Stability of matter in the accelerating spacetime

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1 Introduction

In the seminal paper [1] F. Calogero described the cosmic origin of quantization. In paper [1] the tremor of the cosmic particles is the origin of the quantization and the characteristic acceleration of these particles $a \sim 10^{-10} \text{ m/s}^2$ was calculated. In our earlier paper [2] the same value of the acceleration was obtained and compared to the experimental value of the measured spacetime acceleration. In this paper we define the cosmic force – Planck force, $F_{\text{Planck}} = M_P a_{\text{Planck}} (a_{\text{Planck}} \sim a)$ and study the history of Planck force as the function of the age of the Universe.

Masses introduce a curvature in spacetime, light and matter are forced to move according to spacetime metric. Since all the matter is in motion, the geometry of space is constantly changing. A Einstein relates the curvature of space to the mass/energy density:

$$G = kT.$$  

$G$ is the Einstein curvature tensor and $T$ the stress-energy tensor. The proportionality factor $k$ follows by comparison with Newton’s theory of gravity: $k = G/c^4$ where $G$ is the Newton’s gravity constant and $c$ is the vacuum velocity of light; it amounts to about $2.10^{-43} \text{ N}^{-1}$, expressing the rigidity of spacetime.

In paper [2] the model for the acceleration of spacetime was developed. Prescribing the $-G$ for spacetime and $+G$ for matter the acceleration of spacetime was obtained:

$$a_{\text{Planck}} = -\frac{1}{2} \left( \frac{\pi}{4} \right)^{1/2} \frac{(N + \frac{3}{4})^{1/2}}{M^{3/2}} A_P,$$  

(2)

where $A_P$, Planck acceleration equal, viz.:

$$A_P = \left( \frac{c^2}{\hbar G} \right)^{1/2} = \frac{c}{\tau_P} \approx 10^{51} \text{ms}^{-2}.$$  

(3)

As was shown in paper [2] the $a_{\text{Planck}}$ for $N = M = 10^{60}$ is of the order of the acceleration detected by Pioneer spacecrafts [3].

Considering $A_P$ it is quite natural to define the Planck force $F_{\text{Planck}}$:

$$F_{\text{Planck}} = M_P A_P = \frac{c^4}{G} = k^{-1},$$  

(4)
where
\[ MP = \left( \frac{\hbar c}{G} \right)^{1/2}. \]

From formula (4) we conclude that \( F_{\text{Planck}}^{-1} = \) rigidity of the spacetime. The Planck force, \( F_{\text{Planck}} = \frac{c^4}{G} = 1.2 \times 10^{44} \) N can be written in units which characterize the microspacetime, i.e. GeV and fm.

In that units
\[ k^{-1} = F_{\text{Planck}} = 7.6 \times 10^{38} \text{ GeV/fm}. \]

2 The Planck, Yukawa and Bohr forces

As was shown in paper [2] the present value of Planck force equal
\[ F_{\text{Planck}}^\text{Now}(N = M = 10^{60}) \approx \frac{1}{2} \left( \frac{\pi}{4} \right)^{1/2} 10^{-60} \frac{c^4}{G} = -10^{-22} \frac{\text{GeV}}{\text{fm}}. \] (5)

In paper [3] the Planck time \( \tau_P \) was defined as the relaxation time for spacetime
\[ \tau_P = \frac{\hbar}{MPc^2}. \] (6)

Considering formulae (4) and (6) \( F_{\text{Planck}} \) can be written as
\[ F_{\text{Planck}} = \frac{MPc}{\tau_P}, \] (7)
where \( c \) is the velocity for gravitation propagation. In paper [5] the velocities and relaxation times for thermal energy propagation in atomic and nuclear matter were calculated:
\[ v_{\text{atomic}} = \alpha_{\text{em}}c, \] (8)
\[ v_{\text{nuclear}} = \alpha_{s}c, \]
where \( \alpha_{\text{em}} = \frac{e^2}{\hbar c} = 1/137, \alpha_{s} = 0.15. \) In the subsequent we define atomic and nuclear accelerations:
\[ a_{\text{atomic}} = \frac{\alpha_{\text{em}}c}{\tau_{\text{atomic}}}, \] (9)
\[ a_{\text{nuclear}} = \frac{\alpha_{s}c}{\tau_{\text{nuclear}}}. \]
Considering that \( \tau_{\text{atomic}} = \frac{\hbar}{(m_e \alpha^2 \epsilon^2)} \), \( \tau_{\text{nuclear}} = \frac{\hbar}{(m_N \alpha^2 c^2)} \) one obtains from formula (9)

\[
\begin{align*}
a_{\text{atomic}} &= \frac{m_e c^3 \alpha^3}{\hbar}, \\
a_{\text{nuclear}} &= \frac{m_N c^3 \alpha^3_s}{\hbar}.
\end{align*}
\] 

We define, analogously to Planck force the new forces: \( F_{\text{Bohr}} \), \( F_{\text{Yukawa}} \)

\[
\begin{align*}
F_{\text{Bohr}} &= m_e a_{\text{atomic}} = \frac{(m_e c^2)^2}{\hbar c} \alpha^3_{\text{em}} = 5 \times 10^{-13} \, \text{GeV} / \text{fm}, \\
F_{\text{Yukawa}} &= m_N a_{\text{nuclear}} = \frac{(m_N c^2)^2}{\hbar c} \alpha^3_s = 1.6 \times 10^{-2} \, \text{GeV} / \text{fm}.
\end{align*}
\]

Comparing formulae (5) and (11) we conclude that gradients of Bohr and Yukawa forces are much large than \( F_{\text{Planck}} \), i.e.:

\[
\begin{align*}
\frac{F_{\text{Bohr}}}{F_{\text{Planck}}} &= \frac{5 \times 10^{-13}}{10^{-22}} \sim 10^9, \\
\frac{F_{\text{Yukawa}}}{F_{\text{Planck}}} &= \frac{10^{-2}}{10^{-22}} \sim 10^{20}.
\end{align*}
\]

The formulae (12) guarantee present day stability of matter on the nuclear and atomic levels.

As the time dependence of \( F_{\text{Bohr}} \) and \( F_{\text{Yukawa}} \) are not well established, in the subsequent we will assumed that \( \alpha_s \) and \( \alpha_{\text{em}} \) do not dependent on time. Considering formulae (8) and (11) we obtain

\[
\begin{align*}
\frac{F_{\text{Yukawa}}}{F_{\text{Planck}}} &= \frac{1}{(\frac{\pi}{4})^{1/2}} \frac{(m_N c^2)^2 \alpha^3_s}{M_P c^2 \hbar T}, \\
\frac{F_{\text{Bohr}}}{F_{\text{Planck}}} &= \frac{1}{(\frac{\pi}{4})^{1/2}} \frac{(m_e c^2)^2 \alpha_{\text{em}}}{M_P c^2 \hbar T}.
\end{align*}
\]

As can be realized from formulae (13), (14) in the past \( F_{\text{Planck}} \sim F_{\text{Yukawa}} \) (for \( T = 0.002 \, \text{s} \)) and \( F_{\text{Planck}} \sim F_{\text{Bohr}} \) (for \( T \sim 10^8 \, \text{s} \)), \( T \) = age of universe. The calculated ages define the limits for instability of the nuclei and atoms.
3 The Planck, Yukawa and Bohr particles

In 1900 M. Planck introduced the notion of the universal mass, later on called the Planck mass

\[ M_P = \left( \frac{\hbar c}{G} \right)^{1/2}, \quad F_{Planck} = \frac{M_P c}{\tau_P}. \]  

(15)

Considering the definition of the Yukawa force

\[ F_{Yukawa} = \frac{m_N v_N}{\tau_N} = \frac{m_N \alpha_{strong} c}{\tau_N}, \]  

(16)

de the formula (16) can be written as:

\[ F_{Yukawa} = \frac{m_{Yukawa} c}{\tau_N}, \]  

(17)

where

\[ m_{Yukawa} = m_N \alpha_{strong} \approx 147 \, \text{MeV} \frac{c^2}{\text{MeV}} \sim m_\pi. \]  

(18)

From the definition of the Yukawa force we deduced the mass of the particle which mediates the strong interaction – pion mass postulated by Yukawa in [7].

Accordingly for Bohr force:

\[ F_{Bohr} = \frac{m_e v}{\tau_{Bohr}} = \frac{m_e \alpha_{em} c}{\tau_{Bohr}} = \frac{m_{Bohr} c}{\tau_{Bohr}}, \]  

(19)

\[ m_{Bohr} = m_e \alpha_{em} = 3.7 \, \text{keV} \frac{c^2}{\text{keV}}. \]  

(20)

For the Bohr particle the range of interaction is

\[ r_{Bohr} = \frac{\hbar}{m_{Bohr} c} \sim 0.1 \, \text{nm}, \]  

(21)

which is of the order of atomic radius.

Considering the electromagnetic origin of the mass of the Bohr particle, the planned sources of hard electromagnetic field, e.g. free electron laser (FEL) at TESLA accelerator (DESY) are best suited to the investigation of the properties of the Bohr particles.
4 Possible interpretation of $F_{\mathrm{Planck}}$, $F_{\mathrm{Yukawa}}$ and $F_{\mathrm{Bohr}}$

In an important work, published already in 1951 J. Schwinger demonstrated that in the background of a static uniform electric field, the QED vacuum is unstable and decayed with spontaneous emission of $e^+e^-$ pairs. In the paper Schwinger calculated the critical field strengths $E_S$:

$$E_S = \frac{m_e^2 c^3}{\epsilon h}. \quad (22)$$

Considering formula (22) we define the Schwinger force:

$$F_{\text{Schwinger}}^e = e E_S = \frac{m_e^2 c^3}{\hbar}. \quad (23)$$

Formula (23) can be written as:

$$F_{\text{Schwinger}}^e = \frac{m_e c}{\tau_{\text{Sch}}}, \quad (24)$$

where

$$\tau_{\text{Sch}} = \frac{\hbar}{m_e c^2} \quad (25)$$

is Schwinger relaxation time for the creation of $e^+e^-$ pair. Considering formulae (11) the relation of $F_{\text{Yukawa}}$ and $F_{\text{Bohr}}$ to the Schwinger force can be established

$$F_{\text{Yukawa}} = \alpha_s^3 \left( \frac{m_N}{m_e} \right)^2 F_{\text{Schwinger}}^e, \quad \alpha_s = 0.15, \quad (26)$$

$$F_{\text{Bohr}} = \alpha_{\text{em}}^3 F_{\text{Schwinger}}^e, \quad \alpha_{\text{em}} = \frac{1}{137},$$

and for Planck force

$$F_{\text{Planck}} = \left( \frac{M_P}{m_e} \right)^2 F_{\text{Schwinger}}^e. \quad (27)$$

In Table 1 the values of the $F_{\text{Schwinger}}^e$, $F_{\text{Planck}}$, $F_{\text{Yukawa}}$ and $F_{\text{Bohr}}$ are presented, all in the same units GeV/fm. As in those units the forces span the range $10^{-13}$ to $10^{38}$ it is valuable to recalculate the Yukawa and Bohr
forces in the units natural to nuclear and atomic level. In that case one obtains:

$$F_{\text{Yukawa}} \sim \frac{16 \text{ MeV}}{\text{fm}}. \quad (28)$$

It is quite interesting that $a_v \sim 16 \text{ MeV}$ is the volume part of the binding energy of the nuclei (droplet model).

Table 1: Schwinger, Planck, Yukawa and Bohr forces

| $F_{\text{Schwinger}}$ | $F_{\text{Planck}}$ | $F_{\text{Yukawa}}$ | $F_{\text{Bohr}}$ |
|------------------------|----------------------|----------------------|----------------------|
| [GeV/fm]               | [GeV/fm]             | [GeV/fm]             | [GeV/fm]             |
| $\sim 10^{-6}$         | $\sim 10^{38}$      | $\sim 10^{-2}$       | $\sim 10^{-13}$      |

For the Bohr force considering formula (29) one obtains:

$$F_{\text{Bohr}} \sim \frac{50 \text{ eV}}{0.1 \text{ nm}}. \quad (29)$$

Considering that the Rydberg energy $\sim 27 \text{ eV}$ and Bohr radius $\sim 0.1 \text{ nm}$ formula (29) can be written as

$$F_{\text{Bohr}} \sim \frac{\text{Rydberg energy}}{\text{Bohr radius}}. \quad (30)$$

5 Concluding remarks

In this paper the forces: Planck, Yukawa and Bohr were defined. It was shown that the present value of the Planck force (which is the source of the universe acceleration) $\sim 10^{-22} \text{ GeV/fm}$ is much smaller than the Yukawa ($\sim 10^{-2} \text{ GeV/fm}$) and Bohr $(10^{-13} \text{ GeV/fm})$ forces respectively. This fact guarantees the stability of the matter in the present. However in the past for $T$ (age of the universe), $T < 0.002 \text{ s}$, $F_{\text{Yukawa}} < F_{\text{Planck}} (0.002 \text{ s})$ and $F_{\text{Bohr}} < F_{\text{Planck}} (10^8 \text{ s})$. In this paper the relation of the Schwinger force (for the vacuum creation of the $e^+e^-$ pairs) to the Planck, Yukawa and Bohr force was obtained.
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