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# Wolfgang Pauli's Philosophical Ideas Viewed from the Perspective of His Correspondence

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**Summary.** Pauli grew up under the influence of Ernst Mach, but – like Einstein – he turned away from the radical positivism of most of his contemporaries quite early. Even though he was a rigorous and systematic thinker, he always devoted much attention to paradoxes and to the mystical background of science. Pauli tried to reconcile this attitude with both modern physics and Jung's archetypal psychology. While his publications present the results of more or less longsome searches for insight, his methodical flow of work and the gradual emergence of understanding become visible only in his rich correspondence.

## 1 The Traditional Relation between Physics and Philosophy

Relations between physics and philosophy have a long history, but a fundamental change in these relations occurred with the discovery of quanta.<sup>1</sup> Until then, it was considered the task of physics to identify rationally definable and empirically testable facts within the philosophically conceivable. It “is an attempt”, so Markus Fierz, alluding to the famous prolog to Faust,<sup>2</sup> “to reconstruct the primordial images of appearances wavering in space.” This illustrates how many of our classical notions were anticipated by philosophers, until they could – after proper transformation and adaptation to scientific demands – be completely incorporated into the domain of physics.

A particularly impressive example of such a conceptual development induced by philosophy is the often discussed, long history of the concept of the atom, which could ultimately be absorbed by physics only in recent times. During the 19th and still in the early 20th century renowned scholars such as Gustav Theodor Fechner, Ludwig Boltzmann, Wilhelm Ostwald, Ernst Mach,

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<sup>1</sup> Cf. Arnold Sommerfeld's (1948) talk on “Physics and Philosophy” at an international summer school in Munich at July 3, 1948.

<sup>2</sup> Letter to Pauli, Meyenn (1996), p. XXXV, and Meyenn (1999), p. 636.

and Max Planck disputed questions of a “Physical and Philosophical Doctrine of the Atom”.<sup>3</sup> Only the experiments by Jean Perrin and their theoretical interpretation in the framework of statistical mechanics by Marian von Smoluchowski and Albert Einstein put a definitive end to such questions. The young Wolfgang Pauli could follow these problems at close range when he went to the “Döblinger Gymnasium” at Vienna. There he received his first scientific education under the supervision of his godfather Ernst Mach, who also advised Pauli to learn from the appropriate mathematics textbooks.

Physicists like Pauli were interested in the philosophy and historical origins of our modern scientific concepts early on. However, with the current publication style in the sciences the impact of such philosophical deliberations about the emergence of new ideas is usually not focused at explicitly. For this reason it is mostly very difficult to fathom the role that philosophical questions play in the development of scientific ideas. Because Pauli belonged to those physicists who were raised in the tradition of writing letters, his case puts us into the beneficial situation that we can close this gap of knowledge to a considerable extent.

Pauli always looked for the company of philosophically and historically educated colleagues when he tried to learn about the state of the art of their research. If the person he wanted to talk to was difficult to approach, he often decided to make a detour via their collaborators who were supposed to launch his request in the right moment. In this way, Pauli was able to keep continuous contact to Bohr and Jung even in heavy-duty periods. Because these conversations were often accompanied by correspondence, we possess – particularly for the later years – revealing evidence for his philosophical ideas.

Pauli studied numerous philosophical and other publications by well-known scholars and authors which are partly conserved and can be accessed in the library assembled at CERN in Geneva. During reading he sometimes annotated passages that he found remarkable or objectionable by bulky marks or brief notes. This provides important indications for his thinking, which are also useful for a better understanding of his letters. A comprehensive reprint collection, including publications of more general content, supplements the rich source material that is now available for contemporary historians of science.<sup>4</sup>

## 2 Physical Concepts Without Philosophical Precedents: Quantum Physics and Pauli’s Exclusion Principle

The role of philosophy as a source of ideas rapidly terminated with modern physics. With the more and more boosting art of experimentation physicists

<sup>3</sup> This was the title of a monograph published in 1855 (second edition 1864) by the Leipzig physicist Gustav Theodor Fechner (1801–1887), founder of the field of psychophysics.

<sup>4</sup> See the overview of Pauli’s estate in Section 10 of this contribution.

at the turn of the past century entered realms beyond our daily experience and discovered that both the microcosm and the macrocosm host phenomena that can no longer be mapped onto patterns accessible by our sensory organs. In particular, the realm of the atoms, and the quantum theory describing them, required completely novel conceptions, impossible to find by resorting to existing philosophical approaches.

In his Nobel lecture at Stockholm, Pauli (1946) described the shock “which every physicist, accustomed to the classical way of thinking, experienced when he came to know of Bohr’s ‘basic postulate of quantum theory’ for the first time.” Then he continued to report how he himself managed to overcome this crisis with the help of the already existing work of his two teachers (see Enz and Meyenn, 1994, p. 166):

“At that time there were two approaches to the difficult problems connected with the quantum of action. One was an effort to bring abstract order to the new ideas by looking for a key to translate classical mechanics and electro-dynamics into quantum language which would form a logical generalization of these. This was the direction which was taken by Bohr’s Correspondence Principle. Sommerfeld, however, preferred, in view of the difficulties which blocked the use of the concepts of kinematical models, a direct interpretation as independent of models as possible, of the laws of spectra in terms of integral numbers, following, as Kepler once did in his investigation of the planetary system, an inner feeling for harmony. Both methods, which did not appear to me irreconcilable, influenced me.”

Pauli’s own contribution to the foundations of the new quantum theory was his somewhat Pythagorean-like *exclusion principle*,<sup>5</sup> assigning spin as a classically not existing property to a particular class of elementary particles, which Pauli presented as “antisocial particles” in his Nobel address. Although the exclusion principle, also called “Pauli Verbot”,<sup>6</sup> was still formulated in the framework of the semi-classical Bohr-Sommerfeld quantum theory, its fundamentally non-dynamic character was not clear until Heisenberg discovered the anti-symmetry of the wave function in summer 1926.<sup>7</sup> The requirement of anti-symmetry introduces a novel kind of correlation between electrons that was alien to physics so far. It implies that two particles must neither come too close to each other nor travel with speeds that are too similar to each other.

In a letter of January 24, 1927, Paul Ehrenfest posed the witty question of “whether in recent times hardly a topic proves viable if it did not first receive the blessings of the curse of the Pauli-Verbot? Eventually, the ennobling accolade is hardly anything else than a stylish slap in the face” (Hermann *et al.*, 1979, p. 372). Pauli’s discovery had such a fundamental significance for the behavior of atomistically constituted matter that the Russian physicist Hans

<sup>5</sup> This characterization is due to Einstein in a letter to his friend Michele Besso of November 30, 1949.

<sup>6</sup> A literal translation would be “Pauli proscription”.

<sup>7</sup> A particularly instructive example for the impact of anti-symmetrization on the behavior of two electrons is discussed in Chapter 20 of Margenau (1950).

Hellmann claimed in his “Introduction to Quantum Chemistry” (Hellmann, 1937): “Everything non-classical ultimately follows from the Pauli principle and the existence of a kinetic zero-point energy of the electrons.” A number of phenomena unexplained so far could suddenly be understood: the structure of atoms and molecules, the nature of directed valence forces, ferro- and paramagnetism, the spectra of atoms and molecules, and the stability of matter in general.

Acknowledging the outstanding importance of the discovery of the exclusion principle, the Dutch physicists honored Pauli in 1931 with the Lorentz medal, endowed just a year before. In his humorous address, Ehrenfest (1931, p. 621) could not resist to allude to the pitiless criticism with which Pauli did not even spare his best friends (as the attending Bohr):

“Sometimes you do even accomplish that your closest and most trusted friend impatiently jumps out of his otherwise carefully balanced vocabulary and syntax. . . . Yes, Mr. Pauli, finally you will not succeed to restrain all your contemporaries from appreciating you very highly, even adore you, and thus wish you all the best for your work and for your personal bliss.”

In the new edition of his Handbuch article “Philosophy of Mathematics and Natural Science”, Hermann Weyl (1949) had claimed that Leibniz’s identity principle was a classical precursor of the Pauli principle. Weyl explicitly emphasized that “the Leibniz–Pauli exclusion principle [holds] for electrons but not for photons” (Weyl, 1949, p. 247). Pauli immediately raised vehement objections. Supported by his colleague and philosophical advisor Markus Fierz at Basel he convinced Weyl that his claim was untenable: “A philosophical principle, like the ‘principium identitatis indiscernibilium’, should after all not be understood such that it holds for some object but not for others” (Meyenn, 1993, p. 701).

Further investigations of quantum phenomena revealed additional cases of non-classical behavior, among them the tunnel effect, the indistinguishability of elementary particles (described as “Selbigkeit” by Schrödinger), the fundamentally statistical character of Schrödinger’s wave function, and finally the violation of parity, which troubled Pauli until to the last years of his life.

Given all these new developments, Pauli now posed to philosophers the inverse task to augment their concepts and adapt them to the improved body of knowledge in atomic physics. In a letter to the philosopher Hermann Levin Goldschmidt (1990, p. 41) of February 19, 1949, he wrote:<sup>8</sup>

“It seems to me as a philosophical layman that the task of philosophy consists in generalizing the emerging insights of current physics – that is, all its essential elements – in such a way that it can be applied to fields more general than physics. Such an achievement would, in turn, enrich the individual disciplines and prepare future developments.”

<sup>8</sup> Hermann Levin Goldschmidt (born 1914) had visited a lecture by Pauli at February 8, 1948, and sent him his book *Philosophie der Dialogik* (Goldschmidt, 1948) immediately the next day. Pauli’s letter is a reaction to this book.

Later, in his “Mainz sermon” (see Section 9), Pauli indicated how he thought about this in more detail.

### 3 Pauli, Mach, and Positivism

Positivism was the philosophical guidance system of scientific research, based on classical physics, in the early 20th century (cf. Frank, 1917). It is an attempt to organize scientific progress in terms of clear-cut recipes. Theories were supposed, as Pauli recalled during a philosophy congress in Zürich in summer 1954, “to be derivable by compelling logical conclusions from minute books” (Pauli, 1957, p. 38; see also Kraft, 1950, pp. 108ff; Holton, 1973, p. 145).

Ernst Mach, who had given the seventh edition of his famous “Mechanics” as a gift to Pauli in 1913, also advised Pauli’s father in the education of the precocious boy. As the widow Franca Pauli reported, he was quite hot-tempered, and in one of his outbreaks of displeasure he had even smashed his mother’s valuable Chinese vase. Only after he discovered mathematics and its wonderful presentation in Leonhard Euler’s “Introductio In Analysis Infinitorum” (printed 1748 in Lausanne) and other ambitious mathematical *opera*, the world turned less inane for him. Letters of his father and reports of contemporaries such as the Vienna physicist Hans Thirring testify that Pauli had the reputation of a mathematical genius already in his school days at the Gymnasium in Vienna.<sup>9</sup>

In the fifth chapter of his “Mechanics” Mach discussed the “Relations of Mechanics to Other Domains of Knowledge”. Here Pauli highlighted a paragraph essentially outlining the positivist program:

“The mechanistic world view seems to us as a historically understandable, excusable, maybe even temporarily useful, yet on the whole artificial hypothesis. If we want to remain faithful to the method that led most important scientists such as Galilei, Newton, Carnot, Faraday, Mayer to their

<sup>9</sup> In a letter of August 8, 1914, to Wilhelm Jerusalem, philosopher at the University of Vienna since 1892, Ernst Mach writes from Haar/Munich: “Profesor Pauli spent a few days here with his son. He believes that he is a profound mathematical genius.”

Hans Thirring recalled in a broadcast address at December 19, 1958, that Pauli already as an adolescent showed such extraordinary talent that he was described as a child prodigy “who – as Mozart – met all the expectations. ... During the first world war, 1915 or 1916, a younger colleague of mine, teaching at the Gymnasium in the XIVth quarter, told me one day: ‘Imagine, in the fifth class we have a schoolboy with such a phenomenal talent for mathematics and physics that he promises to become a new Gauss or Boltzmann.’”

When the young Pauli studied with Sommerfeld in Munich, Sommerfeld sometimes asked Pauli for advice to resolve mathematical difficulties. At some occasion Weyl had submitted a new mathematical treatment of a problem to Sommerfeld, whereupon the latter complained (in a letter of January 6, 1920) that “I myself, but even Pauli, had major difficulties to follow your discussion.”

great discoveries, we restrict our physics to the expression of the factual and stay away from hypotheses about anything behind the factual, where nothing is tangible or testable. Then we need to simply determine the real relation between motions of masses, changes of temperature, variations of the values of potential functions, chemical rearrangements, without assuming anything else underneath these elements than physical features or characteristics given to us indirectly or directly by observation.”

Later Pauli dismissed this methodology, also recommended by neo-positivists, as too one-sided and emphasized that a “creative irrational element” is involved when something novel is being found. He saw a promising access to our understanding of the process of scientific discovery in Jung’s psychology of the unconscious, which he began to look into besides his purely scientific research.

#### 4 The Article on Relativity: Felix Klein Introduces Pauli to the Art of Scientific Writing

Already at school Pauli had, supported by the Vienna lecturer Hans Bauer (1891–1953), gotten access to tensor calculus. It was difficult to learn for a schoolboy but inevitable to understand the then new general theory of relativity. So it happened that Pauli in his first semester at the University of Munich surprised his teacher Sommerfeld with two finished contributions to relativity, which even aroused Einstein’s attention. This led Sommerfeld to entrust an article on relativity to Pauli, which was to complete the volume on mechanics within the “Encyclopedia of Mathematical Sciences”.<sup>10</sup>

While other students were occupied with their lectures and exercises, Pauli used the first two years of his study to write this article. He received particular support by the great mathematician Felix Klein in Göttingen. As a founder of the Erlangen program, he was one of the pioneers of relativistic physics. He introduced Pauli “not only into the subject but also into the art of disposition and scientific style.”<sup>11</sup> In addition, Klein provided lecture manuscripts and other notes for Pauli’s work and advised him far beyond usual measures. On April 20, 1920, Klein informed Einstein:<sup>12</sup> “Luckily, at the moment work on the mathematical encyclopedia is making better progress again. In particular, we are approaching relativity theory from astronomical and physical angles

<sup>10</sup> Originally, Einstein was commissioned to write this article. “As Einstein declined this offer”, Sommerfeld said when he recommended Pauli as a corresponding member of the Bavarian Academy of Sciences in 1948, “I proposed to Pauli to write it together with me. But when he showed me his first drafts, I abandoned the idea of a joint project. His article became a masterpiece that is unmatched until today.”

<sup>11</sup> Quoted after a contribution by Wilhelm Wirtinger, Vienna, to the Festschrift for Klein published in 1919.

<sup>12</sup> Buchwald *et al.*, 2004, p. 535.

(Kottler under the supervision of Oppenheim, Pauli under the supervision of Sommerfeld).”

When the 250-pages and 400-footnotes article, finished in December 1920, appeared in print at November 15, 1921, Pauli was already a scientific celebrity. The proficient editor Arnold Berliner was even afraid that Pauli might become megalomaniac because of Einstein's overwhelming appraisals. But the latter could appease him with the remark that this premonition came too late.

By his collaboration with Klein, Pauli had become acquainted with the most esteemed scientists of his time. And he became familiar with the mathematical tools that were exquisitely suitable for dealing with the upcoming problems of theoretical physics. As hardly anyone else he was equally familiar with relativity theory and quantum theory, the two most demanding fields of theoretical physics. So he was ideally prepared for the challenges that physical research had in store for the coming decades.

## 5 Moritz Schlick and the “Vienna Confession”

In an early correspondence with Moritz Schlick, the leading philosopher of the “Vienna Circle” who in 1922 was appointed the chair formerly held by Mach, Pauli evinced his interest for epistemology and natural philosophy.<sup>13</sup> Here he expresses his philosophical inclination for the very first time. On August 15, 1922, Schlick had sent him the fourth edition of his book on “Space and Time in Contemporary Physics” with thanks for the “hours spent in Rostock” together. At this meeting, to which Pauli came from Hamburg, their conversation apparently led into diverging opinions concerning a publication by Joseph Petzoldt, an adherent of Mach. Pauli asserted (Meyenn, 1985, p. 692) that he had “looked carefully into Schlick's objections against positivism once again” and could “no longer acknowledge them as sound.” Underlining his personal conviction, Pauli emphasized once more that he thought of “positivism as a completely coherent world view, free of contradictions”, even though obviously “not the only one possible”.

A few years after the new quantum mechanics was established, Pauli received a programmatic publication from the “Vienna Confession”, just founded by Moritz Schlick, Rudolf Carnap, Hans Hahn, Otto Neurath and

<sup>13</sup> Pauli knew well that Einstein also held Schlick in high esteem, both as a philosopher and as a physicist. Einstein had conveyed to Schlick on December 14, 1915, that he thought of his publications as “among the best that has been written about relativity so far.” He added “you [also] saw correctly that this line of thought had a great influence on my efforts, and more specifically, E. Mach, and even more so Hume, whose ‘Treatise of Human Nature’ I had studied avidly and with admiration shortly before discovering the theory of relativity” (Schulmann *et al.*, 1998, p. 220).

Ludwig Wittgenstein. He still found it quite interesting “but I do not feel entirely affiliated with it” any longer.<sup>14</sup>

During the 1920s Schlick had repeatedly commented on the position of the principle of causality within physics; however, he almost exclusively concerned himself, somewhat one-sidedly, with the consequences brought about by the theory of relativity. Later he turned to quantum theory (Schlick, 1931, p. 145):

“But now that the viability of quantum theoretical concepts is confirmed by the extraordinary success of its applications, and we had quite a few years to get used to the new ideas, now the attempt should no longer be premature to achieve philosophical clarity concerning the meaning and the impact of the thoughts that current physics contributes to the problem of causality.”

This agreeable statement notwithstanding, Schlick failed to address the idea of complementarity, so fundamental for quantum mechanics. Moreover, Pauli criticized Schlick’s imprecise formulation (Meyenn, 1985, p. 56): “The point is that I can interpret everything you say in such a way that I agree. However, much can also be interpreted such that I had to protest. Briefly, I think you did not express yourself precise and clear enough in all the questions you raise.” This might be the origin of the popular Pauli quote “This is not even wrong!”

When Pauli visited the USA in summer 1931 and in winter 1935/36, he met a number of emigrants who now established a closer relationship with him. During a trip to Chicago he got to know the physicist Carl Henry Eckart, a friend of Carnap. Eckart had made important contributions to the development of wave mechanics. Moreover, he had helped to translate Heisenberg’s lectures on “The Physical Principles of Quantum Theory” at the University of Chicago, which stimulated his epistemological interests. Recently, some exchange of letters with Pauli surfaced in Eckart’s estate. These letters give us new insights into Pauli’s philosophical views and general interests during the 1930s.

In a letter of January 17, 1936, Pauli asked Eckart for his “further spiritual and human relation to the Vienna confession”, which he was still attached to (as another letter of February 11, 1936, shows). At the same time he couched

<sup>14</sup> Meyenn, 1985, p. 15; see also Geier (1992). Pauli’s library included Rudolf Carnap’s programmatic volume “Der logische Aufbau der Welt” (Carnap, 1928) which Pauli had carefully read and annotated. Concerning Carnap’s demand (preface, p. V) “to dispel all of metaphysics from philosophy, because its hypotheses cannot be rationally justified” and “every scientific thesis must be rationally substantiated”, Pauli noted: “The fact that science is done at all cannot be rationally justified!”

Pauli’s aversion against an absolutistic attitude with respect to philosophical systems was primarily directed against Kant’s dogmatic *a priori* conditions. He reinforced this in his letter to Goldschmidt (1990, p. 39) of February 19, 1949: “Rational ideas are never necessary or certain and always object to rational criticism. No rational idea resides in an unassailable olympus of necessities of thought.”



his critical stance concerning symbolic logic, which was then much discussed in positivist circles. In particular he saw a restricted role for mathematics to play in future physics:

“The symbolic logic has, according to my opinion, not a direct applicability to physics, because the theoretical physics represents physics by mathematics (‘bildet die Physik auf die Mathematik ab’). So the symbols involved are mathematical symbols and their connection with each other is a mathematical question. (I agree on this point completely with what you quote as Dirac’s opinion.) – But the main difference of mathematics and physics is the connection of the mathematical symbols (or at least some of them) with empirical results – that means in the last end with some sensations which are made artificially simple. And in this latter connection all logical paradoxes or antinomies of the human knowledge come into play. One of them concerns the notions of subject and object and consists in the fact that on the one side it is necessary to distinguish between a recognizing subject and a recognized content in order to be able to formulate any knowledge; that on the other side every content of thoughts is also a part of the subjects. Both sides of the situation of human knowledge are equally important and the best we can do is to put them on the beginning as necessary conceptual antinomies (not ‘paradoxes’).”

## 6 Departing from Positivism: Complementarity, C.G. Jung, and the Problem of Opposites

The epistemological shifts that accompanied the discovery of quantum mechanics and its interpretation were partly responsible for Pauli’s altered view on positivism. But before we go into details, let us give a general overview of Pauli’s philosophical development as he saw it himself:<sup>15</sup>

“What impressed me philosophically at all, I can ... only indicate very briefly: opposite Mach (empiricism) – Plato (ideas at ‘heavenly location’), Kant (the preconditions for the natural sciences of his time are dogmatically fixed and erroneously considered as the quintessential preconditions of human reason, the *a priori* is ascribed to rationally formulated ideas) – modern psychology of the ‘unconscious’ (Freud, C.G. Jung) (the *a priori* lies in pre-conscious states – *esse in anima* – ‘archetype’ as pathway for imagination = pre-existing images as in Plato, Proclus, Kepler). Then: enlightenment (Voltaire, Mach) – on the other hand Vedanta teachings, Schopenhauer (‘will’ as his God). (P.S. Bernard Shaw’s remark that unmasking a heavenly ‘Hauptmann von Köpenick’ does not prove that a real ‘Hauptmann’ exists, as I noted.) The entire East impressed me strongly. China much more than India, both the ideas of the I-Ging (Yin-Yang-polarity) and Laotse. Schopenhauer’s attempt to reconcile Kant and Buddhism seemed very interesting to me but remained unsuccessful as a consequence of Kant’s backwardness and Buddha’s passivity vis-a-vis the world. In general the 17th

<sup>15</sup> Quoted again from the letter to Goldschmidt (1990, pp. 29–31) of February 19, 1949.

century (besides much more ancient times) means a lot to me and the 19th century little. German intellectuality always appeared to me to tend towards dogmatism and kinds of one-sidedness that are foreign to the instincts. How different are the wise men of China! And everything collective-crowdlike is much afar from my taste in general. Furthermore, it seems to me that feeling is as deep as thinking and that *amo ergo sum* would be as justified as the *cogito ergo sum* by Avicenna–Descartes.<sup>16</sup> (P.S. Pathological exaggeration of the thinking function by Hegel.) In this atmosphere, looking for a balance within pairs of opposites, I grew up from the earliest days of my boyhood.”

As one of the founders of the new quantum theory Pauli belonged to the most fervent advocates of the so-called Copenhagen interpretation. In September 1927 he retreated to “Villa Monte Pensada” close to Como together with Bohr for joint discussions of the notion of complementarity.<sup>17</sup> This notion, originally introduced by Bohr, was thought to enable a synthesis of the seemingly contradictory dualism of wave and particle.<sup>18</sup> It turned out that for this purpose extensions of the usual notions of causality and reality were needed. In the quoted letter to Goldschmidt (1990, p. 37) Pauli specified the epistemological significance of complementarity:

“However, the modern physicist does not refer to a ‘complementary’ situation as contradictory but he characterizes his description (since 1927) as contradiction-free (English: ‘self-consistent’). The range of applications of opposing concrete images (such as ‘wave’ and ‘particle’) in the new theory is now delineated in such a way that contradictions cannot occur. What appears are no ‘contradictions’ but is rather a limitation of the applicability of our ways of perception, not only by the possibilities of observation but also by the possibilities of definition (caused by the laws of nature).”

Later on, attempts have been made to apply complementarity also to problems outside physics, e.g. a complementarity of clarity and truth (Pauli’s letter to Goldschmidt, 1990, p. 33):

“If a proposition is too clear, then something goes wrong with its correctness, and if a proposition is true, then its clarity is limited. For every truth contains something partly unknown, only foreboded, and thus also a hidden opposite of its conscious meaning.”

Pauli tried to illustrate the complementary distinction between symbolic and quantitative descriptions with the schema shown in Tables 1 and 2.

Pauli’s epistemological conceptions reveal the influence of Jung’s psychology of the unconscious, with which he concerned himself, also scientifically, since his marriage with Franca in April 1934. For instance, observations of

<sup>16</sup> Pauli used these comparisons also in his “Philosophical Comedy” of 1952, see Meyenn 1996, pp. 464, 493.

<sup>17</sup> This information is due to an interview with Oskar Klein of February 28, 1963.

<sup>18</sup> A clear exposition of this problem area can be found in Pauli (1950).

dreams were considered as options to track processes of the unconscious. During his psychoanalysis Pauli had learned how to decode the language of his dreams; now he wanted to continue this activity out of scientific curiosity. By the technique of *amplification*, the contents of private dreams could be related to and interpreted by events of both own experiences and – in agreement with the idea of a collective unconscious – myths of ancient times or foreign cultures.

It was important for Pauli's efforts to decipher the language of dreams and other manifestations of the unconscious that it can be comprehended only indirectly and *symbolically*.<sup>19</sup> Pauli regarded the quantum mechanical  $\psi$ -function, which relates possible observational data to each other (as a probability amplitude), and adopts the role of Kant's things-in-themselves as such a symbol uniting opposites. In the letter to Goldschmidt (1990, p. 39) of February 19, 1949 he explains:

“The symbol is always an abstract token, be it quantitative or qualitative, be it mathematical-theoretical or emotionally laden. Only part of the symbol can be expressed by conscious concepts, another part acts on the ‘unconscious’ or ‘preconscious’ state of an individual. The same holds for mathematical symbols, for only he is gifted for mathematics for whom mathematical tokens (in the sense mentioned above) have symbolic power. The symbol always is a tertium unifying opposites, what logic alone cannot ‘provide’.”

Pauli considered it as a remarkable coincidence whenever novel concepts appeared simultaneously in completely different areas, e.g. the introduction of the notion of a physical field and the discovery of the unconscious in psychology.<sup>20</sup> As the electromagnetic field

“was theoretically related to a reality, no matter whether or not it can be visualized by suitable means, the unconscious was related to a reality as an edge layer of subliminal ‘contents’ which, however, can possibly influence consciously perceived processes considerably.”

According to Freud, this “subliminal something, somehow controlling consciousness from behind the scene”, was based on “contents repressed from consciousness”. Jung, on the other hand, attributed it also to “collective contents which had never been conscious before”.

For a while Pauli was so fascinated by the interpretation of dreams that some of his friends started to demur. When the mathematician Erich Hecke at Hamburg heard about Pauli's visit to Princeton in fall 1935, he wrote in a letter to Weyl of October 31:

“Probably you took Pauli with you when you traveled back. His wife, whom I find very cute, hopefully accompanied him. Yes, he depends very much on

<sup>19</sup> Compare Pauli's notes on “Modern Examples of Background Physics” which he comprised for Jung in summer 1948 (Meier, 2001, pp. 179–196).

<sup>20</sup> See Pauli (1954), p. 283. He made similar remarks in a letter to C.A. Meier of February 26, 1950 (see Meyenn, 1996, pp. 35ff).

Komplementär

Symbolische Beschreibung  
 Schlüsselsphärische Seite der Erfahrung ein  
 Betrifft sowohl Psyche als auch Physik  
 Vermittelt auf Präzision

Komplementär (Naturwissenschaft-)  
 Quantitative Beschreibung  
 Unvollständig  
 Der Archetypus bleibt unbekannt oder verändert im Nachhinein  
 Ist stets moralisch unverbundlich  
 „Entdecken Naturwissenschaften“

Vorwissenschaftliches Handeln:  
 Nahe Bestimmung der Archetypen (Praxis)  
 Beispiel: Platon's Pyramiden  
 Phantasie = <sup>Träume</sup> <sup>Illusionen</sup> <sup>Wahrheiten</sup>  
 Psyche und Physik <sup>mit</sup> <sup>unterschieden</sup>

(?) <sup>den</sup> <sup>Wahrheiten</sup> <sup>der</sup> <sup>Platonischen</sup> <sup>Praxis</sup> <sup>ist</sup> <sup>zur</sup> <sup>Wahrheit</sup>  
 Hauptpunkt der Debatte der Erkenntnis für die Seele oder „objektive Erkenntnis auch der inneren Welt“

Kepler  
 der <sup>Verkörperung</sup> <sup>wären</sup> <sup>unbekannten</sup> <sup>Gesetze</sup> <sup>hervor</sup> <sup>brachte</sup> <sup>keine</sup> <sup>Psychologie</sup>

Hauptpunkt der „objektiven Erkenntnis“ <sup>„entdeckend“</sup>  
 „(?) <sup>Quelle</sup> <sup>„Hilfswort“</sup> <sup>„Hilfswort“</sup>“  
 „Nur in. S. 100, das in der symbolischen“

Thomson: „Die Seele kehrt wieder“, Hauptfrage: Ist die Seele nur subjektiv, der Psyche des Individuums, supranatur oder doch auch objektiv in der Außenwelt der physikalischen Objekte inpendent vorhanden und drückbar?

Vergang beobachten, so wie es war, dann mathematisch Natur beschreiben, von symbolischer Natur beschreibung abstrahieren. Bei Kepler hieß es, Abstrahieren <sup>Kepler</sup>, <sup>Das</sup> <sup>Die</sup> <sup>Abstrahieren</sup> <sup>beinhaltet</sup> <sup>keine</sup> <sup>zusammenhang</sup> <sup>mit</sup> <sup>keiner</sup> <sup>mathematischen</sup> <sup>Philosophie</sup>.

NACHLASS  
 PROF. W. PAULI  
 10/112

Table 1. Handwritten outline on “complementary modes of description” by Pauli (document 10/112 in the Pauli estate at CERN Geneva)

<b>complementary</b>	
<b>symbolic description</b>	<b>quantitative description</b> (natural science)
includes emotional side of experience	incomplete
concerns both mental and physical aspects	the archetype remains unconscious or moves into the unconscious
abstains from precision	always morally noncommittal
pre-scientific phase: naive use of archetypes (projection)	“orthodox natural science” naive ignorance of archetypal images (illusion that all images arise from ego-consciousness)
example: Fludd's pyramids*) phantasies and dreams of modern man *) dimensions of planetary spheres do not agree with reality	apex: 19th century
mental and physical <i>not distinguished</i>	disregarding the mental origin of all propositions about the physical; only the latter guarantees relations between ideas and perceptions
<b>Kepler</b> the connection between primordial images and laws is already loose; no psychology; attitude of “objective knowledge of the external world”	
attitude of the significance of knowledge for the soul or “objective knowledge of the inner world as well”	lost: the “correspondence” (?) of inside and outside, symbolized by the anima, idea of microcosm–macrocosm
<i>instant: “the soul returns”, main question: is the anima only subjective, associated with the psyche of individuals, or also objectively existing and efficacious in the “external world” of physical objects?</i>  Study the process by which a quantitative mathematical description of nature separates from a symbolic description of nature. Both present in Kepler, <i>partial</i> separation, causing severe clash with hermetic philosophy.	

**Table 2.** Translated reconstruction of Table 1

supporting help, this silly billy, with all his extraordinary intelligence. What I came to know about him most recently concerning his actual condition is really unedifying. For years he is now under treatment by Jung because his nerves caused him great trouble. Lastly he was so obsessed by his treatment that he talked about nothing else than his dreams, and daily affairs played a role for him only insofar as they were reflected by his dreams. This is a huge piece of work for his wife.”

In spite of this psychological pressure Pauli was able to do important research in physics in those years. And he did not only observe and analyze his dreams – he also drew far-reaching consequences as to the role of the unconscious in the evolution of science. In the mentioned letter to Eckart, Pauli referred to his novel views on scientific creativity, as they had changed due to Jung’s psychology:

“A similar antinomy arises from the concepts of ‘consciousness’ and the ‘Unconscious’ – the latter as an idea being on the other hand also a content of the consciousness (ein ‘Bewusstseinsinhalt’). I would like to make the statement that every concept (Begriff) describing our knowledge can by analysis in the last end be reduced to such not further analyzable antinomies (and just if it would be otherwise, then it would be something wrong with the underlying concepts.) – It seems to me that the connection between symbols and experience cannot be enlightened by symbols again because those would remain always on the one side. There must be some place where the individual ‘Hinweise’ to concrete objects come into play.

What we only can do is to show how human knowledge and particular sciences, as physics for instance, *do really proceed*. And then we shall not find confirmed the desires (Wünsche) of individual philosophers and philosophical systems. We shall find neither the pure inductive nor the pure deductive type of physics possible and we shall find sometimes that first the empirical results were present and after that one has found the symbolic mathematical description of them, and sometimes also the opposite was the case.

I personally have, besides, not much interest to fix the state of any science in some accidental point of time axiomatically, but merely to look in what direction a further development of this science is possible. (And so, I think, the most satisfactory situation is, if the axiomatics would always come too late.)”

## 7 Princeton, Panofsky and the Kepler Article

During the war, when Pauli lived in the USA for an extended period of time, he entertained some epistemologically oriented correspondence with the philosopher Hans Reichenbach, who had emigrated to California in 1938. When Reichenbach had finalized the manuscript for his book “Philosophical Foundations of Quantum Mechanics” (Reichenbach, 1944), he asked Pauli for advice

concerning “causal anomalies”.<sup>21</sup> Reichenbach’s proposal of a three-valued logic in this context did not find Pauli’s support. On the other hand he did not want to argue against Reichenbach’s concepts “in the sense of an anti-metaphysical vice squad.”<sup>22</sup> “As a physicist I prefer to leave the laws of logic and the axioms of mathematics untouched as a sound basis.” Although Pauli was familiar with the problematic crisis of axiomatic foundations, he recommended that physicists should act according to the dictum *divide et impera*.<sup>23</sup>

The art historian Erwin Panofsky, who had been a young reader at the University of Hamburg at the same time as Pauli, was of major influence for Pauli’s further career. He was a member of the Humanities Department at the Institute for Advanced Study (IAS) at Princeton since 1935.<sup>24</sup> The stimulation that Pauli received through his contacts with Panofsky and other members of this department, such as the philologist Harold F. Cherniss and the historian Ernst Kantorowicz, sparked his interest in Renaissance philosophy, which eventually led to the Kepler article published in a joint book with Jung in 1952. Inspired by his dream analysis, unveiling his transformation from a *trinitarian* to a *quaternarian* attitude, Pauli intended to illustrate the impact of Jungian *archetypes* and the role of the *collective unconscious* with the example of Kepler.

The idea of such a study apparently originated at the IAS Princeton with its excellent library<sup>25</sup> and a circle of scholars who were open to interdisciplinary topics.<sup>26</sup> In addition to Panofsky, Cherniss and Kantorowicz, it was mainly Max Knoll, the co-inventor of the electron microscope, who stayed at

<sup>21</sup> Reichenbach (1948) authored a contribution entitled “The Principle of Anomaly in Quantum Mechanics” for the issue of the journal *Dialectica* that was edited by Pauli.

<sup>22</sup> Quoted from a letter of Pauli to Reichenbach of January 6, 1943, which will be published in the supplement volume to Pauli’s correspondence edition.

<sup>23</sup> Pauli explained his position in the letter to Eckart of February 29, 1936: “My opinion is that logic and mathematics are different in their content (‘Inhalt’) more than in their form. In mathematics one wants to derive from given axioms new concepts and new consequences. And I think that the particular choice of axioms which is done in mathematics is not accidental. Further I think that just these particular axioms of mathematics are suited to give a scientific description of nature as it does physics.”

<sup>24</sup> Compare Meyenn, 2005, p. 237. Panofsky’s extensive correspondence is being edited by Dieter Wuttke.

<sup>25</sup> At February 26, 1950, Pauli reports from Princeton, full of enthusiasm, “that another colleague at the Humanities Department owns an original version of Fludd’s ‘Philosophia Moysaica’ (it is supposed to be the only copy available in the USA)” (Meyenn, 1996, p. 35).

<sup>26</sup> Pauli’s occupation with Kepler is first mentioned in his letter to Fierz of December 29, 1947 (Meyenn, 1993, pp. 488, 496).

Princeton together with his wife Ursula<sup>27</sup> and was very much interested in *synchronistic phenomena*.<sup>28</sup>

In his study, Pauli related the rise of the modern scientific world view to a repression of religious feelings exclusively into domains of the church. This, he claimed, was accompanied by a transition from a quaternarian to a trinitarian attitude which took place in both collective and personal realms of the psyche (Meyenn, 1993, p. 706):

“For this reason, it is important even today to reformulate the principle of synchronicity as a further principle for the explanation of nature, on equal footing with and independent of causality, i.e. complementing it, in a suitable way. Only such an explanation of nature could be called quaternarian, while present-day physics is still trinitarian.”

## 8 Collaboration with Philosophers at Zurich: “What Went Where?”

After his return to Zurich in spring 1946 Pauli established contacts with the philosophers at his university. In particular, he made friends with the Austrian-Hungarian philosopher Franz Kröner (1889–1958) who had studied physics and mathematics, and later philosophy, at Vienna and joined the Polytechnicum at Zurich as a scientific assistant to Ferdinand Gonseth in 1951 (Meyenn, 1999, p. 111). Pauli became a frequent visitor of the history-of-science seminars run by Gonseth and Paul Bernays.

Moreover, he served on the advisory board of the journal “Dialectica” published by Swiss philosophers. He also helped to organize several philosophical conferences which he animated sanguinely with sketchy formulations, for instance referring to meetings of “Knights at the Round Table”. In 1948 a special issue of “Dialectica” was published on the idea of complementarity under the patronage of Pauli, with contributions by Einstein, Bohr, Heisenberg, Reichenbach, and de Broglie. In a lecture at the “Philosophical Society” Zurich in 1949 Pauli indicated the general possibilities which the idea of complementarity, grown out of atomic physics, holds for a reintegration of a science that has fragmented into many subdisciplines. He deplored that “in contrast to the theory of relativity, this turn in modern physics has been realized only by a small number of philosophical specialists” (Pauli, 1950, p. 72).

Under the impression of the progress of quantum mechanics, Pauli had more and more distanced himself from his earlier positivist stance. However,

<sup>27</sup> Compare Meyenn, 1996, pp. 55f. Knoll (1952) gave a lecture on “Wandlungen der Wissenschaft in unserer Zeit” at the Erano Meeting 1951.

<sup>28</sup> See Meyenn, 1993, pp. 706f. Jung denoted phenomena as synchronistic if they are connected by a common meaning but have no physical explanation (Jung, 1952, p. 83). The notion is derived from Leibniz’s parable of synchronized clocks for the illustration of mind-matter relations.



some physicists regarded the development of quantum physics as a strict consequence of the positivist program. Pauli, on the other hand, emphasized that the epistemological situation of modern physics “was not anticipated by any philosophical system”. He liked to scoff at the tendency of philosophers toward systematization and was noncommittal with respect to any of the philosophical schools ending with ...*ism*.<sup>29</sup> While philosophers like to subordinate their entire thinking under a system, physicists rather tend to be more eclectic. Depending on circumstances they borrow ideas from different philosophical systems and do not care much about philosophical vicissitude. It is this rather positive sense in which one has to interpret Pauli's statement that Fermi was a semi-empirical opportunist because he did not systematically develop his theory of  $\beta$ -decay from first principles.

Anyway, Pauli himself did “not intend to become a founder of religion or philosophy with advancing age”, such as Bohr for instance,<sup>30</sup> “who decidedly has a tendency to perform as the originator of a ‘religion of complementarity’”. My stance is rather to find some balance between extreme directions”, he declared during the philosophy congress at Zurich in 1954.

Much in the spirit of psychological practice Pauli observed subtle changes of historical background. He considered it particularly meaningful when certain concepts disappeared and were replaced by others. Using the example of the vanished concept of freedom in a Cartesian world view, he commented (Meyenn 1996, p. 472):

“Even if one does not share the naive belief in progress of the 19th century, it is very instructive to investigate the history of ideas – and the history of physics and the sciences as well – from the viewpoint: *What went where?* For we learned that every act of conscious realization is paid for by the fact that something which was conscious beforehand – even though sometimes vaguely – falls back into the unconscious and may reappear ‘in an altered shape’ as a revenant.”

In a letter to von Weizsäcker he prompted him to “rewrite the history of ideas and of science from the perspective of the persisting question: What went were?” (Meyenn, 1999, p. 142).

## 9 Science and Occidental Thinking

In fall 1954 Pauli had read “a book on West-Eastern mysticism and another one about telepathy” in preparation for an upcoming congress at Mainz.<sup>31</sup> In an elaborate letter to Jung's secretary Aniela Jaffé he outlined his preliminary

<sup>29</sup> Compare the correspondence with Kröner with some examples of Pauli's derogatory remarks on the idiosyncrasies of philosophers.

<sup>30</sup> Quoted from a letter to Heisenberg of May 13, 1954 (Meyenn, 1999, p. 620).

<sup>31</sup> Compare the commentary by Meyenn (1999), pp. 629f, and a folder labeled “Mainzer Vortrag 1955” and “Unity of Knowledge von Bohr” in Pauli's estate.

ideas with respect to his congress contribution on “Science and Occidental Thinking”. He conceived the interrelation of mystic experience and rational understanding in the evolution of occidental thinking “as a being awake that is a dream, and a dreaming that is like being awake.” After leaving aside this work for a while, he turned back to it early in 1955.

In mid January 1955 he finished a first draft of the text, which now was only to be transcribed and “polished”. “The most difficult thing was that the talk should only take 45 minutes (with an extensive discussion afterwards). However, what I think about the problem of how redemptive knowledge [Heilserkenntnis] and scientific knowledge are related to each other comes out quite well now.” Pauli sent a copy to Kröner, “partly for checking historical details”. In mid February he asked Kröner for information about other participants and traveled to Mainz at March 16 “to sing his song to an unknown crowd” (see letter to Panofsky in Meyenn, 2001, p. 154).

In a compact historical overview of the “problem of the relation between redemptive knowledge and scientific knowledge” Pauli argued that “periods of dispassionate research on critical lines are often succeeded by others in which the aim is to try to include science in a more comprehensive spiritualism involving mystical elements.” Finally he makes the far-reaching statement that (see Enz and Meyenn, 1994, p. 147)

“... at the present time a point has again been reached at which the rationalist outlook has passed its zenith, and is found to be too narrow. Externally all contrasts appear to be extraordinarily accentuated. On one hand the rational way of thought leads to the assumption of a reality which cannot be directly apprehended by the senses, but which is comprehensible by means of mathematical or other symbols, as for instance the atom or the unconscious. But on the other hand the visible effects of this abstract reality are as concrete as atomic explosions, and are by no means necessarily good, indeed sometimes the extreme opposite. A flight from the merely rational, in which the will to power is never quite absent as a background, to its opposite, for example to a Christian or Buddhist mysticism is obvious and is emotionally understandable. Yet I believe that there is no other course for anyone for whom narrow rationalism has lost its force of conviction, and for whom also the magic of a mystical attitude, experiencing the external world in its crowding multiplicity as illusory, is not effective enough, than to expose himself in one way or another to these accentuated contrasts and their conflicts.”

Again Pauli presents a union of opposites as a goal, a kind of theory of everything, in which rational understanding and a mystical experience of unity in the sense of Bohr’s idea of complementarity are to be reconciled.

After his return to Zurich he communicated his general impression about the “current spiritual situation in the occident” to Panofsky (Meyenn, 2001, p. 196):

“In Mainz I realized that *the evil* (inquisition, combats of sects, communism – in my opinion a Christian sect with “matter” as its superior metaphys-

ical principle with the status of a goddess) is not sufficiently accepted as *occidental*. There are gentlemen who carry an “iron curtain” (namely of repression) *in themselves*. The symmetry between inside and outside seems perturbed.”

Pauli was satisfied with the success of his lecture. He appreciated in particular the acquaintance with the historian of science Willy Hartner from Frankfurt, former collaborator of the sinologist Richard Wilhelm whom he admired much. All lectures were published in a volume entitled “Europe – Heritage and Challenge”, edited by the director of the Department for Universal History of the Mainz Institute for European History. After Pauli had received and corrected the page proofs of his text (Pauli, 1956), the volume appeared early in 1956. On the occasion of a visit to Hamburg at the end of November 1955 he repeated his lecture for a different audience in the Jungius Society.

When Fierz proposed to him to “compose a broadly conceived historical-critical study reaching up until present times” under the title “Thoughts and Background Ideas of a Modern Physicist”, Pauli thought seriously about it. Such a study would have created great interest among physicists and non-physicists. However, he did not get around to working on it. As a consequence of the new developments accompanying the discovery of the neutrino, Pauli turned back to physical problems during the last years of his life and postponed his more private interests.

## 10 Overview of Pauli's Scientific Estate

Pauli published more than 200 articles and essays in both German and English language, most of which are reprinted in the two-volume edition of his “Collected Scientific Papers” (Kronig and Weisskopf, 1964). His 1921 article on relativity, his two “Springer Handbuch” articles on the old and the new quantum theory, and his two contributions on radiation theory and atomic theory in “Müller-Pouillet's Lehrbuch der Physik” belong to the classics of physics literature, which served as textbooks for generations of physicists.

Possibly even more impact on the development of theoretical physics had his letters, with which he intervened into ongoing research in an influential way. These letters played an important role in the formation of opinions, were often shown around and willingly collected and conserved because of their contents and incisive formulations. After Pauli's death, his widow recollected many letters with the help of Bohr and some of Pauli's assistants, in order to edit and supply them for historical research. Presently, the published subset of his correspondence comprises about 3500 letters from and to Pauli, which are available for research on 7500 printed pages in eight volumes.<sup>32</sup> Comparing

<sup>32</sup> A little less than half of the letters are letters to Pauli. An additional supplement volume with further 400 letters, manuscripts and various tables and registers, which are to serve a facilitated use of the complete edition, is in preparation.

this amount with the 2500 pages of his published papers provides a rough idea of the influence of the letters on their receivers.

Those letters which Pauli possessed when he was still alive and those which were collected by his widow after his death are now deposited in the Pauli Archive at CERN in Geneva. The archive contains a collection of more than 10.000 reprints, a small library as well as notes, memoranda and manuscripts from Pauli's estate, which can be accessed via the world wide web at [library.cern.ch/archives/pauli/paulimain.html](http://library.cern.ch/archives/pauli/paulimain.html).

A larger number of letters, particularly from the properties of Fierz and Jung and his coworkers are preserved in the history of science collections of ETH Zurich. Other comprehensive collections of Pauli letters are stored in the Niels-Bohr-Institute at Copenhagen and the Werner-Heisenberg-Institute (Max-Planck-Institute for Physics) at Munich. The remaining correspondence is scattered over various archives worldwide and could only be discovered with the help of directories and electronic databases that are available for historians today.

The major part of the letters is of physical content. Because many of them, in particular from the period before and during the war, have been lost, the current inventory provides a somewhat distorted picture of the actual extent of the correspondence with individual correspondents. Nevertheless, the high percentage of letters exchanged with Heisenberg (460 letters, 15%), Fierz (350 letters, 10%) and Bohr (150 letters, 5%) demonstrates the role of those physicists for Pauli's thinking.

Taking into account that Pauli sometimes contacted his correspondents through their close collaborators yields a considerable amount of 300 letters for the psychological correspondence with Jung. Another special case is Pauli's correspondence with ETH Zurich (Enz *et al.*, 1997) which sheds some light on several otherwise enigmatic aspects of Pauli's biography. Moreover, the correspondence with Paul Rosbaud, about 300 letters of which only a few have been made available so far, might be of mainly biographical interest.

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## References

- Buchwald, D.K., Schulmann, R., Illy, J., Kennefick, D.J. and Sauer, T. (eds.) (2004): *The Collected Papers of Albert Einstein. Volume 9. The Berlin Years: Correspondence, January 1919–April 1920*. Princeton University Press, Princeton. English translations in: Hentschel, A.M. (transl.) (2004), Princeton University Press, Princeton.

- Carnap, R. (1928): *Der logische Aufbau der Welt*. Weltkreis-Verlag, Berlin.
- Ehrenfest, P. (1931): Ansprache zur Verleihung der Lorentzmedaille an Professor Wolfgang Pauli am 31. Oktober 1931. In: Klein, M.J. (ed.), *Paul Ehrenfest. Collected Scientific Papers*. North-Holland, Amsterdam, 1959.
- Enz, C.P., Glaus, B. and Oberkofler, G. (1997): *Wolfgang Pauli und sein Wirken an der ETH Zürich*. vdf Hochschulverlag an der ETH, Zürich.
- Enz, C.P. and Meyenn, K. von (eds.) (1994): *Wolfgang Pauli. Writings on Physics and Philosophy*. Springer, Berlin.
- Frank, P. (1917): Die Bedeutung der physikalischen Erkenntnistheorie Machs für das Geistesleben der Gegenwart. *Naturwissenschaften* 5, 65–72.
- Geier, M. (1992): *Der Wiener Kreis: mit Selbstzeugnissen und Bilddokumenten*. Rowohlt, Hamburg.
- Goldschmidt, H.L. (1948): *Philosophie als Dialogik*. Aehren Verlag, Affoltern a.A.
- Goldschmidt, H.L. (1990): *Nochmals Dialogik*. ETH Stiftung Dialogik, Zürich.
- Hellmann, H. (1937): *Einführung in die Quantenchemie*. Deuticke, Leipzig.
- Hermann, A., Meyenn, K. von and Weisskopf, V.F. (eds.) (1979): *Wolfgang Pauli. Wissenschaftlicher Briefwechsel. Band I: 1919–1929*. Springer, New York.
- Holton, G. (1973): *Thematic Origins of Scientific Thought: Kepler to Einstein*. Harvard University Press, Cambridge (Massachusetts).
- Jung, C.G. (1952): Synchronizität als ein Prinzip akausaler Zusammenhänge. In: Jung, C. G., and Pauli, W. (eds.), *Naturerklärung und Psyche*. Rascher Verlag, Zürich, pp. 1–107.
- Margenau, H. (1950): *The Nature of Physical Reality*. McGraw-Hill, New York.
- Meier, C.A. (2001): *Atom and Archetype. The Pauli/Jung letters, 1932–1958*. Princeton University Press, Princeton.
- Meyenn, K. von, (ed.) (1985): *Wolfgang Pauli. Wissenschaftlicher Briefwechsel, Band II: 1930–1939*. Springer, Berlin.
- Meyenn, K. von, (ed.) (1993): *Wolfgang Pauli. Wissenschaftlicher Briefwechsel, Band III: 1940–1949*. Springer, Berlin.
- Meyenn, K. von, (ed.) (1996): *Wolfgang Pauli. Wissenschaftlicher Briefwechsel, Band IV, Teil I: 1950–1952*. Springer, Berlin.
- Meyenn, K. von (ed.) (1999): *Wolfgang Pauli. Wissenschaftlicher Briefwechsel, Band IV, Teil II: 1953–1954*. Springer, Berlin.
- Meyenn, K. von, (ed.) (2001): *Wolfgang Pauli. Wissenschaftlicher Briefwechsel, Band IV, Teil III: 1955–1956*. Springer, Berlin.
- Meyenn, K. von, (ed.) (2005): *Wolfgang Pauli. Wissenschaftlicher Briefwechsel, Band IV, Teil IV-A: 1957*. Springer, Berlin.
- Knoll, M. (1952): Wandlungen der Wissenschaft in unserer Zeit. In: Fröbe-Kapteyn, O. (ed.), *Eranos-Jahrbuch 1951. Band XX. Mensch und Zeit*. Rhein-Verlag, Zürich, pp. 387–436.
- Kraft, V. (1950): *Der Wiener Kreis: der Ursprung des Neopositivismus*. Springer, Wien.
- Kronig, R. and Weisskopf, V.F. (eds.) (1964): *Collected Scientific Papers by Wolfgang Pauli. In Two Volumes*. Interscience, New York.
- Pauli, W. (1950): Die philosophische Bedeutung der Idee der Komplementarität. *Experientia* 6, 72–81.
- Pauli, W. (1954): Naturwissenschaftliche und erkenntnistheoretische Aspekte der Ideen vom Unbewussten. *Dialectica* 8, 283–301.

- Pauli, W. (1956): Die Wissenschaft und das abendländische Denken. In: Göhring, M. (ed.), *Europa – Erbe und Aufgabe*. Steiner, Wiesbaden, pp. 71–79.
- Pauli, W. (1957): Phänomen und physikalische Realität. *Dialectica* **11**, 36–48.
- Reichenbach, H. (1944): *Philosophical Foundations of Quantum Mechanics*. University of California Press, Berkeley.
- Reichenbach, H. (1948): The principle of anomaly in quantum mechanics. *Dialectica* **2**, 337–350.
- Schlick, M. (1931): Die Kausalität in der gegenwärtigen Physik. *Naturwissenschaften* **19**, 145–162.
- Schulmann, R., Kox, A.J., Jansen, M. and Illy, J. (eds.) (1998): *The Collected Papers of Albert Einstein. Volume 8A. The Berlin Years: Correspondence, 1914–1917*. Princeton University Press, Princeton. English translations in: Hentschel, A.M. (transl.) (1998), Princeton University Press, Princeton.
- Sommerfeld, A. (1948): Philosophie und Physik seit 1900. In: *Arnold Sommerfeld. Gesammelte Schriften. Band IV*. Vieweg, Braunschweig, 1968, pp. 640–643.
- Weyl, H. (1949): *Philosophy of Mathematics and Natural Science*. Princeton University Press, Princeton.