The Time Arrow in Planck Gas

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Abstract

In this paper the quantum heat transport equation (QHT) is applied to the study of thermal properties of Planck gas, i.e. gas of the massive particles with mass equal Planck mass, $M_p = (\hbar c/G)^{1/2}$ and relaxation time equals Planck time, $\tau_p = (\hbar G/c^5)^{1/2}$. The quantum of thermal energy for Planck gas, $E^{\mathrm{Planck}} = 10^{19}\,\mathrm{GeV}$ and quantum thermal diffusion coefficient $D^{\mathrm{Planck}} = (\hbar G/c)^{1/2}$ are calculated. Within the framework of QHT the thermal phenomena in Planck gas can be divided into two classes, for time period shorter than τ_p the time reversal symmetry holds and for time period longer than τ_p, time symmetry is broken, i.e. time arrow is created.

Key words: Planck gas; Quantum heat transport; Time arrow

1 Introduction

The enigma of Planck Era, i.e. the event characterized by Planck time, Planck radius and Planck mass is a very attractive for speculations. In this paper we discuss the new (as we think) interpretation of the Planck time. We define Planck gas – the gas of massive particles all with masses equal Planck mass $M_p = (\hbar c/G)^{1/2}$ and relaxation for transport process equals the Planck time: $\tau_p = (\hbar G/c^5)^{1/2}$. To the description of the thermal transport process in Planck gas we apply the quantum heat transport equation (QHT) derived in our earlier paper [1]. The QHT is the specification of the hyperbolic heat conduction equation HHC [1, 2] to the quantum limit of heat transport i.e. when de Broglie wave length, λ_B equals mean free path, λ. When QHT was applied to the description of thermal excitation of the matter it was shown that the excited matter response is quantized on the different levels (atomic, nuclear) with quantum thermal energy equal $E^{\mathrm{atomic}} \sim 9\,\mathrm{eV}$, $E^{\mathrm{nuclear}} \sim 7\,\mathrm{MeV}$. In this paper using QHT we calculate quantum thermal energy for Planck gas the *heaton*, $E^{\mathrm{Planck}} \sim 10^{19}\,\mathrm{GeV}$ and quantum diffusion coefficient for Planck gas

$$D^{\mathrm{Planck}} = \left(\frac{\hbar G}{c}\right)^{1/2}.$$

The QHT for Planck gas is the damped wave equation which for time period $\Delta t \sim \tau_p$ is the hyperbolic wave equation with preserved time reversal symmetry. On the other hand for time period $\Delta t >> \tau_p$ the QHT is parabolic diffusion equation with broken time symmetry. It seems that Planck time τ_p divides the transport phenomena on two classes: for *pre*-Planck times the time reversal symmetry holds and for *post*-Planck time the time symmetry is broken, i.e. time arrow is created.

2 Thermal properties of the Planck gas

In the following we will describe the thermal properties of the Planck gas. To that aim we use hyperbolic heat transport equation (HHC) [1]

$$\frac{\lambda_B}{v_h}\frac{\partial^2 T}{\partial t^2}+\frac{\lambda_B}{\lambda}\frac{\partial T}{\partial t}=\frac{\hbar}{M_p}\nabla^2 T. \tag{1}$$

In equation (1) M_p is the Planck mass λ_B — de Broglie wave length and λ — mean free path for Planck mass. The HHC equation describes the dissipation of the thermal energy induced by temperature gradient ∇T. Recently the dissipation processes in the cosmological context (e.g. viscosity) were described in the frame of EIT (Extended Irreversible Thermodynamics) [2, 3]. With the simple choice for viscous pressure it is shown that dissipative signals propagate with the light velocity, c [2]. Considering that the relaxation time τ is defined as [1],

$$\tau=\frac{\hbar}{M_p v_h^2}, \tag{2}$$

for thermal wave velocity $v_h = c$, one obtains

$$\tau=\frac{\hbar}{M_p c^2}=\left(\frac{\hbar G}{c^5}\right)^{1/2}=\tau_p, \tag{3}$$

i.e. the relaxation time is equal the Planck time τ_p. The gas of massive particles with masses equal Planck mass M_p and relaxation time for transport processes equals Planck time τ_p we will define as the Planck gas.

According to the result of the paper [1] we define the quantum of the thermal energy, the *heaton* for the Planck gas

$$\begin{aligned} E_h &= \hbar\omega=\frac{\hbar}{\tau_p}=\left(\frac{\hbar c}{G}\right)^{1/2}c^2=M_p c^2,\\ E_h &= M_p c^2=E^{\mathrm{Planck}}=10^{19}\,\mathrm{GeV}. \end{aligned} \tag{4}$$

With formula (2) and $v_h = c$ we calculate the mean free path, λ, viz.

$$\lambda = v_h \tau_p = c\tau_p = c\left(\frac{\hbar G}{c^5}\right)^{1/2} = \left(\frac{\hbar G}{c^3}\right)^{1/2}. \tag{5}$$

From formula (5) we conclude that mean free path for Planck gas is equal Planck radius. For Planck mass we can calculate the de Broglie wave length

$$\lambda_B = \frac{\hbar}{M_p v_h} = \frac{\hbar}{M_p c} = \left(\frac{G\hbar}{c^3}\right)^{1/2} = \lambda. \tag{6}$$

As it is defined in paper [1] equation (6) describes the quantum limit of heat transport. When formulae (5), (6), are substituted to the equation (1) we obtain:

$$\tau_p \frac{\partial^2 T}{\partial t^2} + \frac{\partial T}{\partial t} = \frac{\hbar}{M_p} \nabla^2 T. \tag{7}$$

Equation (7) is the quantum hyperbolic heat transport equation (QHT) for Planck gas. Equation (7) can be written as:

$$\frac{\partial^2 T}{\partial t^2} + \left(\frac{c^5}{\hbar G}\right)^{1/2} \frac{\partial T}{\partial t} = c^2 \nabla^2 T. \tag{8}$$

It is interesting to observe that QHT is the damped wave equation and gravitation influences the dissipation of the thermal energy. In paper [4] P. G. Bergmann discussed the conditions for the thermal equilibrium in the presence of the gravitation. As it was shown in that paper, the thermal equilibrium of spatially extended systems is characterized by the "global" temperature and a "local" temperature which is sensitive to the value of the gravitational potential.

On the other hand equation (8) describes the correlated random walk of Planck mass. For mean square displacement of random walkers we have

$$\langle x^2 \rangle = \frac{2\hbar}{M_p}\left[\frac{t}{\tau_p} - \left(1 - e^{-t/\tau_p}\right)\right]. \tag{9}$$

From formula (6), we conclude that, for $t \sim \tau_p$,

$$\langle x^2 \rangle \cong \frac{\hbar}{M_p \tau} t^2 \tag{10}$$

or

$$\langle x^2 \rangle \cong c^2 t^2, \tag{11}$$

and we have thermal wave with velocity c. For $t >> \tau_p$, we have

$$\langle x^2 \rangle \sim \frac{2\hbar\tau}{M_p} \left(\frac{t}{\tau_p} - 1 \right) = \frac{2\hbar}{M_p} t = 2D^{\text{Planck}} t, \tag{12}$$

where

$$D^{\text{Planck}} = \frac{\hbar}{M_p} = \left(\frac{\hbar G}{c} \right)^{1/2} \tag{13}$$

denotes the diffusion coefficient for Planck mass.

We can say that for time period of the order of Planck time QHT describes the propagation of thermal wave with velocity equal c and for time period much longer than τ_p QHT describes the diffusion process with diffusion coefficient dependent on gravitation constant G.

The quantum hyperbolic heat equation (7) as a hyperbolic equation shed a light on the time arrow in Planck gas. When QHT is written in the equivalent form

$$\tau_p \frac{\partial^2 T}{\partial t^2} + \frac{\partial T}{\partial t} = \left(\frac{\hbar G}{c} \right)^{1/2} \nabla^2 T, \tag{14}$$

then, for time period shorter than τ_p, we have preserved time reversal for thermal processes, viz,

$$\frac{1}{c^2} \frac{\partial^2 T}{\partial t^2} = \nabla^2 T, \tag{15}$$

and, for $t >> \tau_p$,

$$\frac{\partial T}{\partial t} = \left(\frac{\hbar G}{c} \right)^{1/2} \nabla^2 T, \tag{16}$$

the time reversal symmetry is broken.

These new properties of QHT open new possibilities for the interpretation of Planck time. Before τ_p thermal processes in Planck gas are symmetrical in time. After τ_p the time symmetry is broken. Moreover it seems that gravitation is activated after τ_p and this fact creates time arrow (formula (16)).

3 Conclusions

In this paper the thermal properties of the Planck gas are discussed. We have developed quantum heat transport equation (QHT) for Planck gas, with quantum thermal diffusion coefficient $D^{\text{Planck}} = (\hbar G/c)^{1/2}$. The quantum of the thermal energy, the *heaton* for Planck gas is defined and calculated, $E^{\text{Planck}} = 10^{19}$ GeV. It is shown that for $t >$ Planck time, the time symmetry is broken.

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