Do aliens know about quantum fields?

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Abstract

We review a few basic ideas about quantum field theory in order to try and understand whether they are actually needed for any possible description of the foundations of physics, also touching upon the broader issue of the connection between physics and mathematics.

Introduction

Quantum field theory was introduced and developed by brilliant geniuses. They liked esoteric ideas, not intended for ordinary people, and wouldn't care to make the mathematics precise (that would spoil the fun).

The theory is presently seen as the basis for our understanding of the physics of elementary particles and interactions among them, with the exception of gravity. It has generated a huge literature, partly dedicated to beautiful and difficult mathematical developments and partly to try and formulate new extended theories which may include quantum gravity. It must be said, however, that up to now no conclusive experimental evidence has been obtained for any of these extensions, and that such uncertainty has fostered an immense proliferation of theories, formalisms, hypotheses.

But we may ask whether quantum field theory is really indispensable in order to understand the foundations of actual physics. Is it conceivable that it is, instead, a byproduct of the way history has unfolded?

Particles and fields

In quantum mechanics the state of a system encodes the probabilities of all possible outcomes of any measures made on it. It may be represented by a *wave function*, namely a field depending on time and spatial position. On the other hand, the measure outcomes are essentially discrete. So we face the field/particle duality issue, which remains essentially unsolved up to now.[1]

A more thorough approach must take into account the fact that particles are created and destroyed, and that even their interactions can be eventually viewed as particle exchanges. Thus a system's generic state, at any given time, has to account for the possible presence of an unlimited number of particles of many different types. One uses a discrete set of basic states, in which each particle has a definite momentum. From the point of view of standard quantum mechanics these are *generalized states*, which do not belong to a Hilbert space but to a larger 'rigged' Hilbert space.

The problem which can be most clearly formulated in this context is then how to calculate transition probabilities between given 'initial' and 'final' states, when quantum interactions occur in a limited region of spacetime. The essential idea is that the initial state evolves, in a deterministic manner, to a certain final state, which is compared to a different final state in order to find the transition probability. But which is the law of this evolution? Here comes the tricky part: the dynamics of the state is driven by a quantum field, valued into an operator algebra $\mathcal{O}$ which is generated by particle emission and absorption operators.

What is a quantum field?

The quantum field is supposed to obey a field equation similar to the equation obeyed by a classical field; actually, the usual 'field quantization' procedure starts from a mathematically classical field theory. Allowing a technicality, we may express this as follows. If the classical field is a section $\phi : M \to E$ of a fiber bundle over the spacetime manifold M, then the corresponding quantum field is a section $\hat{\phi} : M \to \mathcal{O} \otimes E$ of a new 'quantum bundle', obtained by tensorializing the fibers of E by the algebra $\mathcal{O}$ (which is infinite dimensional).

But several serious issues arise. One obvious question is how to find

[1] I exposed my ideas on this topic in my contribution to the 2011 FQXi contest. See also on arXiv.org as 1404.5529 [gr-qc]

a quantum field which is a solution of the field equations. The somewhat surprising answer is that not only we can't, but actually such solution may not exist at all.[2] Even more surprisingly, that doesn't matter (in a sense). One constructs 'formal solutions' expressed as infinite sums of series, in which each term is on turn a possibly non converging generalized integral in many variables.

In order to make actual calculations of transition probabilities one has to truncate the series up to a certain finite order, corresponding to the number of elementary interactions among particles which one bounds himself to consider. Complex 'renormalization' techniques have been developed for 'taming the infinites'. The calculations are performed in 'momentum representation', obtained by Fourier transforms of the fields.

Another issue is that of 'gauge freedom': the classical fields corresponding to particles such as the photon, which mediate the interactions, are *connections*, which are not sections of vector bundles. Hence we cannot construct the fiber 'tensorialization' by the operator algebra $\mathcal{O}$ unless we choose an essentially arbitrary reference field. But now we have not quite the same theory, and further adjustments have to be made. By the way, gauge freedom is also exploited for varying renormalization techniques.

Among other complications we may recall the emergence of 'anomalies' and 'ghost fields'.

So it's fair to say that quantum field theory, its successes notwithstanding, has still a quite uncertain physical and mathematical status, as admitted even by those physicists (actually the majority) who regard it as fundamental. But while they build on it they tend to consider rigorous mathematical clarification as something which will be accomplished sometimes in the future.

Is a quantum field something physical?

In today's physics, asking whether a certain mathematical concept corresponds to a 'real' object can be a very tricky question. 'There is no quantum reality', Niels Bohr said. Nevertheless we do wonder. Some authors give indeed the impression that they view a quantum field as something physical, but that could be just abuse of language. Considering my knowledge of the topic,[3] though limited, I'd have serious difficulties in accepting that point of

[2] See for example N.N. Bogolubov, A.A. Logunov and I.T. Todorov, *Introduction to Axiomatic Quantum Field Theory*, Benjamin (1975), Ch.21.3.

[3] My present research work deals mainly with trying and clarifying basic notion in quantum field theory in differential geometric terms. See for example arXiv:1405.1351

view. I am fairly convinced that the notion of a quantum field is essentially fictitious, and is used just because we can build a kind of working theory on it.

But then we are allowed to ask: could we think and do differently? Or is rather quantum field theory the most natural language in which we are able to express the inner workings of nature? I'm adding a few considerations which make me think that the latter is not the case.

We should keep in mind that quantum field theory, essentially, is known to work in flat spacetime, and that the formalism needs a time function (associated with the choice of an observer). While a kind of independence of the observer can be recovered for some of the main results, a formulation in curved spacetime (that is in the presence of a fixed background gravitational field) has tricky aspects. A fully covariant and observer-independent theory can be actually formulated, but then the relation to quantum states and transition probabilities becomes ill-defined. Hence, in a curved background situation, it seems natural to regard the formalism as a sort of complicate clock carried by the observer, used by her for making predictions about possible outcomes of measures, rather then a description of the actual underlying physics.

I realize that this is a somewhat vague statement, but let me broaden the present discussion by including a quite different idea about what physics may be at the fundamental level.[4] We are accustomed to treat all areas physics, either classical or quantum, as dynamical theories in which systems evolve in time according to certain laws. The very habit to look at things under that category could be the source of a lack of understanding, in particular in relation to the difficulties of interpretation which quantum mechanics has confronted us with since its introduction.

According to a certain, somewhat alternative view, a quantum particle, say a photon, is just a correlation between two spacetime events, not an object which is emitted and then travels until it is absorbed. Spacetime as a whole is a network of such correlations, and we are part of it: we cannot look at it from outside. Since our knowledge and perception are limited, we argue in term of quantum probabilities: knowing about the emission event we try and calculate the probability that the absorption event takes place in a certain position at a given time.

By the way, if we assume that the universe is fundamentally discrete then

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[math-ph] and the bibliography there.

[4]See for example Ken Wharton, *The Universe is not a Computer*, arXiv:1211.7081 [quant-ph]. These ideas are not incompatible with the view I expressed in the essay *Nature's software* (see footnote 1), the title notwithstanding.

it seems reasonable to suppose that the basics rules of its inner workings are much simpler than the sophisticated and intricate mathematics which are needed at a higher computational level, in particular when we try and use quantum field theory. In my opinion this observation is meaningful and suggestive in relation to the broader issue of the *connection between physics and mathematics*, but I'm not going to elaborate on that, now.

Conclusion

Summarizing, I feel that there are compelling reasons not to disregard a certain non-standard view about the foundations of physics. If we accept it, we must conclude that the history of physics could have been different. Perhaps transition probabilities, and other physically meaningful quantities, could be calculated starting from quite different principles and using partly different mathematics.

A well known rule of thumb of journalism says that if a title ends with a question mark then the answer is 'no'. The title of this article has been chosen with that rule in mind. If we ever met scientifically advanced extraterrestrials, would we find that they developed the notion of a quantum field and a theory of it similars to ours? May guess is that they wouldn't, because their scientific history would have likely followed a different path.

Is anybody willing to bet?