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Vacuum polarization of a quantized scalar field in the thermal state in a long throat

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The study of vacuum polarization effects in strong gravitational fields is a pertinent issue since such effects may play a role in the cosmological scenario and the construction of a self-consistent model of black hole evaporation. These effects can be taken into account by solving the semiclassical backreaction equations

$$G^{\mu}_{\nu} = 8\pi\langle T^{\mu}_{\nu}\rangle, \qquad (1)$$

where $\langle T^{\mu}_{\nu}\rangle$ is the expectation value of the stress-energy tensor operator for the quantized fields.

The main difficulty in the theory of semiclassical gravity is that the vacuum polarization effects are determined by the topological and geometrical properties of spacetime as a whole or by the choice of quantum state in which the expectation values are taken. It means that calculation of the functional dependence of $\langle T^{\mu}_{\nu}\rangle_{ren}$ on the metric tensor in an arbitrary spacetime presents formidable difficulty. Only in some spacetimes with high degrees of symmetry for the conformally invariant fields $\langle T_{\mu\nu}\rangle_{ren}$ can be computed and equations of the theory of semiclassical gravity can be solved exactly. Let us stress that the single parameter of length dimensionality in problem (1) is the Planck length l_{PL}. This implies that the characteristic scale l of the spacetime curvature (which corresponds to the solution of equations (1) can differ from l_{PL} only if there is a large dimensionless parameter. As an example of such a parameter one can consider a number of fields the polarization of which is a source of spacetime curvature (*it is assumed, of course, that the characteristic scale of change of the background gravitational field is sufficiently greater than l_{PL} so that the very notion of a classical spacetime still has some meaning*). In the case of massive field, the existence of an additional parameter $1/m$ does not increase the characteristic scale of the spacetime curvature l which is described by the solution of equations (1) (*the characteristic scale of the components G^{μ}_{ν} on the left-hand side of equations (1) is $1/l^2$, on the right-hand side - ${l_{PL}}^2/(m^2 l^6)$)*. For the massless quantized fields such a parameter can be the coupling constants of field to the curvature of spacetime [1]. Another possibility of introducing an additional parameter in the problem (1) is to consider the non-zero temperature of quantum state for the quantized field. It is known (see, e.g., [2]) that in the high-temperature limit (when $T \gg 1/l, T$ being a temperature of thermal state) $\langle T^{\mu}_{\nu}\rangle$ for such a thermal state is proportional to the fourth power of the temperature T.

In this work an analytical approximation of $\langle\varphi^2\rangle$ for a quantized scalar field in a thermal state at arbitrary temperature is considered. The scalar field is assumed to be both massive and massless, with an arbitrary coupling ξ to the scalar curvature, and in a thermal state at an arbitrary temperature T. The gravitational background is assumed to be static spherically symmetric and slowly varying. We have shown that in such spacetime the effect of vacuum polarization of a quantized scalar field in the thermal state does not depend on temperature and conditions at infinity. This implies that in considered situation $\langle\varphi^2\rangle$ is a local quantity for any finite mass m of the quantized field, including $m = 0$.

References

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