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Report

on the thesis by Vardazar Kotanjyan titled "Vacuum quantum effects in non-inertial frames and gravitational fields" presented for the degree of Canditate of Physical and Mathematical Sciences in Specialization **A.04.02-Theoretical Physics**

The study of quantum field-theoretical effects in background of classical gravitational fields remains among the most interesting directions of quantum field theory. The interest is motivated by principal questions of quantization procedure in curved geometries and in backgrounds with horizons and by importance of those effects in cosmology and in the physics of superdense stars and black holes. Additional motivations for investigations of geometrical effects on quantum fields come from condensed matter physics. In a number of condensed matter systems the long-wavelength degrees of freedom are described by relativistic fields and the corresponding background geometry can be curved or may have nontrivial topology. Examples are carbon fullerenes and nanotubes. The thesis by Vardazar Kotanjyan considers the curvature, topology and boundary induced effects on quantum vacua for scalar, fermionic and electromagnetic fields. Highly symmetric geometries are studied for which exact results are obtained for physical characteristics. The thesis presents a sufficiently comprehensive study of the topic and consists of Introduction and three chapters containing the original material.

Introduction contains the literature review on the topic of the research. At the end, the practical importance, the summary of the obtained results, and the contents of separate chapters are briefly described.

In **Chapter 1**, the local characteristics of the Fulling-Rindler vacuum state are investigated for scalar and fermionic fields in background of Rindler spacetime. Though the latter is flat, the presence of the horizon gives rise to effects absent in the Minkowski vacuum of inertial observers. The chapter is divided into two subsections. In the first one a part of spatial dimensions in Rindler spacetime is compactified to a torus and a massive charged scalar field is considered. As physical characteristics of the Fulling-Rindler vacuum state, the expectation values of the field squared and current density are considered in the presence of a constant gauge field. For the evaluation of those quantities, as the first step, the Hadamard two-point function is evaluated. In the corresponding representation the respective two-point function for the Minkowski vacuum is explicitly extracted. That allows to reduce the renormalization of the expectation values to the one for the Minkowski vacuum. They are periodic functions of the magnetic flux with the period of flux quantum. The asymptotics are studied in the limits of large and small proper accelerations. The current density vanishes on the Rindler horizon whereas the field squared diverges. In the second part of Chapter 1 the topology of Rindler spacetime is trivial and a fermionic field is considered. For a massive field the complete set of fermionic modes is found in general number of spatial dimensions. By using those modes, the fermion condensate and the expectation value of the energy-momentum tensor are investigated in the Fulling-Rindler vacuum. For a massless field the fermionic condensate vanishes and the spectral distribution for the components of the energy-momentum tensor has a thermal nature with the Unruh temperature. An interesting point to be mentioned is that the thermal distribution in even number of spatial dimensions is of Bose-Einstein type.

Chapter 2 is devoted to the investigation of the local characteristics of the electromagnetic field in de Sitter spacetime in the presence of a cosmic string type topological defect. General number of spatial dimensions is considered and the problem is complicated by the absence of conformal invariance of the electromagnetic field. As a consequence of that the vacuum energy-momentum tensor for the Bunch-Davies vacuum state has an off-diagonal component that describes an energy flux along the radial direction with respect to the cosmic string core. It is shown that the flux is directed towards the string in all spatial dimensions larger than 3. Depending on the distance from the string and on the value of the planar angle deficit induced by the string, the vacuum energy density can be either positive or negative. Near the string the dominant contribution to the expectation values of diagonal components come from the fluctuations with small wavelengths and the effect of the gravitational field is week. The nonzero energy flux is an effect induced by gravity and it vanishes in the Minkowskian limit. The effects of gravity on the diagonal components are essential at distances from the cosmic string larger than the de Sitter curvature radius. Though the decrease of the topological contributions in the expectation values follow power-law in both de Sitter and Minkowski bulks, the degree of the corresponding fall-off in the first case does not depend on the spatial dimension.

In **Chapter 3**, the anti-de Sitter spacetime is taken as the background geometry. The geometry of boundaries corresponds to two branes perpendicular to the anti-de Sitter boundary. The vacuum densities are investigated for a massive scalar field with general curvature coupling parameter and for Robin boundary conditions on the branes. The expression is derived for the positive frequency Wightman function in the region between the branes. The contribution of the geometry in the absence of the branes is extracted. The main concern in the thesis is the study of brane-induced effects on the characteristics of the vacuum state. As such characteristics the expectation values of the field squared and energy-momentum tensor are considered. Closed analytic expressions for them are derived with detailed asymptotic and numerical analysis. It is shown that, depending on the boundary conditions and also on the distance from the branes, the vacuum energy density and pressures can be either positive or negative. By using the expressions for the vacuum stresses, the Casimir forces are investigated on the branes. The nonzero off-diagonal component of the energy-momentum tensor gives rise to the shear force in addition to the standard normal force. The appearance of the shear force is a qualitatively new feature compared to the problem for parallel plates on the Minkowski bulk or branes parallel to the anti-de Sitter boundary. The direction of the both normal and shear forces depend on the boundary conditions and on the interbrane separation. The forces may also change the sign as functions of the distance from the anti-de Sitter boundary.

Summarizing the above, we can conclude that the thesis provides a sufficiently comprehensive study and Vardazar Kotanjyan shows familiarity with and understanding of the topic. The thesis makes an original contribution to the subject of quantum field theory in curved spacetime.

My comments related to the content of the thesis are as follows.

1. In Chapter 1 the fermionic condensate is investigated for a free Dirac field in the Fulling-Rindler vacuum. It is known that the fermionic condensate is an important quantity in interacting theories like Nambu-Jona-Lasinio or Gross-Neveu models. In particular, the condensate may appear as the order parameter in the corresponding phase transitions. It would be interesting to discuss the results obtained in a broader context.
2. In Chapter 3 the Wightman two-point function is derived in the geometry of two branes by using the complete set of scalar mode functions. By using those modes, the bulk-to-boundary propagator can also be evaluated. The latter is an important quantity in AdS/CFT correspondence. The knowledge of the propagator would make it possible to interpret the obtained results in the context of the conformal field theory living on the AdS boundary.

Those comments can be considered as suggestions for the further research. In the thesis interesting results are obtained on the influence of the gravitational field, nontrivial topology and boundaries on the properties of quantum vacuum. The methods and techniques applied are appropriate to the subject matter. The thesis satisfies the requirements of the Supreme Certifying Committee of the Republic of Armenia for theses seeking the degree of Candidate of Physical and Mathematical Sciences. The results obtained in the thesis are fully presented in the publications.

Based on the above, I conclude that Vardazar Kotanjyan deserves to be awarded the degree of Candidate of Physical and Mathematical Sciences in the specialization A.04.02 - "Theoretical Physics". The abstract completely reflects the content of the thesis.

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