# Quantivity?

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**Abstract**

In fundamental physics several infinities arise, which surely is a sign of flaws of our theories - not of nature itself. It is suggested that a plausible future solution to this longstanding enigma would be a renunciation of locality and relativistic covariance at the most fundamental, quantum, level of nature, making relativity a derived property; "Quantivity".

"Sensible mathematics involves neglecting a quantity when it is small - not neglecting it just because it is infinitely great and you do not want it."
Paul Dirac

In this brief note I will discuss something I have not managed to solve, and nobody else has succeeded with either. Maybe YOU will?

When Paul Dirac created quantum field theory in the late 1920s [1], he initiated the amalgamation of the special theory of relativity with quantum physics. The problem was that the result usually could not be used for detailed calculations as the theory predicted divergences - infinities - obviously at odds with reality, and what was observed in experiments. In the late 1940s Feynman, Schwinger and Tomonaga [2] provisionally remedied this by "packaging" the infinities in a clever way and hiding them away - finally making

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quantum field theory into something that could be used for quantitatively precise calculations (although the infinities still remained, which, among others, Dirac never could accept). One had thus managed to achieve a workable "peaceful coexistence" between special relativity and quantum physics.

But for general relativity - still our best theory of gravity even though it is purely classical - nobody has to this day managed to achieve that for; the trick of hiding the infinities does not work any longer. In addition general relativity predicts, all by itself, completely without regard to quantum physics, its very own infinities (singularities); for example, inside black holes [3] or at the universe's birth in the Big Bang [4] when distances become microscopic.

These various infinities are clear signs that our theories are not yet formulated in an optimal way, as they should reflect *nature* and no infinities exist in it. (The theories are wrong, not nature.)

It also seems obvious that quantum physics is more fundamental than the theory of relativity, as the latter is only a classical theory and a purely logical consequence of reconciling Newton's and Maxwell's old classical theories of mechanics and electromagnetism [5]. The theory of relativity forbids signals to propagate faster than the speed of light (local cause-effect relationship; causality). Quantum physics, on the other hand, is fundamentally non-local - as *experimentally verified* through numerous tests [6] of Bell's theorem [7]: On a fundamental level, nature seems to be immediately and inseparably interconnected, without speed limit.

One can draw several conclusions from this for the formulation of a new and better theory:

- It is wrong to demand that the fundamental microscopic physics should be relativistic.
- Only macroscopic events and causes & effects ("observables" as they are called in physicists' jargon) on our level must obey relativistic rules.
- Relativity, *i.e.*, space-time and its strict locality & causality, should be a derived property from quantum mechanical laws, not a fundamental property of nature.
- Quantum gravity does not result from an active quantization of general relativity [8], instead general relativity (gravitation) is a macroscopic consequence of the more fundamental microscopic quantum laws. Of course, normal quantum physics is formulated *in* space-time, so this is a challenge.

The divergences that arise in quantum field theory, the singularities in general relativity, and the seemingly unsurmountable difficulties of finding a consistent theory of quantum gravity (despite almost a century of attempts [9]) all point to the conclusion that the problems arise from the erroneous assumption of strictly relativistic laws on the fundamental microscopic level. In his acceptance speech for the Nobel Prize for his renormalization of quantum field theory, Richard Feynman [10] said: "I think that the renormalization theory is simply a way to sweep the difficulties of the divergences of electrodynamics under the rug." This by the very man who invented the method. The problem is undoubtedly that our theories are not yet formulated in an optimal way. It is asking too much of nature that it should be relativistic microscopically. This assumption must somehow be relaxed.

Some slightly more detailed pointers are the following:

Physically, one cannot really freely Fourier-transform between $p$- and $x$-space (due to $\hbar \neq 0$) and quantum fields cannot interact in mathematical space-time *points* (evading divergences). Simultaneous $x$- and (inverse) $p$-Fourier transforms exist *only* if $\Delta x \equiv \Delta p \equiv 0$ simultaneously, which is forbidden *physically* (though not mathematically) through $\Delta x \Delta p \geq \hbar/2$, making (classical) strings and higher-dimensional objects, taken as the starting point for a subsequent quantum theory, seem superfluous, as quantum mechanics *itself* creates "fuzzy" higher dimensional quantum "objects" starting from (classical) point particles. The same is true for space-time curvature as, through Einstein's equations $G_{\mu\nu} = \kappa T_{\mu\nu}$, it is generated by the energy-momentum $T_{\mu\nu}$ which quantum mechanically must adhere to the same restrictions. The (causal) light-cone structure is indistinguishable from the classical case only when both $\Delta x$ and $\Delta p$ are large $\Delta x \Delta p \gg \hbar$ (macroscopic), but becomes more and more blurred as $\Delta x$ or $\Delta p$ or both become smaller, and *disappears completely* if $\Delta x \to 0$ and/or $\Delta p \to 0$. This is just a consequence of $\hbar \neq 0$ and constrains both special and general relativity. Also, the limit of locally free-falling reference-frames, which is the physical requirement for transforming away gravity locally (equivalence principle) SR $\leftrightarrow$ GR, cannot really apply as the local reference-frames must be infinitesimal $\Delta x \to 0$ implying that $\Delta p \to \infty$ meaning that they will not obey the assumed free-fall. In quantum field theory $x$ and $p$ are of course again demoted to merely numbers, but that is probably not the right approach considering the ensuing and persistent difficulties. Since point interactions of fields lead at once to infinities $\delta$-functions similarly should have no place in the theory.

What is troublesome is that combinations of infinitely precise $x's$ (*e.g.* $d^4x$) and $p's$ (*e.g.* derivative terms) are simultaneously present in *e.g.* the action functional used to define quantum field theories.

Perhaps a simultaneous formulation in position- and momentum-space, explicitly including the "fuzziness" introduced by quantum mechanics

$$\Delta p_\mu \Delta x_\nu \geq \frac{\hbar}{2}\delta_{\mu\nu}, \tag{1}$$

would be possible, but this still uses space-time (and momentum-energy) coordinates defined *a priori*, which probably is incorrect.

However, this would at least give violation and blurring of the rigid light-cone structure for the interaction of true quantum objects, for which the physical action $\leq \hbar$, while practically preserving relativity for "normal" macroscopic objects for which the action is $\gg \hbar$, for all practical purposes making possible $\Delta p \to 0$ $\Delta x \to 0$ simultaneously, restoring (macroscopic) causality.

We also see that if we measure a particle to be "here", *i.e.* force it into that "pointer-state" ($\Delta x \to 0$) it could move infinitely fast ($\Delta p \to \infty$) in principle having no problem informing an eventual entangled partner-particle which observation has resulted. This can also be seen more formally in Feynman's sum-over-histories approach to quantum mechanics [11]: quantum particles simultaneously take *all* paths, even those with $v \gg c$, but in the classical limit only $v \leq c$ survives, through extremum of action. Quantum particles are "local" only when observed, usually they are spread-out and non-local, strict relativistic causality (a *classical* concept) being inappropriate in the quantum realm.

Relativistic invariants, for example, become "blurred"

$$s^2 = (x_\mu + \Delta x_\mu)(x^\mu + \Delta x^\mu) \tag{2}$$

$$m^2 = (p_\mu + \Delta p_\mu)(p^\mu + \Delta p^\mu) \tag{3}$$

and when gravity is important

$$ds^2 = g_{\mu\nu} d(x^\mu + \Delta x^\mu) d(x^\nu + \Delta x^\nu) \tag{4}$$

where the general metric $g_{\mu\nu}$ is a function of $(x + \Delta x)$

$$m^2 = g_{\mu\nu}(p^\mu + \Delta p^\mu)(p^\nu + \Delta p^\nu) \tag{5}$$

while for "macroscopic" objects we can take $\Delta x \to 0$, $\Delta p \to 0$ to any level of accuracy (due to the smallness of $\hbar$) reproducing the relativistic causal structure we know of for "normal" (non-quantum) objects such as humans, space-shuttles and cats. However, on the quantum level, the uncertainty principle "blurs" world-lines and light-cones, making them really defined only *classically*.

In the manifestly covariant lagrangian formulation one is simultaneously using position- and velocity-variables, *e.g.* space-time integrations $d^4x$ and kinetic $\partial/\partial x^i$ terms in the lagrangian density. This is true also for the gravity lagrangian in the "quantum gravity" action functional

$$\int R\,\sqrt{g}\,d^4x, \tag{6}$$

where $R = R^\mu_\mu = g_{\mu\nu}R^{\mu\nu}$ is the scalar curvature, $g$ the determinant of the metric and $\sqrt{g}\,d^4x$ the invariant 4-volume element, $R \propto T$ containing energy/momentum-terms through Einstein's equations $R = -\kappa T$, inappropriately mixing non-simultaneous entities. A hamiltonian form fares no better, as the hamiltonian itself *simultaneously* includes $x$ and $p$ variables.

The use of infinitely precise $x'$s and $p'$s is appropriate for the classical theory ($\hbar = 0$) but not for the quantum theory ($\hbar \neq 0$) as "fuzziness-free" space-time and momentum-energy entities then no longer are definable simultaneously.

The erroneous insistence on *local* and covariant fundamental theories thus seems to be the origin of infinities. The task of making an alternative into a detailed, and empirically testable/falsifiable theory is another matter. Maybe *you* can solve that?

"Nature does not 'quantize'; it is already quantum. Quantization is a pencil-and-paper activity of theoretical physicists. Our objective must of necessity be, not the right answers, but a start at the more difficult task of asking the right questions. Nature manages to operate without infinities!"
John Wheeler

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