The Role of the Uncertainty Principle in the Very Early Universe

In this article the role of Heisenberg's uncertainty principle in the evolution of the early universe is investigated. By definition the early universe refers to the first 10^{-10} seconds of the universe's existence.1) It refers to an epoch in the evolution of the universe when it was subjected to quantum fluctuations as described in quantum physics. The temperature (10^{32} K) was so hot that the relevant laws of physics became uncertain. 2) But if the universe itself was so profoundly affected by the randomness of quantum fluctuations, how could it evolve into a state of homogeneity and isotropy that we observe today? To answer this question we have to look at what the uncertainty principle says and what it does not say.

Heisenberg's uncertainty principle states the non-commuting of either the position or velocity of a particle. Mathematically it can be stated as

$$\Delta x \, \Delta p \geq h / (4\pi) \qquad (1)$$

The particle does not have a specific position, but is smeared out over all possible values of *x*. However, if you determine the position of the particle, the speed (velocity) becomes smeared out and cannot be determined with accuracy. Heisenberg's uncertainty relations have profound implications. In quantum physics it manifests itself in the form of quantum fluctuations. At the quantum level virtual particles flashed in an out of existence creating the impression of a state of inherent 'fuzziness' in nature at the level of the very small. What it does tell us is the position and momentum of a particle cannot be determined at the same time. There is, however, a perfectly well defined quantum state (see under 2). If the position or momentum of a particle is not measured, the quantum state remains. The standard notion of a symmetric state of the universe is therefore maintained. It is only when an observer makes a measurement of the position or velocity of a particle that the notion of fuzziness at the quantum level appears.

The Planck era

The Planck time of 5×10^{-44} seconds is the first phase of evolution of the early universe. The Planck time and the Planck length ((2×10^{-36} metres) are very small comparing to the Planck mass/energy of 2×10^{-8} kilograms/1×10^{19} GeV (see 1). The Planck energy density (Planck energy divided by the Planck length cubed) is significantly larger than the other Planck units. This is the era when quantum effects and quantum gravity are equally important. This is sometimes seen as the universe emerging from a state of infinity, also called a singularity. Whether a singularity can be avoided is unclear. 3) Some see quantum fluctuations as black holes. 4) At the Planck level quantum fluctuations and quantum gravity are of equal importance and it can therefore be argued that infinities and a singularity in the early universe will disappear when we have a theory of quantum gravity to describe the Planck era.

The Planck era is seen by many theorists as the epoch when the temperature was high enough for the four fundamental forces to be unified. As the universe expanded and cooled the four forces separated. Little is known about this epoch in the evolution of the universe.

Cosmological inflation

The idea that the early universe went through a very brief period of exponential inflation forms one of the key ideas of the evolution of the universe. 5) Such an expansion explains, among problems such as the 'horizon problem, the flatness problem, etc., how the perturbations caused by the fluctuation of virtual particles became imprinted on the Cosmic Microwave Background Radiation (CMBR) in the form of anisotropies, slight variations in the densities and temperature of the CMBR. These anisotropies form the 'seeds' from which stars and galaxies formed. In this process quantum fluctuations became stretched from quantum variations to real variations in the universe, called classical perturbations in physics, i.e. non-quantum. It is predicted that quantum fluctuations caused gravitational waves in the fabric of spacetime itself. So far, no evidence of gravity waves has been observed, but hopefully equipment sensitive enough to detect gravity waves will be built in future. (See 1).

Conclusion

There is no contradiction in the upheavals of the quantum fluctuations in the early universe and the cosmological principles of homogeneity and isotropy. The contribution of quantum fluctuations can be seen in the CMBR where the quantum fluctuations caused anisotropies in CMBR which formed the seeds from which stars and galaxies formed.

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