On the Boltzmann and Avogadro Constants, and the Temperature

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March 24, 2008

Abstract. A new insight into the notion of temperature, originated from the shell-nodal atomic model and the dynamic model of elementary particles, is considered in this paper. We show that a quantum of average energy of a nucleon at the level of the so-called meson frequency ω_0 is close, in value, to the Boltzmann constant k_B. The number of such quanta defines the relative potential-kinetic nucleon energy of a system, equal in value to the absolute temperature. It means that the temperature, as the potential-kinetic energy, according to the revealed peculiarity, is the alternating wave magnitude and is negative for the relative potential energy and positive for the relative kinetic energy. The Boltzmann and Avogadro constants are expressed in new basis through the basic physical constants. Accordingly, we can regard the constants of the resulting values as fundamental.

Key words: Absolute temperature, Negative temperature, Associated mass, Exchange charge, Boltzmann constant, Avogadro constant, Atomic structure, Elementary particles, Heat transfer
PACS numbers: 03.40.Kf, 03.65.Ge, 11.90.+t, 12.10.-g, 12.90.+b, 14.20.Dh, 14.40.-n, 21.10.Dr, 21.60.-n, 32.10.-f, 44.90.+c

1. Introduction

Shell-Nodal Atomic Model (SNM) [1-3] and Dynamic Model of Elementary Particles (DM) [4, 5] allow explaining the structure of matter at atomic and subatomic levels and understanding some unknown sides and misunderstood properties of matter.

One of such fundamental properties is temperature, which reflects an energetic state of a system, being its measure. According to strict thermodynamic definitions, the temperature T expresses the relationship between the change of internal energy U, or enthalpy H, and the change of entropy S of a system:

$$T = \left(\frac{\partial U}{\partial S}\right)_V, \quad \text{or} \qquad T = \left(\frac{\partial H}{\partial S}\right)_P . \tag{1.1}$$

In statistical mechanics that makes theoretical predictions about the behavior of macroscopic systems on the basis of statistical laws governing its component particles, the relation of energy and absolute temperature T is usually given by the inverse thermal energy

$$\beta = \frac{1}{k_B T}\,. \tag{1.2}$$

The constant k_B, called the Boltzmann constant, equal to the ratio of the molar gas constant R_g and the Avogadro constant N_A,

$$k_B = \frac{R_g}{N_A} \quad (J \cdot K^{-1})\,, \tag{1.3}$$

plays a crucial role in this equality. It defines, in particular, the relation between absolute temperature and the kinetic energy of molecules of an ideal gas.

The product k_BT is used in physics as a scaling factor for energy values in molecular scale (sometimes it is used as a pseudo-unit of energy), as many processes and phenomena depends not on the energy alone, but on the ratio of energy and k_BT.

Given a thermodynamic system at an absolute temperature T, the thermal energy carried by each microscopic "degree of freedom" in the system is of the order of $k_B T/2$.

Determination of N_A, and hence k_B, was one of the most difficult problems of chemistry and physics in the second half of the 19th century. The constant N_A was (and still is) so fundamental that for its verifying and precise determination every new idea and theory appeared in physics are at once used. More accurate definition of the value of N_A involves the change of molecular magnitudes and, in particular, the change in value of an elementary charge. The latter is related with N_A through the so-called "Helmholtz relation" $N_A e = F$, where F is the Faraday constant, a fundamental constant equal to $96485.3415(39)\,C \cdot mol^{-1}$.

Many eminent scientists devoted definite periods of their life to study of this problem: beginning from I. Loschmidt (1866), Van der Vaals (1873), S. J.W. Rayleigh (1871), *etc.* in the 19^{th} century, and continuing in the 20^{th} century, beginning from Planck (1901), A. Einstein and J. Perrin (1905-1908), Dewer (1908), E. Rutherforn and Geiger (1908-1910), I. Curie, Boltwood, Debierne (1911), and many others.

In history of physics, the Boltzmann constant has been undergone to the constant changes. We show here only two values of N_A, in particular, obtained by Planck on the basis of his famous black body radiation formula [6], and the modern accepted value [7]:

$$N_A \approx 6.16 \cdot 10^{23}\, mol^{-1} \qquad \text{(Planck, 1901)} \tag{1.4}$$

$$N_A = 6.02214179(30) \cdot 10^{23}\, mol^{-1} \qquad \text{(2006 CODATA)} \tag{1.5}$$

There are no reliable direct experimental methods for the precise determination of the Avogadro constant. The only direct method for the determination of N_A based on study of the Brownian motion has a low accuracy; therefore, it is not used at present.

One of the modern *indirect* methods is based on the calculation of N_A from the density ρ of a pure (and free of defects) crystal, its relative atomic mass M, and the cell length d, determined from x-ray methods. Thus, the recommended value of N_A (1.5) depends on a series of measured parameters related to the structure of matter. A most probable and self-consistent set of the constants N_A, obtained by different methods, that best fits all reliable data is found by statistical methods.

Calculations of N_A (1.4) based on Planck's radiation formula

$$r_\nu = \frac{2\pi\nu^2}{c^2}\frac{h\nu}{e^{\beta\cdot h\nu}-1}, \tag{1.6}$$

where r_ν is the energetic spectral luminosity of atomic space, were carried out at the time when a newborn theory, set forth first by Planck, has called doubts and not yet been accepted. Accordingly, nobody turned serious attention to the value N_A (1.4) obtained by Planck at that time.

From our point of view, the determination based on (1.6) deserves special attention. The matter is that the above formula does not contain quantities related to the structure of matter, as against to the case of the indirect determination with use of modern diffraction methods.

In a case of the determination of N_A on the basis of the SNM and DM, which we consider in this paper, we deal with the direct (similar to Planck's) calculation of N_A from the theoretical formula. It proved to be that the calculated quantity practically coincides with that one (1.4) obtained by Planck. In this connection and because the obtained results shed new light on the nature of k_B and the temperature, it makes sense to present them for public discussion. The more so as a series of fundamental unsolved questions of physics already found their answers in the framework of the SNM and DM. We relate to them, in particular, the nature of mass and charge of elementary particles, the role of c^2 in the famous formula on energy of particles, $E=mc^2$ [4, 5]. The SNM and DM have revealed an internal spatial structure of individual atoms [1-3] and explained from a new point of view the nature of the Lamb shift [8] (without use of the notion of virtual particles) and the anomalous magnetic moment of an electron [9], and other phenomena [1].

2. Spectra of frequencies and associated masses originated from the DM

According to the DM [4, 5], elementary particles recall pulsing spherical microobjects (pulsing thickenings of space), whose mass has associated character. Wave interaction of the particles, more correctly exchange of matter-space-time, is realized on the fundamental frequency of exchange inherent in the atomic and subatomic levels:

$$\omega_e = 1.869162534\cdot 10^{18}\, s^{-1}. \tag{2.1}$$

In dependence on the character of exchange, we distinguish associated masses in the longitudinal exchange (at motion-rest in the cylindrical field of matter-space-time), the associated masses in the transversal exchange (transversal oscillations of the wave beam), and the associated masses in the tangential exchange (at motion-rest in the cylindrical space-field).

We show here only derivation of the spectrum of masses (taken from the author's book [1]) playing the role in the *longitudinal exchange*, because the latter leads to masses of particles constituent of atoms as, for example, π-mesons, μ-mesons, γ-quanta, *etc*. This will help understanding the concept related to the structure of nucleons, set forth first in [1] and used here.

Motion-rest in the cylindrical field of matter-space-time can be presented, at a part of the axial line of length *dz* (Fig. 2.1), (in the simplest case) by the equation of exchange:

$$\rho_z dz \frac{\partial^2 \Psi}{\partial t^2} = -\frac{\partial F}{\partial z} dz \,, \tag{2.2}$$

where ρ_z is the linear density of mass, Ψ is the axial displacement, and *F* is the power of exchange.

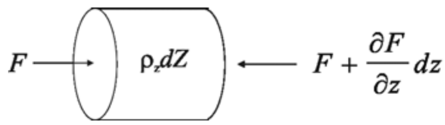

Fig. 2.1. A graph of power of the elementary longitudinal exchange.

Let *w* be the density of energy of basis and *p* the density of energy of superstructure. In a linear approximation, the relative change of energy is $\frac{pS\partial z}{wS\partial z}$, where $wS\partial z$ is the energy of an elementary differential volume $S\partial z$, and $pS\partial z$ is its change.

Assuming that the relative change of energy of exchange is equal to the relative linear change of the elementary volume of space-field, $\frac{pS\partial z}{wS\partial z} = \frac{F\partial z}{wS\partial z} = -\frac{\partial \Psi}{\partial z}$, we obtain $F = -wS\frac{\partial \Psi}{\partial z}$. As a result, the equation of exchange (2.2) takes the form

$$\frac{\partial^2 \Psi}{\partial t^2} = \frac{wS}{\rho_z}\frac{\partial^2 \Psi}{\partial z^2} \quad \text{or} \quad \frac{\partial^2 \Psi}{\partial z^2} = \frac{\rho_z}{wS}\frac{\partial^2 \Psi}{\partial t^2}\,. \tag{2.3}$$

An element of a beam is $\partial z = c\partial t$; hence,

$$\frac{\partial^2 \Psi}{\partial t^2} = \frac{wS}{\rho_z c^2}\frac{\partial^2 \Psi}{\partial t^2} \tag{2.4}$$

and

$$c = \sqrt{wS/\rho_z} \ . \tag{2.5}$$

If we consider the exchange with the density of energy at the level of Young modulus E, then

$$c = \sqrt{ES/\rho_z} \ . \tag{2.6}$$

and

$$\omega = kc = k\sqrt{ES/\rho_z} \ , \tag{2.7}$$

where $k = 2\pi/\lambda$ is the wave number, which takes a series of discrete values.

Let us determine the characteristic spectrum of frequencies. For the hard-facing alloys, the Young modulus lies approximately within $600-680\,GPa$. We select, in the capacity of a calculated magnitude, the characteristic value 654.9, which satisfies the metrological spectrum on the basis of the fundamental measure [10]:

$$\mathrm{E} = 6.549 \cdot 10^{11}\,Pa \ . \tag{2.8}$$

Let the remaining parameters be equal to

$$l = 2\pi r_0, \quad \rho_l = m_e/l, \qquad S = \pi r_0^2, \tag{2.9}$$

where $r_0 = 0.52917720859 \cdot 10^{-8}\,cm$ is the Bohr radius, $m_e = 9.10938215(45) \cdot 10^{-28}\,g$ is the electron mass.

Under these conditions, the formula for the characteristic spectrum of frequencies (2.7) takes the form

$$\omega = 4\omega_0 \cdot r_0 k \ , \tag{2.10}$$

where

$$\omega_0 = \frac{\pi}{2}\sqrt{\frac{Er_0}{2m_e}} = 6.85091084 \cdot 10^{15}\ s^{-1} \approx \frac{\omega_e}{272.88} \ . \tag{2.11}$$

The frequency ω_0 is bound up with the fundamental frequency ω_e (2.1) by the following characteristic ratio:

$$\omega_e/\omega_0 = 272.8103045 \approx 272.8752708 = 2\pi \lg e \cdot 10^2 \ . \tag{2.12}$$

Frequency of the fundamental tone ω_0 is the characteristic frequency of the H-atomic level. If $l = n\lambda$, then $r_0 k = n$ and

$$\omega_n = 4\omega_0 \cdot n \approx \Delta \cdot 10^{16} n\ s^{-1} \ , \tag{2.13}$$

where $\Delta = 2\pi \lg e$ is the fundamental quantum-period [10, 11].

The spectrum of frequencies (2.13) defines the spectrum of associated masses of elementary particles:

$$M_n = \frac{e}{\omega_n} = \frac{e}{4\omega_0} \cdot \frac{1}{n} = \frac{68.5\ m_e}{n}, \tag{2.14}$$

where

$$e = 1.702691582 \cdot 10^{-9}\ g \cdot s^{-1} \tag{2.15}$$

is the elementary *exchange charge* or an *elementary quantum of the rate of mass exchange* (the electron's charge for brevity, its dimension and value originate from the DM [5]).

If $l = n(\lambda/2)$, then $r_0 k = (1/2)n$ and

$$\omega_n = 2\omega_0 \cdot n, \qquad M_n = \frac{e}{\omega_n} = \frac{e}{2\omega_0} \cdot \frac{1}{n} = \frac{137\ m_e}{n}. \tag{2.16}$$

At last, at $l = n(\lambda/4)$, it follows that $r_0 k = (1/4)n$ and

$$\omega_n = \omega_0 \cdot n, \qquad M_n = \frac{e}{\omega_n} = \frac{e}{\omega_0} \cdot \frac{1}{n} = \frac{274\ m_e}{n}. \tag{2.17}$$

Because at $n = 1$, a particle of the mass $M_1 = 274 m_e$ is the π-meson, we will call the frequency ω_0 the *meson frequency*.

At $n = 1, 2, 3, 4,$ we have

$$\begin{array}{lll} 274\ m_e & \Rightarrow & \pi\text{-meson} \\ 137\ m_e & \Rightarrow & \gamma\text{-quantum} \\ 91.3\ m_e & \Rightarrow & \rho\text{-lepton} \\ 68.5\ m_e & \Rightarrow & g\text{-lepton} \end{array} \tag{2.18}$$

Two *g*-leptons form a *γ*-quantum, three *g*-leptons compose a *μ*-meson:

$$205.5\ m_e \quad \Rightarrow \quad \mu\text{-meson}. \tag{2.19}$$

3. The Boltzmann constant and temperature waves

In a spherical field, amplitude of oscillations of the spherical shell of a particle [1-3, 8, 13] is

$$\hat{A}_s = \frac{A_m \hat{e}_l(kr)}{kr}, \tag{3.1}$$

where

$$e_l(kr) = |\hat{e}_l(kr)| = \sqrt{\frac{\pi kr}{2}(J^2_{l+1/2}(kr) + N^2_{l+1/2}(kr))}\,, \qquad kr = z_{m,n}\,, \qquad (3.2)$$

and $z_{m,n}$ are roots of the Bessel functions, $J_{l+1/2}(kr)$ and $N_{l+1/2}(kr)$ [12].

Let us determine a quantum of the average energy of a nucleon at the level of the frequency ω_0, defined by the equation (2.11). We regard this frequency as one of the fundamental frequencies of the atomic level. Under the constant rate of mass exchange [4, 5] (exchange charge) of the value *e*,

$$e = \omega_e m_e = \omega_0 m_\pi\,, \qquad (3.3)$$

where m_e is the electron mass, a particle with the mass $m_\pi \approx 273 m_e$ corresponds to the frequency ω_0. This is the *π*-meson level of masses. This frequency relates to the frequency range of the "electromagnetic" field and defines the characteristic energy of the nucleon level E_s.

The root of Bessel functions, corresponding to the first potential extremum of the first-order spherical function, $z'_{1,1} = a'_{1,1} = 2.08157598$ [12], defines the discrete (quantum) state with this energy, hence, the corresponding quantum of energy is

$$E_s = \frac{m_0 \omega_0^2}{2}\left(\frac{A_m}{a'_{1,1}}\right)^2, \qquad (3.4)$$

where m_0 is the proton mass. Amplitude A_m is determined from the formula [1, 8, 13]

$$A_m = r_0 \sqrt{\frac{2hR}{m_0 c}}\,, \qquad (3.4a)$$

where *h* is the Planck constant, *R* is the Rydberg constant, and *c* is the speed of light.

Denoting the quantum of energy (3.4) as

$$E_s = \frac{k_B}{2}\,, \qquad (3.5)$$

and setting numerical values for all physical quantities entered in (3.4), we arrive at the quantity

$$k_B = m_0 \omega_0^2 \left(A_m / a'_{1,1}\right)^2 = 1.3512886 \cdot 10^{-16}\ erg\,, \qquad (3.6)$$

which is the *characteristic quantum of energy* of H-level. The latter is close in value to the ideal level k_Δ,

$$k_B \approx k_\Delta = \pi \lg e \cdot 10^{-16}\ erg\,, \qquad (3.7)$$

because it is multiple, to an accuracy of the second figure after comma, to a half of the fundamental period-quantum Δ of the Decimal Code of the Universe [10, 11],

$$\Delta = 2\pi \lg e . \tag{3.8}$$

The quantum k_B (3.6) practically coincides, in value, with the Boltzmann constant (1.3) designated in the same manner (letters), but it has the dimension of energy, *J* (or *erg*), in comparison with the Boltzmann constant k_B (1.3) of the dimension $J \cdot K^{-1}$.

Let us denote the *number of quanta of energy* (3.5) by the symbol T_e, and then the nucleonic energy can be rewritten as

$$E_s = \frac{k_B}{2} T_e . \tag{3.9}$$

The characteristic quantum of energy k_B was introduced in science as the ratio (1.3) under the name the *Boltzmann constant* of the dimension $J \cdot K^{-1}$; its value accepted at present [7] is

$$k_B = 1.3806504 \cdot 10^{-23}\ J \cdot K^{-1}. \tag{3.10}$$

Thus, the Boltzmann constant k_B (1.3) corresponds, in (3.9), to the characteristic quantum of energy k_B (3.6), and the absolute temperature *T* corresponds to the number of these quanta T_e.

The nucleon energy has the potential-kinetic character. The potential energy is negative and the kinetic energy is positive. Hence, the relative nucleon energy T_e is the negative one for the potential energy and the positive one for the kinetic energy. Therefore, in a general case, (3.4) can be presented as

$$\hat{E}_s = \frac{m_0 \omega_0^2 A_m^2}{2a_{1,1}'^2} e^{2i\omega t} = \frac{k_B}{2} \hat{T}_e , \tag{3.11}$$

where

$$\hat{T}_e = T_m e^{2i\omega t} . \tag{3.12}$$

is the *relative potential-kinetic energy*.

Motion-rest has the wave character; hence, we must speak about the *wave of relative energy*

$$\hat{T}_e = T_m e^{2i(\omega t - kr)} , \tag{3.13}$$

which satisfies the wave equation

$$\Delta \hat{T}_e - \frac{1}{2c^2} \frac{\partial^2 \hat{T}_e}{\partial t^2} = 0 . \tag{3.14}$$

A *positive component* of the relative energy is known under the name the *absolute temperature*. Modern physics operates mainly with the averaged positive amplitude temperature macrofield of motion-rest with a high part of the state of chaos.

The notion of the *negative absolute temperature* is used in modern physics for the description of a thermodynamical system (for example, quantum generators [14, 15]), which satisfies certain conditions. According to the latter the thermodynamical system (1) must be in thermodynamical equilibrium with environment in order for the system to be described by the temperature at all. There (2) must be an upper limit to the possible energy of the states allowed for the system. The system (3) must be thermally isolated from all systems which do not satisfy both of the first two requirements [16, 17].

At the subatomic level of motion-rest, under the high degree of ordering, the temperature microfield is, in essence, a different expression of the "electromagnetic" field.

According to the equation (3.11), the speed of pulsation of *H*-shell at the temperature of $T_0 = 273\,K$, in a general case, is

$$\upsilon = \frac{\omega_0 A_m}{z'_{m,n}}\sqrt{T_0} \approx \frac{3103}{z'_{m,n}}\; m\cdot s^{-1}. \qquad (3.15)$$

This field of motion-rest generates its own basis level of the wave motion. The maximal speed of pulsation of the nucleon shell, equal to $\upsilon_m = 1490\; m\cdot s^{-1}$, corresponds to the root $z'_{1,1} = a'_{1,1} = 2.08157598$.

At depths of 100–200 *m*, in warm seas, the sound speed amounts to the minimum, which is about $1490\, m\cdot s^{-1}$. In other liquids, sound speed is also close to this value. It allows concluding that carriers of sound waves are nucleons and their field. Consequently, sound waves are extended to all levels of cosmic space. In solid, liquid, and gaseous spaces, the intensity of sound waves is comparatively simply registered by apparatuses. However, in Cosmos their intensity is a negligibly small one and it is natural that the modern technics cannot perceive it.

4. The Avogadro constant

Since $h = 2\pi m_e \upsilon_0 r_0$ and $R = \upsilon_0 / 4\pi r_0 c$, the amplitude (3.4a) can be rewritten as

$$A_m = \frac{m_e \upsilon_0^2}{m_0 c^2} r_0^2, \qquad \text{or} \qquad A_m = \alpha^2 r_0^2 \frac{m_e}{m_0} \qquad (4.1)$$

where $\alpha = \upsilon_0 / c$ is the fine-structure constant, r_0 and υ_0 are the Bohr radius and speed, respectively.

The meaning of the oscillation amplitude of the spherical shell of the hydrogen atom A_m is clearly seen from the above presentation of the form (4.1). The amplitude A_m is proportional to the Bohr radius squared and to the ratio of two characteristic energies of the binary wave system (the hydrogen atom is such a system): an oscillatory energy of the orbiting electron, $m_e \upsilon_0^2$, and the dynamic (carrying) energy of the pulsing proton, $m_0 c^2$ [4, 5].

Hence, setting (4.1) in (3.4), with allowance for (3.5) and because

$$\omega_0 = \omega_e / 10^2 \Delta , \qquad (4.2)$$

$$\lambda\!\!\!^{-}_e = 1/k = c/\omega_e , \qquad (4.3)$$

where k is the wave number, we arrive at

$$E_s = \frac{k_B}{2} = \frac{m_e \omega_0^2}{2a_{1,1}'^2}\left(\frac{\upsilon_0}{c}\right)^2 r_0^2 = \frac{m_e \upsilon_0^2}{2a_{1,1}'^2}\left(\frac{r_0^2}{\lambda\!\!\!^{-}_e{}^2}\right)\frac{1}{10^4 \Delta}\ erg . \qquad (4.4)$$

Thus, the constant k_B of the dimensionality of energy,

$$k_B = 2E_s \qquad (4.5)$$

is the combination (product) of the fundamental parameters (constants), which characterize the wave motion at the atomic level: the oscillatory energy of an electron in the hydrogen atom $m_e \upsilon_0^2$, the Bohr radius r_0, the fundamental wave radius $\lambda\!\!\!^{-}_e$, and the fundamental period-quantum Δ.

The constant k_B (3.6) is "fundamental" in the sense just like "fundamental" is the fine-structure constant α. The latter is a dimensionless quantity, but formed from the four basic physical constants $e, \hbar, c$ and ε_0, being at the same time the ratio of two basic speeds, υ_0 and c, [18]:

$$\alpha = \frac{e^2}{4\pi\varepsilon_0 \hbar c} = \frac{\upsilon_0}{c} . \qquad (4.6)$$

Setting (4.6) in (4.4), the characteristic quantum of energy E_s can be presented also by three fundamental constants: m_e, r_0, ω_0 (we assume that ω_0 must belong to them), and α (which is the combination of other fundamental constants):

$$E_s = \frac{k_B}{2} = \frac{m_e \omega_0^2}{2a_{1,1}'^2}\alpha^2 r_0^2 . \qquad (4.7)$$

Thus, an explicit form of the fundamental constant k_B (see (3.6)) is

$$k_B = m_e \omega_0^2 r_0^2 \alpha^2 (1/a_{1,1}')^2 . \qquad (4.8)$$

Hence, the Avogadro constant N_A can be presented by the following formula:

$$N_A = \frac{R_g}{k_B} = \frac{a_{1,1}'^2 R_g}{m_e \omega_0^2 r_0^2 \alpha^2} . \qquad (4.9)$$

Calculations of N_A carried out with use of this expression, where $R_g = 8.314472(15)\, J \cdot mol^{-1} \cdot K^{-1}$, give

$$N_A = 6.152995046 \cdot 10^{23}\, mol^{-1}. \tag{4.10}$$

We see that the resulting value of N_A practically coincides with (1.4), obtained (theoretically as well) by Planck from his radiation formula (1.6).

5. Conclusion

A new insight into the notion of the temperature of matter, originated from the shell-nodal atomic model and the dynamic model of elementary particles, has been considered in this paper. We have shown that a quantum of an average energy of a nucleon at the level of so-called meson frequency ω_0 almost coincides in value with the Boltzmann constant k_B accepted currently in physics. The number of such quanta defines the relative nucleon potential-kinetic energy of a system, which in essence is what we call the absolute temperature. The latter is the alternating wave magnitude, as the relative potential-kinetic energy, according to the found peculiarity. Therefore, the absolute temperature is negative for the relative potential energy and positive for the relative kinetic energy.

The coincidence of the values of the fundamental constant N_A, obtained theoretically by Planck (1.4) and in this paper (4.10), naturally calls some reflections. Namely a comparison of both data leads to the conclusion that Planck's calculations of 1901 gave the *correct* value of N_A because, as it turned out, it is the *fundamental* constant of the atomic level. In this case, the word "fundamental" means, that the physical constant obtained by Planck is the combination of *fundamental physical constants* (see (4.9), like in the case of the fine-structure constant α (4.6). The modern accepted value of N_A (1.5) obtained from indirect measurements is different from the calculated value (compare (1.4) and (4.10) with (1.5)). It does not respond to the above definition, *i.e.*, to the condition for to be fundamental, and, hence, it is not *fundamental* in the above meaning.

By this reason, it seems to be obvious; the Avogadro and Boltzmann constants must be subjected to the detail analysis and further examination.

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March 24, 2008
Bielsko-Biala