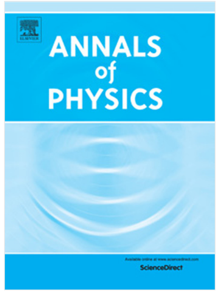

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PII: S0003-4916(17)30224-5
DOI: http://dx.doi.org/10.1016/j.aop.2017.08.004
Reference: YAPHY 67455

To appear in: *Annals of Physics*

Received date : 28 January 2017
Accepted date : 1 August 2017

Equilibrium properties of blackbody radiation with an ultraviolet energy cut-off

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Abstract

We study various equilibrium thermodynamic properties of blackbody radiation (i.e. a photon gas) with an ultraviolet energy cut-off. We find that the energy density, specific heat etc. follow usual acoustic phonon dynamics as have been well studied by Debye. Other thermodynamic quantities like pressure, entropy etc. have also been calculated. The usual Stefan-Boltzmann law gets modified. We observe that the values of the thermodynamic quantities with the energy cut-off is lower than the corresponding values in the theory without any such scale. The phase-space measure is also expected to get modified for an exotic spacetime appearing at Planck scale, which in turn leads to the modification of Planck energy density distribution and the Wien's displacement law. We found that the non-perturbative nature of the thermodynamic quantities in the SR limit (for both unmodified and modified cases), due to nonanalyticity of the leading term, is a general feature of the theory accompanied with an ultraviolet energy cut-off. We have also discussed the possible modification in the case of Big Bang and the Stellar objects and have suggested a table top experiment for verification in effective low energy case.

Keywords: Invariant Energy Scale, DSR, Blackbody Radiation, Incomplete Zeta Function, Debye Theory, Non-perturbative

1. Introduction

It seems that in all the theories attempting to combine gravity with quantum mechanics, a natural length/energy scale emerges, i.e. Planck length/energy. This scale acts as a threshold where a new description of spacetime is expected to appear. Doubly Special Relativity (DSR) attempts to incorporate this threshold as an invariant quantity under a relativistic transformation [1–3]. The motivation of DSR theories is also derived from the observation of interesting effects such as deformation of dispersion relation etc. at very high energy scales [1, 4–7]. The introduction of an observer independent energy scale in DSR formulation, say κ, leads to such a modification in the dispersion relation of a free particle [1, 2, 8, 9]. The energy threshold also acts as a cut-off on the highest possible energy value in the physical (sub-Planckian) world [9, 10]. In the formulation of DSR by Magueijo and Smolin (MS formalism) [9] this sub-Planckian regime which is characterized by the energy $E \leq \kappa$ and the momentum $p \leq \kappa$ is the result of the choice of the $U-$map (this is a map between the standard Lorentz generators and the modified ones resulting in the modification of the Poincare algebra keeping the Lorentz sector intact). This choice of $U-$map is in sync with the expectation of the emergence of the granular structure of spacetime at Planck scale. Similar cut-offs in momentum and/or energy are seen in other DSR formalisms as well [11]. Also, we see similar cut-offs appearing in other candidate quantum gravity theories like noncommutative geometry, string theory, loop quantum gravity and GUP (Generalized Uncertainty Principle) etc. [2, 12–23]. DSR formalism can also be extended to curved spacetime. One such extension was proposed by MS and has been since then studied from various perspectives [24–28]. DSR has also been explored from the point of view of modified/deformed algebra called $\kappa-$Poincare algebra [11, 29–33] .

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