Generalized equations of thermodynamics with hidden variables

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Abstract

For the collective gravithermodynamic Gibbs microstates the connection between all thermodynamic potentials and parameters of matter have been found. This connection is realized with the help of four hidden wave functions that can take arbitrary values with certain probability. The possibility of obtaining the known equations of thermodynamic state of real gases is shown based on the use of both the coordinate velocity of light of the general relativity and the mathematical expectations precisely of these four hidden parameters (wave functions) and functions of them. It is substantiated that in a quasi-equilibrium state, a real gas has spatial homogeneity not only of its entropy but also of the resulting extensive parameter (an indicator the compressibility coefficient). But the radial values of resulting intensive parameter (an indicator of hierarchical complexity and of quasi-equilibrium of cooling down) of a real gas are invariant in time. It has been proven that the orthodox interpretation of general relativity is not consistent with gradually cooling matter and therefore with the evolutionary cooling of the early Universe.

Keywords: thermodynamics, gravity, gravitational field, inert free energy, Gibbs microstate, hidden variables, wave functions.

1. Introduction

Equations of state of matter are a necessary complement to the laws of thermodynamics. They allow the application of the laws of thermodynamics to specific substances and systems, since the laws of thermodynamics by themselves do not provide complete information about the state of the system. Equations of state cannot be derived from the laws of thermodynamics alone. They are obtained experimentally or theoretically, using ideas about the structure of matter, for example, methods of statistical physics.

The most famous equations of state for real gases are the generalized Clapeyron–Mendeleev equation, the van der Waals virial equation (1873) [1], the Dieterici equation (1898) [2], the Berthelot equation (1900–7) [3], the Kamerlingh-Onnes virial equation (1901), the Beattie–Bridgeman equation (1927) [4, 5], the Benedict–Webb–Rubin equation (1940–42) [6 – 9], the Redlich–Kwong equation (1949) [10], the Soave–Redlich–Kwong equation (1972) [11, 12], the Peng-Robinson EOS (1976) [13], etc. [14 – 35].

Studies of the spatially uniform compressibility coefficient of gases and liquids are important [21, 23, 27, 36 – 39]. It may also be important for the analysis of the cooling process of the hot Universe (when the Universe was uniformly filled mainly with hydrogen) to find out the value of the time-invariant intensive thermodynamic parameter $A_\rho = T^2 S / pV$. The most popular, practical, and perfect are the van der Waals virial equation [1, 15 – 17, 24] and the Benedict–Webb–Rubin equation of state [6 – 9, 18, 20, 25 – 35]. But they are also purely empirical and artificial. After all, they are based on the use of only coefficients and corrections, and not hidden thermodynamic parameters, which are wave functions capable of taking any values with a certain probability. Therefore, these equations of the thermodynamic state of matter do not allow us to obtain a set of multitude Gibbs microstates for matter. Moreover, they do not allow us to obtain equations of spatially inhomogeneous quasi-equilibrium thermodynamic states of astronomical gas clusters that gradually cool down. It is to the solution of these important and urgent problems that the proposed in the article results of careful theoretical research of the author are devoted.

Internal energy U of real gases and liquids depends on many pairs of their intensive (A_i) and extensive (a_i) thermodynamic parameters. However, it can also be shown as a sum of internal energy of hypothetic ideal gas (liquid) U_{id} and output of multiplication of resulting intensive ($A_\rho(r) = TS / R_T(t) = T^2 S / pV$) and extensive ($a_\rho(t) \equiv R_T = pV / T$) thermodynamic parameters:

$$U = U_{id} + \sum_{i=2}^{n} A_i a_i = U_{id} + A_\rho a_\rho ,$$

$$dU = T_{id} dS_{id} + A_\rho da_\rho - pdV = TdS - pdV ,$$

where: $T_{id}=TR_T/R_{UT}$, $S_{id}=SR_{UT}/R_T$, $A_\rho a_\rho = T_{id} S_{id} = TS$. For gases: $a_i=R_{UT}B_iV^{1-i}$, B_i is virial coefficients that depend on both temperature and individual gas properties [40], while R_{UT} is universal gas constant and $R_T(r)=pV/T=\mathbf{const}(t)$ is thermodynamic parameter of gas, that determines the compressibility coefficient $Z = R_T / R_{UT}$ of the gas and does not vary in space at conditions of quasi-equilibrium cooling down of gas (is the same on any radial distance r from the gravitational attraction center in the comoving to it frame of reference of spatial coordinates and time t (FR)). And exactly this invariability in space of $R_T(t)$ is responsible for the fact that properties of real gases that gradually cools are close to properties of hypothetical ideal gas.

“Ideal” component U_{id} of internal energy is de facto identical to Helmholtz free energy F_T, while “ideal” component H_{Tid} of enthalpy is identical to the Gibbs free energy G:

$$U_{id} = U - a_\rho A_\rho = U - ST = F_T , \qquad H_{Tid}=H_T-a_\rho A_\rho=H_T-ST=G ,$$

$$dU_{id} = T_{id} dS_{id} - a_\rho dA_\rho - pdV = (TdS - \frac{TS}{R_T} dR_T) - (SdT + TdS - \frac{TS}{R_T} dR_T) - pdV = -SdT - pdV = dF_T ,$$

$$dH_{Tid}=T_{id}dS_{id}-a_\rho dA_\rho+Vdp=-SdT+Vdp=dG .$$

This, of course, is caused by the absence of binding energy ($\sum_{i=2}^{n} A_i a_i = A_\rho a_\rho = 0$) in ideal gas and ideal liquid due to the absence of electromagnetic interaction of their molecules and atoms. Self-organization of hierarchically more complicated interactions and interconnections in matter is in the tendency of Helmholtz and Gibbs free energies to their minimum.

Lower layers of matter, loaded by its upper layers form the extended system. The energy of such extended system [40] that consists of the whole gravithermodynamically bonded matter is indeed equivalent to enthalpy of a supercooled matter. Moreover, as it is shown further, parameter a_ρ (in contrast to A_ρ parameter) takes the same value in the whole space filled by matter that gradually cools ($(\partial a_\rho/\partial r)_t=0$). And, therefore, Gibbs free energy “behaves” as it is expected: it only changes in space along the radial coordinate r together with the gravitational potential. And when Gibbs energy changes in time together with the gravitational potential, it “behaves” like multiplicative component of enthalpy (like the energy of extended system). This is quite logical and reflected in static equations of GR gravitational field.

If during the inertial motion of matter the main role is played by conserving Lagrangian of its ordinary rest energy and Hamiltonian of its inert free energy, then during the quasi-equilibrium (quasi-uniform) motion of matter that gradually cools the main role is played by gradually decreasing Lagrangians of its ordinary rest energy W_0 (identical to the multiplicative component of Gibbs free energy G_0) and of multiplicative component of its thermodynamic internal energy [41, 42]. And therefore, according to the Lagrangian construction[1] of the energy-momentum tensor of matter that gradually cools, not only the parameter $b = v_l^2 c^{-2}$ of the gravitational field equations, but also the relativistic shrinkage $\Gamma_m = (1 - v_m^2 v_l^{-2})^{-1/2}$ of the radial dimensions of the matter are hidden thermodynamic parameters. Namely, for the non-rigid FR which is comoving with the gas that gradually cools, we will have the following gravitational field equations (which correspond not to the metric space-time continuum (STC), but to the inseparable from matter its own physical STC, in which there is no radial motion of the molecules of matter, and time is counted by the clocks comoving with it):

$$b_c' / a_c b_c r - r^{-2}(1 - 1/a_c) + \Lambda = \kappa(p - ST/V) = (\kappa T_{00} / \sqrt{b}\Gamma_m V)(R_T - S) = \kappa T_{00} R_{TS} / \sqrt{b_c} V \,,$$

$$a_c' / a_c^2 r + r^{-2}(1 - 1/a_c) - \Lambda = \kappa(\mu_{gr} c^2 - p) = \kappa(\mu_{00} c^2 - p_{00}) / \sqrt{b}\Gamma_m = \kappa U_{00} / \sqrt{b_c} V \,,$$

$$(\ln a_c b_c)' / a_c r = \kappa G_0 / V = (U_{00} / V + p - ST/V) = (\kappa / \sqrt{b}\Gamma_m V)(U_{00} + T_{00} R_{TS}) = \kappa G_{00} / \sqrt{b_c} V \,,$$

where: $b_c = b\Gamma_m^2 = v_l^2 c^{-2} \Gamma_m^2 = v_{lc}^2 c^{-2}$, $U_{00} = (m_{00} c^2 - p_{00} V) = U_0 \sqrt{b_c} = (U - U_{ad}) v_l \Gamma_m / c = \mathbf{const}(r)$, $G_{00} = G_0 \sqrt{b_c} = (G_T - U_{ad}) v_l \Gamma_m / c = \mathbf{const}(r)$, $S = \mathbf{const}(r)$[2], $R_T = pV/T = \mathbf{const}(r)$, $R_{TS} = R_T - S = \mathbf{const}(r)$, $T_{00} = T\Gamma_m v_l / c = \mathbf{const}(r,t)$, $A_\rho = TS / R_T = T^2 S / pV = \mathbf{const}(t)$.

Moreover, the thermodynamic processes in matter confront the intranuclear evolutionary and gravitational processes in it. While in mechanics the main role is played by the inert free energy $\mathbf{H} \equiv E = m_{in0} c^2 \Gamma_m = m_{00} c v_l \Gamma_m$ (equivalent to inertial mass $m_{in} = m_{00} v_l \Gamma_m / c$), in thermodynamics the main role is given not only to the internal energy U, but also enthalpy and Gibbs free energy $G = G_0 + U_{ad} = G_{00} / v_l \Gamma_m + U_{ad} = \mathbf{L}_m + U_{ad}$, the main part of which is an ordinary rest energy $W_0 \equiv G_0 = U + pV - pS - U_{ad} \equiv \mathbf{L}_m = m_{gr0} c^2 / \Gamma_m = m_{00} c^3 / v_l \Gamma_m = W_{00} / \sqrt{b_c}$ (equivalent to gravitational mass $m_{gr} = m_{00} c / v_l \Gamma_m$) of matter that gradually cools. Here: $U_{ad} = U_T - U_0 = \mathbf{const}(r) > 0$ is spatially homogeneous additive compensation of multiplicative representation U_0 of internal energy U of matter and, consequently, does not depend on the strength of gravitational field.

Therefore, in relativistic gravithermodynamics (RGTD) [41, 42] the frequency of intranuclear interaction $f_G = q_N N_{RE} = q_N N_E / \Gamma_E = \eta_m v_l \Gamma_m / c = v_{lc} / v_{lc/cr} \le \eta_m$ corresponds to inversely proportional to it frequency of electromagnetic interaction of matter molecules:

$$f_I = \chi_m / f_G = q_M N_I = (v_{cm} / c) N_I = \psi_m c / v_l = \psi_{m0} c / v_{lc} = \chi_m v_{lc/cr} / v_{lc} \ge \psi_m \qquad (f_{Gcr} = 1,$$

$f_{Icr} = 1$ when conditionally $\chi_m = \chi_{m0} = 1$).

This frequency is changing together with the change of velocity of light $v_{cm} = c q_M \le v_l$ in matter (that corresponds to radiation refractive index n_m at the wavelength of maximum of energy of thermal radiation) and with the change of internal scale factor[3] $N_I = \delta l_{cr} / \delta l \le 1$ of matter [41 – 46].

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[1] Obviously, instead of the Hamiltonian construction, the hidden Lagrangian construction of the energy-momentum tensor of matter should be used in the comoving with expanding Universe frame of references of spatial coordinates and time. After all, the evolutionary self-contraction of matter in it can be caused by the evolutionary decrease of the coordinate velocity of light in it, which is a hidden thermodynamic parameter of matter.

[2] Therefore, entropy is spatially homogeneous not only in a maximally cooled matter, but also in a gradually cooling matter that has a non-rigid FR.

[3] It is obvious, the every matter forms in gravitational field its own thermodynamic STC, the curvature of which partially compensates the curvature of STC of the whole gravithermodynamically bonded matter.

Here: $\psi_{m0} = \chi_m / \eta_m = \chi_m v_{lc/cr} / c = \chi_m v_{lcr} \Gamma_{mcr} / c$, $\psi_m = \psi_{m0} / \Gamma_m = \chi_m / \eta_m \Gamma_m = \chi_m v_{lcr} \Gamma_{mcr} / c\Gamma_m$, $\eta_m = c / v_{lc/cr} = c / \Gamma_{mcr} v_{lcr}$ and $\chi_m = \chi_{m0}$ are the constants of matter that cools to the limit (χ_{m0}, ψ_{m0}) and of matter that gradually cools (χ_m, ψ_m)[4], which is not identical for different matters and for their various phase or aggregate states and not dependent both on strength of gravitational field and on matter thermodynamic parameters; v_l and v_{lcr} are maximum possible (limit) velocities of matter (which are identical to the vacuum coordinate velocities of light of GR) in any point and on the phase boundary of the same matter (or on the boundary of different matters) correspondingly; $v_{lc} = v_l \Gamma_m > v_l$ and $v_{lc/cr} = v_{lcr} \Gamma_{mcr}$ are the limit velocity of matter that gradually cools in the comoving with it the non-rigid FR; Γ_{mcr} is the Lorentz shrinkage of dimensions of matter (that moves in the process of quasi-equilibrium cooling down) on the phase boundary of the same matter or with another matter; δl_{cr} is minimal possible distance of electromagnetic interaction between molecules of certain matter or its critical value; *c* is constant of the velocity of light.

In contrast to used in cosmology spatially inhomogeneous external scaling factor N_E, which is the cause of the curvature of matter intrinsic space, internal scaling factor N_I takes nonsimilar values for different matters and depends on thermodynamic state of matter. This factor characterizes the distinction between average statistic value of interaction distance δl in the atoms of concrete matter and the value of this distance δl_{cr} that corresponds to critical equilibrium values of internal energy multiplicative component U_{cr}, Gibbs free energy G_{cr}, temperature T_{cr}, pressure p_{cr}. And if parameter $q_M = v_{cm}/c = 1/n_m < 1$ characterizes the difference of real velocity of electromagnetic interaction propagation in matter from the constant of velocity of light *c*, then N_I is responsible for compensation of the influence of increase of propagation velocity of electromagnetic wave on the frequency of electromagnetic interaction f_I of matter microobjects. If for gases and simplest liquids the dependencies of instantaneous values of their thermodynamic parameters and potentials on q_M and $N_I = \sigma_m / N_{RE} = \sigma_m / \Gamma_{mE} N_E$ ($\sigma_m = \mathbf{const}(r)$) allow to separate these variables, then instantaneous value of their Gibbs free energy (that corresponds to their instantaneous thermodynamic microstates) can be expressed via these two parameters and via their function R_T in the following way:

$$\breve{G}(q_M,N_I,\breve{R}_T)=\breve{U}(q_M,N_I,\breve{R}_T)-\breve{S}(q_M,N_I,\breve{R}_T)\breve{T}(q_M,N_I,\breve{R}_T)+\breve{V}(q_M,N_I)\breve{p}(q_M,N_I)\,.$$

2. The instantaneous values of main thermodynamic parameters and potentials of gases and simple liquids

Methods of thermodynamics allow us to analyze equilibrium states of matter even when there is no analytic dependence of thermal energy of matter on its thermodynamic parameters. In order to identify some features, let us consider the simplest analytical dependencies for gases and simple

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[4] These constants unambiguously correspond only to the homogeneous matter of not layered astronomical body that does not possesses any matter outside its borders. In any other case it is only gaugely changed since due to logarithmicity of gravitational potential (that is formed based on correspondent thermodynamic potential) it does not directly influence the strength of gravitational field. Changes of the strength of gravitational field in it take place under the influence of other matters on the formation of its spatially inhomogeneous thermodynamic state [41 – 46]. When there is a violation of thermodynamic equilibrium with environment they can substantially influence on the magnitude of limit velocity of motion of matter and, thus, on the magnitude of ordinary internal energy of matter and equivalent to it gravitational mass. So, for example, in spite of the increasing of thermal energy of matter during its heating its ordinary internal energy and, therefore, gravitational mass are ostensibly decreasing [47 – 49]. And this decrease in the gravitational mass of heated bodies is due to its equivalence not to thermodynamic internal (free thermal) energy at all, but actually to multiplicative component of Gibbs free energy.

liquids. According to them the instantaneous values of main thermodynamic parameters and potentials can be represented in the following way [41, 42, 46]:

$$\breve{S}=-\left(\frac{\partial\breve{G}}{\partial\breve{T}}\right)_{\breve{p}}=-\left(\frac{\partial\breve{F}_T}{\partial\breve{T}}\right)_{\breve{V}}=\frac{\beta_{ST}\breve{R}_T}{\beta_{pV}}(\hat{S}),\qquad \breve{T}=\left(\frac{\partial\breve{H}_T}{\partial\breve{S}}\right)_{\breve{p}}=\left(\frac{\partial\breve{U}}{\partial\breve{S}}\right)_{\breve{V}}=\frac{\beta_{pV}U_{cr}}{\breve{R}_T}(\hat{T})=\frac{c\psi_{m0}\beta_{pV}U_{cr}}{\Gamma_m v_l\breve{R}_T}=\frac{\beta_{pV}\breve{U}_0}{\breve{R}_T},$$

$$\breve{V}=\left(\frac{\partial\breve{H}_T}{\partial\breve{p}}\right)_{\breve{S}}=\left(\frac{\partial\breve{G}}{\partial\breve{p}}\right)_{\breve{T}}=\frac{U_{cr}}{p_l}(\hat{V}),\qquad \breve{p}=-\left(\frac{\partial\breve{U}}{\partial\breve{V}}\right)_{\breve{S}}=-\left(\frac{\partial\breve{F}_T}{\partial\breve{V}}\right)_{\breve{T}}=(\hat{p})\beta_{pV}p_l,$$

$$\breve{U}=\breve{U}_0+\breve{U}_{ad}=\frac{R_{UT}\breve{Z}\breve{T}}{\beta_{pV}}+\breve{U}_{ad}=\frac{\breve{R}_T\breve{T}}{\beta_{pV}}+\int_{\breve{R}_{T0}}^{\breve{R}_T}\frac{\breve{T}\breve{S}}{\breve{R}_T}d\breve{R}_T=\frac{\breve{p}\breve{V}}{\beta_{pV}}+\beta_{ST}\int_{\breve{R}_{T0}}^{\breve{R}_T}(\hat{T})(\hat{S})\frac{d\breve{R}_T}{\breve{R}_T}=$$

$$=U_{cr}\left[q_M N_I+\beta_{ST}\int_{\breve{R}_{T0}}^{\breve{R}_T}(q_M N_I/\breve{R}_T)\ln(q_M^{1}N_I)d\breve{R}_T\right]=\breve{a}_\rho\breve{T}/\beta_{pV}+\int_{\breve{a}_{\rho0}}^{\breve{a}_\rho}\breve{A}_\rho d\breve{a}_\rho=$$

$$=U_{cr}\left[\left(\frac{p_l\breve{V}}{U_{cr}}\right)^{-\beta_{pV}}\exp\left(\frac{\beta_{pV}\breve{S}}{\breve{R}_T}\right)+\beta_{pV}\int_{\breve{R}_{T0}}^{\breve{R}_T}\left(\frac{p_l\breve{V}}{U_{cr}}\right)^{-\beta_{pV}}\exp\left(\frac{\beta_{pV}\breve{S}}{\breve{R}_T}\right)\frac{\breve{S}}{\breve{R}_T^2}d\breve{R}_T\right]=$$

$$=U_{cr}\left[\left(\frac{\breve{p}}{\beta_{pV}p_l}\right)^{\frac{\beta_{pV}}{\beta_H}}\exp\left(\frac{\beta_{pV}\breve{S}}{\beta_H\breve{R}_T}\right)+\beta_{pV}\int_{\breve{R}_{T0}}^{\breve{R}_T}\left(\frac{\breve{p}}{\beta_{pV}p_l}\right)^{\frac{\beta_{pV}}{\beta_H}}\exp\left(\frac{\beta_{pV}\breve{S}}{\beta_H\breve{R}_T}\right)\frac{\breve{S}}{\breve{R}_T^2}d\breve{R}_T\right]=$$

$$=\left\{\breve{R}_T\breve{T}+\int_{\breve{R}_{T0}}^{\breve{R}_T}\left[\beta_H\ln\left(\frac{\breve{R}_T\breve{T}}{U_{cr}\beta_{pV}}\right)-\beta_{pV}\ln\left(\frac{\breve{p}}{p_l\beta_{pV}}\right)\right]\breve{T}d\breve{R}_T\right\}\frac{1}{\beta_{pV}}=$$

$$=U_{cr}\left[(\hat{T})+\beta_{ST}\int_{\breve{R}_{T0}}^{\breve{R}_T}(\hat{T})(\hat{S})\frac{d\breve{R}_T}{\breve{R}_T}\right]=\frac{1}{\beta_{pV}}\left\{\breve{R}_T\breve{T}+\int_{\breve{R}_{T0}}^{\breve{R}_T}\left[\ln\left(\frac{\breve{R}_T\breve{T}}{\beta_{pV}U_{cr}}\right)+\beta_{pV}\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]\breve{T}d\breve{R}_T\right\},$$

$$\breve{F}_T=\breve{U}-\breve{S}\breve{T}=U_{cr}\left[(\hat{T})-\beta_{ST}\int_{[(\hat{S})(\hat{T})/\breve{R}_T]_0}^{(\hat{T})(\hat{S})/\breve{R}_T}\breve{R}_T d\left(\frac{(\hat{T})(\hat{S})}{\breve{R}_T}\right)\right]=\breve{F}_{T0}+\int_{\breve{R}_{T0}}^{\breve{R}_T}\frac{\breve{S}\breve{T}}{\breve{R}_T}d\breve{R}_T=$$

$$=U_{cr}\left\{[1-\ln(\hat{T})-\beta_{pV}\ln(\hat{V})](\hat{T})+\int_{\breve{R}_{T0}}^{\breve{R}_T}[\ln(\hat{T})+\beta_{pV}\ln(\hat{V})](\hat{T})/\breve{R}_T]d\breve{R}_T\right\}=$$

$$=\breve{U}_0(1-\beta_{pV}\breve{S}/\breve{R}_T+\breve{U}_{ad}=\breve{T}(R_{UT}\breve{Z}/\beta_{pV}-\breve{S})+\breve{U}_{ad}=$$

$$=\frac{1}{\beta_{pV}}\left\{\breve{R}_T\breve{T}\left[1-\ln\left(\frac{\breve{R}_T\breve{T}}{\beta_{pV}U_{cr}}\right)-\beta_{pV}\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]+\int_{\breve{R}_{T0}}^{\breve{R}_T}\left[\ln\left(\frac{\breve{R}_T\breve{T}}{\beta_{pV}}\right)+\beta_{pV}\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]\breve{T}d\breve{R}_T\right\},$$

$$\breve{H}_T=\breve{U}+\breve{p}\breve{V}=\breve{U}+\breve{R}_T\breve{T}=\breve{U}_0(1+\beta_{pV})+\breve{U}_{ad}=R_{UT}\breve{Z}\breve{T}(1/\beta_{pV}+1)+\breve{U}_{ad}=$$

$$=\breve{H}_{T0}+\int_{\breve{R}_{T0}}^{\breve{R}_T}\frac{\breve{T}\breve{S}}{\breve{R}_T}d\breve{R}_T=\frac{\beta_H\breve{R}_T\breve{T}}{\beta_{pV}}+\int_{\breve{R}_{T0}}^{\breve{R}_T}\frac{\breve{T}\breve{S}}{\breve{R}_T}d\breve{R}_T=U_{cr}\left[\beta_H(\hat{T})+\beta_{ST}\int_{\breve{R}_{T0}}^{\breve{R}_T}\frac{(\hat{T})(\hat{S})}{\breve{R}_T}d\breve{R}_T\right]=$$

$$=U_{cr}\left[\beta_H\left(\frac{\breve{p}}{\beta_{pV}p_l}\right)^{\frac{\beta_{pV}}{\beta_H}}\exp\left(\frac{\beta_{pV}\breve{S}}{\beta_H\breve{R}_T}\right)+\beta_{pV}\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}\left(\frac{\breve{p}}{\beta_{pV}p_l}\right)^{\frac{\beta_{pV}}{\beta_H}}\exp\left(\frac{\beta_{pV}\breve{S}}{\beta_H\breve{R}_T}\right)\frac{\breve{S}}{\breve{R}_T^2}d\breve{R}_T\right]=$$

$$=\frac{\beta_H}{\beta_{pV}}\left\{\breve{R}_T\breve{T}+\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}\left[\ln\left(\frac{\breve{R}_T\breve{T}}{\beta_{pV}U_{cr}}\right)-\frac{\beta_{pV}}{\beta_H}\ln\left(\frac{\breve{p}}{\beta_{pV}p_l}\right)\right]\breve{T}d\breve{R}_T\right\}=$$

$$=\frac{1}{\beta_{pV}}\left\{\beta_H\breve{R}_T\breve{T}+\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}\left[\ln\left(\frac{\breve{R}_T\breve{T}}{\beta_{pV}U_{cr}}\right)+\beta_{pV}\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]\breve{T}d\breve{R}_T\right\}=$$

$$=c\psi_{m0}U_{cr}\left\{\frac{\beta_H}{\Gamma_m v_l}+\beta_{ST}\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}\left[\ln\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)-(\mathtt{l}-1)\ln n_m\right]\frac{d\breve{R}_T}{\breve{R}_T\Gamma_m v_l}\right\},$$

$$\breve{G}=U_{cr}\left[\beta_H(\hat{T})-\beta_{ST}\int\limits_{[(\hat{S})(\hat{T})/\breve{R}_T]_0}^{(\hat{S})(\hat{T})/\breve{R}_T}\breve{R}_T d\left(\frac{(\hat{S})(\hat{T})}{\breve{R}_T}\right)\right]=\breve{U}_0\left[1+\beta_{pV}\left(1-\frac{\breve{S}}{\breve{R}_T}\right)\right]+\breve{U}_{ad}=\breve{T}\left[R_{UT}\breve{Z}\left(\frac{1}{\beta_{pV}}+1\right)-\breve{S}\right]+\breve{U}_{ad}=$$

$$=\breve{H}_T-\breve{S}\breve{T}=\breve{G}_0+\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}\frac{\breve{S}\breve{T}}{\breve{R}_T}d\breve{R}_T=\beta_H U_{cr}\left\{\left[1-\ln(\hat{T})+\frac{\beta_{pV}}{\beta_H}\ln(\hat{p})\right](\hat{T})+\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}\left[\ln(\hat{T})-\frac{\beta_{pV}}{\beta_H}\ln(\hat{p})\right]\frac{(\hat{T})}{\breve{R}_T}d\breve{R}_T\right\}=$$

$$=\breve{H}_{T0}-\int\limits_{\breve{A}_{\rho0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho=\frac{\beta_H\breve{a}_\rho\breve{T}}{\beta_{pV}}-\int\limits_{\breve{A}_{\rho0}}^{\breve{A}_\rho}\breve{a}_\rho d\breve{A}_\rho=\frac{\beta_H\breve{R}_T\breve{T}}{\beta_{pV}}\left[1-\ln\left(\frac{\breve{R}_T\breve{T}}{\beta_{pv}U_{cr}}\right)+\frac{\beta_{pV}}{\beta_H}\ln\left(\frac{\breve{p}}{\beta_{pV}p_l}\right)\right]+$$

$$+\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}\left[\frac{\beta_H}{\beta_{pV}}\ln\left(\frac{\breve{R}_T\breve{T}}{\beta_{pV}U_{cr}}\right)-\ln\left(\frac{\breve{p}}{\beta_{pV}p_l}\right)\right]\breve{T}d\breve{R}_T=\frac{\beta_G R_{UT}\breve{Z}\breve{T}}{\beta_{pV}}+\breve{U}_{ad}=U_{cr}f_I[1+\beta_{pV}-\beta_{ST}\ln(f_I^{\mathtt{l}}N_I^{1-\mathtt{l}})]+\breve{U}_{ad}=$$

$$=c\psi_{m0}U_{cr}\left\{\frac{\beta_H}{\Gamma_m v_l}-\int\limits_{\breve{A}_{\rho0}}^{\breve{A}_\rho}\breve{R}_T d\left(\frac{\beta_{ST}}{\breve{R}_T\Gamma_m v_l}\left[\ln\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)-(\mathtt{l}-1)\ln n_m\right]\right)\right\}=$$

$$=\frac{c\psi_{m0}U_{cr}\beta_{ST}}{\Gamma_m v_l}\left\{\left[\frac{\beta_H}{\beta_{ST}}-\ln\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)+(\mathtt{l}-1)\ln n_m\right]+\Gamma_m v_l\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}\left[\ln\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)-(\mathtt{l}-1)\ln n_m\right]\frac{d\breve{R}_T}{\breve{R}_T\Gamma_m v_l}\right\},$$

where: $\breve{U}_0=(\hat{T})U_{cr}$, $\breve{H}_{T0}=\beta_H\breve{U}_0$, $\breve{G}_0=\beta_G\breve{U}_0$, $\breve{F}_{T0}$ are multiplicatively dependent on $q_M=1/n_m$ and N_I components of instantaneous values of internal energy, enthalpy, Gibbs free energy and Helmholtz free energy of instantaneous Gibbs microstate of matter correspondingly;

$\breve{U}_{ad}=\sum\limits_{i=2}^{n}\int\limits_{\breve{a}_{i0}}^{\breve{a}_i}\breve{A}_i d\breve{a}_i=\int\limits_{\breve{a}_{\rho0}}^{\breve{a}_\rho}\breve{A}_\rho d\breve{a}_\rho=\int\limits_{\breve{R}_{T0}}^{\breve{R}_T}(\breve{T}\breve{S}/\breve{R}_T)d\breve{R}_T>0$ is instantaneous value of realized via negative feedback partial additive compensation of multiplicative representation of thermodynamic potentials of microstate of matter (a multiplicative decrease in its free energies over time);

$\breve{a}_\rho\equiv\breve{R}_T=\breve{p}\breve{V}/\breve{T}$ and $\breve{A}_\rho=\breve{T}\breve{S}/\breve{R}_T=\breve{T}^2\breve{S}/\breve{p}\breve{V}$ are respectively, extensive and intensive resulting thermodynamic parameters of the real gas;

$(\hat{S})=\ln(q_M^{\mathtt{l}}N_I)=\ln(f_I^{\mathtt{l}}N^{1-\mathtt{l}})$, $(\hat{V})=q_M^{-1/\mathrm{k}}N_I^{-\mathrm{m}}=q_M^{\mathrm{m}-1/\mathrm{k}}f_I^{-\mathrm{m}}=f_I^{-1/\mathrm{k}}N_I^{1/\mathrm{k}-\mathrm{m}}=(\Gamma_m v_l/c\psi_{m0})^{1/\beta_{pV}}\exp(\breve{S}/\breve{R}_T)$,

$(\hat{p})=q_M^{1+1/\mathrm{k}}N_I^{1+\mathrm{m}}=q_M^{1/\mathrm{k}-\mathrm{m}}f_I^{1+\mathrm{m}}=f_I^{1+1/\mathrm{k}}N_I^{\mathrm{m}-1/\mathrm{k}}=(\Gamma_m v_l/c\psi_{m0})^{-\beta_H/\beta_{pV}}\exp(-\breve{S}/\breve{R}_T)$,

$(\hat{T})=(\hat{p})(\hat{V})=q_M N_I=f_I=\chi_m/f_G=\psi_m c/v_{cv}\equiv\psi_{m0}c/\Gamma_m v_l=\psi_{m0}b^{-1/2}/\Gamma_m$ are normalized values of thermodynamic parameters (entropy, molar volume, pressure and temperature) of Gibbs microstates of matter;

$$\beta_{pV}=\frac{\breve{p}\breve{V}}{\breve{U}_0}=\frac{\mathrm{k}(\mathrm{l}-1)}{\mathrm{k}\,\mathrm{l}\,\mathrm{m}-1}>0,\quad \beta_H=\frac{\breve{H}_{T0}}{\breve{U}_0}=1+\beta_{pV}=\frac{\mathrm{k}(\mathrm{l}\,\mathrm{m}+\mathrm{l}-1)-1}{\mathrm{k}\,\mathrm{l}\,\mathrm{m}-1},\quad \beta_{ST}=\frac{\breve{S}\breve{T}}{\breve{U}_0\ln(q_M^{\mathrm{l}}N_I)}=\frac{\mathrm{km}-1}{\mathrm{k}\,\mathrm{l}\,\mathrm{m}-1}>0,$$

$$\beta_{pT}=\beta_{pV}\left(1-\frac{\breve{S}}{\breve{R}_T}\right),\quad \beta_G=\frac{\breve{G}_0}{\breve{U}_0}=1+\beta_{pT}=1+\beta_{pV}-\beta_{ST}\ln(q_M^{\mathrm{l}}N_I)=\beta_H-\frac{\mathrm{l}(\mathrm{km}-1)}{\mathrm{k}\,\mathrm{l}\,\mathrm{m}-1}\ln q_M-\frac{\mathrm{km}-1}{\mathrm{k}\,\mathrm{l}\,\mathrm{m}-1}\ln N_I=$$

$$=\frac{\mathrm{k}(\mathrm{l}\,\mathrm{m}+\mathrm{l}-1)-1}{\mathrm{k}\,\mathrm{l}\,\mathrm{m}-1}-\frac{\mathrm{l}(\mathrm{km}-1)}{\mathrm{k}\,\mathrm{l}\,\mathrm{m}-1}\ln f_I+\frac{(\mathrm{km}-1)(\mathrm{l}-1)}{\mathrm{k}\,\mathrm{l}\,\mathrm{m}-1}\ln N_I,$$

$$\beta_{GR}=\frac{\breve{G}}{\breve{U}_0}=1+\beta_{pV}-\frac{\beta_{ST}}{(\hat{T})}\int_{\breve{A}_{\rho0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho=\frac{\mathrm{k}(\mathrm{l}\mathrm{m}+\mathrm{l}-1)-1}{\mathrm{k}\mathrm{l}\mathrm{m}-1}-\frac{\mathrm{km}-1}{(\mathrm{k}\mathrm{l}\mathrm{m}-1)q_M N_I}\int_{[(\hat{S}\}(\hat{T})/\breve{R}_T]_0}^{(\hat{S})(\hat{T})/\breve{R}_T}\breve{R}_T d\left[\frac{q_M N_I\ln(q_M^{\mathrm{l}}N_I)}{\breve{R}_T}\right];$$

$p_l(p_{lE},a)=\mathrm{n}\,p_{cr}=\mathbf{const}(r)$, $p_{lE}=\mathrm{n}_E\,p_{cr}\neq\mathbf{const}(r)$, while: $\mathrm{n}=\mathbf{const}(r)$ and $\mathrm{n}_E\neq\mathbf{const}(r)$ are the hidden variables that are the indicatorsi of the magnitudes of instantaneous microfluctuations of values of pressure and molar volume when $\breve{p}\breve{V}=\mathbf{const}$ and during not absolutely rigid retention of occupied by gas constant volume in the intrinsic space of matter and in Euclidean space correspondingly [50]; $\mathrm{k}=\mathbf{const}(r)$, $\mathrm{l}=\mathbf{const}(r)$, $\mathrm{m}=\mathbf{const}(r)$ are spatially homogeneous hidden variables that are indicators of the influence of parameters $q_M=1/n_m$ and $N_I=\sigma_m/N_{RE}$ on the parameters of thermodynamic microstates of latently coherent matter[5].

Variables k, l , m and n characterize instantaneous collective microstates of the whole gravithermodynamically bonded matter and similarly to the wave functions of quantum mechanics can take with certain probability any arbitrary instantaneous values. The probability that Gibbs microstate of matter have instantaneous energy, the corresponding certain composition of values of these variables, obviously, is represented by canonic Gibbs distribution. The concrete mathematical expectations $\breve{k}(R_T)$, $\breve{l}(R_T)$, $\breve{m}(R_T)$, $\breve{n}(R_T)$, $\breve{n}_E(R_T,a)$ of those variables (that depend on the parameter R_T) correspond to parameters of a thermodynamic macrostate of matter. It is exactly the dependence of the mathematical expectation $\breve{n}_E(R_T,a)$[6] of the hidden parameter n_E also on the index of curvature a of the intrinsic space of matter that is responsible for its curvature.

Normalized values of thermodynamic parameters of instantaneous microstates of matter are mutually related via the following dependencies:

$$(\hat{S})=\mathrm{l}\ln q_M+\ln N_I=\mathrm{l}\ln\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)-(\mathrm{l}-1)\ln\left(\frac{\sigma_m}{N_{RE}}\right)=\frac{\beta_H}{\beta_{ST}}\ln(\hat{T})-\frac{\beta_{pV}}{\beta_{ST}}\ln(\hat{p})=\frac{\ln(\hat{T})}{\beta_{ST}}+\frac{\beta_{pV}}{\beta_{ST}}\ln(\hat{V})=\frac{\beta_H}{\beta_{ST}}\ln(\hat{V})+\frac{\ln(\hat{p})}{\beta_{ST}},$$

$$\ln(\hat{T})=\ln q_M+\ln N_I=\ln\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)=\frac{\beta_{ST}}{\beta_H}(\hat{S})+\frac{\beta_{pV}}{\beta_H}\ln(\hat{p})=\beta_{ST}(\hat{S})-\beta_{pV}\ln(\hat{V})=\ln(\hat{p})+\ln(\hat{V}),\quad (1)$$

$$\ln(\hat{V})=-\frac{\ln q_M}{\mathrm{k}}-\mathrm{m}\ln N_I=-\mathrm{m}\ln\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)+\frac{1-\mathrm{km}}{\mathrm{k}}\ln n_m=\frac{\beta_{ST}}{\beta_H}(\hat{S})-\frac{\ln(\hat{p})}{\beta_H}=\frac{\beta_{ST}}{\beta_{pV}}(\hat{S})-\frac{\ln(\hat{T})}{\beta_{pV}}=\ln(\hat{T})-\ln(\hat{p}),\quad (2)$$

$$\ln(\hat{p})=\frac{\mathrm{k}+1}{\mathrm{k}}\ln q_M+(\mathrm{m}+1)\ln N_I=(\mathrm{m}+1)\ln\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)+\frac{\mathrm{km}-1}{\mathrm{k}}\ln n_m=$$

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[5] It is possible that latent coherence of matter is brought on (together with the new moment of its proper time) by the next turn of spiral wave of space-time modulation of dielectric and magnetic permeabilities of physical vacuum [43, 51].

[6] Differential equations of the gravitational field specify only the radial gradients of the parameters a and b, and not their absolute values. Therefore, at the same point in space, the values of not only the real velocity of radiation propagation v_{cm} , but also of the parameter $b=v_l^2c^{-2}$ may differ for different substances that border each other in the same space. But the value of the parameter a is taken to be the same for them both in GR and in RGTD. However, the possibility of its change together with the change in pressure in the gas cylinder is not excluded.

$$=\beta_{ST}(\hat{S})-\beta_H\ln(\hat{V})=\frac{\beta_{ST}}{\beta_{pV}}(\hat{S})+\frac{\beta_H}{\beta_{pV}}\ln(\hat{T})=\ln(\hat{T})-\ln(\hat{V}). \qquad (3)$$

As it was expected, all instantaneous thermodynamic potentials reach their minimum independently both on the values of variables k, l , m, n, and on the value of spatial gas-related (liquid-related) parameter $\breve{R}_T$:

$$\left(\frac{\partial\breve{U}}{\partial\breve{R}_T}\right)_{\breve{S},\breve{V}}=0, \qquad \left(\frac{\partial\breve{H}_T}{\partial\breve{R}_T}\right)_{\breve{S},\breve{p}}=0, \qquad \left(\frac{\partial\breve{F}_T}{\partial\breve{R}_T}\right)_{\breve{T},\breve{V}}=0, \qquad \left(\frac{\partial\breve{G}}{\partial\breve{R}_T}\right)_{\breve{T},\breve{p}}=0.$$

And, moreover, the change in space of available thermodynamic parameters of matter that gradually cools is inevitably accompanied by the change of its hidden thermodynamic parameters Γ_m and v_l:

$$\left(\frac{\partial U}{\partial\overset{\frown}{r}}\right)_t=T\left(\frac{\partial S}{\partial\overset{\frown}{r}}\right)_t-p\left(\frac{\partial V}{\partial\overset{\frown}{r}}\right)_t=-U_0\left[\left(\frac{\partial\ln\Gamma_m}{\partial\overset{\frown}{r}}\right)_t+\left(\frac{\partial\ln v_l}{\partial\overset{\frown}{r}}\right)_t\right],$$

$$\left(\frac{\partial H_T}{\partial\overset{\frown}{r}}\right)_t=T\left(\frac{\partial S}{\partial\overset{\frown}{r}}\right)_t+V\left(\frac{\partial p}{\partial\overset{\frown}{r}}\right)_t=-H_{T0}\left[\left(\frac{\partial\ln\Gamma_m}{\partial\overset{\frown}{r}}\right)_t+\left(\frac{\partial\ln v_l}{\partial\overset{\frown}{r}}\right)_t\right],$$

$$\mathbf{F}_{gr}=\left(\frac{\partial G}{\partial\overset{\frown}{r}}\right)_t=-S\left(\frac{\partial T}{\partial\overset{\frown}{r}}\right)_t+V\left(\frac{\partial p}{\partial\overset{\frown}{r}}\right)_t=-G_0\left[\left(\frac{\partial\ln\Gamma_m}{\partial\overset{\frown}{r}}\right)_t+\left(\frac{\partial\ln v_l}{\partial\overset{\frown}{r}}\right)_t\right],$$

where: $\partial\overset{\frown}{r}$ is the increment of metric radial distance.

And the bigger the distance from matter to the gravitational attraction center the smaller is its internal energy. That is why in contrast to inert free energy (which is the greater the greater the distance from the substance to the gravitational attraction center) the thermal energy behaves like a negative mass. And this is confirmed by numerous investigations of the influence of heating of matter on its weight [47 – 49].

Precisely the condition of spatial homogeneity of the compressibility coefficient of RGTD-bonded matter $Z(t)=R_T(t)/R_{UT}=\mathbf{const}(r)$[7] determines the spatial distribution of the set of main thermodynamic parameters of this matter that gradually cools.

Of course, every matter has its values of gravitational potentials, since the common for the whole RGTD-bonded matter gravitational field forms only its gradients in the space. However, in order to make all thermodynamic parameters of all individual thermodynamic STC of these matters conformed with the parameters *a* and *b* of Schwarzschild solution of common for them gravitational field the appropriate conditions should be fulfilled.

3. Instantaneous values of all main thermodynamic parameters and potentials of RGTD-bonded matter

Since parameter:

$$R_T=\frac{TS}{A_\rho}=\frac{U_{cr}\widetilde{\beta}_{ST}q_M N_I\ln(q_M^{\tilde{l}}N_I)}{A_\rho}=\frac{U_{cr}\widetilde{\beta}_{ST}c\psi_{m0}[\ln\psi_{m0}-\ln\Gamma_m-\ln(v_l/c)-(1-\tilde{l})\ln(v_{cm}/c)]}{A_\rho\Gamma_m v_l}\neq R_{T0}$$

expressed not only via constants (including also A_ρ=**const**(*t*) which characterizes the quasi-equilibrium of the process of cooling down of matter throughout the whole time), but also via velocity of the light in matter v_{cm}, limit velocity of motion v_l and Lorentz shrinkage of dimensions

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[7] This is nothing more than the expression of the tendency to align the magnitudes of any intensive parameters of matters in the whole filled with them space. Only such main (field) intensive thermodynamic parameters as temperature and pressure in principle cannot be (or become) absolutely spatially homogenous in quasi-equilibriumly cooling down matter. Some other the fielded intensive thermodynamic parameters, which are related to the possibility of appearance of not only gravitational but also magnetic and electric fields in the RGTD-bonded matter, also cannot become absolutely spatially homogenous.

of the matter that moves in the process of quasi-equilibriumly cooling down $\Gamma_m \neq \mathbf{const}(r)$ ($\psi_m = \psi_{m0}/\Gamma_m \neq \mathbf{const}(r)$), then only via them we can in temporal form (via A_ρ) or in spatial form (via $a_\rho \equiv R_T$) express instantaneous values of all main thermodynamic parameters and potentials of RGTD-bonded matter:

$$\breve{T} = \frac{\breve{A}_\rho \beta_{pV}}{\beta_{ST}(\mathrm{l}\ln q_M + \ln N_I)} = \frac{\breve{A}_\rho \beta_{pV}}{\beta_{ST}[\ln\psi_{m0} - \ln\Gamma_m - \ln(v_l/c) + (\mathrm{l}-1)\ln(v_{cm}/c)]} =$$

$$= \frac{U_{cr}\beta_{pV} q_M N_I}{\breve{R}_T} = \frac{U_{cr}\beta_{pV} c\psi_{m0}}{\breve{R}_T \Gamma_m v_l} = \frac{\breve{p}\breve{V}}{\breve{R}_T} = \frac{U_{cr}\beta_{pV}}{\breve{R}_T}\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{S}}{\breve{R}_T}\right)\right]^{\beta_{pV}} =$$

$$= \beta_{pV}\breve{A}_\rho\left[\ln\left(\frac{\breve{p}}{p_l\beta_{pV}}\right) + (1+\beta_{pV})\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]^{-1} = \frac{U_{cr}\beta_{pV}}{\breve{R}_T}\left[\frac{\breve{p}}{p_l\beta_{pV}}\exp\left(\frac{\breve{S}}{\breve{R}_T}\right)\right]^{\frac{\beta_{pV}}{1+\beta_{pV}}},$$

$$\breve{S} = \frac{U_{cr}\beta_{ST}^2 q_M N_I(\mathrm{l}\ln q_M + \ln N_I)^2}{\beta_{pV}\breve{A}_\rho} = \frac{\beta_{ST}\breve{R}_T(\mathrm{l}\ln q_M + \ln N_I)}{\beta_{pV}} =$$

$$= \frac{U_{cr} c\psi_{m0}\beta_{ST}^2[\ln\psi_{m0} - \ln(v_{lc}/c) + (\mathrm{l}-1)\ln(v_{cm}/c)]^2}{\beta_{pV}\breve{A}_\rho v_{lc}} =$$

$$= (\beta_{ST}\breve{R}_T/\beta_{pV})[\ln\psi_{m0} - \ln\Gamma_m - \ln(v_l/c) + (\mathrm{l}-1)\ln(v_{cm}/c)] =$$

$$= \frac{U_{cr}\beta_{pV}\breve{A}_\rho}{\breve{T}^2}\left[\frac{\breve{p}}{p_l\beta_{pV}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\frac{\beta_{pV}}{\beta_H}} = \frac{U_{cr}\beta_{pV}\breve{A}_\rho}{\breve{T}^2}\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\beta_{pV}} =$$

$$= (\beta_{pV}^{-2}\breve{p}\breve{V}/\breve{A}_\rho)[\ln(\breve{p}/p_l\beta_{pV}) + \beta_H\ln(\breve{V}p_l/U_{cr})]^2,$$

$$\breve{p} = p_l\beta_{pV} q_M^{1+1/\mathrm{k}} N_I^{1+\mathrm{m}} = p_l\beta_{pV}\left(\frac{c\psi_{m0}}{\Gamma_m v_l}\right)^{1+\mathrm{m}}\left(\frac{c}{v_{cm}}\right)^{\mathrm{m}-1/\mathrm{k}} = \frac{\breve{R}_T\breve{T}}{\breve{V}} =$$

$$= p_l\beta_{pV}\left(\frac{U_{cr}}{p_l\breve{V}}\right)^{1+\beta_{pV}}\exp\left(\frac{\beta_{pV}\breve{A}_\rho}{\breve{T}}\right) = p_l\beta_{pV}\left(\frac{\breve{R}_T\breve{T}}{U_{cr}\beta_{pV}}\right)^{1+1/\beta_{pV}}\exp\left(-\frac{\breve{S}}{\breve{R}_T}\right) =$$

$$= p_l\beta_{pV}\left(\frac{\breve{S}\breve{T}^2}{U_{cr}\beta_{pV}\breve{A}_\rho}\right)^{1+\frac{1}{\beta_{pV}}}\exp\left(-\frac{\breve{A}_\rho}{\breve{T}}\right) = p_l\beta_{pV}\left(\frac{U_{cr}}{p_l\breve{V}}\right)^{1+\beta_{pV}}\exp\left(\frac{\beta_{pV}\breve{S}}{\breve{R}_T}\right),$$

$$\breve{V} = \frac{U_{cr}}{p_l q_M^{1/\mathrm{k}} N_I^{\mathrm{m}}} = \frac{U_{cr}}{p_l}\left(\frac{\Gamma_m v_l}{c\psi_{m0}}\right)^{\mathrm{m}}\left(\frac{v_{cm}}{c}\right)^{\mathrm{m}-\frac{1}{\mathrm{k}}} = \frac{\breve{R}_T\breve{T}}{\breve{p}} =$$

$$= \frac{U_{cr}}{p_l}\left[\left(\frac{p_l\beta_{pV}}{\breve{p}}\right)\exp\left(\frac{\beta_{pV}\breve{A}_\rho}{\breve{T}}\right)\right]^{\frac{1}{1+\beta_{pV}}} = \frac{U_{cr}}{p_l}\left(\frac{U_{cr}\beta_{pV}}{\breve{R}_T\breve{T}}\right)^{\frac{1}{\beta_{pV}}}\exp\left(\frac{\breve{S}}{\breve{R}_T}\right) =$$

$$= \frac{U_{cr}}{p_l}\left(\frac{U_{cr}\beta_{pV}\breve{A}_\rho}{\breve{S}\breve{T}^2}\right)^{\frac{1}{\beta_{pV}}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right) = \frac{U_{cr}}{p_l}\left[\left(\frac{p_l\beta_{pV}}{\breve{p}}\right)\exp\left(\frac{\beta_{pV}\breve{S}}{\breve{R}_T}\right)\right]^{\frac{1}{1+\beta_{pV}}},$$

$$\breve{U} = \breve{U}_0 + \breve{U}_{ad} = U_{cr} q_M N_I + \int_{\breve{R}_{T0}}^{\breve{R}_T}\breve{S}\breve{T}\frac{d\breve{R}_T}{\breve{R}_T} = \breve{U}_0 + \breve{A}_\rho\breve{R}_T - U_{ad}^* = \breve{U}_0 + \breve{S}\breve{T} - \int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{S}\breve{T}\frac{d\breve{A}_\rho}{\breve{A}_\rho} =$$

$$=U_{cr}[1+\beta_{ST}\ln(q_M^1 N_I)]q_M N_I-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho=\frac{U_{cr}\psi_{m0}c}{\Gamma_m v_l}+\int_{\breve{R}_{T0}}^{\breve{R}_T}\breve{S}\breve{T}\frac{d\breve{R}_T}{\breve{R}_T}=\breve{S}\breve{T}\left(1+\frac{\breve{T}}{\beta_{pV}\breve{A}_\rho}\right)-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{S}\breve{T}\frac{d\breve{A}_\rho}{\breve{A}_\rho}=$$

$$=U_{cr}\left(1+\frac{\beta_{pV}\breve{A}_\rho}{\breve{T}}\right)\left[\frac{\breve{p}}{p_l\beta_{pv}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\frac{\beta_{pV}}{1+\beta_{pV}}}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho=$$

$$=U_{cr}\left(1+\frac{\beta_{pV}\breve{A}_\rho}{\breve{T}}\right)\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\beta_{pV}}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{R}_T a\breve{A}_\rho=\frac{\breve{p}\breve{V}}{\beta_{pV}}\left[1+\ln\left(\frac{\breve{p}}{p_l\beta_{pV}}\right)+(1+\beta_{pV})\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho\ ,$$

$$\breve{F}_T=\breve{U}_0-\breve{U}_{ad}^*=U_{cr}q_M N_I-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho=\frac{U_{cr}c\psi_{m0}}{v_{lc}}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho=\breve{U}_0-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{S}\breve{T}\frac{d\breve{A}_\rho}{\breve{A}_\rho}=$$

$$=\frac{\breve{p}\breve{V}}{\beta_{pV}}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\frac{\breve{p}\breve{V}}{\beta_{pV}}\left[\ln\left(\frac{\breve{p}}{p_l\beta_{pV}}\right)+(1+\beta_{pV})\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]\frac{d\breve{A}_\rho}{\breve{A}_\rho}=\frac{\breve{S}\breve{T}^2}{\beta_{pV}\breve{A}_\rho}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{S}\breve{T}\frac{d\breve{A}_\rho}{\breve{A}_\rho}=$$

$$=U_{cr}\left\{\left[\frac{\breve{p}}{p_l\beta_{pv}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\frac{\beta_{pV}}{1+\beta_{pV}}}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\frac{\beta_{pV}}{\breve{T}}\left[\frac{\breve{p}}{p_l\beta_{pV}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\frac{\beta_{pV}}{1+\beta_{pV}}}d\breve{A}_\rho\right\}=$$

$$=U_{cr}\left\{\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\beta_{pV}}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\frac{\beta_{pV}}{\breve{T}}\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\beta_{pV}}d\breve{A}_\rho\right\},$$

$$\breve{H}_T=\breve{H}_{T0}+\breve{a}_\rho\breve{A}_\rho-\breve{U}_{ad}^*=\breve{H}_{T0}+\breve{S}\breve{T}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{S}\breve{T}\frac{d\breve{A}_\rho}{\breve{A}_\rho}=U_{cr}(1+\beta_{pV})q_M N_I+\int_{\breve{R}_{T0}}^{\breve{R}_T}\breve{A}_\rho d\breve{R}_T=$$

$$=\breve{H}_{T0}+\breve{U}_{ad}=U_{cr}[(1+\beta_{pV})+\beta_{ST}\ln(q_M^1 N_I)]q_M N_I-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho=$$

$$=\frac{U_{cr}(1+\beta_{pV})\psi_{m0}c}{\Gamma_m v_l}+\int_{\breve{R}_{T0}}^{\breve{R}_T}\breve{S}\breve{T}\frac{d\breve{R}_T}{\breve{R}_T}=\breve{S}\breve{T}\left(1+\frac{(1+\beta_{pV})\breve{T}}{\beta_{pV}\breve{A}_\rho}\right)-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{S}\breve{T}\frac{d\breve{A}_\rho}{\breve{A}_\rho}=$$

$$=U_{cr}\left\{\left(1+\beta_{pV}+\frac{\beta_{pV}\breve{A}_\rho}{\breve{T}}\right)\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\beta_{pV}}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\frac{\beta_{pV}}{\breve{T}}\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{A}_\rho}{\breve{T}}\right)\right]^{\beta_{pV}}d\breve{A}_\rho\right\}=$$

$$=U_{cr}\left(1+\beta_{pV}+\frac{\beta_{pV}\breve{A}_\rho}{\breve{T}}\right)\left[\frac{\breve{p}}{p_l\beta_{pV}}\exp\frac{\breve{A}_\rho}{\breve{T}}\right]^{\frac{\beta_{pV}}{1+\beta_{pV}}}-U_{cr}\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\frac{\beta_{pV}}{\breve{T}}\left[\frac{\breve{p}}{p_l\beta_{pV}}\exp\frac{\breve{A}_\rho}{\breve{T}}\right]^{\frac{\beta_{pV}}{1+\beta_{pV}}}d\breve{A}_\rho=$$

$$=\frac{\breve{p}\breve{V}(1+\beta_{pV})}{\beta_{pV}}\left[1+\frac{1}{1+\beta_{pV}}\ln\left(\frac{\breve{p}}{p_l\beta_{pV}}\right)+\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]-\frac{1}{\beta_{pV}}\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{p}\breve{V}\left[\ln\left(\frac{\breve{p}}{p_l\beta_{pV}}\right)+(1+\beta_{pV})\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]\frac{d\breve{A}_\rho}{\breve{A}_\rho},$$

$$\breve{G}=\breve{H}_{T0}-\breve{U}_{ad}^*=\frac{U_{cr}(1+\beta_{pV})\psi_{m0}c}{v_{lc}}-\breve{U}_{ad}^*=\frac{(1+\beta_{pV})\breve{R}_T\breve{T}}{\beta_{pV}}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{R}_T d\breve{A}_\rho=\frac{(1+\beta_{pV})\breve{S}\breve{T}^2}{\beta_{pV}\breve{A}_\rho}-\int_{\breve{A}_{\rho 0}}^{\breve{A}_\rho}\breve{S}\breve{T}\frac{d\breve{A}_\rho}{\breve{A}_\rho}=$$

$$=\frac{(1+\beta_{pV})\breve{p}\breve{V}}{\beta_{pV}}-\int\limits_{\breve{A}_{\rho 0}}^{\breve{A}_{\rho}}\frac{\breve{p}\breve{V}}{\beta_{pV}}\left[\ln\left(\frac{\breve{p}}{p_l\beta_{pV}}\right)+(1+\beta_{pV})\ln\left(\frac{p_l\breve{V}}{U_{cr}}\right)\right]\frac{d\breve{A}_{\rho}}{\breve{A}_{\rho}}=$$

$$=U_{cr}\left\{(1+\beta_{pV})\left[\frac{\breve{p}}{p_l\beta_{pv}}\exp\left(\frac{\breve{A}_{\rho}}{\breve{T}}\right)\right]^{\frac{\beta_{pV}}{1+\beta_{pV}}}-\int\limits_{\breve{A}_{\rho 0}}^{\breve{A}_{\rho}}\frac{\beta_{pV}}{\breve{T}}\left[\frac{\breve{p}}{p_l\beta_{pV}}\exp\left(\frac{\breve{A}_{\rho}}{\breve{T}}\right)\right]^{\frac{\beta_{pV}}{1+\beta_{pV}}}d\breve{A}_{\rho}\right\}=$$

$$=U_{cr}\left\{(1+\beta_{pV})\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{A}_{\rho}}{\breve{T}}\right)\right]^{\beta_{pV}}-\int\limits_{\breve{A}_{\rho 0}}^{\breve{A}_{\rho}}\frac{\beta_{pV}}{\breve{T}}\left[\frac{U_{cr}}{p_l\breve{V}}\exp\left(\frac{\breve{A}_{\rho}}{\breve{T}}\right)\right]^{\beta_{pV}}d\breve{A}_{\rho}\right\},$$

where: $\left(\frac{\partial\breve{U}}{\partial\breve{A}_{\rho}}\right)_{\breve{S},\breve{V}}=0$, $\left(\frac{\partial\breve{H}_T}{\partial\breve{A}_{\rho}}\right)_{\breve{S},\breve{p}}=0$, $\left(\frac{\partial\breve{F}_T}{\partial\breve{A}_{\rho}}\right)_{\breve{T},\breve{V}}=0$, $\left(\frac{\partial\breve{G}}{\partial\breve{A}_{\rho}}\right)_{\breve{T},\breve{p}}=0$;

$v_{lc}=\Gamma_m v_l$ is the limit velocity of matter that gradually cools in comoving with it FR (in its own space-time continuum (STC), in which the radial motion of molecules of matter that gradually cools is absent); $\breve{U}^*_{ad}=\int\limits_{\breve{A}_{\rho 0}}^{\breve{A}_{\rho}}\breve{R}_T d\breve{A}_{\rho}=\int\limits_{\breve{A}_{\rho 0}}^{\breve{A}_{\rho}}(\breve{S}\breve{T}/\breve{A}_{\rho})d\breve{A}_{\rho}\geq 0$ is instantaneous value of partial additive compensation of multiplicative representation of thermodynamic potentials of matter microstate (multiplicative increase of bound energy as we approach the gravitational attraction center); $\breve{G}$ is the instantaneous value of Gibbs energy G (that is similar to the Lagrangian, since it constantly tends to its minimum too).

As we can see, due to $A_{\rho}(r)=\mathbf{const}(t)$ when homogeneous matter is quasi-equilibrium cooling down the gravitational changes in time of its Gibbs free energy and Helmholtz free energy take place similarly to the changes in space of multiplicative component of internal energy U_0 and enthalpy H_{T0} correspondingly[8]. Precisely, if:

$$\left(\frac{\partial U}{\partial\widehat{t}}\right)_r=-(U_0+U^*_{ad})\left\{1+\frac{\widetilde{\beta}_{ST}}{1+\widetilde{\beta}_{ST}\left[\ln(c\psi_{m0}/v_{lc})+(\widetilde{l}-1)\ln n_m\right]}\right\}\left[\left(\frac{\partial\ln v_l}{\partial\widehat{t}}\right)_r+\left(\frac{\partial\ln\Gamma_m}{\partial\widehat{t}}\right)_r\right]+$$

$$+\frac{(U_0+U^*_{ad})\widetilde{\beta}_{ST}(\overleftrightarrow{l}-1)}{1+\widetilde{\beta}_{ST}[\ln(c\psi_{m0}/\Gamma_m v_l)+(\widetilde{l}-1)\ln n_m]}\left(\frac{\partial\ln n_m}{\partial\widehat{t}}\right)_r\text{, then:}$$

$$\left(\frac{\partial F_T}{\partial\widehat{t}}\right)_r=-S\left(\frac{\partial T}{\partial\widehat{t}}\right)_r-p\left(\frac{\partial V}{\partial\widehat{t}}\right)_r=-U_0\left(\frac{\partial\ln v_{lc}}{\partial\widehat{t}}\right)_r=-U_0\left[\left(\frac{\partial\ln\Gamma_m}{\partial\widehat{t}}\right)_r+\left(\frac{\partial\ln v_l}{\partial\widehat{t}}\right)_r\right],$$

$$\left(\frac{\partial G}{\partial\widehat{t}}\right)_r=-S\left(\frac{\partial T}{\partial\widehat{t}}\right)_r+V\left(\frac{\partial p}{\partial\widehat{t}}\right)_r=-H_{T0}\left(\frac{\partial\ln v_{lc}}{\partial\widehat{t}}\right)_r=-H_{T0}\left[\left(\frac{\partial\ln\Gamma_m}{\partial\widehat{t}}\right)_r+\left(\frac{\partial\ln v_l}{\partial\widehat{t}}\right)_r\right],$$

where: $\partial\widehat{t}$ is the increment of metric time of matter that gradually cools in a comoving with it FR.

Moreover, the multiplicative component of only the Gibbs free energy is proportional to the absolute temperature of matter not only in space but also in time. It is smaller the lower the temperature and, consequently, the higher the limit velocity v_{lc} of the molecules of matter (and the corresponding coordinate pseudovacuum velocity of light v_{cv} of GR).

The equations of thermodynamic state of gas for a predominantly hydrogen Universe would be as follows:

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[8] The authors of GR, obviously, intuitively understood this fact. That is why GR is the genial creation, despite the fact that it ignores the principal invariance of thermodynamic parameters and potentials relatively to space-time transformations.

$$^{U}U=U_{0}+A_{\rho}R_{T}, \qquad ^{U}F=U_{0}, \qquad ^{U}H_{T}=H_{T0}+A_{\rho}R_{T}, \qquad A_{\rho}=T^{2}S/pV=\mathbf{const}(t),$$

$$^{U}G={}^{U}H_{T0}=\frac{\widetilde{\beta}_{H}R_{T}T}{\widetilde{\beta}_{pV}}=\frac{\widetilde{\beta}_{H}pV}{\widetilde{\beta}_{pV}}=\frac{\widetilde{\beta}_{H}ST^{2}}{\widetilde{\beta}_{pV}A_{\rho}}=U_{cr}\widetilde{\beta}_{H}\left(\frac{p}{\widetilde{\beta}_{pV}p_{l}}\right)^{\frac{\widetilde{\beta}_{pV}}{\widetilde{\beta}_{H}}}\exp\left(\frac{\widetilde{\beta}_{pV}S}{\widetilde{\beta}_{H}R_{T}}\right),$$

$$d^{U}U=TdS-pdV+A_{\rho}dR_{T}, \quad d^{U}F=TdS-pdV, \quad d^{U}H_{T}=TdS+Vdp+A_{\rho}dR_{T}, \quad d^{U}G=TdS+Vdp$$

In the process of free fall of matter in gravitational field the Helmholtz and Gibbs thermodynamic free energies, as well as the Hamiltonian of inert free energy of matter, are conserved not only due to the presence of weightlessness in its FR ($v_{lc}=v_{l}\Gamma_{m}=\mathbf{const}(t)$), but also due to the total compensation of the influence of gravitation on its thermodynamic state by the motion. However it is possible only in hypothetical absolutely empty space. But when there is a resistance to motion these energies will be gradually increasing due to the matter cannot reach the required for their conservation value Γ_{m} and thus also due to accommodation of the matter of falling body to the new thermodynamic state of matter of the environment.

Before the appearance of spatial inhomogeneity of limit velocity of matter v_{l} the only thing that could interfere its distancing from the future gravitational attraction center (due to tending of its Gibbs thermodynamic energy to its minimum) was the electromagnetic interaction of its molecules. That is why the hypothetic ideal gas and ideal liquid in principle cannot create their gravitational field.

As we see, here we have a dependency of spatial distribution of intrinsic values of these thermodynamic parameters and potentials (not the dependency of spatial distribution of other their values observed by other clocks and by other length standards) on v_{lc} (and, so, also on Γ_{m} and v_{l}). It would be non-logical if Γ_{m} and v_{l} would not influence on spatial distribution of the set of intrinsic values of main thermodynamic parameters of matter. So this does not contradict to invariance of thermodynamic parameters and potentials of matter relatively to the space-time transformations [43]. On the contrary, it only confirms the fact that limit velocity of matter motion v_{l}, as well as Γ_{m}, is the internal hidden RGTD-parameter of matter and not the non-dependent on certain RGTD-state of matter external gravitational parameter.

4. Physical and other thermodynamic characteristics of matter

Obviously, the stability of magnitude of extensive parameter $A_{\rho}=T^{2}S/pV$ takes place in the process of quasi-equilibrium cooling down of matter. If we experimentally find its averaged value for researched matter at the beginning of the research or if we measure the increments of thermodynamic parameters:

$$\left(\frac{\partial\ln S}{\partial\widehat{t}}\right)_{r}=\left(\frac{\partial\ln p}{\partial\widehat{t}}\right)_{r}+\left(\frac{\partial\ln V}{\partial\widehat{t}}\right)_{r}-2\left(\frac{\partial\ln T}{\partial\widehat{t}}\right)_{r},$$

we can determine its entropy:

$$S=\frac{U_{cr}\widetilde{\beta}_{pV}A_{\rho}}{T^{2}}\left[\frac{p}{p_{l}\widetilde{\beta}_{pv}}\exp\left(\frac{A_{\rho}}{T}\right)\right]^{\frac{\widetilde{\beta}_{pV}}{\widetilde{\beta}_{H}}}=\frac{U_{cr}\widetilde{\beta}_{pV}A_{\rho}}{T^{2}}\left[\frac{U_{cr}}{p_{l}V}\exp\left(\frac{A_{\rho}}{T}\right)\right]^{\widetilde{\beta}_{pV}}=\frac{pV}{\widetilde{\beta}_{pV}^{2}A_{\rho}}\left[\ln\left(\frac{p}{\widetilde{\beta}_{pV}p_{l}}\right)+\widetilde{\beta}_{H}\ln\left(\frac{p_{l}V}{U_{cr}}\right)\right]^{2}=$$

$$=\frac{A_{\rho}R_{T}}{T}=R_{T}\left[\frac{1}{\widetilde{\beta}_{pV}}\ln\left(\frac{R_{T}T}{\widetilde{\beta}_{pV}U_{cr}}\right)+\ln\left(\frac{p_{cr}V}{U_{cr}}\right)\right]=R_{T}\left[\widetilde{\varepsilon}+\frac{1}{\widetilde{\beta}_{pV}}(\ln R_{T}+\ln T)+\ln V\right]=$$

$$=R_{T}\left[\left(1+\frac{1}{\widetilde{\beta}_{pV}}\right)\ln\left(\frac{R_{T}T}{\widetilde{\beta}_{pV}U_{cr}}\right)-\ln\left(\frac{p}{\widetilde{\beta}_{pV}\widetilde{p}_{l}}\right)\right]=R_{T}\left[\widetilde{\varepsilon}+\left(1+\frac{1}{\widetilde{\beta}_{pV}}\right)(\ln R_{T}+\ln T)-\ln p\right]=$$

$$=R_T\left[\left(1+\frac{1}{\widetilde{\beta}_{pV}}\right)\ln\left(\frac{\widetilde{p}_l V}{U_{cr}}\right)+\frac{1}{\widetilde{\beta}_{pV}}\ln\left(\frac{p}{\widetilde{\beta}_{pV}\widetilde{p}_l}\right)\right]=R_T\left[\widetilde{\varepsilon}+\left(1+\frac{1}{\widetilde{\beta}_{pV}}\right)\ln V+\frac{\ln p}{\widetilde{\beta}_{pV}}\right],$$

where: $\widetilde{\varepsilon}=\ln\widetilde{p}_l-(1+1/\widetilde{\beta}_{pV})\ln(m_{00}c^3/v_{lcr})-(\ln\widetilde{\beta}_{pV})/\widetilde{\beta}_{pV}=\mathbf{const}(\Delta t)$ and $\widetilde{\beta}_{pV}=\mathbf{const}(\Delta t)$ are mathematical expectations of the values of functions of arbitrary changing hidden variables k, l, m, n, which are the strictly constant magnitudes during the whole not very long time of the existence of any Gibbs thermodynamic microstate.

However, if we know $\widetilde{\varepsilon}$ and $\widetilde{\beta}_{pV}$ and if we determine only the molar volume of gas that gradually cools and the pressure in it, then we can determine only its bond energy:

$$W_{bnd}=ST=Vp\left[\widetilde{\varepsilon}+\left(1+\frac{1}{\widetilde{\beta}_{pV}}\right)\ln V+\frac{\ln p}{\widetilde{\beta}_{pV}}\right]. \qquad (6)$$

In order to determine the entropy and, thus, the value of parameter A_p we should additionally measure the temperature of the gas. It is obvious that parameters $\widetilde{\varepsilon}$ and $\widetilde{\beta}_{pV}$ of the equation of the state of gas (6) can be determined also experimentally in the process of controlled change of its bond energy as well as of all its thermodynamic parameters.

The research of thermodynamic properties of matter should be performed only in its equilibrium states or using the dependencies of its thermodynamic potentials on thermodynamic parameters that take into account the variability of parameter R_T in the process of this research ($R_T\neq\mathbf{const}(t)$). In order to determine both the thermal expansion coefficient α and pressure γ and the elastic modulus K_T of gas or liquid it is enough to know only the thermal equation of the state (i.e. the gas compressibility coefficient $Z = R_T / R_{UT}$, which is determined by the parameter $R_T = pV / R_T$):

$$\alpha=\frac{1}{V_0}\left(\frac{\partial V}{\partial T}\right)_p=\frac{1}{V_0 p}\left[R_T+T\left(\frac{\partial R_T}{\partial T}\right)_p\right], \qquad \gamma=\frac{1}{p_0}\left(\frac{\partial p}{\partial T}\right)_V=\frac{1}{p_0 V}\left[R_T-T\left(\frac{\partial R_T}{\partial T}\right)_V\right],$$

$$K_T=-V_0\left(\frac{\partial p}{\partial V}\right)_T=\frac{R_T T}{V_0}-T\left(\frac{\partial R_T}{\partial V}\right)_T.$$

In order to determine their thermal capacity when volume and pressure are invariant[9] and, thus, all their thermodynamic potentials we should know not only R_T and critical phasic values of pressure p_{cr} and of internal energy multiplicative component $U_{cr}=m_{00}c^3/v_{lcr}$, but also the mathematical expectation $\widetilde{\beta}_{pV}$ of the value of hidden variable $\beta_{pV}=\breve{p}\breve{V}/\breve{U}_0$:

$$C_V=\left(\frac{\partial U}{\partial T}\right)_V=\frac{1}{\widetilde{\beta}_{pV}}\left[R_T+T\left(1+\frac{\widetilde{\beta}_{pV}S}{R_T}\right)\left(\frac{\partial R_T}{\partial T}\right)_V\right]=$$

$$=\frac{1}{\widetilde{\beta}_{pv}}\left\{R_T+T\left[1+(1+\widetilde{\beta}_{pV})\ln\left(\frac{R_T T}{\widetilde{\beta}_{pV}U_{cr}}\right)-\widetilde{\beta}_{pV}\ln\left(\frac{p}{\widetilde{\beta}_{pV}p_l}\right)\right]\left(\frac{\partial R_T}{\partial T}\right)_V\right\}=$$

$$=T\left(\frac{\partial S}{\partial T}\right)_V=\frac{1}{\widetilde{\beta}_{pv}}\left\{R_T+T\left[1+\ln\left(\frac{R_T T}{\widetilde{\beta}_{pV}U_{cr}}\right)+\widetilde{\beta}_{pV}\ln\left(\frac{p_l V}{U_{cr}}\right)\right]\left(\frac{\partial R_T}{\partial T}\right)_V\right\},$$

$$C_p=T\left(\frac{\partial S}{\partial T}\right)_p=\left(\frac{\partial U}{\partial T}\right)_p+R_T+T\left(\frac{\partial R_T}{\partial T}\right)_p=\frac{1+\widetilde{\beta}_{pV}}{\widetilde{\beta}_{pV}}\left[R_T+T\left(1+\frac{\widetilde{\beta}_{pV}S}{(1+\widetilde{\beta}_{pV})R_T}\right)\left(\frac{\partial R_T}{\partial T}\right)_p\right],$$

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[9] Heat capacity when pressure is invariant is determined not by internal energy of the matter itself, but by equivalent to its enthalpy the energy of extended system that consists of this matter and the load that supports the needed pressure.

$$C_p - C_V = R_T + T\left[\left(\frac{1+\tilde{\beta}_{pV}}{\tilde{\beta}_{pV}} + \frac{S}{R_T}\right)\left(\frac{\partial R_T}{\partial T}\right)_p - \left(\frac{1}{\tilde{\beta}_{pV}} + \frac{S}{R_T}\right)\left(\frac{\partial R_T}{\partial T}\right)_V\right], \qquad U = \frac{R_T T}{\tilde{\beta}_{pV}} + \int_{R_{T0}}^{R_T} \frac{TS}{R_T} dR_T .$$

Based on thermodynamic dependencies of thermal capacities when volume and pressure are invariant we can determine the mathematical expectation of dependencies of these functions on individual parameters R_T and θ, and, consequently, on any pair of main thermodynamic parameters:

$$\tilde{\beta}_{pV} = \frac{R_T T}{U_0} = \frac{R_T\left[\left(\frac{\partial R_T}{\partial T}\right)_p - \left(\frac{\partial R_T}{\partial T}\right)_V\right]}{C_V\left(\frac{\partial R_T}{\partial T}\right)_p - (C_p - R_T)\left(\frac{\partial R_T}{\partial T}\right)_V + T\left(\frac{\partial R_T}{\partial T}\right)_p\left(\frac{\partial R_T}{\partial T}\right)_V} .$$

The following correspond to the thermal Van der Waals equation [1] of the state of real gases:

$$R_T = \frac{pV}{T} = \frac{R_{UT}}{(1+a_m/pV^2)(1-b_m/V)} = \frac{R_{UT}V}{V-b_m} - \frac{a_m}{TV} = R_{UT}\left[\frac{V}{V-b_m} - \theta\right], \qquad \theta = \frac{a_m}{R_{UT}TV},$$

$$dV = \frac{V^2[R_{UT}dT - (V-b_m)dp]}{pV^2 - a_m(1-2b_m/V)}, \qquad \left(\frac{\partial R_T}{\partial T}\right)_V = \frac{a_m}{T^2V} = \frac{R_{UT}\theta}{T},$$

$$\left(\frac{dR_T}{\partial T}\right)_p = \frac{p}{T}\left[\left(\frac{\partial V}{\partial T}\right)_p - \frac{V}{T}\right] = \frac{a_m(1-2b_m/V)/(TV) + R_{UT} - R_T}{T[1-a_m(1-2b_m/V)/(pV^2)]} = \frac{R_T\{R_{UT}[1+\theta(1-2b_m/V] - R_T\}}{T[R_T - R_{UT}\theta(1-2b_m/V)]},$$

$$\tilde{\beta}_{pV} = \frac{R_T\{R_T[R_{UT}(1-2\theta\, b_m/V) - R_T] + R_{UT}^2\theta^2(1-2b_m/V)\}}{R_T(C_V + R_{UT}\theta)\{R_{UT}[1+\theta(1-2b_m/V)] - R_T\} - R_{UT}\theta(C_p - R_T)[R_T - R_{UT}\theta(1-2b_m/V)]},$$

where: a_m and b_m are individual constants of certain matter.

According to this we receive the simple expression for the entropy of hypothetical ideal gas:

$$S = C_{V0}\ln\left(\frac{C_{V0}T}{U_{cr}}\right) + R_{UT}\ln\left(\frac{C_{V0}p_{cr}V}{R_{UT}U_{cr}}\right) = S_{cr} + C_{V0}\ln\left(\frac{T}{T_{cr}}\right) + R_{UT}\ln\left(\frac{V}{V_{cr}}\right) = S_k + C_{V0}\ln\left(\frac{T}{T_k}\right) + R_{UT}\ln\left(\frac{V}{V_k}\right),$$

where: $S_{cr} = (C_{V0} + R_{UT})\ln(C_{V0}T_{cr}/U_{cr})$, $C_{V0} = R_{UT}/\tilde{\beta}_{pV}$; $V_{cr} = R_{UT}T_{cr}/p_{cr}$ and T_{cr} are critical phasic values of molar volume and temperature of ideal gas; V_k and T_k are their another arbitrary values.

The following expressions correspond to more precise Dieterici [2] first thermal equation that uses an exponent with the same parameter $\theta = a_m/(R_{UT}TV)$:

$$R_T = \frac{R_{UT}}{1-b_m/V}\exp(-\theta), \qquad dV = \frac{R_{UT}(1+\theta)\exp(-\theta)dT - (V-b_m)dp}{p - a_mV^{-2}\exp(-\theta)},$$

$$\left(\frac{dR_T}{\partial T}\right)_p = \frac{R_{UT}(1+2\theta)\exp(-\theta) - R_T}{T[1-a_m\exp(-\theta)/(pV^2)]} = \frac{R_T[R_{UT}(1+2\theta)\exp(-\theta) - R_T]}{T[R_T - R_{UT}\theta\exp(-\theta)]} = \frac{R_T\Psi}{T},$$

$$\left(\frac{\partial R_T}{\partial T}\right)_V = \frac{R_T\theta}{T}, \qquad C_V = (1+\theta)\frac{R_T}{\tilde{\beta}_{pV}} + \theta\, S, \qquad C_p = (1+\Psi)\frac{(1+\tilde{\beta}_{pV})R_T}{\tilde{\beta}_{pV}} + \Psi S,$$

$$C_p - C_V = [(1+\Psi)(1+1/\tilde{\beta}_{pV}) - (1+\theta)/\tilde{\beta}_{pV}] + (\Psi - \theta)S,$$

$$\tilde{\beta}_{pV} = \frac{(\Psi-\theta)R_T}{\Psi C_V - \theta C_p + \theta(1+\Psi)R_T} = \frac{R_T(1+\theta)[R_{UT}(1+\theta)\exp(-\theta) - R_T]}{R_{UT}[(1+2\theta)C_V + \theta^2C_p + \theta(1+\theta)R_T]\exp(-\theta) - R_T(C_V + \theta C_p)} .$$

Obviously, experimentally found heat capacities of gases can be represented as functions of only R_T and θ parameters.

Hidden variables β_{ST} and β_{pV} are invariant magnitudes in any moment of time that corresponds to the certain Gibbs collective microstate of the whole RGTD-bonded matter. And, thus, their derivatives by any thermodynamic parameter are equal to zero. The same can be told regarding mathematical expectations of those hidden variables $\widetilde{\beta}_{ST}$ and $\widetilde{\beta}_{pV}$, despite the dependence of their values on other thermodynamic parameters of matter.

Conclusion

Now we know for sure about the four hidden thermodynamic parameters (k, l , m, and n) and functions on them (β_{pV} , β_H , β_{ST}, β_{pT} , β_G, β_{GR}), and functions of the explicit thermodynamic parameters (A_ρ , $a_\rho \equiv R_T$, Z, U_{ad} , U^*_{ad} , C_p , C_V ,K_T , α , γ and etc), as well as critical (U_{cr} , S_{cr} , p_{cr} , T_{cr}) and spatially homogeneous (T_{00} , U_{00} , H_{00} , G_{00}) thermodynamic parameters. That is why it is now possible to experimentally determine at the points of phase transitions the critical values, and at the control points the standard values of the mathematical expectations of the hidden parameters, as well as of the corresponding explicit thermodynamic parameters. And on the basis of all this it is possible to obtain exact equations of thermodynamic state of real gases and liquids without using corrections. And this is facilitated by the spatial homogeneity of the hidden thermodynamic parameters, which correspond to the spatially inhomogeneous states of real matter. Of course, this will not deny the expediency of using also approximate equations of thermodynamic state of matter based on the use of corrections.

Enthalpy, which consists of the Lagrangian of its own multiplicative component and additive compensation of its multiplicative representation, is de facto the total energy of matter since it includes even the released thermal energy and the released kinetic energy of its motion. Enthalpy of matter (as well as Gibbs free energy, which own multiplicative component is identical to the ordinary rest energy of matter and is equivalent to its gravitational mass) is equal in all FRs of bodies that move inertially relatively to it. And exactly this is the guarantee of Lorentz-invariance of all thermodynamic potentials and parameters of matter. Since matter motion is accompanied by the all-sided conformally-gaugely self-contraction of its size in background Euclidean space of the Universe the rate of the intrinsic time of inertially moving body is not dilated but, quite the contrary, remains invariant, despite the presence of gravitational decreasing of the rate of intrinsic time for nearby static objects. De facto the motion of the matter as well as its gravitational self-contraction in background Euclidean space of the Universe leads to its advance over unobservable in people's world evolutionary self-contraction of the conventionally motionless matter in the Universe. That is why the release of kinetic energy is always accompanied by the decreasing of limit velocity of matter motion (that is identical to coordinate velocity of light in GR) and the decreasing of its inert free energy.

The ordinary rest energy of matter is bonded in a different ways in different physical processes. That is why we have various free energies in different processes. Both the change of the inert free energy of matter (caused by its inertial motion) and its evolutionary decrease in CFREU do not directly influence the thermodynamic parameters of matter that are changed only in thermodynamic processes. That is why it is fundamentally unobservable in intrinsic FRs of matter in the similar way as evolutionary and caused by motion reduction of molar volume of matter is unobservable in comoving with expanding Universe FR. The gravitational reduction of molar volume of matter when approaching the gravitational attraction center is also unobservable directly in intrinsic FRs of matter. However, we still can say about its presence in Euclidean space of CFREU due to the presence of gravitational curvature of intrinsic space of matter.

The hidden thermodynamic parameters discovered here (which, similarly to wave functions, can take on any values with a certain probability) confirmed Gibbs's idea of the presence of a multitude of instantaneous thermodynamic microstates in matter that is in an invariable quasi-equilibrial state. The another important thing is the substantiation of the fact that the coordinate velocity of light and the indicators of the relativistic-gravitational decrease in the molar volume of matter in the background Euclidean space do belong to the hidden internal thermodynamic parameters [50]. Therefore, an external relativistic interpretation of thermodynamics is not needed. And therefore, all thermodynamic parameters and potentials are invariant both gravitationally and relativistically. After all, all gravitational and relativistic influences on them are already contained in their formation as hidden parameters.

The acceptance of the fact of existence of an extensive parameter (that is spatially homogeneous in the gravitational field), characterizing the compressibility of gases, and a spatially inhomogeneous intensive thermodynamic parameter (that is invariant during the gas leisurely cooling process) allows us to consider the gravitational field as a consequence of a spatially inhomogeneous gravithermodynamic state of both any continuous matter and arbitrarily rarefied gas-dust matter of the cosmic vacuum.

The proved here equivalence of the Hamiltonian of the inert free energy to the inertial mass of matter, and the equivalence of Lagrangian of the ordinary rest energy (and the multiplicative component of the Gibbs free energy identical to it) of matter to a much larger gravitational mass [41, 42] have solved the problem of the shortage in baryonic mass in distant galaxies of the Universe. And it is this, together with the logarithmic gravitational potential [52, 53], that allows us to abandon the need for non-baryonic dark matter in the Universe.

References

[1] Van der Waals, J.D. 1893 Thermodynamische theorie der capillariteit in de onderstelling van continue dichtheidsverandering. *Verhand. Kon. Akad. V Wetensch. Amst.* Sect. 1 (Dutch; English Translation in *J. Stat. Phys.,* 1979, **20,**:197).

[2] Dieterici C. 1899 *Ann. Phys. Chem. Wiedemanns Ann.* **69**, 685.

[3] Berthelot D. 1907 in *Travaux et Mémoires du Bureau international des Poids et Mesures* – T. XIII (Paris: *Gauthier-Villars*).

[4] Beattie J.A., Bridgeman O.C. 1927 A New Equation of State for Fluids. I. Application to Gaseous Ethyl Ether and Carbon Dioxide. *Journal of the American Chemical Society*. **49**, No. 7, 1665–1667.

[5] Beattie J.A., Bridgeman O.C. 1928 in *Proceedings of the American Academy of Arts and Sciences*. **63**, 229.

[6] Benedict M., Webb G.B., Rubin L.C. 1940 An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and Their Mixtures: I. Methane, Ethane, Propane, and n-Butane, *Journal of Chemical Physics*. **8**, No. 4, 334–345, doi: 10.1063/1.1750658, ISSN 0021-9606.

[7] Benedict M., Webb G.B., Rubin L.C. 1942 An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and Their Mixtures: II. Mixtures of Methane, Ethane, Propane and n-Butane, *Journal of Chemical Physics*. **10**, No. 12, 747–758.

[8] Benedict M., Webb G.B., Rubin L.C. 1951 An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and Their Mixtures: III. Constants for Twelve Hydrocarbons. *Chemical Engineering Progress*. **47**, No. 8, 419–422.

[9] Benedict M., Webb G.B., Rubin L.C. 1951 An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and Their Mixtures: IV. Fugacities and Liquid-Vapor Equilibria. *Chemical Engineering Progress*. **47**, No. 9, 449–454.

[10] Redlich O., Kwong J.N.S. 1949 On the Thermodynamics of Solutions. V. An Equation of State. Fugacities of Gaseous Solutions. *Chemical Reviews*. **44,** № 1, 233–244.

[11] Soave, G. 1972 “Equilibrium constants from a modified Redlich-Kwong equation of state”, Chemical Engineering Science, **27**, No. 6, 1197-1203, DOI: https://doi.org/10.1016/0009-2509(72)80096-4.

[12] Yushan, Z., Zhihong, X. 1999 “Lipschitz optimization for phase stability analysis: Application to Soave–Redlich–Kwong equation of state”, Fluid Phase Equilibria, **162**, No. 1, 19-29, DOI: https://doi.org/10.1016/S0378-3812(99)00173-9.

[13] Abudour, A.M., Mohammad S.A., R.L. Robinson Jr,. Gasem K.A.M. 2014“Generalized binary interaction parameters for the Peng–Robinson equation of state”, Fluid Phase Equilibria, Vol. **383**, 156-173, DOI: https://doi.org/10.1016/j.fluid.2014.10.006.

[14] Toshitomo B.J. 1960 New equation of state applicable to gases and liquids. *Technol. Res.*, **5**, 1.

[15] Donth E. 1966 The second virial coefficient and the interaction potential of spherically symmetric molecules. Z. phyz. Chem. Soc. (DDR), 233, No. 3–4, 177.

[16] Garbo R., Simo C. 1967 Generalized calculation of the second virial coefficient of two- and three-dimensional gases. *Afinidad*, **24**, No. 250, 291.

[17] Chuch P.L., Prausnitz J.M. 1967 The third virial coefficient of non-polar gases and their mixtures. *AIChE J.*, **13**, 896.

[18] Cooper H.W., Goldfrank J.C. 1967 Constant equations of state of Benedict – Webb – Rubin and new correlations. *Hydrocarbon Processing*. **46**, No. 12, 141.

[19] Chandhuri P.M., Maihur G.P., Stager R.A. 1968 Equation of state of liquids. *Canad. J. Chem. Eng.* **46**, 132.

[20] Edmister W.C., Vairogs J., Klekers A.J. 1968 A generalized Benedict – Webb – Rubin equation of state. *The American Institute of Chemical Engineers Journal.* **14**, No. 3, 479.

[21] Edmister W.C. 1968 Calculation of compressibility coefficients and volatility coefficients from the Redlich – Kwong equation.. *Hydrocarbon Processing*.. **47**, No. 9, 239.

[22] Keller J., Keller M.C. 1968 Equation of state for simple classical liquids. *Rev. soc. qulm.* Mexico, **12**, 217A.

[23] Chuch P.L., Prausnitz J.M. 1969 Generalized relationship of compressibility coefficients of normal liquids. *AIChE J.*, **15**, 471.

[24] Carra S., Zanderighi L. 1970 Second virial coefficients and thermodynamic properties of polar gases. *Chim. et ind.*, **52**, 249.

[25] Starling, Kenneth E. 1973 Fluid Properties for Light Petroleum Systems, *Gulf Publishing Company*, 270, ISBN 978-0872012936.

[26] Jacobsen, Richard T., Stewart, Richard B. 1973 "Thermodynamic Properties of Nitrogen Including Liquid and Vapor Phases from 63 K to 2000 K with Pressures to 10,000 Bar." *Journal of Physical and Chemical Reference Data*, **2,** No. 4, 757–922, doi:10.1063/1.3253132.

[27] Nishiumi H. 1980 An improved generalized BWR equation of state with three polar parameters applicable to polar substances. *Journal of Chemical Engineering of Japan*. **13**, No. 3, 178–183.

[28] Younglove, B.A., Ely, J.F. 1987 "Thermophysical Properties of Fluids II Methane, Ethane, Propane, Isobutane, and Normal Butane". *Journal of Physical and Chemical Reference Data*, **16** No. 4, 577, doi: 10.1063/1.555785*,* ISSN 0047-2689.

[29] Reid, R.C., Prausnitz, J.M., Poling, Bruce E. 1987 The Properties of Gases & Liquids (4th ed.), New York: *McGraw-Hill*, 741, ISBN 978-0070517998.

[30] Widia, B.S. 2003 Variation of Density with Composition for Natural Gas Mixtures in the Supercritical Region (thesis), Texas *A&M University*, 11.

[31] Tsuji, Tomoya, Tanaka Shuichiro, Hiaki Toshihiko 2004 P-V-T-x relationship for CO2+C4H10 and CO2+iC4H10 binary gas mixtures and the partial molar volume of C4H10 and iC4H10 at 360.00 K *J. Supercritical Fluids*, **29**, 215.

[32] Tsuji, Tomoya, Hiaki Toshihiko, Namba Mitsuo 2006 Benedict-Webb-Rubin Equation of State for an alternative fuel, Dimethyl ether, and Estimation of Thermophysical Properties. *AIChE Annual Meeting*, Conference Proceedings (San Francisco, CA 11/12-17/2006).

[33] Asano, Yuta, and Fuchizaki Kazuhiro 2014 Modified Benedict–Webb–Rubin Equation of State for the Modified Lennard-Jones Fluid. *J. Phys. Soc. Jpn*. **83**, 034601.

[34] Tsuji, Tomoya, Hoshina Taka Aki, Kinoshita Shinichi, Yoshida Atsumasa 2022 Eight Constants in the Benedict-Webb-Rubin Equation of State for 1-Pentyne and Their Validity for Bubble Point Pressure with Propane or Dimethyl Ether. *Journal of The Japan Petroleum Institute*, **65**, No. 3, 97–109.

[35] Changyu, You, Zhaoyang Chen, et al. 2024 Benedict–Webb–Rubin–Starling Equation of State + Hydrate Thermodynamic Theories: An Enhanced Prediction Method for CO_2 Solubility and CO_2 Hydrate Phase Equilibrium in Pure Water/NaCl Aqueous Solution System. *Energies,* **17,** No. 10, 2356, https://doi.org/10.3390/en17102356.

[36] Nasri, Zakia, Binous Housam 2007 Applications of the Soave-Redlich-Kwong Equation of State Using Mathematic. *Journal of Chemical Engineering of Japan*, **40,** No. 6, 534–538.

[37] Kareem, Lateef A, Iwalewa Tajudeen M., Al-Marhoun Muhammad 2015 New explicit correlation for the compressibility factor of natural gas: linearized z-factor isotherms. *Journal of Petroleum Exploration and Production Technology*, **6**, 481–492.

[38] Ghanem, Alaa, Gouda Mohammed F., et al. 2022 Predicting the Compressibility Factor of Natural Gas by Using Statistical Modeling and Neural Network. *Energies,* **15** No. 5, 1807, https://doi.org/10.3390/en15051807.

[39] Kanchev, Neven, Stoyanov Nikolay, Milushev Georgi 2025 Prediction of the Natural Gas Compressibility Factor by using MLP and RBF Artificial Neural Networks. *Measurement Science Review*, **25,** No. 1, 1–9, https://doi.org/10.2478/msr-2025-0001.

[40] Bazarov, I.P. 1964, *Thermodynamics*. New York: *Pergamon Press* [distributed in the Western Hemisphere by Macmillan, New York].

[41] Danylchenko, Pavlo: 2025, Foundations of Relativistic Gravithermodynamics 6th online edition, https://elibrary.com.ua/m/articles/view/FOUNDATIONS-OF-RELATIVISTIC-GRAVITHERMODYNAMICS-6th.

[42] Danylchenko P 2022 *Foundations of Relativistic Gravithermodynamics*. Vinnytsia: TVORY [ISBN: 978-617-552-072-7] (in Ukrainian)

[43] Danylchenko P 2008 United nature of gravitational and thermodynamic properties of matter. *Introduction to Relativistic Gravithermodynamics*. Vinnytsia: Nova knyga [ISBN: 978-966-382-141-2] 19–59 (in Russian) https://elibrary.com.ua/m/articles//download/11187/3431

[44] Danylchenko P 2008 United nature of gravitational and thermodynamic properties of matter. *Abstracts of the RUSGRAV-13, June 23–8*. Moscow: PFUR [ISBN: 978-5-209-03274-8] 109

[45] Danylchenko P 2010 Foundations of Relativistic Gravithermodynamics. *Nauk. visn. Volyn'Univ*. **6**, 64–71 (in Russian), http://pavlo-danylchenko.narod.ru/docs/VisnykVolyn.pdf.

[46] Danylchenko P 2022 The instantaneous values of main thermodynamic parameters and potentials that are characteristic to Gibbs thermodynamic microstates. *Proceed. XI Int. Conference RNAOPM-2022*. Lutsk: Volyn Univer. Press "Vezha" 101–7.

[47] Einstein A, Infeld L 1938 Is heat a substance? *The Evolution of Physics: The Growth of Ideas from Early Concepts to Relativity and Quanta*. London: The scientific book club III Charing Gross Road

[48] Chen Y, Cook A 1993 Gravitational Experiments in the Laboratory. *Cambridge Univ. Press*

[49] Dmitriev A 2005 *Controllable gravitation.* Moscow: Novi centr (in Russian)

[50] Zeldovich Ya, Grischuk L 1988 General relativity is correct! (Methodical notes). *Physics-Uspekhi* (in Russian) **155**, 517–*27*

[51] Danylchenko P 2014 Spiralwave model of the Universe. *Proceedings of all-Ukrainian seminar on theoretical and mathematical physics: in honour of 85th anniversary of Anatoli Swidzynski, Lutsk Feb. 27 – Mar. 1 2014*, Lutsk: Volyn Univer. Press "Vezha" 21-26 (in Russian) https://elibrary.com.ua/m/articles/view/СПИРАЛЬНОВОЛНОВАЯ-МОДЕЛЬ-ВСЕЛЕННОЙ

[52] Danylchenko P 2020 Theoretical misconceptions and imaginary entities in astronomy, cosmology and physics. *Foundations and consequences of Relativistic Gravithermodynamics* (in Ukrainian), Vinnytsia: Nova knyga [ISBN: 978-966-382-843-5] 85–128 (in Ukrainian), https://elibrary.com.ua/m/book//download/34/3755

[53] Danylchenko P 2025 Theoretical misconceptions and imaginary entities in astronomy, cosmology and physics, https://elibrary.com.ua/m/articles/view/Theoretical-misconceptions-and-imaginary-entities-in-astronomy-cosmology-and-physics-6th (6th online edition)