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AND EXPERIMENTAL PERSPECTIVES ON QUANTUM PHYSICS

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QUANTUM WORDS FOR A QUANTUM WORLD

A little-known movie by Alfred Hitchcock, *Torn Curtain* (1966) – admittedly not one of his best – tells a story of spying and science. It features a strange scene, where two physicists confront one another on some theoretical question. Their "discussion", if it may be so called, consists solely in one of them writing some equations on the blackboard, only to have the other angrily grabbing the eraser and wiping out the formulas to write new ones of his own, etc., without ever uttering a single word. This picture of theoretical physics as an aphasic knowledge entirely consisting of mathematical symbols, as common as it may be in popular representations, we know to be wrong, of course, and we have to acknowledge that, far from being mute, we are a very talkative kind; physics is made out of words. What I wish to question here, however, is the very nature of our relationship with language, particularly as concerns quantum theory. My thesis will be that we have been somewhat offhand and rather indifferent with respect to the words we use, or rather *without* respect for them, and that this attitude has reinforced, and sometimes perhaps even produced some of the persisting epistemological and pedagogical difficulties in our field – not to speak of the new cultural problems that we are facing.

I. QUANTUM PHYSICS AND ORDINARY LANGUAGE

It is obviously impossible to discuss this question without going back to Bohr and his famous argument on the use of language in quantum physics, which he stated again and again. His position, as we all know, was that there is, and can be, no specific way of expressing quantum physics. He wrote, for instance:

> (...) it is decisive to recognize that, however far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms. The argument is simply that by the word 'experiment' we refer to a situation where we can tell others what we have done and what we have learned and that, therefore, the account of the experimental arrangement and of the results of the observations must be expressed in unambiguous language with suitable application of the terminology of classical physics.[1]

Beyond the traditionally acknowledged obscurity of Bohr's writings, it has not been sufficiently remarked, to my mind, that his standpoint here lacks not only clarity but consistency as well. The deep ambiguities it contains spring up if one compares the preceding quotation with an apparently very similar one:

It lies in in the nature of physical observation (...) that all experience must ultimately be expressed in terms of classical concepts. The unambiguous interpretation of any measurement must be essentially framed in terms of the classical physical theories, and we may say that in this sense the language of Newton and Maxwell will remain the language of physicists for all time. (...) Even when the phenomena transcend the scope of classical physical theories, the account of the experimental arrangement and the recording of observations must be given in plain language, suitably supplemented by technical physical terminology. This is a clear logical demand, since the very word 'experiment' refers to a situation where we can tell others what we have done and what we have learned.[2]

It is in fact quite unclear in what sense Bohr uses the word "language". If he refers to language in general, then his position is uncontroversial and verges on triviality; as a matter of fact, human language (beyond the variety of specific languages) is one, and there can be no spoken or written communication outside of it, whether in physics or elsewhere. The impossibility of creating *ex nihilo* a novel language, with syntactic structures previously unheard of, has nothing to do with quantum physics as such, and simply derives from the necessary continuity and commonality of all human experience. The difficulties arise when going from syntactic to semantic considerations, and, more specifically, to the "terms" we use for describing the world. One might certainly argue that science should not introduce any particular term and stick to the words of everyday language, in order to avoid creating a gap between common experience and scientific practice. But the whole of science should then be rewritten anew, since right from its beginnings it has taken to create new words or coopt old ones in order to express its specific notions. Bohr of course is quite aware that it is impossible to do science without using special words. He nevertheless considers scientific terminology as an "unessential convention", which does not lead to a break with "common langage", but only in so far as classical physics is concerned:

From a logical standpoint, we can by an objective description understand a communication of experience to others by means of a language which does not admit ambiguity as regards the perception of such communications. In classical physics, this goal was secured by the circumstance that, apart from unessential conventions of terminology, the description is based on pictures and ideas embodied in common language, adapted to our orientation in daily-life events. The exploration of new fields of physical experience has, however, revealed unsuspected limitations of such approach and has demanded a radical revision of the foundations for the unambiguous application of our most elementary concepts (...).[3]

These "new fields" are of course those of quantum physics. It seems, however, very hard to justify setting up a boundary within science itself and to decree that it was all right to invent new terms up to, say, 1900, but not afterwards.

In fact, the unintuitive character of the new physics, which is invoked by Bohr to justify sticking to classical terms, is by no means a specificity of the quantum domain. Nineteenth century physics has witnessed a continuous and manifold departure from the common understanding of the world. Thermodynamics as well as electromagnetism go so far beyond our usual ideas that they could not be dealt with in "plain language"; there is no such thing as "*the* language of Newton and Maxwell", to use Bohr's words. Indeed, most of the classical terms he seems to take for granted as having a clear meaning, were introduced in physics during the nineteenth century and certainly did not belong to ordinary speech. Consider for instance "energy" – a term foreign to the language of Newton: the very concept was not clarified before the middle of the last century, and the word was certainly not used in common parlance, as it has come to be in the past decades. A stronger argument yet could be made around "entropy".

The clearest case in point is perhaps the notion of "field" which took many decades to emerge, from Faraday to Maxwell – who, apparently, was the first to use the word in his famous 1865 paper,[4] although the idea as we understand it today was not yet clear to him; he still thought of the field as a certain dynamical state of a mechanically conceived ether. The electromagnetic field would not obtain its ontological status before the 1900's and the final demise of the ether. In some sense then, the word preceded the idea and prepared its full extension; any forbidding pronouncement as to the introduction of non-(archeo)classical (i. e. mechanistic) terms would certainly have delayed and hampered the developments of electromagnetism, and beyond of the whole of physics as we understand it today. For it may be argued that the deepest revolution in modern physics did not take place in 1905 (relativity) or 1905-1913 (quanta), but precisely in 1865, with the advent of a completely new physical entity, of a non-mechanistic nature, continuous and non-localized:

Before Maxwell, people thought of physical reality – in so far as it represented events in nature – as material points (...). After Maxwell, they thought of physical reality as represented by continuous fields, not mechanically explicable (...). This change in the conception of reality is the most profound and the most fruitful that physics have experienced since Newton.[5]

So said Einstein at the centenary of Maxwell's birth, that is, in 1931 – well beyond the advent of quantum theory. Although this is not what Bohr had in mind, we may perhaps take quite literally his assertion that it is "the exploration of new *fields* of physical experience [which] has demanded a radical revision (...) of our most elementary concepts".

Yet, one may feel some uneasiness in Bohr's position when he admits that the use of plain language is to be "suitably supplemented by technical physical terminology". Does Bohr consider such "technical" terms as not properly belonging to language and fulfilling, perhaps, a purely formal purpose, similar to symbolic formulas, the only function of such terms being to label without ambiguities theoretical procedures or designate specific pieces of experimental apparatus? But, as hinted at on the above examples, even technical terms are true words and carry a heavy load of historical connotations and conceptual associations. As such, it is hard to imagine what could be a criterion to separate and discriminate this "technical physical terminology" from the englobing matrix of "plain language". Many of these technical terms are borrowed from lay vocabulary and given a restricted and specific meaning, which nevertheless cannot suffice to cut them from their deep

vernacular roots in the fields of nonscientific practice (of course, "root" – in algebra – precisely is an example, as well as "field"...). And many words initially created for and to be found in professional scientific discourse slowly leak out to find their way in common parlance, where they take on original meanings which cannot but come back within the scientific discourse to give it new colours ("energy" and "entropy", "electricity" and "magnetism" are cases in point).

It is intriguing though to realize that Bohr belonged to the first generation of physicists for whom the concept of field could be taken for granted; one may wonder how he could consider the then very recent ideas and words of field theory as belonging to an indefinite and undifferentiated "classical physics". The explanation is probably that an impending breakthrough is necessarily thought of as much more difficult that an already accomplished one – for those who do have to make the break. Confronted by the extraordinary difficult task of setting up a new theory, it is conceivable that Bohr did not want or need to apply distinctions within what was by then the established science. His strategy (contrarily to Heisenberg's, for instance) was to rely as heavily as possible on this classical physics and to try using it as far as possible – farther than its *a priori* domain of validity. It has often been remarked that Bohr, a true Moses-like figure, did not really enter the Promised Land of quantum theory. He used with an admirable dexterity the Principle of Correspondence and the notion of complementarity to supplement classical physics with the lightest possible quantal touch able to open new vistas on the quantum domain[6]. One can then understand the deep heuristic role of his insistance on classical descriptions – and admire the extent of the results he obtained from such an *a priori* entrenched position. This being said in earnest, and lest I would still be accused of lese-majesty, let me hide myself behind a more authorized statement:

> I know that it is not N. B.'s fault, he has just not found the time to study philosophy. But I deeply deplore that by his authority the brains of one or two or three generations will be upset and prevented from thinking about problems that 'He' pretends to have solved.[7]

What is not so easy to understand is that, while the followers of Bohr bravely entered the new land and started developing a genuine conceptual framework, going well beyond the limited frontier regions accessible with the help of the sole Principle of Correspondence, they did not produce as well a specific terminology, at least on the same scale and with the same determination. This is all the more perplexing since Heisenberg, for instance, entertained a view of the role of language in science quite different from Bohr's and much more dynamical[8].

It is time to reaffirm that the creation of new words is a constitutive process of science, which should accompany the emergence of its new ideas, as it has done for most of the history of science – except during the century just ending, where linguistic inventivity has been drastically reduced, at least in physics (mathematics and biology certainly fare much better in that respect). It is even a double paradox that physicists have never produced so many new ideas and so few new words, and that they have used common and concrete words all the more so since their ideas became more esoteric and abstract (see "quarks" and their "colors", "big bang" and

"chaos", etc.). One cannot help to think that this linguistic weakness is in some way linked to the domination of a single language, which moreover has been used for decades by non-native speakers – I refer here to most of the great names of physics in the thirties who experienced a certainly rather painful and perhaps inhibitory transition from German to English. In recent times, it is probably the overtaking of science communication proper by mere advertising that explains the simplistic borrowing of picturesque but misleading common words, as in expressions like "big bang", "coloured quarks" or "butterfly effect".

II. QUANTUM PHYSICS AND EXTRAORDINARY LANGUAGE

The past decades have seen a tremendous extension in our capacities for manipulating and exploiting quantum phenomena from the individual atomic scale (single electron electronics, single atoms optics, nanotechnologies) to the macroscopic (lasers, superconductors, superfluids, etc.). It is worth emphasizing that such feats not only were unforeseen by our great predecessors, but even declared unattainable in principle. In any case, our growing familiarity with quantum phenomena has led us to a new intuition and, necessarily, to new ways of expression. Accordingly, we, quantum physicists, do have created quite a few words; in effect, we do *not* obey Bohr's rule restricting our language to the ordinary classical one – even those among us who continue paying lip service to the alleged Copenhagen orthodoxy. Any paper in the field is witness to this statement.

So, we do cultivate new flowers in our terminological garden. But my contention is that we do not take good care of it; by the way, I would not object to your interpreting this opinion as reflecting the old opposition between the apparently free growth of English gardens and the meticulously controlled planning of French ones. Be that as it may, any amateur gardener knows that some up-keep is necessary, and that it consists as well in the weeding of obsolete vegetation as in the tending of young plants and in the sowing of new varieties.

a) Weeding

Quantum physics is by now old enough – almost a century – to have known the complex processses of internal recasting and reshuffling of ideas which naturally lead quite a few expressions to obsolescence. However, we too often keep using uncritically such terms although they have lost most of their meaning. This is not a process particular to quantum physics of course (think of the Maxwellian

"displacement current"*), but it is certainly more marked here. Here is a short list of terms we could well dispense with:

- "**Complementarity**". As already alluded to, this Bohrian notion is but a sort of safe-conduct allowing a denizen of the classical domain to make some incursions into the quantum realm without running into trouble. Deep inside this quantum realm, the conflicting classical views that complementarity is supposed to keep apart cease to hold altogether. It is certainly too simplistic to hope that a new reality can be fully described by the mere use, however ingenious, of previously conflicting ideas. Let us not forget, after all, that complementarity was not so convincing an idea, even to Bohr's closest co-workers, such as Heisenberg or Pauli, not to speak of Schrödinger who, privately and lately at least, did not hesitate to speak of "...that silly and entirely unphilosophical twaddle from Kopenhagen about subject and object and complementarity and what not." [5]
- "**Wave-particle duality**". Closely linked to the preceding argument, the description of quantum objects by a duality between two classical aspects is in fact of limited validity. While it is a very useful point of view for the first contacts with these strange objects, it is by far not sufficient to take into account all the subtleties of their behaviour. Australian settlers, on their first observations of a weird animal, named it "duckmole" on account of its mole-like fur and form and duck-like beak and feet; but duck-mole duality certainly is insufficient for a full appreciation of the specificities of the platypus (which, by the way, already had a name of its own before European scientists came to study it – namely, "mallingong"). In fact, the expression "wave-particle duality" offers not an *answer* to the question of the nature of physical entities, but asks a *question* – and a nontrivial one: how is it that quantum objects do appear at the classical approximation either as waves or as particles? Or, more precisely, what are the conditions of validity of these two (exclusive but non complementary!) approximate descriptions? In any case, as an epistemological solution to the general problem of the nature of reality, "wave-particle duality" falls very short of its goal; Schrödinger again:

> I believe the problem of 'the real world around us' to be much older, much deeper and more difficult to put in order than that old particle-wave duality about which there is at present so much ado, and its palliative – complementarity – which, to be honest, has not yet got beyond the rhetoric stage and, in my opinion, never will.[9]

- "**Indeterminism**". Here also, this term, far from elucidating a concrete problem, does in fact hides it under a veil of abstract generality. Quantum theory per se is quite deterministic, as the time development of states is governed by a strict evolution equation. The difficulty is that this determinism is incompatible with

*From now on, I will use the awkard looking reversed quotation marks to single out the terms I question.

the one of classical physics, as they do not refer to the same physical magnitudes! Here also, indeterminism appears when the quantum realm is considered from the outside, or, at least, from its problematic and fuzzy borderline with the classical domain.

- "**Uncertainty (principle)**". First of all, there is no "principle" here; the Heisenberg inequalities nowadays clearly appear as a consequence of the full-fledged quantum theory, and do not stand as one of its basic independent assumptions. But above all, the very idea of "uncertainties" once again is an undue importation from a domain into another; the margin of ignorance necessarily associated to any experimental measurement (uncertainty proper) was likened to the margin of indefiniteness of a quantum magnitude. The confusion partly resulted from Heisenberg having operationally introduced his inequalities through the analysis of a gedanken experiment (the famous 'microscope'), before they could be shown to derive from a more general theoretical reasoning. The situation was still muddled by a complex story of hesitation and mistranslation, Heisenberg himself using "Unsicherheit", "Ungenauigkeit" (uncertainty), but finally settling for "Unbestimmtheit", that is "indeterminacy", which is certainly a better wording, and had some success, before being, alas, eclipsed[10]. Nothing puts into a clearer light the unbecoming character of the "uncertainty" terminology than the comparison of the (classical) undulatory inequalities with the (quantum) Heisenberg inequalities. In the first case, the spectral bandwidth of the frequency spectrum of some signal, $\Delta\nu$, is linked with its characteristic time extension Δt by $\Delta\nu . \Delta t > 1$; mere multiplication by the Planck constant h leads to $\Delta E . \Delta t > h$. How comes that the "spectral widths", "extensions" or "dispersions" – we are not in want of terms![11] – of the first case become "uncertainties" in the second? The situation is in fact very ironical, for the term "uncertainty", although it is used in the most orthodox presentations of quantum mechanics, would seem to express much better the reservations of its neoclassical opponents; if one does believe that the electron in fact is somewhere, that is, has a definite position, according to some hidden variable theory, then its dispersion in position is but a provisional and superficial character, due to our ignorance – an uncertainty, indeed.
- "**Observables**". The founders of quantum physics developed a critical analysis of experiment and measurement in the quantum domain, which greatly assisted them in getting rid of some classical prejudices and building the new theory. In so doing, the emphasis put on the act of observation and its limits led them to insist on the observability – or not – of physical quantities. Accordingly, the term "observable" came to substitute for that of physical properties or magnitudes. There is absolutely no reason to stick to this quite misleading terminology, indiscriminately applied to all formally defined properties (hermitian operators in the hilbertian formalism) although very few of them can *actually* be observed, not to speak of the fact that we still lack, even in the simplest cases of effectively observable quantities, a thorough analysis of the concrete and complex process of measurement. The epistemological weakness of the term is

put into full light when one remembers how it made its first appearance in the seminal 1925 paper by Heisenberg introducing matrix mechanics, the abstract of which read: "The present paper seeks to establish a basis for theoretical quantum mechanics founded exclusively upon relationships between quantities which in principle are observables".[12] Heisenberg then went on to exclude from such quantities the very position of an electron – that is, the simplest and commonest of today's "observables".

- "**Interpretation**". It has not been sufficiently remarked how strange is the rather sudden appearance, within quantum physics, of the idea that the theory should be "interpreted". This idea certainly does not belong to the classical tradition, that "of Newton and Maxwell", where the challenge of a new doctrine was simply to understand it. The notion of interpretation echoes the logical-positivist standpoint that theoretical contents is to be equated to its mathematical framework; the formalism, taken at face value, is meaningless and subject only to logically consistency internal criteria, so that it asks for external semantic rules establishing its correspondences with empirical data. But such a point of view certainly was not Bohr's; in fact, the very term of "interpretation" did appear only in connection with the late and mainly polemical invention of "the Copenhagen interpretation", in the fifties[13]. As such, it does not even belong to the original epistemological corpus of quantum theory, and apparently was not that much missed during the tense discussions of the thirties.

In order to assess the relevance of the preceding criticisms, as well as to convince oneself that it is in fact possible to get rid of obsolete terminology, one may compare the standard written formulations of quantum physics, especially its very repetitive textbooks, where the above expressions are plentiful, with the spoken communication in the labs or conferences; real shop talk makes in fact very little use of "complementarity", "wave-particle duality", "indeterminism", "uncertainties" or "interpretation" – which means that their necessity is, to say the least, open to question.

b) Sowing

I would now like to propose a few neologisms, the purpose of their introduction being to emphasize the specific and intrinsic character of quantum physics. In inventing new words, there are good reasons to follow the traditional method of scientific terminology, that is, to rely on Greco-Latin roots. While this strategy may run counter to the temptation of public advertising and media attention, it has the merit of *not* capturing too easily the lay minds by the use of concrete and pseudo-intuitive wordings and to stress the real difficulty of new scientific concepts. I will come back to this point in my conclusions. A second argument for not shying away from scholarly and literate terms is that they offer a better prospect for mutual

understanding between different languages, as such words usually may be adapted (and adopted) with very little changes – at least in Indo-European languages.

- Let us start by considering the term "quantum mechanics" itself. I will not make a quixotic attempt at questioning the reference to the (latin) *quanta*, although its emphasis on the discrete aspects of the new physics is certainly overdone. While the discretization of energy clearly was the most conspicuous and revolutionary phenomenon for Planck and his contemporaries at the beginning of the century, de Broglie showed us twenty years later that entities previously thought as belonging to the realm of spatial discreteness (classical particles) did in fact exhibit continuous characteristics as well. Quantum theory eventually is not more discrete or continuous that classical theory; it is only much more subtle as to the interplay of continuity and discreteness, for both these notions now relate to the same (quantum) entities instead of bearing upon different ones (classical waves *or* particles). It would nevertheless be preposterous to call into question the root "quantum" in our terminology. However, the term "mechanics" which usually accompanies it, certainly is much more obnoxious as it defaces a theory which has nothing to do with the machines (*mechanē*) at the origin of classical mechanics. Furthermore, quantum theory historically is legatee (and epistemologically is donee) not only to (classical) mechanics, but to (classical) wave theory as well; stressing the first aspect yields a distorted view. So why not drop altogether the mechanical connotation, and resort to the word "**quantics**" to designate this branch of physics? Such a nominalized adjective follows the very general model of standard terms as acoustics, thermodynamics, electronics, etc. – and, for that matter, physics itself. I cannot see any objection to the use of such a simple and natural wording. Note that it would also clarify the relationship between "quantum mechanics" and "quantum field theory" (further obscured by the alleged "second quantization"); it would be enough to call the first one "galilean quantics" while the second one would go by the name of "einsteinian quantics". A side benefit of adopting the term "quantics" is that it renders obsolete the need to specify "mechanics" by the epithet "classical" – "mechanics" alone would suffice.
- I now come to the two main ideas which have emerged lately – much too late, indeed! – as the most genuine and profound characteristics of quantics. I refer to "non-locality" and "non-separability", as they have come to be called. The trouble with these terms is their negative formulation: they depict quantics by what it is not, thus failing to properly spell out the theory for itself (*an sich*). If one does believe that this world is a quantum one, and that its classical description is but an approximation (as poorly understood as it may be), it would seem fitting to positively describe its very nature. This is an opportunity to use the traditional resources of Greek and Latin. Instead of "non-locality", let me then propose the term "**pantopy**", the property of being in all (*pan*) places (*topoi*) at once, the construction of which is rather familiar (see utopy, etc.). Of course, we could have used an already existing word, namely "ubiquity", but I tend to prefer a new one, as their shades of meaning are not exactly identical (in botany,

for instance, ubiquity refers to the possibility of finding a given species in almost any place, implying the simultaneous existence of different individuals in many places). Let me mention, only for the fun of it, yet another posibility. Besides *ubique* (= anywhere), root of the term ubiquity, there is another Latin adverb, with the same general meaning, namely *undique*; the new term "**undiquity**" would then have the same sense, and contain as well a nice implicit pun on the undulatory aspects of quantics. The term "non-separability", besides its negative connotation, has the drawback of being simultaneously rather vague and too concrete, as the idea of separation in common parlance is closely linked to spatiality in ordinary space, while here, in the quantum domain, it refers to the more abstract state (Hilbert) space. It is sobering to note that our present understanding of "non-separability" in fact only expresses our realizing, at last!, the very nature of a tensor product of vector spaces as being much larger than the set of its tensor factored vectors. A neologism then should be based on the more specific concept of "entanglement" which has come to express this idea. The corresponding notion of folding, intertwining, interlacing, etc. is rendered in Greek by the word *emplexis*, from the verb *plekô*. It is thus straightforward to propose the term "**implexity**" which has the double advantage of paying regards to David Bohm's insistance on "implicate order" of quantics, and to take a natural place in an long and familiar series of words, like complexity and perplexity (both of which, after all, already properly characterizing the context of quantum theory...). One could then go on to replace "entanglement" itself with its too concrete connotations, which, furthermore are rather different in other languages (the original Schrödinger's "Verschränkung" and the French "enchevêtrement" are certainly not exact equivalents), by the related "**implexion**", and, instead of an "entangled" state, speak of an "**implexed**" one.

- As a last example of the terminological reform I am pleading for, let me consider one more important and usual quantum term. The behaviour of identical "quantum particles" (see below for a better name) is usually described by their so-called "statistics" (Fermi-Dirac or Bose-Einstein), even when one deals with but a few of them and no proper statistical argument is relevant. As a matter of fact, the statistical description of a large number of such identical objects is just a consequence of a deeper property, which manifests itself as soon as we have two identical ones and consider the transformation of their collective state under permutation. I thus advocate the term "**permutability**" (or perhaps the shorter but less familiar "**permutancy**") to indicate this property.

c) Tending

Whatever may be the impact of the deliberate creation of such new terms for quantum physics and their fate, it is worthwhile noticing and hailing the apparition already of some rather adequate words, more or less commonly used. We will be

content with a few examples, which will enable us to strengthen our previous arguments.

- I have stressed in the above critique of "wave-particle duality", that there is indeed a classical dualism, but a quantum monism. A quantum entity is *neither* a wave, *nor* a particle, so that it seems fitting to find a generic name for all these things which, according to Feynman, "all behave in a crazy way, but at least in one and the same way":[14] protons, electrons, photons (which, by the way, were christened by Lewis in 1926, more than 20 years after their invention by Einstein; this at least is an example of a successful neologism!), positrons (which, incidentally, should better be called "positons", as in French), phonons, rotons, gluons, etc. The general acceptance and fecundity of the suffix "-on" for designating the specific quantum entities make it quite natural to follow Bunge, who some decades ago proposed for them the generic neologism "**quantons**". Since then, it has made in the literature a slow but continuous progression, which, to my mind, is to be determinedly supported[15]. Note that the unquestioned use of the (totally nonclassical!) terms "fermions" and "bosons" to denote the two categories of quantum objects cries for a common term of the same kind.
- In the same vein, one must greet the advent of "**qubits**" in quantum communication theory (what about "quommunication"?), which, after all follow the old and perhaps too neglected nowadays Dirac's terminology, contrasting "c-numbers" and "q-numbers" (certainly a better term than the more common "observables").
- One of the best recent terminological innovations surely is "**decoherence**" about which must be noted that it is built in exactly the opposite way as "non-locality" and "non-separability"; namely, a phenomenon which characterizes the process leading from quantum to classical theory is rightly designated by a negation of the former.

III. WORDS MATTER

Lest I should be misunderstood, let me make clear that I do not believe in the possibility of a "scientifically pure" and "epistemologically correct" terminology, settling the matter of words once and for all. Quite on the contrary, the idea is that we should recognize the inescapable historicity and cultural embedding of our formulations, and keep working on them. Sisyphus, along with his stone, had to carry words, and to cope with language for accomplishing his never ending task.

I am personally convinced that a permanent critical re-examination of our vocabulary, leading to the elimination of obsolete terms and introduction of new ones, would help us in getting a better grasp on our ideas. I find it pityful that so many wonderfully delicate and subtle experiments keep being framed in a formulation which does not render full justice to their novelty[16]. A second purpose of the advocated reform is educational. As a matter of fact, several of the proposals made here find their origin in my teaching experience, and have already been thoroughly tested on these grounds[17].

But our responsibility in these matters goes well beyond our professional tasks, be they research or teaching. It is widely recognized today that, in the very interest of the scientific enterprise, we have to share our knowledge with the lay public. But how can we expect the sophisticated concepts we forge and the experiments we run to be correctly understood by the unitiated if we are so careless in expressing them that our own understanding is hampered? Against naive expectations (or fears), the use of a more esoteric vocabulary, provided it is suitably tailored and explained, does not run counter to the effort of promoting a better public understanding of science. Quite on the contrary, by helping to point out the specifics and novelties of scientific concepts, and their differences with respect to common notions, this linguistic demand goes into the right direction. Efficient popularization is not achieved by blurring the distinctions between scientific and ordinary knowledge, and pretending in the existence of a continuous transition, but in pointing out the gaps which separate them, and assesssing their real width and depth.

In any case, we have little right to criticize and patronize those in other fields, scientific or not, if they take in an admittedly simplistic or naive way the very words we deliver onto them; let us not forget the parabola of the beam and the moat. I am here alluding to the so-called "Sokal hoax" and the ongoing discussions it has started[18]. Beyond the details of this affair, it is no less than the very place of physics within contemporary culture which is at stakes.

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3. Niels Bohr, "Physical Science and the Study of Religions", *Studia Orientalia Ioanni Pedersen septuagenario A.D. VII id. Nov. Anno MCMLIII*, Copenhagen: Ginar Mimles-Gaard 1953, pp. 385-390.
4. James Clerk Maxwell, "A Dynamical Theory of the Electromagnetic Field", in *Phil. Trans. R.Soc.* 155, 1865, pp.459-512.
5. Quoted by John Hendry, *James Clerk Maxwell and the Theory of the Electromagnetic Field*, Adam-Hilger 1986, p.267.
6. The role of "safeguard" played by "complementarity" and its relation with the question of the limits of the ordinary language has been analyzed by Catherine Chevalley, "Complémentarité et langage dans l'interprétation de Copenhague", *Rev. Hist. Sci.* XXXVIII-3/4, 1985, pp. 251-292.
7. Erwin Schrödinger, letter to Léon Brillouin, Bozen, 6 November 1959, New-York: American Institute of Physics, Niels Bohr Library-Brillouin Archives (unpublished, courtesy of Rémi Mosseri).

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10. Jean-Marc Lévy-Leblond & Françoise Balibar, "When did the indeterminacy principle become the uncertainty principle?" (Answer to Query #62), *American Journal of Physics* 66, 1998, pp.278-279.
11. For instance, Schrödinger, in his essential 1935 paper, while speaking of the "Heisenberg Ungenauigkeitsbeziehung", calls "Toleranz- oder Variationsbreiten" the quantities involved; Erwin Schrödinger, "Die gegenwärtige Situation in der Quantenmechanik", *Die Naturwissenschaften* 1935, pp. 807-812, 823-828, 844-849.
12. Werner Heisenberg, *Zeitschrift für Physik* 33, 1925, pp.879; English translation in B.L. van der Waerden (Ed.), *Sources of Quantum Mechanics*, Amsterdam: New Holland 1967.
13. See the contribution of Catherine Chevalley in this volume, "Why do we find Bohr obscure?".
14. Richard Feynman, *The Character of Physical Law*, Cambridg: MIT Press, 1967.
15. See Jean-Marc Lévy-Leblond, "Classical Apples and Quantum Potatoes", *Eur.J. Phys.* 2, 1981, pp.44-, and "Neither Waves, nor Particles, but Quantons", *Nature* 334, 1988, p. 6177.
16. As a very recent example, see S. Dürr, T. Nonn & G. Remp, "Origin of Quantum-mechanical Complementarity probed by a 'which-way' Experiment in an Atom Interferometer", *Nature* 395, 1998, pp. 33-37. In this paper, the whole epistemological discussion of the results of a beautiful experiment is marred by a fake opposition between "complementarity" and "uncertainty", both unsuitable.
17. The textbook by Jean-Marc Lévy-Leblond & Françoise Balibar, *Quantics* (t.1, *Rudiments*), Amsterdam: North-Holland 1984, puts in practice some of these recommendations.
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