Quasi-particles leave the lab

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1 Introduction

The "Open Session" of the *ETSF Young Researchers' Meeting in Hamburg* taking place in June 2018 in Hamburg gave me the chance to talk *meta* to physicists. Thus I turned towards a topic that has long occupied my mind: the issue of reductionism in science; or rather how a position opposed to reductionism can be argued and what follows from it for research. Moving away from fundamental laws of nature, a *third space* opens between the realms of Nature and Culture, a space already filled by the "many natures" of scientific concepts. In this movement I mainly follow ideas of Latour (1991) and Viveiros de Castro (2012), while some analysis is carried out in the spirit of Wittgenstein's philosophy of language. In parts such views have already been expressed in the article (in German) "Die Verletzlichkeit der Realität" (Penz, 2018).

2 More Is Different

Philip W. Anderson in his article "More Is Different" (Anderson, 1972) argues for the emergence of interesting effects that cannot be simply described in terms of underlying entities on different levels of complexity. Yet he starts out with the following words:

> The reductionist hypothesis may still be a topic of controversy among philosophers, but among the great majority of active scientists I think it is accepted without question. The workings of our minds and bodies, and of all the animate or inanimate matter of which we have any detailed knowledge, are assumed to be controlled by the same set of fundamental laws, which except under certain extreme conditions we feel we know pretty well.

It is already interesting to note here that he restricts himself to things "of which we have any detailed knowledge", which means the respective admissible methods of knowledge production, undoubtedly those of the natural sciences, considerably limit the domain of applicability of reductionism. Still he clearly argues in favour of a generally reductionist viewpoint within the natural sciences, but not in its the simplistic form that he describes in the second paragraph: that fundamental research is only concerned with laws at the lowest order of complexity, deep within matter and far out in space, while everything in-between is fully explained by those laws. That would mean that the domain that actually matters most to us humans, between micro and macro, offers no opportunity for fundamental studies, while on the other hand we observe that the more "fundamental" a law gets, the less relevant it seems for most other areas of science.

Anderson wants to oppose such a simplistic belief and starts with an example from molecular physics: the arguably simple molecule NH_3 (ammonia). He states: "The chemists will tell you that ammonia 'is' a triangular pyramid." This structure explains the electric dipole moment, that can easily be measured, and other physical and chemical properties. But we have here an obvious breach in the laws of symmetry that govern our fundamental equations: How can there arise a vector quantity, a preferred direction, in an isotropic environment? Of course quantum physics can resolve this puzzle: the little pyramid also exists in a reflected state and the "real", stationary state of ammonia is a superposition of both, with zero dipole moment. Between the two possibilities of a symmetric and an anti-symmetric superposition an energy gap opens in the microwave spectrum that allows the construction of an ammonia MASER, as described in Feynman et al. (2005, III.9).

But the puzzle remains, because from where does the structure of the molecule come in the first place? The fundamental basis for chemistry is usually assumed to be the molecular (Coulomb) Hamiltonian that includes kinetic terms for both electrons and nuclei, as well as the respective Coulomb interactions between all particles. In the famous words of Dirac (1929):

> The general theory of quantum mechanics is now almost complete, the imperfections that still remain being in connection with the exact fitting in of the theory with relativity ideas. [...] The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known, and the difficulty is only that the exact application of these laws leads to equations much too complicated to be soluble. It therefore becomes desirable that approximate practical methods of applying quantum mechanics should be developed, which can lead to an explanation of the main features of complex atomic systems without too much computation.

The eigenstates of a molecular Hamiltonian should give the stationary wave-functions for whole molecules and fully explain their chemical structure. And of course the eigenspaces respect the full symmetry of space and are invariant under the permutation of identical building blocks. How can the specific structure of a molecule with its considerably smaller symmetry group arise from such an eigenspace of large degeneracy? This is only possible when the symmetry is broken: by external influences (for example of molecules that miraculously already have structure) or by putting in some structure by hand. (Sutcliffe and Woolley, 2012) The second approach amounts to the usual Born–Oppenheimer approximation for solving the electronic Schrödinger equation, where the nuclei positions are fixed (clamped nuclei) and only then are released again to move to even lower energies on the potential energy surfaces.

Of course one could also try to resolve the riddle "reductionistic": by looking for deeper, more fundamental laws in subatomic physics that explain the observed structures. This means going further down into uncharted domains, away from direct experiment and currently available techniques. And this path obviously increases computational difficulties that will inevitably run against an exponential wall that is already sky-high when considering the Schrödinger equation of a few electrons.

Anderson, although subscribing to the reductionist hypothesis in the beginning of his article, writes about real "fundamental" research at each stage on every single page (of total four) of his article, thus somehow undermining his own commitment to reductionism. On each level of complexity, sort of by adding more particles, entirely new effects appear that obey their respective laws. In the opening paragraphs Anderson made a difference between "fundamental laws" and research of just fundamental character, but it is not quite clear why such a difference should exist. Why not just accept that laws from chemistry or other levels of complexity can have an equally fundamental status and yield explanations that are just as valid. Such laws will have the flavour of phenomenology from a reductionist standpoint, but this is exactly why they connect much more directly to our experiences. The laws on deeper levels still survive as models, abstractions, mnemonic or pedagogic techniques, used to structure phenomenological laws and to find new ones. (Cartwright, 1983)

Yet we tend to think about our phenomenological laws – those that we actually compare to the empirically available data – as derived directly from some "in principle exact theory" (DFT, GW) by means of approximations. To achieve better results we then correct these approximations by the next order of expansion, by some *ad hoc* extra term, or by fitting a set of parameters. To this the next stage of corrections is applied, moving us away even further from the original "fundamental" law of nature that we think we have once "discovered", while getting closer to the experiment. At each level some underlying information is lost, but also new components get added. So it is strange to say that the original theory that does not even touch empiricism is “in principle exact”. This basic theory (like the full Schrödinger equation) is more a cognitive tool and serves as the starting point for all following adaptions. But instead of always giving those results only approximative status and fitting them closer and closer to data, we could construct different laws for new entities with the old ones still serving as an inspiration and guidance. In this no strict and binding method has to be followed, rather one can work under the dictum of an “anything goes” (Feyerabend, 1993). We can dare and come up with *new* fundamentality in the actual staging of things, following de Sousa Santos (1992) in his verdict over science:

> Science does not discover; rather it creates.

If we dare, the pyramid of sciences as the hegemonic order of knowledge breaks down. It reveals itself more like a net than a hierarchical structure; chemistry is *not* just applied many-body quantum mechanics, biology is *not* specialised organic chemistry etc.; but of course they still *do* overlap and influence each other.

At this point it is interesting to remind oneself of the ammonia superposition, where a molecule structure that is determined by more chemical laws is inserted in a purely quantum mechanical Hilbert space setting. This means the application of the theories is not limited to their assumed hierarchy, we can put (quantum) physics on top of chemistry that stands in parts again on top of physics. And we can even do the same with cats!

3 Many natures and language games

The origin of so-called quasi-particles is the mathematical manipulation of Hilbert space operators that stand for common particles into something that shares the same structure, but shows different interactions. Transformation to the new quasi-particle coordinates considerably simplifies the Hamiltonian of the system. Judging just from the general form of description nothing really distinguishes the particle from the quasi-particle, they are included in two different formulations of the same situation. We could have also started from the simplified Hamiltonian and transform it into a more complicated but equivalent particle Hamiltonian with extra interaction terms. So is the ascription of a real particle status just an ontological commitment and nothing fundamental?

To trace the meaning of an entity in science we turn to the Wittgenstein’s philosophy of language (Schönherr-Mann, 2017), because that is wherein science resides: in language.

Take "particle" as a word and apply Wittgenstein's "Meaning as Use" as explained in Stanford Encyclopedia of Philosophy: Ludwig Wittgenstein, 3.3:

> "For a *large* class of cases of the employment of the word 'meaning'—though not for all—this word can be explained in this way: the meaning of a word is its use in the language. This basic statement is what underlies the change of perspective most typical of the later phase of Wittgenstein's thought: a change from a conception of meaning as representation to a view which looks to use as the crux of the investigation. Traditional theories of meaning in the history of philosophy were intent on pointing to something exterior to the proposition which endows it with sense. This 'something' could generally be located either in an objective space, or inside the mind as mental representation. [...] when investigating meaning, the philosopher must "look and see" the variety of uses to which the word is put.

We can replace "word" $\leftrightarrow$ "particle" (or any other concept) and "language" $\leftrightarrow$ "science" and get: "The meaning of a particle is its use in the science." Or: "The scientist much look and see the variety of uses to which the concept is put." To be more strict and oriented towards laws: "The meaning of an entity lies in the rules of its use." This statement is especially true for quasi-particles, which every scientist familiar with them would probably explain in exactly that way. In Stanford Encyclopedia of Philosophy: Ludwig Wittgenstein, 3.4 the still prevalent urge towards unified and universal theories is discussed:

> It is here that Wittgenstein's rejection of general explanations, and definitions based on sufficient and necessary conditions, is best pronounced. Instead of these symptoms of the philosopher's "craving for generality", he points to 'family resemblance' as the more suitable analogy for the means of connecting particular uses of the same word. There is no reason to look, as we have done traditionally–and dogmatically–for one, essential core in which the meaning of a word is located and which is, therefore, common to all uses of that word. We should, instead, travel with the word's uses through "a complicated network of similarities overlapping and criss-crossing". Family resemblance also serves to exhibit the lack of boundaries and the distance from exactness that characterize different uses of the same concept. Such boundaries and exactness are the definitive traits of form–be it Platonic form, Aristotelian form, or the general form of a proposition adumbrated in the Tractatus. It is from such forms that applications of concepts can be deduced, but this is precisely what Wittgenstein now eschews in favor of appeal to similarity of

a kind with family resemblance.

Let's follow this when asking the question: "What *is* particle X?" The answer cannot be a general statement about objective reality any more, but will tell stories from the particle's appearance within the sciences and at other places. A particle can still be *fundamental* if it is used in a *fundamental* way, e.g. to explain many emergent phenomena, but that does not make it a fundamental particle *per se*, only within the context of such uses. Radically put: a particle is *nothing* outside its physical theory, like a word has no meaning outside of a sentence. A theory is true (useful) within its respective scope. If the uses and demands change, so will the theory and the truth assignments. Such a stance towards the "reality" of objects must not be taken to be against all forms of realism, but surely rules out the privileged choice of a certain set of entities from our theory as being constituents of reality (entity realism of *one* nature). This is expressed by Gelfert, cited after Falkenburg (2015):

> If one were to grant quasi-particles the same degree of reality as electrons, one would violate the very intuitions that lie at the heart of entity realism, namely, that there is a set of basic substantive entities that have priority over composite or derivative phenomena.

Indeed we can go much further and ask for the different uses of the concept "electron" and finally will only be left with family resemblance instead of a monistic thing. What an electron *is*, is determined by its use in theories as well as in technology (explanation and use), thus there is not *one nature* of the electron. The electrons of classical and relativistic mechanics, non-relativistic quantum mechanics and Dirac theory, many-body and solid state physics, semi-conductors and superconductivity, QED and particle physics are quite different entities. The word "electron" gets its meaning only within a sentence, embedded in a context, the one of a mathematical theory or laboratory experiment, technological device or everyday phenomena, or in a certain combination of such events. The original electron was never revealed to us by nature, rather we keenly observed phenomena or ingeniously created artificial settings to which an explanation (sentence) containing "electrons" can be applied. And a great deal of effects are actually only present in sealed off environments, meticulously controlled situations, i.e., very specialized contexts.

The multi-nature of particles means of course that they can hardly be seen as something fundamental, a *real* element of *one nature*. Nature as a whole is non-divisible and does not somehow extract entities by itself.[1] This is only done within language which explains

[1] Or phrased differently in the words of Illich (1973): "The world does not contain any information. It is as it is."

the origin of “many natures”. The natures of a particle share some attributes (family resemblance) but not as much as to be able to call them the same “thing”. Actually a “thing” is always the topic of debate, something to be decided about, linked to the old germanic word of assembly: the *Thing*. (Latour, 2011) It is *what is the case*, but a “case” like in a legal procedure, something that has to be settled within a group of stakeholders, for example by the scientific practices of physics. Such debates within the specialized sciences can be seen as complex language games in the sense of Wittgenstein, the use of words within a certain environment and with a respective set of rules that are never eternally fixed or universal.

This is not to say that a particle is *only* “text” or “discourse”, but *what it is* is also deeply rooted in text and discourse, just as well as in scientific and technological practise, in collective and social movements. The objects of physics are inseparably connected to their theoretical prediction, the experimental efforts that led to their discovery, the descriptions given about them in papers and text-books, their emergence in new technology, and all current stagings where they appear as actors. This gives them the status of “quasi-objects” (Latour, 1991), hybrids, queer lifeforms (Barad, 2012) that are located between the poles of Nature and Culture, Object and Subject, Universal and Constructed. Their appropriate description cannot be nailed down to a few elementary properties and fundamental equations that describe their “nature”. Rather, if we want to take them as a primitive entities, we have to map a huge trajectory that follows them through human just as well as natural history. Their birth was as much the Big Bang as their first experimental verification. Their continued appearance changes in every play they take part in, through paradigm shifts and technological advances.

4 Consequences

What consequences should one draw from such a perspective?

What we call “nature” in our sciences is nothing that comes with a pre-existing order just waiting to be discovered by us, while the “cultural” domain is purely constructed by our will. This artificial borderline will fall and reveal the double face of things as quasi-objects. The old “matters of fact” where deprived of all context. But taking the quasi-objects serious means to also admit the existence of a tightly knit web of relations between particles, theory, machines, code, text, scientists, and society. This web embeds physics as a powerful intellectual instrument between multiple fields: other sciences, technology, economy, politics, etc.; able to create new interesting things (*Things*). A science that manages to conduct research without cutting the web will be dehumanized to a much lesser degree and does not cast itself into a realm of ethical agnosticism ("I am just doing research."). Questions of responsibility, ethics, and about purpose are just as important as mathematical proofs and code debugging. And finally the grand unification can be something to be aspired in culture instead of nature. Unification means capturing all intellectual streams, erecting theoretical aqueducts (de Sousa Santos, 1992), and steer them into one ocean of global discourse.

What could that mean more concretely? Some ideas:

- The future paradigm of natural sciences will unsurprisingly be dominated by ubiquitous computing. Massive data crunching algorithms and machine learning will master the task of getting the best out of approximations to established laws and fitting them to experiments. We will thus all inevitably transform to pure programmers. Or we dare to also practise completely new physics that uses different basic entities, novel models, and fresh mathematics instead of just proclaiming that truly all natural laws are fully known and research is now only about applications and better computational techniques. Such science as an art of creation can always move on, as long as we have a will to create.

- If we admit the social component of our scientific work, this part deserves the same level of scrutiny we are used to apply to the "objective" part. Just like we write down our derivations and save our measurements, all (wrong) ideas have to be noted, the story of the research process must be told, the various influences registered, the numerous possible intellectual branchings recorded. We should not even be shy to express what we liked and what we disliked, what drove us crazy and what kept us sleepless. The whole intellectual and even emotional history is contributing in forming the context, the net, with gives the scientific result its meaning (or proves that it is meaningless). Without it, the facts are like words without a sentence.

- It sounds like a triviality to state that complex problems demand complex strategies to solve them. But then breaking down highly entangled phenomena like climate change to deal with them in terms of primitive entities and fundamental laws is not the way to go. Rather they deserve their own science that upholds strong links to established fields and does not trace out the humanitarian or social component. If we stop believing that nature is "one" – eternal, fixed, invincible – it can instead achieve dignity and wonder for us.

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