

Pauli's ideas on mind and matter in the context of contemporary science

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1 Wolfgang Pauli

Wolfgang Pauli (1900–1958) was one of the greatest physicists of the past century. He played a leading role in the development of modern physics and was known for his ruthless intellectual integrity.¹ Pauli first became famed through the publication of his encyclopedia article on the theory of relativity (Pauli 1921) when he was still a student of Sommerfeld's. Einstein much admired this article, which remained a classic.

Together with Bohr, Heisenberg, Schrödinger and Dirac, Pauli laid the foundations of quantum theory. In 1945 he received the Nobel Prize in physics for his “decisive contribution through his discovery in 1925 of a new law of Nature, the exclusion principle or Pauli principle.”² Heisenberg (1968, p. 45) characterized Pauli's approach to physics as follows:

“He tried first of all to be inspired by the experiments and to see in a kind of intuitive way how things are connected, and at the same time he tried to rationalize his intuitions and to find a rigorous mathematical scheme so that he really could prove everything what he said. . . . Pauli has through his whole life published much less than he could have published if he had abandoned one of these two postulates.”

Pauli communicated his thoughts primarily in long letters to his friends and colleagues. Therefore, many of his seminal ideas remained unpublished (cf. Pais 2000, pp. 210–262). He was hardly ever concerned that much of his work thus went uncredited. Goudsmit (1961, p. 19), the co-discoverer of the electron spin, reports that Pauli cryptically remarked: “I can afford not to be quoted.”

This state of affairs applies in particular to Pauli's wide range of philosophical, psychological and historical interests which are barely reflected in his published articles. In the second half of his life, Pauli was highly critical to “the merely rational” and looked for a world-view that respects science but also goes beyond it. He had a passion for phenomena which elude the grasp of reason, but he was reluctant to make this public – an attitude which also characterized his political stance. In a letter to Born he wrote:³

“My impact should consist in how I *live*, what I *believe* and in the ideas that I communicate more or less directly to a small circle of scholars and friends – but not in speaking to a large public.”

Pauli specified his position in a letter to Bohr:⁴

“In my attitude in favour of an *indirect* effect only on the bulk of other persons I am – last not least – also influenced by the philosophy of *Laotse*,

¹ Compare the biography by Enz (2002).

² Quoted from the presentation speech by Professor I. Waller, member of the Nobel Committee for Physics, on December 10, 1945.

³ Letter by Pauli to Born of January 21, 1951. Quoted in von Meyenn (1996), p. 243. Translated by the authors.

⁴ Letter by Pauli to Bohr of June, 6, 1950. Quoted in von Meyenn (1996), p. 112.

in which so much emphasis is laid on the indirect action, that his ideal of a good ruler is one, whom one does not consciously notice at all.”

Pauli’s thoughts on topics beyond physics are likely to be appreciated as inspiring sources for the present and future development of Western science and culture. In recent years many of his ideas, expressed in his letters,⁵ provoked an increasing interest in the communities of philosophers, psychologists, and natural scientists. Pauli understood that physics necessarily gives an incomplete view of nature, and he was looking for an extended scientific framework. However, the fact that the often colloquial and speculative style of his letters is in striking contrast to his careful and refined publications should advise us to act with caution. His accounts are extremely stimulating, but they should be considered as first groping attempts rather than definitive proposals.

In this contribution, we will give an overview of Pauli’s extraphysical interests. He himself reviewed the main body of his corresponding views in three publications, the Kepler article (Pauli 1952), the paper on Jung’s ideas of the unconscious (Pauli 1954b), and the contribution to a conference at Mainz (Pauli 1956b). But his extensive correspondence provides a much more comprehensive source of material in this respect. Pauli’s interest in Jung’s depth psychology was mainly focused on its structural, conceptual aspects. Therefore, we will not enter into the discussion of questions of psychological therapy as they may be recognized in parts of the Pauli-Jung dialog.⁶ Pauli’s scientific work in the narrow sense and its impact on specific problems of contemporary theoretical physics⁷ will be addressed only insofar as they arise in the context of more general issues.

The following sections 2, 3 and 4 provide the basis for a detailed understanding of Pauli’s ideas on mind and matter. Section 2 is devoted to the basic importance that Pauli ascribed to symmetry principles and to symmetry breaking. Section 3 addresses the role of symbols (in the Jungian sense) in theory formation. In section 4 we introduce Pauli’s ideas, based on those of Bohr, concerning a generalized notion of complementarity. In section 5, we present the key issue of Pauli’s extraphysical interests: the psychophysical problem of how relations between mind and matter can be reasonably circumscribed and conceived. Section 6 extends this theme into the significance of concepts of time for the psychophysical problem. Section 7 gives some material concerning Pauli’s ideas on biological evolution and the nature of mutations. We conclude this overview in section 8.

⁵ Published in the immense *Scientific Correspondence* (more than 7000 pages, waiting to be translated into English): Hermann, von Meyenn & Weisskopf (1979), von Meyenn (1985), von Meyenn (1993), von Meyenn (1996), von Meyenn (1999), von Meyenn (2001), von Meyenn (2005a), von Meyenn (2005b).

⁶ Various psychological aspects of this type have been discussed by Erkelens (2002) and by Lindorff (2004).

⁷ For competent reviews compare Enz (1973) and Enz (2002)

2 Symmetries and their breakdown

2.1 Symmetries in physics

Symmetry in its group-theoretical formulation has become the most fundamental theme of modern theoretical physics. It is defined as *invariance under a specified group of transformations*. While in former times symmetries were deduced from known dynamical equations, in modern physics symmetries are considered as a *primary concept*, sometimes called a *first principle*. At first sight, such fundamental symmetries seem to be in flagrant contradiction with all familiar phenomenological realities. For example, the laws of physics treat all directions of space as equivalent, but in everyday life there is a vital difference between horizontal and vertical directions. The fact that the observed phenomena generally do not exhibit the symmetries of the laws that govern them was clearly recognized by Pierre Curie (1894):

“Asymmetry is what creates a phenomenon.”

In a perfectly symmetric situation there are no distinctions, so that reality does not appear in a structured form. That is, fundamental symmetries are not empirically accessible in a direct way. They can only be retrospectively inferred by phenomena that exist due to *broken symmetries*. Nevertheless, hidden symmetries are theoretical tools of great importance. There is a deep connection between symmetries and conservation laws. A fundamental theorem by Emmy Noether (1918) implies:

*For every continuous symmetry, there exists a conservation law.
For every conservation law, there exists a continuous symmetry.*

By convention, the most fundamental natural laws should not depend on particular specific conditions. We arrange our theories in such a way that the most fundamental laws are valid at all places and at all times. In this context, Pauli asserts:⁸

“Laws of nature *are* neither causes nor do they act. They *can* only contain statements about causes; they are, at a time, the most germane human expression for order relations in the cosmos.”

We *posit* that time and space are homogeneous and that space is isotropic. The conserved quantity related to the time-translation symmetry is called *energy*, the conserved quantity related to the space-translation symmetry is called *momentum*, and the conserved quantity related to the rotational symmetry is called *angular momentum*.

Symmetries, which we assume to be valid, are not necessarily manifest in the world of observed phenomena. These phenomena are due to *broken symmetries*. For a long time, symmetry breaking has been applied to the description of

⁸ Letter by Pauli to von Weizsäcker of Mai 21, 1953. Letter 1568 in von Meyenn (1999), p. 139. Translated by the authors.

nature in an implicit and heuristic way, without detailed or even formal accounts. Today, the breakdown of symmetry is a mathematically well-defined concept:⁹

If the equations of motion of a system possess a symmetry
which is not shared by the most stable state of the system,
we speak of a *spontaneously broken symmetry*.

Therefore we have to distinguish between the *symmetry of the laws* and the *asymmetry of the state of a system*. In general, the most stable state of a system fails to have the full symmetry of the underlying dynamical laws. This implies that the first principles of physics do not determine uniquely the *tremendous variety* of observable physical phenomena.

The breakdown of symmetry can be related to *dynamical instabilities*. An early example (from 1757) is due to Euler, who showed that there is a maximum axial force that a long, thin rod can carry without buckling.¹⁰ The physical description of this situation is invariant for all rotations around the axis of the rod. As long as the applied force is less than a critical value, the state with lowest energy is unique and invariant under this symmetry. With any larger force the rod is unstable against small perturbations from straightness and will cause the rod to bend sideways into any plane containing the axis of the unloaded rod. As a result, an infinite number of equivalent lowest-energy stable states appear, which are no longer rotationally symmetric but are related to each other by a rotation.

In such a way, any symmetry breaking leads to a multiplicity of lowest-energy states, called *degenerate states*, which are related to each other by the transformation of the original symmetry group. Spontaneous symmetry breakdown is one of the basic features accompanying collective phenomena, such as phase transitions in statistical mechanics or ground-state excitations in field theory.¹¹ Well-known examples are ferromagnetism (involving the spontaneous breakdown of the rotation symmetry), crystallization (requiring the spontaneous breakdown of the translation and rotation symmetry), superfluidity (related to the breakdown of the special Galilei symmetry), or superconductivity (connected with the spontaneous breakdown of particle number conservation).

In addition to these continuous symmetries there are three important discrete symmetry operations: *time inversion* T (a transformation of variables in which time t is replaced by $-t$), *parity change* P (a transformation that changes the algebraic sign of the coordinate system), and *charge conjugation* C (a transformation of each particle to the corresponding antiparticle). These discrete symmetries can be broken as well. For example, handedness or chirality is a

⁹ In algebraic quantum theory a symmetry is an automorphism on the algebra of observables. The symmetry is said to be spontaneously broken if this automorphism is not implemented by unitary operators.

¹⁰ “*Sur la force des colonnes*”, presented to the Berlin Academy on September 1, 1757. Published in *Memoires de l’academie des sciences de Berlin* **13**, 1759, pp. 252–282. A copy of the original paper is available on the internet:

<http://www.math.dartmouth.edu/~euler/pages/E238.html>

¹¹ Compare the reviews by Guralnik, Hagen & Kibble (1968); Bernstein, (1974).

well-known phenomenon violating parity conservation in many biological organisms. The chirality of most biomolecules also necessitates a spontaneously broken parity symmetry. The so-called *arrow of time* in irreversible processes exhibits the breakdown of the time-inversion symmetry of the most fundamental dynamical laws. Only this broken symmetry allows us to distinguish between past and future.

2.2 Pauli and symmetry principles

Symmetries and the associated conservation laws were always in the focus of Pauli's interest. The editors of Pauli's Collected Works say (Kronig and Weiskopf 1964, p. viii):

“For Pauli, the invariants in physics were the symbols
of ultimate truth which must be attained by
penetrating through the accidental details of things.”

The prominent role of symmetries in Pauli's work is well illustrated by Weyl (1952, p. 126): “all a priori statements in physics have their origin in symmetry.” Pauli believed that the scope of the mathematical group concept has not yet been exhausted (Pauli 1957b, p. 40). In a discussion Pauli (1953) said:

“I am very much in favour of the general principle to bring empirical conservation laws and invariance properties in connection with mathematical groups of transformations of the laws of nature.”

The following selected examples demonstrate how Pauli's belief in symmetries has influenced his research strategy in fundamental theoretical physics.

Hydrogen atom: A few months ahead of Schrödinger, Pauli (1926b) solved the eigenvalue problem of the hydrogen atom algebraically in terms of Heisenberg's new matrix mechanics. The crucial point of this masterstroke was Pauli's discovery that an additional constant of motion for the Kepler problem¹² leads to a hidden Lie-algebraic symmetry. Later this *hidden symmetry* was related to the invariance under the rotation group $O(4)$ in four-dimensional space (Fock 1935, Bargmann 1936), which explained the “accidental” degeneracy of the energy levels of the hydrogen atom with the same principal quantum number. In 1926 Pauli did not yet have the appropriate group-theoretical tools necessary for a full discussion at his disposal. He compiled them much later in lectures at the ETH Zürich and at CERN.¹³ Nowadays hidden symmetries have become a new area of mathematics that is of far-reaching significance in physics and engineering (cf. Moser 1979).

¹² Discovered in 1710 by Johann Bernoulli and used by Laplace in his great monograph on celestial mechanics of 1799. Nowadays this constant of motion is often called the Lenz vector, since Lenz used it in the framework of the old quantum theory of the hydrogen atom. Pauli was Lenz's assistant at Hamburg in 1922. In his monograph on the old quantum theory, Pauli (1926a, p.133) discussed the results of Lenz in detail.

¹³ Pauli (1956a), reprinted as Pauli (1965).

At the same time, Schrödinger (1926) constructed a family of Gaussian wave packets which do not spread under the time evolution of the one-dimensional harmonic oscillator and follow its classical trajectory. He speculated that a similar set of non-spreading quantum states for the hydrogen atom could be constructed.¹⁴ For many decades all attempts in this direction were abortive. The decisive idea for a convincing solution (Barut and Xu 1993) was to use the hidden $O(4)$ -symmetry of the Kepler problem and the Kustaanheimo–Stiefel projection from four-dimensional to three-dimensional space (Kustaanheimo and Stiefel 1965). The corresponding coherent states have become indispensable for the theoretical description of the dynamics of highly excited atoms generated by strong short laser pulses. The associated atomic Rydberg states mimic the classical behavior of electrons on Bohr–Sommerfeld ellipses and are correctly described by the $O(4)$ -nonspreading coherent states which travel along elliptic Kepler orbits.

The Keplerian coherent quantum states do not only describe atomic Rydberg states but also *all* macroscopic Kepler orbits of celestial mechanics with an astonishing accuracy. This conceptually important result shows that quantum theory is not restricted to the microscopic domain. Without any limiting procedures, it gives rise to a complete and precise dynamical *Boolean* description of macroscopic phenomena. Provided that proper initial conditions are chosen, such *locally Boolean* quantum-theoretical descriptions mimic situations familiar from classical mechanics. They are compatible with quantum mechanics since the non-Boolean logical structure of quantum theory is *partially Boolean* in the sense that it consists of Boolean substructures which are composed in a non-Boolean fashion. This will be discussed in more detail in Sec. 3.

Neutrino: Pauli’s belief in the absolute credibility of symmetry principles led him to defend conservation laws even when at that time the empirical evidence was doubtful. His prediction of the neutrino is a great example. Around 1927 there was an intense controversy about missing energy in radioactive β -decay. Bohr suggested that energy might not be conserved after all. Pauli did not accept this proposal:¹⁵

“I am myself fairly convinced . . . that Bohr with his corresponding deliberations concerning a violation of energy conservation is *entirely* on the *wrong* track!”

“The idea of a violation of the conservation of energy in β -decay is and remains, in my opinion, cheap and very clumsy philosophy.”

In a famous open letter of 1930, Pauli suggested the existence of a new electrically neutral particle (which he proposed to call *neutron*, later renamed *neutrino*

¹⁴ Compare also the letter by Schrödinger to Lorentz of Juni 6, 1926, and the letter by Lorentz to Schrödinger of June 19, 1926, published in Przibram (1963), pp. 51–68.

¹⁵ Letters by Pauli to Klein of February 18, 1929 (letter 216 in Hermann, von Meyenn & Weisskopf (1979), p. 490), and of February 10, 1930 (letter 242 in von Meyenn (1985), p. 4). Translated by the authors.

by Fermi) to save the conservation of energy in nuclear β -decay.¹⁶ Pauli confessed his proposal to the astronomer Baade (quoted by Hoyle 1967):

“I’ve done a terrible thing today, something which no theoretical physicist should ever do. I have suggested something that can never be verified experimentally.”

Baade proposed a bet in favor of the neutrino. When, three decades later, Reines and Cowan (1959) detected the neutrino, Pauli paid the champagne.

Pauli principle: Pauli’s exclusion principle (Pauli 1925b) explains why everyday matter does not collapse. Pauli formulated this principle in terms of the Bohr–Sommerfeld theory even before the creation of quantum mechanics. Shortly after Heisenberg (1926) used the indistinguishability of the electrons of an atomic system to get appropriate representations of the permutation group, Dirac and Pauli were the first to reformulate the exclusion principle group-theoretically as a *permutation symmetry principle*.¹⁷

Since elementary systems of the same kind are indistinguishable, every observable quantity is invariant under permutations of the numbering of the elementary systems. Consequently, the quantum state of an elementary system has to transform according to an irreducible representation of the permutation group. However, this does not determine which representation has to be used for a particular kind of systems. The deeper reason for the empirical fact that the states of a system of identical fermions transform antisymmetrically under permutations, while boson states transform symmetrically, has been elucidated by Pauli (1940) in his group-theoretical proof of the fundamental *spin-statistics theorem* in the framework of Lorentz-relativistic quantum field theory. He concludes this proof with the remark that “the connection between spin and statistics is one of the most important applications of the special relativity theory.”

CPT theorem: In 1954 Pauli wrote a theoretical paper on *mirror symmetry* in physics (Pauli 1955), although there was nothing in the world of physics which would make such an undertaking urgent. However, as Pauli recalls, the mirror symmetry was an important topic for him personally.¹⁸ His corresponding fascination can be regarded as an example of his belief in deep connections between mind and matter and an inevitable consonance of “inside” and “outside”.¹⁹

¹⁶ Letter by Pauli to Meitner and coworkers of December 4, 1930. Letter 259 in von Meyenn (1985), pp. 39–40. It was not until 1934 that Pauli’s prediction of a new particle with zero charge, zero mass, and spin 1/2 was published as a discussion remark to a report by Heisenberg (1934), pp. 324–325.

¹⁷ Dirac (1926) [received August, 26, 1926]; Pauli (1927) [received December, 16, 1926], footnote 1 on p. 83.

¹⁸ Compare the letter by Pauli to Jung of August 5, 1957. Letter 2682 in von Meyenn (2005a), pp. 506–511.

¹⁹ Compare the letters by Pauli to Kronig of March 10, 1946 (letter 807 in von Meyenn (1993), p. 346) and to von Weizsäcker of Mai 21, 1953 (letter 1568 in von Meyenn (1999), p. 140).

According to Pauli²⁰

“unconscious motives are always involved thereby. Now, ‘mirroring’ is an archetype, it is ‘nous’ and it is ‘physis’. . . . This has something to do with physics. Physics relies on a relation of mirror symmetry between mind and nature. Now the story moves on. At that time I had vivid, almost parapsychological dreams about mirroring, while I worked mathematically during the day. . . . I would call that, for instance, a kind of synchronicity, since there are unconscious motives when one is engaged in something, that this is now represented in dreams, that some archetype is constellated which later made me think about mirroring.”

The result of Pauli’s mathematical inquiry was the CPT-theorem. It refers, under very general conditions, to an invariance under the combined discrete symmetry operations of charge conjugation C, parity change P and time reversal T.²¹ All experiments so far have confirmed that all physical laws are invariant under the combined CPT-symmetry. CPT invariance is also a key feature of the standard model. The laws governing gravity, electromagnetism, and the strong interaction are even invariant with respect to C, P and T independently.

In a famous paper, Lee and Yang (1956) pointed out that β -decay, governed by the weak interaction, had not yet been tested for invariance under P. The experiments performed by Wu and her colleagues²² showed to the great surprise of Pauli that the weak interaction violates parity invariance. The existence of parity violation in our fundamental laws has led to new insights into the secrets of chiral objects and the nature of space. However, it does not violate CPT-invariance, so the CPT-theorem received an entirely unexpected significance. For example, it is a consequence of CPT-symmetry (and not of the stronger condition of C-invariance) that the masses, lifetimes, charges, spins and magnetic moments of a particle and of its antiparticle match exactly. Moreover, if CPT-symmetry is broken in field theory, then Lorentz symmetry is also broken.

Late collaboration with Heisenberg: As a consequence of the non-conservation of parity, Pauli discovered a group of transformations relating left- and right-handed neutrinos and antineutrinos – the so-called *Pauli group* (Pauli 1957). In 1957, he started an initially enthusiastic collaboration with Heisenberg on his nonlinear spinor equation which should provide a unified description of all elementary particles. One reason for Pauli’s excitement about this project was that this spinor equation was invariant under the Pauli group.

The discussions between Heisenberg and Pauli²³ give an enlightening exam-

²⁰ In a conversation with Bender on April 30, 1957. Quoted from von Meyenn (2005a), p. 338. Translated by the authors.

²¹ Often referred to as the *Lüders-Pauli theorem*, but Pauli (compare Pauli, W. (1955) and his letter to Weisskopf of October 12, 1954, letter 1890 in von Meyenn (1999), p. 787) acknowledged the related contributions by Schwinger (1951), Schwinger (1953), Lüders (1954), Bell (1955).

²² Compare the review by Wu (1960).

²³ Compare the *Scientific Correspondence 1957/58*, von Meyenn (2005a) and von Meyenn (2005b).

ple of the genesis of scientific ideas (even though these attempts turned out to be abortive), with its interplay of different intellectual temperaments and all its ups and downs between excitement and frustration of emotionally engaged scientists – a much more realistic picture of actual creative activity than many books on the philosophy of science suggest. Pauli clearly realized that both Heisenberg and he himself were deeply fascinated:²⁴

“What fascinates Heisenberg is also the *mirror archetype*. . . . As a consequence of this fascination, he reproduces his obsessions over and over again and cannot listen to (or read) what others say.”

In January 1958 he expressed his own situation to Aniela Jaffé:²⁵

“. . . a new physical-mathematical theory of elementary particles is emerging . . . there is *much* mirroring (as a mathematical operation) and a *quaternarian* archetype – ‘director Spiegler’ – dictates to me what I ought to write and calculate.”

A critical, deep and psychologically informed thinker such as Pauli cannot have failed to notice that he was in danger of becoming inflated by archetypal contents. In April 1958 he withdrew his participation in Heisenberg’s project.²⁶ In July 1958 at the Conference on High Energy Physics, hosted by CERN, Pauli responded to Heisenberg’s talk:²⁷

“I completely disagree with the answer of Heisenberg
– not only unnatural but mathematically impossible.”

In spite of the fact that this attempt at a unified field theory of elementary particles was not successful, the proposal of a degenerate ground state of relativistic quantum field theory which lacks the full global symmetry turned out to be a powerful idea of great significance and played a crucial role in the development of the standard model of particle physics.

Heisenberg’s and Pauli’s ideas have been fully understood only more recently. In quantum field theory the ground state is called the *vacuum state*. If the dynamical laws are invariant under a continuous global symmetry (which holds for all points in the spacetime) but only asymmetric configurations can be realized, one obtains a continuous family of *degenerate vacuum states*. Such a spontaneously broken symmetries are possible only in systems with infinitely many degrees of freedom. They are responsible for the overwhelming richness

²⁴ Compare for example the letter by Pauli to Fierz of February 15, 1957. Letter 2517 in von Meyenn (2005a), p. 225. Translated by the authors.

²⁵ Letter by Pauli to Jaffé of January 5, 1958. Letter 2825 in von Meyenn (2005b), pp. 807–808. Translated by the authors.

²⁶ There exists an unpublished preprint, reproduced in Heisenberg & Pauli (1958). In April 1958 Pauli sent a retraction to all colleagues who had received the preprint. Pauli got angry about Heisenberg’s radio and newspaper advertisements (“Weltformel”), but this was hardly the deeper reason for his withdrawal from their work (as claimed by Dürr (1993), p. 328). An elaboration of Heisenberg’s own ideas was published in the so-called “five-men paper”, Dürr, Heisenberg, Mitter, Schlieder, and Yamazaki (1959).

²⁷ Quoted from *CERN Courier*, July/August 2000, p. 12.

of our world of experience, but this does not mean that the fundamental laws of nature are asymmetric.²⁸

3 Theories as symbolic constructions

3.1 Where do ideas come from?

The discourse between Heisenberg and Pauli in 1957 and 1958 demonstrates vividly that scientific work as a human activity is much more subtle than a purely rational enterprise. Achieving understanding is a laborious process, guided by unconscious processes long before their result can be consciously formulated in rational terms. There is some contemporary research on creative work, focusing on psychological investigations of the solution of insight problems (Knoblich and Öllinger 2006) and studies based on biographical sources (Simonton 1988). This does, however, not address Pauli's views and concerns (Pauli 1957b, p. 38, translated by the authors):

“I hope that no one still maintains that theories are deduced by strict logical conclusions from laboratory-books, a view which was still quite fashionable in my student days. Theories are established through an *understanding* inspired by empirical material, an understanding which is best construed, following Plato, as an emerging correspondence of internal images and external objects and their behavior. The possibility of understanding demonstrates again the presence of typical dispositions regulating both inner and outer conditions of human beings.”

With Mach as his godfather, Pauli's initial scientific work was in line with a strong spirit of positivism. “Later on he was converted under the influence of Bohr's idea of complementarity and of the archetype concept of Jung to a follower of a Platonic-Pythagorean idealism.”²⁹

Pauli emphasized that all understanding is a tedious process initiated by the unconscious long before conscious contents can be rationally formulated (Pauli 1952, pp. 112–113, translated by the authors):

“Insofar as these images are ‘expressions of a suspected but still unknown state of affairs’, they can be denoted as symbolic in the sense of Jung's proposal for a definition of a symbol. As ordering factors and formers of images in this world of symbols, archetypes operate as the sought-after bridge between sensory perceptions and ideas and, accordingly, are a necessary presupposition for the development of a scientific theory of nature. However, one must beware of locating this a priori of knowledge in the conscious mind and relating it to particular, rationally expressable ideas.”

²⁸ This has been mathematically explained by the fact that for systems with infinitely many degrees of freedom there are infinitely many inequivalent representations of the canonical commutation relations. For a recent review with further details see Strocchi (2005).

²⁹ Quoted from von Meyenn (1987), p. 332. Compare also the letter by Pauli to Fierz of January 7, 1948; letter 939 in von Meyenn (1993).

Creative scientists are in danger of regarding the emergence of ideas as his personal success alone, not realizing that these ideas precede his ego-awareness and can even act on it in a possessive way. Cultivating only the rational side of the psyche and rejecting its non-rational parts as non-existent or irrelevant can lead to severe difficulties when confronted with compelling primordial ideas. As Jung (1966, par. 472) said:

“... if the individual identifies himself with the contents awaiting integration, a positive or negative inflation results. Positive inflation comes very near to a more or less conscious megalomania; negative inflation is felt as an annihilation of the ego.”

It is hard to escape the detrimental effects of being fascinated by primordial ideas when one encounters their inflationary effect. This insight may prompt us to deal with the fascination of scientific work in a responsible manner.

3.2 The reality of symbols

Pauli was convinced of deep relations between matter and mind, hence between physics and psychology.³⁰ He promoted the idea of a background reality that is inevitably symbolic:³¹

“When the layman says ‘reality’, he usually thinks that he is talking about something evident and well-known; by contrast it seems to me that it is the most important and exceedingly difficult task of our time to work out a new idea of reality. . . . What I have in mind concerning such a new idea of reality, is – in provisional terms – the *idea of the reality of the symbol*. On the one hand, a symbol is a product of human effort, on the other hand it indicates an objective order in the cosmos of which humans are only a part.”

Here, Pauli uses the concept of the “symbol” in the Jungian sense. For Jung symbols represent *archetypal ideas*, which do not refer to explicitly accessible elements of everyday reality. Therefore, Jung’s usage of the concept of the symbol is not metaphorical or allegorical (Jung 1971, par. 816):

“[A] symbol . . . is an expression for something that cannot be characterized in any other or better way.”

The role of symbols in Jung’s depth psychology may be related to Cassirer’s philosophy of symbolic forms. According to Cassirer, human reason alone does not provide a comprehensive access to reality. Man grasps reality with the help of *symbolic forms*, understood as a fundamental primitive function which manifests itself in all human culture, be it language, myth, art, religion or science. It is considered as *the essential function of human consciousness* (Cassirer 1944, p. 25):

³⁰ Letter by Pauli to Kronig of March 10, 1946. Letter 807 in von Meyenn (1993), p. 346.

³¹ Letter by Pauli to Fierz of August 12, 1948. Letter 971 in von Meyenn (1993), p. 559. Translated by the authors.

“No longer in a merely physical universe,
man lives in a symbolic universe.”

Cassirer strictly distinguishes the concept of a “symbol” from the concept of a “signal” (Cassirer 1944, p. 32):

“Symbols – in the proper sense of this term – cannot be reduced to mere signals. Signals and symbols belong to two different universes of discourse: a signal is a part of the physical world of being; a symbol is a part of the human world of meaning. Signals are ‘operators’; symbols are ‘designators.’ Signals, even when understood and used as such, have nevertheless a sort of physical or substantial being; symbols have only a functional value.”

All animals know how to interpret and react on signals. Cassirer characterizes human beings by their unique ability to use *symbolic forms*. A symbol cultivates *ideas* and *concepts*. *Symbols are the vehicles of meaning* (Langer 1978, p. 52).

3.3 Visualizable images versus symbolic constructions

The history of the concept of explanation in physics shows a distinct tendency to advance from visually intelligible models to mathematically formulated conceptual abstractions that are beyond sensory perception. Pauli’s introduction of the “classically not describable two-valuedness” of the electron spin (Pauli 1925a, p. 385) is an object lesson. This idea, which is at the basis of the *Pauli principle*, was first ridiculed,³² and in his Nobel lecture Pauli (1946) recalled that “... physicists found it difficult to understand the exclusion principle, since no meaning in terms of a model was given to the fourth degree of freedom of the electron.”

In 1925, Goudsmit and Uhlenbeck proposed that the “classically undescrivable degree of freedom” of the electron could be explained by an angular momentum due to the spinning of an electron around its own axis (Uhlenbeck and Goudsmit 1925, 1926). This picturesque model of a “spinning electron” was not accepted by Pauli, who declared it as an erroneous doctrine (“Irrlehre”³³) and explained:³⁴

“So much I think is certain – despite our good friend Kramers and his colorful picture books. – ‘And the children, they love to listen.’ Even though the demand of those children for concrete illustrations (‘Anschaulichkeit’) is partly legitimate and healthful, it must never be considered as an argument for retaining particular conceptual systems in physics. Once a new system is conceptually settled, it will be vividly imaginable (‘anschaulich’) as well.”

³² Compare the postcard by Heisenberg to Pauli of December 15, 1924, letter 76 in Hermann, von Meyenn & Weisskopf (1979).

³³ Letter by Pauli to Bohr of March 5, 1926. Letter 124 in Hermann, von Meyenn & Weisskopf (1979), p. 302.

³⁴ Letter by Pauli to Bohr of December 12, 1924. Letter 74 in Hermann, von Meyenn & Weisskopf (1979), p. 188.

Nowadays we know that the spin does not correspond to any rotational motion so that the model of an electron as a little spinning top is a misleading analogy. The final resolution of the spin problem was again given by Pauli:³⁵

“We shall . . . understand by the spin of a particle an angular momentum in general, which cannot be traced to the translational motion of the particle and the magnitude of which (in contrast to those of its components) will be considered as a fixed number.”

Many years later it has been recognized that the spin is a necessary consequence of the isotropy of space, so that the seemingly ad hoc introduction of the Pauli spin matrices can be understood in terms of group-theoretical first principles. Pauli (1955, p. 30) summarized this historic episode as follows:

“After a brief period of spiritual and human confusion, caused by a provisional restriction to ‘Anschaulichkeit,’ a general agreement was reached following the substitution of abstract mathematical symbols . . . for concrete pictures. Especially the concrete picture of rotation has been replaced by mathematical characteristics of the representations of the group of rotations in three dimensional space.”

This example shows that the criteria for the intelligibility of scientific theories change in the course of time from visually imaginative to abstract representations that are beyond sensory perception.

The platonically inspired view that information about abstract objects is acquired by means of a faculty of *mathematical intuition* appeals to many theoreticians and mathematicians. For instance, Weyl (1949b) regarded science as a symbolic construction and the creative scientist as an architect in the world of symbols (Weyl 1946, p. 218):

“True, the physicist’s contemplation is not a purely passive attitude – it is creative construction, but construction in symbols, resembling the creative work of the musician.”

For Pauli, the mathematical representation of a scientific state of affairs is a predominantly symbolic description. He even went so far as to propose this as an important condition for mathematical talent:³⁶

“Only a fraction of a symbol can be expressed by conscious ideas, another fraction acts upon the human ‘unconscious’ or ‘preconscious’. The same holds for mathematical notation, for only those have a talent for mathematics who are capable of perceiving its symbolic power.”

Pauli believed that the unifying power of mathematical symbolism is far from being exhausted. He even ventured to say that it extends further than physics

³⁵ Pauli (1933), p. 185. English translation taken from Pauli (1980), p. 112.

³⁶ Letter by Pauli to Goldschmidt of February 19, 1949, quoted from Goldschmidt (1990), p. 39. Translated by the authors.

does in this respect.³⁷ As we will see in the remaining sections, there are a number of directions into which this statement can be taken.

4 Complementarity beyond physics

In 1927 Bohr introduced in his “Como Lecture” (Bohr 1928, p. 566) the concept of *complementarity* in quantum mechanics as a “rational generalization” of the framework of classical physics. A few years later, he wrote (Bohr 1934, p. 10) that the notion of quantum phenomena

“forces us to adopt a new mode of description designated as *complementary* in the sense that any given application of classical concepts precludes the simultaneous use of other classical concepts which in a different connection are equally necessary for the elucidation of the phenomena.”

No formal definition of complementarity can be found in Bohr’s papers which are often cryptic and contain obscure passages. Moreover, Bohr himself used the term with different meanings, which generated much dispute concerning its precise understanding. While many physicists found Bohr’s notion of complementarity too unclear,³⁸ Pauli was a determined advocate of complementarity. In his handbook article of 1933 Pauli characterized it as follows:³⁹

“If . . . the use of a classical concept excludes that of *another*, we call both concepts (e.g., position and momentum co-ordinates of particle) *complementary* (to each other), following Bohr. We might call modern quantum theory ‘The Theory of Complementarity’ (in analogy with the terminology ‘Theory of Relativity’).”

Although there are no serious problems to understand and apply the mathematical formalism of quantum physics, it forced us to drastically revise our traditional ideas about the nature of matter. Pauli commented this situation as follows (Pauli 1948, p. 307):

“every gain of knowledge of atomic objects by observations has to be paid for by a loss of other knowledge. . . . Which knowledge is obtained and which other knowledge is irrevocably lost is left to the free choice of the experimenter, who may choose between mutually exclusive experimental arrangements. It is this situation which Bohr called “complementarity” and which has changed so radically the principles underlying our description of phenomena by laws of nature and even our ideas of physical reality.”

The concept of complementarity is neither exclusively related to the wave-particle duality (from which Bohr’s ideas originated) nor to canonically conjugated quantities in quantum theory, nor even to physics in general. *Complementarity refers to the existence of mutually exclusive, incompatible aspects which*

³⁷ Compare Pauli’s manuscript “Modern Examples of Background Physics”, published in Meier (1992), p. 192, translated into English in Meier (2001).

³⁸ Compare for example Einstein (1949), p. 674, and Broglie (1973), p. 17.

³⁹ Pauli, (1933), p. 89. English translation taken from Pauli (1980), p. 7.

cannot be combined in a single description based on a Boolean, two-valued logic. This limitation of Boolean descriptions, which is clearly recognized in quantum physics, is also relevant in many other fields. In fact, James (1890, p. 206) introduced the notion of complementarity, long before Bohr, to describe split modes of consciousness “which coexist but mutually ignore each other.” Bergson (1911, p. 344) contemplated about the necessity to consider *two opposed although complementary ways of knowing*. Similarly, Bernays (1946, p. 79) pointed out that an understanding of mathematical existence in the discussion of existential versus constructive aspects of mathematics requires complementary perspectives.

The extensive writings of Bohr about complementarity, particularly in his later years, make it clear (cf. Kalckar 1985, 1996; Favrholt, 1999) that Bohr’s preeminent concern was to extend the idea of complementarity beyond physics. Quantum physical examples are just a very special case within the broad range of applications that Bohr had in mind. In the same spirit, Pauli advanced the opinion that the “issue of complementarity within physics naturally leads beyond the narrow field of physics to analogous conditions of human knowledge.”⁴⁰ Pauli presumed⁴¹

“that in the *complementarity of physics*, with its overcoming of the wave-particle duality, there is a sort of *model or paradigm of that other, more comprehensive conjunctio*.”

Pauli shared Gonseth’s (1948) interest “to formulate the idea of complementarity so generally that no explicit reference is made anymore to physics in [a] proper sense” (Pauli 1948, p. 310). Moreover, Pauli suggested that Bohr’s (1948) definition of

“the word *phenomenon* to refer exclusively to observations obtained under specified circumstances including an account of the whole experiment”

should be used for such a formulation. Bohr’s quotation emphasizes that a proper account of the experimental context is mandatory for a clear-cut definition of an observed phenomenon. Generalizing this important point, any stated proposition must be regarded as bound to a context, and different contexts can imply complementary propositions with a non-Boolean logical structure.

On the other hand, it is crucial to insist with Bohr (1949, p. 209) that “by the word ‘experiment’ we refer to a situation where we can tell others what we have done and what we have learned”:

“For this purpose, it is decisive to recognize that, *however far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms*.”

This requires a domain of discourse with a Boolean logical structure, characterized by a two-valued logic based on the law of the excluded middle, asserting

⁴⁰ Pauli (1950), p. 79, translated by the authors.

⁴¹ Quoted from a letter by Pauli to Jung of February, 27, 1953. Letter 1526 in von Meyenn (1999), p. 52. Translated by the authors.

that every proposition is either true or false. That is, *classical* is here to be interpreted as *Boolean*, not as macroscopic.

Combining the conditions of classicality and contextuality, it follows that a unified formal framework for the concept of complementarity requires both a locally Boolean and a globally non-Boolean logical structure. Such structures can be obtained by pasting together well-understood Boolean substructures in a consistent manner. In this way we get a manifold-like structure that is locally Boolean but may be more complicated and subtle when viewed as a whole.

Two aspects represented in such a structure are called *incompatible* if they cannot be represented in one and the same Boolean algebra. Since two complementary aspects have to pertain to a common reference, this structure has to be implemented by some compatibility relation. Therefore an appropriate structure for complementary aspects has to be globally non-Boolean, locally Boolean, and must satisfy appropriate compatibility conditions on any overlapping pair of aspects.

The family of non-Boolean but locally Boolean structures is sufficiently rich to encompass the many aspects of complementarity in various areas of knowledge. Depending on how one chooses the compatibility relation one gets complementarity theories based on Boolean atlases (Domotor 1974), Boolean manifolds (Hardegree and Frazer 1981), or on transitive partial Boolean algebras (Kochen and Specker 1965a,b). Such non-Boolean but locally Boolean descriptions can account for a globally holistic conception of nature about which contextual Boolean propositions are possible locally.

Besides the well-known cases of quantum mechanics and quantum field theory, there are many non-Boolean propositional systems outside of physics which can be successfully formalized in this way.⁴² In such systems every gain of knowledge involves a projection from the non-Boolean structure onto a Boolean context. Context-independent Boolean descriptions of a non-Boolean world do not exist. In other words, we perceive nature always contextually, filtered through a Boolean frame, so that *every phenomenon and every observable pattern is conditional*.

5 The psychophysical problem

5.1 Pauli's commitment to the mind-matter problem

During Pauli's lifetime, only a few intimates knew his far-reaching commitment to the problem of how to conceive the relationship between mind and matter. For almost three decades Pauli had a deep and active interest for this problem, particularly from a Jungian perspective, but there are only few remarks in his publications which reflect this commitment. Combining physical and psycholog-

⁴² Compare for example the discussions in the context of pattern recognition (Kulikowski, 1970; Schadach, 1973), of mind-body relations (Watanabe, 1961), of theory reduction (Primas, 1977), or of non-commutative probability and information theory (Watanabe, 1969; Niestegge, 2001).

ical understandings, Pauli imagined a reality which cannot be directly accessed but only indirectly referred to symbolically. In a letter to Rosenfeld he wrote:⁴³

“For the *invisible reality*, of which we have small pieces of evidence in both quantum physics and the psychology of the unconscious, a *symbolic*, psychophysical unitary language must *ultimately* be adequate, and this is the far goal which I actually aspire. I am quite confident that the final objective is the same, independent of whether one starts from the psyche (ideas) or from physis (matter). Therefore, I consider the old distinction between materialism and idealism as obsolete.”

In continuation of his correspondence with Rosenfeld, Pauli insisted that consciousness, in particular human consciousness, only refers to a fraction of what he addresses as psyche or the mental:⁴⁴

“... we know the existence of objective unconscious factors in the psyche, so there is probably a psyche long before there is consciousness. This *Unconscious* of a species of animals will presumably produce ‘archetypical pictures’ and with this ‘patterns of behaviour’. The adaptation and the physical experience will react backwards on the unconscious psyche and here we are: I am accepting the evolutionary point of view but I stay complementary (and symmetrical) with respect to the distinction ‘matter versus psyche’. There is *no* ‘decision’ in favour of materialism for me but there is also psyche long before there is consciousness. ... The idea of a ‘Geist’ or a ‘Weltgeist’ (as the Germans like to say) as origin of all ‘Geschehen’ is rejected by me for the reason that ‘Geist’ is too much similar to ‘human consciousness’ and much too ‘anschaulich’.”

Pauli speculated that a science of the future will refer to such a basic reality as neither psychic nor physical but somehow both of them and somehow neither of them.⁴⁵ He suggested that the mental and the material domains of the basic reality should be understood as complementary aspects under which this reality can appear:⁴⁶

“The general problem of the relation between psyche and physis, between inside and outside, can hardly be regarded as solved by the term ‘psychophysical parallelism’ advanced in the last century. Yet, perhaps, modern science has brought us closer to a more satisfying conception of this relationship, as it has established the notion of *complementarity* within physics. It would be most satisfactory if physis and psyche could be conceived as complementary aspects of the same reality.”

⁴³ Letter by Pauli to Rosenfeld of April 1, 1952. Letter 1391 in von Meyenn (1996), p. 593. Translated by the authors.

⁴⁴ Letter by Pauli to Rosenfeld of April 16, 1952. Letter 1399 in von Meyenn (1996), p. 610–611.

⁴⁵ Letter by Pauli to Pais of August 17, 1950. Letter 1147 in von Meyenn (1996), p. 152.

⁴⁶ Pauli (1952), p. 164. Translated by the authors.

Pauli's suggestion to consider mind and matter as complementary aspects of the same reality has sometimes been misunderstood in the sense that conscious human observers need to be included as an essential new feature of quantum mechanics.⁴⁷ Pauli clarified this misrepresentation succinctly:⁴⁸

“Once the physical observer has chosen his experimental arrangement, he has no further influence on the result which is objectively registered and generally accessible. Subjective properties of the observer or his psychological state are as irrelevant in the quantum mechanical laws of nature as in classical physics.”

5.2 Archetypes and *unus mundus*

Central for Jung's depth psychology is the concept of archetypes. His understanding of the nature of archetypes matured over nearly half a century. First he thought they were psychic images as they appear in dreams, fantasies, legends and myths. Later he came to recognize archetypes as essentially extra-psychic and coined the notion “psychoid” for this situation. It expresses Jung's conviction that archetypes are exclusively non-psychic although they can manifest themselves in the psychic domain.

Finally, Jung supposed that archetypes generate the underlying structures of both the psyche and the material world. He used the term *unus mundus* to describe the psychophysically neutral, unitary ground which underlies the duality of mind and matter (Jung 1970, par. 767):

“Undoubtedly the idea of the *unus mundus* is founded on the assumption that the multiplicity of the empirical world rests on an underlying unity, and that not two or more fundamentally different worlds exist side by side or are mingled with one another. Rather, everything divided and different belongs to one and the same world, which is not the world of sense but a postulate whose probability is vouched for by the fact that until now no one has been able to discover a world in which the known laws of nature are invalid. That even the psychic world, which is so extraordinarily different from the physical world, does not have its roots outside the one cosmos is evident from the undeniable fact that causal connections exist between the psyche and the body which point to their underlying unitary nature.”

For the concept of the *unus mundus* it is crucial to understand that its mental and material domains are neither identical nor completely separated. In fact they are correlated by the action of archetypal ordering factors:⁴⁹

⁴⁷ For example the Jungian psychologist Marie-Louise von Franz claimed: “Heute wissen die Physiker, daß ihre eigene psychische Konstellation einen Einfluß hat auf ein subatomares Experiment.” (Geerk, 1989, p. 143.)

⁴⁸ Pauli (1954b), p. 286. Translated by the authors.

⁴⁹ Letter by Pauli to Fierz of January 7, 1948. Letter 929 in von Meyenn (1993), pp. 496–497. Translated by the authors.

“The ordering and regulating factors must be placed beyond the distinction of ‘physical’ and ‘psychic’ – as Plato’s ‘ideas’ share the notion of a concept and of a force of nature (they create actions out of themselves). I am very much in favor of referring to the ‘ordering’ and ‘regulating’ factors in terms of ‘archetypes’; but then it would be inadmissible to *define* them as contents of the *psyche*. The mentioned inner images (‘dominant features of the collective unconscious’ after Jung) are rather *psychic* manifestations of the archetypes which, *however*, would *also* have to put forth, create, condition anything lawlike in the behavior of the corporeal world. The laws of this world would then be the *physical manifestations of the archetypes*. . . . Each law of nature should then have an inner correspondence and vice versa, even though this is not always directly visible today.”

It was clear to Pauli that some kind of mind-matter distinction is inevitable for a scientific description of reality. Therefore, he did not nurture naive beliefs about premature psychophysical unification scenarios. However, he pondered the option that the development of Western science might have led to a situation in which the chance for such a unified view on a solid basis has increased as compared to previous attempts:⁵⁰

“It is true that the distinction of ‘physical’ and ‘psychic’ is inevitable in the empirical world of phenomena, and it was the mistake of the alchemists to apply a monistic (neutral) language to concrete chemical processes. But since matter has now turned into an abstract, invisible reality for the modern physicist, the prospects for a psychophysical monism have become much more auspicious.”

5.3 Breaking the symmetry of the unus mundus

Archetypal ordering factors are assumed to operate at the deepest level of the unitary symmetry of the unus mundus, underlying both mind and matter. Pauli emphasized that this ultimate reality is impersonal⁵¹ and proposed that mind and matter can be considered to emerge by a breakdown of the psychophysical symmetry of the unus mundus:⁵²

Dichotomy and symmetry reduction, that is the gist of the matter!
 . . . Dichotomy is an ancient attribute of the *devil*. . .
 The two divine gentlemen – Christ and the devil – are supposed to realize
 that they have become *much more symmetric* meanwhile.

⁵⁰ Letter by Pauli to Jung of February 27, 1953. Letter 1526 in von Meyenn (1999), p. 49. Translated by the authors.

⁵¹ Compare the remark by Pauli in the letter to Sambursky of October 7, 1957. Letter 2704 in von Meyenn (2005a), p. 555.

⁵² Letter by Pauli to Heisenberg of December 21, 1957. Letter 2805 in von Meyenn (2005a), p. 736. Translated by the authors.

The relationship between psychology and physics thus resembles a *mirror image*.⁵³

“Physics relies on a mirror symmetry between mind and nature.”

“At the same time, mirroring is an archetypal background which is most tightly related to the *psychophysical problem*.”

If one takes the idea of a symmetry breaking seriously for the relation between mind and matter, the starting point for advancements in its understanding has to be the relationship between parts and wholes. From a scientific point of view it seems to be promising to use the well-developed conceptual framework of modern quantum theory as a guideline. An essential feature of quantum theory is that it *refers to the material world as a whole which does not consist of parts*. We can describe this undivided material world only if we introduce distinctions which create frames of reference as they are necessary for any kind of cognition and description. “Our world ‘divides into facts’ because we so divide it” (Langer 1978), p. 273).

In his therapeutic work Jung often observed the simultaneous occurrence of two meaningfully, but not causally, connected events, for which he coined the term *synchronicity*.⁵⁴ But for years he hesitated to publish his corresponding ideas. It was Pauli who encouraged him to write them down as a comprehensive account. The final version (Jung 1952) was the result of several revisions inspired by Pauli’s numerous comments.⁵⁵ Jung’s notion of a synchronicity of pairwise arranged events in the mental and the material domains, correlated by a common meaning, is tightly related to the idea of a broken symmetry of the *unus mundus*. The synchronistic correlation between the events can be regarded as a retrospective indication, a remnant as it were, of the unity of the archetypal reality of the *unus mundus* from which they emerge.

Since synchronistic phenomena are not necessarily simultaneous, synchronicity is a somewhat misleading term. For this reason Pauli preferred to speak of meaningful correspondences (“*Sinnkorrespondenzen*”) under the influence of an archetypal acausal ordering. He suggested that the aspects of meaning and goal-orientedness in synchronicity might force science to revive the historically repressed concept of finality as a complement to causality (see also section 6.3).

While Jung considered synchronicity as a relatively rare phenomenon, Meier (1975) presumed that “synchronicity is as common as causality” (see also Meier 1950, 1988). He proposed to understand even psychosomatic and, ultimately, psychocerebral relations in terms of a generalized kind of synchronicity. Although Jung hesitated to agree with such an extension, modern dual-aspect approaches to consciousness (see section 4.4 below) suggest that the basic idea may still be worth exploring. After all, the relation between conscious states

⁵³ Pauli in a conversation with Bender on April 30, 1957 (quoted from von Meyenn (2005a), p. 338) and in a letter to Meier of March 16, 1957 (letter 2578 in von Meyenn (2005a), p. 318). Translated by the authors.

⁵⁴ First mentioned in an obituary for Richard Wilhelm in *Neue Zürcher Zeitung*, March 6, 1930.

⁵⁵ See the Pauli–Jung correspondence between June 1949 and February 1951 in Meier (1992).

and brain states is the best known and least controversial example of a mind-matter relation. But it must be admitted that (at best) only sketches of an approach have been suggested for how to flesh this attractive idea out in detail. Proposals with both solid theoretical grounding and clear empirical relevance are certainly lacking so far.

5.4 Related approaches

Treating mind and matter as two domains of description with equal importance, arising from the broken symmetry of an underlying, more basic reality, leads to an epistemically dualistic approach. It says that mind and matter are to be distinguished for the purpose of our modes of knowledge acquisition; they are not considered to be distinct a priori. The concept of the *unus mundus* provides an ontological level of description without any split of mental and material domains, which is more fundamental than the descriptive level with split domains. One can address the transition from the fundamental level to that with mind and matter separated in terms of emergence, if one thinks of it as an emergence of the distinction of mind and matter (rather than the emergence of mind from matter).

In the history of philosophy, such a conception has early been discussed by, e.g., Spinoza and Leibniz. For Spinoza, there is one fundamental substance, a “*causa sui*”, from which all (not only two) particular manifestations derive as differentiations. In Leibniz’s conception, mental and material domains of reality exist in parallel. Their parallelism is guaranteed by a “preestablished harmony”, preestablished by divine wisdom. In the 20th century, Feigl (1958) proposed a related conception, today known as identity theory, in which mental states and brain states are considered as aspects of so-called “central states”.⁵⁶

A modern version of such a “dual-aspect” approach has been advocated by Chalmers (1996) in the context of what he calls the “hard problem” of consciousness. For Chalmers the key issue is the relation between the subjective experience of a conscious mental state (first-person account) and its neural correlate (third-person account). He discusses whether a concept of information might be relevant for assessing the fundamental level of reality whose description does not distinguish brain states and mental states. Since information in its usual understanding is a clearly epistemic term, corresponding approaches contradict the ontic significance required for a description without mind-matter distinction. Such approaches are either ill-defined to begin with, or they need much clarification and refinement to be viable.⁵⁷

An eminent physicist with a strong interest in mind-matter questions was Wigner. As for Pauli, a major guideline in Wigner’s work can be characterized by invariance and symmetry principles. Revising his early, questionable

⁵⁶ For a review of related frameworks of thinking of this kind, compare for example Popper & Eccles (1977).

⁵⁷ Among contemporary physicists, Zeilinger seems to advocate such a position. Partly based on ideas by von Weizsäcker he considers information as the most fundamental notion of quantum mechanics (cf. Brukner & Zeilinger (2003)).

conjectures about the role of consciousness in the reduction of wavepackets, he still believed “that the present laws of physics are at least incomplete without a translation into terms of mental phenomena”, and indicated the possibility of an extension of the presently accepted laws of nature (Wigner 1970):

“It will be based on the assumption that a picture will be discovered which will provide us with a view encompassing both mental and physical phenomena and describe regularities in both domains from a unified point of view.”

Apart from unsatisfying attempts to formulate hidden variable approaches to quantum theory, Bohm is another example for a dual-aspect approach to mind and matter. His ideas about explicate and implicate order are particularly relevant in this context. While the notion of an explicate order characterizes an operationally and, thus, epistemically accessible reality, the notion of an implicate order deals with the realm of ontology. Bohm refers to the mind-matter distinction at the level of an explicate order, which is based on an implicate order without that distinction (Bohm 1990):

“At each level of subtlety there will be a ‘mental pole’ and a ‘physical pole’ . . . But the deeper reality is something beyond either mind or matter, both of which are only aspects that serve as terms for analysis.”

In his more recent contributions, d’Espagnat (1997, 1999) has made explicit indications with respect to the relationship between mind and matter. He uses the notion of an independent “ ‘Ultimate Reality’ that is neither mental nor material (or, equivalently, is both), for it is conceptually prior to the mind-matter splitting” (Espagnat 1999, p. 267). It is interesting to note that on d’Espagnat’s view there is an additional distinction between an “independent reality” and an “empirical reality” within the material domain, which is conceptually posterior to the mind-matter distinction and should in principle be in the realm of physical theories, excluding any reference to mental states or processes.

6 Time and nowness

6.1 From mind and matter to time

In order to grasp in detail what Pauli means by “complementary aspects of reality”, one needs to know what the only vaguely characterized concepts of “complementarity”, “mind”, and “matter” mean precisely. Even the answer to the apparently easy question “what is matter?” has changed dramatically several times since 1644, when Descartes characterized matter as extended substance (*res extensa*) in his *Principia Philosophiae*. Science has developed in a way leading to the refutation of the original arguments of Descartes. According to modern physics matter cannot be characterized by any concept of “extension” – besides localized matter there are nonlocal manifestations of matter and physical energy. In this respect, Pauli (1954a, p. 1129) wrote:

“Matter has always been and will always be one of the main objects of physics. . . . even light has become matter now, due to Einstein’s discoveries. It has mass and also weight; it is not different from ordinary matter, it too having both energy and momentum. . . . Taking the existence of all these transmutations into account, what remains of the old ideas of matter and substance? The answer is *energy*. This is the true substance, that which is conserved; only the form in which it appears is changing.”

As addressed in section 2, conservation laws emerge from deep symmetry principles. The contemporary definition of energy as a conserved quantity associated with time-translation invariance is based on Noether’s theorem. As a consequence, “the old ideas of matter and substance” are fundamentally related to the *homogeneity of physical time*.

6.2 Time in fundamental physics

In quantum mechanics physical observables are represented by selfadjoint operators. In his handbook article on the general principles of quantum mechanics, Pauli pointed out that the existence of a selfadjoint time operator is incompatible with the semi-bounded spectrum of the Hamiltonian. As a result, Pauli (1933, Ziff. 8, p. 140) concluded that a quantum mechanical time operator must be abandoned and that time in quantum mechanics has to be regarded as an ordinary number (c-number). This remark has been found puzzling and gave rise to a vast literature with many unconvincing formal attempts to circumvent this conclusion. Yet, already in the early days of quantum mechanics, Pauli proposed a deeper conceptual explanation:⁵⁸

“Now if one deliberates where the problem occurs as to make statements about the temporal instants of transition processes from the viewpoint of the new theory, one soon realizes that time actually does not enter into the new theory at all.”

“However, ‘time’ t in general has no physically real, but only a formal significance.”

The physical time which is related to matter and substance is not the time we experience mentally but a homogeneous *parameter time* referring to an *external* clock carried by an inertial observer, which is not part of the physical system under discussion. Moreover, there is nothing that “flows” or “passes” in this physical time.

All fundamental physical dynamical laws are invariant under the translation of this parameter time so that they do not contain any tensed notions. The indexical element *now* – the brief interval that divides the past from the future – is absent in all fundamental physical theories, in both classical physics and quantum physics, and in both Galilei-relativistic and Lorentz-relativistic

⁵⁸ Letter by Pauli to Bohr of November 17, 1925. Letter 106 in Hermann, von Meyenn & Weisskopf (1979), p. 260, and letter by Pauli to Heisenberg of January 31, 1926. Letter 118 in Hermann, von Meyenn & Weisskopf (1979), p. 283. Translated by the authors.

formulations. In particular, Minkowski's space-time of special relativity admits no privileged decomposition in space and time and undercuts the distinction between past, present and future. Eddington (1920, p. 51) observed very early that it is only the phenomenon of *consciousness* that requires to consider the *passage of time*:

“Events do not happen; they are just there, and we come across them.”

That is, any proper account of the flow of time must incorporate the concept of a conscious observer. In the succinct words of Weyl (1949a, p. 116):

“The objective world simply *is*, it does not *happen*. Only to the gaze of my consciousness, crawling upward along the line of my body, does a section of this world come to life as a fleeting image in space which continuously changes in time.”

Einstein expressed the fact that events in Minkowski's four-dimensional world are not objective by relating them to the notion of *nowness*. The “*now* loses for the spatially extended world its objective meaning” (Einstein 1961, p. vii and p. 170). The later development of general relativity theory led Gödel (1995, p. 236) to conclude:

“... we can say that what remains of time in relativity theory as an objective reality inherent in the things neither has the structure of a linear ordering nor the character of flowing or allowing change. Something of this kind, however can hardly be called time.”

6.3 Time in experimental physics

The most consequential accomplishment of Newton was his insight that the *laws of nature* have to be separated from *initial conditions* for these laws.⁵⁹ In experimental physics it is always taken for granted that the future differs from past and present and that experimenters have the freedom to choose or to manipulate (within appropriate limits) the initial conditions and to repeat their experiments at any particular instant.

The division into past and future is closely associated with our ideas of causation and free will. This has also been underlined by Pauli:⁶⁰

“It is true that [in a quantized field theory] future is not yet distinguished from past. From my point of view such a distinction should, however, not be introduced into quantum theory by an additional principle, but derives from the physical situation insofar as the result of a previous observation is usually assumed as known, and then one asks for the statistical distribution of results of later observations.”

⁵⁹ Compare Houtappel, Van Dam & Wigner (1965), p. 596; Wigner (1964), pp. 996–996; Wigner (1983), p. 1365. Initial conditions and laws of nature are distinguished in Newton's *Philosophia Naturalis Principia Mathematica*, though only in an implicit fashion.

⁶⁰ Letter by Pauli to Rivier of August 23, 1948. Letter 975 in von Meyenn (1993), p. 568. Translated by the authors.

Here Pauli refers to an observer with a memory and with the ability to distinguish between past and future. Since these features are not included in or derivable from the first principles of theoretical physics, our description of the behavior of matter is fundamentally incomplete:⁶¹

“The famous ‘incompleteness’ of quantum mechanics (Einstein) is indeed there somehow-somewhere, but of course it cannot be removed by returning to classical field physics (that is only a ‘neurotic misunderstanding’ of Einstein). Rather, it has to do *with holistic relationships between ‘inside’ and ‘outside’ which current science does not comprehend.*”

In the sense of this quote, the external clock time of physics needs to be complemented by an internal time with *nowness* for a conceptually clean specification of the initial conditions of physical experiments. By requiring the *freedom* to choose initial conditions, every experimental investigation *breaks the homogeneity of time*. In contrast to the homogeneous parameter time of fundamental physics, the time of everyday life essentially involves *tense* and has a preferred point of reference – the *now*. However, the first principles of physics do not offer the conceptual tools for a definition of the *now*. Pauli expected that the problem of time was a major stumbling block to our deeper understanding of reality:⁶²

“More and more I expect a further revolution of basic notions in physics, where I am particularly dissatisfied with the way in which the space-time continuum is introduced at present. (Of course it is ingenious to disband time from ordering causal sequences and – ‘as once in May’ – use it as a romping place for probabilities. But if one replaces *ingenious* by *impudent*, this is not less true. In fact, something *happens* only during an *observation*, where – as Bohr and Stern finally convinced me – entropy increases necessarily. *Between* observations *nothing happens at all, only time* has reversibly proceeded on our mathematical papers!) This space-time continuum has now become a Nessus shirt which we cannot take off again! (Instead of ‘Nessus shirt’ you can also say ‘prejudice’, but this would, first, sound too harmless and, second, shift the mistake too much from a mere conception to a judgment.)”

6.4 Physical time and mental time

As discussed in the preceding section, every experiment demands the distinction of past and future and the concept of the *now*. This requires a conscious mind in a state of mental presence – an element of reality which is clearly not included in the first principles of physics. Therefore time appears to have two aspects which one may call physical and mental. They refer to two mutually exclusive,

⁶¹ Letter by Pauli to Fierz of August 10, 1954. Letter 1864 in von Meyenn (1999), pp. 744–745. Translated by the authors.

⁶² Letter by Pauli to Fierz of March 30, 1947. Letter 877 in von Meyenn (1993), pp. 435–436. Translated by the authors.

complementary ways of looking at a fundamental ordering principle. As physics does not broach the issue of mental presence, physical parameter time conveys its experienced meaning only through the medium of mental time. The present of mental time is the instance at which mental presence is experienced. Characteristic for mental time are the intuitive conceptions of the present, of nowness, and of its tensedness, which distinguishes a fixed past from an open future.

At the psychophysically neutral level of the *unus mundus* there is no time at all. Time emerges as an epistemic ordering parameter due to a symmetry breaking of the primordial reality referred to as the *unus mundus*. The associated distinction leads to a tensed and a tenseless domain. In this sense, tenseless physics is an incomplete description of reality as a whole. On the other hand, the notions of tensed time and the present are closely associated with the mental presence of subjective experience. The idea that mental presence is mandatory for consciousness has been succinctly expressed recently (Franck 2004): “Ignoring the presence means to ignore the very existence of consciousness.” This situation implies a deep and largely unexplored relationship between human experience and physical nature.

In the non-Boolean framework of modern quantum theory the idea of a temporal symmetry breaking of a timeless acausal order in the sense of Pauli and Jung can be implemented such that a tensed mental domain and a tenseless physical time emerge. The holistic nature of the *unus mundus* implies that the states describing the material and the mental domain are entangled.⁶³

6.5 Process ontology

A philosophical framework to address these difficult questions is provided by process ontology. The basic idea is that processes rather than substances such as mind and matter constitute the most basic elements of reality. Early in the 20th century, Whitehead revitalized this approach, which can be traced back to the Presocratics, with his “Process and Reality” (Whitehead 1978). He developed a concept of events (“actual occasions”) which each have a physical and a mental pole, a picture clearly giving rise to panpsychism. Whitehead tried, ultimately unsuccessfully, to establish his notion of an event in the sciences of his time, in particular in Einstein’s relativity theory.

Whitehead himself did not consider the possibility that his philosophy might be more properly related to quantum theory. Corresponding studies were initiated later by philosophically inclined physicists such as Burgers (1963), Shimony (1965), Stapp (1979). More recently Haag (1999, 2004) discussed an ontological model for quantum physics in which the notion of events is of central significance. Conventional quantum objects are regarded as causal links between events. Localization in space and time refers to events, not to objects. On Haag’s account the intrinsic indeterminacy of quantum theory implies to consider both possibilities and facts, leading to the distinction between future and past.

⁶³ A mathematical model in which the tensed mental time is synchronized with the tenseless time of physics by quantum correlations has been discussed by Primas (2003).

From a philosophical point of view, Klose (2002) analyzed Whitehead's work with particular emphasis on the notion of time, Malin (2001) related elements of Whitehead's thinking to quantum mechanics, and Hättich's (2004) recent account addresses Whitehead's philosophy mainly with respect to contemporary quantum field theory. The connections between quantum physics and Whitehead's process philosophy are discussed from different perspectives in the recent collection of essays edited by Eastman and Keeton (2004). It turns out that the implementation of events in Whitehead's sense into quantum theory is everything else than straightforward. The even more difficult inclusion of mental time remains mostly unaddressed.

7 Biological evolution and random mutations

7.1 On the randomness of mutations

In addition to the psychophysical problem, the topic of biological evolution played a prominent role in Pauli's extraphysical interests. Before the advent of molecular biology in the 1940s, the mainstream position with respect to biological evolution was referred to by the term *Modern Synthesis*. A key concept of this position was that the genetic variation within a population arises by *random mutations*, not by adaptively directed mutations and recombinations (Mayr 1982). Pauli was not convinced that the evolution of life could be explained by random mutations only and questioned this aspect of the Darwinian model of natural evolution:⁶⁴

“As a physicist, I should like to critically object that this model has not been supported by an affirmative estimate of probabilities so far. Such an estimate of the theoretical *time scale* of evolution as implied by the model should be compared with the empirical time scale. *One would need to show that, according to the assumed model, the probability of de facto existing purposeful features to evolve was sufficiently high on the empirically known time scale. Such an estimate has nowhere been attempted though.*”

In order to achieve plausible evidence in favor of the Darwinian model, Pauli insisted that the probabilities for large-scale evolution need to be calculated realistically and consistent with mathematical probability theory:⁶⁵

“In discussions with biologists I met large difficulties when they apply the concept of ‘natural selection’ in a rather wide field, without being able to estimate the probability of the occurrence *in a empirically given time* of just those events, which have been important for the biological evolution. Treating the empirical time scale of the evolution theoretically as infinity they have then an easy game, apparently to avoid the concept of purposiveness. While they pretend to stay in this way completely ‘scientific’

⁶⁴ Pauli (1954b), p. 298. Translated by the authors.

⁶⁵ Letter by Pauli to Bohr of February 15, 1955, letter 2015 in von Meyenn (2001), p. 105.

and ‘rational’, they become actually very irrational, particularly because they use the word ‘chance’, not any longer combined with estimations of a mathematically defined probability, in its application to very rare single events more or less synonymous with the old word ‘miracle’.”

Beyond the sloppy usage of the notion of chance by many biologists, Pauli also pointed out that this concept may even be altogether misplaced in particular applications to biological evolution:⁶⁶

“I am of course getting angry if biologists try to use the general concept ‘chance’ in order to explain phenomena which are so typical for living organisms as, for instance, those appearing in the biological evolution.”

In a seminal paper, Luria and Delbrück (1943) reported experimental results suggesting that bacterial mutations bore no relation to any pressures exerted by their environment. Most biologists took this as a confirmation of the dogma that heritable variations only result from random genetic changes. In addition, the successes of molecular biology led to the influential reductionistic stance that quantum mechanics and physical chemistry together with Mendelian genetics are in principle sufficient to explain biological evolution. Pauli emphasized his discomfort with this “orthodox view” in a letter to Delbrück:⁶⁷

“Probably the situation is a *complex* one and beside the holy chance there exist processes with a *directed goal* and *also* causal influences of the environment on inherited properties on the way over the cytoplasm.”

But Delbrück was entirely unwilling to consider seriously anything like purposiveness or adaptive mutations:⁶⁸

“My elaborations concerning neo-Darwinism made [Delbrück] very angry. He talked about a ‘plot of unemployed theoretical physicists against biology’.”

Mayr, one of the founders of *Modern Synthesis*, rejected Pauli’s (and Bohr’s) criticism as well. Similar to Delbrück, he played it down as based on an “oversimplified understanding of the biological processes involved in evolution” (Mayr 1982, p. 429).

7.2 Epigenetic inheritance

Today we know that there are heritable changes in gene functions that occur without a change in the sequence of DNA. Such stable alterations in gene expression that arise during development are referred to as *epigenetic inheritance*.

⁶⁶ Letter by Pauli to Delbrück of February 6, 1954. Letter 1720 in von Meyenn (1999), p. 472.

⁶⁷ Letter by Pauli to Delbrück of February 4, 1954. Letter 1712 in von Meyenn (1999), p. 452.

⁶⁸ Letter by Pauli to Elsasser of September 30, 1958. Letter 3067 in von Meyenn (2005a), p. 1271. Translated by the authors.

This term has a long history with different meanings. Waddington coined the notion of *epigenetics* (a combination of *epigenesis* and *genetics*⁶⁹) as a translation of the German “Entwicklungsmechanik”, intended to describe the study of the processes by which genotypes give rise to phenotypes. He explained (Waddington 1956, p. 10):

“Its literal translation [of ‘Entwicklungsmechanik’] in English is ‘developmental mechanics,’ a phrase which is not only rather long and clumsy as the name of a branch of science, but which carries a perhaps unfortunate suggestion that only machine-like, physical processes are being envisaged. Another rather awkward phrase, ‘experimental embryology,’ is often used in English in its place. Perhaps the most satisfactory expression would be ‘epigenetics.’ This is derived from the Greek word *epigenesis*, which Aristotle used for the theory that development is brought about through a series of causal interactions between the various parts; it also reminds one that genetic factors are among the most important determinants of development.”

After the discovery of the structure of DNA, the possibility of epigenetic inheritance was largely ignored. But the end of the 20th century brought an increase of interest in the role of environmental factors in determining phenotypes. Early evidence for such factors derived from research on the genomes of unicellular organisms. In the last three decades many additional results were accumulated, showing that epigenetic inheritance plays a significant role in the evolution of complex organisms.⁷⁰ Because new experimental results challenged the prevailing dogma of geneticism, epigenetics has become widely recognized. Today it constitutes an established area of biology whose core topic is the notion that not all heritable information leading to the phenotype is fixed in the DNA base sequence.

Not long after Pauli’s death the group of Sonneborn developed microsurgery techniques to alter the pattern of cilia on the surface of *Paramecium Aurelia* (a unicellular animal). They found in a series of striking experiments that these changes were transmitted permanently to the offspring through mitosis and meiosis (Beisson and Sonneborn 1965). Similar phenomena have been demonstrated in other ciliates (Nelsen, Frankel and Jenkins 1989).

Most surprisingly, the propagation of the alterations to offspring was not due to changes in the chromosomal genome. Although this appears to violate Mendel’s genetic laws, it does not support the overall concept of Lamarckian evolution. A genuinely Lamarckian mechanism would require that a protein-based genetic variation generates newly acquired inherited traits. But, according to Chernoff (2001, p. 58), a “proof of adequate inherited adaptive change in protein structure is missing thus far. However, no one can now exclude the possibility that such a proof can be obtained in the future.”

⁶⁹ For a discussion of the historical and conceptual links between epigenesis and epigenetics, compare Speybroeck (2000, 2002).

⁷⁰ Compare the reviews by Landman (1991), Lenski & Mittler (1993), Jablonka & Lamb (1998), Chernoff (2001).

Two decades later, Cairns and co-workers proposed the occurrence of advantageous *directed mutation* in bacteria based on “experiments suggesting that cells may have mechanisms for choosing which mutations will occur” (Cairns, Overbaugh and Miller 1988). This so-called *directed-mutation hypothesis* claims that living organisms possess the ability to select for beneficial mutations when stressed. This hypothesis challenges the central dogma of genetics that the likelihood for a particular mutation to occur is independent of its phenotypic consequences. Therefore, it was first considered as a heretical Lamarckian notion by the biological community. “It was like hearing about a unicorn” (Stahl 1988).

There are now further impressive experiments supporting the results of Cairns (Gillis 1991). These investigations have stimulated much research and have kept the attention of biologists for several years. Even though the implications of the results are still controversial, they have challenged traditional thinking about spontaneous random mutations.

Many biologists tried to unriddle these results by neo-Darwinian explanations without directed mutations, but accepting the possibility of non-random mutations. Since “nobody wants to give the appearance of straying from the neo-Darwinian fold” (Gillis 1991, p. 202), explanations are generally formulated without using Lamarckian language. Terms such as “adaptive mutability” and “hypermutation” have been coined for the apparent alteration rate of mutability under specific environmental factors. Jablonka and Lamb (2005, p. 80) summarize the present-day situation as follows:

“On balance we think that the experimental evidence that is now available suggests that Cairns and his colleagues were probably wrong; they were not dealing with mutations that were produced in direct response to the environmental challenge they imposed. However, what emerged from the work their paper stimulated and subsequent molecular studies is important, because it has resulted in a far less simplistic view of the nature of mutations and mutational processes. There is now good experimental evidence, as well as theoretical reasons, for thinking that the generation of mutations and other types of genetic variation is not a totally unregulated process.”

Now it is widely accepted that some hereditary variations are non-random, that some acquired information is inherited, and that evolutionary change can result from instruction as well as selection. But no *mechanisms* for this behavior has yet gained universal acceptance (Aertsen and Michiels 2005, Rosenberg 2001). The recent *Encyclopedia of Evolution* concludes (Jablonka and Lamb 2002, p. 604): “It is clear that evolutionary adaptations predominantly arise from natural selection, but there is probably also a role for Lamarckism, not as rival to Darwin’s evolutionary theory but as a part of it.”

7.3 Causal and final explanations

Pauli did not agree with the neo-Darwinistic views of modern biology but proposed to take seriously the option of final causes as complementary to efficient causes. He argued that a Darwinian-style evolutionary logic in which chance plays the role of a *deus ex machina* leaves much to be desired:⁷¹

“This model of evolution is an attempt, in line with ideas of the second half of the 19th century, to adhere to the total elimination of all traces of finality. This must, then, somehow be replaced by introducing elements of chance.”

In his *Lecture to the Foreign People*⁷² Pauli did not rule out that the introduction of chance arises from a premature rejection of meaningful final (goal-oriented) processes. With this background, he speculated about a still unknown third type of laws of nature in addition to deterministic and stochastic versions:⁷³

“According to this hypothesis, which differs from both the Darwinian and the Lamarckian conception, we encounter here a third type of laws of nature which consists in corrections to chance fluctuations due to meaningful or purposeful coincidences of causally unconnected events.”

Only few biologists have the courage to refer to final causes since teleological approaches are reputed to lack explanatory power. This premise is usually accepted on faith and without logical evidence. The disrepute of teleological accounts is partly (and ironically) due to the strange belief (defended, e.g., by Stegmüller 1984) that they require a causal explanation in terms of ghosts, demons or an intelligent creator.

Contemporary molecular biology is to a considerable extent based on pragmatic working rules of *experimental* physics which, as explained in section 5.3, do not have a firm foundation in the *first principles* of physics. In the currently accepted fundamental laws of physics there is no preferred direction of physical processes with respect to time. Hence, *physics alone does not allow to distinguish cause and effect* in the sense of efficient causation. The symmetry breaking required for a causal description of an experiment (in the sense that “the stimulus precedes the response”) demands that the past is factual while the future is contingent.

This requirement is related to the old controversy between causal and final descriptions in the important aspect of their assumed direction of time. The first principles of physics permit backward deterministic and forward non-deterministic processes (with statistical predictions) as well as forward deterministic and backward non-deterministic processes (with statistical retrodictions).

⁷¹ Pauli (1954b), p. 297. Translated by the authors.

⁷² According to Pauli (von Meyenn, 2005a, p. 350) the phrase “Foreign People” refers to thoughts not yet assimilated with consciousness. The *Lecture to the Foreign People* (*Vorlesung an die fremden Leute*) is part of the essay *The Piano Lesson* (*Die Klavierstunde*), dedicated to Marie-Louise von Franz, and was not intended for publication (attachment to a letter of October 30, 1953, letter 1667 in von Meyenn (1999), pp. 327–340.)

⁷³ Quoted from the *Lecture to the Foreign People*. Translated by the authors.

As far as their direction is concerned, causal and final descriptions have the same significance in the first place (Primas 1992). The rejection of final causes does not follow from first principles of physics, but is motivated by our ability to construct causal instruments and machines. The claim that final processes are impossible is a dogmatic metaphysical preconception that should not be accepted uncritically.

In an unpublished manuscript *Remarks on the Psychology of the Evolution of Scientific Concepts*, Pauli made some interesting comments connecting his ideas on final causation to human consciousness:⁷⁴

“It cannot be excluded that the images, which certainly exert a strong influence on the direction of conscious attention (even if they remain unperceived), are not only to be causally evaluated as a backslide to pre-scientific thinking but also finally directed to a goal. In the latter regard they might contain the seeds of anticipated future developments. It is tempting to assume that the goal-oriented direction of these background images is similar to the approach of matter to modern psychology in the historical disguise of alchemy. . . . Therefore I came, already some time ago, to the conclusion that the goal of images (goal understood in terms of teleology) cannot be a further retraction of mental projections from matter but rather, ultimately, a reconstitution of a state (that was realized, however insufficiently, in alchemy), whose mental and physical aspects are described with the same scientific terminology.”

Admitting the highly speculative character of these remarks, we must leave it to the future to show whether non-random biological mutations will one day be associated with a modern conception of final causation. But even on the basis of present knowledge it is clear that Pauli’s uneasiness with the straight Darwinian picture of biological evolution was fully justified.

8 Summary and conclusions

Pauli’s strong interests beyond physics, as expressed mainly in his correspondence with colleagues and in unpublished manuscripts, may be summarized in the following different, but not unrelated, topical areas.

- In line with Pauli’s work on broken and hidden symmetries, it has become clear that *complementary* and *non-Boolean descriptions* are not only significant in quantum physics. They can also be appropriate for situations outside quantum physics. Psychology and cognitive science are areas in which this insight may be particularly valuable.
- Pauli often emphasized that processes of *creative thinking*, insufficiently understood until today, are neither reducible to rational, logical operations alone nor to collecting empirical facts alone. Factors which might

⁷⁴ From the undated manuscript *Bemerkungen zur Psychologie der naturwissenschaftlichen Begriffsbildung* in the literary remains of Pauli. Quoted by von Meyenn (1994), pp. 21. Translated by the authors.

be related to unconscious activity need to be explored in order to make first steps toward scientific access to the nature of scientific (and other) discoveries.

- The *psychophysical problem*, i.e. the problem of how the mental and the material are related to one another, has more than traditional dualist or materialist options for a solution. A dual-aspect kind of conception proposed by Pauli and Jung, combining an epistemic dualism with a psychophysically neutral ontic monism, offers an interesting alternative which attracts increasing attention. Recently, Chalmers presented an influential version of such a scheme for the relationship of consciousness and brain.
- Related to the mind-matter problem, the distinction between *tenseless physical time and tensed mental time*, including the notion of *nowness*, is of crucial importance. In this respect, a process-oriented perspective (e.g., à la Whitehead) might be helpful for the construction of a refined framework merging the established body of physical knowledge with novel ideas concerning mental time and mentality in general.
- A number of observations concerning *biological evolution* over the last few decades have confirmed Pauli's suspicion that a concept of genetic mutations which is based on blind chance alone is too narrow. *Epigenetic inheritance* characterizes non-random changes in genetic expression that are passed on to offspring without being linked to alterations in DNA sequences. Whether or not this justifies the notion of final causation as opposed to efficient causation remains an open question.

Many of Pauli's extraphysical imaginations are outside and partly against mainstream science. Although they have been disregarded for a long time, they have the potential to broaden and extend current scientific discourse. Pauli himself hesitated to share his visionary ideas with the scientific community in general:⁷⁵

"The unconscious blames me that I withheld something like a confession, destined for the general public, that I did not follow my 'mission' due to conventional resistances."

So it remains to us to take up Pauli's vision,⁷⁶

"to integrate natural science within a greater holistic picture."

This is clearly an extremely ambitious goal, which requires deep and broad knowledge from natural sciences, social sciences and the humanities. At the same time, it requires the ability to combine approaches, methods and results from these areas in an integrative and interdisciplinary fashion. For solid, serious

⁷⁵ Letter by Pauli to Jung of February 27, 1953. Letter 1526 in von Meyenn (1999), p. 51. Translated by the authors.

⁷⁶ Letter by Pauli to Huber of July 13, 1957. Letter 2667 in von Meyenn (2005a), p. 484. Translated by the authors.

and substantial work along these lines it is mandatory to be both open and critical, both speculative and conservative:⁷⁷

“In my opinion, it is a *narrow* path of truth (no matter whether scientific or other truth) which guides us through between the Scylla of a blue haze of mysticism and the Charybdis of a sterile rationalism. This path will always be full of traps, and one can fall to *both* sides.”

Ultimately, it may be expected that the basically rational stance of the sciences alone turns out to be not strong enough to provide comprehensive insight into the deeper mysteries of mind and nature. Although all mature sciences of today depend essentially on rational thinking, mathematics itself has demonstrated that the logical consistency of a formal theory and its completeness are sometimes irreconcilable. This may be valid more than ever if, in addition to pure rationality, intuition and other transrational (as opposed to irrational) modes of knowledge become significant and cannot be disregarded:⁷⁸

“I do advocate an unlimited right of reason to control systems of thought; however, I allude to an extrarational mode of knowledge, which is acquired with resources different from reason. I think that this extrarational mode of knowledge is primordial and essential. There is not only thinking, there is also instinct, emotion, intuition, etc., and these additional psychological functions appear to me of highest significance wherever the wholeness of human beings is apprehended (as in a conversion, which you have in mind, too). If, however, our thinking observes these other functions objectively, without perturbing them, it will be apprehended as well if a conversion occurs, and a ‘new mode of thinking’ can emerge.”

⁷⁷ Letter by Pauli to Weisskopf of February 8, 1954. Letter 1716 in von Meyenn (1999), p. 466. Translated by the authors.

⁷⁸ Letter by Pauli to Jaspers of September 30, 1958. Letter 3071 in von Meyenn (2005b), p. 1275. Translated by the authors.

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