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Virtual Processes and Virtual Particles: Real or Fictitious?

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Abstract

The notions of a virtual process and a virtual quantum, central in current field theories, are usually justified by means of the so-called fourth indeterminacy relation between energy and time. But since the latter formula is meaningless in quantum theory, virtual processes and virtual quanta turn out to be fictions. A number of consequences follow.

In quantum theory a process is called *virtual* if (i) it does not conserve energy but (ii) it lasts for too short a time to be observable. Correspondingly, a field quantum (photon, pion, etc.) is said to be *virtual* if it takes part in a virtual process as an intermediary. Quantum electrodynamics and mesodynamics are choked with virtual processes and virtual quanta. Thus nucleons are said to be surrounded by clouds of virtual pions, which can be shaken off in a collision. And interactions are often regarded as exchange forces and the thing that is supposedly being exchanged is called a virtual quantum. A typical example is the reversible, but of course unobservable, process that would be responsible for the strong interactions, namely $p \rightarrow n + \pi^+$.

These concepts originated in the attempt to assign a physical meaning to every term in a perturbation expansion or, equivalently, to give a literal interpretation of every Feynman diagram. A possible additional motivation was the desire to understand field theory in terms of particles. Whatever the source of the concepts of virtual processes and virtual quanta, they are usually taken seriously rather than as metaphors or as mnemonic devices. So much so that their introduction is frequently justified. The usual justification for hypothesizing such unobservable, but allegedly real, objects involves the so-called fourth indeterminacy inequality, i.e.

$$\Delta E . \Delta t \geqslant \hbar/2$$

On setting ΔE equal to the energy of the virtual or transfer quantum, and interpreting Δt as the duration of the process, one gets an extremely small value for the latter even for atomic processes. For a virtual pion emitted by a proton and then reabsorbed by the resulting neutron, $\Delta E = 140$ MeV, whence $\Delta t \geqslant 10^{-24}$ s. And this is, clearly, too short a period for the process to be observable, hence for the hypothesis to be refutable.

Unfortunately, the argument employed to justify the very existence of virtual processes and quanta rests on three faulty premises. The first is the philosophical assumption that a law of nature, such as energy conservation, can be violated as long as no one is observing. The second is that the rest energy of a virtual quantum and the duration of a virtual process can be regarded as mean standard deviations—which are the mathematically well defined and physically meaningful concepts occurring in the genuine

Heisenberg inequalities, namely those involving the linear momentum and the position coordinate operators. The third premise is the fourth indeterminacy inequality, which is neither an axiom nor a theorem of quantum mechanics and is, moreover, meaningless in it, since time is not a dynamical variable but a scatter-free parameter, and $p^0 = i\hbar\partial/\partial x^0$, $x^0 = ct$, is not the energy operator (Bunge, 1970).

Surely from a logical point of view there is nothing wrong with the reasoning used to justify a virtual process (or quantum) hypothesis. But it is materially unsound because it involves false or meaningless premises. And it is methodologically wrong, for it consists in hanging one fiction from another in the style of Ptolemaic astronomy. Moreover, it is impossible to correct the argument while keeping the basic assumptions that entail energy conservation. The only way to restore consistency would be to give up those assumptions, thus squarely abandoning the energy conservation theorems and the quantum numbers associated with them. But then no theoretical framework would remain to house the virtual processes and quanta.

We conclude that virtual processes and virtual quanta, as defined at the beginning of this note, are fictions and as such have no rightful place in a physical theory. In general, if a term in a perturbation expansion, or a Feynman diagram, violates a well-corroborated physical principle (like conservation or 'causality'), then we should either give it up or abstain from assigning it a physical meaning: we should regard it instead, at best, as a computational intermediary (Bunge, 1955, 1959).

Our analysis has the following consequences. First, quantum theories should be interpreted in such a way that they do not involve virtual processes and virtual quanta. In particular, exchange forces must be reinterpreted in this sense. Second, the hypothesis that every nucleon is surrounded by a cloud of virtual mesons that escape detection should be replaced by some realistic hypothesis concerning the nucleon structure and/or the meson field (which should in turn not be reduced to a system of particles). Third, the idea that mass values are indicative of interaction strengths (presumably a heir to Mach's ill-fated 'principle') must go likewise. Fourth, and consequently, a whole set of problems vanishes automatically—e.g. the question why should the μ meson exist although it has the same interactions as the electron. Fifth, and philosophically most important, the weird metaphysical notion of a virtual object, as something real but not quite, must go. Sixth, and methodologically most important, a new hypothesis should not be accepted, even if heuristically fertile, if it contradicts well-corroborated and accepted formulas. Particularly, any Ptolemaic attempts to patch up one fiction with another should be resisted.

References

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