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SHADOWS OF LANGUAGE IN PHYSICS AND CYBERNETICS

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Abstract. In a large variety of disciplines, fundamental studies often straddle in self-referential situations, in need of relativization to language and complementaristic resolution. In such attempts, the languages at play are hardly visible themselves. Only shadows of language, somewhat characteristic of the various disciplines, become visible and tractable. We select two domains, quantum mechanics and cybernetics, for a comparative study of their complementarity concepts with consequence for understandings of observability, describability, and objectivity. In particular, we compare Bohr-Pauli's "non-detachability of the observer" and von Foerster's aphorisms for objectivity.

In quantum mechanics, with its emphasis on experimentability and measurability, Bohr's primary view of complementarity takes the form of a tension between definability and measurability. In cybernetics, we have a central interest in inferribility above the more constructive measurability, and the linguistic complementarity takes the form of a tension between describability and interpretability.

In quests for a complete quantum mechanical measurement language, we face an interesting situation, that of simulating semantic measurability by syntactic inferribility. It calls for a cybernetic tie, whereby the two processes of assertibility, by measurability and by provability, become united under complementarity. Although semantic and syntactic processes are complementary within the measurement language, they may be unfolded in levels of constructivity, allowing identification of the lowest levels. Namely, identification of the constructivity level of a basic measurement sentence, i.e., a sentence which can be affirmed by a direct measurement (without involving further inferences), with the lowest constructivity level of syntactic provability.

We exemplify with an explanation of a recent challenge against Bohr's wave-particle compementarity. Namely, by the so called double-prism experiment of Ghose, Home, and Agarwal. We find the experiment quite interesting, not by the alleged challenge, but by realizing that its interpretation requires a levelled approach to quantum theory.

1 *Shadows of Language and the Linguistic Complementarity*

Language is hard to objectify, except for its visible shadows that are generated, characteristically, in the light of its own description and interpretation processes. We are in the midst of language when trying to get a perspective of it.

> "When it was objected that reality is more fundamental than language and lies beneath language, Bohr answered, 'We are suspended in language in such a way that we cannot say what is up and what is down'."

This early Bohrian insight of our "nondetachability" from language is quoted from [20]. Indeed, our living, thinking, and communication are all phenomena of language. In genetic language, inner cerebral language, and external communication language. Our suspensions in language make it difficult for us to descriptively talk *of* it *in* it.

However, a complementaristic comprehension of language is possible. Namely, with language as a whole of description and interpretation processes, yet a whole which has no such parts fully expressible within itself. Descriptions and interpretations are autonomously complementary parts of language. We refer to this autonomous part-whole relation as the *linguistic complementarity*.

It may happen that a metalanguage has evolved, and then the description and interpretation processes of an object language can be completely described in the metalanguage.

Not all languages have metalanguages, however, and certain languages, like our natural communication languages, have evolved with high introspective capacities. In them, we can understand and say a great deal – although not all – of the languages themselves. In particular, by studies of lower level languages and their complementarities, which we can describe in the natural language, we tend to inductively infer about the complementarity of the external communication language itself. However, such an inductive inference does not allow the conclusion that also this language has a metalanguage, or that such a metalanguage will evolve. The only thing we can say for sure is that every language is complementaristic. This assertion is based on the requirement of a *finite representability of the descriptions in every language*. Without that, a "language" would not admit communication, or control, and thus be no language.

In [15, 16, 17] we have developed a number of equivalent views of the linguistic complementarity.

> **The Linguistic Complementarity**. In its complementaristic understanding, the phenomenon of language is a whole of description and interpretation processes, yet a whole which has no such parts expressible within itself. This constitutes a paradigm for complementarity, the *linguistic complementarity*. Any other known form of complementarity, from proposals from Bergson to

Bohr, have been found [15] reducible to the linguistic complementarity, and the reductions themselves do provide an understanding of the complementarities. There are various related ways of looking at the linguistic complementarity:

(i) as descriptional incompleteness: in no language, its interpretation process can be completely described in the language itself;

(ii) as a tension between describability and interpretability within a language;

(iii) as degrees of partiality of self–reference (introspection) within a language: complete self–reference within a language is impossible;

(iv) as a principle of "nondetachability of language".

There are many scientific disciplines which do succeed in fragmenting themselves well enough into detached disciplines such that their descriptions or theories appear "language-independent". Then there is no need for trying to objectify, within the disciplines, the language which is in use in formulating the theories. Examples are classical domains of physics, biology, etc, which describe phenomena that are not themselves linguistic. That is, phenomena which do not involve, in a sense of trying to objectify, description-interpretation processes like processes of measurement, computation, information, observation, formalization, cognition, etc.

Quantum mechanics, however, with its interest in the measurement process as a physical phenomenon, is a domain for which the nondetachability of language (or of the observer) becomes a "hot" issue whenever interpretability problems are considered. The same holds true for cybernetics with its central interests in attempting objectification of phenomena of self-reference.

In what follows we will make a few comparisons, out from the linguistic complementarity, between quantum mechanical and cybernetic ways to recognize the nondetachability of language.

Furthermore, in quests for a complete quantum mechanical measurement language, we face a cybernetically interesting situation, that of simulating semantic measurability by syntactic inferribility. Although semantic and syntatic processes are complementary within the measurement language, a simulation of one in the other may still be *partially* successful, namely in terms of constructivity. We propose to identify the constructivity level of a basic measurement sentence, i.e., a sentence which can be asserted by a

direct measurement (without involving further inferences), with the lowest constructivity level of syntactic provability.

We exemplify the levelled approach to quantum measurement theory with an explanation of a recent challenge against Bohr's wave-particle complementarity. Namely, by the so called double-prism experiment of Ghose, Home, and Agrawal. We find the experiment quite interesting, not by the alleged challenge, but by realizing that its interpretation requires a levelled approach to quantum theory.

2 *Specific Views of Complementarity in Quantum Mechanics*

When Bohr introduced the concept of complementarity in quantum mechanics, in his Como paper [2], he did so with a clear argument out from Planck's quantum postulate. To distinguish the here defined concept from later views, we use to refer to it (cf [15, 16, 17]) as **Bohr's primary view of complementarity**: *a tension between definability and observability.* The tension, or "weighing the possibilities of definition and observation" has an unmistakable continuous gradation (as seen on page 582 of [2]). Later on, after Shannon's inception of statistical information in cybernetics, the tension was given an information-theoretic interpretation by Wootters and Zurek [30].

In [15, 16] we have explained Bohr's primary view of complementarity as a case of the linguistic complementarity, namely as a tension between describability and interpretability in a quantum mechanical measurement language where the interpretation processes are observation processes (measurement processes). In a general linguistic case, the continuous character of the tension between describability and interpretability is argued in terms of a general semantic concept of information [19].

In his later writings [3], Bohr also developed a view of complementarity in terms of a concept of *phenomenon*, namely as a *systemic whole* of an atomic process in interaction with a measuring apparatus. We have in [15] referred to this view as **Bohrs View of Complementarity in Terms of Phenomena**.

For example, in quantum physics a photon *per se* is not an appropriate object. But a "photon–investigated–in–an–interference–experiment" is, as a phenomenon (showing a wave-like feature), an appropriate quantum physical object. Again, a "photon–investigated–in–a–which–path–experiment" is to be regarded *another, complementary* phenomenon (showing a particle-like feature).

From a general point of view, Bohr's procedure here, namely to resolve a problem in terms of a proposed indivisibility of a phenomenon, is natural and sound. It has been called a **complementaristic resolution** by Lindenberg and Oppenheim [13]. It is hierarchical in nature, and depends on the establishment of the *unsolvability* of a problem within a certain domain (an *intradomain* problem), which is made do disappear in mowing to a wholistic conceptualisation.

We have a particular case of the complementaristic resolution in the double–slit experiment, without and with modifications for "which path" measurements. Here Bohr argued the impossibility of a simultaneous measuring of both wave and particle properties of a quantum object, the **wave–particle complementarity**, with reference to the Heisenberg uncertainty relation for position and momentum. Also de Broglie, although somewhat reluctant to Bohr's concept of wave–particle complementarity, once argued [4] (page 83) an unsolvable intradomain problem with reference to Heisenberg's uncertainty relations.

A main difference between Bohr's primary view of complementarity, and his view of complementarity in terms of phenomena, is that the latter requires some specific demonstration of an unsolvable intradomain problem. Whereas the former is built around the quantum postulate as a generally accepted quantum mechanical principle. By way of example, the wave–particle complementarity may easily be criticized the way a particular cause of the required intradomain unsolvability can be criticized on general grounds.

In quantum mechanics, Bohr's views of complementarity have been influential primarily for questions of interpretability of quantum theory. Yet, in several philosophical discussions on interpretability, reference to Bohr complementarity tends to be very indirect. Like in referring to alleged philosophical views of Bohr on a quantum mechanical reality (a topic that Bohr usually avoided), as if such views were to be identified with "Bohr's principle of complementarity". Bohr's clearly stated primary view of complementarity, with its kinship to the later to come metamathematical insights (incompleteness of formal systems) may today be more appealing to a metamathematician than to some quantum philosophers.

By way of example, Selleri writes in [23] under a section "simultaneous reality of incompatible observables":

> "It is a fact of the history of modern physics that Bohr never spent a word in trying to justify his philosophical position, which he adopted under the well documented influence of S. Kierkegaard, H. Hoffding, and W. James."

What Bohr clearly argues in [2] is his concept of complementarity, not as a philosophical position but as a consequence of Planck's quantum postulate. If by "Bohr's philosophical position", Selleri is referring to Bohr's wishes to remain on a measurable ground, he may be right. By comparison, how often do we find intuitionistic mathematicians explain their philosophical positions.

Selleri ends his paper [23]:

> "All this evidence, and much more that can be found in the references ..., strengthens the independent conclusion obtained in the present paper, that Bohr created complementarity under the influence of the philosophical ideas of Danish existentialism. By doing so he *freely* decided to introduce a strange new idea into physics, the idea that fundamental problems cannot be solved and that we have to live with the dilemmas!"

Even with a correct interpretation of complementarity here, that of [2], Bohr's primary view of complementarity may have appeared astonishing in 1927. Today, however, it appears a remarkable insight into the interdependence of definability and observability well before Gödel's insights into the limitative nature of describability (formalizability) in formal systems. We know today, primarily from metamathematics, that there are truly fundamental situations, like the "nondetachability of language" (cf also the quotation on Bohr in the beginning of our paper), the inaccessibility from within constructive branches of mathematics of certain wider mathematical results, etc. These situations are, however, not to be regarded as problems – unless we cannot understand them and entertain false hopes of overcoming them.

What such examples learn, however, is not to overlook that Bohr complementarity concerns possibilities and impossibilities which are *relativized* to quantum mechanical *measurability*. Just like the wider mathematical resuts become accessible when we transcend constructive mathematics, Bohr complementarity is not preventive for quantum theoretical inferences on a higher level of constructivity than that of pure measurability. We will examplify in terms of the double-prism experiment in a later section.

Also the linguistic complementarity is relativized, namely with respect to the language in which its complementary descriptions and interpretations occur. Which means, that if we sacrify the *communicability* of ideas, we may freely entertain personal views of going beyond Wittgenstein's aphorism 7 in [29]: "What we cannot speak about we must consign to silence". But as long as we do communicate, which is vital for example for scientists testing their ideas, we are communicating in a shared language whose complementarity is

then non-transcended as a highest level for relativization. This may explain why the linguistic complementarity is a general concept to which every other known form of complementarity has been found reducible (cf [15]).

3 *Cartesian and Heisenberg Cuts and Bohr-Pauli's "Detachability of the Observer"*

The topic of the "detachability of the observer" is related with the ideas of making conceptual "cuts", like in separating mind and matter, observer and the observed, measuring apparatus and system measured upon, inside and outside, etc. By way of well known examples, the *Cartesian cut* separates the whole reality into mind and body at the same time that an interaction (or "intermingling"; cf page 56 in Descartes [5]; cf also [16]) is recognized whereby, in spite of the cut, a whole is maintained. The *Heisenberg cut* (see Primas [22]), which presupposes the Cartesian cut, divides in addition the purely material universe of discourse into a material object and material observing tools (with interactions, but no Einstein-Podolsky-Rosen correlations, between the observed object and the observing tools).

The Bohr-Pauli dialogue on the detachability of the obsever (cf [16]) ought to be sufficiently well understood from the following quotations from a letter which Pauli wrote to Bohr in 1955, printed in Laurikainen's book [12].

> "To a certain extent I am therefore glad, that eventually I found something [indicating disagreement]: the definition and the use of the expression 'detached observer', which appears on page 10 above of your lecture and which reappears on page 13 in connection with biology. According to my own point of view the degree of this 'detachment' is gradually lessened in our theoretical explanation of nature and I am expecting further steps in this direction. ..., it seems to me quite appropriate to call the conceptual description of nature in classical physics, which Einstein so emphatically wishes to retain, 'the ideal of the detached observer'. To put it drastically the observer has according to this ideal to disappear entirely in a discrete manner as hidden spectator, never as actor, nature being left alone in a predetermined course of events, independent of the way in which the phenomena are observed. 'Like the moon has a definite position' Einstein said to me last winter, 'whether or not we look at the moon, the same must also hold for the atomic objects, as there is no sharp distinction possible

> between these and macroscopic objects. Observation cannot *create* an element of reality like a position, there must be something contained in the complete description of physical reality which corresponds to the *possibility* of observing a position, already before the observation has been actually made.' I hope that I quoted Einstein correctly; it is always difficult to quote somebody out of memory with whom one does not agree. It is precisely this kind of postulate which I call the ideal of the detached observer. In quantum mechanics, on the contrary, an observation hic et nunc changes in general the 'state' of the observed system in a way not contained in the mathematically formulated *laws*, which only apply to the automatical time dependence of the state of a *closed* system. I think here on the passage to a new phenomenon by observation which is technically taken into account by the so–called 'reduction of the wave packets'. As it is allowed to consider the instruments of observation as a kind of prolongation of the sense organs of the observer, I consider the impredictable change of the state by a single observation — in spite of the objective character of the result of every observation and notwithstanding the statistical laws for the frequencies of repeated observation under equal conditions — to be *an abandonment of the idea of the isolation (detachment) of the observer from the course of physical events outside himself.*
>
> ...
>
> Probably you mean by 'our position as detached observers' something entirely different than I do, as for me this new relation of the observer to the course of physical events is entirely *identical* with the fact, that our situation as regards objective description in 'this field of experience' gave rise to the demand of a renewed revision of the foundations for 'the unambiguous use of our elementary concepts', logically expressed by the notion of complementarity."

In our general concept of language, observation (even when restricted to measurement) is a linguistic process, essentially an interpretation process. Compare how we tend to look at the meaning (interpretation) of a sentence (description) as the conditions under which the sentence is true, and how truth in a measurement–language is to be identified with that which is measured.

A natural way of trying to objectify the linguistic observation (measurement) process is to consider it the behaviour of an observer. However, to speak of the (non)detachability of an observer would then seem to imply an embodiment of observation, which already from the outset makes it possi-

ble to detach it, as any object can be considered in isolation. But this may not be what Bohr and Pauli are discussing — in spite of their terminology. What they really are referring to is an observation or measurement process, a behaviour, which is linguistic rather than corporeal.

Let us for a moment change the vocabulary in considering a (non)detachability of language instead of that of an observer (cf view iv of the linguistic complementarity). Then, with language in its complementaristic conception, let us try to understand the meaning of such a (non)detachability. Furthermore, let us move from an observation language to a language in general. Now, with language a complementaristic whole of descriptions and interpretations (conceived in a metalanguage), we first notice that *sentences* indeed are detachable as finite strings of symbols. This is what makes it possible not only to isolate them, but to transmit and reproduce them — a prerequisite for communication; cf reproduction of books, or partial self-reproduction of DNA strings. But interpretations of descriptions cannot be detached — except to the degree they can be described in the language. Meanings can only be isolated for objective comprehension to the extent that they can be fully described in the language. But that is impossible according to view (i) of the linguistic complementarity.

The nondetachability of language, view (iv) of the linguistic complementarity, means that it is not possible to isolate, as a linguistic act, a language as some object which can be fully talked about and understood as if detached from itself. What is needed is a conceptualization of language as a complementaristic phenomenon. That is, as a truly wholistic phenomenon which cannot be *autonomously* fragmented into parts (descriptions, interpretations). Meaning that it cannot be completely captured in descriptions. A nondescribed access to the interpretation processes of the language is unavoidable for a full comprehension.

Now, when applied to an observation language, its nondetachability conforms well with Pauli's view of the nondetachability of an observer. Also the way Pauli connects to complementarity is identifiable in the linguistic case. It seems reasonable that the gradual lessening of the detachment, which Pauli speaks of in connection with our theoretical explanation of nature, and where he expects further steps, is in line with a general linguistic context where degrees of nondetachability may be related to degrees of partiality of linguistic introspection according to view (iii) of the linguistic complementarity.

Next, consider Bohr's apparently different view on the detachability of the observer (page 61 in [12]):

"Der Begriff Komplementarität bedeutet in keiner Weise ein Ver-

> lassen unserer Stellung als aussenstehende Beobachter, er muss vielmehr als logischer Ausdruck für unsere Situation bezüglich objektiver Beschreibung in diesem Erfahrungsbereich angesehen werden."

In the light of the previous discussion, this may appear surprizing (cf [12]). But if Bohr here with "aussenstehende Beobachter" (detached observer) is referring to ourselves as observers of *phenomena*, there is perfect agreement with his view of complementarity in terms of phenomena (see section 2).

The very idea of a complementaristic resolution (section 2) amounts to an established necessity of abandoning observability of features of a microstructure, and to conceive of it together with the measuring apparatus, as an undecomposable whole, a phenomenon, that *is* observable as such a whole.

4 *von Foerster's Aphorisms for Objectivity*

In von Foerster's book *Observing Systems* [26] there is an introduction, by Varela, with a collection of characteristic von Foerster aphorisms. In the present context of observability and measurability, we select the following pair for contemplation:

(i) *Objectivity*: the properties of the observer shall not enter in the description of his observations;

(ii) *Post-Objectivity*: the descriptions of observations shall reveal the properties of the observer.

We first notice that the aphorisms are interestingly *free* of reference to *objects* under observation. Also, what is observed, the observations, only enter in terms of "*descriptions of observations*".

With a Heisenberg cut, let us apply the aphorisms to the case of observation by quantum mechanical measurement. The observer is then identified with a measurement process.

First, assume that the *descriptions*, which occur in the "description of (the observer's) observations", already from the outset are objective in the sense of being unambiguously interpretable in a shared language. Compare Bohr's plea for using a simple fragment of natural language for the description of experimental set-up and of measured results, a fragment of language which he assumed nonambiguous. Under the assumptions, the aphorisms transform into:

(i*) *Objectivity**: the properties of the measurement process shall not enter in the description of its measurements;

(ii*) *Post-Objectivity**: the description of measurements shall reveal the properties of the measurement process.

We see how objectivity* reasonably well coincides with the classical case of a "detached observer" in the sense of Pauli.

Again, post-objectivity* is similar to a Bohrian complementaristic resolution in terms of *phenomena*, whereby a photon *per se* has to be replaced by, for example, a photon-investigated-in-an-interference-experiment, or by a photon-investigated-in-a-which-path-experiment. By our arguments from the previous section, post-objectivity* is both compatible with a "non-detached observer" and with an objective* (meta-) observer of *phenomena*.

Next, consider a broadend context of a Cartesian cut, without special reference to a Heisenberg cut, allowing also the occurring "descriptions" to come under the domain of objectivity under investigation. We assume that these descriptions are not produced by a metadescriber but by the observer (measurement process) himself. Then post-objectivity* becomes problematic in confronting view (i) of the linguistic complementarity: in no (quantum mechanical) language can there be a theory, or description, of its own interpretation (measurement) process.

In fact, a strong post-objectivity, with "description" included in the domain of objectivity and with "reveal" in the strong sense of *making known by description*, would be impossible, by confronting view (iv) of the linguistic complementarity.

Resolutions of the involved self-reference problems, resulting in weaker forms of objectivity, are to be found in terms of hierarchies which allow unfoldments of the self-references. We meet various ways of generating such hierarchies in logic and language (cf [11, 24, 14]), physics (cf [7, 1, 16]), and cybernetics (cf [25]).

In the following section we reveal a situation in quantum theory, whereby a *physical* level of constructivity (in terms of measurement) *is brought in contact* with *linguistic* levels of constructivity in the quantum mechanical language. From a wide cybernetic perspective, such a contact strengthens the view that hierarchies in the description of nature become less arbitrary the deeper the introspective power of the language, or the lesser the degree of its detachment.

5 *Measurability and Inferribility; a Cybernetic Tie in Terms of Levels of Constructivity*

In a quantum mechanical measurement language L, there are *basic measurement sentences* which can be *physically decided*, namely by measurements.

The purpose of a quantum mechanical measurement theory, T, in the language L, is to describe basic measurements. Such that, if a basic measurement sentence is *provable* in T, then we know that it is also verifiable by measurement.

We are confronted with two modes of assertibility, by *physical* measurement, and by *linguistic syntactic* inference. In general, the two modes are kept apart by Cartesian or Heisenberg cuts, arguable in terms of problems of complete self-reference. Forms of *partial* self-reference are, however, legitimate. Which may also be expressed in terms of realizable *degrees* of self-reference in a language, *degrees* of introspection in a language, etc.

We will look into the possibility of performing, not another cut, but a tie, let be loose, between physical measurability and linguistic syntactic inferribility. Namely, in asking if they can have in common a lowest level of constructivity (realizability) in a hierarchy of such levels.

Let us first look into a *difference* between inferribility and measurability, which is in fact suggestive of degrees, or levels, of constructivity. Let the theory T be *sound* (everything provable in T is true). If A is a verified measurement statement, and T contains the inference (theorem) $A \Rightarrow B$, i.e.

$$\vdash_T (A \Rightarrow B),$$

then, although B of course must be true, it does **not** in general follow that B is also a *measurement sentence*. What are the inferences (theorems) of T which preserve measurability? Can formulas for basic measurement statements be distinguished by syntactic criteria of well-formedness? Here the quantum mechanical concept of measurability is confronted against the metamathematical concept of T-inferribility.

In von Neumann's formulation of quantum mechanics [27] the observables correspond to self-adjoint operators acting on a Hilbert state space. If A is a self-adjoint operator corresponding to some observable, then its spectral values are interpreted as the possible values which one may obtain in a measurement of this observable.

The characterization, or construction, of observables in terms of operators is obviously fundamental for the generation of basic measurement statements. Primas [21], pp 62-3, in referring to pioneer quantum mechanics, explaines

further how to construct new observables from old:

> If A is a self-adjoint operator, then there exists a unique *spectral resolution* E on the spectrum Ω of A such that
>
> $$A = \int_\Omega \omega \; E(d\omega).$$
>
> ... If A is a self-adjoint operator corresponding to some observable, then its spectral values are interpreted as the possible values which one may obtain in an ideal measurement of this observable.
>
> ... A real Borel function F of an observable A represents a new observable $F(A)$ which can be measured by the very same apparatus used for A by replacing the scale of its meter by a new one in which every number ω is replaced by $F(\omega)$. In terms of von Neumann's spectral theorem, this means that the spectral resolution of A
>
> $$A = \int_\Omega \omega \; E(d\omega),$$
>
> imples the spectral resolution of $F(A)$
>
> $$F(A) = \int_\Omega F(\omega) \; E(d\omega).$$

We notice here a first trace of a **merger** between two ideas. **On the one hand**, the idea of a *mathematical* construction of new physical (self-adjoint) operators $F(A)$ from old A, whereby new measurement values $F(\omega)$ result from old ω.

This F-construction is, at least in von Neumann's original formulation [27], without any restriction on F to be realizable in some constructivist perspective. On page 248 of [27], von Neumann writes:

> "If the operator R corresponds to the quantity $\mathcal{R}$, then the operator $F(R)$ corresponds to the quantity $F(\mathcal{R})$ [$F(\lambda)$ an arbitrary real function]."

And, **on the other hand**, we have the idea of an *instrument* construction, of how to construct a new measuring instrument from an old, where *realizability conditions* are obviously present. In order for one experimenter to effectively

communicate to another how a meter scale is to be obtained, he must resort only to constructivist proceses.

There are no ties between the two ideas in von Neumann's quantum theory with "$F(\lambda)$ an arbitrary real function". Most real functions are not even computable.

We seem to have a real problem here. Can such a tie be established? How is the quantum theory T, with its rules for well-formedness for the basic measurement sentences and its rules of inference, to be formulated such that we in T can decide which inferences from measurement statements are again measurement sentences.

First of all, we have to impose on quantum theory the condition that the F's be *computable*. Otherwise, we could think of quantum mechanics as an effective phenomenon being able to answer noncomputable problems.

But such a computability restriction on the F's is not enough. It would allow for quantum theory arbitrary complex inferences, only that they are recursive (computable) – which every rule of inference, for any formal theory, is anyway.

In order to give to quantum theory an intended meaning of *measurement theory*, if not of a full *measurability theory*, it seems necessary to equip it with *levels*, distinguishing fundamental measurement inferences from higher (less constructive) inferences. Examples of complex inferences in quantum theory do we have in theorems about the noncomputability of the domain-problem for the quantum mechanical operators [10]. The theorem that tunnelling (in the double prism experiment; see the following section) is an "exclusive wave-phenomenon", is also on a level higher than that of a basic measurement statement (cf [17]).

Quantum theory does indeed contain very complex inferences and, as we will examplify in the next section, it may even be of physical interest not to treat all its inferences on a par but to try to distinguish between them in terms of levels of constructivity with physical relevance as well as linguistic.

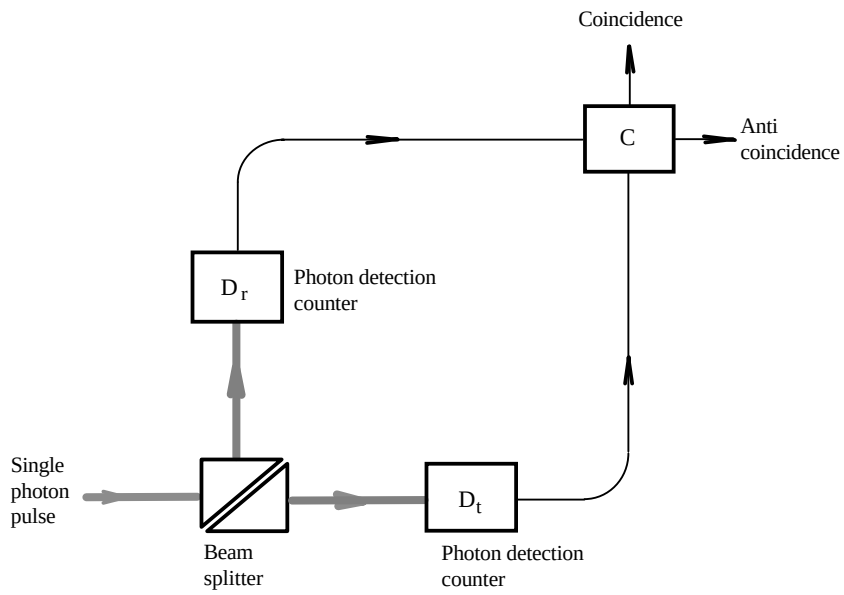
A development of levels which are both logical, like syntactic constraints on well-formedness, and also quantum physical measurement constraints, is not likely to appear in some absolute way. That would seem to imply a physical theory of our linguistic cerebral processes (beyond mere measurements). Rather, it points toward a linguistic relativization with language in its complementaristic conception. The philosophy of linguistic models for quantum theory (cf [16]) is a step in this direction.

In particular cases, the simpler idea of a quantum theory with only two levels (basic measurement statements, and inferences which are not basic mea-

surement statements) may be helpful even without some precise demarcation of the levels. The challenge from the double-prism experiment of the Bohr wave-particle complementarity, may be taken as an example.

6 *Levels of Constructivity Enforced by the Double–Prism Experiment*

Recently a "double–prism experiment" has been proposed by Ghose, Home, and Agarwal [8] as a challenge to the Bohr wave–particle complementarity. In the experiment a "beam-splitter" in the form of a double-prism is used. Since quanta are supposed to be indivisible, experiments to split them are expected to exhibit revealing properties.



A single experimental arrangement to display *both classical wave and particle-like propagation* of single photon states of light.

After Ghose, Home, and Agarwal [9]

The choice of a double-prism as beam-splitter, instead of say a semitransparent mirror, is interesting in a further sense. Namely, that it is then possible to infer a simultaneous wave and particle nature of a single photon state of light under investigation. This is in [8] argued to contradict the wave–particle complementarity.

As illustrated in the above figure, the double-prism prepares for a reflection path and a tunnelling path. A source is used which emits a single photon state of light. The prism gap is chosen such that if transmission along the tunnelling path occurs, which is indicated by a click in a photon detector counter D_t in that path, then the transmitted phenomenon must have wave-nature (not preventing a simultaneous particle nature). In the reflection path there is another photon detector counter D_r. Repeated runs indicate strict anticoincidence (no coincidence) between the two counters, supporting the hypothesis that the behaviour of the emitted entities is particle like. Obviously, the experiment supports further hypotheses about a *simultaneous* wave *and* particle nature of the emitted single photon states of light.

The inference of a wave-and-particle nature of the photons is suggested (cf [8]) as a falsification of the Bohr wave-particle complementarity.

However, as we have argued in [17], the inference of a wave-and-particle nature is on a level which is above that of strict measurability. The wave-nature of the the entity which is transmitted along the tunnnelling path is never directly measured.

Therefore, the result of the experiment does not challenge Bohr's wave-particle complementarity in its *constructivist understanding* preventing a simultaneous direct *measurement* of wave-like and particle-like properties.

Our argument in [17] is based on the injection of *linguistic* information levels for inferences in quantum measurement theory. These levels can also be referred to complexity classes of *realizing automata*. Thereby the (cybernetic) concept of automaton will occur as the (loose) tie between physical measurability and linguistic inferribility.

This is how we think of the double-prism experiment as highly interesting. It raises the quest of a *levelled* approach to quantum mechanics as a theory of measurement. Not with some arbitrary introduction of levels. But with a hierarchy where, on a lowest level, physical constructivity in terms of measurability will coincide with linguistic constructivity in terms of metamathematical realizability.

7 *Conclusions*

The shadows of language that we have seen in physics and cybernetics allow a complementaristic conception of language. We have exposed such shadows as cuts (section 3) and ties (sections 5 and 6). Cuts allow descriptions – we always describe by fragmentation – and ties provide unifying interpretations. Both within physics, and within cybernetics, there are interplays between cutting and tying.

Within quantum mechanics we find clear-cut experimental situations as characteristic objects for testing theories, and for understandings. The more advanced the experiments become (cf the possibility of preparing single photon states of light), the larger the pressure towards ties with the deeper (constructive) nature of the language in use for the descriptions.

Within cybernetics the tying activities seem to dominate. We do not often find comparably clear-cut experimental situations. Yet, here we find interest in unifying interpretations – of cuts! That is, in language.

Cutting and tying as interplays *between physics and cybernetics* is, again, an interesting domain of inquiry for a cybernetician. Still wider such interplays, including further central domains like biology, may provide suitable testing grounds for general interdisciplinary activites. For example, in testing a concept like "strangification" (Verfremdung). That concept, within so called constructive realism [28], has been suggested as method of detecting implicit presuppositions behind the interpretation of contextual systems of sentences. It may be looked at as a linguistic process (cf [18]).

There is no easy way of going from interdisciplinary thinking to actually realizing interdisciplinary thought. Compare the recent attempt "Einstein Meets Magritte" [6] as an interdisciplinary reflection on science, nature, human action and society. Yet, how to overcome such difficulties is what Heinz von Foerster, throughout his long inspiring life, has demonstrated in exceptionally clear ways. And still is, as showed by his brilliant performance in closing the *Einstein Meets Magritte* conference.

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