

# Constructing the Myth of the Copenhagen Interpretation

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## 1. Introduction: The Historiographical Problem of the Copenhagen Interpretation

The difficulties surrounding the interpretation of quantum mechanics were apparent from as early as the mid-1920s, when the theory first took mathematical form, in the shape of the matrix mechanics worked out by Heisenberg, Born and Jordan, and Schrodinger's wave mechanics. Between 1925 and 1927 a number of leading physicists had already recognised that quantum mechanics called for a drastic revision of the very foundations of traditional physics and epistemology. According to the now familiar historical account, this period of interpretation of the new theory was finally worked out in discussions between Bohr and Heisenberg in Copenhagen in 1927. The viewpoint that emerged from these discussions, which would later become known as the 'Copenhagen interpretation', was quickly accepted by Pauli, Dirac, Born, Jordan and Ehrenfest as having finally resolved the paradoxes of quantum theory. As Dugald Murdoch explains:

By the end of 1927 the Copenhagen interpretation had established itself as the dominant interpretation of quantum mechanics. Central to that interpretation were the ideas of Bohr, the main outlines of which were presented at the Centennial Conference in Como in September 1927 and the Fifth Solvay Conference in Brussels in October that same year. At the latter conference Einstein first voiced his doubts about the newly emerging orthodoxy (Murdoch, 1994, p. 303)

Here Murdoch gives the standard view found in much of the literature. The 'Copenhagen interpretation of quantum mechanics', so this story goes, quickly established itself as the orthodox view, in spite of the persistent criticisms of physicists such as Einstein, Schrödinger, Planck and von Laue. But what exactly is the Copenhagen interpretation? One of course might appeal to the uncertainty principle or the statistical interpretation of the  $\psi$ -function. But what does it tell us about the underlying reality of the quantum world, or our knowledge of that reality? This question turns out to be far more difficult to answer than might be imagined, and opinions on this differ. As John Cramer explains, "Despite an extensive literature which refers to, discusses, and criticizes the Copenhagen interpretation of quantum mechanics, nowhere [in the writings of the founders of quantum mechanics] does there seem to be any concise statement which defines the full Copenhagen interpretation" (Cramer, 1986, p. 649).

Here lies the central problem facing the historian wishing to make sense of the emergence of the orthodox interpretation of quantum mechanics. While the writings of physicists like Bohr, Born, Heisenberg, Pauli, Dirac, Jordan and von Neumann are generally thought to form the basis of the Copenhagen viewpoint, they seem to have been written more in what Heisenberg referred to as the “*Kopenhagener Geist*”, rather than providing a definite unified agreement on the interpretation of the theory (Heisenberg, 1930, x).

Bohr’s ideas are widely regarded as the central to the Copenhagen interpretation. To quote Murdoch: “Bohr’s construal of quantum mechanics established itself as the basis of the orthodox interpretation – the ‘Copenhagen interpretation’” (Murdoch 1987, p. 179). However, as has been repeatedly pointed out, Bohr’s writings were often elusive, tending to leave different readers with different impressions of his views. Although many of the leading physicists of the 1930s, including Pauli, Heisenberg, Jordan and Rosenfeld became enthusiastic supporters of the Bohr’s viewpoint, which he termed ‘complementarity’, as we shall see, opinions differed widely as to how to understand the notion both epistemologically and ontologically (Kragh, 1999, p. 211; Jammer, 1974, p. 202). Indeed, over the last thirty years, it has become increasingly apparent that the founding fathers of quantum mechanics were in fundamental disagreement about what the so-called Copenhagen interpretation of quantum mechanics. As Mara Beller puts it:

Full acknowledgement of its contradictions casts great doubt on the existence of a common basis for the “Copenhagen interpretation”, and perhaps on the notion of a conceptual framework in general... It is difficult to find a common denominator, any idea, commitment which was not broken at one time or another. This is not to say there was no consensus about radical departure necessitated by the quantum theory. It is the exact and consistent agreement about what would constitute such a departure that was lacking (Beller, 1999, pp. 187-8).

Notions like wave-particle duality, indeterminism, and the indispensability of the classical concepts are frequently cited as part and parcel of the Copenhagen interpretation, yet as Mara Beller points out, “none of them commands unwavering commitment even from Bohr’s closest collaborators” (Beller, 1999, pp. 187). Dirac and Wigner, for example, found nothing substantially new or enlightening in Bohr’s notion of complementarity, and instead saw Heisenberg’s paper on the uncertainty principle as the decisive turning point in resolving the difficulties that had plagued physicists throughout the 1920s.<sup>1</sup> This attitude stands in sharp

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<sup>1</sup> In his interview with Kuhn, Dirac admitted: “I never liked complementarity ... It does not give us any

contrast with physicists like Rosenfeld, Jordan and Pauli, who insisted that Bohr's idea of complementarity was indispensable to any proper understanding of the foundations of quantum mechanics (Pauli, [1950] 1994; Jordan, 1944; Rosenfeld, [1953] 1979).<sup>2</sup>

The difficulties which inevitably emerge from the attempts to make sense of the Copenhagen interpretation stem from the fundamental disagreements which were never settled among the founders of quantum mechanics in the 1930s and which emerged with somewhat greater clarity in the 1950s and 1960s. This has led to the view, which finds its clearest expression in the work of Mara Beller that we should deny “the very possibility of presenting the Copenhagen interpretation as a coherent philosophical framework” (Beller, 1999, p. 173). One finds a similar point of view in the work of Erhard Scheibe (1973, p. 9) and John Hendry (1984, p. 1) and more recently in papers by Catherine Chevalley (1999) Don Howard (2004). However, recognition of this point raises a number of important questions, which have been only touched on, but to my knowledge have not as yet received any systematic treatment: How are we to account for the appearance (or should we say illusion) of consensus achieved in the absence of any genuine agreement between key protagonists? How did so many different philosophical viewpoints come under the banner of the ‘Copenhagen interpretation’? And, what purpose or what philosophical or ideological agendas did the construction of the myth of the “Copenhagen interpretation” serve? While Mara Beller's book *Quantum Dialogue* provides a good starting point for exploring these questions, there is I believe still much more to be said on the subject.

This paper serves as a preliminary exploration of these questions in the hope of gaining a better understanding of what Don Howard has appropriately called the ‘myth’ of the Copenhagen interpretation. Here I want to pursue the idea, which is to be found in the writings of Chevalley and Howard, that while the *theory of quantum mechanics* is a product of the 1920s, the *Copenhagen interpretation*, contrary to the standard line, is a construction of the 1950s and 1960s. This is not to say that serious attempts were not made to interpret quantum mechanics from a philosophical perspective in the 1930s. But rather that the idea of

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new formula” (AHQP). When the report of Bohr's Como lecture arrived in Göttingen in September 1927, Wigner is said to have remarked “Bohr's principle will not change the way we do physics.” (*Discussion Sections at Symposium on the Foundations of Modern Physics: The Copenhagen Interpretation 60 Years after the Como Lecture*, 1987, p. 7) Wigner himself recalled: “When Heisenberg published his article on the Uncertainty Principle, I saw almost at once that he had ended the quantum troubles. I picked up the phone and called someone – it was either von Neumann or Leo Szilard. I said ‘Now we can go to sleep. The problem is solved’” (Wigner, 1992, p. 87). It is worth noting that Wigner never mentioned correspondence and complementarity in his writings.

<sup>2</sup> In 1933 Pauli went so far as to describe quantum mechanics as the ‘theory of complementarity’, analogously to the theory of relativity (Pauli, [1933] 1980, p. 7). For Jordan: “The idea of complementarity must be viewed as the most significant result for philosophy that crystallized out of modern physics” (Jordan, 1944, p. 131).

a unitary interpretation only emerges in the 1950s in the context of the challenge of Soviet Marxist critique of quantum mechanics, Heisenberg's announcement of the unified 'Copenhagen interpretation' in 1955, and Wigner's papers on the measurement problem in the early 1960s. However, before we explore these, it is necessary to first explore some of the hidden differences between the defenders of the orthodox view in quantum mechanics which emerged in the period from the 1930 to the 1950s.

## 2. Understanding the Unity and Divergence of the Copenhagen School

Let me begin with the central issue that divided the 'orthodox' camp, from their opponents. During the late 1920s and 1930s there emerged a vigorous debate between Bohr, Heisenberg, Born, Pauli and Jordan on the one hand, and dissenting figures like Einstein, Schrödinger, Planck and von Laue on the other. The issue here was not about whether quantum mechanics was a correct theory, but whether it was in some sense 'complete'. On 9 November 1927, Einstein wrote to Sommerfeld explaining that in his view quantum mechanics "might be a correct theory of statistical laws, but it still is an insufficient conception of the individual elementary processes". From Einstein's perspective, at least, the "thesis that the  $\psi$ -function characterizes the individual system *exhaustively*" was the basic attitude of those who subscribed to the orthodox view (Einstein, 1949, p. 681). And indeed this view was defended in one form or another by many physicists belonging to the so-called Copenhagen school.<sup>3</sup> To this extent, there does appear to have been widespread agreement on this point among a number of 'orthodox' physicists.

Yet, when we examine more closely at what exactly was understood by 'completeness' in the debates over quantum mechanics, things begin to unravel. Don Howard has argued that that the notions of separability and entanglement lie at the heart of Einstein's challenge to the completeness of quantum mechanics, however this was not widely understood by Einstein's contemporaries (Howard, 1985). The fact remains that there was no agreement, even among those who defended the 'completeness' of quantum mechanics, what the term really meant, let alone any agreement on what grounds to defend the thesis. As Einstein remarked in 1949: "Of the "orthodox" theoreticians whose position I know, Niels Bohr's seems to me to come nearest to doing justice to the problem" (Einstein, 1949, p. 681). Einstein's comment here suggests, quite rightly, that Bohr's views on this question were not universally accepted or

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<sup>3</sup> In 1970 Leslie Ballentine agreed with the earlier assessment given by Paul Feyerabend, that "the Copenhagen interpretation contains assumptions which are not 'essential parts of the structure of quantum mechanics'", in particular, "the assumption that the quantum state description is the most complete possible description of an individual physical system" (Ballentine, 1970, p. 358).

widely understood, even by those who claimed to be his followers. Whereas Bohr appealed to an epistemological analysis of the mutually exclusive conditions of observation, many of the ‘orthodox’ physicists such as Heisenberg and Heitler simply appealed to the axiomatic or logical completeness of quantum mechanics (Maheu, 1971; Heitler, 1949, p. 194). Others made mention of von Neumann’s proof that the results of quantum mechanics were irreconcilable with hidden-variables theories (Pauli, 1948, p. 310). At the Symposium on *Observation and Interpretation of Modern Physics* in 1957, Marcus Fierz conceded that “at the moment there is no possibility of proof” that quantum mechanics gives the most complete description possible. But he argued that one could just as easily question the completeness of ‘classical mechanics’. In this context Fierz argued that any physicist searching to find a more complete theory of quantum mechanics “should not only discard Bohr’s ideas on what a physical theory can be, but even those of Newton” (Körner, 1957, p. 96).

When discussions turned to the question of completeness of quantum mechanics at the Unesco Colloquium on *Science and Synthesis* in 1965, Jean-Paul Vigiér soon recognised that disagreement on the problem was inevitable because “we have here representatives of several versions of the Copenhagen interpretation” (Maheu, 1971, p. 143). In assessing the view of “the Copenhagen school” that quantum mechanics represents a ‘complete’ theory, Vigiér emphasised that “the various representatives of this school, even those present at this forum, are not basically in agreement” (Maheu, 1971, p. 145). What is critical to realise here is that the claim of ‘completeness’, which was associated with the ‘orthodox’ view, is compatible with a range of different physical and philosophical interpretations of quantum mechanics.

David Hull, in his book *Science as a Process*, has argued that “the rigidity with which scientists insist on their preferred terminology is matched only by the semantic plasticity of that terminology” (Hull, 1988, p. 295). This is not only true of terms like ‘completeness’, but also of terms such as ‘wave-particle duality’ and ‘indeterminacy’ and ‘complementarity’. Thus, while we might agree with Edward McKinnon that “the Copenhagen interpretation includes the uncertainty principle; the idea that photons, electrons, and other “particles” exhibit both wave and particle properties; [and] the probabilistic interpretation of the *wave function*”, (MacKinnon, 1985, p. 110) exactly what each of these terms meant varied for different physicists. As I have argued elsewhere, Bohr and Heisenberg understood the wave-particle duality and the complementarity of space-time and causal descriptions in radically different ways, a fact which was disguised by their use of the same terminology (Camilleri, 2006, 2007). While it is certainly true, as Arthur Miller notes, that “Heisenberg came to accept the wave-particle duality of light and matter” (Miller, 1988, p. 39), Heisenberg’s understanding was based on the equivalence of Born’s statistical interpretation of the  $\psi$ -

function in many-dimensional configuration space (particle picture) and the Jordan-Klein-Wigner's quantization of matter waves in three-dimensional space (wave picture). This stands in contrast to Bohr's views that wave and particle pictures can be employed only in complementary but mutually exclusive experimental arrangements (Camilleri, 2006; Beller, 1999). Similarly, the meaning of the uncertainty principle was the subject of much debate and disagreement in the 1930s despite the frequent reference to it as a central tenet of the orthodox interpretation of quantum mechanics.<sup>4</sup>

Many physicists in the orthodox camp such as Heisenberg, Born and Jordan presented themselves as loyal supporters of Bohr's view of wave-particle complementarity or the indeterminacy principle, while their writings betray a series of misunderstandings, confusions, and outright disagreement on several key issues. Terms like wave-particle duality, complementarity, indeterminacy and completeness formed part of the shared vocabulary for the Copenhagen school, but beneath the veneer of agreement, one finds hidden disagreements as to what these terms meant. The continual reference to these 'basic tents' of the orthodox interpretation, in the absence of any genuine consensus over their meaning, was one of key factors which served to give the impression of a unified stance.

### **3. Niels Bohr and the Philosophical Interpretations of Complementarity**

According to Heisenberg, Bohr was "primarily a philosopher and not a physicist" (Heisenberg, 1967, p. 95). This characterization of Bohr's mode of thinking is echoed by many of those who came into contact with Bohr. As early as 1926, Schrodinger remarked that in discussions with Bohr on the problems of quantum mechanics, "the conversation is almost immediately driven into *philosophical* questions" (Moore, 1989, p. 228 emphasis added). Bohr work emerges from a European tradition of the philosopher-physicist, which meant that epistemological considerations were an integral part of his approach to physics. This made Bohr's work, and in particular his notion of complementarity which he developed between 1927 and 1938, extremely interesting to many of the philosophers and philosophically-minded physicists he came into contact with.<sup>5</sup> Here my aim is not to give an account of Bohr's philosophical view of quantum mechanics – this would take me far beyond the scope of this paper and we already have an extensive literature on that topic – but a brief survey the

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<sup>4</sup> As Catherine Chevalley puts this succinctly: "Certainly almost everyone would include Complementarity and the Uncertainty Principle – but then there is no agreement about what is Complementarity, nor is there about the exact status of Heisenberg's principle" (C. Chevalley, 1999, p. 71 footnote 5). In his doctoral dissertation Ernan McMullin (1954) presented a number of different interpretations of the uncertainty principle.

<sup>5</sup> Bohr's relevant articles from this period can be found reprinted in volumes 6 and 7 of his collected works (Bohr, 1985; Bohr, 1996).

different philosophical perspectives through which his writings were interpreted, and show how these interpretations formed part of the kaleidoscope of views which would fall under the banner of the ‘Copenhagen interpretation’.

The dominant philosophical school interested in science during the time quantum mechanics rose to prominence in the late 1920s and early 1930s was logical positivism. It is therefore no surprise to find that many of the contemporaries of the founders of quantum mechanics understood Bohr’s notion of complementarity and in particular his emphasis on paying careful attention to conditions of measurement as a clear expression of modern positivism (Degen, 1989, p. 26). We can see this most clearly in the 1930s through the work of physicists such as Pascual Jordan and Philip Franck, who were closely aligned with the Vienna Circle, and were keen to enlist Bohr as an ally to the logical positivist movement.<sup>6</sup> As Franck was to put it in his essay on the interpretations of quantum mechanics in 1938, Bohr’s formulation of complementarity presented at the 1936 Unity of Science conference in Copenhagen is “fully compatible with the formulations of logical empiricism” (Franck, 1975, p. 179). Pascual Jordan went further in 1936, stating that “the epistemological viewpoint of Bohr and Heisenberg is that of positivism” (Jordan, 1936, vii).

Despite the efforts of the logical positivists, Bohr himself was continually frustrated by the failure of the logical positivists to understand his idea of complementarity (U. Röseberg, 1995). In fact, as Anton Degen points out, “most of the founders of quantum mechanics did *not* subscribe to a positivist philosophy of science, even though they may have had leanings in that direction earlier in their careers” (Degen 1989, p. 17). This is particularly evident in the case of Pauli and Heisenberg, whose writings in the 1920s bear the influence of Mach’s critical positivism, only to move in quite different directions later (Laurikainen, 1988; Camilleri, 2005a). Indeed by the 1950s we can see a series of fervent denials of positivism from the physicists of the orthodox camp, notably Bohr, Heisenberg and Pauli.<sup>7</sup> Nevertheless it has become widespread view, expressed in much literature today that “a positivist attitude”

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<sup>6</sup> Ulrich Röseberg has investigated the ways in which Bohr and the logical positivists misunderstood one another (Röseberg 1995).

<sup>7</sup> Reporting on his conversations with Bohr in Copenhagen in 1957, Fock explained that Bohr had made it clear that “he was not a positivist” (Fock, 1957). In his Gifford lectures in 1955-6 Heisenberg emphasized that “the Copenhagen interpretation of quantum theory is in no way positivistic. For whereas positivism is based on the sensual perceptions of the observer as the elements of reality, the Copenhagen interpretation regards things and processes which are describable in terms of classical concepts, i.e., the actual, as the foundation of any physical interpretation” (Heisenberg, 1958, pp. 127). Similar denials of positivism can be found in the writings of Pauli. In a letter written to Markus Fierz on 6 Jan 1952, Pauli took a similar view: “What Mr. Bohm found particularly teasing and irritating in me is the circumstance that I declare myself not to be a positivist... he believes, indeed, to have ‘demonstrated’ that only ‘the positivistic prejudice’ stands as an obstacle to the acceptance of his causal doctrine of hidden parameters”. (Laurikainen, 1988, p. 195)

is central to the Copenhagen interpretation (Cushing, 1994, p. 27). Indeed the debate between orthodox and heterodox views of quantum mechanics has frequently been translated in terms of a conflict between two positions, that of positivism and that of realism. The tendency present in much of the current literature to draw the battle; lines between Bohr and Einstein as a debate between positivism and realism, has not only has distorted and obscured Bohr's philosophical views, but also Einstein's, whose position turns out to be rather more subtle than many have made it out to be (Chevalley, 1992, pp. 67-8).<sup>8</sup>

While logical positivism emerged as the dominant philosophical school of thought that aligned itself with Bohr's view of quantum mechanics and thus with the 'Copenhagen school', it was by no means the only one. In the early 1930s Heisenberg and Weizsäcker engaged in a series of critical discussions in Leipzig with the visiting Kantian scholar Grete Hermann, on how Bohr's view of quantum mechanics could be reconciled with Kant's epistemology. Hermann's work during the 1930s reveals the influence of her background under the particular neo-Kantian school of Leonard Nelson, yet it also owes much to the way in which Heisenberg and Weizsäcker had interpreted Bohr's doctrine of the indispensability of classical concepts in the description of experience. (Hermann, 1935, 1937a, 1937b, 1937c).<sup>9</sup> The central issue for Heisenberg and Weizsäcker was how Kant's notion of the *a priori* could be transformed in the light of Bohr's idea of complementarity (Heisenberg, 1958; pp. 80-83; Heisenberg, 1971, pp. 117-124; Weizsäcker, 1941a, 1941b, 1952).<sup>10</sup> As Heisenberg explained in 1934, "the question raised by Kant, and much discussed ever since, concerning the *a priori* forms of intuition and categories ... has been put into new light", for "as Bohr particularly has stressed, the applicability of these forms of intuition, and of the law of causality is the premise of every scientific experience even in modern physics" (Heisenberg, 1934, 700). The forms of our intuition – space and time – are then "more than merely empirically given, because they are, as Kant rightly emphasizes ... the first presupposition of all possible experience" (Heisenberg, [1942] 1984, p. 284). Whereas Jordan and Franck saw Bohr's viewpoint as signifying the triumph of positivism, Weizsäcker saw it as a vindication of Kant's fundamental insight into the nature of human knowledge. As he was to put it: "The alliance between Kantians and physicists was premature in Kant's time, and still is; in Bohr, we begin to perceive its possibility" (Weizsäcker, [1966] 1994, p. 185).

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<sup>8</sup> The recent literature on Bohr has to a large extent, corrected this misconception that he was a positivist. See Folse (1985), Murdoch (1987), Honner (1987), Faye (1991), Faye and Folse (1994). For a more complete picture of Einstein's 'realism', see Fine (1986) and Howard (1993)

<sup>9</sup> An interesting study of Hermann's work is currently being undertaken by Léna Soler (unpublished manuscript).

<sup>10</sup> A more thorough analysis of Heisenberg's transformation of the Kantian notion of the *a priori* can be found in Camilleri (2005b).

Different philosophical interpretations of Bohr's thought also emerged among his closest collaborators in Copenhagen. Aage Petersen, who was Bohr's assistant during the 1950s, argued that Bohr's philosophical view was grounded in his view of the primacy of language over reality. According to Petersen, when confronted with the view that "it must be reality which, so to speak, lies beneath language, and of which language is a picture", Bohr would simply reply – "We are suspended in language in such a way that we cannot say what is up and what is down. The word 'reality' is also a word, a word which we must learn to use correctly'" (Petersen, 1963, p. 11). This view, according to which "there is no quantum world", has often been taken as a direct expression of Bohr's own thoughts on the language-reality problem, and has thus been associated with the orthodox view.

Petersen's linguistic interpretation of Bohr, nevertheless, stands in sharp contrast to the one presented by Belgian physicist Léon Rosenfeld, who was Bohr's assistant in Copenhagen in the 1930s, and later assumed the role as Bohr's self-appointed spokesman in the 1940s and 1950s (Rosenfeld, [1953] 1979; Rosenfeld, [1957] 1979). Bryce de Witt described Rosenfeld as "Probably the greatest champion of the so-called Copenhagen Interpretation" (Interview with de Witt, cited in Jacobsen, p. 7). In vigorously defending Bohr against those who made him out to be a positivist, or a Kantian, Rosenfeld argued for a Marxist-materialist interpretation of complementarity, arguing in 1953 that it constituted "the first example of a precise dialectical scheme" (Rosenfeld, [1953] 1979, p. 481). Anja Jacobsen's recent work has shed new light on the critical role that dialectical materialism played in Rosenfeld's defence of Bohr's complementarity from the late 1940s and through the 1950s (Jacobsen, forthcoming). While Rosenfeld occasionally expressed some reluctance about labeling Bohr a dialectical materialist, on other occasions he was happy to claim that Bohr was a Marxist who simply didn't know it (Jacobsen, p. 42).<sup>11</sup> Rosenfeld's tendency to interpret Bohr's ideas within a Marxist framework was roundly criticized by a number of other members of so-called Copenhagen School in the 1950s, notably Wolfgang Pauli and Max Born.<sup>12</sup>

Bohr's failure to explain his ideas clearly and unambiguously have become part of the folklore of the history of quantum mechanics. This is of course not to suggest that Bohr did not present a philosophically coherent, and immensely interesting, interpretation of quantum

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<sup>11</sup> In a different context, the Soviet physicist Vladimir Fock's visit to Copenhagen in February-March 1957 was also seen as cause for seeing a greater reconciliation between the Copenhagen interpretation and the Soviet version of dialectical materialism (Graham, 1988).

<sup>12</sup> When editing a volume in honor of Bohr, Pauli wrote to Heisenberg on 13 May 1954 saying that he had managed to prevent Rosenfeld, whom he labeled Rosenfeld  $\sqrt{\text{Trotsky} \times \text{Bohr}}$  from adorning his paper with banalities on materialism. (Pauli, 1999, pp. 620-1). In the 1950s Max Born wrote to Rosenfeld, the length of writing a paper, which was never published. See Freire (2001) and Sovak (1976).

mechanics, but there is undoubtedly a sense in which Bohr's writings and utterances had the distinctive quality of lending themselves, perhaps without the benefit of careful study, to a range of different philosophical interpretations. Though Bohr himself rejected many of the 'isms' of contemporary philosophy, he was at the same time reluctant to publicly criticize different philosophical interpretations of his thought. In his interview with Kuhn in 1962 Bohr lamented that "no man who calls himself a philosopher understands what one means by complementary description" (AHQP), yet it is difficult to find Bohr ever publicly criticizing his colleagues in print.<sup>13</sup> Indeed, as Pauli commented on the occasion of Bohr's 60<sup>th</sup> birthday:

Bohr himself integrated, in lectures at international congresses and at those carefully planned conferences in Copenhagen, the diverse scientific standpoints and epistemological attitudes of the physicists, and thereby imparted to all participants in these conferences, the feeling of belonging, in spite of all their dissensions to one large family (Pauli, [1945] 1994, p. 51).

Throughout the 1930s and 1940s Bohr was taken as an ally in a number of distinct philosophical movements including certain strands of neo-positivism, neo-Kantianism, dialectical materialism, and linguistic idealism.<sup>14</sup> Different philosophical schools of thought seized on the opportunity to reinterpret Bohr's interpretation of quantum mechanics by recasting it in their own distinctive philosophical voice. The orthodox view was seen to be perfectly compatible with a number of different philosophical viewpoints. This afforded the orthodoxy a certain interpretive flexibility, which enabled it to be used to give legitimacy to a range of different philosophical viewpoints. In this way, Heisenberg, Weizsäcker, Franck, Jordan, Rosenfeld, and Petersen were able to appeal to Bohr's interpretation as giving support to their particular philosophical interpretation of quantum mechanics.

By the 1950s the diversity of epistemological viewpoints, each of which aligned themselves with Bohr's view, actually contributed to the impression of a unitary Copenhagen interpretation. Whereas in the 1930s and 1940s the disagreements between Rosenfeld, Franck and Weizsäcker are best construed as a clash of different philosophical interpretations of quantum mechanics, as had been in the case with the theory of relativity (Hentschel, 1990), in the 1950s in the context of the emergence of a new threat from the Bohm, de Broglie and

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<sup>13</sup> I should acknowledge that Petersen's interpretation it must be said, only after Bohr's death.

<sup>14</sup> After his death in 1962, a "pragmatist" interpretation of Bohr's work emerges more prominently in the secondary literature (Holton 1970; Stapp 1972; Murdoch, 1987). This was perhaps in no small part due to Bohr's revelation, in his interview with Kuhn shortly before his death, that he had been taken with several passages from William James' work on psychology (AHQP). More recently Bohr's *oeuvre* was been situated in the context of the contemporary debate between realism and anti-realism (Folse, 1985; Faye, 1991; Folse and Faye, 1994)

Vigier, as well as Soviet physicists such as Blokhitsev and Alexandrov, the different schools of thought closed ranks in identifying themselves with Bohr – the canonical author – whose writings were taken as a direct expression of the ‘authentic’ Copenhagen interpretation.

#### **4. Soviet Marxism and the Subjectivist Idealism of the Copenhagen School**

Let me now turn my attention from defenders to the philosophical critics of Bohr’s views on quantum mechanics. In her work on the history of the interpretations of quantum mechanics, Mara Beller argues that it was the “victors” who perpetrated the illusion of agreement among themselves (Beller, 1999, pp. 188-90). However, it was not only the defenders of the orthodoxy who gave the impression that there was a unified philosophical viewpoint lay behind the new quantum mechanics. Nowhere is this more evident than in the case of the Soviet critique of quantum mechanics, which reached its crescendo in the early 1950s. Thanks to the work of historians of science like Loren Graham (1966, 1972, 1988), Olival Freire (1997, 2004), Andrew Cross (1991), and Alexander Vucinich (1991), we are now in a much better position to understand the impact of Soviet-Marxist ideology on the debates over quantum mechanics in the 1950s, and the impact they had on physicists in the West. My interest, however, is not in emergence of a visible heterodoxy in 1950s, but rather the impact Soviet Marxist views may have had in the formation of the image of the ‘Copenhagen interpretation’ during this time.

The ideological attack on the ‘Copenhagen School’ of quantum mechanics, was closely tied to the Soviet critique of positivism inspired by Lenin’s widely read *Materialism and Empirio-Criticism*. As Wolfhard Boeselager explains, whereas the logical positivists saw themselves as opposed to all metaphysics, transcendentalisms, and idealisms as obscurantist and regressive modes of thought, for the Soviet Marxists these were precisely the hidden agendas of the rise of modern positivism. Soviet Marxists universally condemned positivism as using the terminology of science in the interests of “subjective idealism”. As Boeselager explains, it is characteristic of the Leninist method to show that “positivists in reality hold views different from those which they proclaim”. To this extent, the Soviet critique of neo-positivism was characterised by a tendency to depict positivism as an anti-scientific and pro-religious “idealist” bourgeois philosophy, in spite of claims of its adherents to the contrary. It was also characteristic of Soviet critics of positivism “to lump together authors with sometimes very different views”. This technique was also applied to authors from different eras – like Berkeley or Hume – whose views had already been condemned (Boeselager, 1975, p. 38).

The synthetic method described here is in clear evidence in the attack on the orthodoxy in quantum mechanics which emerges from the Soviet Union in the 1930s. As Vucinich explains for many of the Soviet critics such as Uranovskii and Maksimov “identified physical idealism, a label used interchangeably with “subjectivism” and “agnosticism”, as the official philosophy of quantum mechanics as presented by the Copenhagen school”. This was a term which “covered *all epistemological orientations which violated Lenin’s view that knowledge reflected the eternal world and which challenged the role of causality as the basic explanatory position in science*” (Vucinich, 1991, p. 238). This is a critical insight into the invention of the myth of the Copenhagen interpretation, for it shows us that the ‘Copenhagen interpretation’ was as much a construction of those who opposed the orthodox view (completeness) of quantum mechanics, as those who defended it.

While before the Second World War, there was some degree of tolerance afforded to Soviet physicists, after the Second World War the “orthodox interpretation” was officially banned. The defining event was the speech delivered by Stalin’s assistant in the Central Committee of the Party, Andrei A. Zhdanov on June 24, 1947. The occasion was a discussion and condemnation of G. F. Aleksandrov’s book *History of Western European Philosophy*. While Zdanov only referred to modern physics briefly in the conclusion of his speech, this marked the beginning of an intense ideological campaign – sometimes termed *Zdanovshchina* in the literature – which had a profound effect on Soviet physics, including the interpretation of quantum theory. The major consequence of all this was a decision reached at the 1947 Meeting of the Academy of Sciences to effectively ban ‘complementarity’ in the Soviet Union from 1947 to 1958. Any acceptable interpretation of quantum mechanics would have to assert the objective reality of particles, and would show that the statistical theory could be understood materialistically.

A surge of publications condemning the ‘orthodox’ interpretation of quantum mechanics emerged from the Soviet Union during this time. The critics counted among others the physicists A. A. Maksimov, A. D. Aleksandrov, Ia. P. Terletskii, B. G. Kuznetsov, and D. I. Blokhintsev. Perhaps the most important and influential critic was Blokhintsev, whose paper ‘Criticism of the Philosophical Views of the Copenhagen School’, was published in French by *Les Éditions de Nouvelle Critique*, a publisher with strong ties to the French Communist Party and in German in *Sowjetwissenschaft* (Blokhintsev, 1952; 1953). Importantly from our point of view, it was, so far as I can tell, the first mention of a “Copenhagen school”. In 1955 Heisenberg quoted Blokhintsev’s paper, which he had stated: “among the different idealistic trends in contemporary physics, the so-called Copenhagen school is the most reactionary. The present article is devoted to the unmasking of idealistic and agnostic speculations of this

school on the basic problems of quantum mechanics” (Heisenberg, 1955, p. 21). It is worth emphasising that here Blokhintsev describes his task as “unmasking” the implicit idealist viewpoint of the Copenhagen interpretation. To this extent, the Marxist critics did not deem it necessary, or even worthwhile, to make a careful study of the philosophical writings of Bohr, or Heisenberg, or Pauli, but simply to reconstruct the subjective idealism which they saw as underpinning the Copenhagen point of view of the statistical interpretation of quantum mechanics.<sup>15</sup>

Andrew Cross has documented the considerable support that the Soviet critique of quantum mechanics enjoyed in France in the early 1950s, where a number of Marxist physicists expressed their criticisms of the “subjectivism” and “idealism” at the heart of the orthodox view (Cross, 1991, pp. 746-751). In a letter to Pauli in 1952 Rosenfeld wrote that in Paris “the youth is in arms against [Bohr] ‘under the banner of Marxism’”, though Rosenfeld hastened to add that in his view this was against the spirit “of what Marx had really meant” (Pauli to Rosenfeld, 20 March 1952 in Pauli, 1996, p. 592). Among the leading physicist in this movement was Jean-Paul Vigièr, whose Marxist leanings were a source of motivation in the development of a new hidden-variables theory of quantum mechanics in collaboration with David Bohm (Cross, 1991; Freire, 2004). The characterisation of the orthodox view of quantum mechanics as “idealist” can be found even among many prominent physicists during this time, even those who were not Marxist in their orientation. In 1953, Louis de Broglie argued the “present day interpretation” inevitably ended in subjectivism:

Actually this interpretation by seeking to describe quantum phenomena solely by means of the continuous  $\psi$ -function whose statistical character is certain, logically ends in a kind of subjectivism akin to idealism in its philosophical meaning, and it tends to deny the existence of a physical reality independent of observation (de Broglie, 1954, p. 235).

In the United States, the Marxist philosopher of science Hans Freistaedt complained of a crisis of physics brought about by the positivist interpretation of quantum mechanics, which was nothing but a thinly disguised form of “subjective idealism” (Freistaedt, 1953). Mario Bunge was another who promoted the “idealist” view of the Copenhagen school, along Marxist lines in the 1950s. According to Bunge, “the celebrated crisis of determinism is nothing but a consequence of the adoption of an idealist theory of knowledge: it is not a simply result of modern physics, but a tenet of neopositivism” (Bunge, 1959, p. 181). Indeed

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<sup>15</sup> This was also true some more recent Marxist critiques of the Copenhagen interpretation of quantum mechanics in the 1970s. See Thekadath (1974) and Jayaraman (1975).

Bunge's critique of the orthodox interpretation is a model of the Leninist method of critique outlined earlier. The Copenhagen school of quantum mechanics is charged with defending a positivistic standpoint. The label positivism is used interchangeably with subjective idealism. Schlick's positivism is identified as irrational (p. 191). Rosenfeld is denigrated as a positivist in spite of his claims to the contrary. Weizsäcker is branded a "theologian" (p. 183). And the "subjective idealism" of the orthodox view is equated with the outmoded and already dispensed with Berkeley's metaphysics. (pp. 178-9). Drawing the fundamental battle lines of the debate over quantum mechanics, Bunge declared: "What is at stake in this discussion is not a physical dispute about the structure of micro-objects, but the whole theory of knowledge with its old struggle between materialism and immaterialism" (Bunge, 1959, p. 178).

### **5. Reconstructing the Orthodoxy: The Genealogy of the Copenhagen Interpretation**

It seems more than just coincidence that the Marxist critique of the orthodox quantum mechanics in the 1950s in the West roughly coincides with the first use of the term 'Copenhagen interpretation'. As Helge Kragh points out, "the term 'Copenhagen interpretation' was not used in the 1930s but first entered the physicist's vocabulary in 1955 when Heisenberg used it in criticizing certain unorthodox interpretations of quantum mechanics" (Kragh, 1999, p. 210). Catherine Chevalley emphasises that "None of the founders of quantum mechanics – not even Einstein, Schrödinger or L. de Broglie – ever used the term before that time", nor is the expression "to be found in the philosophical literature of that time" (C. Chevalley, 1999, p. 62). It is therefore worth quoting from Heisenberg's 1955 article where the term first appears:

The months which followed Schrödinger's visit [in September 1926] were a time of the most intensive work in Copenhagen, from which there finally emerged what is called the "Copenhagen interpretation of quantum theory" (Heisenberg, 1955, p. 14). From the spring of 1927, therefore, there existed a complete, unambiguous mathematical procedure for the interpretation of experiments on atoms or for predicting their results ... Since the Solvay conference of 1927, the "Copenhagen interpretation" has been fairly generally accepted, and has formed the basis of all practical applications of quantum theory (Heisenberg, 1955, p. 16).

Heisenberg's historical narrative of the genesis of the Copenhagen interpretation has been rehearsed in numerous subsequent treatments of the development of quantum mechanics (E.g. Petersen, 1968, p. 1; A. Miller, 1988, p. 27). As Heisenberg's account above suggests, the Solvay conference marks a significant turning point in the history of quantum physics in

establishing the Copenhagen orthodoxy. This was certainly the feeling of many physicists, notably Ehrenfest, who participated in the discussions in Brussels. However this historical reconstruction serves to conceal the internal division between key protagonists such as Bohr, Heisenberg, Born and Dirac, which is evident in the discussion that took place at the 1927 Solvay conference itself, and the fact that important shifts and trajectories in both Bohr's and Heisenberg's thought occurred *after* 1927.<sup>16</sup> Indeed, Rosenfeld later recalled that by 1927 Bohr still "felt that this search for a firm foundation had not yet been completed in quantum mechanics, in spite of the considerable clarification the question had already received from Heisenberg's analysis of the indeterminacy relations". It was not until 1936 that Bohr felt he had brought to a conclusion the "task of deepening and consolidating the conceptual foundation of quantum theory" (Rosenfeld, 1967, p. 115).<sup>17</sup>

The 1927 Solvay conference did bring about widespread agreement that the development of quantum theory had been brought to a "provisional conclusion" through the "systematic construction of the mathematical formalism of wave mechanics" (Pauli, [1950] 1994, p. 36). But here I maintain it did not bring about agreement on how to philosophically interpret that theory. This task actually *began* in 1927 with Bohr's Como paper, but was taken up by a number of physicists and philosophers in the 1930s and 1940s. Yet Heisenberg's 1955 article gives the impression that a certain philosophical point of view definitely emerged in Copenhagen during this time. As he explained: "What was born in Copenhagen in 1927 was not only an unambiguous prescription for the interpretation of experiments, but also a language in which one spoke about Nature on the atomic scale, and in so far a part of philosophy" (Heisenberg, 1955, p. 16).

While the term 'Copenhagen interpretation' became part of the vocabulary of historians and philosophers of quantum mechanics after the mid-1950s, many of the philosophical views in Heisenberg's 1955 article were disputed by his colleagues. It is ironic that while many of the leading physicists of the Copenhagen school saw their battle against the emergence of heterodox views in the 1950s, such as Bohm's, as an expression of a strictly philosophical debate concerning ontology and epistemology and not of physics, there were in disagreement

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<sup>16</sup> Important here was the transformation of the respective views of wave-particle duality and complementarity of Heisenberg and Bohr after 1927. Following the publication of the Jordan-Wigner paper on the quantization of matter waves, on 23 July 1928 Heisenberg wrote to Bohr declaring that "I now believe the fundamental questions are completely solved" (AHQP).

<sup>17</sup> This account accords with the point made by Murdoch and Faye, according to which Bohr's thought undergoes a transformation in 1935. As Murdoch puts it, "After 1935 Bohr expressed the indefinability thesis in what may be called 'semantic' as distinct from 'ontic' terms" (Murdoch, 1987, p. 145). In a similar vein Jan Faye writes: "After 1935 his grounds for asserting complementarity were not so much epistemological as they were conceptual or semantical." (Faye, 1991, p. 186).

amongst themselves as to the epistemological point of view to adopt (Freire, 2005a, pp. 19-28). Rosenfeld must have been incensed to find that Heisenberg had criticized the opponents of the Copenhagen interpretation for their desire to return to “the ontology of materialism” (Heisenberg, 1955, p. 17). Indeed Heisenberg ended his article by pointing out that the “idealistic argument that certain ideas are *a priori* ideas, i.e. come before all natural science, is here correct” (Heisenberg, 1955, p. 28). In a critical review of Heisenberg’s 1956 Gifford lectures published as *Physics and Philosophy*, Rosenfeld offered the following comments:

With regard to the epistemological problems just mentioned, Heisenberg’s exposition naturally follows the line of argument which he has himself so decisively contributed to establish, and which he calls, in homage to Niels Bohr’s great leadership, the “Copenhagen interpretation”... But the account he gives of the “Copenhagen” ideas is unfortunately not so good as it ought to be; and certainly not one of the physicists now working in Copenhagen would subscribe to the general philosophical attitude underlying this account. Altogether it would be better to discard such an ambiguous expression as “Copenhagen interpretation”, were it only because it falsely suggests that there could be other possible interpretations of quantum theory (Rosenfeld, 1960, p. 831).

While disagreement ensued about precisely what was meant by the Copenhagen interpretation, the term quickly was in widespread use. A number of philosophers attempted to clarify the issue by defining and reconstructing the ‘authentic’ Copenhagen interpretation. This often took the form of attempting to give “a minimal account of what many physicists would understand as the ‘core meaning’ of the Copenhagen interpretation” (Hanson, 1959, pp. 327-8). One finds this approach in the writings of philosophers such as Hanson (1958, 1959), Ballentine (1970), Stapp (1972), and MacKinnon (1985). As Stapp was put it: the task now was to “give an account of the *logical essence* of the Copenhagen interpretation” which in no way should be confused with “the inhomogeneous range of opinions which constitute the Copenhagen interpretation itself” (Stapp, 1972, p. 1099).

Yet, while the pragmatic definition of the Copenhagen interpretation presented by philosophers like Hanson and Stapp clarified many issues, at the same time these papers also inadvertently contributed to the confusion. They did this, firstly, by ignoring many of the epistemological and ontological issues which arose in the 1930s that many physicists felt lay at the heart of any *interpretation* of quantum mechanics. Secondly, these papers only served to further entrench the view that beneath the mass of conflicting voices, there is such a thing as the ‘Copenhagen interpretation’ which should be the object of careful historical and

philosophical inquiry, thereby perpetuating the myth. And thirdly, on careful inspection we find, sometimes substantial, disagreement among philosophers like Stapp, Ballentine and Hanson on how to understand the ‘Copenhagen interpretation’, which has only served to increased the number of different ways in which the term has been employed since the 1950s. Asher Peres has recently lamented the fact that: “There seems to be at least as many different Copenhagen interpretations as people who use that term, probably there are more” (Peres, 1999, p. 6).

## **6. Eugene Wigner and the Subjectivist Interpretation of Measurement**

We come now to one of the more intriguing aspects of the so-called Copenhagen interpretation – the idea that consciousness is somehow involved in the collapse of the wave packet (Bierman, 2003). As Steven French explains: “The Copenhagen, or ‘orthodox’, solution [to the measurement problem] is typically understood as having proposed that something non-physical — namely, the mind or consciousness — must ‘reduce’ the superposition to give what we observe” (French, 2002, p. 468). Though this idea that has become virtually synonymous with the Copenhagen interpretation, so far as I can tell, none of the founders of quantum mechanics ever seriously entertained this notion, at least in print. While certain passages from Heisenberg or Jordan in the late 1920s and 1930s have often been read as endorsing a subjectivist view of the role of the observer, interpreting these passages in this way, is in my view, a misconception.<sup>18</sup>

Aware that Bohr’s discussion of the importance of taking into account the “agencies of observation” might be misconstrued as entailing some kind of radical subjectivism, the logical positivists in the 1930s, notably Philip Franck, categorically rejected such an interpretation, arguing instead, quite correctly, that all talk of the observer in Bohr’s view of quantum mechanics must be understood as referring to the measuring apparatus. In his paper at the ‘Unity of Science congress in 1936, Franck warned against the idealist and subjectivist views of the quantum mechanics. “No support whatsoever of subjectivistic natural science”, he asserted vehemently, “can possibly be derived from that situation” (Franck, 1938, p. 31). In a paper in 1949 on the problem of measurement in quantum mechanics, Jordan explicitly stated that in the “more orthodox formulations of quantum mechanics one is accustomed to saying the process of observation (or measurement) makes the photon decide between the two possibilities”, but in his view “what is here called ‘observation’ must not be interpreted as any

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<sup>18</sup> In his discussion of the reduction of the wave packet in his 1927 paper Heisenberg states the “the ‘orbit’ only comes into being when we observe it” (Heisenberg, [1927] 1983, p. 73). Yet this need not be interpreted as referring to the presence of a conscious observer.

mental process, but as a purely physical one” (Jordan, 1949, p. 271). Although Heisenberg did sometimes speak of a subjective element in quantum physics, this should not be taken to mean that the consciousness of the ‘observer’ plays a crucial role in the measurement interaction. In *Physics and Philosophy* in 1958, Heisenberg argued that “the transition from the ‘possible’ to the ‘actual’ takes place during the act of observation” but this transition occurs “applies to the physical, not the psychical act of observation”. Only once the “interaction of the object with the measuring device” has taken place can we speak of the actualization, but here he was careful to point out that “it is not connected with the act of registration of the result, by the mind of observer” (Heisenberg, 1958, p. 54).

So where did this view come from? And how did this view come to be associated with the likes of Bohr and Heisenberg? Scholars have often traced this view to von Neumann’s analysis of measurement in his *Mathematische Grundlagen der Quantenmechanik* published in 1932 (von Neumann, 1955). Whereas in Bohr’s complementarity, the measurement device is described using the concepts of classical physics, and not according to the laws of quantum mechanics, in von Neumann’s presentation, the measurement device is given a quantum-mechanical treatment (Bub, 1995). According to von Neumann’s formal treatment of the problem, when we observe a quantum system, there is an instantaneous change of the wave function in Hilbert space – it collapses – a process which is not described by the Schrödinger equation. Precisely what von Neumann’s philosophical views on this matter were is more difficult to judge, though as Becker and Gavroglou have observed there is no evidence of him endorsing a realist view of the wave function, nor does he make any explicit reference to the need to introduce the consciousness of the observer in the measuring chain (Becker, 2004; Gavroglou, 1995, p. 171).<sup>19</sup> Rather it was the 1939 monograph *La Théorie de l’Observation en Mécanique Quantique* by London and Bauer which we find the first explicit mention of the claim that the reduction of the wave function was the result of the conscious activity of the human mind (French, 2002).

Drawing on the analysis of measurement given by John von Neumann, London and Bauer made an extensive analysis of measurement in quantum theory, drawing the radical conclusion that a “measurement is achieved only when the position of the pointer has been *observed*”. Here the authors noted “the essential role played by the *consciousness of the observer*” in the process of observation (London & Bauer [1939] 1983, p. 251). Steven

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<sup>19</sup> In spite of von Neumann’s care to avoid committing himself to a subjectivist view of the collapse of the wave function, it appears that after the London-Bauer essay in 1939, his text was widely read as having endorsed just this view. For example, in Jordan’s 1949 article on measurement, he attributes to von Neumann the view that “no physical process can convert a ‘pure case’ into a ‘mixture’... he assumes this to be only a mental process of the observer” (Jordan, 1949, p. 270)

French has argued that London's philosophical understanding of the role of consciousness in measurement must be understood in the context of his commitment to Husserlian phenomenology, which he studied while in Göttingen (French, 2002). In French's view, later versions of the London-Bauer thesis lack the philosophical subtlety found in the original text. Notwithstanding the explicit reference to the conscious observer in Heitler's 1949 contribution to the Einstein *Festschrift*, the idea appears to have made little impact over the next two decades.<sup>20</sup> Yet, by the early 1960s the idea had risen to prominence largely through a series of articles by the Hungarian physicist – Eugene Wigner. Wigner's work would exert an immense influence in the 1960s and was critical in changing the image of the 'Copenhagen interpretation'.<sup>21</sup>

What makes Wigner's work in the early 1960s so interesting is that he presented this interpretation as an inevitable conclusion of the discovery of quantum mechanics in the 1920s. In 1961 Wigner remarked: "it will remain remarkable, in whatever way our future concepts may develop, that the very study of external world led to the conclusion that the content of consciousness is an ultimate reality" (Wigner [1961] 1983, p. 169). Referring to the development of quantum theory in the 1920s Wigner again stated: "through the creation of quantum mechanics, the concept of consciousness came to the fore again: it was not possible to formulate the laws of quantum mechanics in a fully consistent way without reference to the consciousness". (Wigner [1961] 1983, p. 169) In a widely read paper on the measurement problem, Wigner expressed the following point of view:

Having spoken to many friends on the subject which will be discussed here, it became clear to me that it is useful to review the standard view of the late "Twenties", and this will be the first task of this article. The standard view is an outgrowth of Heisenberg's paper in which the uncertainty relation was first formulated. The far-reaching implications of the consequences of Heisenberg's ideas were first fully appreciated, I believe, by von Neumann, but many other arrived independently at conclusions similar to his. There is a very nice little book, by London and Bauer, which summarizes quite completely what I call the orthodox view (Wigner, [1963] 1983, p. 325).

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<sup>20</sup> In his contribution, Heitler wrote: "The self-registering first screen does not itself make future observations certain, unless the result is acknowledged by a *conscious* being. We see, therefore, that here the *observer* appears as a necessary part of the whole structure, and in his full capacity as a conscious being. The separation of the world into an "objective outside reality" and "us", the self-conscious onlookers, can no longer be maintained" (Heitler, 1949, pp. 194-5).

<sup>21</sup> Wigner's work sparked a series of debates throughout the 1960s concerning the role of the observer in quantum theory. See the exchange of views between Putnam, Margenau, and Wigner (Putnam, 1961; 1964; Margenau & Wigner, 1962; 1964).

Wigner here traces what he terms the “orthodox” view of London and Bauer to the emergence of quantum mechanics in the late 1920s initially to Heisenberg’s 1927 paper. Yet, as I stated earlier, there is little evidence that any of the founding fathers of quantum mechanics – Bohr, Heisenberg, Pauli, Jordan, Dirac, and Born – ever explicitly canvassed the idea that consciousness plays a central role in the act of measurement during this time.<sup>22</sup> Nor is this idea to be found in the criticisms of the orthodox view of quantum mechanics in the 1930s levelled by Einstein, Schrödinger, Planck and von Laue. Wigner’s work serves as a classic case of the physicist rewriting history. In the mid-1950s Heisenberg had reconstructed the development of quantum mechanics through his invention of the ‘Copenhagen interpretation’, but by the early 1960s Wigner provides a different reconstruction of the orthodox view, in which Bohr is curiously written out of the story. As Jeffery Bubb points out, it has now become commonplace to regard “such radical views as Wigner’s, that ‘the quantum description of objects is influenced by impressions entering consciousness’ ... as consistent with the Copenhagen interpretation” (Bubb, 1997, p. 190).

In lending support to his own version of the orthodoxy, in a footnote Wigner actually quoted two passages from Heisenberg’s essay ‘The Physicist’s Conception of Nature’, and reinterpreted them for the benefit of his readers as defending a thoroughly subjectivist view of measurement in quantum mechanics. In the passage quoted by Wigner, Heisenberg had argued that the mathematical laws of quantum mechanics “deal no longer with the particles themselves but with our knowledge of the elementary particles”. To this extent, Heisenberg maintained that in quantum theory the classical “conception of objective reality has evaporated into the clarity of a mathematics that represents no longer the behaviour of elementary particles but rather our knowledge of this behaviour”. (Wigner, [1961] 1983, p. 169). Interpreting these passages for his readers in 1961, Wigner explained: “The ‘our’ in this sentence refers to the observer who plays a singular role in the epistemology of quantum mechanics. He will be referred to in the first person and statements made by the first person will always refer to the observer” (p. 169). However, it seems obvious that the passages in question quoted by Wigner are simply statement of the epistemic interpretation of the wave function, and say nothing about introducing a subjectivist view of measurement. Indeed, as noted earlier, in 1958 Heisenberg had categorically rejected such a possibility.

By the late 1960s a number of writers would identify Wigner’s views with those of Bohr. In his criticism of Bohr, Popper deemed it important “to exorcize the ghost called

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<sup>22</sup> Laurikainen (1988) claims that Pauli endorsed the idea that consciousness plays a critical role in the collapse of the wave packet, but I can find nothing to corroborate his interpretation.

‘consciousness’ or ‘the observer’ from quantum mechanics” (1968, p. 7) Popper argued that it was unfortunately “still necessary to *discuss the Copenhagen* interpretation”, because according to that interpretation “we have to regard “*the observer*” or “*the subject*” as particularly important” (Popper, 1968, p. 10 emphasis in original). In 1973 Mario Bunge reiterated this view, complaining that “the Copenhagen doctrine is logically inconsistent, and this blemish derives from its adopting a subjectivist philosophy” (Bunge, 1973, p. 89). Here Bunge named “Bohr, Heisenberg, Born, Dirac, Pauli and von Neumann” as members of the Copenhagen school, who “by smuggling the observer into QM renders the latter psychophysical rather than purely physical” (p. 91). The extent to which Wigner’s views subverted the orthodox position can be seen in the case of the Princeton physicist John Wheeler, who was in communication with Bohr during the 1940s and 1950s. In 1977 Wheeler wrote to Niels Bohr’s son Aage Bohr in 1977 expressing some confusion over Bohr’s views:

I have the impression, perhaps mistaken, that that your father at one time thought that for the making of an observation it only took in the end an irreversible account of amplification; but that later on he changed his position to something closer to the idea that no observation is an observation unless it enters the consciousness. However, I am not able to find anything to document this supposed change of view, and my understanding of the history may be quite wrong (Wheeler to Aage Bohr, 25 February 1977, cited in Freire, 2005b, p. 17).

The reply was predictable – the younger Bohr explained that his father had never entertained the idea that consciousness is central to the process of observation in quantum mechanics. But Wheeler’s confusion over this point is a nice illustration of the extent to which Wigner’s subjectivist interpretation had managed to subvert the orthodoxy by the 1960s. To be fair, the mistake was not universal. Some physicists and philosophers did see the emergence of two distinctive views, both of which claimed to the orthodoxy, in the 1960s. Abner Shimony in his 1963 paper on ‘The Role of the Observer in Quantum Theory’ drew the careful distinction between the views of Bohr and Wigner regarding how the measurement interaction was to be understood (Shimony, 1963).<sup>23</sup> Similarly in 1969 Feyerabend defended Bohr against “Popper’s accusation of *subjectivism*”, arguing that this was a muddled distortion of Bohr’s views. Here Feyerabend urged philosophers seeking to make sense of quantum mechanics to go “Back to Bohr!” (Feyerabend, 1969, p. 103-4).<sup>24</sup>

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<sup>23</sup> In his 1997 introductory essay to part A, volume 3 of Wigner’s *Collected Works*, Shimony was careful to point out that ““For Wigner the term “orthodox” refers not to Bohr’s Copenhagen Interpretation and its variants but to von Neumann’s” (Shimony, 1997, p. 407).

<sup>24</sup> Feyerabend’s papers on complementarity (1968, 1969) in my view represents the first of a series of serious attempts by philosophers to come to grips with Bohr’s view of complementarity – an effort

Yet even where the divergences between Bohr and Wigner were recognised, the subjectivist interpretation of the collapse of the wave packet tended to persist as the dominant characterization of the orthodox view. This is evident in Leslie Ballentine's widely read article on the statistical interpretation of quantum mechanics. In a footnote Ballentine acknowledged that: "Although both claim orthodoxy, there now seems to be a difference of opinion between what may be called the Copenhagen school represented by Rosenfeld and the Princeton School represented by Wigner" (Ballentine, 1970, p. 360). However, later in the paper, in addressing the measurement problem in quantum mechanics, Ballentine completely ignores Bohr's complementarity approach, preferring rather to criticise the "orthodox" quantum theory of measurement formulated by von Neumann and Wigner, according to which "the passive act of observation by a conscious observer is essential to the understanding of quantum theory" (Ballentine, 1970, p. 369). This neatly illustrates the extent to which Wigner's historical reconstruction had succeeded in displacing Bohr's own views from the "orthodox" interpretation of quantum mechanics.

## 7. Conclusion

The last twenty years have witnessed a concerted effort on the part of scholars to distinguish Bohr's views from those who claimed to speak on his behalf. As Chevalley has argued: "what makes Bohr difficult to read is the fact that his views were identified with the so-called '*Copenhagen Interpretation of Quantum Mechanics*', while such a thing only emerged as a frame for discussion in the 1950s" (Chevalley, 1999, p. 59). Don Howard adopts much the same attitude, contending that "the Copenhagen interpretation corresponds only in part to Bohr's view". Elsewhere he puts it in more forceful terms: "Bohr's complementarity interpretation is not at all what came to be regarded as the Copenhagen interpretation". However, I would stress, it is a misunderstanding to think that *any* single view can be regarded as *the* Copenhagen interpretation. Any one of a plethora of different philosophical viewpoints has at one time or another come to stand for the Copenhagen interpretation.

In examining the myth of the Copenhagen interpretation, this paper has attempted to shed some new light on 'how' and 'why' the myth was invented. While Beller focuses on the rhetorical strategies employed by physicists, her account does not pay sufficiently close attention to the way in which the shared vocabulary of the Copenhagen school tended to obscure the differences which existed within it. The semantic plasticity or if you like, the

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which gathered momentum after the Bohr centennial in 1985.

polysemy, of concepts such as completeness, wave-particle duality, indeterminacy, and complementarity served to disguise the disagreements between the physicists who used these terms with little regard for the different meanings these terms had. More important still, however, were the historical reconstructions of physicists like Heisenberg and Wigner in the 1950s and 1960s, which attempted to trace the emergence of the “orthodox interpretation” and with it a particular philosophical viewpoint to the late 1920s. Their rewriting of history completely ignores the different philosophical points of view which took shape in the 1930s and 1940s associated with the interpretation of quantum mechanics.

The invention of the Copenhagen interpretation in the 1950s brought together a number of different philosophical views, and in doing so served dual strategies of legitimation and delegitimation. Firstly by identifying Bohr’s view (and by implication, the views of his followers such as Heisenberg, Born, Dirac, Pauli), with a particular epistemological point of view, one could give legitimacy to that philosophy as underpinning the prevailing orthodoxy in physics. Thus philosophical schools of thought, which emerged during the 1930s and 1940s, such as logical positivism, neo-Kantianism, and dialectical materialism drew on the authority of physics in enlisting Bohr as a chief ally in their cause. However the construction of a unified ‘Copenhagen interpretation’ was also made to serve a different purpose. By identifying Bohr and the Copenhagen school, with an outmoded or condemned philosophical position such as subjective idealism, or Machian positivism, opponents of the orthodoxy could delegitimize it in an effort to give impetus to a new program of interpreting the formalism of quantum mechanics. This was precisely what happened in the case of Soviet Marxism, but one can also find this tendency in many of the more recent attempts to interpret quantum mechanics from a ‘realist’ perspective.

In concluding, it is worth noting that both the legitimation and delegitimation strategies continue to be invoked today - and in doing so they perpetuate of the idea that there is a single philosophical framework behind the Copenhagen interpretation. As an example here I cite the recent work of Kalervo Laurikainen and Roger Fjelland. Laurikainen’s study of Pauli’s thought has led him to conclusion that the conscious observer does indeed play a central role in quantum mechanics, a view which he (in my view mistakenly) attributes to Pauli. While acknowledging there were considerable disagreements between Bohr, Heisenberg and Pauli over the interpretation of quantum mechanics, Laurikainen somehow arrives at the conclusion that Pauli, not Bohr, “was the most consistent representative of the philosophical attitude which can be discerned behind the original Copenhagen interpretation” (Laurikainen, 1988, p. 158). Fjelland, on the other hand, attempts to show “that there are interesting parallels between Bohr’s philosophy and phenomenology (in particularly the latter Edmund Husserl),

and that the Copenhagen interpretation of quantum mechanics is much closer to phenomenology than to positivism” (Fjelland, 2002, pp. 57-8). Both these authors continue to refer to the ‘Copenhagen interpretation’ in an effort to lend weight to their own philosophical agendas.

A deeper understanding of the important disagreements within the ‘Copenhagen school’ and the strategies which helped to form the impression of consensus, remains important because it can help to rid us of the persistent tendency to look for the ‘authentic’ Copenhagen interpretation, as a guiding historiographical concept. It is time to dispel the myth of the “Copenhagen interpretation” and let the different philosophical interpretations of quantum mechanics which emerged in the 1930s take their place alongside one another, not as part of a single homogenous orthodox view, but as competing attempts to make sense of one of the enigmas of twentieth century thought – the interpretation of quantum mechanics.

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