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Editorial

Perspectives on Decay and Time Evolution of Metastable States: From Particle Physics to Cosmology

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Many, if not most of the quantum states which constitute the building blocks of nature, are unstable and decay spontaneously. As such they require a special treatment in quantum mechanics which displays new effects as compared to a classical theory. Examples of such unstable states can be found in the Standard Model of particle theory including quarks, heavy gauge bosons, leptons heavier than the electron, baryons heavier than the proton, and all mesons made up from a quark and an antiquark. In nuclear physics the word "radioactivity" is a synonym for the instability of the nuclei which either de-excite emitting a photon, decay via a cluster emission (of which the alpha decay is the most famous and the best studied example of a quantum tunneling process) or undergo the weak transition known as beta decay or inverse beta decay. In atomic physics, excited states are indeed considered as unstable and in a similar way we could treat excited molecules. Finally, the whole universe can tunnel from a false vacuum into a lower lying energy state which from the point of view of quantum mechanics is understood as a spontaneous decay. Indeed, in quantum mechanics a decay process is quite natural as any state will decay unless we have a conservation law (symmetry) which forbids it. Quantum mechanics allows also a unified treatment of the spontaneous decay which can be applied to all unstable states and exhibits new phenomena ("new" as compared to the classical "exponential decay") at short and large times. At small times the exponential decay law is replaced by a power law and is closely related to the Zeno and anti-Zeno effect which loosely speaking states that "watched states decay differently," a fact which can be even applied in cosmology. This behavior is followed by the exponential decay law. At large times, the latter again gets replaced by a new power law preceded by a transition region in which the survival probability can grow locally. This also finds applications in cosmology. The deviations from the exponential decay are a genuine quantum effect.

The ramifications of the spontaneous decay process in understanding nature and its applications are widely spread. It is the photon emission of excited atoms which gives information of the matter far away from our sun. It is the beta decay which plays a decisive role in the nucleosynthesis of elements heavier than iron. It is the alpha decay of thorium and uranium which in part heats up the inner core of the earth, making it fluid, allowing for the continental drift and the magnetic field. It is the inverse beta decay supplying us with the positron needed in medical tomography whose one version relies on the decay of the positronium.

The present special issue consists of articles which deal with instability from a scale as small as that of elementary particles to that of the universe itself. On the way, the authors discover interesting phenomena related to the effects of relativity, violation of symmetries, and the bizarre behaviour of the universe under certain conditions. Chen and Wang, for example, consider the tunneling of the universe within the scenario of an inhomogeneous quantum vacuum and, calculating the tunneling amplitude of the universe from nothing, they find that the inhomogeneity leads to a faster tunneling. In contrast to this approach which uses the Friedmann-Lemaitre-Robertson-Walker metric, M. Gogberashvili considers a different approach using Einstein's static universe metric and investigates the effects of the strong static gravitational field. A. Stachowski et al. bring in a new player, the metastable dark energy, in the investigation of the evolution of the universe. G. J. M. Zilioti et al. attempt to resolve some cosmological puzzles within decaying vacuum models. A completely different approach using concepts from statistical physics is introduced by Z. Haba to study the evolution of the expanding universe. Going over to smaller scales, the paper by T. V. Obikhod and I. A. Petrenko studies the properties of new particles predicted by the theories of extra dimensions. The survival probabilities of moving unstable particles are considered by E. V. Stefanovich, F. Giraldi, and F. Giacosa in three different papers. The feasibility of testing the time reversal symmetry in a purely leptonic system is reported by the Jagellonian-PET team from their pilot measurement involving the three photon decay of a positronium atom. Finally, the probability distribution of tunneling times of particles in connection with the recent laser induced tunnel ionization experiments is presented by J. T. Lunardi and L. A. Manzoni.

Conflicts of Interest

The editors declare that there are no conflicts of interest regarding the publication of this special issue.

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