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# Interpretation of "The Wave Function of the Universe"

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Hawking and Hartle interpreted their wave function of the universe as giving the probability for the universe to appear from nothing. However, this is not a correct interpretation, since the normalization presupposes a universe, not nothing. Transition probabilities require a measure on the initial state and a physical result requires a physical initial state.

Hawking and Hartle have, by a path integral approach, derived a formula they call "the wave function of the Universe." Since there are no boundary conditions involved, Hawking and Hartle (1983) propose the following interpretation:

> One can interpret the functional integral over all compact four-geometries bounded by a given three-geometry as giving the amplitude for that three-geometry to arise from a zero three-geometry, i.e., a single point. In other words, the ground state is the amplitude for the Universe to appear from nothing.

This article questions the interpretation that they calculate the amplitude for the universe to appear from nothing.

Before interpreting a wave function as an amplitude for probabilities, the normalization must be clear. In the case of a single particle, without creation or destruction, the wave function is normalized by requiring that the integral of the probabilities over the whole space must yield one at any moment; the particle must be somewhere. In the case of quantum fields, normalization of the wave function, describing the probability amplitude of different field configurations in space at a certain moment, is achieved by requiring that there is one field configuration at any moment. (This might be a vacuum configuration.) In the case of the wave function of the universe, in the absence of matter fields, Hartle and Hawking (1983) use for the

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normalization the following formula (4.3):

$$\int \delta h\, \bar{\psi}_0[h_{ij}]\psi_0[h_{ij}] = 1$$

This is the natural extension of the previous cases, requiring that the probability of having a metric at a three-dimensional spacelike surface is one. However, if this is the way normalization is achieved, the wave function for the ground state gives not the amplitude that a universe arises from nothing, but that the ground state arises, given that there is a metric, i.e., a universe.

The normalization problem exemplifies more general objections to talking about "the probability for the Universe to appear from nothing." Mathematical probabilities are defined in relation to a set of possible outcomes. The probability of finding "head" when tossing a coin is $\frac{1}{2}$, but there is a 50% chance of getting a *real* "head" if and only if someone tosses a coin, so if and only if one of the possible outcomes is realized. ("Real" is a philosophically much disputed concept, but I take it to be the consensus among physicists that the universe is more real than mathematical ideas about universes.) The normalization given above is a normalization over a set of possible outcomes. A mathematical probability of getting a universe from nothing does not give a physical universe, but only the idea of a physical universe. There has to be some input of "physical reality." Perhaps this is implied in the "nothing," but that makes it into a physical entity, a physical "nothing" and not nothing at all.

Physical probabilities, as exemplified by radioactive decay, start with something, a first situation (particle in space and time) becoming another situation (other particles in space and time). The probability is the chance that the transition from situation one to situation two happens during a certain interval of time, or that a particle is found in a certain volume of space, or something like that. Even if one reduces the entities in the first situation as much as possible (no energy, no matter fields, etc.), to make sense of talking about probabilities is only possible if there is some structure with measure (like time) present in the first situation. It is not clear how otherwise the probability for transition from situation one to situation two could be defined.

In fact, many articles on "creation of universes from nothing" admit something like this. Even a weird structure, like "a zero three-geometry, i.e. a single point," as the citation of Hartle and Hawking has it, is not nothing. Others start with a Minkowski or De Sitter metric (Atkatz and Pagels, 1982; Brout *et al.*, 1978; Brout *et al.*, 1980; Gott, 1982) or a vacuum with fluctuations of all physical fields, including the gravitational field, which implies that the classical notions of space and time break down (Grishchuk and

Zeldovich, 1982; Vilenkin, 1983). Recently, Vilenkin proposed a wave function which "can be thought of as describing the state which was called 'nothing'" (Vilenkin, 1986).

If one supposes a transition from some initial state (Minkowski, De Sitter, quantum gravity) to a universe like ours, there arises another problem if the original situation is supposed to have existed without beginning. If the transition probability is finite, the initial state cannot have existed since past eternity, as pointed out by Linde (1983). However, this seems to be more like a technical problem, perhaps solvable in the near future.

If the program of Hartle and Hawking is going to work, it will be possible to explain the structure of the universe without assuming initial conditions and without a breakdown of the laws of physics at some initial singularity. This is very interesting, for it might answer the metaphysical question "Why is the universe as it is." However, this is not an answer to the question of how probable it is that a universe appeared from nothing. For the moment, that remains a metaphysical question. Mathematical probabilities need reality, and physical probabilities need some measure on the initial state. It is not a temporary problem in our understanding, as suggested by Zeldovich and Starobinsky (1984): "at the moment it is not clear just what the meaning of the 'closed-world birth probability' is and how that probability is to be normalized." There is a fundamental dilemma: probabilities as in quantum theory weaken the concept of nothing; really "nothing" is not open to calculations of probabilities.

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