A RELATION OF THE MASS OF THE UNIVERSE WITH THE CHARACTERISTIC SIZES OF ELEMENTARY PARTICLES

N.A. Miskinova and B. N. Shvilkin
Department of Physics,
Moscow Technical University of Communications and Informatics,
8a Aviamotornaya St. Moscow 111024, Russia, E-mail: namisk@yandex.ru,

Department of Polimer and Crystal Physics, Faculty of Physics, M.V. Lomonosov

Moscow State University, Moscow 119991, Russia, E-mail: bshvilkin@yandex.ru

Abstract
We show that the mass of the mater equal to the mass of the observable part of our Universe is reached at Planck density in the volume which size is comparable with the nucleon size and is close to the pion Compton wavelength.

The dimension analysis in physics often leads to the discovery of essentially important laws. Max Planck, for example, by the dimension analysis managed to introduce sizes, having dimensional lengths and time, the so-called Planck length and time [1], the extreme smallness of which have led to concept of discrete behavior of space and time. The Plank length $\ell_P \approx 10^{-33}$ sm defines the "quantum" of dimensional distance, and the time $\tau_P \approx 10^{-44}$ s defines the time "quantum". As a result from the dimension analysis the conclusion has been drawn on the necessity of building the quantum theory for discrete space-time [2] (see also [3] and the references therein).

Let's carry out the analysis of dimensional Planck values in application to the expanding Universe. At the beginning of expansion of the Universe the substance was in a so-called vacuum state [4]. The matter density was extremely great and was sustained constant. This density called Planck density is possible to express through Planck dimensional values:

$$m_P = \sqrt{\frac{\hbar c}{G}} \approx 2.1764 \times 10^{-5} \text{g} \tag{1}$$

- Planck mass, and

$$\ell_P = \sqrt{\frac{\hbar G}{c^3}} \approx 1.6163 \times 10^{-33} \text{ cm} - \tag{2}$$

-Planck length, $\hbar = 1.054571628\,(53) \times 10^{-27}$ erg $\cdot$ s – Planck constant, $G = 6.67428\,(67) \times 10^{-8}$ $cm^3 \cdot g \cdot s^{-2}$ - Newtonian gravitation constant, and $c = 299792458$ m $\cdot$ s^{-1} – a speed of light in vacuum (here and below values of physical and astrophysical constants are taken from [5]).

The substance in a vacuum state was characterized by gravitational repulsion (negative pressure), and it caused the powerful initial push, which caused almost instant expansion of material, so-called inflation [4].

At some instant of time the size of the Universe was insignificantly small, it was defined by the size of the Planck cell with volume $\ell_P^3 \approx 4.22 \times 10^{-99}$ cm^3. The density of material in this cell was huge (see Eqs. (1) and (2)):

$$\rho_P = \frac{m_P}{\ell_P^3} = \frac{c^5}{\hbar G^2} \approx 5.15 \times 10^{93} \text{ g} \cdot \text{cm}^{-3}. \tag{3}$$

And it was so despite of small mass of material inside the Planck volume, of about 10^{-5} g, and rather small number of nucleons $m_P / m_p \approx 1.30 \times 10^{19}$, comparable with Loschmidt number $N_L \approx 2.69 \times 10^{19}$ (number of molecules' in 1 cm^3 of ideal gas under normal conditions).

It is considered that the Planck density dividing quantum and classical space-time, defines a state of matter which conditionally is taken over for the "beginning" or the "birth" of our Universe [4].

While material dilating, the volume occupied by it became more and more. Also the mass of substance, because of negative energy of gravitation, thus increased at almost constant density. So it proceeded until the vacuum substance through an insignificant instant has not turned in the quantum mode to the usual matter of the Universe. For this shortest time the Universe has swelled incredibly (see, for example, [4]).

Let's estimate, what mass of material with the Planck density can be concentrated in the sphere volume with radius equal to the Compton wavelength of the π meson. As it is known, this size defines the range of nuclear forces and is close to the nucleon size (the rms charge radius of the proton $r_p \approx 0.88 \times 10^{-13}$ cm [5]) and to the radius of confinement (holding quarks and gluons inside hadrons) [6]. In a case of π^0 meson we have length and the corresponding volume

$$\lambda_\pi^0 = 1.46 \times 10^{-13} \text{ cm}, \ V_0 = \frac{4\pi}{3} \lambda_{\pi^0}^3 \approx 1.31 \times 10^{-38} \text{ cm}^3. \tag{4}$$

For the π^+-meson

$$\lambda_\pi^+ = 1.41 \times 10^{-13} \text{ c m}, \ V_+ = \frac{4\pi}{3} \lambda_{\pi^+}^3 \approx 1.18 \times 10^{-38} \text{ cm}^3. \tag{5}$$

The mass of matter in volume V_0 at the Planck density (3) is equal to

$$M_0 = \rho_P V_0 = \frac{4\pi}{3} m_P \left(\frac{\lambda_{\pi^0}}{\ell_P} \right)^3 = 6.75 \times 10^{55} \text{ g}. \tag{6}$$

Similarly,

$$M_+ = \frac{4\pi}{3} m_P \left(\frac{\lambda_{\pi^+}}{\ell_P} \right)^3 = 6.10 \times 10^{55} \text{ g}. \tag{7}$$

Masses (6) and (7) are equivalent to the total mass of approximately 4×10^{79} nucleons.

The obtained values of masses M_0 and M_+ appear to be of the same order of magnitude with mass of an observable part of our Universe. According to modern knowledge

$$M_U = \frac{4\pi}{3}\rho_c(ct_0)^3 = 8.84 \times 10^{55} \text{ g}, \tag{6}$$

where $t_0 = 13.69\,(13) \times 10^9$ yr is the age of the Universe, $\rho_c = 1.87835\,(19) \times 10^{-29}\,h^2\,\text{g}\cdot\text{cm}^{-3}$ is the critical density of the Universe, $h = 0.72\,(3)$ is the present day normalized Hubble expansion rate.

Comparison of the masses (6) – (8) shows that difference between them is rather small:

$$\frac{M_U - M_0}{M_U} \approx 0.24,\; \frac{M_U - M_+}{M_U} \approx 0.31,\; \frac{M_0 - M_+}{M_+} \approx 0.10.$$

Let's define also the effective dimension r_c from relation $M_U = (4\pi/3)\rho_P r_c^3$, whence

$$r_c = \left(\frac{3}{4\pi}\frac{M_U}{\rho_P}\right)^{\frac{1}{3}} \approx 1.60 \times 10^{-13} \text{ cm}.$$

This size differs from the pion Compton wavelength a little (see Eqs. (4) and (5)):

$$\frac{r_c - \lambdabar_{\pi^0}}{\lambdabar_{\pi^0}} \approx 0.09,\; \frac{r_c - \lambdabar_{\pi^+}}{\lambdabar_{\pi^+}} \approx 0.13.$$

The presented data allows us to assume that the typical hadron size and the mass in the corresponding volume at the Planck density are the characteristic size and the critical mass at the Big Bang originated from the Planck length and mass at the birth of the Universe.

In conclusion, it is shown that the mass of a "Planck nucleon" (a sphere with a radius of order of the size of the nucleon filled with matter of the Planck density) is close to the mass of an observable part of our Universe.

References

1. M. Plank. Selected works. M.: Nauka, 1975. P.232.
2. V. Ambarzumian, D. Iwanenko. / / Z. Phys., **64**. P.563-567 (1930).
3. A.P. Vyaltsev. Discrete space-time. M.: Com Book, 2007.
4. I.D. Novikov. Inflation model of the early Universe. / / Bulletin of the Russian Academy of Sciences, **71**, № 10, p. 886 - 899 (2001).
5. Particle Data Group: K. Nakamura et al. Review of Particle Physics / / J. Phys. G. **37**, 075021 (2010).
6. L.B. Okun. Elementary Particle Physics (Nauka, Moscow, 1988) [in Russian].