Léna Soler

THE CONTRIBUTIONS OF GRETE HENRY-HERMANN TO THE PHILOSOPHY OF PHYSICS

Introduction by Fernando Leal

Professor Soler's paper is an extraordinary attempt at explaining in simple words why Grete Henry-Hermann's work in the philosophy of physics is so important in itself and as part of the Critical Philosophy tradition. She had already written an extended scholarly commentary on Grete's most important monograph,[1] and assumes for this paper some knowledge of the general structure of Kant's philosophy. Readers might find the following summary of some use.

Kant conceived of human cognition as three-tiered: first comes *intuition* (or the senses), then *understanding*, finally crowned by *reason*. By means of intuition we are capable of acquaintance with particular things and events; by means of understanding we are able to comprehend general propositions; by means of reason we are capable of constructing whole theoretical structures. Each cognitive tier possesses a distinct set of ultimates: space and time are the conditions for sensory activity; causality and other general categories are the conditions for understanding; the conviction that nature forms an orderly unity capable of theoretical comprehension – and other all-encompassing ideas – is the foundation for reason as the builder of theories.

Each cognitive tier builds upon the preceding one: the understanding elaborates the products of intuition by means of categories such as causality, while reason in its turn elaborates the products of the understanding by means of ideas such as the unity of nature. The final outcome of the whole process is, for instance, a physical theory. Now 20th century physics first challenged the contents of Kant's *faculty of intuition* through the changed conception of space and time contained in Einstein's general theory of relativity; then it challenged the contents of Kant's *faculty of understanding* through the attack on general causality in quantum physics, which is the subject of this paper. It can even be argued that the incompatibility of descriptions within quantum mechanics that Professor Soler discusses at the end of this paper challenges the contents of Kant's *faculty of reason* (the unity of nature), which is further compromised by the fact that physicists have so far been unable to make relativity theory and quantum physics (which many would want to say are among the best and most powerful theories ever built by the human intellect) compatible with each other.

It is, incidentally, the third, crowning tier of reason that, in its practical (not merely theoretical or cognitive) use, gives rise to the whole of ethics. Most of Kant's predecessors held that ethics was the outcome of the practical use of at least one of the other two tiers: if they took the understanding as the basis of ethics, then their ethics was a matter of prudence and enlightened self-interest; if they preferred sensory intuition as a foundation, then ethics would be a matter of empathy, sympathy, love, shame, guilt, or some other moral emotion. It may strike the reader that such approaches more or less correspond both to scientific attempts and to the ordinary, commonsensical way of addressing the problem of explicating the ground of our moral behaviour.

In that sense, however, Kant has always been a bit lonely in taking his extreme position that no such foundation in understanding or intuition could ever be adequate to support the weight of ethical conduct; ethics have to be grounded on reason and the realm of reason's ideas. As for Grete Henry-Hermann, she tried to draw the consequences from the new physics for a Kantian kind of ethics in her profound paper 'Conquering Chance' (original German 1953; English translation in the journal *Philosophical Investigations*, Vol. 14, No. 1, January 1991). Quantum theory had taught us to think that nature needs apparently contradictory, yet actually complementary, perspectives to be captured and theorized about (see sections III and IV of Professor Soler's paper). So Grete started to develop the idea that human action could also be considered from two complementary perspectives (one causal and observer-centred, the other actor-centred and oriented toward ends and values) that would together account for the possibility of ethical action as well as constant revision of our decisions and projects. Nelson's conception of a closed process of individual character formation coupled with a definitive political constitution as the key to conquer chance once and for all (so that justice would prevail) was thus criticized as a dogmatic relic of the old mechanistic standpoint.

Fernando Leal, Guadalajara, Mexico, 2004

[1] From a personal communication by Professor Soler, we gather that she came to hear about Grete Henry-Hermann's work during her DEA study (in France, the university year and work that is just before a PhD). Michel Bitbol, her DEA director and a well-known author in philosophy of physics, noticed a passage in Max Jammer's celebrated book about the history of quantum physics (see note 16 in main paper below), in which that author discusses pioneering aspects of Henry-Hermann's work. Professor Bitbol suggested that Léna Soler study this astonishingly unknown work. Struck by the interesting character of this work, Léna Soler decided to instigate the French translation of it with a long commentary (see note 7 below).

The paper by Léna Soler

Grete Henry-Hermann made major contributions to the philosophy of physics which, although almost unknown, especially outside Germany, are extremely important in their fundamental implications.[1]

A pupil and great admirer of Leonard Nelson, Grete Henry-Hermann followed her teacher in concerning herself primarily with ethics and political philosophy. Her works on the philosophy of science occupy a relatively marginal position. What was it, then, that caused Grete Henry-Hermann to take an interest in physics?

I. The philosophy of science in Grete Henry-Hermann's work

Around the 1930s, a number of participants in the debates concerning quantum mechanics, still a very young science at that time, took the view that the new physics called into question, indeed definitively refuted, some fundamental aspects of the Critical Philosophy inaugurated by Kant.

Grete Henry-Hermann, following Nelson, considered Kant's philosophy, or more precisely its reinterpretation by Fries, to be the basis on which 20th century philosophy should unfold. It was therefore of crucial importance to her to investigate whether 20th century physics *does* or does *not* effectively refute the fundamental principles of Kantian philosophy.

The principal published texts in which Grete Henry-Hermann sets out her reflections on this subject, on the philosophy of science, are relatively few in number and are confined to a limited period; in fact, they comprise three relatively short essays produced during the years 1934–1937:

1. 'Die naturphilosophischen Grundlagen der Quantenmechanik' ('The Philosophic Foundations of Quantum Mechanics') 1935;[2]

2. *Die Bedeutung der modernen Physik für die Theorie der Erkenntnis* (*The Significance of Modern Physics for the Theory of Knowledge*) 1937;[3]

3. 'Über die Grundlagen physikalischer Aussagen in den älteren und der modernen Theorien' ('On the Foundations of Physical Statements in Earlier and Modern Theories') 1937.[4]

Apart from these texts several less important articles exist[5] which will not be considered here.

The truly major text – the one which contains Grete Henry-Hermann's fundamental theses and arguments – is that of 1935, which deals with quantum mechanics. The later texts either revisit the developments of 1935 or apply analytical principles similar to those of 1935 to the theory of relativity, and arrive at convergent conclusions. For this reason, the essay of 1935, 'Die naturphilosophischen Grundlagen der Quantenmechanik' ('The Philosophic Foundations of Quantum Mechanics') will form the primary focus of this paper.[6]

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[1] Editors' note: This paper is a revised and extended version of a conference speech, delivered on 2nd March 2001 in Bremen at the invitation of the Philosophisch-Politische Akademie on the occasion of the Grete Hermann Centenary Celebration. It has been translated from the French by Dr Edmund Jephcott (A & G Translations) for the Society for the Furtherance of the Critical Philosophy. The translation has been edited by the SFCP. Professor Fernando Leal provided valuable advice on, and translation of, some of Grete Henry-Hermann's original work cited here.

[2] Published in *Abhandlungen der Fries'schen Schule,* Neue Folge, 1935. Leonard Nelson edited this from 1904, (reviving the enterprise begun by two followers of Fries, Apelt and Schleiden, and which was continued from 1847 to 1849, until being interrupted during the 1848 Revolution because of political disagreements between the editors). A summary of this essay by Grete Henry-Hermann was also published in *Die Naturwissenschaften*, 23, No. 42, 1935, pp.718–721.

[3] From Grete Hermann, E. May, Th. Vogel, *Die Bedeutung der modernen Physik für die Theorie der Erkenntnis: Drei mit dem Richard-Avenarius-Preis ausgezeichnete Arbeiten (The Significance of Modern Physics for the Theory of Knowledge: Three Essays awarded the Richard Avenarius Prize),* Verlag von S. Hirzel, Leipzig, 1937, pp. 1–44.

[4] Published by Öffentliches Leben, Leipzig 1937; also in: *Abhandlungen der Fries'schen Schule*, Neue Folge, 6, No. 3/4, 1937, pp.309–398.

[5] Grete Henry-Hermann's contributions to the philosophy of science comprise four other articles:

- The first, from 1935, *Physikalishe Zeitschrift*, 36, pp.481–482, is a review of the work by Karl Popper *The Logic of Scientific Discovery,* which was written in 1934 and later became famous.
- The second is the text of a short talk given in Copenhagen in June 1936, at the Second International Congress for the Unity of Science: 'Zum Vortrag Schlicks', *Erkenntnis*, Vol. 6, Book 5/6, p.342. This was a reply to a paper by Moritz Schlick regarding the causal problem, in which Grete Hermann brought to bear the theses of 1935.
- The third, 'Die Naturphilosophische Bedeutung des Übergangs von der klassischen zur modernen Physik' ('The Philosophic Significance of the Transition from Classical to Modern Physics'), represents Grete Henry-Hermann's contribution to the 9th International Congress of Philosophy, 'Congrès Descartes', held in Paris in 1937 (in:*Travaux du IXe Congrès International de Philosophie 'Congrès Descartes'*, published by Raymond Bayer, Paris, VII, pp.99–101); in it the conclusions from the essay of 1935 are again summarised.
- Finally, an article of about ten pages from 1948, entitled 'Die Kausalität in der Physik' ('Causality in Physics') (*Studium Generale*, Vol. 1, No. 6, pp.375–383), provides an extremely clear synthesis of Grete Henry-Hermann's previous works.

[6] This essay was translated into French in 1996, at Léna Soler's instigation, by Alexandre Schnell, and published by Vrin as *Les fondements philosophiques de la mécanique quantique*, with an introduction and a long critical postface by Léna Soler.

II. Physics and causality in the 1930s

It is convenient to begin with a few words on the way in which the relationships between physics and causality were thought about in the 1930s. There were several authors, including Grete Henry-Hermann, reflecting on the links between physics and the Kantian category of causality. Following others, Grete Henry-Hermann formulated the question in these terms:

- Kant listed the conditions of possibility of knowledge, and therefore in particular of *any future physics*.
- These conditions include the category of causality, which seems to indicate that the predictions of any science worthy of the name (for Kant, of any physics) must be strictly deterministic. There must be a *one-to-one univocal connection between cause and effect,* or between the initial conditions and the final conditions: one and the same cause can produce only *one single,* well-defined effect.
- The predictions of the (then) young quantum mechanics are *statistical* (one and the same initial state can be followed by *several different* final states, and one knows *only in advance* the *probability* of each possible result).
- Should we therefore conclude that the Kantian category of causality is refuted by the existence of the new physics, that strict causality is actually not a *necessary* condition of any physics?

As we can see, Grete Henry-Hermann wants to call Kant before the tribunal of history. In listing the conditions determining the possibility of any future physics Kant had drawn his inspiration from the physics of his time (that of Newton). Do his propositions still hold good for a physics which seemed to break so radically and scandalously with the principles of the physics retrospectively called 'classical'?

Grete Henry-Hermann was not the first to have posed this type of question. A number of philosophers and physicists had already investigated the problem in the case of the theory of relativity. They inquired whether relativity theory refuted the conditions set out by Kant, that is, Euclidian space and absolute time. With the emergence of quantum physics, it was the turn of the pure concepts of understanding to come under threat, in particular the concept of causality.

Independently of Kantian philosophy, the question of causality was preoccupying physicists themselves at that time. They posed the problem in the following terms: should it be admitted that quantum physics, and its statistical predictions, express no more than a deficiency of human knowledge? Stated differently, should it be admitted that certain variables, as yet unknown to physicists, do actually exist and univocally determine all measurement results? Are there 'hidden variables' – or parameters – which, if known, would enable any given cause to be in a one-to-one correspondence with a single definite effect? Or again, should the statistical character of predictions, that is, the association of a plurality of possible effects with a given cause, be recognized as definitive because it expressed a fundamental aspect of phenomena, or of our relationship to phenomena? Such was the debate concerning hidden variables.

Grete Henry-Hermann addressed both the above questions. The conclusions she reached can be summed up briefly as follows:

- Quantum physics does not refute the category of causality.
- There are no hidden variables; quantum physics is complete and its predictions will remain statistical.

Considered in detail, Grete Henry-Hermann's conclusions, and the arguments supporting them, are complex and subtle. A full understanding of them would require extensive discussion drawing simultaneously on a knowledge of philosophy, physics, and history.[7] Because of this attention is confined to the following:

- a number of noteworthy points which give Grete Henry-Hermann's essay its major interest;
- a brief indication of what makes up the central originality of her thesis concerning quantum physics;
- some brief remarks concerning the strengths and weaknesses of Grete Henry-Hermann's interpretation; and
- some general conclusions concerning the relationship between critical philosophy and quantum physics.

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[7] See Léna Soler, postface to G. Hermann, *Les fondements philosophiques de la mécanique quantique*, Paris, Vrin, 1996.

III. Noteworthy aspects of Grete Henry-Hermann's work in the philosophy of science

1. Firstly, Grete Henry-Hermann's attempt to confront quantum physics with Kantian philosophy is, chronologically, one of the first. Philosophers of science are often accused of lagging behind the advancement of science. For once, the accusation does not apply. Grete Henry-Hermann was truly a pioneer in engaging in a philosophical interpretation of quantum physics.[8]

Indeed, in 1934 quantum physics was a physical theory worthy of the name for only a few years. Since the Solvay Congress of 1927, the term 'quantum mechanics' had referred to something fairly definite and stable: a formalism[9] which was a synthesis of Heisenberg's matrix mechanics, Schrödinger's wave mechanics and Dirac's theory of transformations – together with a global interpretation of this formalism, proposed by Bohr and Heisenberg and later called the 'Copenhagen interpretation' or the 'orthodox interpretation'. Grete Henry-Hermann was to adopt numerous ingredients of this interpretation in her own account: the complementarity of wave and particle representations, and of the conjugate variables[10] of position and velocity; the idea that the results obtained have validity only in relation to an experimental situation, etc.

2. Grete Henry-Hermann had a twofold training, both scientific and philosophical. This is uncommon enough to deserve mention, and clearly is not without relevance to her contributions to the philosophy of science. Indeed, Grete Henry-Hermann had sufficient mastery of physics to be able to study in depth the theory and its formalism, and to engage in high-level dialogue with scientists.

3. Grete Henry-Hermann's text of 1935 is the outcome of discussions she held with a group of major physicists who were the originators of quantum physics. Indeed, in the course of 1934, Grete Henry-Hermann visited Leipzig, one of the centres which contributed most, with Göttingen and Copenhagen, not only to the development of quantum theory but to the clarification of its philosophical foundations. Werner Heisenberg, the famous pioneer in this venture, organized a seminar in Leipzig bringing together a considerable number of eminent scientists, such as the Swiss Félix Bloch, the Soviet scientist Landau, and from Germany, Peierls, Karl Friedrich Hund and Edward Teller, as well as Carl Friedrich von Weizsäcker who was still very young at that time. The latter, despite his training as a physicist, took a passionate interest in the philosophical questions raised by the new physics and for this reason was to play a leading role in the dialogue with Grete Henry-Hermann. It was at the end of this year of debate with these prestigious figures that Grete Henry-Hermann wrote the essay of 1935.

By the end of these discussions it seems that she had succeeded in convincing Heisenberg of her point of view.[11] In his scientific autobiography, *Physics and Beyond,* Heisenberg devoted an entire chapter to the discussions between Grete Henry-Hermann, von Weizsäcker and himself. This chapter, entitled 'Quantum Mechanics and Kantian Philosophy', presents the content of the arguments and their progress, together with the compromise agreement which emerged from them. His tone at the end is quite positive: "we had the feeling that we had all learned a good deal about the relationship between Kant's philosophy and modern science".[12]

Von Weizsäcker, for his part, reviewed Grete Henry-Hermann's essay in highly eulogistic terms in an article published in 1936 in *Physikalische*

[8] With a few others, for example: Alexandre Kojève, *L'idée du déterminisme dans la physique classique et dans la physique moderne* (*The Idea of Determinism in Classical and Modern Physics*), Paris, Le Livre de Poche (written in 1932, but only published posthumously in 1990); Gaston Bachelard, *Le nouvel esprit scientifique*, Paris, Presses Universitaires de France, 1934 (published in English as *The New Scientific Spirit*; Beacon Press, 1986); Ernst Cassirer, 'Determinismus und Indeterminismus in der modernen Physik', *Göteborgs Högskolas Arssskrift,* XLII, 1937, (published in English as 'Determinism and Indeterminism in Modern Physics': *Historical and Systematic Studies in the Problems of Causality*, New Haven, Yale University Press, 1956).

[9] Editors' note: The concept of 'formalism' refers to a mathematical calculation device. For instance, if I say 'a + b = b + a', this is part of a formalism. As in high school algebra, the formula expresses the arithmetical law that the order in which we add two numbers does not affect the sum. The great power of modern mathematics is that the same formalism can be interpreted in very different ways. Thus the formula 'a + b = b + a' could also refer to truth values in logic (the letters would then refer to propositions insofar as they are true or false, and the plus sign would refer to logical disjunction, i.e., to the proposition that it is only false if both propositions are false). Formalism thus allows for generalization but, in the case of quantum mechanics, what people wanted was an interpretation that went beyond mathematics and made physical sense. The Copenhagen interpretation, devised by Niels Bohr, has been dominant for a long time; but Einstein, and a few other physicists, have never been convinced by it.

[10] Editors' note: The term 'conjugate variables' refers to any two pairs of variables linked by the so-called 'Heisenberg relations', which means that the precision with which we can measure any one of them is limited by the precision with which we can measure the other one. Thus, in classical physics, a moving object was supposed to have a pair of motion properties like position and momentum in such a way that we could measure both variables with the same (indefinitely great) amount of precision. This is no longer the case with quantum objects: you cannot define both, and consequently cannot measure both, with indefinitely great precision. In the case of conjugate variables, what you win in precision concerning one of them is lost concerning the other one.

[11] To begin with, at least; he seems later to have changed his mind under the influence of Bohr.

[12] Werner Heisenberg, *Physics and Beyond*, London, Allen and Unwin, 1971, p.124. Original German published in 1969.

Zeitschrift,[13] presenting Grete Henry-Hermann's essay as the first "positive and indisputable contribution to elucidating the implications of quantum mechanics for the theory of knowledge", and adding that "a fruitful debate on this subject could hardly be opened in a clearer or more objective manner". Moreover, in his book *The World View of Physics*[14], von Weizsäcker develops a conception of the relationship between critical philosophy and quantum physics which in many respects is akin to that of Grete Henry-Hermann.[15]

4. In addition to the original ideas she developed on the relationship between the Kantian category of causality and quantum physics, to which we shall return in a moment, Grete Henry-Hermann's essay of 1935 contains the first critique of von Neumann's argument which aimed to demonstrate the impossibility of completing quantum physics by means of hidden parameters.[16]

Von Neumann claimed to prove, in 1931, that the statistical character of quantum physics was not due to a deficiency in human knowledge, and that it was pointless to hope to discover hidden variables. Quantum mechanics was complete, in the sense that the physicist already knew everything there is to be known; and that the reason why the predictions of quantum physics were statistical, is that the quantum world itself was not deterministic, in the sense that one and the same cause could really produce different effects.

[13] C.F von Weizsäcker, review of Grete Hermann, 'Die naturphilosophischen Grundlagen der Quantenmechanik', *Physikalische Zeitschrift*, Vol. 37, No. 14, 1936, pp.527–528.

[14] C.F. von Weizsäcker, *The World View of Physics,* London, Routledge and Kegan Paul, 1952.

[15] In an unpublished interview of von Weizsäcker by T.S. Kuhn and dated 9 July 1963, von Weizsäcker, addressing the question of the relationship between physics and philosophy, emphasised that around 1933–34 the Leipzig group formed a unified bloc defending the new ideas associated with physics against attacks by philosophers. He then went on spontaneously to speak of Grete Hermann, emphasising above all, in the brief account he gave of her, her twofold training in mathematics and philosophy. von Weizsäcker referred to her as an extremely intelligent person and remarked that her great clarity of mind made discussion with her easy. He added that Grete Hermann was probably right in maintaining that Kantian philosophy, correctly interpreted, was in no way placed in difficulty by modern physics, itself correctly interpreted. He also alluded to a manuscript dealing with causality in quantum physics that Grete Hermann had sent to Bohr and Heisenberg before arriving in Leipzig. He said that at that time, Bohr had asked von Weizsäcker to read the manuscript and possibly respond to it, which the latter had done, indicating in his letter in what way the theses of the article seemed to him erroneous. Having received a letter with very similar contents from Heisenberg, Grete Hermann had decided to travel to Leipzig, to discuss the matter with the two physicists in person (for references to this interview, see Archives for the History of Quantum Physics, J.L Heilbron and T.S. Kuhn, *Sources for the History of Quantum Physics: An Inventory and Report*, The American Philosophical Society, Philadelphia 1967).

[16] Max Jammer, *The Philosophy of Quantum Mechanics*, Wiley-Interscience, 1974, p.272.

Historically, von Neumann's proof played an important role. Indeed, up to 1964 it was regarded as firmly established, and between 1931 and 1964, its existence and supposed validity deterred physicists from trying to develop theories of hidden variables.

The reason why the situation changed in 1964, was because in that year John Bell attacked von Neumann's so-called 'proof',[17] which since then appeared to specialists to have been definitively refuted. Yet in 1935, *thirty years before Bell,* Grete Henry-Hermann had produced a refutation of von Neumann, based on arguments very similar to those of Bell in 1964.[18] However, this refutation by Grete

[17] J.S. Bell, 'On the problem of hidden variables in quantum mechanics', *Review of Modern Physics*, 38, pp.447–452, 1966.

[18] Grete Henry-Hermann identified as problematic the premise of von Neumann's reasoning on which, thirty years later, John Bell was to base his famous refutation. This premise, the condition of additivity, stipulates that the expectation value of the sum of two physical quantities is equal to the sum of each of their expectation values. Such a property, trivial for variables capable of being measured simultaneously (variables of classical physics or non-conjugate variables of quantum physics) needs to be proved in the case of the conjugate quantities of quantum physics. Grete Hermann and Bell both insist on this point. According to the former:

> the sum of two of these quantities is by no means immediately definite. Because precise measurement of one of them excludes that of the other, so that these two quantities cannot simultaneously admit precise values, the conventional definition of the sum of two quantities is no longer valid. It is only by means of a detour through certain mathematical operators associated with these quantities that formalism introduces the concept of the sum of such quantities.
> (Hermann, 'Die naturphilosophischen Grundlagen der Quantenmechanik' ('The Philosophic Foundations of Quantum Mechanics') 1935, §7).

In a similar way, Bell notes:

> A measurement of a sum of noncommuting observables cannot be made by combining trivially the results of separate observations on the two terms – it requires a quite distinct experiment. [...] The additivity of expectation values [...] is a quite peculiar property of quantum mechanical states, not to be expected a priori.
> (J.S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, Cambridge, Cambridge University Press, 1987, p.4).

In the words of the young Grete Hermann, von Neumann's argumentation

> although indisputable from a mathematical point of view, introduces into its formal premises, without justifying it, a statement equivalent to the thesis which it is supposed to demonstrate. [...] Expressed verbally: the expectation value of a sum of physical quantities is equal to the sum of the expectation values of the two quantities. Von Neumann's entire demonstration rests on this presupposition and collapses with it. (Hermann, *op.cit.*, §10).

In the words of Bell, "von Neumann's essential assumption is: any real, linear combination of any two Hermitian operators represents an observable, and the same linear combination of expectation values is the expectation value of the combination." (J.S. Bell, *op.cit.*, p.4).

Henry-Hermann had remained entirely unknown (which one may find surprising, bearing in mind that physicists such as Heisenberg and von Weizsäcker must have known of it).

If Grete Henry-Hermann's refutation had not remained a dead letter, the history of the interpretations of quantum physics would certainly have been very different. Theories involving hidden variables, which have proliferated since the 1960s, would undoubtedly have flourished much earlier, and the Copenhagen interpretation, so long regarded as the only acceptable available interpretation, would perhaps have enjoyed a less exclusive monopoly.

IV. The core of Grete Henry-Hermann's original interpretation

Let us now turn to Grete Henry-Hermann's way of conceiving the links between quantum physics and Kantian philosophy. With her refutation of von Neumann's proof Grete Henry-Hermann had reopened the door to the possibility of discovering hidden variables. One might therefore believe that she was about to engage in an attempt to save the Kantian category of causality, by invoking, as others had done, the existence of hidden variables determining a unique effect for each cause. But that is not the case. Grete Henry-Hermann set out on a profoundly original path: that of retaining the universal validity of the pure concept of causality, while accepting, with Bohr and Heisenberg, the definitive character of statistical predictions.

The original core of her interpretation is, in essence, the following. The results of measurements actually obtained for quantum objects cannot be univocally predicted with certainty. However, *after* having effectively obtained a quantum measurement, and *after* having gained knowledge of its result (previously not foreseeable with certainty), it is possible by working backwards, to reconstitute, *retrospectively and completely,* the causal chain which has necessarily produced such a result.

To properly grasp what is meant by these causal chains reconstructed *a posteriori*, it is necessary to emphasize that the causal chains under consideration connect:

- on the one hand, a phenomenon (the phenomenon resulting from measurement – for example, a spot on a screen);
- and on the other hand, the value of a theoretical variable[19] (for example, the value of the quantity of movement).

The effect is the phenomenon resulting from the measurement. The cause is the value of the variable.

This type of causal chain already plays a part in classical physics; for example, when you measure a weight, the observed phenomenon corresponding to the effect is the stopping of the needle on the scale at a certain graduation mark; and the cause of this phenomenon, is the determinate weight of the object weighed. The link between the two is a causal scenario of the following kind: the weight causes the vertical displacement of the scale pan, which in turn causes, through a series of specifiable mechanical actions, the deflection of the needle.

Grete Henry-Hermann transposed this classical theory of measurement to the case of quantum measurements. For example, take the case of measuring the quantity of movement of an electron by illuminating this electron under a microscope. Because the electron is illuminated, there is therefore an interaction between electron and incident light; this light is captured on a screen; from it information about the electron is derived. The effect, the phenomenon resulting from the experiment, is a discrete impact on the screen. The cause is the quantity of movement of the electron at the instant of interaction with the incident light. There are two differences between this and the classical case:

1. Contrary to the situation in classical physics, in quantum physics *the causal scenario cannot be anticipated*; it is known *only once the measurement has actually been made and only once the phenomenon obtained has actually been observed.*
2. In quantum physics, although the causal scenario connecting the cause to the effect continues to make use of classical concepts such as wave or particle, it involves, *at the same time and with regard to the same object*, representations which, according to the classical account, are antagonistic. Here Grete Henry-Hermann reverts to Bohr's idea of complementarity. The same physical system, depending on the moments of the same scenario, is treated now as a wave, now as a particle.

For instance, in our example, the light which interacts with the electron is treated first as corpuscular (the situation is represented as an electron–proton collision), then as undulatory (after the interaction, the light is seen as a flat wave which passes through the lenses of the microscope and converges at a point on the screen).

For every measurement carried out on a quantum object it is possible, according to Grete Henry-Hermann, to reconstitute a causal chain of this type *a posteriori*. In addition, Grete Henry-Hermann proposes a verification procedure, which she calls a

[19] Editors' note: The concept of a 'theoretical variable' refers to a variable that is not just observed (not just a phenomenon, like a spot on a screen) but instead is part and parcel of a theory. Thus, in order to measure the quantity of movement you need a theory that connects several variables with each other. You don't see quantity of movement with your naked eyes; you infer it on the basis of a physical theory.

"mediate procedure", for her *a posteriori* causal reconstitutions. By this procedure, which cannot be discussed at length here, she believed she had proved that her causal scenarios were not only possible, but also *necessary*. From this, Grete Henry-Hermann draws the following conclusions:

> 1. Because the causes of any phenomenon resulting from a quantum measurement can always be univocally determined (albeit only a posteriori); because a single causal scenario continues in quantum physics to connect the phenomena resulting from the measurement to the theoretical variables; then, the Kantian category of causality remains a necessary condition of quantum physics.
> 2. Because one is already in possession of all the causes which determine any result of measurement, the hypothesis of possible hidden variables loses all credibility; to seek additional parameters which are supposed to put an end to the statistical character of the quantum description becomes, in principle, pointless.

V. Strengths and weaknesses of Henry-Hermann's interpretation

The main strength of Grete Henry-Hermann's interpretation, the essential point which she establishes, is that, in order to exist, both classical physics and quantum physics require that the physicist be able to establish a *one-to-one* connection between:

- the great diversity of phenomena which constitute the results of measurement (impacts on screens, deflections of needles, etc.);
- and the values of a limited number of variables involved in theory (position, velocity, quantity of movement, etc.).

Very judiciously, Grete Henry-Hermann places the accent on the *only one-to-one connection which remains necessary to the very existence of quantum physics*. If the physicist were unable to interpret univocally a given phenomenon resulting from measurement *as* the definite value of *this theoretical variable*, the phenomena constituting the results of measurement *would lose all meaning*, all connection with our theories. With this, Grete Henry-Hermann emphasizes an absolutely crucial point.

The weak point of Grete Henry-Hermann's thesis, is that she is not content with asserting that the one-to-one character of the connection under consideration is a condition of the possibility of physics. She goes much further in interpreting this one-to-one connection. Indeed, she asserts:

- that this connection is *causal in type*;
- that the concept of causality involved *is in essence similar* to the Kantian concept of causality; and
- that the *a posteriori* causal scenario is *necessary*.

Each of these three points is open to question. For example, one can readily imagine, in linking the cause to the effect, other scenarios than the ones proposed by Grete Henry-Hermann. And since there is no means of deciding between the two propositions, it undermines the assumed necessity of Henry-Hermann's scenarios.

Or again, one might stress that the causal scenarios proposed by Grete Henry-Hermann connect the phenomena resulting from measurement to *only one* of the two *conjugate variables*, and that it remains impossible *to bring together, at the same time, two of these causal chains*, one of which would culminate in one of the variables (for instance the electron's position), and the other in the conjugate variable (here the quantity of movement).

Grete Henry-Hermann's interpretation, therefore, in no way allows the conjugate variables to be combined, and thus in no way allows, for example, reconstitution of the continuous trajectory of an object. Now, it is precisely on the basis of the possibility of gaining access to such continuous trajectories, that the physicists of the classical era conceived of causality. For them, causal behaviour meant that the values of two conjugate variables of an object at a given time (position p and velocity q) univocally determined the subsequent trajectory (the effects). Here one can readily attack Grete Henry-Hermann's conclusions by claiming that the concept of causality involved is very different from the classical, Kantian concept of causality (or at least cannot be identified with it).

VI. A general comparison between critical philosophy and quantum physics

Having shown to her satisfaction that the category of causality, the Kantian category which seemed the most threatened by the advent of quantum physics, continued to constitute a condition of possibility of quantum physics, Grete Henry-Hermann went on to consider, on the most general level, the question of the relationship between quantum physics and critical philosophy.

Her conclusion is that quantum physics and critical philosophy converge with regard to essentials, at least if 'critical philosophy' is understood to mean, as Grete Henry-Hermann understood it, not the Kantian system taken in its precisely literal form, but Kantian philosophy as re-read, clarified and reinterpreted by Fries.

Grete Henry-Hermann compares the principal assertions of critical philosophy and of quantum mechanics on three points:

(a) For critical philosophy, the Kantian categories "provide the theoretical schema needed to interpret perception".[20] Now, in order to interpret the results of measurement, quantum physics must necessarily make use of classical concepts. Thus, in classical physics, as in quantum mechanics, the *same* fundamental classical concepts mediate the transition from the diverse material of sense data to knowledge of nature, although in the second case their applicability is limited.[21] Quantum physics and classical physics therefore rest, once and for all, on the same conditions of possibility. The *a priori* forms listed by Kant are not specifically threatened by the advent of quantum physics.

(b) What has just been said implies that quantum physics also does not call specifically into question the assertion of critical philosophy that the table of Kantian categories is complete, i.e. that Kant's twelve pure concepts are *sufficient* to order the flux of sensations for knowledge. The advent of quantum theory obliges us neither to add a pure concept to the table, nor to remove or modify one.

(c) If one subscribes to the clarification, carried out by Fries, then by Nelson, of the true implications of the Kantian theses, critical philosophy also shows that the application of the categories to the diversity of phenomena remains limited, in the sense that the pure concepts are only ideal models which, as "simple analogies", provide the "guiding thread to the interpretation of perception".[22] This means that description extends only to the structures of connections, but *never*, properly speaking, isolates *absolute* substances,[23] causes or effects. Description therefore remains relative. Nevertheless, the structures of connections represent spatial–temporal relationships which are objective and unequivocally determinate.

Quantum mechanics confirms the limits of the application of the fundamental concepts which make knowledge possible: the classical concepts, like the categories, are no more than analogies, which should not be understood literally. Classical physics is concerned only with differential equations within which nothing refers properly speaking to substances, causes or effects, although such concepts remain indispensable in guiding research and organizing the diversity of perception into a knowledge of macroscopic objects. In the same way, quantum physics does not enable the systems it describes to be identified with waves or particles properly speaking, although it cannot do without such concepts in organizing the diverse material of perception into a knowledge of atomic phenomena.

In fact, quantum physics goes still further than critical philosophy. It confirms that physics has access only to structures of connections, and shows *in addition* that these structures of connections *are in each case relative to the experimental situation* by means of which the experimenter gains knowledge of them. This, according to Grete Henry-Hermann, is

[20] Hermann, *op.cit.*, §17.

[21] Of course, to conclude from this that the Kantian categories continue to constitute the conditions of possibility of quantum physics, it would also be necessary to have demonstrated that the entire edifice of classical physics does actually rest on such categories. According to Grete Henry-Hermann, such a demonstration remains to be produced and goes outside the framework of her own essay.

Kant believed he had provided such a proof, at least with regard to the physics of his time. In *The Metaphysical Foundations of the Science of Nature,* 1786 (published as *Metaphysical Foundations of Natural Science*, London, Bobbs Merill, 1970) he sets out to demonstrate that the twelve categories listed in the *Critique of Pure Reason* do indeed constitute the necessary conditions of the possibility of physics. If this demonstration is examined, it appears that it aims to posit, as the foundation of physics, laws which are no different to the essential principles which subtend Newtonian physics (conservation of matter, principle of inertia and law of action and reaction). Apart from the fact that this demonstration itself does not stand up well to criticism, in any event, a modern epistemology could hardly have recourse to it to prove that the Kantian categories continue to constitute the conditions of the possibility of classical physics after Kant, in particular in field theory.

[22] Hermann, *op.cit.*, §17. Editors' note: The term 'analogies' comes from Kant's philosophy. He called the principle of causality (and that of substance) 'analogies of experience'. The analogies of experience are the group of three principles which serve as rules for the objective employment of the categories of *relation* ('analogy' is Greek for 'relation'). The other three groups of categories besides relation (viz. quantity, quality and modality) also have corresponding principles. The general function of all principles is to determine how things must appear to finite beings in time. In the case of the analogies, this is to determine how things appear to be *related* in time.

[23] Editors' note: Pre-Kantian philosophers have what we can call an 'absolute' conception of substances (as well as an 'absolute' conception of causes), whereas Kant does not. Substances and causes – the central stuff of Kant's table of categories – are not, for him, identical with the 'substances' and 'causes' of pre-Kantian or classical philosophy. The words are the same as those of classical philosophy, yet the meaning is subtly different. So, whereas for pre-Kantian philosophers (say, Aquinas, Descartes or Locke) a substance would be a kind of *thing* (e.g. tables, trees or horses), a substance for Kant would be a *cognitive device* to organize experience in a particular way, through the relationship between properties or qualities and whatever serves as a basis or support for these. Thus, in relation to science, if we consider a table to be a 'substance' according to classical philosophy, that is, as a basis or support for properties or qualities (such as hardness, and so on), it may be legitimate for a physicist to use the same way of thinking (viewing something as a basis for something else) to try and understand objects that we would not, ordinarily, consider to be substances at all, e.g. an electromagnetic field.

the major teaching of the philosophy of the new physics: quantum mechanics, far from contradicting the fundamental principles of critical philosophy, radicalizes them still further.

Finally, quantum mechanics, like critical philosophy but to a still greater degree, forces us to abandon the dream of a universal science capable of embracing all aspects of reality within a single description. Indeed, not only is knowledge, as Kant's analysis had already shown, divided into different types of description (psychology, physics, ethics, etc.), which constitute so many perspectives on the world; but, in addition, as is shown by quantum theory, the disintegration of truth into a multitude of perspectives is now infiltrating the very heart of physics:

> The novelty introduced by quantum mechanics with regard to the philosophy of nature can be described as follows: the splitting of truth goes further than philosophy and natural science had thus far assumed. It penetrates into the very knowledge which physics has of nature. Instead of just setting a boundary between the latter and other possible ways of apprehending reality [e.g. axiological, ethical, aesthetic, etc.], it also separates different but equally justified representations within the mode of description in physics [e.g. waves and particles inter alia], which cannot be a synthesized single image of nature.[24]

Grete Henry-Hermann insists, however, that these convergences between quantum physics and critical philosophy should not mask the independence of the paths followed by each of these two types of discourse: quantum description "rests manifestly on the teachings of experiment and is entirely independent of philosophical speculation," while the critical system "rests integrally on mathematical and philosophical reflections".[25]

But, according to Grete Henry-Hermann, this observation confers still greater value on critical philosophy. For her, the fact that these convergences had been achieved at the end of wholly independent approaches based on distinct principles, underlines the credibility of the fundamental principles of critical philosophy. Such convergence, she wrote, "signifies, if not a justification, then at any rate a very important empirical corroboration"[26] of this philosophy. In short, the prestige attaching to the exact sciences is to an extent reflected back on critical philosophy.

This section is concluded in homage to Grete Henry-Hermann – to the subtlety and philosophical fertility of her analyses of these difficult questions – by quoting the words with which she herself concludes her fundamental essay of 1935, which was to provide the inspiration for all her later writings on the philosophy of science:

> If the undeniable merit of physical research is to have decisively furthered the understanding of the philosophic foundations of our knowledge of nature, nevertheless such a progress implies as little a break with past philosophy as quantum mechanics does with respect to classical physics. On the contrary, careful examination of the issue shows that, in spite of the obvious discrepancies of quantum mechanics with the apparent conclusions of critical philosophy, the decisive discoveries of quantum mechanics are consistent with the principles of that philosophy, so that the latter illuminate the former in their significance for physical knowledge.[27]

CONCLUSION

This paper is confined to presenting, as faithfully as possible, an overview of Grete Henry-Hermann's contributions to the philosophy of physics. Of course, the conceptions of Grete Henry-Hermann, like any philosophical analyses, are open to criticism from various directions. These critiques, which have been barely sketched here, show how fruitful Grete Henry-Hermann's position is, and how it provides an excellent springboard for subtle analyses of quantum physics and of the concept of causality.

All in all, Grete Henry-Hermann provides a major and original contribution to the philosophy of quantum physics, and in particular to the analysis of the relationships between physics and Kantian philosophy. One can only regret that this contribution has not been, and is not, better known.

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[24] *ibid.*, §18. Quotation translated from the original German by Professor Fernando Leal.
[25] *ibid.*, §18.
[26] *ibid.*, §17.
[27] *ibid.*, §18. Quotation translated from the original German by Professor Fernando Leal.