not a competing explanatory principle, but a clearer view of when mechanistic concepts apply and when they don't. By looking for broader applications of complementarity, Bohr was engaged in a kind of philosophizing that Wilfrid Sellars famously described as the attempt "to understand how things, in the broadest possible sense of the term, hang together, in the broadest possible sense of the term." This kind of wide-ranging thinking has recently become respectable again in philosophy of science, which has returned to many of the themes that engaged Bohr: the dependence of physical description on perspective, the conditions under which objectivity is secured, the role of concrete practices in fixing descriptive content. Current discussions of reductionism and anti-reductionism revisit questions Bohr was already grappling with—though usually without any awareness of the intellectual framework he inherited from Høffding and Nielsen. We shall return below to Bohr's positive vision of how the sciences hang together—a vision quite different from both the reductionism of the Vienna Circle and the fragmented ontologies now fashionable in some quarters.

4 Bohr's philosophy in general

Bohr had a philosophy. It was not a collection of slogans or a defensive posture adopted under pressure from Einstein. It was a worked-out view of the conditions under which objective description is possible—a view with deep roots in Danish thought and with implications that extend well beyond quantum mechanics. This is not to say that Bohr was always right, or always consistent. But he was facing real problems head on, and he brought serious intellectual resources to bear on them.

[15] See the section on "Sjæl og Legeme" in (Høffding, 1882), where he discusses the work of Claude Bernard. See also (Normandin, 2007).

Moreover, for Bohr—as for Høffding before him—it mattered that one's views hang together. Physics was not a compartment sealed off from the rest of life. A view about the conditions of physical description should cohere with one's views about knowledge, about language, about what it means to be a human subject in the world.

4.1 Subject and object

Bohr's most formidable critic was John Bell, the Irish physicist who began his diatribe in the 1960s. (Bohr died in 1962, and the two of them never met.) Bell had a remarkable talent for making Bohr's views seem implausible by baptizing them with catchy — and faintly derisive — names. Most famously, he reduced Bohr's nuanced talk of a movable boundary between subject and object to the phrase "the shifty split" (Bell, 1990).

Bell understood Bohr as claiming that every experiment must be described as having two parts: a quantum object and a classical measuring device. And Bell then pressed what appears to be entirely reasonable demands: First, why describe the measuring device as classical if it is made of quantum stuff? Second, where, exactly, is the line to be drawn between the quantum and classical worlds? If the split is a feature of the world, then its mobility would be problematic — it suggests arbitrariness, or worse, subjectivity.

But this diagnosis rests on a mislocation of the split. Bohr's "split" is not intended as division that a subject should apply among the objects that he is describing; it is the presupposed division between who is describing, and what is being described.[16] Once that is seen, Bell's worry loses its grip. What shifts is not the structure of the world, but what is taken to be part of the self that is describing, and what it taken to be a part of the object that is described.

Bohr claimed that the subject–object distinction is the fundamental problem of epistemology — an idea he inherited from Høffding, and one with deep roots in German idealism.[17] In Kant, the distinction between subject and object is

[16]For further discussion, see (Halvorson and Butterfield, 2023). There is no implication here that the self is "outside the world" or is non-physical. The split is not ontological; it is, rather, the way that the human brain makes sense of the world.

[17]". . . the relation between subject and object which forms the core of the problem of knowledge" (Bohr, 1934a). Modern philosophy of science begins with Hume's powerful skeptical arguments, and Kant's attempt to secure the rationality of scientific knowledge in their wake. German idealism's obsession with the subject-object problem was their attempt to fix problems with Kant's *Ding an Sich*.

fixed by the general structure of human cognition; in the idealist tradition that followed — especially in Johann Gottlieb Fichte — it becomes something that can shift with the standpoint one adopts and the activity one is engaged in. Bohr's most direct point of contact with these ideas was through Høffding, whose writings presented Kantian and post-Kantian philosophy in a sober, empirically minded form for a Scandinavian audience. What Bohr added to this tradition was a disciplined application of subject–object philosophy to a concrete problem: how to communicate, in an unambiguous way, what one is doing — and observing — in the laboratory.

It is in this spirit that Bohr often illustrated the movability of the subject–object distinction by means of simple analogies drawn from ordinary experience. As several of his collaborators later recalled, he would ask his listeners to imagine a person finding their way through a dark room with the aid of a stick. Depending on how the stick is used, the boundary between subject and object shifts in a perfectly natural way. When the stick is grasped firmly, its tip functions as an extension of the subject's sensory apparatus, and the effective boundary lies at the end of the stick. When the stick is held loosely, by contrast, the stick itself becomes something encountered — an object to be examined rather than a means of examination. In Oskar Klein's recollection, Bohr chose this example precisely to show that the distinction between subject and object is not fixed by the intrinsic nature of the things involved, but by the role they play within a concrete situation (Rozental, 1967).

The lesson Bohr intended to draw from this analogy was not that the subject-object distinction is arbitrary or merely psychological. On the contrary, the distinction is indispensable for any unambiguous description of experience. What the example brings out is that the location of the boundary is determined by functional considerations, namely by which parts of the physical situation are being used to define the conditions under which phenomena are observed. Classical physics could largely ignore this feature, since the boundary could be drawn in a stable and practically unproblematic way. Quantum mechanics, however, makes the contextual character of this distinction explicit and unavoidable.

4.2 Realism

Einstein and Bohr were both visionary scientists, and yet they disagreed frequently on the way that physics should go in the future. It is tempting to attribute their disagreements to a fundamental difference in worldview, and some writers have tried to characterize this difference by saying that Einstein was a "realist" while Bohr was an "antirealist". This way of classifying Bohr has by now even been adopted by contemporary physicists — primarily as a way of distancing themselves for Bohr. The Nobel laureate Steven Weinberg, for example, once remarked that he preferred a realist view to what he took to be Bohr's antirealism (Weinberg, 2017). Similarly, Jim Al-Khalili writes that

> Bohr argued that it is wrong to think that the task of physics is to find out how nature is — or to know the 'real essence of the phenomena' — but rather to concern itself only with what we can say about nature: the 'aspects of our experience'. . . .

He then goes on to say that, unlike Bohr, he sides with a realist view.

This coarse-grained classification of scientists as realist or antirealist is difficult to defend on historical grounds. Neither Einstein nor Bohr articulated philosophical convictions that can be straightforwardly mapped onto these categories. Moreover, it borders on slander to describe a historical scientist as an antirealist, since this suggests a lack of interest in discovering facts about reality. It is hard to see how such a charge could plausibly apply to Niels Bohr, who spent his entire career trying to understand the inner workings of atoms.

That said, Bohr did hold a comparatively humble view of human beings' capacity to understand domains for which their cognitive and conceptual resources were not originally adapted. He insists that the physicist must exercise great care when attempting to make true claims about domains that may differ in fundamental ways from the kinds of objects and processes encountered in everyday experience. But this is not a recommendation of blanket agnosticism about what lies "beyond our experience." On the contrary, Bohr thought that his "complementarity" approach provided precisely the means to extend our concepts beyond their original domains of application — while avoiding inconsistency.

The opposition between realism and antirealism is therefore a misleading lens through which to view Bohr's position. A more illuminating axis — one that more closely traces Bohr's own intellectual background — is the rejection of any attempt to collapse the distinction between subject and object at a fundamental level. From Poul Martin Møller through Søren Kierkegaard, Rasmus Nielsen, and Harald Høffding, Danish philosophers repeatedly resisted the Hegelian ambition to show how reflection could ultimately eliminate the standpoint of the reflecting subject — that there could be a description without a describer. The shared insight was not that reality depends on the subject, but that intelligible description does: one cannot step outside all perspectives and still claim to describe the world meaningfully.

Bohr inherits this picture in which there is no “ultimate subject” (see Favrholdt, 2015, Chap V). What is distinctive about Bohr is that he takes this philosophical stance as a practical recipe for how to think of the task of constructing and applying a physical theory. Quantum mechanics forces the physicist to confront situations in which the measuring apparatus and the measured system cannot be sharply separated, and where no single description can be taken to exhaust the physical situation. Rather than treating this as a reason to abandon objectivity, Bohr treats it as a reason to rethink what objectivity in physics requires.

Bohr’s proposal is that physics can be practiced consistently without assuming that any particular description — or any particular describer — provides a final, all-encompassing picture of reality. Instead, objectivity is secured through the mutual compatibility of different descriptions, each tied to well-defined experimental conditions, and each respecting the limits of its own applicability.

4.3 Free will

Physics tells us which courses of events are possible, and which are impossible. According to classical Newtonian physics, the state of the world at one time completely determines its state at all subsequent times — which would seem to preclude any form of human free will. But things seem to change with quantum physics, and the apparent breakdown of determinism in atomic processes seems to promise a way out of the classical opposition between freedom and causal necessity. But Bohr resisted this tempting line of thought. Although he had strongly positive views about human agency, he did not believe that developments in quantum physics themselves could decide questions such as free will or vitalism.

> I am far from sharing, however, the widespread opinion that the recent development in the field of atomic physics could directly help us in deciding such questions as ‘mechanism or vitalism’ and ‘free will or causal necessity’ in favor of the one or the other alternative. Just the fact that the paradoxes of atomic physics could be solved not by a one sided attitude towards the old problem of ‘determinism or indeterminism,’ but only by examining the possibilities of observation and definition, should rather stimulate us to a renewed examination of the position in this respect in the biological and psychological problems at issue. (Bohr,

1937, p. 295)

Quite to the contrary, Bohr believes that "the feeling of free will" is a necessary concomitant of human agency. More fundamentally, Bohr believes that recognition of humans' dual role as "spectator and actor" is the solution both of the free will problem and of the troubles at the root of quantum mechanics.

> Just the impossibility in introspection of sharply distinguishing between subject and object as is essential to the ideal of causality would seem to provide the natural play for the feeling of free will. (Bohr, 1937, p. 297)

The idea here is that an attribution of unbroken causal succession (recall the law of conservation of momentum) requires that the person making the description assumes that he is not interfering with the object being described. In other words, causality assumes that a line has been drawn between subject and object. However, acts of introspection present a problem for drawing such a strict line, and so the ideal of causality will often not be applicable in such situations.

A closely related idea can already be found in the work of Harald Høffding. In his psychological and ethical writings, Høffding repeatedly emphasizes that introspection resists the sharp separation between subject and object presupposed by causal explanation. When we turn reflective attention upon our own mental life, we do not encounter ourselves as detached observers standing outside the causal nexus, but rather as participants whose acts of attention are themselves part of what is being described. For this reason, Høffding argues, the ideal of strict causal determination—appropriate and indispensable in the natural sciences—cannot be straightforwardly extended to the inner life without distortion. It is precisely this impossibility of fully objectifying the self in introspection, Høffding suggests, that underwrites the persistent and unavoidable "feeling of freedom," even in a world governed by causal law (Høffding, 1882; Høffding, 1887, §§47–49). Bohr's remarks about the impossibility of sharply distinguishing subject and object in introspection thus echo a well-established line of thought in Danish philosophy, one that predates quantum mechanics and situates the free will problem at the level of description rather than metaphysical indeterminacy.

Unlike Bohr, Høffding seems to assume that causal determinism holds without exception from a standpoint outside experience — as it were, from a God's-eye point of view — even as he stresses that introspection resists a sharp separation of subject and object. The feeling of free will is thus treated as a feature of our first-person standpoint, compatible with a fully determined world in itself. In this respect Høffding's position is structurally similar to contemporary compatibilist views — such as that defended by Ismael (2016) or Rovelli (2013; 2023) — according to which the world is fully law-governed while agency and deliberation are understood as perspectival features of agents embedded within it.

Bohr, by contrast, never suggests that determinism reigns "in the last analysis." For him, causality is an ideal whose applicability depends on the possibility of drawing a clear subject–object distinction; where such a distinction cannot be made — even in principle — the demand for unbroken causal succession simply loses its sense. In this respect, Bohr's view goes beyond Høffding's compatibilism, replacing a globally valid causal order with a contextual conception of description.

While Bohr did not think that quantum physics proves the existence of free will, he nevertheless gave human choice a central role in his understanding of quantum mechanics. The key idea is that we cannot speak coherently about physical events at all until we first choose how we are going to describe them.

Bohr illustrates this point by analogy with relativity theory. In relativity, we must choose a frame of reference before we can say where things are or how fast they are moving, but that choice is essentially harmless: from any one frame, we can always reconstruct what the description would have been from any other frame, and the underlying reality is the same. Quantum mechanics, Bohr argues, is different in a crucial way. Here, the choice of descriptive framework is not reversible. If an observer chooses to describe a system in terms of its location, then the very conditions required to ascribe a definite momentum to that system are destroyed. Choosing a descriptive framework in quantum mechanics does not merely reveal an already-defined reality; it helps determine what can count as a physical fact at all. That is why Bohr saw our freedom to choose a mode of description as playing a genuinely constitutive role in physical reality.

It should be stressed, once again, that Bohr does not endorse global perspectivalism. In particular, he does not believe that contextual analysis provides the right framework for understanding all forms of human knowledge. On the contrary, he holds that in most everyday situations there is no need to keep track of contexts — that unambiguous communication is possible precisely because the relevant contextual distinctions can be ignored without loss.[18] The appeal to context is therefore

[18]Bohr makes this point explicitly in connection with Einstein's theory of relativity: in regimes where velocities are small compared to the speed of light, one may, for all practical purposes, treat a single reference frame as preferred.

not a general philosophical doctrine but a response to specific breakdowns in the conditions of description, and Bohr's insistence on context marks a limit to the applicability of certain concepts rather than a rejection of objective knowledge as such.

4.4 The unity of science

Bohr was, in many respects, a person of his culture — in this case, the Danish intellectual milieu of the early twentieth century. He was an empiricist, but without the narrowness or doctrinaire spirit often associated with eighteenth-century British empiricism. He sought systematic understanding, but without the rigid hierarchies of German metaphysics. Bohr's temperament was instead eclectic and experimental: he was willing to borrow, adapt, and revise whatever conceptual tools were needed to make sense of a concrete problem. He was, in this sense, a pragmatist — not because he dismissed truth, but because he refused to treat it as something that could be grasped once and for all. In the spirit of Søren Kierkegaard's famous praise of Gotthold Ephraim Lessing, if God were to offer truth in one hand and the lifelong striving for it in the other, Bohr would have chosen the latter.

These broad characteristics of Bohr's thought also characterize his view of the relationship between the different sciences. Bohr famously said that "life" cannot be explained, i.e. cannot be reduced to physics: "the very existence of life must in biology be considered as an elementary fact, just as in atomic physics the existence of the quantum of action has to be taken as a basic fact that cannot be derived from ordinary mechanical physics" (Bohr, 1933, p. 422). This claim might make it seem that Bohr is a defender of a layered picture of reality — a sort of anti-reductionism. But that makes Bohr out to be more of a metaphysician than he was. Bohr never tried to justify his methodology by any a priori ontological picture, neither a reductionist ontology, nor an anti-reductionist ontology. Like Høffding before him, he regarded questions about ultimate ontology as above his paygrade—not meaningless, but just not the most pressing questions on his research agenda.

In fact, Bohr's practice as a scientist — and the way he ran his Institute — suggests that he regarded the individual sciences not as autonomous layers stacked on top of one another, but as parts of a single, living intellectual enterprise. The Institute for Theoretical Physics in Copenhagen was never conceived as a narrowly disciplinary space. It was a place where physicists, chemists, and, increasingly, biologists could work side by side, sharing techniques, concepts, and experimental problems. At the most practical level, this openness bore fruit in work such as George de Hevesy's studies of radioactive isotopes, carried out in close proximity to Bohr's group. That work, which later earned de Hevesy the Nobel Prize in Chemistry, laid the foundations for tracer methods that are now indispensable in biology and medicine, including modern nuclear imaging techniques.

Examples like this help to dispel the idea that Bohr's resistance to reductionism rested on any doctrine about irreducible "levels" of reality. What unified the sciences, in Bohr's eyes, was not a single foundational theory to which all others must be reduced, but a shared commitment to intelligibility, communicability, and experimental control. Physics did not sit beneath chemistry or biology as their metaphysical ground; rather, it provided a repertoire of concepts, methods, and instruments that could be taken up, transformed, and redeployed in new contexts. Conversely, developments in chemistry and biology continually pressed physics to refine its own conceptual resources.

This way of thinking also helps to explain Bohr's repeated use of the word unity in the titles of his lectures and essays — most notably in "The Unity of Knowledge" (Bohr, 1955b; Bohr, 1961). What he had in mind was not a completed system or a finished synthesis, but an ongoing process of mutual adjustment between different forms of inquiry. The unity of science was something to be achieved in practice, through dialogue and cooperation across disciplines, rather than something to be read off from a prior metaphysical blueprint.

It is therefore important not to confuse Bohr's talk of unity with either the reductionist ideal of the Vienna Circle or the now-common view that the unity of science consists in showing how all higher-level descriptions are fixed by microphysical facts. For the logical empiricists, unity meant translation into a single privileged language, ideally that of fundamental physics; for many today, it means grounding all other sciences in microphysics. Bohr rejected both pictures. He did not deny the central role of physics or the deep interconnections among the sciences, but he resisted the idea that unity requires reduction, logical reconstruction, or the elimination of autonomous modes of description. Unity, for Bohr, was something achieved in practice: through the coordination of distinct forms of description, each tailored to its own domain, constrained by clarity and empirical accountability, and capable of being brought into coherent relation without being forced into a single mold.

5 Conclusion

I have tried to sketch a picture of who Niels Bohr was as a physicist and a thinker. In this picture, Bohr appears neither as a mystic obscurantist nor as a technocratic instrumentalist, but as a deeply humane and philosophically reflective scientist. He understood science as a fundamentally human enterprise — one that aims not merely at prediction and control, but at understanding. For Bohr, the value of science lay not only in its capacity to control, or extract value from nature, but also in its ability to orient us intellectually and, in a modest way, to elevate the human spirit.

It is therefore a historically consequential mistake that some prominent defenders of science in the late twentieth century came to regard Bohr as a symbol of science's supposed retreat from clarity, realism, or rationality. In positioning themselves against Bohr, they believed they were standing up for science against philosophical confusion or cultural relativism. In fact, they were directing their criticism at one of science's most thoughtful public advocates — someone who took both the intellectual and the ethical dimensions of scientific practice seriously.

Our present historical moment makes this misreading especially consequential. Science today is more thoroughly instrumentalized than ever before. It is increasingly valued for its role in driving technology, optimizing systems, and generating wealth. In the process, forms of inquiry are encouraged in which judgment, interpretation, and even explanation are progressively delegated to machines, frequently at the cost of scientists' own understanding of the systems they study. For some, these developments have delivered extraordinary benefits. But for many others, scientific expertise is experienced less as a shared human achievement than as a distant force — one that structures life, labor, and opportunity in ways that are opaque and inflexible. From this perspective, the triumph of science might seem to enable new and subtler forms of serfdom.

Bohr worried about this possibility long before it became a familiar theme. He insisted that science could not be divorced from the conditions under which it is communicated, taught, and understood. Clarity, for Bohr, was not a matter of stripping away the human point of view, but of acknowledging it honestly. Objectivity did not require the elimination of the subject, but a careful articulation of the conditions under which meaningful description is possible.

In this sense, Bohr was a prophet of sorts — not because he foresaw the details of our technological future, but because he understood that science is something human beings do for the sake of understanding, and that a science no one understands has lost its point. If we are uneasy today about the place of science in our collective life, that unease is not a reason to move beyond Bohr. It may be a reason to listen to him again.

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