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Book Review:
From Chemistry to Consciousness – A Legacy to Hans Primas

Harald Atmanspacher and Ulrich Müller-Herold
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Takuya F. Segawa, Department of Physics, ETH Zurich, Otto-Stern-Weg 1, 8093 Zurich, Switzerland.
segawat@ethz.ch

Hans Primas (1928-2014) was a Swiss chemist, engineer, professor for theoretical chemistry at ETH Zurich and a philosopher of science. “From Chemistry to Consciousness – A Legacy to Hans Primas“ is a tribute to him and his exceptional work, told by former students, collaborators and scientific companions [1]. Eight essays cover his wide scientific range from spectroscopy to theoretical chemistry and quantum physics, so to arrive at the philosophy of science and consciousness. Hans Primas’ unconventional curriculum is fascinating per se; having never graduated from high school or university, he attended lectures by a Nobel laureate in physics (Wolfgang Pauli) and shortly after supervised a doctoral thesis of a later Nobel laureate in chemistry (*Richard Ernst*). As *William Seager* boils it down in his essay, it is *the marriage of technical sophistication, deep scientific knowledge and openness to metaphysical speculation* that made Primas extraordinary. Although his research topics evolved considerably over half a century, his mathematical language (algebra and group theory) combined with his dedication to quantum mechanics remained unchanged. With algebraic quantum mechanics, he applied the same theory to chemistry *and* consciousness. Primas found a continuous source of inspiration in the philosophical teachings of quantum mechanics. Key ideas that come up in several essays are properties that *emerge through a defined context* and the importance to distinguish between *ontic (“the way it is”)* and *epistemic (“our knowledge about it”)* viewpoints.

Richard Ernst begins with a short story of Primas’ childhood in Zurich. An early turning point in Primas’ life was a serious typhus infection at the age of fourteen that prevented him from attending high school for several months. After recovering, he could not go back to high school, since he had missed too many courses. Since passing the final high school exam “matura” is compulsory to study at a university in Switzerland, Primas started an apprenticeship as a laboratory assistant in an analytical chemistry laboratory and continued later as a student of the Winterthur Technical School (Technikum Winterthur). Thanks to his excellent graduation, his teacher recommended him to Hans Heinrich Günthard at ETH Zurich. Günthard, himself an alumnus of the Technikum, was on the way to establish the Laboratory of Physical Chemistry, which had the task of developing the emerging spectroscopic techniques to revolutionize analytical chemistry. To be able to attend lectures at ETH without having a matura, Primas could enroll in a rather unusual manner as “Fachhörer” (listener). Günthard’s strong advice to Primas was to catch up his matura, so that the courses he attended could be recognized in a retroactive manner. However, Primas never passed a matura. After attending one week of a matura preparation class, his conclusion was clear: “I would never survive this kind of course.”

Interestingly, Primas did not go to any chemistry course at ETH but enrolled at the department of physics and mathematics. Besides the introductory lectures of the first term, he attended the advanced lectures given by Wolfgang Pauli. This 'impertinence' caused a citation by the rector himself. Upon Primas' inquiry, asking if his behavior was legally forbidden, he was reluctantly allowed to go ahead.

Primas started to carry out research in the field of vibrational infrared spectroscopy. His first publications with Günthard contain experimental infrared spectra, but already at this early point of his career, the core of Primas' work lies in the mathematical spectral analysis using quantum mechanics, linear algebra and symmetry arguments. After this successful initial phase, Günthard proposed that Primas launch nuclear magnetic resonance (NMR) at ETH by building a spectrometer from scratch. In the early 1950's, NMR was a new technique coming from nuclear physics and only a few visionary chemists were starting to realize its huge potential for molecular structure determination. Primas changed field, designed and built an NMR spectrometer, discovered theoretical challenges to be tackled and soon started to supervise PhD students. His second PhD student was Richard Ernst, only five years younger than his supervisor. When Ernst defended his PhD thesis in front of Günthard and Primas in 1962, Hans Primas already had the title of a professor.

After his PhD, Ernst left for Silicon Valley, where he invented *Fourier transform NMR spectroscopy* together with Weston Anderson. Later, back as a professor for physical chemistry at ETH (and a faculty colleague of Hans Primas), he extended NMR spectroscopy to two and more dimensions. These seminal contributions led to his Nobel Prize in Chemistry in 1991. By that time, Primas had already left NMR for more than two decades.

Geoffrey Bodenhausen, today himself a professor for NMR spectroscopy, was an undergraduate student in chemistry at ETH in the early 1970s. Having attended Primas lectures in quantum mechanics and group theory, he remembers him as one of the most impressive of many brilliant faculty members: a truly inspiring teacher. Primas often made the point that asking good questions is far greater a challenge for scientists than providing answers. Both Ernst and Bodenhausen agree that one of Primas' greatest contribution to the field of NMR was his concept of 'superoperators' [2]. Superoperators act on operators, like operators act on quantum states. Thereby going to a higher dimension, an NMR spectrum can be calculated directly, without taking the detour via eigenvalues and eigenfunctions. This method is still essential today in the theory of magnetic resonance. Richard Ernst concluded: "In ten years, Primas achieved more than other successful scientists do in a lifetime" [3]. However, Primas wanted to move on and choose his own field of research.

And this was theoretical chemistry, as it is told by *Ulrich Müller-Herold*. Müller-Herold was a collaborator of Hans Primas over many years and shares with him the rather untypical CV: After becoming a medical doctor, he studied chemistry and joined Primas' group in 1973. Primas' inaugural lecture, entitled "What are electrons?" [4], illustrates his research project for the next twenty years in an exemplary manner: he asked fundamental questions. Primas pointed out that physicists and chemists are not talking about the same things, when they speak of electrons. Quantum mechanics says that electrons are indistinguishable, but for chemists an electron 'sitting' on an atom or molecule is individual and localized. Primas explained that these 'quasi-electrons' of the chemist can be justified and actually rather meant orbitals than electrons.

To revise the foundations of quantum chemistry, Primas chose the language of algebraic quantum mechanics, a formalism that goes beyond Schrödinger's equation. At the heart of his research was the molecule in chemistry, behaving in a way at the same time classical and quantal, an effect that could not be explained using *pioneer* quantum mechanics. The hint as to how to solve this problem came from an unexpected helper: Josef-Maria Jauch, a professor for theoretical physics at the University of Geneva and the reviewer of his grant proposal. Jauch had previously described systems with 'superselection rules' (the topic of *Domenico Giulini*'s essay), where observables that commute with all other observables appeared. These were the classical observables that Primas was looking for, embedded in a quantum mechanical description.

During his scientific reorientation, Primas did not publish a single paper within seven years. From today's perspective, this is almost as incredible as becoming a professor without a university degree.

Domenico Giulini was a member of the 'decoherence group' (the later authors of Ref. [5]), when he met Hans Primas for the first time in Heidelberg in 1992 for a scientific exchange. He witnessed a heated discussion, where Primas attacked the "false statements" of pioneer quantum mechanics, namely the superposition principle, which is a central idea behind the decoherence theory. This was the first time, when Giulini came into contact with the algebraic view of quantum mechanics. However, for Giulini, many of the initial contradictions between *pioneer* and *algebraic* quantum mechanics disappeared after a longer and deeper look. To him, the true driving force throughout the continuing discussions was the interplay between *intuitive hypothesizing (the group)* versus *rigorous deduction (Primas)*.

William Seager focuses on the philosophical aspects of Primas' work. Primas often stressed the great irony that a long period of reductionistic and atomistic science finally culminated in the discovery of quantum mechanics. Atoms and elementary particles have kept their names, but for Primas, they are now only *patters* and not anymore *building blocks of reality*: "the material world is a whole that is not made out of parts". Still today, a hundred years after the revolution of quantum mechanics, science is largely based on an atomistic ontology and the idea of reductionism remains deeply rooted. Primas's answer to reductionism was emergence [6]. He developed the concepts of "endophysics", a *context-independent* ontic domain at the level of a basic theory and "exophysics", a *context-dependent* epistemic domain. While exophysics can be experienced via measurements, the underlying endophysics is inaccessible. Seager compares Primas' view with the *many-worlds interpretation* of quantum mechanics, which has recently received much attention. Originally proposed by Hugh Everett in the 1950s, this interpretation questions the collapse of a quantum system into one of its components of the superposition. Instead, it proposes that a quantum measurement creates a new superposition that also includes the measurement apparatus and the experimenter. Every measurement splits the world into different components of the superposition, creating many worlds. Seager now performs the "irresistible mapping": What Primas calls endophysics is the universal wavefunction in an immense superposition in the many-worlds interpretation. Exophysics on the other hand corresponds to the branches of the foliation. While the former pair is quantal, the latter pair is classical. Experiments and daily experiences are related to the branches and the universal wavefunction remains inaccessible. This metaphysical dependence running from the whole to the parts reminds Seager of Spinoza's holistic monism, where the universal wavefunction would be God. Seager points out that most philosophers, who accept the many-worlds interpretation, regard the theory as a way to reduce mental to physical: A physicalistic approach that is undoubtedly opposed to Primas' ideas.

Robert Bishop and *Peter beim Graben* take up Primas' idea of *contextual emergence* and apply it to another important field of his research: the relation between deterministic and stochastic behavior. They show that neither determinism nor stochasticity are universal, but both contextual. Stochastic behaviors can emerge from deterministic descriptions and vice versa. Therefore, the same system can appear deterministic or stochastic, solely depending on the descriptive level. The parting from a universal determinism calls for a revisions of our metaphysical assumptions and conceptions.

Basil Hiley first came into contact with Primas' ideas on algebraic quantum mechanics in 1977, when he discovered the manuscript "Quantum Mechanical System Theory" [7] in David Bohm's room at Birkbeck College in London – a discovery that strongly influenced his thinking about quantum theory.

He shares with Primas the critical view on the Hilbert space formalism that shows great predictive power but at the same time, fails to provide a physical intuition ("unsolved interpretational problems, such as the measurement problem, schizophrenic cats and the like"). He compares Primas' algebraic approach to Bohm's notion on *implicate* and *explicate* order. In contrast to the Boolean logic of classical physics (there is only 'true' or 'false'), the logic of quantum mechanics is non-Boolean (there is more than 'true' or 'false'). However, the results of any experiment must be described in a Boolean structure. Primas explains this transition from the *factual* domain (non-Boolean) to the *empirical* domain (Boolean) by detaching the observer and his instruments from properties that are considered non-essential. The resulting *patterns* depend inherently on the context of the experiment. This is similar to Bohm's relation between the *implicate* order, being the total non-Boolean structure, and the *explicate* order, which is the Boolean substructure within the more general non-Boolean structure.

In 1991, *Harald Atmanspacher* was a postdoc in physics when he first met Hans Primas at the Cortona Week, a transdisciplinary meeting organized by ETH. Their discussion started first with the Pauli-Jung dialog, expanded to the relationship between mental and physical and was accompanied by a crash-course in algebraic quantum theory. This was the starting point of their joint work on the *psychophysical problem* in the correspondences (1932-1958) between Wolfgang Pauli and Carl Gustav Jung. Atmanspacher and Primas identified Pauli and Jung's ideas as a *dual-aspect monism*: The mental and material domain are, in the sense of quantum mechanics, complementary to each other. They emerge by a symmetry breaking from Jung's underlying *unus mundus*, which is psychophysically neutral and holistic.

Inspired by the Pauli-Jung conjecture, Primas took up one of the great unsolved mysteries of physics and philosophy: time [8,9]. While our mental time is *tensed* and knows past, present and, future, time in physics is *tenseless* and only relates events with 'earlier than', 'simultaneous with', and 'later than'. For Primas, there is no time in the *unus mundus*. The concept of time *emerges* through a contextual breaking of the primordial symmetry. The *mental* domain is then associated with the *tensed* time and the *material* domain with the *tenseless* time. Primas assumed that time operator T is a *not* a classical observable. The synchronization of the tensed mental time and the tenseless physical time is obtained by a *time-entanglement between mind and matter*. The indeterminacy of the time operator ΔT represents the duration of the now, which only becomes zero if T approaches the classical limit. Primas thereby fulfills Leibniz' idea of the *pre-established harmony*: body and soul are two clocks, perfectly synchronized at the beginning by God.

Hans Primas continued his work on time, mind and matter until his death. He left a last manuscript over 600 pages that was edited by Atmanspacher and will be published soon under the title "Knowledge and Time".

Due to his mathematical language, many of Hans Primas' papers are difficult to read. "From Chemistry to Consciousness – A Legacy to Hans Primas" is an ideal introduction to Primas' general ideas and concepts: it is accessible but deep at the same time. Overlooking Hans Primas' impressive journey through the disciplines, one may ask oneself where his transition from science to philosophy did happen. Presumably, for Primas there was no transition at all and all his research belonged equally to natural science *and* philosophy. In this sense, Hans Primas was literally a *doctor of philosophy* and it is an irony that he never held the title of a *PhD*.

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