Entropy, and topological phase analysis in quantum simulations of the early universe with finite temperature effects

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The most widely accepted theory to explain the evolution of the cosmos is an inflationary model which describes the evolution of the early universe. This model is supported by experimental observations of thermal fluctuations in the cosmic microwave background radiation (CMB) detected in all directions. The origin of the CMB is thought to be a residue from the "Big Bang" at the beginning of the universe. We make use of Coleman's model [1,2] of the decay of the false vacuum to explain the quantum effects that may have occurred to cause the "Big Bang", such as quantum tunnelling and spontaneous decay of a scalar quantum field. Understanding this process is not only vital to the foundations of cosmology, but also to other disciplines of physics as well.

We present a numerical model to study and simulate the quantum evolution of the early universe realized using a Bose-Einstein condensate. Here we expand on the previous work done by O. Fialko et al. [3, 4] where we include temperature effects on false vacuum tunnelling. We also investigate the topological properties of the bubble universes formed. We show an acceleration in quantum vacuum nucleation at finite temperature, and at high temperatures, we observe short lived bubbles due to thermalization of the BEC. We make use of a nonlocal observable called the topological phase entropy, which provides information about the phase structure in the true vacuum in our simulations. We report on a fascinating effect where true vacuum bubbles with distinct phases are formed. The simulations indicate an increase in topological phase entropy initially, reaching a peak during the tunnelling event, and then a decrease with time to the phase-ordered vacuum state. This highlights the potential formation of multiple universes with one of two possible distinct topological phases, which may provide an insight into the particle-antiparticle asymmetry seen in our universe.

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