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PROSPECTS FOR SIMULATING HEAT AND MASS TRANSFER IN INTENSIFICATION AND SCALING OF TECHNOLOGICAL PROCESSES

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A system of correlations is suggested that are obtained based on scaling a universal space-time dependence and that allow one to calculate fundamental physical constants with the accuracy of their experimental determination, thus creating a theoretical foundation for simulating in a single system the concepts of heat and mass transfer and chemical and biochemical conversions in intensification and scaling of technological processes.

Optimum, environmentally safe functioning and development of present-day technologies are based on advances in many sciences and require their integration, especially on a fundamental level, in order to decrease the needed informational output of experimental investigations. This refers first of all to heat and mass transfer phenomena that ensure progress in technological processes in intensification and increase of the spatial scale of their implementation. Use of a single system of concepts in the form of space-time correlations can become a basis for integrating the efforts of various sciences provided that these correlations allow for the entire variety of concepts known at this time. The touchstone here is the sufficiency of the information put into universal space-time dependences for calculating basic fundamental constants.

At the present time practically all the sciences employ space-time characteristics to a greater or lesser extent. It is only necessary to integrate them into a single system.

Considerable promise is offered by a system of dimensionless functionally related space-time characteristics that employs a functional time in the form of a relaxation time τ_r in the course of which the deviation of the system from the equilibrium state changes by a factor of e (e is the base of natural logarithms).

As a time characteristic, the quantity τ_r^{-1} is usually used, which is the reciprocal of the relaxation time and is known as the volumetric heat and mass transfer coefficient, the specific rate (rate constant) of conversion in chemical and biochemical technology, and the angular frequency (angular velocity) in physics, with the instantaneous values of the indicated quantity being represented in the form of a fraction of its value at the center of the source at the beginning of the process. The relative, functionally related spatial characteristic is the ratio of the current distance from the source to the distance from it at which the relative time characteristic is $\omega = e^{-1}$, i.e., e times smaller than the initial unit value.

In such a space-time system the intensification and spatial scaling of processes are correspondingly manifested in the change in the time and space characteristics.

The simplest (universal) relationship between the functionally related time, ω, and space, l, characteristics can be represented in the form of a system of equations:

$$\omega = (1 - l^{1.5}\delta)^2 , \tag{1}$$

$$l^3\omega^2 = C_1 , \tag{2}$$

having the common point K with the space, l_K, and time, ω_K, characteristics, with Eq. (1) being valid for $l \le l_K$ and Eq. (2) for $l \ge l_K$.

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Equation (1) is a transformation of Schlichting's [1] form of the universal hydrodynamic profile of the longitudinal velocity component in the cross section of the main portion of submerged tubulent jets and wakes behind bodies. Equation (2) asserts the invariance of the combination of quantities $l^3\omega^2$ with the mean value C_t = 0.10286 that was found experimentally in [2, 3] for $l > l_K$.

The coefficient $\delta = 1 - e^{-0.5} = 0.39346934028737$ in Eq. (1) provides the conversion from the relative functionally related spatial characteristic l to the relative characteristic l_0 adopted in [1] and equal to the ratio of the current spatial characteristic to the maximum distance of the action of the source:

$$l_0 = l\delta^{2/3}. \tag{3}$$

An analysis of the system of equations (1) and (2) shows that the simplest space-time relationship (unit velocity) $w = l\omega$ first increases with increase in l, attains the maximum value

$$w_{\max} = l_{\max}\,\omega_{\max} = (4\delta)^{-2/3}\,9/16 = 0.41572735400907 \tag{4}$$

at $l_{\max} = (4\delta)^{-2/3}$, and then decreases, obeying, in the case of $l > l_K$ in accordance with Eq. (2), an inversely proportional dependence on $l^{0.5}$.

The system of equations (1) and (2) allows one to carry out scaling by changing one (space or time) or both characteristics by a factor of n, as well as by raising to the m-th power.

For example, upon increasing 10-fold the space characteristic and subsequently raising the system to the tenth power, we obtain the system

$$\omega_{10} = [1 - (l_{10}\cdot 10^{-10})^{0.15}\,\delta\,]^{20}, \tag{1a}$$

$$(l_{10})^3\,(\omega_{10})^2 = C_t^{10}\cdot 10^{30}, \tag{2a}$$

where $\omega_{10} = \omega^{10}$, $l_{10} = (l\cdot 10)^{10}$ are the resulting values of the space-time characteristics.

Within the accuracy of experimental determination of C_t it is possible to propose several specific values of it, in particular, a convenient calculated value of $C_{\text{t.cal.}}$ that corresponds to the system of equations (1) and (2) at $l = l_K = 10^{0.2/3}$:

$$C_{\text{t.cal.}} = 10^{0.2}\,(1 - 10^{0.1}\delta)^4 = 0.10279360506882.$$

The invariant $C_{\text{t.l.vel.}}$ calculated from the velocity of light c = 299792458 m/sec has a value that is numerically close to that of $C_{\text{t.cal.}}$:

$$C_{\text{t.l.vel.}} = 0.1\,(c_m/c)^{\sqrt{2}} = c^{-\sqrt{2}}\cdot 10^{11} = 0.10279339173235, \tag{5}$$

where $c_m = 10^{6\sqrt{2}} = 305690100.16384$ is the model value of the maximum dimensionless velocity that corresponds to the concepts of gravitational mass with a 10-fold increase in the space-time characteristics and subsequent taking of the tenth power. Finally, the invariant $C_{\text{t.real}}$, which is close to experimental values of C_t, can be represented in the form $C_{\text{t.real}} = 2\cdot 10^{11}\,w_{\max}^{10}/c = 0.10287155487642$, where $w_{\max}^{10}$ is the maximum unit velocity upon raising the system of space-time characteristics to the tenth power.

The ratio of $C_{\text{t.l.vel.}}$ to this invariant is equal to

$$\gamma = C_{\text{t.l.vel.}}/C_{\text{t.real}} = (c^{1-\sqrt{2}}/\sqrt{2}\,)/\beta = 0.99924018712192, \tag{6}$$

where $\beta = \sqrt{2}\,w_{\max}^{10} = 2.1807255362031\cdot 10^{-4}$.

Equality of $C_{\text{t.l.vel.}}$ and $C_{\text{t.cal.}}$ is attained at the velocity c in Eq. (5) equal to $c_0 = c_m^{0.9}/\omega_K^{\sqrt{2}}$ = 299792018.04847 and representing the dimensionless calculated velocity.

TABLE 1. Calculation of Fundamental Constants

Notation of constants	Calculated dependences	Values of constants	
		calculated	reference [4]
c	$c_m^{0.999}(\delta^{-0.4\sqrt{2}/3}/c_m^{0.009})^{1/0.99}\varepsilon^{12}$	299792458.16577	299792458 $\text{m}\cdot\text{sec}^{-1}$
r_e	$2\cdot 10^{28}\beta^2\gamma^2\delta^4 c^{-4}\theta^{0.4}\varepsilon^{-6}$	$2.81794089\cdot 10^{-15}$	$2.81794092(38)\cdot 10^{-15}$ m
m_e	$10^{-28}\beta\gamma^{-1.6}\delta^{-4}\varepsilon^{6}$	$9.10939246\cdot 10^{-31}$	$9.1093897(54)\cdot 10^{-31}$ kg
e_0	$(2\cdot 10^7\beta^3\gamma^{0.4}c^{-4}\theta^{0.4})^{0.5}$	$1.60217756\cdot 10^{-19}$	$1.60217733(49)\cdot 10^{-19}$ C
α	$2^{0.2}(\beta\gamma)^{0.6}\varepsilon^{-5}$	$7.29735303\cdot 10^{-3}$	$7.29735308(33)\cdot 10^{-3}$
$\hbar$	$2\alpha^{-1}\beta^3\gamma^{0.4}c^{-3}\theta^{0.4}$	$1.05457297\cdot 10^{-34}$	$1.05457266(63)\cdot 10^{-34}$ $\text{J}\cdot\text{sec}$
m_p	$m_e(c/r_e^2)^{0.2\log e}\theta^2$	$1.67262291\cdot 10^{-27}$	$1.6726231(10)\cdot 10^{-27}$ kg
m_n	$m_p + 0.01 m_e r_e c^2\gamma_0$	$1.67492825\cdot 10^{-27}$	$1.6749286(10)\cdot 10^{-27}$ kg
$m_{a.m.u.}$	$m_e(c/r_e^2)^{0.2\log e}\gamma_0^{9.6}\varepsilon^{10}$	$1.66054014\cdot 10^{-27}$	$1.6605402(10)\cdot 10^{-27}$ kg
R	$20\,w_{max}$	8.31454708	8.314510(70) $\text{J}\cdot\text{mole}^{-1}\cdot\text{K}^{-1}$
K	$10^3 m_{a.m.u.}R$	$1.38066392\cdot 10^{-23}$	$1.380658(12)\cdot 10^{-23}$ $\text{J}\cdot\text{K}^{-1}$
G	$0.5(C_{t.l.vel.}/\gamma_0)^{10}(C_{t.l.vel.}\cdot 10)^{0.2}\theta^{2/3}$	$6.67252833\cdot 10^{-11}$	$6.67259(85)\cdot 10^{-11}$ $\text{m}^3\cdot\text{sec}^{-2}\cdot\text{kg}^{-1}$

The velocities c_0 and c can be considered as certain stable intermediate values in attaining c_m that lie at the level of the third approximation $c_m^{0.999} = 299775470.21239$.

On the basis of such representations, taking account of the $\delta^{-2/3}$-fold increase of the spatial characteristic according to Eq. (3) upon converting to the functionally related space-time correlations, we obtain a dependence for calculating the dimensionless value of the velocity c:

$$c = c_m^{0.999}\,[(\delta^{-2/3})^{0.2\sqrt{2}}/c_m^{0.009}]^{1/0.99}\,\varepsilon^{12} = 299792458.16577\,, \tag{7}$$

where $\varepsilon = [(\delta^{-2/3})^{0.2\sqrt{2}/9999}]^{1/12} = 1.0000014658262$ is a quantity that can be used as a multiplier that corrects the level of approximation of c_m, for example, in calculating c_0:

$$c_0 = c/\varepsilon = c_m^{0.999}\,[(\delta^{-2/3})^{0.2\sqrt{2}}/c_m^{0.009}]^{1/0.99}\,\varepsilon^{11} = 299792018.72277\,. \tag{8}$$

The velocity c can also be calculated by means of the second approximation of c_m:

$$c = c_m^{0.99}\,\delta^{-0.4\sqrt{2}/3}\,\theta = 299792458.16577\,, \tag{9}$$

where $\theta = 1.0000179808376$ is a quantity that equally with ε characterizes the level of approximation of c_m.

The quantities β, γ, δ, $C_{t.l.vel.}$, the calculated velocity of light $c = 299792458.16577$, the correcting multipliers ε and θ, and the calculated quantity $\gamma_0 = 1 - 10^{-e}\delta = 0.99924728760324$ (which, according to Eq. (1), is the value of $\omega^{0.5}$ at $l = 10^{-2e/3}$, to which γ tends) that result from the analysis of the system of equations (1) and (2) were used for determining fundamental physical constants. In these calculations the quantities γ and $C_{t.l.vel.}$ were evaluated using $c = 299792458.16577$ and amounted to $\gamma = 0.99924018689305$ and $C_{t.l.vel.} = 0.10279339165197$, respectively.

Table 1 presents calculated dependences for determining the constants and gives a comparison of the results of the calculations with their reference (experimental) [4] values; this allows one to see the commensurability of the accuracy of the calculations with the accuracy of experimental determination of these constants.

The calculated dependences were obtained on the basis of well-known relations between the fundamental constants that were supplemented with new ones determined from the space-time relations.

Thus, the well-known equation of the Coulomb interaction of electric charges

$$r_e c^2 = k_0 e_0^2 / m_e , \tag{10}$$

where r_e is the classical radius of an electron, m_e is the rest mass of an electron, and e_0 the elementary charge; $k_0 = c^2 \cdot 10^{-7}$ m/F is the proportionality constant in Coulomb's law (in the mks system), was supplemented with the equations for calculating the invariants $r_e c^2$ and $k_0 e_0^2$:

$$r_e c^2 = (C_{\text{t.l.vel.}} \delta^2 \cdot 10^3)^2 \, \theta^{0.4} \, \varepsilon^{-6} = 2 \cdot 10^{28} \beta^2 \gamma^2 \delta^4 \theta^{0.4} \varepsilon^{-6} c^{-2} , \tag{11}$$

$$k_0 \, e_0^2 = \beta^3 \, (\sqrt{2} \, \gamma^{0.2} \theta^{0.2} / c)^2 . \tag{12}$$

According to Eq. (11), the invariant $r_e c^2$ corresponds to the system of equations (1) and (2) transformed by increasing 10-fold the spatial characteristic l, recalculated to the ordinary relative characteristic l_0 according to Eq. (3), and subsequently raising the system to the second power.

The invariant $k_0 e_0^2$ is determined according to Eq. (12) as that passing through the point with the coordinates $l = \beta$ and $\omega = \sqrt{2} \gamma^{0.2} \theta^{0.2} / c$. The system of equations (10)-(12) makes it possible to calculate r_e, m_e, and e_0.

The fine-structure constant α corresponds to the transformation of the system of equations (1) and (2) by raising it to the sixth power, since the calculation is based on the quantity $\beta^{0.6}$, which is proportional to $w_{\max}^6$.

In calculations of the masses of the proton m_p, the neutron m_n, and the atomic mass unit $m_{\text{a.m.u.}}$, we used the ratio of the velocities w for a change in the conditions of constancy of the invariant $r_e c^2$ of the spatial characteristic l from the minimum value $l_1 = r_e$ (at $w_1 = c$) to the mean value $l_2 = \omega_2$ at $w_2 = (r_e c^2)^{0.4}$:

$$w_1 / w_2 = c / (r_e c^2)^{0.4} = (c / r_e^2)^{0.2} . \tag{13}$$

The universal gas constant R is twice the value of the maximum unit velocity $w_{\max} \cdot 10$ upon transformation of the system of equations (1) and (2) by a 10-fold increase in the quantity l.

The Planck, $\hbar$, and, Boltzmann, k, constants are calculated from well-known relations, in particular,

$$\hbar = k_0 \, e_0^2 / (\alpha c) = 2 \alpha^{-1} \beta^3 \gamma^{0.4} c^{-3} \theta^{0.4} , \tag{14}$$

while the invariant $C_{\text{t.l.vel.}}$ and its transformation are used for determining the gravitational constant G.

The possibility of using space-time correlations for calculating fundamental constants with the accuracy of their experimental determination forms a real theoretical basis for simulation of heat and mass transfer in a single system of concepts with chemical and biochemical conversions, especially in intensification and scaling of technological processes.

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