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HERMENEUTIC PHILOSOPHY OF SCIENCE, VAN GOGH'S EYES, AND GOD

Essays in Honor of Patrick A. Heelan, S.J.

Edited by

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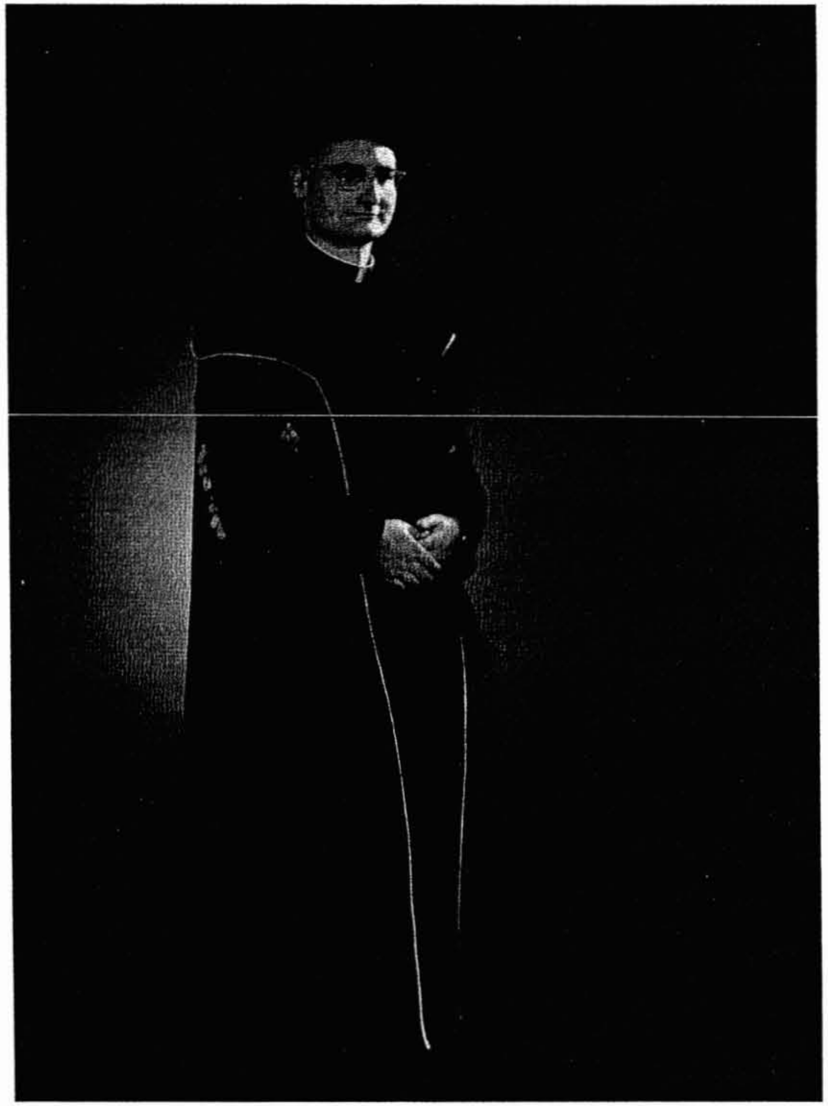
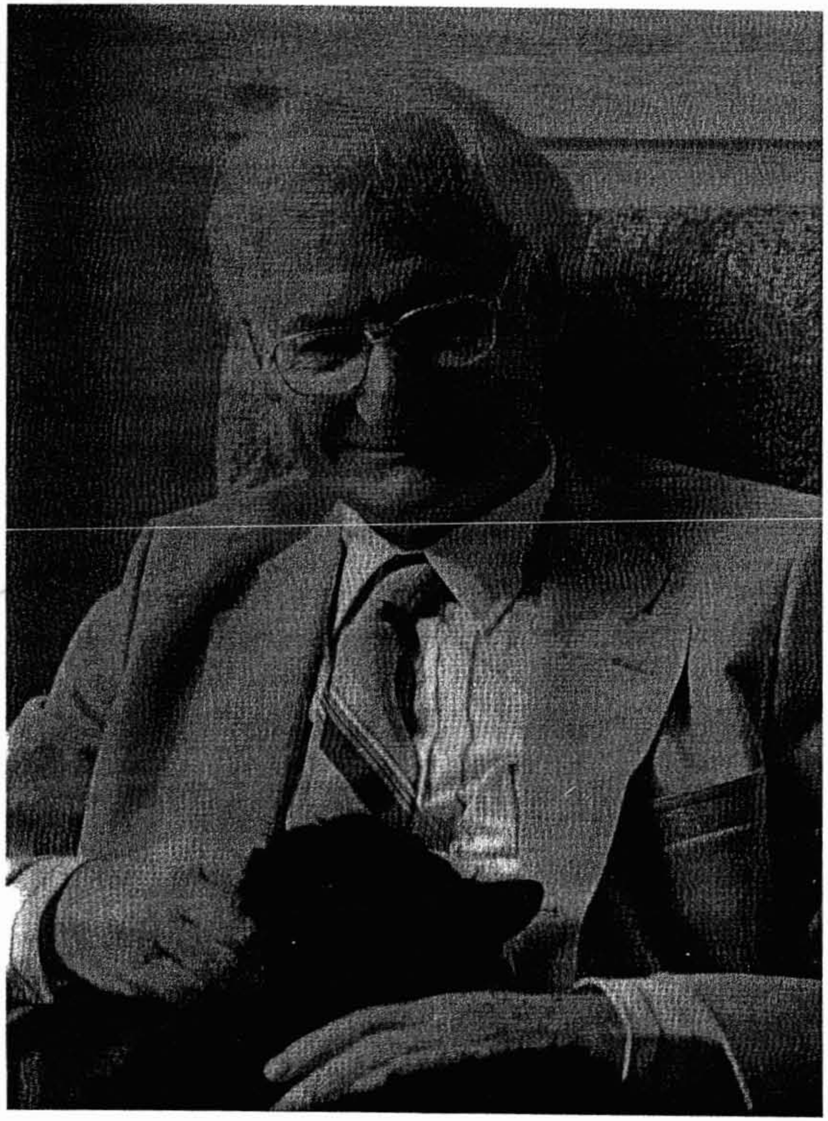


Patrick A. Heelan, S.J., Université Catholique de Louvain, 1964



Patrick A. Heelan, S.J.
Photograph by Ursula Bernis†

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RAGNAR FJELLAND

THE "COPENHAGEN INTERPRETATION" OF QUANTUM MECHANICS AND PHENOMENOLOGY

INTRODUCTION: THE "SCIENCE WARS"

The conflict that has come to be known as the "Science Wars" started when the biologist, Paul R. Gross, and the mathematician, Norman Levitt, published the book, *Higher Superstition: The Academic Left and Its Quarrels with Science*. The book was a fierce attack on certain quarters within the history of science, philosophy of science and sociology of science – such as existentialism, phenomenology, postmodernism, feminism, multiculturalism and so on. The next year, 1995, the book was followed up with a conference in New York given by the New York Academy of Sciences titled *The Flight from Science and Reason*. The conflict gained momentum when the physicist Alan Sokal published the article "Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity" in the journal for cultural studies, *Social Text*. Soon after the article was published, Sokal revealed that the entire thing had been a hoax. He had intentionally written an article that contained a lot of nonsense, however it was written using fashionably correct terminology with references to a range of "postmodern" thinkers. The hoax gained worldwide publicity, and many of the participants in the debate have claimed that this debate shows that C.P. Snow's "two cultures" still exist.[1]

Yet the fronts in this debate do not coincide with Snow's "two cultures" right off. The two camps are not divided between the humanities/social sciences on the one side and the natural sciences/technology on the other. The majority of the contributors to *The Flight from Science and Reason* were humanists and social scientists. Among these were a well-known philosopher of science (Mario Bunge) and a well-known historian of science (Gerard Holton). At the outset, therefore, the issues raised apply to different academic disciplines. Alleged irrational tendencies in the natural sciences were also attacked. That Ilya Prigogine would be criticized could be expected. But it has not been generally recognized that Niels Bohr and Werner Heisenberg were attacked from the very beginning. Indeed, *Higher Superstition* has an article attacking Bohr and Heisenberg, accusing them of advocating irrationalism and subjectivism.[2]

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The stumbling block is what is known as the "Copenhagen interpretation of quantum mechanics." The name alludes to the central role played by Bohr and his institute in Copenhagen in the development of the interpretation. However, it was early accepted by the majority of physicists, and in ordinary discourse the "Copenhagen interpretation of quantum mechanics" is synonymous with "quantum mechanics."

One example is the article by Mara Beller, professor of history and philosophy of science at the Hebrew University of Jerusalem: "At Whom are We Laughing?" Its main thesis is that Sokal's hoax applies to the founders of quantum mechanics as much as it applies to the "postmodern" milieus that Sokal wanted to ridicule.[3] The irony is that the attacks on Bohr and Heisenberg indirectly constitute an assault on what may be regarded as the very foundation of modern physics.

In this article I shall try to show that the attack on (the Copenhagen intepretation of) quantum mechanics in the Science Wars is no accident, and that quantum mechanics and phenomenology have more in common than being attacked in the Science Wars.

A SHORT HISTORY OF QUANTUM MECHANICS

It is now one hundred years since Max Planck hesitatingly introduced the notion of the quantum, as an attempt to solve a specific problem in physics concerning so-called black-body radiation. The next step was taken by Albert Einstein in 1905. He was able to explain a hitherto unexplained phenomenon related to the photoelectric effect by assuming that light can only transfer energy in specific quantities, so-called light quanta or photons. In 1913, Bohr proposed his model of the hydrogen atom, which implies that electrons in an atom can only circle the nucleus in certain orbits, and that a light quantum is absorbed or emitted when the electron jumps from one orbit to another. This was in accord with Einstein's photon hypothesis. In 1924, Louis de Broglie assumed that matter, for example electrons, may be regarded as waves. But this assumption implied a paradox. Light, which was previously regarded as waves, revealed properties which could only be explained by assuming that it consisted of particles. Matter, which was regarded as being made up of particles, revealed properties that could only be explained by assuming that the alleged particles behaved as waves. But can something be both a wave and a particle at the same time?

Bohr early recognized that quantum mechanics was incompatible with some of the basic assumptions in classical physics, assumptions that had been taken for granted since Galileo and Descartes. One assumption was that a complete description of the world in the final outcome had to be deterministic. Another was that objectivity means describing reality as it is independently of man. According to Bohr and his pupil Heisenberg[4] it is impossible to maintain this notion of objectivity. The observer has to be taken into consideration, and they emphasized that in quantum mechanics it is impossible to maintain an absolute separation between the knowing subject and the object of knowledge. In Heisenberg's words:

> ...the traditional requirement of science ...permits a division of the world into subject and object (observer and observed)...This assumption is not permissible in atomic physics; the interaction between observer and object causes uncontrollable large changes in the system being observed, because of the discontinuous changes characteristic of the atomic processes.[5]

Therefore, in observing a property, for example, the position of an electron, a disturbance of the object is unavoidable. In 1927 Heisenberg formulated his famous uncertainty relations, according to which the product of the uncertainties in two (non-commuting) entities must necessarily exceed a given constant. This can be written

$$\Delta x \cdot \Delta p \geq h/4\pi$$

For example, x can denote the position of a particle, and p its linear momentum. Δx is then the uncertainty in the determination of the position, and Δp is the uncertainty in the determination of the momentum of the same particle. h is Planck's constant. The implications are radical. For example, if we know the position of a particle exactly, its momentum is totally unknown, and if we know the momentum exactly, its position is totally unknown.

However, this relation may be interpreted in different ways. One might argue that the particle has a well-defined position and momentum, but our knowledge of these magnitudes is limited. This is the *hidden variable interpretation* of quantum mechanics. We shall later see that among others Albert Einstein maintained this view. However, according to the Copenhagen interpretation, we cannot ascribe physical reality to magnitudes that are not measured. Heisenberg put it this way:

> When one wants to clarify the meaning of the words "the position of an object," for example an electron (relative to a given frame of reference), one has to specify certain experiments with which one can measure the "position of the electron": if this is not the case, the words have no meaning.[6]

EINSTEIN: QUANTUM MECHANICS IS INCOMPLETE

Although the Copenhagen interpretation was quickly accepted by the majority of physicists, there were some famous dissidents. They count Einstein, Schrödinger, and Bohm, to name a few. In a paper from 1935, "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?" Einstein and his co-authors Podolsky and Rosen challenged the Copenhagen interpretation. Because this article set the stage for all subsequent debates on the interpretation of quantum mechanics, I outline the main arguments of the article.

Einstein, Podolsky, and Rosen start with two criteria which any acceptable theory must satisfy: 1) It must be correct and 2) it must be complete. The first criterion was not a problem, because quantum mechanics was in agreement with known observations at the time. Therefore, the paper discusses the second criterion exclusively, the question if quantum mechanics may be regarded as a complete theory. Completeness is defined as the requirement that "every element of the physical reality must have a counterpart in the physical theory (condition of completeness)." But the term "physical reality" which appears in the definition cannot be taken for granted. The authors do not attempt to give a complete definition of reality, but give the following criterion, which is crucial in the later discussion:

> If, without in any way disturbing a system, we can predict with certainty (i.e. with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity [criterion of physical reality].[7]

The first deals with the observation of a single particle. According to Heisenberg's uncertainty principle, in the case that the position is exactly known, the momentum is completely unknown. According to the criterion of physical reality the momentum has no physical reality because it cannot be predicted at all. In this case one may argue that this is due to the inevitable disturbance of the system in carrying out measurements. So far it looks plausible. However, when Einstein, Podolsky and Rosen extend the example to two particles, an apparent paradox arises. I shall give a simplified version of the example, leaving out all technicalities, but retaining the essential features. In the thought experiment two particles have interacted so that we know that they have correlated properties. The properties used by Einstein, Podolsky and Rosen are position and momentum of each particle. After the interaction the two particles fly off in different directions. They do not interact any more, and may therefore be regarded as two separate systems.

Let us call the two particles I and II respectively, and we carry out measurements on particle I. Because the two particles are correlated, we can infer from particle I to particle II. We have then two possibilities: 1) We can either measure the position of particle I, and infer the position of particle II, or 2) we can measure the momentum of particle I, and infer the momentum of particle II. According to Einstein, Podolsky, and Rosen, the paradox arises in the following way: On particle I we either measure the position or the momentum. When one of them is measured, the other is excluded. This follows directly from Heisenberg's uncertainty relations and can be explained by the inevitable disturbance involved in the measuring process. We should keep in mind that according to the Copenhagen interpretation the unknown property has no physical reality, and this applies to particle II as well as to particle I. Therefore, in case 1) the position of particle II has no physical reality, and in case 2) the momentum of particle II has no physical reality. But according to Einstein, Podolsky, and Rosen, particle II is a different system, separated from particle I. In observing particle I, particle II has not been affected. They therefore ask the question: How is it possible that what we observe on particle I, may determine which property of particle II has physical reality?

Einstein, Podolsky, and Rosen propose two possible alternatives: The first alternative is that the magnitudes do not have physical reality when they are not observed[8]. According to their view this implies that the event that particle I is observed is transmitted to particle II with a velocity that exceeds the velocity of light. According to the special theory of relativity signals cannot be transmitted faster than the velocity of light ("Einstein locality"). Therefore, this alternative violates Einstein locality, and Einstein, Podolsky, and Rosen exclude this possibility. (Einstein later called this alternative "spooky action at a distance"). According to the second alternative there are elements of physical reality (in case 1 the momentum of particle II and in case 2 the position of particle II) which are not represented in the theory. They conclude that the theory is incomplete.

In an article with the same title as Einstein, Podolsky, and Rosen's article, Bohr answered the criticism, and argued that quantum mechanics is indeed complete. He makes two main points. The first is that the expression "without in any way disturbing the system," in the criterion of physical reality is inadequate. Any description of physical reality must include the *measuring instruments* required to observe this reality. Bohr gives a detailed analysis of measurements of the position and momentum of a particle. The conclusion of these considerations reflects "even at this stage"

> there is essentially the question of *an influence on the very conditions which define the possible types of predictions regarding the future behavior of the system*. Since these conditions constitute an inherent element of the description of any phenomenon to which the term "physical reality" can be properly attached, we see that the argumentation of the mentioned authors does not justify their conclusion that quantum-mechanical description is essentially incomplete.[9]

Bohr's second point is that the two particles in the thought experiment cannot be separated into two systems. Even if the two particles are travelling in opposite directions with the speed of light, they are from a quantum mechanical point of view one unseparable system. Bohr therefore choses the second of Einstein, Podolsky, and Rosen's alternatives: violation of Einstein locality (non-locality or quantum entanglement).

Bohr rejected Einstein, Podolsky, and Rosen's definition of physical reality. His own alternative goes like this: "In objective description, it is indeed more appropriate to use the word phenomenon only to refer to observations obtained under specified circumstances, including an account of the whole experimental arrangement."[10]

It is worth noticing that whereas Einstein, Podolsky, and Rosen's definition of physical reality is basically the same as Galileo's and Descartes', Bohr's definition is more in accordance with the notion of objectivity held by a working scientist. The basic requirement in experimental science is the reproduceabililty of an experiment by fellow scientists. However, this is only feasible when an adequate description of the experimental setting is provided.

The controversy between Bohr and Einstein concerned the philosophical interpretation of quantum mechanics, and not its empirical validity. On the contrary, it looked as if the two interpretations would always yield the same predictions. However, in 1964, John Bell formulated the relations that have later been known as the "Bell inequalities." If Einstein, Podolsky and Rosen's interpretation of quantum mechanics was correct, the inequalities would not be violated, but if the Copenhagen interpretation was correct, they would in some situations be violated. Therefore, it looked as if the controversy could be settled through experiments. The first experiments were carried out in 1972, and later a series of experiments have been carried out, the most famous being the "Aspect experiments." With a few exceptions they have all violated the Bell inequalities and supported the Copenhagen interpretation. However, needless to say, the experimental results have not ended the controversy.[11]

IS THE COPENHAGEN INTERPRETATION POSITIVIST?

Bohr's and Heisenberg's position is sometimes regarded as positivist or instrumentalist. Like Ernst Mach they allegedly regarded physical magnitudes as nothing but theoretical constructions. There are reasons for maintaining that at least Heisenberg was influenced by Mach, and if we look at the quotation from Heisenberg cited above, this allegation has some plausibility. There are also quotations from Bohr that have a positivist flavour. One example is the following: "There is no quantum world. There is only an abstract quantum description. It is a mistake to think that it is the task of physics to find how nature is. Physics is about what we can say about nature."[12]

But nevertheless it is a misunderstanding to regard the Copenhagen interpretation of quantum mechanics as positivism. The root of this misunderstanding is the simple dichotomy used in much of the literature addressing this question. It is inferred that Bohr was a positivist by using the following argument: Einstein was a realist and there was a fundamental disagreement between Bohr and Einstein. Therefore, Bohr was a positivist. In this context, "realism" means Einstein's realism. But Einstein's realism is not the only realist alternative. We remember that according to realism, scientific objectivity describes physical reality independently of man. This is essentially the realism of Galileo and Descartes. Bohr doubtless did not accept such a naive realism. But this does not make him a positivist.[13] To avoid this fallacy requires distinctions other than the realist/ instrumentalist dichotomy. I shall not discuss realism. But I shall try to show that there are interesting parallels between Bohr's philosophy and phenomenology (in particular the later Edmund Husserl), and that the Copenhagen interpretation of quantum mechanics is much closer to phenomenology than to positivism.

THE REJECTION OF "OBJECTIVISM"

The primary source of Husserl's later philosophy is the (partly unfinished) manuscripts that were later published as *Die Krisis der europäischen Wissenschaften und transzendentale Phänomenologie*, mainly written around 1935.[14] As the title indicates, Husserl was concerned with what he regarded as a deep crisis in modern science. In spite of tremendous success, the crisis was rooted in a lack of understanding of modern science, and he traces this lack of understanding back to Galileo Galilei and the birth of modern science.

Husserl's Galileo is different from the traditional view of Galileo using a telescope to observe the moons of Jupiter. Husserl emphasizes the importance of measurement and the uses of mathematics in Galileo's science. According to Husserl there is nothing wrong with making measurements the basis of science. The problem is that Galileo took the mathematizability of nature more or less for granted, and he had no reason for asking for the very meaning of this mathematization. Therefore, he was "at once a discoverer and a concealing genius."[15]

Husserl was not the only one to maintain this view. The view of Galileo as a good empiricist was modified in the 1930's, and different authors pointed to the "Platonist" elements of his philosophy of science. One of the first was the French historian of science Alexandre Koyré.[16] According to Koyré, modern science is characterised by two changes, which are intimately related: the geometrization of space and what he calls "dissolution of the Cosmos." By the second phrase Koyré means the substitution of an abstract Euclidean space for the orderly Cosmos of pre-Galilean physics. As geometrization is the most fundamental of these two, the very essence of modern science, according to Koyré, is geometrization. Hence "... the precursor and inspirer of classical physics was not Buridan or Nicole Oresme but Archimedes."[17]

Thus we can draw a line from Plato via Archimedes and to Galileo. Galileo developed an "abstract" physics, in which the laws of motion, the law of freely falling bodies, are deduced "abstractly" without involving the idea of force, and without recourse to experiments with real bodies. The "experiments" that Galileo appealed to, even those which he did actually perform, were not any more than thought experiments.[18] These are the only kind that could be performed on the objects of his physics, because the objects of Galileo's physics were not real, but ideal bodies. Real, material bodies cannot be introduced into the unreal space of geometry. According to Koyré, Aristotle understood this perfectly well. But he had not understood that one can postulate abstract bodies, as had been recognised by Plato, and as had been done by the Platonist Archimedes. There was, however, one important difference. Plato and Archimedes could not think of setting these abstract bodies in motion. This was first carried out by Galileo.[19]

At another locus where Koyré describes the disagreement between Galileo and his Aristotelian opponents, he places an even stronger emphasis on the Platonist aspect of Galileo's science:

> No wonder that the Aristotelian felt himself astonished and bewildered by this amazing attempt to explain the real by the impossible – or, which is the same thing, to explain real being by mathematical being, because, as I have mentioned already, these bodies moving in straight lines in infinite empty space are not *real* bodies moving in *real* space, but *mathematical* bodies moving in *mathematical* space.[20]

Koyré was a historian of science. But Husserl regarded history as a key to the present, thus his project may be regarded as a "rational reconstruction" of Galileo's science, and of modern science in general. His basic idea is that the fundamental misunderstanding of modern science is that one has forgotten that even the most theoretical sciences are grounded in the life-world. In Husserl's words:

> Briefly reminding ourselves of our earlier discussions, let us recall the fact we have emphasized, namely, that science is a human spiritual accomplishment which presupposes as its point of departure, both historically and for each new student, the intuitive surrounding world of life, pregiven as existing for all in common. Furthermore, it is an accomplishment which, in being practiced and carried forward, continues to presuppose this surrounding world as it is given in its particularity to the scientist. For example, for the physicist it is the world in which he sees his measuring instruments, hears timebeats, estimates visible magnitudes, etc. – the world in which, furthermore, he knows himself to be included with all his activity and all his theoretical ideas.[21]

Husserl does not mention quantum mechanics, but he makes explicit reference to the theory of relativity. According to Husserl, the theory of relativity relies on Michelson's experiment (usually known as the Michelson-Morley experiment), including his apparatus with scales of measurement, etc.[22] Although the reference to the Michelson-Morley experiment is historically erroneous,[23] his main point is correct: measuring instruments are explicitly referred to in the (special) theory of relativity.

Bohr's position is similar to Husserl's, although to my knowledge none of them ever referred to each other. Bohr never tired of emphasizing that physics is a human accomplishment, and presupposes skill and ordinary language. The human agent cannot be abstracted away from the results of science. Therefore, objectivity in science is not depicting a world independently of man. According to Bohr, it is impossible to maintain such an ideal of objectivity. Objectivity must rather be understood as *intersubjectivity*.[24] In a letter to the Danish author H. P. E. Hansen, Bohr writes: "In physics we learn [...] time and again that our task is not to penetrate into the essence of things, the meaning of which we don't know anyway, but rather to develop concepts which allow us to talk in a productive way about phenomena in nature."[25]

Attention has often focussed on Bohr's emphasis on ordinary language as a precondition for the language of physics, and one draws a parallel to Wittgenstein's later philosophy. However, it can be argued that Wittgenstein's later philosophy entails a relativism: language is an integrated part of a lifestyle, and one lifestyle is as good as another. There is no yardstick to measure and compare them. However, in Bohr there is no trace of this kind of relativism. In the next section I shall try to show why.

AN ALTERNATIVE ACCOUNT OF SCIENTIFIC OBJECTIVITY

We have seen that both Bohr and Husserl pointed to the importance of technology, in particular instruments, in science. Bohr, for example, emphasized the indispensability of "rigid, stable bodies like measuring rods, pointers, clocks, plates etc." in making observations.[26] However, according to Bohr, the measuring instruments must be described in the language of classical physics. One might think that it is quite the opposite, that quantum mechanics is a precondition for classical physics, because quantum mechanics describes the world at a more fundamental level than classical physics. Formally classical physics is a limiting case of quantum mechanics, when we operate at a scale where Heisenberg's uncertainty relation is insignificant. Nevertheless, Bohr argued that classical physics – in a certain sense – is a precondition for quantum mechanics. His argument is that the measuring instruments must obey the laws of classical physics in order to function as measuring instruments. This is one of the more difficult points of Bohr's theory, and one of the most important.

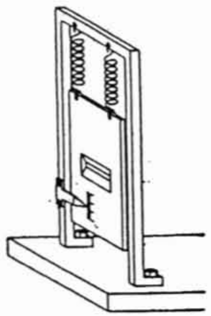

Figure 1a.

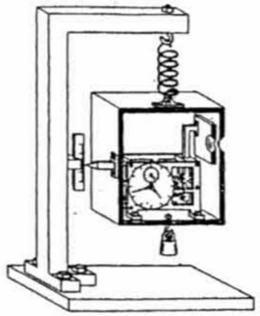

Figure 1b.

Measuring instruments constructed by Bohr for use in the thought experiments discussed with Einstein.

I will go one step further, and emphasize the importance of Euclidean geometry in the construction and operation of scientific instruments. Therefore, as Husserl argued, a proper understanding of Euclidean geometry is the key to understanding the mathematical sciences. This view is supported by Bohr's own illustrations (Figures 1a and 1b and 2). The instrument consists of a diaphragm with a slit suspended by weak springs from a solid yoke bolted to the support. It is important to recognize that the bolts and the springs in Bohr's illustrations are not just ornamental. They are there to show which parts of the instruments are rigidly connected, and which parts are moveable. Even more striking are the basic Euclidean forms of the instruments. The bolts and the springs can be replaced by technically more sophisticated devices, but in the last resort we need rigid bodies to carry out measurements.

The philosopher of science Ronald Giere reports how surprised he was when he noticed that the geometrical forms of a cyclotron facility were clearly visible in aerial photographs.[27]

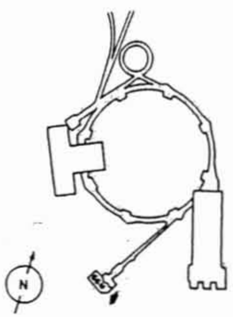

Figure 2. The CERN proton syncrotron from 1967.

Figure 2 gives an illustration of an accelerator. The basic Euclidean forms, straight line, circle and right angle, are evident. Giere points to the fact that geometrical aspects also appear in formal and informal presentations in particle physics. He seeks part of the explanation for this in cognitive patterns in our brains, making us predisposed to Euclidean geometry. He refers to experiments with rats which allegedly demonstrate that rats are also predisposed to Euclidean geometry. However, although I certainly agree with Giere when he points to the significance of Euclidean geometry, I disagree with his explanation of its significance. I think he is wrong in indicating that our perceived world is Euclidean. Heelan has shown convincingly that the structure of perceived space is not Euclidean.[28]The history of geometry supports this view. For example, Greek geometry was *not* a theory of (the structure of) *space*. The two relevant Greek words are "*topos*" and "*chora*." Neither of these words should be translated as "space," and especially not as "Euclidean space." I think Martin Heidegger is right when he asserts that the Greeks had neither a word nor a concept for what we call "space."[29] What Cornford says of Plato's use of the word "*chora*" could be said of the Greek use of that word in general:

> *Chora* is used of the post, station, office, 'place' that is filled, not vacant space... 'Place' would, indeed, be a less misleading translation of *chora* than 'space', because 'place' does not suggest an infinite extent of vacancy lying beyond the finite sphere of the universe.[30]

Aristotle's theory of the universe as a system of "natural places" is very well in agreement with this view. The natural place of a thing cannot be determined by, say, three values in a coordinate system. To be in a natural place means to be part of a whole. I think it is a good analogy to the Greek conception of place to say that a thing is in its natural place in the same way as an organ is in its natural place in the organism. Indeed, the Greek way of thinking was highly organic. This applied both to their thinking about society, nature and the universe.

In "The Origin of Geometry,"[31] Husserl sets out to trace the origin of Euclidean geometry. He reconstructs the origin of geometry roughly as follows: The world consists of material bodies, with different shapes and "material" qualities (color, warmth, weight, hardness and so on). For technical praxis some particular shapes were preferred. These are partly selected, partly produced and improved according to certain directions of gradualness. Husserl describes how special forms are singled out: surfaces according to if they are more or less smooth, more or less perfect. Edges according to if they are more or less rough or even, for example more or less pure lines, angles, more or less perfect points. Among surfaces, even surfaces are preferred and among lines, straight lines are preferred, and so on. As technology makes progress, there is an increasing interest in what is technically more refined. The ideal of perfection is pushed further and further. So there is always an open horizon of *conceivable* improvements to be further pursued.

The ideal shapes of Euclidean geometry, like straight lines and planes, grew out of the praxis of technical perfecting. Husserl called them *limit-shapes* [*Limesgestalten*]. These can be regarded as the ideal limit that the process of perfection is approaching. When these ideal shapes are made our objects of investigation, when we are engaged in determining them and in constructing new shapes out of those already determined, we are "geometers." Therefore, the ideal geometrical figures are produced by the "method of idealization."

Patrick Heelan objects that Husserl makes an unwarranted assumption: we cannot in general assume that "the sequence of particulars–and the technologies necessary to produce or recognize them – is *infinitely perfectible.*"[32] On the contrary, the practising experimental scientist knows that there is no such ideal limit: "Experience with experimental processes indicates that for every kind of measurement process, there is an optimal level of precision beyond which the validity of background assumptions fail." I think Heelan is right. Husserl's background from pure mathematics and his focus on an axiomatic ideal of mathematics and scientific theories prevented him from being fully aware of the preconditions of scientific practice. However, he was aware of some of the preconditions of measurements, for example in the following quotation:

> This purpose [of producing objectivity] is obviously served by the *art of measuring*. This art involves a great deal, of which the actual measuring is only the concluding part. On the one hand, for the bodily shapes of rivers, mountains, buildings, etc., which as a rule lack strictly determining concepts and names, it must create such concepts – first for their "forms" (in terms of pictured similarity).[33]

It is interesting to notice that Husserl mentions rivers and mountains. That the problems involved in measuring this kind of object are far from trivial has later been demonstrated by the mathematician Benoit Mandelbrot. He asked what might look like a trivial question: How long is a coastline? He had observed that when he asked how long the coast of for example Britain is, he always got one of two answers: "I don't know, it is not my field," or "I don't know, but I will look it up in an encyclopaedia." In both cases it is assumed that the question has an unambiguous answer. But it is not that easy, and Mandelbrot used the coast of Britain to illustrate the difficulties involved. A coastline is an example of an object where the ideal limit does not exist. It is a fractal curve, and strictly speaking it is infinitely long.[34]

ANTI-REDUCTIONISM

It is one of the main insights of Husserl's *Crisis* that almost all philosophers since Descartes have taken a scientific world view as their starting point. In contrast to this the slogan of phenomenology was: "*Zur Sache selbst.*" I think that an even better characterization of Husserl's later philosophy would be the slogan: "Back to the life-world!"

The most important difference between the life-world and the world of physics is that the former has meaning, whereas the latter does not. This fundamental aspect of the life-world may be illuminated by Heidegger's analysis of the concept of a thing in *Sein und Zeit*. Heidegger starts by asking: Is it not an obvious starting point to claim that the world consists of things? His answer is "No." According to Heidegger the entities of the world of science are the result of theoretical attitude. But this way of looking at things is secondary. Primarily we use and regard things as articles for everyday use. A hammer (to take one of Heidegger's favourite examples) is primarily an article which we use for driving nails and so on, and only secondarily it is a physical thing. Hence the hammer has a meaning, it refers to what tasks it can be used to perform. To understand the meaning of a hammer is precisely to know what it can be used for, and how to use it. Heidegger points out that the meaning of articles does not come in addition to their being physical objects. On the contrary, to regard something as a physical object presupposes an assumption of it as a tool. The experimental physicist normally uses more complicated equipment than hammers, but measuring instruments are nevertheless tools. To make experiments he has to handle those instruments in a competent manner, and he needs good instruments. If he is incompetent or his tools are bad, the measurements will be poor as well. But how can we decide if an instrument, for instance a watch, is a good one? Regarded as a physical object it can neither be good nor bad. But regarded as a tool its quality can be assessed, and it is assessed in relation to the function it was constructed to perform.

One of the explicit aims of Husserl's *Crisis* was to demonstrate that a "scientific" psychology cannot be constructed after the ideal of physics. "The world of physics" is grounded in the life-world, and constructed by idealization, as indicated previously. "The world of psychology" *is* rather the life-world. Therefore, Husserl's program for psychology was contrary to the "unity of science" movement of the logical positivists. His program was rather the "disunity of science." Bohr maintained a similar view. His alternative to reductionism in both biology and psychology was the notion of complementarity. He first used the term *complementarity* in 1927 in the discussion of the particle/wave dualism in quantum mechanics: The particle and wave pictures display complementary, mutually excluding aspects of matter. Bohr later extended the notion of complementarity to biology and psychology. For example, free will and determinism are examples of complementary phenomena.

However, although free will and causal explanation of human actions represent complementary aspects, they are not on the same par. In the same way as Husserl argued for the primacy of the life-world *vis à vis* (for example) the world of physics, the notions of free will and of life are prior to notions like determinism and control. The following quotation on the irreducibility of the phenomenon of life supports this view:[35]

> [W]e must keep in mind, however, that the conditions holding for biological and physical researches are not directly comparable, since the necessity of keeping the object alive imposes a restriction on the former, which finds no counterpart in the latter. Thus we should doubtlessly kill an animal if we tried to carry the investigation of its organs so far that we could describe the rôle played by single atoms in vital functions. In every experiment on living organisms, there must remain an uncertainty as regards the physical conditions to which they are subjected, and the idea suggests itself that the minimal freedom we must allow the organism in this respect is just large enough to permit it, so to say, to hide its ultimate secrets from us. On this view, the existence of life must in biology be considered as an elementary fact that cannot be explained, but must be taken as a starting point in biology, in similar way as the quantum of action, which appears as an irrational element from the point of view of classical mechanical physics, taken together with the existence of the elementary particles, forms the foundation of atomic physics. The asserted impossibility of a physical or chemical explanation of the function peculiar to life would in this sense be analogous to the insufficience of the mechanical analysis for the understanding of the stability of the atoms.[36]

CONCLUSION

The "Science Wars" are about many things. However, I want to draw the attention to an article by one who has been fighting at the frontlines from the very beginning: Norman Levitt. He was the co-author both of *Higher Superstition* and *The Flight from Science and Reason*. In a recent article, Levitt sums up the state of modern science:

> I shall merely assert what can easily be argued: From the conceptual point of view, the sciences are in an unprecedentedly robust state of health, strength, and vigor. Theoretical understanding from biology to physics is deeper and sharper than it has ever been. Overall, there is greater unity and greater cross-fertilization among the various scientific disciplines than has ever been seen. The monistic, reductionistic point of view that form the main philosophical current of science seems increasingly to be vindicated by a string of breakthroughs.[37]

I think that *monistic* and *reductionistic* are key words here. According to this view of science, both phenomenology and (the Copenhagen interpretation of) quantum mechanics are regarded as "subjectivist" and therefore anti-science. Hence it is no accident that they are both under fire in the "science wars."

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I want to thank the Niels Bohr Archive for the permission to reproduce the two drawings in Figure 1 and I thank CERN for the permission to reproduce Figure 2 (CERN/PIO/RA 77-4).

NOTES

[1] I want to point out that I find Sokal's article both clever and amusing, and that I regard the reaction of the editors of *Social Text* as both irrational and even ridiculous.

[2] Sheldon Goldstein, "Quantum Philosophy: The Flight from Reason in Science" in Paul Gross & Norman Levitt, eds., *Higher Superstition: The Academic Left and Its Quarrels with Science* (Baltimore: Johns Hopkins University Press, 1994). 119-126.

[3] Mara Beller, "The Sokal Hoax: At Whom Are We Laughing?," *Physics Today*, September 1998: 29.

[4] In this article I stress the close relationship between Bohr and Heisenberg. However, as pointed out by Patrick A. Heelan, *Quantum Mechanics and Objectivity. A Study of the Physical Philosophy of Werner Heisenberg* (The Hague: Martinus Nijhoff, 1965) there were no doubt important differences between them.

[5] Werner Heisenberg, *Physikalische Prinzipien der Quantentheorie* (Mannheim: Bibliographisches Institut 1958 [1930]): 48

[6] Heisenberg, "The Physical Content of Quantum Kinematics and Dynamics," reprinted in J.A. Wheeler, W.H. Zurek, eds., *Quantum Theory and Measurement* (Princeton: Princeton University Press, 1983 [1927]), 64.

[7] Albert Einstein, Boris Podolsky, and Nathan Rosen. "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47/1935:777-80, reprinted in J.A. Wheeler and W.H. Zurek, eds., *Quantum Theory and Measurement*.

[8] In an article with the title "Is the Moon There When Nobody Looks?" (*Physics Today*, April 1985: 38-47) David Mermin quotes the following passage from Abraham Pais: "We often discussed his notions on objective reality. I recall that during one walk Einstein suddenly stopped, turned to me and asked whether I really believed that the moon exists only when I look at it." Pais, *'Subtle is the Lord...' The Science and Life of Albert Einstein* (Oxford: Oxford University Press, 1983).

[9] Niels Bohr, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 48/1935:696-702, reprinted in Wheeler and Zurek, eds., *Quantum Theory and Measurement*, 148.

[10] Bohr, "Science and the Unity of Knowledge," reprinted in Niels Bohr: *Collected Works*, vol. 10 (Amsterdam: Elsevier, 1999 [1955]), 79–98. 89.

[11] On the Bell inequalities and EPR experiments, see for example J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics* (Cambridge: Cambridge University Press, 1987).

[12] Quoted from Abraham Pais, *Niels Bohr's Time, in Physics, Philosophy and Polity* (Oxford: Clarendon Press, 1991), 426.

[13] In support of this view, see for example Dugald Murdoch, *Niels Bohr's Philosophy of Physics* (Cambridge: Cambridge University Press, 1989).

[14] For historical details, see Heelan, "Husserl's Later Philosophy of Natural Science," *Philosophy of Science* 54/1987: 368. Heelan has a much more detailed description of Husserl's project in *Crisis* than I can offer here.

[15] Edmund Husserl, *Die Krisis der europäischen Wissenschaften und die transzendentale Phänomenologie*, Walter Biemel, ed. (The Hague: Nijhoff, 1954), 52.

[16] See Edwin A. Burtt, *The Metaphysical Foundation of Modern Physical Science* (London: Routledge and Kegan Paul, 1972, Sec. rev. ed. [1924]). On the Platonist aspects of Galileo's science, see especially pp. 64-73.

[17] Alexandre Koyré, *Galileo Studies* (London: Harvester, 1978 [1939]): 3.

[18] Needless to say, this is an extreme interpretation. An almost opposite view, stressing the importance of Galileo's experiments, can be found in Stillman Drake, *Galileo at Work* (Chicago and London: University of Chicago Press, 1978). However, without following Koyré all the way, one may nevertheless maintain that he focussed on an essential aspect of Galileo's science.

[19] Koyré, 37-38.

[20] Koyré, "Galileo and Plato" in Koyré: *Metaphysics and Measurement* (Baltimore: Johns Hopkins University Press, 1968 [1943]), 34.

[21] Husserl, 121.

[22] *Ibid.*, 125.

[23] For more details, see Pais *'Subtle is the Lord...' The Science and Life of Albert Einstein*, 116–117.

[24] Cf. Murdoch, 105.

[25] 20 July 1935. In Pais, *Niels Bohr's Time, in Physics, Philosophy and Polity*, 446.

[26] David Favrholdt, *Fysik, bevidsthed, liv. Studier i Niels Bohrs filosofi* (Odense: Odense Universitetsforlag 1995), 89.

[27] Ronald H. Giere, *Explaining Science: A Cognitive Approach* (Chicago: University of Chicago Press, 1988), 133.

[28] Heelan, *Space-Perception and the Philosophy of Science* (Berkeley: University of California Press, 1988).

[29] Heidegger, "Vom Wesen und Begriff der fysis" in *Wegmarken* (Frankfurt: Klostermann, 1978), 246.

[30] F. M. Cornford, *Plato's Cosmology. The Timaeus of Plato* (London: Routledge & Kegan Paul, 1977), 200n.

[31] Included as Appendix VI in the English translation of Edmunds Husserl's, *The Crisis of the European Sciences and Transcendental Phenomenology*, trans. D. Carr (Evanston, IL: Northwestern University Press, 1970).

[32] Heelan, *Space-Perception and the Philosophy of Science*, 378.

[33] Husserl, 1954, 27.

[34] Benoit Mandelbrot, *The Fractal Geometry of Nature* (New York: Freeman and Company, 1983), 25ff.

[35] For a more detailed discussion of complementarity and biology, see Henry J. Folse Jr., "Complementarity and the Description of Nature in Biological Science," *Biology and Philosophy* 5/1990: 211–224.

[36] Bohr, "Light and Life" in Bohr, *Collected Works*, vol. 10: 34.

[37] Norman Levitt, "The End of Science, the Central Dogma of Science Studies, Monsieur Jourdain, and Uncle Vanya" in Noretta Koertge, ed., *A House Built on Sand. Exposing Postmodernist Myths About Science* (New York and Oxford: Oxford University Press, 1998), 280.