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THE ACCELERATION HORIZON AND THE THERMODYNAMICS OF ISOLATED PARTICLE

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Abstract. In this paper, we demonstrate the de Broglie's hypothesis of the existence of a thermodynamic particle is correct. For stochastic model of electron, we demonstrate that the electron as stochastic oscillator (system in accelerated motion) “sees” the stochastic Classical Zero-Point Field (CZPF) as a Planckian field with temperature equal to the anticipated de Broglie temperature ($T_o \cong mc^2/k_B$). Using the event horizon for a small bubble in vacuum that oscillating frequency equal to zitterbewegung frequency, we show that it behaves like an electric charge that have a stochastic motion and scattering the stochastic Classical Zero-Point Field (CZPF).

Keywords: Broglie's hypothesis; event horizon; Classical Zero-Point Field.

1. Introduction

The article is trying to establish a link between the isolated particle thermodynamics and the acceleration horizon in the framework of stochastic physics.

Louis de Broglie, in order to explain quantum effects as an interaction of microscopic systems with a sub-quantum environment, proposed a

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thermodynamics of the isolated particle, *i.e.* the hidden thermodynamics of isolated particles (de Broglie, 1961; de Broglie, 1967) in which the particle is modelled as a thermodynamic system in interaction with the sub-quantum medium (the stochastic medium).

In the stochastic electrodynamics (stochastic physics of the charged particles), stochastic environment is modelled as a homogeneous and isotropic background of electromagnetic waves having randomly distributed phases.

Because this background is analogue the of the zero fluctuations background of the vacuum in quantum electrodynamics, was named Classical Zero-Point Field-CZPF (Puthoff, 1989; Boyer, 1969; Rueda, 1978; Rueda and Lecompte, 1979; Rueda, 1981; Rueda and Cavalleri, 1983).

To an accelerated observer (non-inertial) the electromagnetic radiation background with the zero temperature is perceived as a background of thermal radiation with temperature proportional to acceleration. This phenomenon is known as Unruh-Davies effect (Unruh, 1976; Davies, 1975). Timothy M. Boyer deduced the formula expressing the thermal radiation temperature depending on acceleration in the framework of the stochastic electrodynamics (Boyer, 1980).

In the second part of the paper we determine the average temperature corresponding to the modelled particles as an oscillator electrically charged in interaction with CZPF.

In the third part, we demonstrate that the angular frequency corresponding to the maximum (per Wien's displacement law) the Planckian background attached of the particle is angular frequency own of particle (modelled as a stochastic oscillator).

In the fourth part, we analyse the properties of the acceleration (Rindler, 2001) for a system (a particle) in oscillatory motion. We obtain the expressions of energy densities and the radiation entropy from the particle horizon. With these get to the expressions of energy, entropy and power corresponding to the particle horizon.

In the fifth part, we study the problem of the stochastic model horizon of electron and we find results like those of the second part.

The sixth part is devoted to discussions and conclusions.

2. The Average Temperature Corresponding to a Particle in Interaction with CZPF

A particle with the electric charge q_e and mass m is modelled like an oscillator with the natural angular frequency ω_0 in interaction with the CZPF background of vectors (Simaciu *et al.*, 1995; Simaciu and Ciubotariu, 2001).

$$\vec{E}_0(\vec{r},t) = \mathrm{Re}\sum_{\lambda=1}^{2}\int d^3k\,\hat{\in}\left(\frac{\hbar\omega}{8\pi^3\varepsilon_0}\right)^{1/2}\exp\left[-i\left(\omega t-\vec{k}\vec{r}-\theta\right)\right], \tag{1a}$$

$$\vec{H}_0(\vec{r},t) = \mathrm{Re}\sum_{\lambda=1}^{2}\int d^3k\left(\hat{k}\times\hat{\in}\right)\left(\frac{\hbar\omega}{8\pi^3\mu_0}\right)^{1/2}\exp\left[-i\left(\omega t-\vec{k}\vec{r}-\theta\right)\right]. \tag{1b}$$

Below the action of CZPF (fund) background, the particle running a nonrelativistic oscillatory motion given by the equation

$$\ddot{\vec{r}} + \omega_0^2\vec{r} = \frac{q}{m}\vec{E}_0 + \Gamma\dddot{\vec{r}}\ , \tag{2}$$

with the radiation damping coefficient $\Gamma = q^2 / 6\pi\varepsilon_0 mc^3 = 2e^2 / 3mc^3$.

The solution of this equation is

$$\vec{r} = \frac{q}{Dm}\vec{E}_0\,, \tag{3}$$

with $D = \omega_0^2 - \omega^2 - i\Gamma\omega^3$ and $DD^* = |D|^2 = \left(\omega_0^2-\omega^2\right)^2 + \Gamma^2\omega^6$.

The acceleration of the oscillator is

$$\vec{a} = \ddot{\vec{r}} = \frac{q}{Dm}\ddot{\vec{E}}_0 = \frac{q\omega^2}{Dm}\vec{E}_0\,. \tag{4a}$$

The average acceleration (we average after the random phase) is zero and the average square of the acceleration is

$$\left\langle \vec{a}^2\right\rangle = \frac{q^2}{m^2}\left\langle\frac{\omega^4\vec{E}_0^2}{|D|^2}\right\rangle \neq 0\,. \tag{4b}$$

Substituting the expression of the electric intensity of CZPF background (1a) in $\left\langle\omega^4\left(\vec{E}_0^2/|D|^2\right)\right\rangle$ result that

$$\left\langle\frac{\omega^4\vec{E}_0^2}{|D|^2}\right\rangle = \frac{1}{2}\left\langle \mathrm{Re}\sum_{\lambda=1}^{2}\sum_{\lambda'=1}^{2}\int\frac{\omega^4}{D^*}d^3k\int\frac{d^3k'}{D'}\hat{\in}\hat{\in}'\left(\frac{\hbar\omega}{8\pi^3\varepsilon_0}\right)^{1/2}\left(\frac{\hbar\omega'}{8\pi^3\varepsilon_0}\right)^{1/2}\cdot\right.$$
$$\left.\exp\left[i(\vec{k}-\vec{k}')\vec{r} - i(\omega-\omega')t + i\theta - i\theta'\right]\right\rangle = \tag{5}$$
$$\frac{1}{\varepsilon_0}\int\frac{\hbar\omega^7}{2\pi^2c^3|D|^2}d\omega = \frac{1}{\varepsilon_0}\int\frac{\omega^4\rho(\omega)}{|D|^2}d\omega.$$

If we replace in (5) the section of scattering of the plan-polarized radiation by the particle

$$\sigma(\omega) = \frac{\sigma_T\omega^4}{DD^*} = \frac{8\pi}{3}\left(\frac{e^2}{mc^2}\right)^2\frac{\omega^4}{|D|^2} = \frac{6\pi\Gamma^2c^2\omega^4}{|D|^2}\,, \tag{6}$$

result that

$$\left\langle \frac{\omega^4 \vec{E}_0^2}{|D|^2} \right\rangle = \frac{3}{8\pi\varepsilon_0}\left(\frac{mc^2}{e^2}\right)^2 \int \frac{\omega^4 \rho(\omega)}{|D|^2} d\omega \ . \tag{7}$$

Substituting (7) in (4) we obtain as follow

$$\left\langle \vec{a}^2 \right\rangle = \frac{q^2}{m^2}\left\langle \frac{\omega^4 \vec{E}_0^2}{|D|^2} \right\rangle = \frac{3q^2}{8\pi\varepsilon_0}\left(\frac{c^2}{e^2}\right)^2 \int \frac{\omega^4 \rho(\omega)}{|D|^2} d\omega = \frac{3}{2}\left(\frac{c^4}{e^2}\right)\int \sigma(\omega)\rho(\omega) d\omega . \tag{8}$$

Excepting a factor of the unity order that depends of the expression the scattering section of an isotropic background, according to the paper (Simaciu and Ciubotariu, 2001) integral

$$P_a = P_e = P_{\hat{i}} = \int c\sigma(\omega)\rho(\omega) d\omega , \tag{9}$$

represent scattered power (the power absorbed is equal to the radiated power and therefore the CZPF background is scattered by oscillator) by the oscillator from CZPF.

Replacing (9) in (8) result the Larmor relationship (Jackson, 1975)

$$P_e = \frac{2}{3}\left(\frac{e^2}{c^3}\right)\left\langle \vec{a}^2 \right\rangle . \tag{10}$$

If is calculated the absorbed power according to the equation (9), result

$$P_a = \int_0^\infty c\sigma(\omega)\rho(\omega) d\omega = \frac{e^2 \hbar \omega_0^3}{mc^3} , \tag{11}$$

Equalling the two relations we obtain expression of the mean square acceleration

$$\left\langle \vec{a}^2 \right\rangle = \frac{3\hbar\omega_0^3}{2m} \tag{12}$$

and the average acceleration of the oscillator is

$$a_m = \sqrt{\left\langle \vec{a}^2 \right\rangle} = \omega_0 \sqrt{\frac{3\hbar\omega_0}{2m}} . \tag{13}$$

According to the works (Boyer, 1984), for particle accelerated the CZPF background becomes a Planckian background with temperature

$$T = \frac{\hbar}{2\pi c k_B} a \tag{14}$$

which also includes of the zero-point field.

Replacing (13) in (14) result:

$$T_o = \frac{\hbar}{2\pi c k_B} a_m = \frac{\hbar\omega_0}{k_B}\sqrt{\frac{3\hbar\omega_0}{8\pi^2 mc^2}} . \tag{15}$$

If the total energy of the oscillator (as a two-dimensional system with two degrees of freedom) is

$$mc^2 = \hbar\omega_0 , \tag{16}$$

replacing (15) result:

$$T_o = \frac{\hbar}{2\pi c k_B} a_m \cong \frac{\hbar\omega_0}{k_B}\sqrt{\frac{3}{8\pi^2}} = \frac{mc^2}{k_B}\sqrt{\frac{3}{8\pi^2}} , \tag{17}$$

i.e. the oscillator acts as a particle submerged in a thermostat having the temperature proportional to the mass of the oscillator (de Broglie, 1961; de Broglie,1962).

A similar result is obtained according to the approach made by Feynman (Feynman, 1964, Ch. 41, § 2) of an oscillator charged in interaction with the of equilibrium thermal radiation having the temperature T .

According to the relation (41.4) from (Feynman, 1964), the power radiated by an oscillator is proportional to the energy of the oscillator W_o

$$P_e = \Gamma W_o = \frac{2}{3}\left(\frac{e^2\omega_0^2}{mc^3}\right) W_o . \tag{18}$$

If the oscillator is in equilibrium with a thermostat having the temperature T , its average (medium) energy is

$$W_o = 2\frac{k_B T}{2} = k_B T , \tag{19}$$

for a one-dimensional oscillator.

Replacing (19) in (18) result

$$P_e = \Gamma W_o = \frac{2}{3}\left(\frac{e^2\omega_0^2}{mc^3}\right) k_B T . \tag{20}$$

If the oscillator is in interaction with CZPF background, absorbed power is given by (11). Equalling (18) with (11) result the zero energy of the oscillator

$$W_o = 3\frac{\hbar\omega_0}{2} . \tag{21}$$

Since the power absorbed was calculated for a three-dimensional oscillator, result that the energy for a one-dimensional oscillator in interaction with CZPF is

$$W_{o1} = \frac{\hbar\omega_0}{2} . \tag{22}$$

3. The Wien's Displacement Law for the Thermostat Attached of the Particle

According to Wien's displacement law (Boyer, 1984), the Planckian background attached of the particle has a maximum for the wavelength

$$\lambda_m T_d = \frac{ch}{x_m k_B},\ x_m = 4{,}965 \tag{23a}$$

or

$$\lambda_m = \frac{ch}{x_m k_B T_d} \text{ or } \nu_m = \frac{c}{\lambda_m} = \frac{x_m k_B}{2\pi\hbar} T_o \text{ or } \omega_m = \frac{x_m k_B}{\hbar} T_o \ . \tag{23b}$$

Replacing the expression of the oscillator temperature (17) in (23b), result the remarkable relationship

$$\omega_m = \frac{mc^2}{\hbar}\sqrt{\frac{3x_m^2}{8\pi^2}} = \omega_0\sqrt{\frac{3x_m^2}{8\pi^2}} \cong \omega_0 . \tag{24}$$

Relation (24) demonstrates that the particle, as oscillator, absorbs and emits resonant from CZPF background, the natural angular frequency being angular frequency for which Planckian background has the spectral density $\rho(\omega,T)$.

4. The Properties of the Acceleration Horizon

4.1. The Horizon of a System in Accelerated Movement

A system in accelerated motion on Ox the direction, with acceleration a, perceive a horizon at distance (Rindler, 2001),

$$d_o = \frac{c^2}{a} . \tag{25}$$

The horizon is a plane perpendicular to the direction of movement located at distance given by (25)

From physical point of view, the existence of horizon is interpreted as limit until which the system can interact through fields that propagate at the speed of light. Systems located beyond the horizon, $x > d_o$, no longer interact with the system located in the origin of coordinates - are not causally related to accelerated system. In this case, area and volume of the horizon are infinite because on directions in the sense of the acceleration, horizon radius is infinite.

4.2. The Horizon of a System in Oscillatory Motion

Either a physical system which accomplish an oscillatory movement by amplitude q_0 and the angular frequency ω

$$q(t) = q_0 \sin(\omega t) . \tag{26}$$

Acceleration of this system is

$$\ddot{q} = q_0\omega^2 \sin(\omega t) = \omega^2 q . \tag{27}$$

We consider that a particle in the physical vacuum is a bubble (Leighton, 1994). The radius of this bubble is at equilibrium R. The bubble executes under the action of the vacuum waves radial oscillations of instant amplitude $q << R$, given by (26).

An observer at instantly rest on the surface of the bubble perceives a horizon of the acceleration by spherical form with variable radius.

Replacing equation (27) in the expression of the horizon distance result

$$r_o(t) = \frac{c^2}{\omega^2 q(t)} = \frac{c^2}{\omega^2 q_0 \sin(\omega t)} \tag{28}$$

and $c^2 / \omega^2 q_0 \le r_o(t) \le \infty$.

The horizon radius relative to the centre of the bubble is

$$R_o(t) = R + r_o(t) = R + \frac{c^2}{\omega^2 q(t)}. \tag{29}$$

This radius of the horizon mediated in time can be calculated using the average acceleration of the horizon surface

$$a_m = \sqrt{\left\langle (\ddot{q})^2 \right\rangle_t} = q_0\omega^2 \sqrt{\left\langle \sin^2(\omega t) \right\rangle_t} = \frac{q_0\omega^2}{\sqrt{2}}. \tag{30}$$

With this average acceleration, average radius of horizon as against the bubble centre is

$$R_m = R + \frac{c^2\sqrt{2}}{\omega^2 q_0}. \tag{31}$$

The average area of horizon is

$$A_m = 4\pi R_m^2 = 4\pi R^2 \left(1 + \frac{\sqrt{2}c^2}{R q_0 \omega^2}\right)^2 \tag{32}$$

and

$$V_m = \frac{4\pi}{3} R_m^3 = \frac{4\pi}{3} R^3 \left(1 + \frac{\sqrt{2}c^2}{R q_0 \omega^2}\right)^3 \tag{33}$$

is the volume of the accelerate horizon.

4.3. Energy's and Entropy's Densities from Particle Horizon

The observer from bubble surface perceives the CZPF background of as a of background of thermal radiation having temperature proportional to acceleration, according to the relation (14).

The energy density of this radiation is

$$w = \frac{4\sigma_{SB}}{c} T^4. \tag{34}$$

Replacing (14) in (34) result

$$w(a)=\frac{\sigma_{SB}\hbar^4}{2^2\pi^4c^5k^4}a^4 . \tag{35}$$

Because the Stefan-Boltzmann constant has the expression

$$\sigma_{SB}=\frac{3(1,082)k^4}{2\pi^2c^2\hbar^3} , \tag{36}$$

resulting, through replacement within (35)

$$w(a)=\frac{3(1,082)\hbar}{2^3\pi^6c^7}a^4 . \tag{37}$$

The expression of entropy density of the radiation is

$$w_S(a)=\int\frac{dw(a)}{T(a)}=\frac{2^4\sigma_{SB}}{3c}\left(T(a)\right)^3 . \tag{38}$$

Replacing (14) and (36) in (38), result

$$w_S(a)=\frac{(1,082)k}{\pi^5c^6}a^3 . \tag{39}$$

4.4. Energy, Entropy and Power of Particle Horizon

The energy contained by the horizon with radius given by the relations (31) and having the volume given by (33) is, with $a=a_m$

$$W(a_m)=V_m w(a_m)=\frac{(1,082)\hbar}{2\pi^5c}\left(1+\frac{Rq_0\omega^2}{c^2\sqrt{2}}\right)^3\frac{q_0\omega^2}{\sqrt{2}} . \tag{40}$$

The entropy contained in the horizon volume is with (33) and (38), for $a=a_m$

$$S(a_m)=V_m w_S(a_m)=\frac{4(1,082)}{3\pi^4}\left(1+\frac{Rq_0\omega^2}{c^2\sqrt{2}}\right)^3 k . \tag{41}$$

We find corresponding power for this radiation considering that is emitted through the area the horizon (32), with $a=a_m$

$$P(a_m)=A_m I(a_m)=A_m\frac{cw(a_m)}{3}=\frac{(1,082)\hbar}{2\pi^5c^2}\left(1+\frac{Rq_0\omega^2}{c^2\sqrt{2}}\right)^2\left(\frac{q_0\omega^2}{\sqrt{2}}\right)^2 . \tag{42}$$

If we consider approximation of small oscillations, that is $q_o<<R$, $c/\omega>>q_0$ and $Rq_0\omega^2/c^2<<1$, result that entropy from volume of the horizon is a constant

$$S(a_m)\cong\frac{4(1,082)}{3\pi^4}k \tag{43}$$

and dispersed power (absorbed and emitted, at equilibrium) is of Larmor type

$$P(a_m) \cong \frac{(1,082)\hbar}{2\pi^5 c^2}\left(\frac{q_0\omega^2}{\sqrt{2}}\right)^2 = \frac{(1,082)\hbar}{2\pi^5 c^2} a_m^2, \tag{44}$$

i.e. it is power emitted of an accelerated electric charge. According to the classical theory, a charged particle with electrical charge and which is a in an accelerated motion radiates a power given by Larmor relation (Jackson, 1975)

$$P_L = \frac{2}{3}\frac{e^2}{c^3}a^2 = \frac{2}{3}\left(\frac{e^2}{\hbar c}\right)\frac{\hbar}{c^2}a^2. \tag{45}$$

Comparing relations (45) and (46), result, with $a = a_m$

$$\frac{e^2}{\hbar c} = \frac{3(1,082)}{2^2\pi^5}. \tag{46}$$

The difference between the two values is relatively small: $e^2/\hbar c \cong 1/137$ and $3(1,082)/\left(2^2\pi^5\right) \cong 1/102$. Improving the model can lead to parameter values which determine the equality of constants.

5. The Horizon of Stochastic Model for Electron

In stochastic physics (Simaciu and Ciubotariu, 2001) the electron is a two-dimensional oscillator (circular motion), that changes the plan of the circular motion with zitter frequency (equivalent of movement on a sphere). Result that this model is just a case of generating a spherical acceleration horizon.

According to this model, the speed on orbit is $\upsilon = c$, and replacing in (25) and (29) with $R = R_e$ result the centripetal acceleration and the horizon radius:

$$a_{ce} = \frac{c^2}{R_e}, \tag{47}$$

$$R_{oce} = 2\frac{c^2}{a_{ce}} = 2R_e. \tag{48}$$

Replacing those sizes in the energy expressions (40) and power (42), with $a = a_m = a_{ce}$ result

$$W_e(a_{ce}) = V(a_{ce})w(a_{ce}) = \frac{2^2(1,082)\hbar}{\pi^5 c}a_{ce}, \tag{49}$$

$$P_e(a_{ce}) = \frac{(1,082)\hbar}{\pi^5 c^2}a_{ce}^2. \tag{50}$$

Outside of the acceleration horizon, is issued radiation with power given by relations (50 and 51). According to the classical theory of the oscillator electrically charged, this radiates a power given by relation (45) which becomes, with $a = a_{ce}$,

$$P_L = \frac{2}{3}\left(\frac{e^2}{\hbar c}\right)\frac{\hbar}{c^2}\cdot a_{ce}^2 . \tag{51}$$

Comparing the expression (51) with expressions of power emitted by the accelerating horizon (51) or (50), result that power issued of the horizon could be interpreted as the power radiated by oscillator, if the coefficients front the expression $\hbar a_{ce} / c^2$ are equal. These coefficients have the values:

$$\frac{2}{3}\left(\frac{e^2}{\hbar c}\right) = 4{,}86\cdot 10^{-3},\ \frac{1{,}082}{\pi^5} = 3{,}53\cdot 10^{-3} . \tag{52}$$

The coincidence of expressions powers is not accidental. We found the result from Section 4.4. An analysis more exact for mechanisms for the generating of horizon for a system which execute a moving of oscillation three-dimensional, is likely to lead to better coincidence of the powers relations.

If we replace in the expression (49) the acceleration corresponding to the model of electron, $R_e = \hbar / m_e c, a_{ce} = m_e c^3 / \hbar$ result:

$$W_e(a_{ce}) = \frac{2^2(1{,}082)\hbar}{\pi^5 c}\cdot\frac{m_e c^3}{\hbar} = \frac{2^2(1{,}082)}{\pi^5} m_e c^2 .$$

It follows that there is a connection between the thermal radiation energy captured in the volume of horizon and energy electron $m_e c^2$.

6. Discussion and Conclusions

We emphasized the fact that de Broglie's hypothesis about the existence a thermodynamic of the particle is correct. In the case of electron stochastic model, we demonstrated that the electron as stochastic oscillator and therefore system in accelerated motion “sees” the CZPF background like a Planckian background with temperature equal to the anticipated one by Broglie ($T_o \cong mc^2/k_B$).

It is interesting that the angular frequency corresponding to the maximum of spectral density of the Planckian background is equal to the natural frequency of the stochastic oscillator (expression 24). This behaviour of the stochastic oscillator is consistent with bubble model (a hole in the physical vacuum) oscillating radially, for an electrically charged particle. The oscillations are induced and maintained by the interaction of the bubble with the zero oscillations of the vacuum. At equilibrium bubble absorbs and emits waves with angular frequency nearly, as size, to the natural frequency. For electron, this is the zitterbewegung frequency. According the results section 4 and 5, the two models, punctual task that absorbs and emits radiation of CZPF (in other words scattered this radiation) and the bubble in vacuum radial's oscillating (centre bubble's is at rest) are equivalent.

Two such bubbles interact with forces of attraction or repulsion, depending on the phase difference of the oscillations. This phenomenon is known in acoustic as Bjerknes secondary interaction (Bjerknes, 1906; Bjerknes, 1915; Bărbat *et al*., 1999). This interaction has been studied theoretically and experimentally only in case the two bubbles are in the field of plane acoustic waves that propagate or is stationary. The highlighting a task acoustic electric type is made only studying the interaction two bubbles with a thermal background of acoustic waves. In this case the bubble absorbs energy from the background, at resonance, for natural frequency. This acoustic model will be studied in a future study.

The existence of a spherical horizon, for the particle models proposed in the paper, brings into question and the existence of gravitational charge corresponding to the particle. This connection exists because the gravitational interaction for a body with mass involves a horizon of events in case collapsing at a radius equal to the Schwarzschild radius (the radius of black hole) (Rindler, 2001).

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ORIZONTUL ACCELERĂRII ŞI TERMODINAMICA PARTICULEI IZOLATE

(Rezumat)

În lucrare demonstrăm că ipoteza lui de Broglie a existenţei unei termodinamici a particulei este corectă. În cazul modelului stocastic de electron demonstrăm că electronul, ca oscilator stocastic şi deci sistem în mişcare accelerată, "vede" fondul CZPF ca un fond planckian cu temperatura egală cu cea anticipată de Broglie ($T_o \cong mc^2/k_B$). Folosind orizontul evenimentelor, pentru o bulă din vacuum care execută mici oscilaţii egale cu frecvenţa de zitterbewegung, arătăm că aceasta se comportă ca o sarcină electrică care se mişcă stocastic şi împrăştie Classical Zero-Point Field (CZPF).