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Quantum Physics Stripped of Mathematics. Who Ordered That?

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Over the last 30 years, productions aimed at bringing scientific knowledge within the grasp of the general public have been the object of rather severe criticism. In effect, up until recently, discourses bearing on scientific popularization, issued from either of the various politico-pragmatic and socio-linguistic perspectives, have generally amounted to an acknowledgement of failure. Whether it be through hard statistics showing at once the need for vulgarization and the lack of funds invested in its activity, or through close textual or discursive examination of popular presentations, the diagnosis is constantly restated: scientific vulgarization does not live up to its democratic promises. In the last few years, efforts have been made to qualify those negative reports, mainly through the working out of a series of distinctions. Several abstract, monolithic conceptions such as the *general reader*, or the *middle man* have been shown to correspond to concrete, diversified realities. Popularization itself has been shown to involve a variety of practices whose diversity was not previously taken into account. Moreover, certain rhetorical strategies, such as reformulation, once thought to be exclusively employed by *middle men*, are now known to be used by scientists in their communications with peers in disciplines other than their own.[1] Nevertheless, while all this discriminating activity is taking place, little is actually done to move beyond the diagnosis previously cited and establish the conditions of possibility for a more promising prognosis.

In view of the above considerations, I have tried to design my own investigations into the problematic of popularization in a manner that would make it possible to

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1. For a comprehensive, though somewhat dated, perspective on the state of affairs I am briefly outlining here, see Section I of *Vulgariser la science. Le Procès de l'ignorance*, ed. by D. Jacobi and B. Schiele (Seyssel: Champ Vallon, 1988).

generate specific, although partial, solutions to the difficulties encountered in the practice of vulgarization. I have thus chosen to focus my attention upon a particular scientific domain and attempt to cover all the efforts that have been made to render accessible the body of knowledge it comprises. There were many reasons to select quantum physics, the practical and somewhat paradoxical one being its distinctive esoteric character, which ensured a corpus of manageable size. In other words, the fact that quantum physics has been the object of relatively few popular expositions allowed the exhaustive treatment I was after. This being said, I have, up until now, only been able to examine the written facet of the popularisation of quantum physics, a limitation further restricted by my concentration on books.

My intention in gathering the thirty-some book corpus upon which my analysis is based was to see whether one could unearth concrete explanations for some of the shortcomings of popularization – which others had been content to forcefully render manifest. Convinced that ideological effects are generally not produced deliberately by those responsible for their dissemination, my hope was to find tangible, and as such removable, obstacles to the realization of popular works by those who produce them. Indeed, while the abstract discourse of the critics makes it possible to portray vulgarization as a pretense, it seems absurd to pretend that those who produce it willfully participate in that pretense. The contradiction between the avowed aims and the actual realizations of popularization is sometimes so blatant that it cannot be actually occuring, or happening as a thing encountered, at the level at which it is discerned by the critics. Hence the necessity to look further into the matter.

Of course, if one digs deep enough, one is likely to find money, or the lack of it, as a major obstacle to the broad circulation of scientific knowledge. But, given the current economic situation, I do not intend to dig that far. I propose instead to descend from the analytical level (where x is not what it claims to be) and the moral level (where *x* is not what it should be) to a level just above the material one (where *x* simply cannot be) at which today's *mot d'ordre* of "intelligent spending" is likely to be most pertinent. I am talking about the conceptual level, where *x* is not what it desperately tries to be, and where money is often wasted as a consequence of our inability or failure to define sensible and feasible goals. As it were, the

contradictions found at that level usually stem from our habit of leaving things unquestioned that could be put into question. In the case of quantum physics, the impeding contradiction arises from the encounter between *a science which exhausts itself in its mathematical formalism*, and a latent definition of popular exposition which points toward *a discourse which systematically dispenses with mathematics*.

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Before entering into these matters, I want to characterize the corpus upon which my remarks will be based. To begin with, all the books to which I will refer are addressed to the general public, which a great variety of terms, such as the "layman", the "non-scientist", the "unintiated", "those who do not have a scientific mental set", "taxpayers", "housewises", etc., serve to denote. In some cases, the "specialists in other scientific disciplines", as well as physicists themselves, are explicitly included among the general readers the author seeks to reach. In fact, those priviledged readers are sometimes the only ones to whom certain popular books on physics turn out to be accessible. Also characteristic of all the books is the fact that, barring one exception, they have been written by specialists, i.e., physicists of all statuses, some Nobelists, some whose fame has not extended beyond the small circle of physicists, and some lesser known researchers and university professors. The only book written by a non-specialist, and often cited for that very reason, is Gary Zukav's *The Dancing Wu Li Masters.*

And finally, although some may include one or two chapters on the theory of relativity, all the books have quantum physics as their principal subject. And here, the variety of approaches and emphases is quite diversified. Each book contains a mosaic of institutional, socio-biographical, theoretical, experimental, philosophical and technological information, which may leave out one or two of the above elements, or definitely accentuate one or some of them. Generally speaking, however, two main categories may be distinguished: the books that recount the search for the fundamental constituents of matter, and those that explore the various interpretations of quantum theory and their philosophical implications. Apart from these, a few more *specialized* books may be mentioned, each of which respectively: focusses on the technological applications of quantum physics (Han); examines the incidence of physical knowledge on the formation of perceptual

schemes (Postle); explores the connections between Eastern mysticism and modern physics (Capra) and describes the techniques and problems in experimental high-energy physics (Hoffmann). In the midst of this diversity of aims and means, one universal constant may be said to emerge: *the pledge made by each and every author to avoid introducing complex mathematics into his discussion*. Whether this be presented as a limitation upon the content or upon the linguistic framework of a given book, the restriction – to which we find but one genuine exception[2] – is found everywhere. Thus, besides being written by specialists who purport to address themselves to the general public, the one thing which all the books have in common is their avowed forbearance of complex mathematics.

Now, if we look at an author's attempt to discuss quantum physics without the use of complex mathematics as a self-imposed choice, we may be surprised to note how often this same math crops up, once presumably buried for good. But in fact, we find only two or three instances where complex mathematics does not reappear once the decision to avoid it has been stated. In some cases it is merely evoked: an author may, for instance, remark that the eludication of x – which stands for any mathematical object he may happen to fall upon – lies "outside", or "beyond", or "far beyond" the scope of his discussion. Such purely descriptive reminders are quite common and more likely to go unnoticed than expressions such as "the reader is spared the calculations involved in x"(Born 189) or "I am certain you feel relieved we won't get into the elucidation of x"(Han 90) where the author plays with the emotions of his reader with a lesser amount of subtlety. More definitely lacking in subtlety are the instances where the author constantly reminds his reader that he "*cannot* go into the details" of x, of y, and of z, or worse, that he "unfortunately" or "regrettably" cannot go into those same enlightening details.

Another no less *popular* mode of re-introducing complex mathematics into a space from which it is barred by convention is to post it in places where it needs only be looked at. Authors who feel bound by their initial promise to the reader, have the decency, when they can't refrain from *talking shop*, to set off their mathematical splutter from the body of their exposition – where the reader may or may not venture, according to his degree of perseverance. But in certain cases, parenthesis,

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2. Richard Feynman's *QED* which will be discussed below.

frames, appendices, and other such polite devices simply cannot do. So it happens that the reader of popular books on quantum physics is at times invited to "skim through" this or that section or chapter in a given book in order "not to get bogged down." The most incredibly sophisticated instance of such courteous management of the reader's attention encountered in my corpus is found in a coffee table style book wherein the reader is actually provided with entertainment as he skips from page to page: "the following chapter may be hard going [warn the authors], so you [the reader] may just want to look at the pictures" (Hey and Walters 6).

The above illustrations may give the impression that writers of popular books on quantum physics generally find it difficult to keep their promises. The truth is that some of them, as was mentioned before, do treat the mathematical issue as an open and shut case, and simply do not return to it. Still others find ways to bring it up again in a matter that is not too unsettling to the reader. Here is how they generally proceed: "x is too complicated to describe here, but y is of more interest"(Feinberg 137); or "x would carry us too far into mathematical abstractions, but something of the spirit of the work can perhaps be conveyed"(Hoffmann 19); or again, "it is difficult to appreciate this point without more mathematics, but some understanding may be gleaned"(Rae). The "but" strategy, as it may be called, reminds the reader that mathematical languages are an option, which happens to be unavailable because of the discursive context, but which both the writer and the reader can do without – though in the last instance all the reader can derive from a non-mathematical treatment of the point under discussion is "some understanding."

Generally speaking, however, complex mathematics, whether evoked or instanciated, are used, no doubt unconsciously, to put the reader back in his place. With varying degrees of explicitness, they offer him a perspective on the kind of knowledge he is actually given access to and on the demands his curiosity makes on the specialists. When too much pertinent stuff is said to lie outside the scope of a given book, he is made to feel patronized by someone who knows much more than what he can possibly tell. When expressions of regret confirm the impression of constraint, he is forced to realize that his interlocutor would much rather be exchanging with his peers than with an *ignoramous* like himself. And finally, when mathematics is actually spelled out, with no attempt to simplify it, the reader

might be confident enough to estimate that he did not get his money's worth, but he is more likely to feel that quantum physics, even served as pablum, lies far beyond his modest grasp. He will however never find himself so thoroughly infantilized as he would be under the spell of Hey and Walters' *conversation piece* (a book previously referred to) wherein readers are basically turned into toddlers, since they cannot even understand the text which the pictures are meant to illustrate.

To sum up, the reader of popular books on quantum physics, through all the little hints and gestures by which expositors mark their frustrations with the discursive framework of vulgarization, is brought to the awareness that he fools himself in thinking that he is actually getting *the real thing* – a situation which is indeed best described in ideological terms. Popularizers not only withhold pertinent information, they actually use that information to turn the relationship of confidence they establish with their readers into a power relationship. At least, as Pierre Bourdieu would put it, *tout se passe comme si*, everything seems to indicate that some sort of conspiracy underscores the apparent efforts to vulgarize quantum physics. And a question imposes itself: Just who said that complex mathematics should not enter a popular discussion of quantum physics?

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J.C. Polkinghorne is a physicist of modest reknown who harbors a passionate love for mathematics. J.C. Polkinhorne is also a priest of the Anglican Church. He has written two books on quantum physics. In the first of those two books, called *The Particle Play*, he has attempted a playful introduction to the "mysteries" of quantum physics, in which he carefully wove the metaphor of his title into each and every chapter of his book. Intent on reaching the "general reader", or "patient taxpayer," through his writing, he tried to "dispense with mathematics altogether." But that was more than he could bear, for he knew that mathematics, that "pure invention of the human mind"(62) whose patterns are inexplicably reproduced in the physical world, "hold the key to the entire universe"(63). It thus came to be that, while trying to minister to the scientifically poor, J.C. Polkinghorne became a tragic figure on the stage of his own play – as he watched his readership crumble into an unwieldy diversity. Trying desperately to attend to

"the non-mathematical reader", to "those whose mind is troubled", to "those who cannot understand", to the "mathematically sqeamish", as well as to those who followed him when he spoke his jargon, he was finally forced to admit, from the depth of his mathematician's soul, and just before the curtain dropped, that "to vulgarize is to stumblingly express in allusive prose"(107) what can only be put properly in mathematical terms.

Five years later, in 1984, J.C. Polkinghorne published a second book, *The Quantum World*, whose readership he defined as "any person of reasonable intelligence and persistence", and wherein he claimed to have "exchewed the use of mathematics beyond the ability to read a simple equation." J.C. Polkinghorne had seen the light. Following his deeply felt intuition, he had placed mathematics, the one language that gives quantum physics its "natural and perfect expression"(23ff), at the center of the stage. And when he bravely declared: "we need to sally forth into the mathematical jungle of vector space"(24), we, the readers, saw in him the guide we had been praying for. But our valiant troops were soon decimated, when our leader began to single out among his followers the "physically knowledgeable", those with "stronger stomachs", those "with knowledge of simple trigonometry", those "attempting a professional grasp of quantum theory", etc., and left us, "the perrennially mathematically innocent", his "mathematically weaker brethren" skipping pages on the banks of the mathematical river he spewed before our eyes.

As it turns out, *The Quantum World* is no miracle of vulgarization. It is, however, an exceptionnally valuable critique of the Copenhagen interpretation of quantum theory. And this comes as no surprise, for its author, whose two loves have made a friend of solitude, is a free thinker: though he may not have known how to use it efficiently, Polkinghorne has found in complex mathematics the key to the popularization of quantum physics. In other words, as a free spirit, he was impervious to the *force of habit* by which the communication to large audiences of knowledge derived from the exact sciences has come to imply the evacuation, from so-called popular discourses, of all traces of advanced mathematics. For a long time, it has been possible for the high priests of physics to satisfy the masses without giving them access to their *sacred texts*. For each and every mathematical term that they used, they could point to physical realities, the most abstract of which could still be apprehended intuitively. With the advent of the quantum

revolution, however, a new age has dawned on the art of vulgarizing physics. Though it may become *popular*, quantum physics won't be *popularized* until the mathematics that it involves is brought within the grasp of the general reader.

To say that quantum physics *involves* mathematics is to understate greatly the intimacy of the ties that connect the study of fundamental interactions with that of quantity and order. Quantum physics is in fact so thoroughly saturated with mathematics that many a physicist would claim that the one is nothing – except perhaps gibberish – without the other. In point of fact, this is probably the most revolutionary aspect of quantum physics: that it actually constitutes and thrives as a *physical* theory for which there is no known *physical* interpretation (at least none that is amenable to proof) and for which, some surmise, there may never be. This basically amounts to saying that quantum theory is – perhaps merely – a mathematical formalism whose dynamic structure corresponds exactly to that of the physical world as we observe it. How this comes to be, we cannot say, and we may never know.

Now, these strange facts are sometimes acknowledged by writers of popular books on the subject. For instance, those who write about the many interpretations of quantum theory might inform their reader, in passing, that the object of their discourse would be considered totally irrelevant by most physicists. What keeps the *honest reader* reading when presented with such admissions is probably the perspective of learning something about physics which physicists themselves do not know. Some writers actually encourage such devious calculations – perhaps to compensate for leaving their readers mathematically benighted. But what about the converse perspective of getting laughed out of a roomful of physicists for claiming to know anything about quantum physics after having read Nick Herbert's *Quantum Reality* or Zven Ortoli and Jean-Pierre Pharabod's *Le Cantique des Quantiques*? A well versed reader could probably stand his ground, but what's the sense? Although vulgarization is perfectly designed to produce this sort of power play, it is surely not all that it is meant to induce.

The readers of books exclusively devoted to the minute description of each and every particle and their mutual interactions probably stand more chance to engage in a real dialogue with the specialists. After all, books of that nature purposefully

leave out as extraneous such isssues as Bohr's complementarity, Schrodinger's Cat, Wigner's friend and Bell's inequality, to which most physicists are indifferent anyway. Moreover, the Copenhagen interpretation, which normally – though often implicitly – underlies non-speculative treatments of quantum physics may provide a few reliable leaders. Indeed, most physicists who claim not to care at all about the philosophical implications of their work are found to adhere to the Copenhagen interpretation – perhaps by osmosis, but perhaps also because the latter is a hyper-realistic interpretative scheme which basically denies the possibility of interpretation, thus procuring positively solid grounds for a revolution. But once readers and specialists have agreed that words like "particle", "wave", "orbit" and "trajectory" are too imprecise to be used or simply not pertinent anymore, or that words like "jump", "quarks", "colour" and "flavour" do not really mean what they say, what is there left to exchange about? And worse, what language could possibly be used to communicate? The obvious answer is, of course: mathematics!

But, before yielding to this argument, we must ask, as the obvious objection may be raised, why should we let *physicists* decide what is interesting for *us* about physics?[3] *They* may think that quantum physics has superseded the need for interpretation. But *we* may feel, as some of *them* actually do, that the interpretative effort, however futile or reactionary it is made to appear, should be pursued. We may in effect feel that, barring this *nobler* pursuit, quantum physics is nothing but a meaningless exercise in structural mastery. We may further explain the current idealistic *status quo* as reflecting the limited point of view of mere practitioners which our broader, non-specialized perspective enables us to transcend. But physicists would soon recognize in our stance the superior attitude of philosophers which so infuriates them. And since, unlike philosophers, we do not possess the mathematical lore with which to buttress the defense of our posistion, we would soon be labelled and dismissed as nostalgic upholders of the epistemological values of a bygone, classical age.

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3. Physicists rather than vulgarizers are named here because, as was mentioned above, the popularization of quantum physics in book form is almost exclusively the work of physicsts.

So again, what's the sense? To be sure, our acquaintance with the mathematics behind which physicists are always free to retreat would not guaranty a rational dialogue between us – since there are no rational grounds upon which to settle the dispute. But it would certainly help preventing not only the constant short-circuiting of our exchanges, but also our implication in a conflict that is really taking place over our heads. In view of this, why not then try to gain some degree of mathematical literacy? Why not investigate the physicists' claims that mathematics, as a language, but also as a mode of thinking, will open new horizons for our imagination and perhaps even emancipate us totally from our present concerns. After all, we only run the risk of finding ourselves better equipped to defend a position which we might still consider pertinent to hold.

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The above proposition leads me to discuss a very singular book which was previously alluded to as an exception to the general habit of suppressing complex mathematics from popular books on quantum physics. *QED,* or quantum electrodynamics as *physicists* would refer to it, is the work of Richard Feynman, a Nobel Prize recipient who is also said to be "the acknowledged master of clear explanation in physics." Feynman's intention in writing this exceptionally well planned and executed book, is to provide the reader with "an insight into the everyday practice of physicists" by revealing to him what the latter really do "when they make all those complicated calculations." Starting from a precise definition of his subject and of the level at which he intends to treat it, Feynman generates, in a playful matter-of-fact tone, a scrupulously accurate discourse, wherein everything that is excluded is carefully mentioned, and everything that threatens to blur the clarity of the exposition is systematically neutralized. Feynman thereby reproduces, with the precision of a watchmaker, the finely chiseled outline and the transparent substance of that which he calls the "jewel" of physics, quantum electrodynamics.

In order to clearly inform his reader as to the kind of mathematical knowledge one is likely to derive from his book, Feynman offers two simple analogies. In the first one, a Maya priest is asked to explain how to subtract two numbers. The priest responds by inviting his interlocutor to count 584 beans and put them in a pot,

then count the 236 beans to be subtracted and put them aside, and finally, count the beans left in the pot and get the correct answer. The alternative response would have been to teach his interlocutor the rules and workings of the "system of bars and dots" he normally uses for that operation. But this would have taken years. Moreover, the roundabout way of doing things, although quite tedious, allows one to see very clearly what is actually accomplished, in a much more efficient way, by the other procedure (11-12). In the second analogy, Feynman plays down the difficulty of calculating the probable position at which a given electron will emit a photon by drawing a distinction between the rules involved in the calculation, and the calculation itself. "It's like playing checkers" he says, the rules are simple, but they must be applied over and over (95).

In those two analogies, complex mathematics is presented as devices or series of tricks used by professionals to perform efficiently large numbers of simple operations. Obviously, only some of the mathematical tools used by quantum physicists can be so characterized. On this account, the limitations of Feynman's approach basically reflect the narrow scope of his subject. Indeed, as an object of vulgarization, QED, especially considered as a practice, and precisely because of the availability of the visual aids which Feynman's diagrams constitute, does not pose as much difficulty as other branches of quantum physics or quantum theory itself do. The insufficiency of Feynman's approach rather lies in the fact that while it does provide the reader with a notion of what QED physicists do on a daily basis, it accomplishes very little in the way of *lifting the veil on the priest's secrets.* To use Feynman's imagery, the entire discussion is carefully kept at the "beans in the pot" level of the analogy. No effort is made to work the analogy back from its second, simplistic, term to its more complex point of departure. In fact, what corresponds to the Maya priest's "system of dots and lines" is not even named, let alone described. Feynman's simplistic treatment is so thorough that one could actually have read his book entirely, and still not be aware of knowing anything about "vectors" or "Feynman diagrams." While the omission of the second of these two technical terms may be attributed to the author's (false?) humility, the systematic use of "little arrows" for the second is almost an insult to the reader's intelligence.

QED is thus clearly not, in my opinion, a model to be emulated. It is however an indication as to the kind of popular material a different attitude towards complex mathematics on the part of vulgarizers could possibly yield. To be sure, the mathematical barrier which prevents the ordinary reader from gaining total access to quantum physical knowledge cannot be entirely removed. But further efforts must be invested in its dissolution before it may simply be branded an obstacle "that isn't going to go away" (Postle 93). Moreover, there is little doubt, given the notorious difficulty of the subject, that those efforts should be of a collective kind. Yet, an examination of popular works on quantum physics as a possible intertextual enterprise fails to yield the interactive picture one would expect. What emerges instead is a rather loosely connected mosaic of individual undertakings. Whether they be acknowledged or not, mutual borrowings of expositional strategies, beyond the most elementary organisational structures, are practically non existent. Even bibliographical references generally fail to reveal any intent on the part of writers to collaborate with, or build upon the work of predecessors who nonetheless, and somewhat unavailingly, keep growing in numbers. In effect, the popularization of quantum physics turns out to be the work of individuals, almost exclusively *scientists*, who pretend to carry out their tasks without recourse to any imagination beside their own.

To return to the more specific issue of complex mathematics, the following may be said. Despite all the evidence I have presented above, a few instances can be cited where an author attempts to grapple with difficult mathematics for the benefit of his reader.[4] But those very rare occurances where a vow to forbear the mathematical issue is productively breached merely suffice to demonstrate that the task at hand is not totally unfeasible. In other words, the reader of popular books on quantum physics may not need be left totally in the dark as to what he is missing. At the very least, the space he is prohibited to enter could be charted for him and the tools of exploration minimally sketched. Eventually, as popularizers develop the skills of a practice which, at this point, they do not even envisage, they might find themselves quite capable to keep their promises and deliver the goods they advertize. If this means *genuine initiation* for the reader, it may also involve

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4. To give but one example, Heinz Pagels attempts a relatively elaborate elucidation of gauge symmetry in his *Cosmic Code* (263f).

some form of gain for scientists. Indeed, as the latter find ways to picture not *quantum reality*, but the math employed to manipulate it, their imaginative powers might awaken from the iconoclastic slumber quantum physics has thrust them into. And thus the way might be paved for the next revolution in physics. But this can only begin to unfold with the realization that a certain conception of the popularization of physics, carried over from the ante-quantum era, must be reviewed – unless vulgarizers are willing to continue playing the *sacred texts* game to which that outdated conception perfectly lends itself.

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