The Kinetics Of Nonequilibrium Universe. I. The Condition Of Local Thermodynamical Equilibrium.
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Abstract

In terms of fundamental principles of quantum theory of interacting particles and relativistic kinetic theory there was carried out an analysis of the main principle of standard cosmological scenario - the initial existence of local thermodynamical equilibrium. It has been shown, that condition of the existence of local thermodynamical equilibrium in Universe is determined essentially by means of function of total cross-section of particles’ interaction from the kinematic invariant and in case of scaling’s recovery in range of superhigh energies it is initially broken.

1 Standard View On The Establishing Of LTE In Universe

The most prevalent, established from the very first papers on cosmology, point of view on the problem of local thermodynamic equilibrium (LTE) in early Universe, is posed in well-known J.B.Zeldovich’s and I.D.Novikov’s monograph [I]. (1975):

“...As it was mentioned above, all particles lay in thermodynamical equilibrium at high temperature. Actually, for the existence of the thermodynamical equilibrium it is required that processes, establishing the equilibrium have to run faster, than plasma’s establishment. More precisely, it is necessary, that during the period of process, which establishes the equilibrium (τ), there were far less of character time of plasma parameters’ variation (ρ, T etc).

In isotropic solution ρ = \(\frac{\alpha}{Gt^2}\), where α is of one order. Therefore time, essential for the variation of density from some value ρ up to \(\left(\frac{1}{c}\right)\) ρ ≈ 0,4ρ,

\[\Delta t = \frac{1}{\sqrt{G\rho}}\]

Thus, \(\Delta t\) is of order \(t\). From the other hand, equilibrium’s establishment time is

\[\tau = \frac{1}{\sigma n v}\] (6.2.6)

where \(\sigma\) - reaction’s cross-section, \(n\) - concentration of particles, \(v\) - velocity of their movement. At high temperatures \(v \approx c\). Value \(n\) is determined by formula (6.2.5): \(n = n_1 t^{-3/2}\) \((n_1 = \text{const})\). Therefore

\[\tau = \frac{c^{3/2}}{\sigma n_1 c}\] (6.2.7)
For the thermodynamical equilibrium is necessary:

\[ \tau = \frac{t^{3/2}}{\sigma n_1 c} < \Delta t \approx t \]  

(6.2.8)

or

\[ \sigma > t^{1/2} n_1 c. \]  

(6.2.9)

Therefore thermodynamical equilibrium exists at \( t \to 0 \), if only \( \sigma \) does not decrease sufficiently fast together with the extension of particles’ energy. One may hope, that condition (6.2.9) is fulfilled in fact. Thus, for example, it is beyond any doubt, that at high temperatures the number of pairs \( e^+, e^- \) does not differ from the equilibrium one. In fact, let us consider as an example the moment, when \( T = 1 \) MeV, \( t = 1 \) sec, \( n_{e^+} \approx n_{e^-} \approx 10^{31} \text{ cm}^{-3} \). The annihilation’s cross-section \( \sigma_1 \) of order \( 10^{-24} \text{ cm}^2 \), particles’ velocity of light velocity’s order; consequently, time of equilibrium establishment is of order

\[ \tau = \frac{1}{\sigma_1 n c} = 10^{-17}. \]

Thus, \( \tau \) is insignificant in comparison with \( t = 1 \) sec. Full equilibrium \( e^+ + e^- \leftrightarrow 2 \gamma \) is provided.

Rather later, in 1980, possibly, under the influence of calibration field theory’s results this viewpoint has been stated more carefully [2]:

“The problem of thermodynamical equilibrium in the initial plasma is extremely important. If in ordinary cases equilibrium is reached after the lapse of sufficiently great time, here the situation is exactly opposite. At great \( t \) expansion velocity of Universe proves to be greater than velocity of reactions between particles and equilibrium has no time to establish. The older the world becomes, the more nonequilibrium it proves to be. On the contrary, at small times \( t \) reactions between particles become very fast in consequence of density’s increase and elementary particles’ gas, as a matter of fact proves to be equilibrium. Let us illustrate it in detail. Expansion velocity of Universe is \( \dot{a}/a \sim 1/t \). From the other hand, the velocity of thermodynamical equilibrium’s establishment is \( \dot{n}/n \sim n v \sigma \), where \( n \) - concentration of particles, \( v \) - their velocity, and \( \sigma \) - interaction cross-section. Equilibrium, which is violated by world’s expansion, has time to recover, if:

\[ n v \sigma t \geq 1. \]  

(2.3)

At \( T \gtrsim m \) density of particles \( n \) by value order is equal to \( n(t) \approx (t t_{Pl})^{-3/2} \), where \( t_{Pl} = G^{1/2} \approx 10^{-43} \text{c} \) - Planck time; the inverse value \( T_{Pl} = t_{Pl}^{-1} \approx 10^{19} \text{GeV} \) is called Planck temperature (or mass). If interaction of particles is described by unified calibrating theory, then \( \sigma \sim \alpha^2 T^{-2} \); in case when temperature is greater than intermediate bosons’ masses, \( m_X \approx 10^{15} \text{ GeV} \). Connection constant \( \alpha \) at that constitutes by order of value \( 10^{-2} \). Since temperature depends on time by means of law \( T \approx (t t_{Pl})^{-1/2} \), condition of equilibrium (2.3) is fair at \( t > \alpha^{-2} t_{Pl} \). However at farther increase of \( t \) (and decrease of temperature) situation becomes equilibrium again.... Thus, at very small times
\( t < t_{Pl} \) Universe, possibly, is equilibrium; then at \( t_{Pl} < t \lesssim \alpha^{-4}t_{Pl} \) there is a nonequilibrium period and at \( \alpha^{-4}t_{Pl} > t > t^0 \) equilibrium recovers again..."

2 The Instructive Example

Let us consider in detail given in book [1] example with annihilation reaction. But for the estimation of LTE establishment condition we will use not numerical values of parameters, given in this book, but theirs analytic values. The total cross-section of electron-positron pair’s annihilation reaction is equal to (see for example, [3]):

\[
\sigma = \pi r_0^2 \frac{\alpha^2}{4v_0^2\varepsilon_0^2} \left\{ \frac{3 - v_0^4}{v_0} \ln \frac{1 + v_0}{1 - v_0} + 2(v_0^2 - 2) \right\},
\]

where \( \alpha = e^2/4\pi \) - constant of fine structure, \( \varepsilon_0 \) - energy of colliding particles in c.m. system, \( v_0 \) - their velocity in the same system. In particular, at ultrarelativistic energies of particles \( \varepsilon \gg m \); \( v_0 \to 1 \) formula (1) gives:

\[
\sigma = \pi \frac{\alpha^2}{\varepsilon_0} \left( \ln \frac{2\varepsilon_0}{m} - 1 \right).
\]

Since for ultrarelativistic particles \( \varepsilon \sim t^{-1/2} \), then substituting this relation into (2), and after that into (6.2.8), we will obtain instead of (6.2.9) the inverse inequality:

\[
t > t_1,
\]

- i.e. for the annihilation reaction LTE is absent in early times, and recovers in later times. Is it possible that numerical estimates, given in [1] are incorrect? Undoubtedly, these estimates are correct, but at their finding there was implicitly supposed, that in point of time \( t = 1c \):

1. the number of electron-positron pairs in plasma did not differ from the equilibrium value, determined by temperature \( T(t) \) in given point of time;

2. plasma’s temperature \( T(t) \) in this point of time was determined by formulas for locally equilibrium Universe, energy density in which is proportional to \( T^4(t) \).

Thus, in book [1], like, nevertheless in many others, has been given an interesting result, which can be expressed by following logical formula:

*If in early Universe LTE existed, then LTE existed!*\(^1\)

The logical fault of such a conclusion is obvious. But in spite of obvious falseness, this conclusion: *“on early stages of Universe there existed an LTE, which has been broken on later ones”* - was the foundation for construction of cosmological evolution ideology, which with one or another variations in time is called *“the standard cosmological scenario”*.

\(^1\)Here inequalities should be replaced by inverse ones, but this is a quotation. (Yu.I.)

\(^2\)Here and farther we choose the universal system of units: \( G = h = c = k = 1, k \) - Boltzmann constant.
3 The Ideology Of Standard Cosmological Scenario And Its Consequences

Let us consider basic features of standard cosmological scenario (SCS), not wounding for the time being problems of Universe stability theory and connected with it problems of large-scale structure’s formation.

3.1 Space Homogeneity And Isotropy

The first important statement of standard cosmological scenario, as well as of overwhelming majority of cosmological models, is the supposition about homogeneity and isotropy of three-dimensional space, that leads to Friedman metric:

\[ ds^2 = a^2(\eta)(d\eta^2 - dl^2) = dt^2 - a^2(t)dl^2, \]  

where:

\[ dl^2 = d\chi^2 + \rho^2(\chi)(d\theta^2 + \sin^2\theta d\phi^2), \]

\[ \rho(\chi) = \begin{cases} \sinh(\chi), & k = -1; \\ \chi, & k = 0; \\ \sin(\chi), & k = +1 \end{cases}, \]

\[ k \] - curvature index of three-dimensional space: \( k = 0 \) for zero three-dimensional curvature, \( k = 1 \) - for constant positive three-dimensional curvature, and \( k = -1 \) - for constant negative three-dimensional curvature. As is well known, Friedman metric allows rotation group \( O(3) \), generated by three Killing vectors \( \xi^i \):

\[ \{ \xi^i_1 = \delta^i_\chi; \]
\[ \xi^i_2 = \delta^i_\theta \sin \varphi + \delta^i_\varphi \cos \varphi \cot \theta; \]
\[ \xi^i_3 = \delta^i_\varphi \cos \varphi - \delta^i_\theta \sin \varphi \cot \theta, \]

only two of which are linearly independent, such that:

\[ L_\xi g_{ij} = \xi_{(i,j)} = 0. \]

Besides, metric (5) allows spacelike Killing tensor field \( \xi_{ij} \):

\[ \xi_{ij} = a^2(\eta)(g_{44}\delta^i_4 \delta^j_4 - g_{ij}) \]

such that:

\[ \xi_{(ij,k)} = 0, \]

and timelike vector of conformal motion:

\[ \xi = \delta^i_4, \]
such that:

\[ L \xi g_{ij} = \xi_{(i,j)} = 2 \frac{a'}{a} g_{ij}, \quad (11) \]

As is well known, tensor of energy-momentum succeeds symmetry of space-time in consequence of chain of relations:

\[ L \xi g_{ij} = 0 \Rightarrow L R_{ijkl} = 0 \Rightarrow \]

and Einstein equations:

\[ L \xi R_{ij} = 0 \Rightarrow L T_{ij} = 0. \]

Therefore tensor of energy-momentum of Friedman Universe takes algebraic structure of Friedman metric, i.e., the structure of EMT of ideal isotropic liquid:

\[ T^{ij} = (\varepsilon + p) u^i u^j - p g^{ij}, \quad (12) \]

where

\[ u^i = 1/\sqrt{g_{44}} \delta^i_4 \quad (13) \]

- velocity vector of matter, \( \varepsilon(\eta), p(\eta) \) - its energy density and pressure.

Einstein equations at that are reduced to two independent equations (see for example, [4]):

\[ \frac{1}{a^2} (\dot{a}^2 + k) = \frac{8\pi}{3} \varepsilon; \quad (14) \]

\[ \dot{\varepsilon} + 3 \frac{\ddot{a}}{a} (\varepsilon + p) = 0, \quad (15) \]

where differentiation by time \( t \) is denoted by point. If we know the equation of state, i.e., the relation of form:

\[ p = p(\varepsilon), \quad (16) \]

then equation (15) is integrated in quadratures:

\[ a = a(\varepsilon). \quad (17) \]

Substituting the solution (17) in equation (14), we will obtain closed differential equation of first order relatively to \( \varepsilon(\eta) \). In case of barotropic state equation:

\[ p = \varrho \varepsilon \quad (18) \]

Einstein equations are easily integrated for early Universe \( (t \to 0) \), as is well-known the behavior of solutions in this case does not depend on the curvature index \( k \) (see for example, [4]) and does not differ from the behavior of solutions for the space flat Universe \( (k = 0) \):

\[ a = a_1 t^{2/3(\varrho + 1)}; \quad \varepsilon = \frac{1}{6\pi(\varrho + 1)^2 t^2}, \quad \varrho + 1 \neq 0 \quad (19) \]
and at \( \varrho = -1 \) we obtain the inflationary solution:

\[
    a = a_1 e^{\Lambda t}, \quad \varepsilon = \frac{3\Lambda^2}{8\pi} = \text{const.} \tag{20}
\]

Efforts of great number of theorists are directed to the formation of such field models, which ensure required state equation management: inflation, secondary acceleration, dark matter etc. The dynamics of Friedman Universe geometry is exhausted by this, but the dynamics of matter in this Universe is not.

### 3.2 LTE And Algebra Of Interactions

The second important statement of SCS is the hypothesis about initial thermodynamical equilibrium of Universe, what became the governing factor in theory of hot Universe formation. Starting from the modern state of Universe and turning back its history with the account of Friedman solution, describing the homogenous cosmological expansion, as well as taking into account the conservation law of number of particles and energy, we come to the stage of hydrogen’s recombination, before which photons laid in LTE state with electrons and ions.

Thus, in early stages of cosmological expansion act laws of equilibrium thermodynamics, which are completely determined by local-equilibrium distribution functions of particles.

So, let reactions of following type run in plasma:

\[
    \sum_A \nu_A a_A \rightleftharpoons \sum_B \nu'_B a'_B \tag{21}
\]

where \( a_A, a'_B \) - sort of particles (name), \( \nu_A, \nu'_B \) - theirs numbers in this reaction. Then local-equilibrium distribution functions have form, (see for example, [5]):

\[
    f^0_a (x, p) = \left[ \exp \left( -\mu_a + \left( u, p \right) \over T \right) \pm 1 \right]^{-1} \tag{22}
\]

where \( T(x) \) - temperature and \( u(x) \) - unit timelike vector of macroscopic velocity \( (u, u) = 1 \), the same for all sorts of particles \( a \); \( \mu_a(x) \) - chemical potentials, which are described by series of equations of chemical equilibrium:

\[
    \sum_A \mu_A \nu_A = \sum_B \mu'_B \nu'_B, \tag{23}
\]

representing the system of linear homogenous algebraic equations relatively to \( \mu_a \). If in \( k \) reaction of type (21) certain vector currents, created by corresponding charges \( q_A, q'_B \), are conserved, then for such reactions the conservation law of charge is fulfilled:

\[
    \sum_A q_A \nu^K_A - \sum_B q'_B \nu^K_B = 0. \tag{24}
\]

\(^3\)From the point of view of which we have spoken above.
Algebra of interactions of elementary particles, i.e., in fact, schemes of reactions (21), allowed in one or another field-theoretical model of particles' interactions, leads to conservation laws of certain generalized currents. Actually, algebra of interactions of elementary particles is determined by integers $\nu^K_n$, which are equal to number of particles of sort $n$, participating in reaction denoted by index $K$, i.e., by matrix $[\nu^K_n]$. Let $N$- number of fundamental particles’, including also antiparticles, in concrete field-theoretical model. Let us rewrite reactions (21) in unified form:

$$\sum_{A=1}^{N} \nu^K_A a_A = 0; \quad (K = 1, 2, \ldots)$$

(25)

where $\nu^K_A$ can take already any integer values: positive, negative and zero. In any closed field theory should be:

$$\text{rank} [\nu^K_A] < N,$$

(26)

in the opposite case there will be such particle, which can be obtained from others in not a single reaction (25), i.e., will not interact with others, that right now withdraws it outside the limits of given field theory, making the mentioned one non-closed. In consequence of (26) we always can choose $N$ numbers $G_A$, simultaneously different from zero, such that:

$$\sum_{A=1}^{N} \nu^K_A G_A = 0; \quad (K = 1, 2, \ldots).$$

(27)

Let for definiteness

$$\text{rank} [\nu^K_A] = r < N.$$

Then there exist $N - r$ linear-independent solutions (27), which we will denote by means of symbols $G^s_A$ ($s = 1, N$) and call generalized charges. Since $\nu^K_A$ - integers, solution of equations (27) can always be represented in rational numbers. Therefore, multiplying equations (27) by appropriating multipliers, we always can express theirs solutions in integers, i.e., integer values can be attached to generalized charges. Thus, in any closed field theory we will have corresponding laws of generalized macroscopic currents [5]:

$$J^i_s = \sum_{A=1}^{N} G^s_A \int_{P(x)} p^i f_A dP,$$

(28)

Since conditions of chemical equilibrium (23) further take form, formally identical to equations (27):

$$\sum_{A=1}^{N} \nu^K_A \mu_A = 0; \quad (K = 1, 2, \ldots),$$

(29)
then solutions of these equations with accuracy to within multiplier do not differ from the solution of equations (27):

\[\mu^s_A = \sigma G^s_A, \quad (30)\]

where \(\sigma\) - common multiplier for all particles. From this it, for example, right now follows, that if certain generalized currents are conserved (for example, the electric current), then massless quantum’s chemical potentials of such field are equal to zero, and chemical potentials of corresponding charged particles and antiparticles are equal by absolute value and have opposite signs.

Further, in homogenous and isotropic Universe all thermodynamical functions should depend only on time, and vector of macroscopic velocity should be equal to (13). Then:

\[0 f_a (t, p) = \left[ \exp \left( -\lambda_a (t) + \frac{E_a (p)}{T(t)} \right) \pm 1 \right]^{-1}, \quad (31)\]

where:

\[E_a (p) = \sqrt{m^2_a + p^2}, \quad (32)\]

- energy of particles \((p^2 = -g_{\alpha\beta}p^\alpha p^\beta\) - three-dimensional momentum’s square),

\[\lambda_a (t) = \frac{\mu_a (t)}{T(t)}, \quad (33)\]

- reduced chemical potentials, which also satisfy system of equations of chemical equilibrium

\[\sum_{A=1}^{N} \nu_A^K \lambda_A = 0; \quad (K = 1, 2, \ldots). \quad (34)\]

In consequence of homogeneity of Universe and its isotropy conservation laws of generalized currents (28) in metric (4) on account of (13) take form:

\[a^3 (t) \sum_A G_A \Delta n_A (t) = \text{const}, \quad (35)\]

where \(\Delta n_A\) - difference of densities of particles and antiparticles of sort “A” with generalized charge \(G_A\).

### 3.3 High Entropy

The third important statement of SCS is the statement of high value of specific entropy, falling at one baryon in modern Universe. More precisely, speech is about relation of photons’ quantity to baryons. It is convenient to incorporate the inverse value:

\[\delta_B = \frac{n_B}{n_\gamma} \approx 10^{-10} \div 10^{-9} \ll 1, \quad (36)\]
where \(n_B, n_\gamma\) - densities of number of baryons and photons in modern Universe, correspondingly.

Equilibrium densities of particles’ number, \(0_n\), entropy, \(0_s\), and energy, \(0_\varepsilon\), for gas of massless particles are equal (see for example, [6]):

\[
0_n = \frac{\rho}{2\pi^2} \int_0^\infty \frac{p^2 dp}{e^{p/T} + 1} = \frac{\rho T^3}{\pi^2} g_a \zeta(3); \tag{37}
\]

\[
0_s = \frac{d}{dT} \frac{\rho}{3\pi^2} \int_0^\infty \frac{p^3 dp}{e^{p/T} + 1} = \frac{2\pi^2 \rho T^3}{45} g_e; \tag{38}
\]

\[
0_\varepsilon = \frac{\rho}{2\pi^2} \int_0^\infty \frac{p^3 dp}{e^{p/T} + 1} = \frac{\rho \pi^2 T^4}{30} g_e, \tag{39}
\]

where \(\rho\) - number of independent polarizations of (spin) particle (\(\rho = 2\) - for photons and massless neutrino), \(g_a\) - statistical factor (\(g_a = 1\) - for bosons, for fermions: \(g_a = 3/4,\) \(g_e = 7/8\)), sign “+” corresponds fermions, “-” - bosons, \(\zeta(x)\) - Riemann function.

The summary energy density of massless particles is equal to:

\[
\varepsilon = \sum_a 0_\varepsilon a = \mathcal{N} \frac{\pi^2 T^4}{15}, \tag{40}
\]

where

\[
\mathcal{N} = \frac{1}{2} \left[ \sum_B (2S + 1) + \frac{7}{8} \sum_F (2S + 1) \right] \tag{41}
\]

- effective number of particles’ types \((S\) - particle’s spin\footnote{In field models of interactions of type SU(5) \(\mathcal{N} \sim 100 \div 200.\)} \(\sum\) summation is carried out by bosons (B) and fermions (F), correspondingly. Then summary entropy density is equal to:

\[
s = \sum_a 0_s a = \mathcal{N} \frac{4\pi^2 T^3}{45} \tag{42}
\]

Let us consider now ultrarelativistic particles (baryons, leptons), laying in thermal equilibrium, rest mass of which is different from zero. Since chemical potentials of particles and antiparticles are equal by value and have opposite signs, we will obtain an expression for difference of massive baryons (leptons) of certain type:

\[
\Delta n = \frac{\rho}{2\pi^2} \int_0^\infty \left[ \frac{1}{e^{-\lambda + E(p)/T} + 1} - \frac{1}{e^{\lambda + E(p)/T} + 1} \right] p^2 dp. \tag{43}
\]
Supposing:
\[ \lambda_A = \frac{\mu_A}{T} \ll 1 \]  
(44)

and proceeding to limit \( m \to 0 \) in integrals of type (43), we will obtain, expanding these integrals in series by smallness of \( \lambda \):
\[ \Delta n_0 \approx \frac{\rho}{\pi^2} \int_0^\infty \frac{e^{p/T}}{(e^{p/T} + 1)^2} dp = \frac{\lambda T^3}{3}, \]
(45)

where for definiteness we have put \( \rho = 2 \) (\( S=1/2 \)).

Thus, using formulas (37) (45), we will obtain the relation for equilibrium ratio of baryons’ excess to number of photons:
\[ \delta_B = \frac{\Delta n_0}{n_\gamma} = \frac{\rho}{6\zeta(3)} \approx 1.369\lambda, \]
(46)

- an equilibrium relative excess of baryons, \( \delta_B \), practically coincides with their reduced chemical potential:
\[ \delta_B \sim \lambda. \]
(47)

Since according to (37) and (38) equilibrium density of ultrarelativistic particles’ entropy is proportional to equilibrium density of particles’ number - \( \rho \sim n \), in standard cosmological scenario there draws a conclusion about smallness of particles’ chemical potentials on ultrarelativistic stage of evolution of Universe, i.e., about striking high degree of charge symmetry of Universe in the beginning of evolution:
\[ \lambda \sim 10^{-10} \div 10^{-9} \ll 1. \]
(48)

### 3.4 Far-reaching Consequences

From this right away arises the idea, whether Universe was from the very beginning completely charge symmetrical or not; and small excess of baryons (\( \sim 10^{-10} \)) originated in consequence of some mechanisms of spontaneous symmetry breaking, which could take place at superhigh energies of interacting particles, greatly exceeding principal experimental possibilities of mankind. Exactly such idea has been stated by Sakharov [7](1967) and after that developed as a theory of baryogenesis on the basis of SU(5)-model in papers [8] - [16]. Baryogenesis theory applied sufficiently strict conditions on minimal mass values of extra-massive X-bosons (see for example [13]):
\[ m_X \geq 10^{16}\text{Gev}. \]
(49)

Later in more exact author’s calculations this limitation has been reduced in 1.5 order ([17] - [20]):
\[ m_X \geq 5 \cdot 10^{14}\text{Gev}, \]
(50)
however, this does not change the matter of fact - the standard cosmological scenario establishes limits on parameters of one or another field theory of fundamental interactions. We can recall a whole series of such “cosmological” limitations on elementary particles’ masses (neutrino, hadrons, gravitino etc.) and other constants of fundamental interactions, obtained on the basis of standard cosmological scenario (see for example, fore-quoted book [1], which presents the peculiar encyclopedia of such limitations) and evoked earlier the enthusiasm of hot model’s followers. In turn, the combination of conceptions of thermodynamical equilibrium and singular initial condition of Universe with classical Hawking’s results of particles’ creation by singularities has led to outwardly alluring idea of vacuum origin of Universe, thus having made the initial phase of Universe absolutely rigid and non-alternative.

Let us note, that such tendency - the obtaining of “cosmological” limitations on parameters of fundamental interactions on the basis of SCS’s consequences is utterly dangerous for the development of the theory of fundamental interactions at high energies - theories of fundamental interactions become hostages of phenomenological equilibrium model of Universe! This situation is illustrated on fig. 1 in form of vicious circle. Exactly this vicious circle has led the modern cosmology to the ideological crisis, when the hope of Higgs bosons has gone and has appeared the series of new experimental data, refereing to the structure of Universe and unambiguously interpreted within the limits of SCS as the appeal to reconsideration of field theories’ fundamental principles. Isn’t it easier to reconsider the validity of principles of SCS itself?

![Figure 1: The Vicious Circle Of Cosmology](image-url)
4 More Detailed Analysis Of LTE Conditions

4.1 The Influence Of Universe’s singularity on LTE Establishment

The first difference, which strikes our eyes at comparison of cosmological process of LTE establishment with the ordinary process - is the presence of the beginning of common history of particles and their interactions in cosmology as against the ordinary situation, which is induced by the presence of cosmological singularity in point of time $t = 0$. First, in consequence of causality principle LTE can not be established in times of Planck order or smaller. Actually, in sphere, formed by light horizon of some one particle, is packed:

$$N_t = \frac{4\pi}{3}t^3n(t)$$  \hspace{1cm} (51)

of other particles, where $n(t)$ - their number density. If $N_t < 1$, the interaction between particles can not take place, and LTE will not establish. In hot model according to [19] and [10] ultrarelativistic plasma’s temperature will vary by law:

$$T_0(t) = \left(\frac{45}{32\pi^3N}\right)^{\frac{1}{4}}t^{-\frac{1}{2}},$$  \hspace{1cm} (52)

therefore at use of equilibrium concentrations [37] the relation [51] in case of standard model SU(5) takes form:

$$N_t \sim 0,33t^{\frac{3}{2}}.$$  \hspace{1cm} (53)

Thus, even at use of equilibrium concentrations of hot model LTE can not be established at $t \lesssim t_{pl}$. But then initial concentrations not in the least have to be equilibrium, - they can turn to be greatly lower than last ones. But in this case the establishment of LTE is put off for times later than Planck ones [22].

Second, more detailed dynamical analysis of particles’ correlation functions also displays certain principal differen ces of cosmological situation from the ordinary one. As the model problem, which is solved exactly, we can consider the decay of heavy electro-neutral rest massive particle into two ultrarelativistic charged antiparticles (Fig. 2).

The exact solution of this problem is produced in A.V.Smirnov’s paper [23] and is reduced to the substitution of kernel $W_{ij}$ of relativistic integral of coulomb collisions of Belyaev-Budker [24] for the kernel $\bar{W}_{ij}$ by rule:

$$\bar{W}_{ij} = W_{ij}\Theta(t),$$

where:

$$\Theta(t) = \begin{cases} 
0, & 0 < t < \lambda_{pl}; \\
\ln \frac{t}{\lambda_{pl}}, & \lambda_{pl} < t < \lambda_D; \\
\frac{1}{\lambda_{pl}}, & t > \lambda_D,
\end{cases} \hspace{1cm} (54)$$
\( \lambda_D \) - Debye-Hückel radius, \( \Lambda \) - coulomb logarithm. This solution strictly shows, that particles’ correlation before Planck times is absent and only later on begin to increase logarithmically slow up to classic relaxation times.

Figure 2: Light horizon of two ultrarelativistic charges \( q \) and \( -q \), appeared at the decay of electro-neutral massive particle \( M \) in point of time \( t = 0 \).

### 4.2 Conditions Of LTE

Listed in section 3 principles of SCS are based on the condition of LTE fulfilment in early Universe, - exactly this condition is the main dogma of SCS. Therefore first of all we exactly should check the fulfilment of this condition in early Universe, using modern representations of elementary particles’ interaction in range of superhigh energies.

Since Universe’s expansion temp is \( \dot{a}/a \), more strict, than (6.2.8) condition of LTE establishment has a form of:

\[
\tau_{e ff} \frac{\dot{a}}{a} < 1.
\]  

(55)

If numbers of particles, participating in given reaction are conserved:

\[
n(t) = \frac{n_1}{a^3(t)},
\]  

(56)

where for definiteness we lay here and further:

\[
a(1) = 1
\]  

(57)

\((t = 1 \text{ corresponds to planck point of time}), n_1 = n(1)\)- particles’ number density in this moment. According to [41] the choice of such normalization of scale factor corresponds to the choice of planck length units in planck point of time. At this normalization in case of barotropic equation of state [18] we obtain from [19]:

\[
a = t^{2/3(\rho+1)}; \quad \frac{\dot{a}}{a} = \frac{2(\rho + 1)}{3t}, \quad (\rho \neq 1),
\]  

(58)
and from (20):

\[ a = e^{\Lambda(t-1)}; \quad \frac{\dot{a}}{a} = \Lambda, \quad (\rho = -1). \]

(59)

For more strict analysis of LTE condition it is necessary to account the dependence of ultrarelativistic particles’ interaction cross-section \( \sigma_{eff} \) from their kinetic energy \( E_{cm} \) in c.m.system. Since this energy is the function of cosmological time, effective cross-section of scattering, as a matter of fact, is also the function of time: \( \sigma_{eff} = \sigma_{eff}(t) \). Therefore condition of LTE (55) takes form:

\[
\frac{\dot{a}a^2}{n_1 \sigma_{eff}(1) \sigma_{eff}(t)} < 1.
\]

(60)

For the clarification of function of effective interaction cross-section from time it is necessary to consider in detail the kinematics of four-particle reactions.

4.3 The Kinematics Of Four-Particle Reactions And The Total Cross-Section Of Scattering

Four-particle reactions of type:

\[ a + b \rightarrow c + d \]

(61)

are completely described by means of two kinematic invariants, \( s \) and \( t \), which posses following meaning: \( \sqrt{s} \)- energy of colliding particle in center of mass (C.M.S):

\[ s = (p_a + p_b)^2 = (p_c + p_d)^2, \]

(62)

and \( t \)-relativistic square of transmitted momentum\(^{5}\)

Figure 3: The diagram of four-particle reaction

\[ t = (p_c - p_a)^2 = (p_b - p_d)^2, \]

(63)

\(^{5}\)Author hopes that following notation’s coincidence will not confuse readers: \( t \) - time in Freedmans’ metric, \( s \) - its interval, simultaneously \( t, s \) - kinematic invariants. This notation is standard and we didn’t consider that it is necessary to change it.
where momentum squares are understood as scalar four-piece squares:

\[ p_a^2 = (p_a, p_a) = (p^4)^2 - (p^1)^2 - (p^2)^2 - (p^3)^2 = m_a^2, \]

e etc. For example:

\[ (p_a + p_b)^2 = p_a^2 + 2(p_a p_b) + p_b^2 = m_a^2 + 2(p_a p_b) + m_b^2. \]

Invariant scattering amplitudes \( F(s, t) \), determined as a result of averaging-out of invariant scattering amplitudes by particles state, \( c \) and \( d \), turn out to be depending only on these two invariants (e.g., see [21]):

\[ \sum |M_{F,i}|^2 = \frac{|F(s, t)|^2}{(2S_c + 1)(2S_d + 1)}, \quad (64) \]

where \( S_i \) - are spins. Using invariant amplitude \( F(s, t) \) full cross-section of reaction is determined (61) (see [21]):

\[ \sigma_{tot} = \frac{1}{16\pi \lambda^2(s, m_a^2, m_b^2)} \int_{t_{min}}^0 dt |F(s, t)|^2, \quad (65) \]

where \( \lambda \) - triangle function:

\[ \lambda(a, b, c) = a^2 + b^2 + c^2 - 2ab - 2ac - 2bc; \]

\[ t_{min} = -\frac{\lambda^2}{s}. \]

In ultrarelativistic limit:

\[ \frac{p_i}{m_i} \rightarrow \infty \quad (66) \]

we have:

\[ s \rightarrow 2(p_a, p_b); \quad t \rightarrow -2(p_a, p_b), \quad (67) \]

\[ \frac{s}{m_i^2} \rightarrow \infty; \quad \lambda \rightarrow s^2, \quad (68) \]

and formula (65) is considerably simplified by introduction of dimensionless variable:

\[ x = -\frac{t}{s}; \quad (69) \]

\[ \sigma_{tot}(s) = \frac{1}{16\pi s} \int_0^1 dx |F(s, x)|^2. \quad (70) \]

Thus, in ultrarelativistic limit total cross-section of scattering depends only from the kinematic invariant \( s \) - square of energy of colliding particles in c.m.system:

\[ \sigma_{tot} = \sigma_{tot}(s). \]

Exactly this dependence will manage the establishment of local thermodynamical equilibrium in early Universe.
4.4 The Influence Of Interaction Cross-section’s Dependence From The Kinematic Invariant $s$ Upon LTE Establishment

Supposing henceforth the effective interaction cross-section is equal to total one, we will investigate the dependence of LTE establishment from the form of function $\sigma_{tot}(s)$. Let us suppose that for ultrarelativistic particles there exists the power dependence of total cross-section of scattering from the kinematic invariant (see [22]):

$$\sigma_{tot}(s) \sim s^\alpha, \quad \alpha = \text{Const.} \quad (71)$$

Since in isotropic expanding Universe the integral of motion is modulus of conformal momentum of particle $P$:

$$a(t)p = P = \text{Const}, \quad (72)$$
in ultrarelativistic limit [60] according to (67) and (72) the asymptotic behavior of kinematic invariant is described by expression:

$$\frac{p}{m} \to \infty \Rightarrow s \to \frac{s_1}{a^2(t)}, \quad (73)$$

where $s_1 = s(1)$. Thus, according to (71) we will obtain:

$$\sigma_{tot}(t) = \sigma_{tot}(1)a^{-2\alpha}(t). \quad (74)$$

Substituting this dependence into LTE condition (60), we will obtain the explicit dependence of LTE condition from the scale factor:

$$\dot{a}a^{2(1-\alpha)} < n_1\sigma_{tot}(1). \quad (75)$$

In that way, using solutions of Einstein equations for early Universe in case of barotropic equation of state ($\rho \neq -1$), [58], we will obtain from (75) the condition of LTE in early Universe:

$$t^{[4\alpha+3(1-\rho)]/(1+\rho)} < n_1\sigma_{tot}(1), \quad (76)$$

from which follows, that at fulfillment of condition:

$$4\alpha + 3(1-\rho) > 0, \quad (77)$$

LTE is maintained in early stages of expansion, and is violated in late, i.e., at:

$$\alpha > -\frac{3}{4}(1-\rho) \Rightarrow \text{LTE} : t < t_0, \quad (78)$$

and at fulfillment of inverse to (78) condition LTE is violated in early stages and is recovered in later stages. In case of ultrarelativistic equation of state $\rho = 1/3$ we will obtain from (75) the condition of existence of LTE in early stages [22]:

$$\alpha > -\frac{1}{2} \Rightarrow \text{LTE} : t < t_0, \quad (p = \frac{1}{3}\varepsilon). \quad (79)$$
In case of extremely rigid equation of state $\rho = 1$ the condition of LTE maintenance in early stages and violation in later is equivalent to condition:

$$\alpha > 0 \Rightarrow LTE: t < t_0, \quad (p = \varepsilon).$$

(80)

In particular, at $\alpha = 0$ (the interaction cross-section is constant) in case of extremely rigid equation of state time at all comes out from the condition of LTE [22], - in this stage of expansion either LTE in universe is always maintained or it is absent at all. In case of inflation $\rho = -1$ LTE condition (76) should be substituted for the following:

$$e^{\Lambda(3+2\alpha)(t-1)} < n_1 \sigma _{tot}(1),$$

(81)

therefore at:

$$\alpha > -\frac{3}{2}$$

(82)

LTE is maintained in early stages and is violated in later ones. *Thus, the dependence of total cross-section of particles’ interaction from the kinematic invariant $s$ in range of superhigh values of energy plays the key role at clarification of problem of LTE existence in early Universe.*

5 Scaling Of Relativistic Particles’ Interaction

5.1 Limitations On Scattering Cross-section’s Asymptotic Behavior, Following From The Axiomatic Theory Of S-Matrix

There arises the question, what is the relation $\sigma _{tot}(s)$ in reality? For analysis of kinetics of processes in early Universe it is necessary to know the asymptotic behavior of invariant amplitudes $F(s, t)$ in limit (66). Modern experimental opportunities have coefficient restriction $\sqrt{s}$ at degree of hundreds GeV. It would be risky to bear on that or other field model of interaction for prediction of asymptotic behavior of scattering crosssection in the range of superhigh energies. It is more rational in recent conditions to bear on axiomatic theory of $S$-matrix conclusions get on basis of fundamental laws of unitarity, causality, scale invariance etc. Unitarity of $S$-matrix leads to well-known asymptotic relation (see, e.g., [30]):

$$\frac{d \sigma}{d t} \bigg|_{s \to \infty} \sim \frac{1}{s^2}$$

(83)

for variables $s$ higher than unitary limit, i.e., under the condition (66) if $m_i$ means the masses of all intermediate particles. But from (70) results:

$$F(s, 1) \big|_{s \to \infty} \sim \text{Const.}$$

(84)
In the sixties of XX century on basis of axiomatic theory of \( S \)-matrix were received stringent restrictions of asymptotic behavior of total cross-sections and invariant scattering amplitudes:

\[
\frac{C_1}{s^2 \ln s} < \sigma_{\text{tot}}(s) < C_2 \ln^2 s,
\]

(85)

where \( C_1, C_2 \) - unknown constants. Upper limit [31] was determined in works [31]-[33], lower limit - in [34], [35] (see also review in book [36]). We also notice restriction to invariant scattering amplitudes (see, e.g., [36]):

\[
|F(s, t)| \leq |F(s, 0)|;
\]

(86)

\[
C'_1 < |F(s, 0)| < C'_2 s \ln^2 s.
\]

(87)

Therefore, invariant scattering amplitudes in limit (86) must be functions of variable \( x = -t/s \), i.e.:

\[
|F(s, t)| = |F(x)|, \quad (s \to \infty).
\]

(88)

But in consequence of (70)

\[
\sigma_{\text{tot}}(s) = \frac{1}{16\pi s} \int_0^1 dx |F(x)|^2 = \frac{\text{Const}}{s},
\]

(89)

the total cross-section behaves itself such as the cross-section of electromagnetic interaction, i.e. scaling is recovered at superhigh energies.

Scaling asymptotics of cross-section (89) lies strictly between possible extreme asymptotics of complete scattering cross-section (85). Moreover, at fulfilment of (89) relations, obtained on basis of axiomatic theory of \( S \)-matrix (83) and (84) are automatically realized.

Further, as described above, scaling exists for pure electromagnetic interactions in consequence of their scale invariance. As an example we will consider the annihilation cross-section of ultrarelativistic electron-positron pair (2), which can be rewritten with the help of kinematic invariant \( s \) in obviously scaling form:

\[
\sigma_{ee \rightarrow \gamma \gamma} = \frac{\pi \alpha^2}{s} \ln \frac{2s}{m} - 1.
\]

(90)

For lepton-hadron interaction assumption of scaling existence has been offered in works [37], [38]. In particular, for total cross-section of reaction

\[
e^+ e^+ \rightarrow \text{hadrons}
\]

the following expression has been obtained:

\[
\sigma_{\text{tot}} = \frac{4\pi \alpha^2}{3s} \sum e_i^2,
\]

where \( \alpha \) - fine structure constant, \( e_i \) - charges of fundamental fermion fields. Data, received on Stanford accelerator, verify existence of scaling for this interactions. Apparently, for gravitational interactions scaling also must recover under superhigh energies in consequence of scale invariance of gravitational interactions in WKB-approximation [40]. A great number of analogous examples, presenting surely established facts, can be given.
5.2 The Asymptotic Conformal Invariance Of Relativistic Kinetic Theory

The question is which consequences about thermodynamical equilibrium’s establishment in early Universe gives us the strict relativistic kinetic theory? Relativistic kinetic equations relatively to macroscopic distribution function $f_a(x^i, p^k)$ of particles of sort $a$ are, [25]-[29]:

$$p^i \tilde{\nabla}_i f_a(x, p) = \sum_{b, c, d} J_{ab\leftrightarrow cd}(x, p), \quad (91)$$

where $\tilde{\nabla}$ - operator of covariant Cartan differentiation in phase space $X \times P$:

$$\tilde{\nabla} = \nabla_i + \Gamma^j_{ik} p^k \frac{\partial}{\partial p^j}. \quad (92)$$

By means of distribution function $f_a(x, p)$ macroscopic moments are defined:

$$n^i_a(x) = \int_{P(x)} f_a(x, p) p^i dP, \quad (93)$$

- number of particles’ of sort $a$ flux density vector and

$$T^{ik}_a(x) = \int_{P(x)} p^i p^k f_a(x, p) dP, \quad (94)$$

- particles’ of sort $a$ tensor of energy-momentum, where

$$dP = \sqrt{-g} d^3p / p^4 \quad (95)$$

- invariant differential of momentum space’s volume. Swinging the formula (94) by means of metric tensor $g_{ik}$, in consequence of normalization relation of 4 - momentum:

$$(p, p) = m_a^2, \quad (96)$$

we will obtain:

$$T^i_a(x) = m_a^2 \int_{P(x)} f_a(x, p) dP, \quad (97)$$

where $T^i_a(x)$ - spur of particles’ of sort $a$ tensor of energy-momentum.

In case of homogenous isotropic distribution $f(\eta, p)$ in Friedman metric [5] kinetic equations take form:

$$\frac{\partial f_a}{\partial t} - \frac{a}{a'} \frac{\partial f_a}{\partial p} = \frac{1}{\sqrt{m_a^2 + p^2}} \sum_{b, c, d} J_{ab\leftrightarrow cd}(t, p), \quad (98)$$

or in variables $\eta, p$:

$$\frac{\partial f_a}{\partial \eta} - \frac{a'}{a} \frac{\partial f_a}{\partial p} = \frac{a(\eta)}{\sqrt{m_a^2 + p^2}} \sum_{b, c, d} J_{ab\leftrightarrow cd}(t, p), \quad (99)$$

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where by means of a point is denoted the derivative by time $t$, and by means of a stroke - the derivative by time variable $\eta$, at that:

$$a(\eta) d\eta = dt.$$ 

In paper [29] it has been proved the following theorem: *In ultrarelativistic limit under the conditions of non - gravitational macroscopic field equations' conformal invariance and scale invariance of matrix elements of interaction kinetic equations are conformally invariant.*

Aforesaid means literally the following:

- Let us consider two conformally corresponding metrics in common coordination:

$$ds^2 = \sigma^2 ds'^2. \quad (100)$$

- We will suppose, that at such transformation potentials of scalar and vector fields are transformed by rule:

$$\bar{\Phi} = \Phi/\sigma; \quad \bar{A_i} = A_i + \partial_i \varphi, \quad (101)$$

where $\varphi(x)$ - scalar function, chosen in such way, that calibration condition, imposed on vector potential stays changeless at conformal transformation.

- We will suppose, that at such transformation canonical generalized momentums of particles, $P_i$, are transformed by law:

$$\bar{P_i} = P_i - \partial_i \varphi; \quad \bar{A_i} = A_i + \partial_i \varphi. \quad (102)$$

- Let us suppose, that at conformal transformation in ultrarelativistic limit, when characteristic scales of the system are smaller than compton scales of particles, all field equations for non-gravitational interactions are asymptotically conformally invariant and matrix elements of interaction change only in the issue of phase space’s transformation at conformal transformations:

$$|M(p, q| p', q')|^2 = \sigma^2(\eta)|M(p, q| p', q')|^2 \quad (103)$$

- Then in ultrarelativistic limit the integral of pair collisions in kinetic equations is transformed by law:

$$\bar{I}_{ab+cd}(\bar{P_a}) = \sigma^{-2} I_{ab+cd}(P_a); \quad (104)$$

What corresponds to WKB-approximation.
The left side of kinetic equations (98) at that is transformed accurately within members $O(p^2/m^2)$ by law:

$$\bar{K}(x, \bar{P}) = \sigma^{-2}K(x, P),$$

(105)

where $K(x, P)$ - operator in the left side of kinetic equations.

Thus, if $f(x, P)$ - the solution of the kinetic equation in metric $g_{ij}$, $f(x, \bar{P})$ in ultrarelativistic limit will be the solution of kinetic equation in conformally corresponding metrics.

Using the conformal invariance of kinetic equations and the fact, that, firstly, Friedman Universe (4) at $k = 0$ is conformally-flat with the conformal multiplier $\sigma = a(\eta)$, and, secondly, that in early stages of cosmological expansion, when $\eta \to 0$, Friedman metric tends asymptotically to the space-flat, regardless of the curvature index of three-dimensional space, $k$. Therefore according to aforesaid theorem the solution of kinetic equations in metric (4) will coincide with solutions of corresponding kinetic equations in flat space, $f_a(\eta, \bar{P}_a)$, where in corresponding kinetic equations it is necessary to carry out a substitution of kinematic invariant $s$ for $\bar{s}$ by rule:

$$\bar{s} = a^2(\eta)s,$$

i.e., $\bar{\sigma}_{tot} = \text{Const}$. But in that case $\bar{\tau}_{eff} = \text{Const}$, and we come to the well-known result of standard kinetic theory: LTE is recovered in plasma at

$$\eta \geq \bar{\tau}_{eff}.$$

Thus, strict conclusions of relativistic kinetic theory relatively to the recovery of LTE in ultrarelativistic plasma are in full correspondence with the qualitative conclusion, given in the previous section.

5.3 The Universal Asymptotic Cross-Section Of Scattering

Further we will suppose the presence of scaling at energies above the unitary limit $s \to \infty$. There arises the question about the meaning of constant in formula (89) and also about the logarithmic correction of this constant. This value can be estimated with the help of simple considerations. If the idea of association of all interactions on Planck scales of energy $E_{pl} = m_{pl} = 1$, is correct, then at $s \sim 1$ all interactions should be described by the united scattering cross-section, produced from three fundamental constants $G, h, c$, i.e., in chosen system of units should be:

$$\sigma|_{s=1} = \pi l_{pl}^2 \quad (= \pi).$$

(106)

However in order that on Planck scales of energy scattering cross-section could fall up to such value, starting from the values of order of $\sigma_T = 8\pi \alpha^2/3m_e^2$
\( m_e - \text{electron's mass, } \sigma_T - \text{Tompson scattering cross-section} \) for electromagnetic interactions, i.e., at \( s \sim m_e^2 \), it should fall in inverse proportion to \( s \), i.e., but again by scaling law. Improving this dependence logarithmically, we will incorporate The Universal Asymptotic Cross-section Of Scattering (ACS), introduced in papers [41], [42]:

\[
\sigma_0(s) = \frac{2\pi}{s \left( 1 + \ln^2 \frac{s}{s_0} \right)} = \frac{2\pi}{s\Lambda(s)},
\]

(107)

where \( s_0 = 4 - \text{square of total energy of two colliding Planck masses,} \)

\[
\Lambda(s) = 1 + \ln^2 \frac{s}{s_0} \approx \text{Const},
\]

(108)

- logarithmic factor.

Incorporated by formula (107), cross-section of scattering \( \sigma_0 \), ACS, possesses the series of outstanding features:

1. ACS, is produced only from fundamental constants \( G, \hbar, c; \)

2. ACS, behaves itself in such way, that its values lie strictly in the middle of possible extreme limits of cross-section’s asymptotic behavior [50], established with the help of the asymptotic theory of \( S \)-matrix;

3. ACS, to a logarithmic accuracy is scaling cross-section of scattering;

4. For reactions of photon’s scattering on non-relativistic electron \( (s = m_e^2) \) formula (107) gives \( \sigma_0 = 4/3\sigma_T \sim \sigma_T; \)

5. For electro-weak interactions \( (s = m_W^2, \text{where } m_w - \text{mass of intermediate W-boson}) \) at \( \sin^2 \theta_W = 0.22 \) (see for example [30]) we will obtain from (107) \( \sigma_0 = 0, 78\sigma_W \), where \( \sigma_W = G_F^2 m_W^2/\pi - \text{cross-section of } \nu e - \text{scattering with the account of intermediate W-boson;} \)

6. At Planck values of energy \( \sigma_0(m_{pl}^2) \approx \sigma_{pl}. \)

These outstanding features of ACS and its values’ amazing coincidence with well-known processes’ cross-sections in the huge range of energy values (from \( m_e \) to \( 10^{22} m_e \)) hardly can be casual, that allows us to apply ACS further in a capacity of sure formula for the asymptotic value of scattering-cross-sections for all interactions.

Let us note, that coincidence of large-scale behavior of cross-sections of elementary particles’ interactions in range of superhigh energies with ACS does not mean, that the same coincidence will conserve in small scales of energies. Cross-sections’ local deviations from ACS will necessarily take place in form of so-called resonances (see Fig. 4). \(^5\)

\(^5\)Let us note, that this fact is one more independent argument in favour of scaling’s existence in range of high energies.
The real dependence of total cross-section of interaction on particles’ energy. By means of dot line is shown the behavior of ACS. Ranges of resonances in fact can have much more complicated local structure.

However, the influence of such resonances on general evolution of cosmological plasma will disappear while energy of particles \[ (43) \] will increase. Actually, masses of intermediate particles, producing resonance, are of resonance’s energy’s order, which, in its turn, is equal to the kinetic energy of interacting particles:

\[ M \sim E \approx \sqrt{s}. \]

Therefore with the increase of the kinematic invariant \( s \) increase also masses of intermediate particles, determining resonances. But, as is well-known, there is the following relation between resonance’s half-width and mass of the intermediate particle\[ (8) \]:

\[ \Gamma \sim M^{-1}. \]

Therefore with the growth of energy resonances become more and more narrow:

\[ \Gamma \sim \frac{1}{\sqrt{s}}, \]

such that their contribution in the kinetics of LTE establishment becomes more and more weak.

Thus, summing up the results of the paper, we can receive following consequences:

\[ \text{This relation follows from the Geisenberg indeterminancy principle.} \]
• The existence of LTE in early stages of Universe’s evolution is determined by the dependence of cross-sections of elementary particles’ interactions in the range of superhigh energies on kinematic invariant, $s$, - energy of interacting particles in c.m.system;

• In case of ultrarelativistic equation of state of cosmological plasma and power dependence of cross-section of interaction on kinematic $\sigma \sim s^\alpha$ LTE is absent in early stages of Universe’s expansion at $\alpha < -1/2$;

• The quantum theory of field predicts the recovery of scaling of interactions at superhigh energies of particles in consequence of conformal invariance in ultrarelativistic limit of fundamental field equations. Elementary particles’ cross-sections of interactions at that in the range of superhigh energies are inverse in proportion to the kinematic invariant $s$;

• In conditions of scaling of interactions LTE should be violated in early Universe and should be recovered in later stages;

• Since LTE is absent in early stages of Universe, the initial distribution of particles can be random and can differ greatly from the equilibrium one;

• Since all particles’ interactions at superhigh energies are unified, interactions of all particles in this range can be qualitative correctly described by means of the universal asymptotic cross-section of scattering, ACS, which possesses the scaling character.

Since further we will investigate the kinetics of reactions only in the range of superhigh energies, where all interactions are described, as we suppose, by ACS, no difference can be made between particles in integrals of interactions, accounting only where it is essential, their spin and other characteristics. From this point of view all interactions are unified at superhigh energies, what greatly simplifies the investigation of such processes. In the next article we will research the kinetics of LTE establishment in the early Universe, using ACS for the description of particles’ interactions in the range of superhigh energies, and also we will clarify the boundaries of arbitrariness of initial distribution of particles.

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