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Is Our World Becoming Less Quantum?

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Abstract According to the general idea of quantization, all physical dependencies are only approximately deterministic, and all physical "constants" are actually varying. A natural conclusion – that some physicists made – is that Planck's constant (that determines the magnitude of quantum effects) can also vary. In this paper, we use another general physics idea – the second law of thermodynamics – to conclude that with time, this constant can only decrease. Thus, with time (we are talking cosmological scales, of course), our world is becoming less quantum.

1 Formulation of the Problem

Our world is a quantum world. According to modern physics, our world is a quantum world, a world described by quantum physics.

In order to formulate the problem that we will be solving in this paper, let us recall the main physical idea behind quantization. To convincingly describe this idea, let us briefly recall how physics came up with the quantum ideas in the first place; see, e.g., [1, 8].

Classical mechanics. Before quantum physics appeared, physics was described by deterministic equations, namely, by Newton's equations. According to Newton's equations

$$m \cdot \ddot{x}_i = F_i, \tag{1}$$

the trajectory $x_i(t)$ of a particle with mass m is uniquely determined by this particle's original location $x_i(t_0)$, original velocity $\dot{x}_i(t_0)$, and the forces $F_i(x_j, t)$.

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The forces acting on a particle are, in their turn, uniquely determined by the locations and velocities of other particles. For example, the gravitational force $F_i^{(a)}(t)$ acting on the particle a of mass $m^{(a)}$ located at the point $x_i^{(a)}$ is equal to

$$F_i^{(a)}(t) = G \cdot \sum_b \frac{m^{(a)} \cdot m^{(b)} \cdot (x_i^{(b)} - x_i^{(a)})}{\|x^{(b)} - x^{(a)}\|^3}, \tag{2}$$

where the sum is taken over all other bodies b, and $\|x\| \stackrel{\text{def}}{=} \sqrt{x_1^2 + x_2^2 + x_3^2}$.

Usually, the forces are described in terms of the corresponding field – which is, in turn, uniquely determined by the locations and velocities of all the particles.

Need to go beyond classical mechanics. In the traditional (non-quantum) mechanics, all the processes are deterministic.

It turns out that many processes in the world – radioactivity was probably the first example – are probabilistic. We cannot predict when an atom will experience a radioactive decay – we can only predict the probability of this happening.

Original (first) quantization. The need to take into account that many processes in the real world are probabilistic led to the development of the original quantum mechanics. In this formalism, the particle's trajectory is *not* determined uniquely by its original state and all the forces. When we know the original location and velocity of a particle, and we know the fields (hence the forces), we can only predict the probability distribution on the set of all possible trajectories – or, to be more precise, the probabilities of different possible results of measuring coordinates and velocities.

To what extent predictions are probabilistic is determined by a constant $\hbar$ introduced by Max Planck, one of the founders of quantum physics. The smaller the Planck's constant, the closer all the trajectories to the Newton's ones.

How this probabilistic idea is related to a more traditional understanding of quantization. Planck did not start with the probabilistic nature of physics.

His original idea was different – that while in Newtonian physics, the values of all physical quantities change continuously, in reality, some quantities can only take values from some discrete set. In this case, transitions have to be abrupt. So, whether the object will change to a new state cannot be determined only by the state itself: for some time, the object stays in the same state, and then jumps to another state. This cannot be deterministic – thus we need a probabilistic description.

Towards second quantization. The original quantum mechanics worked very well – until it turned out that its predictions are not always in full accordance with the experiment. The solution – known as second quantization – came from the observation that while in the original quantum mechanics, the dependence of the trajectory on the fields is probabilistic, this theory still assumed that the fields themselves are uniquely determined by the positions and velocities of all the particles.

A natural idea was therefore to take into account that the fields are also not uniquely determined by the positions and velocities of all the particles, that all this information about the particles only enables us to predict the probabilistic distribution on the set of all possible fields. This idea enabled researchers to match the theory with experimental data. The resulting quantum field theories are, at present, the main way how the world's processes are described in modern physics.

Beyond second quantization. In the first quantization, the probability distribution of the set of all the trajectories is uniquely determined by the particle's initial locations and velocities. The dependence of this probability distribution on the particle's locations and velocities is determined by the corresponding fields which are, in turn, uniquely determined by the particles' locations and velocities.

In the second quantization, the dependence of the field on the particles' initial locations and velocities also becomes probabilistic. Thus, the probability distribution on the set of all trajectories is no longer uniquely determined by the particle's initial locations and velocities.

A natural next idea is to assume that the probability distribution on the set of all possible fields is also not uniquely determine by the particles' initial locations and velocities, that all we can predict is the probability distribution on the set of all probability distributions, etc. The effect of this "third" quantization is too small to be noticeable at present, but this led many physicists – most famous of them John Wheeler – to formulate the general idea of quantization as saying that every dependence is probabilistic, and to analyze interesting consequences of this idea with respect to space-time; see, e.g., [5].

Mathematical interruption: but is not probability distribution of the set of probability distributions the same as just a probability distribution? Not really. Suppose that we have a probability 0.5 that a coin falls head. This means that for each coin out of the large set of minted coins, if we flip this coin many times, in half of the cases this coin will fall head, and in half of the cases, it will fall tail.

Suppose now that instead of the fixed probability $p = 0.5$, we have a probability distribution on the set of all possible values p. This would means that for some coin, if we flip it many times, we will consistently get head 0.6 of the time, while for some other coin, we may consistently get head 0.4 of the time. Yes, if we combine all the experiment results together, we still get 0.5, but overall, the experiment results are different from what we would have observed if we had probability $p = 0.5$.

Back to physics: according to the general quantization idea, Planck's constant is no longer a constant. The same general logic leads to a conclusion that the local value of any physical constant is no longer a constant, that it can fluctuate from one moment to another, from one spatial location to another. For the speed of light – the parameter that, according to relativity theory, describing the space-time – these variations are well known: this is exactly what General Relativity teaches, that the space-time differs from one point to another.

But an interesting – and not as well accepted – conclusion is that the Planck's constant – that determines how deterministic is the dependence – is also not constant, it fluctuates from one point of space-time to another. Theories in which Planck's constant is actually a new physical field have indeed been proposed.

Now, we can formulate the problem that we analyze in this paper.

What are the possible consequences of taking into account that Planck's constant is not a constant? This is the question that we study in this paper.

2 Analysis of the Problem and the Resulting Conclusion

Idea. In our analysis, we cannot rely on specific equations – since the whole idea is that all equations are approximate. Instead, we have to rely on general principles.

One of these principles is the second law of thermodynamics – that the entropy S of any closed system, including the world as a whole, can only increase.

What is entropy? For a probabilistic distribution, entropy is the average number of "yes"-"no" questions that one needs to ask to uniquely determine the state; see, e.g., [4, 7].

If we have N original states, then we can divide these states into two equal parts and by a single question determine whether the current state belongs to the first half or to the second half. So, each question divides the number of states by 2. Thus, k questions divide the number of possible states by 2^k, to $N/2^k$. Hence, to be left with a single possible state, the needed number of questions k is determined by the condition that $N/2^k = 1$, i.e., that $2^k = N$ and $k = \log_2(N)$.

We need to take uncertainty principle into account. The world consists of particles. At each moment of time, the state of each particle is characterized by its location and it velocity – or, what is equivalent, its momentum. In quantum physics, we cannot determine both coordinate x_i and the corresponding momentum p_i exactly: there is the Uncertainty Principle, according to which the accuracies Δx_i and Δp_i with which we can determine these two quantities satisfy the inequality $\Delta x_i \cdot \Delta p_i \geq \hbar$. In other words, the state of each particle is characterized not by a single point $(x,p) = (x_1,x_2,x_3,p_1,p_2,p_3)$ in the 6-D space (known as *phase space*), but by an area of 6-D volume $\hbar^3$.

Thus, the number N of distinguishable states can be obtained if we divide the 6-D volume V of the set of all possible points (x,p) by $\hbar^3$: $N = V/\hbar^3$.

Conclusion: our world is becoming less quantum. The entropy $k = \log_2(N)$ can only increase, thus the number of states N can also only increase. For a fixed V, the only way for the number of states N to increase is when the Planck's constant $\hbar$ decreases.

Thus, once we accept the general conclusion that Planck's constant can change, the only direction is which it can globally change is by decreasing. Since the value of this constant determines the intensity of quantum effects, this means that our world is becoming less and less quantum.

Not to worry. Of course, we are talking changes in cosmological time: so far, no macro-time experiments have found any change in the Planck's constant.

How this affects our ability to compute – and thus, to predict. On the one hand, if the world is becoming more deterministic, it will become easier to predict its future state: all we need to do is predict one state, not the whole probability distribution on the set of all possible states.

On the other hand, our general ability to compute will decrease – since it will no longer be possible to use quantum computing, which is known to drastically decrease the computation time of many important computations; see, e.g., [2, 3, 6].

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