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Physical bases for a triad of biological similarity theories

Fundamentos físicos para una tríada de teorías de similitud biológica

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The dimensional analysis of physics, based on the MLT-system (M = mass, L = length, T = time), can be applied to the living world, from mycoplasmas (10^{-13} g) to the blue whales (10^{8} g). Body mass (M), or body weight (W), are utilized as convenient reference systems, since they represent the integrated masses of all elementary particles –at the atomic level– which conform an organism. A triad of biological similarities (mechanical, biological, transport) have been previously described. Each similarity was based on two postulates, of which the first was common to all three, *i.e.*, the constancy of body density; whereas the second postulates were specific for each of the three theories. In this study a physical foundation for these second postulates, based on three universal constants of nature, is presented, these are: 1) the acceleration of gravity ($g = LT^{-2}$); 2) the velocity of light ($c = LT^{-1}$); and 3) the mass-specific quantum ($h/m = L^2T^{-1}$). The realm of each of these biological similarities is the following: 1) the *gravitational or mechanical similarity* (where g = constant), deals mainly with the relationship between a whole organism and its environment, particularly with locomotion. The acceleration of gravity (g) is also one of the determining factors of the "potential" energy ($E = m \cdot g \cdot H$), where *m* is the mass, and *H* is the height above the reference level; 2) the *electrodynamic similarity* (formerly *biological similarity)*, (c = constant), is able to quantitatively define the internal organization of an organism from both a morphological and a physiological point of view. This similarity is related to the "kinetic" energy ($1/2\ mv^2$), and is equivalent to the mass-specific energy (E/m), as well as to the mass-specific work or heat capacity, and to the mass-specific enthalpy of each organism; and 3) the *quantum or transport similarity* (h/m = constant), should be applied when the physico-chemical properties of living matter are studied at the atomic level, in particular the diffusion processes due to brownian motion. The invariance of the mass-specific quantum (h/m) is thoroughly analysed with regards to the metabolic activity of mitochondria (oxidative phophorylation). It is interesting to note, that in the *gravitational similarity* the "biological space" is Euclidean or three-dimensional ($V \alpha L^3$), whereas in the *electrodynamic* and *quantum* similarities, space is four-dimensional ($V \alpha L^4$). The corresponding "space-time" relationship for the three similarities are the following: 1) in the *gravitational* similarity $T \alpha L^{1/2}$; 2) in the *electrodynamic* similarity $T \alpha L$; and 3) in the *quantum* similarity $T \alpha L^2$. The triad of biological similarities can be falsified by comparing the spectrum of theoretical predictions with the experimental findings (log-log plots), which can be expressed in accordance with Huxley's allometric power ecuation ($Y = aW^b$), where *Y* = any biological function; *W* = body weight; *a* = empirical parameter; and *b* = allometric exponent which can be compared with the theoretically calculated reduced exponents.

In previous papers (Günther, 1975a, b; Günther and Morgado, 1982; 1984) three independent similarity criteria were postulated which can be applied to all living beings; these are:

1. a *mechanical similarity,* which relates whole organisms and their environment, particularly with regards to locomotion;

2. a *biological similarity,* which deals with the quantitative study of the internal morphometry and physiometry of organisms, irrespective of their sizes, and

3. a *transport similarity,* which analyses diffusion processes at the cellular level, as well as the transport of matter and of heat; in the latter case, from the mitochondriae to the surface of the body.

In the present study we attempt to interpret the above triad of biological similarities by means of three universal constant, i. e., the acceleration of gravity (g); the velocity of light (c); and the quantum of action (h). These three physically based biological similarities are equivalent to

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the former 1) mechanical, 2) biological, and 3) transport similarities, whose validity could be confirmed by comparing the theoretical predictions with the empirical findings, when expressed in accordance with Huxley's allometric equation.

Each of the above similarity criteria is based on two postulates, the first of which is common to all three, i.e., that the chemical composition of all organisms is almost identical. Morowitz (1968) has shown that the primary atomic components of living systems (1-60% of body weight) are: C, H, N, O, P; whereas the secondary components (0.05-1%) are: Na, Mg, S, Cl, K, Ca.

The first postulate

If one assumes that the chemical architecture of all living beings is almost the same, both in prototype (p) and model (m), then the density ($\rho = ML^{-3}$) is $\rho_p/\rho_m = 1.0$. This assertion is corroborated by the fact that all organisms –irrespective of their size– are on the verge of flotation when placed in an aqueous medium (Economos, 1982). The term *prototype* (p) means a large or a small organism to which a *model* (m) organism is geometrically and physically or chemical related.

By applying the canonical dimensional analysis (MLT-system, where M is the mass, L is the length, and T is the time dimension) and the corresponding adimensional ratios for mass ($M_p/M_m = \mu$), length ($L_p/L_m = \lambda$) and time ($T_p/T_m = \tau$), the above mentioned density ratio yields $\mu\lambda^{-3} = 1.0$, or

$$\mu = \lambda^3 \qquad (1)$$

Nevertheless, it is worth mentioning that Eq. 1 is valid only for the gravitational similarity, since in the electrodynamic and quantum similarities Eq. 1 will be $\mu = \lambda^4$ (four-dimensional space, as will be discussed later).

The second postulates

The second postulates differ in each case, depending upon the similarity criterion involved.

1. *Gravitational similarity*

In this case it is assumed that prototype (p) and model (m) are subjected to the same gravitational force, which is represented by the permanent attraction of two masses (organism and earth). Consequently, the acceleration of gravity ($g = LT^{-2}$) is the same for prototype (p) and for model (m), with the result that $g_p/g_m = 1.0$. If this relationship is expressed in accordance with the corresponding adimensional ratios, then we have $\lambda\tau^{-2} = 1.0$, and

$$\tau = \lambda^{1/2} \qquad (2)$$

It is interesting to note that a minor difference exists (5‰) between the acceleration of gravity (g) at the equator ($g_e = 978.06$ cm sec^{-2}) and that at the polar regions ($g_p = 983.23$ cm sec^{-2}).

On the other hand, body mass (M) is proportional to body weight (W) due to the constancy of the acceleration of gravity ($W = M \cdot g$). Furthermore, body mass (M) is equivalent to the sum of the weights of all the atoms which conform an organism, and these atomic weights are mainly determined by the sum of the masses of protons (p) and neutrons (n) inside each nucleus. The mass of an orbital electron (e) is 1836 times smaller than that of protons and neutrons. If one wishes to add the corresponding electron masses, then the sum of one proton (p) and one electron (e) is equivalent to the mass of one atom of hydrogen (H).

In order to illustrate the paramount importance of nucleons (protons and neutrons) in determining body mass (M), and the minuteness of the volume occupied by them, in comparison with the atomic volumes, it suffices to mention (Florey, 1966) that the nuclear-mass density is 1.5×10^{17} g/cm^3 and consequently a 70 kg man should occupy a volume of 4.66×10^{-13} cm^3, and would be less than 1 μm long, *i.e.*, a man would be barely visible with the light microscope.

2. *Electrodynamic similarity*

The second postulate of this biological similarity is based on the constancy of the

velocity of light (c), as was postulated by Günther & Guerra (1955).

In order to obtain the dimensional uniformity of all electrodynamic equations (Hund, 1961) a constant factor is always utilized ($1/\sqrt{\epsilon_0 \cdot \mu_0} = c$), where ϵ_0 = electric permitivity of vacuum, μ_0 = magnetic permeability of the vacuum ($\cdot 4\pi \times 10^{-7}$), and c the velocity of light. Moreover, it is assumed that the speed of light (c) is invariant in an isotropic medium, and consequently the value of c should be the same in both prototype (c_p) and model (c_m), which means that $c_p/c_m = 1.0$ The adimensional ratio for a velocity ($v = LT^{-1}$) is $\lambda\tau^{-1}$, from which we obtain

$$\tau = \lambda \qquad (3)$$

Oxidative phosphorylation is associated, in agreement with Mitchell's (1977) chemiostatic theory, with a two electron transfer and a proton pump at the inner mitochondrial membrane. To illustrate the paramount importance of electrodynamic phenomena at the cellular level, it can be shown that the potential difference between NADH and molecular oxygen is about 1.2 volts and that each atom of O_2 is capable of accepting 2 electrons. Furthermore, Hinkle & McCarty (1978) have calculated that in a man at rest ($\dot{V}O_2 \cong 350$ ml O_2/min) the total current in all mitochondria is about 100 amperes, so that a power of 120 watts is generated. On the other hand, in elite endurance athletes (Nadel, 1985) a 20-fold increase of oxygen consumption over the resting uptake has been observed, which yields a power equivalent to about 2 kilowatts.

In addition, the mitochondrion is the major site of heat production (Himms-Hagen, 1976) during cellular oxidation. Only about 25% of the free energy released is conserved as ATP, while the remaining 75% appears as heat. The mass-specific heat capacity of animals, considered as thermodynamic systems (Heusner, 1983), is equivalent to $|M^0L^2T^{-2}\theta^{-1}|$, in which temperature ($\theta$) is an intrinsic property, whose ratio for prototype (p) and model (m) is (θ_p/θ_m) and equal to 1.0. Consequently, the corresponding reduction coefficient $\chi = \lambda^2\tau^{-2} = 1$, hence $\tau = \lambda$.

In conclusion, Lambert and Teissier (1927) *a priori* postulate for a biological similarity ($\tau = \lambda$) is equivalent to the electrodynamic similarity based on the constancy of the velocity of light (c), and also to the mass-specific heat capacity described by Heusner (1983).

3. *Quantum similarity*

According to Elsasser (1966) "there is no evidence at all that the basic laws of atomic and molecular physics (quantum mechanics) show any difference in the living organisms as compared to inorganic matter", and in consequence, "quantum theory, and hence Chemistry, is the same *in vivo* as *in vitro*".

This similarity criterion is based on the constancy of Planck's quantum of action (h), whose numerical value is $h = 6.626 \times 10^{-27}$ erg sec. This fundamental constant of nature (h) can now be correlated with the mass of some of the elementary and stable particles (Laidler, 1978; Moore, 1962), such as electrons and protons:

a) if we consider the ratio (h/m) for the negatively charged electron (e^-), whose mass (Weast, 1983) is 0.910×10^{-27} g, we obtain a numerical value of 7.281 (erg sec)/g for the above mentioned ratio;

b) for the proton the (h/m) ratio is 0.00396 (erg sec)/g.

It is worth mentioning, that these two subatomic particles (protons and electrons) are directly involved in the oxidation of substrates in each mitochondrion. During substrate oxidation, and in agreement with the vectorial metabolic concept of chemiosmotic reactions (Mitchell, 1977, Chance, 1977) a long sequence of redox reactions take place, in which a pair of electrons ($2e^-$) crosses the inner mitochondrial membrane on three occasions and on each of which two protons ($2H^+$) are extruded, creating a proton gradient and an electrical potential.

The (h/m) ratio can also be deduced from the following two equations:

a) From Compton's equation. The wavelength (λ) of a particle is $\lambda = h/m \cdot c$; consequently from it we can obtain the corresponding dimensional equivalence:

$$\left|\frac{h}{m}\right| = \lambda \cdot c = L \cdot (LT^{-1}) = \left| L^2 T^{-1} \right| \quad (4)$$

b) The h/m ratio can also be obtained form the De Broglie's wavelength (λ), which, and in accordance with quantum mechanics, is related to a particle by virtue of its momentum, and which can be defined as $\lambda = h/mv$, where *m* is the observed mass of the particle, and *v* its velocity. From De Broglie's equation we obtain:

$$\left|\frac{h}{m}\right| = \lambda \cdot v = L\,(LT^{-1}) = \left| L^2 T^{-1} \right| \quad (5)$$

In conclusion, in both instances (Eq. 4 & 5) the dimensional analysis yields the same result, which can be expressed by means of the above mentioned adimensional ratios, and then we have:

$$\tau = \lambda^2 \quad (6)$$

The general equation of biological similarity

From the corresponding two postulates it is possible to obtain three independent similarity criteria by replacing the pertinent exponents in Newton's reduction coefficient

$$\chi = \mu^{\alpha} \cdot \lambda^{\beta} \cdot \tau^{\gamma} \quad (7)$$

where μ = mass ratio, λ = length ratio, and τ = time ratio.

a) In the *gravitational similarity*, the first postulate is equivalent to $\mu = \lambda^3$, and the second to $\tau = \lambda^{1/2}$. If these equivalences are introduced into Eq. 7 we obtain

$$\chi = \lambda^{3\alpha} \cdot \lambda^{\beta} \cdot \lambda^{1/2\gamma} \quad (8)$$

which is equivalent to

$$\chi = \lambda^{3\alpha + \beta + 1/2\gamma} \quad (9)$$

b) In the case of the *electrodynamic similarity*, the first postulate is equivalent to ($\mu = \lambda^4$) and the second to $\tau = \lambda$. The reduction coefficient (χ) in this case will be:

$$\chi = \lambda^{4\alpha + \beta + \gamma} \quad (10)$$

c) Finally, in the *quantum similarity*, we also have $\mu = \lambda^4$, and $\tau = \lambda^2$, both of which yield a Newtonian reduction coefficient of

$$\chi = \lambda^{4\alpha + \beta + 2\gamma} \quad (11)$$

As a result of the above, we have obtained three different similarity criteria, which differ in the numerical value of the exponent (α) of the mass ratio (μ), as well as the exponent (γ) of the time ratio (τ).

Due to theoretical and practical reasons, it is more convenient in Biology to utilize the mass ratio (μ) or the weight ratio ($\omega = W_p/W_m$), than the length ratio (λ). Therefore, Eq. 9 of the *gravitational similarity* is converted into a new expression if one takes into account that $\lambda = \mu^{1/3}$, or $\lambda = \omega^{1/3}$. Furthermore, since the acceleration of gravity (g) is practically constant on earth ($W = M \cdot g$), and consequently weight (W) and mass (M) are proportional to each other ($\mu = \omega$), we can rewrite Eq. 9 as follows:

$$\chi = \omega^{1/3\,(3\alpha + \beta + 1/2\gamma)} \quad (12)$$

and finally,

$$\chi = \omega^{\alpha + 1/3\beta + 1/6\gamma} \quad (13)$$

The same procedure can be utilized for the other two similarities (*electrodynamic* and *quantum similarities*); but, instead of $\omega = \lambda^3$ we have to utilize $\omega = \lambda^4$ as the first postulate for reasons which were discussed extensively in previous papers (Günther & Morgado, 1982; 1984). This four-dimensional space ($V \alpha L^4$) can be visualized, as in Physics (Feedman & Van Nieuwenhuizen, 1985), by means of a plane surface (Fig. 1) whose coordinates are L_1 and L_2, where each point can be defined in agreement with Euclidean geometry. At the intersections of these two coordinate lines, and tangent to the plane at every point, cylindrical structures can be imagined, whose heights are equal to L_3, and the corresponding radii or diameters of these cylinders can be defined as L_4. In consequence, any point (P) on the cylindrical surfaces can be determined by means of four coordinates. Nevertheless, the time dimension (T) is absent in the

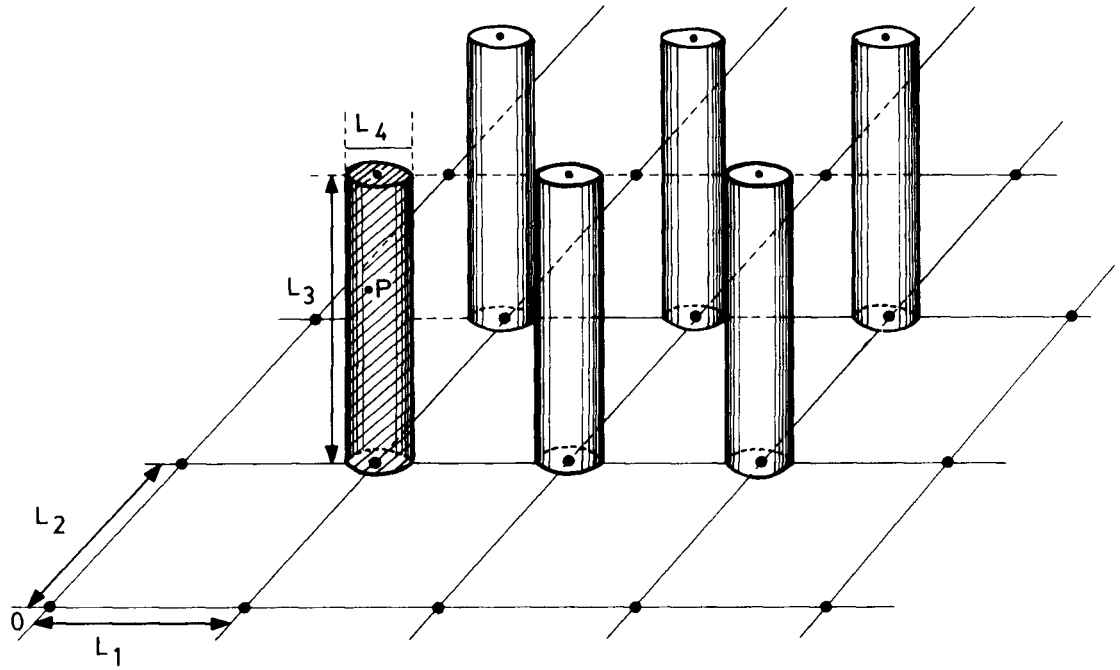

Fig. 1: Illustration of a four-dimensional cylinder-world of living beings, where the two-dimensional reference plane represents the cross-sections of an organ, in accordance with the Euclidean geometry (L_1 and L_2). At each intersection of the coordinate lines, a cylindrical structure is imagined as a tangent to the plane at every point. The longitudinal dimension of each cylinder corresponds to L_3 and the radial or diametral dimension to L_4. In order to specify a point (P) on the surface of the dashed cylinder four coordinates are necessary. Each cylinder represents a morphological unit (capillary, nephron, axon, collagenous or elastic fibers, etc.), which pertains to the microscopic structure of the corresponding organ or system.

structures shown in Fig. 1, but if a volume flow (L^3T^{-1}) should appear inside any of these cylindrical tubuli, then we will have $L_3 \cdot (L_4)^2T^{-1}$. The same will take place when matter or energy is transported across the cylindrical surface ($L_3 \cdot L_4$) by means of diffusion (see Fig. 2). In this latter case, each particle at rest has a volume $V \alpha L^3$, where again the physical time dimension (T) is absent; but, due to brownian motion, a particle acquires a momentum (Mv), and consequently we have (MLT^{-1}), and the time dimension (T) appears associated with the vector (L_4), or with the fourth dimension ($T \alpha L_4$).

Space-time relationship in biological sciences has been discussed recently (Günther & Morgado, 1985).

In a previous paper (Günther, 1983) it was emphasized that the cylindrical form is prevalent in living beings (plants and animals), both as hollow structures (ducts) or as compact columns. The hollow cylinders conduct air, blood, secretions or excretions, whereas the compact cylinders are represented by bones, muscles, nerves, and different fibers of the connective tissue. A common feature of these cylinders is that the transport of matter (MT^{-1}) is made along the main axis (L_3 in Fig. 1), whereas the exchange of matter or of energy is performed through the corresponding surface area (L_3 times L_4). The same is true for the compact cylinders, where the force vectors are oriented in accordance to the main axis (L_3) and the exchange of energy and matter is made through the external surface of each cylinder (L_3 times L_4).

The four-dimensional space of the *electrodynamic similarity* yields the following general equation

$$\chi = \lambda^{4\alpha + \beta + \gamma} \qquad (14)$$

which can also be expressed as the power of the weight ratio (ω), and in consequence we obtain

$$\chi = \omega^{\alpha + 1/4\beta + 1/4\gamma} \qquad (15)$$

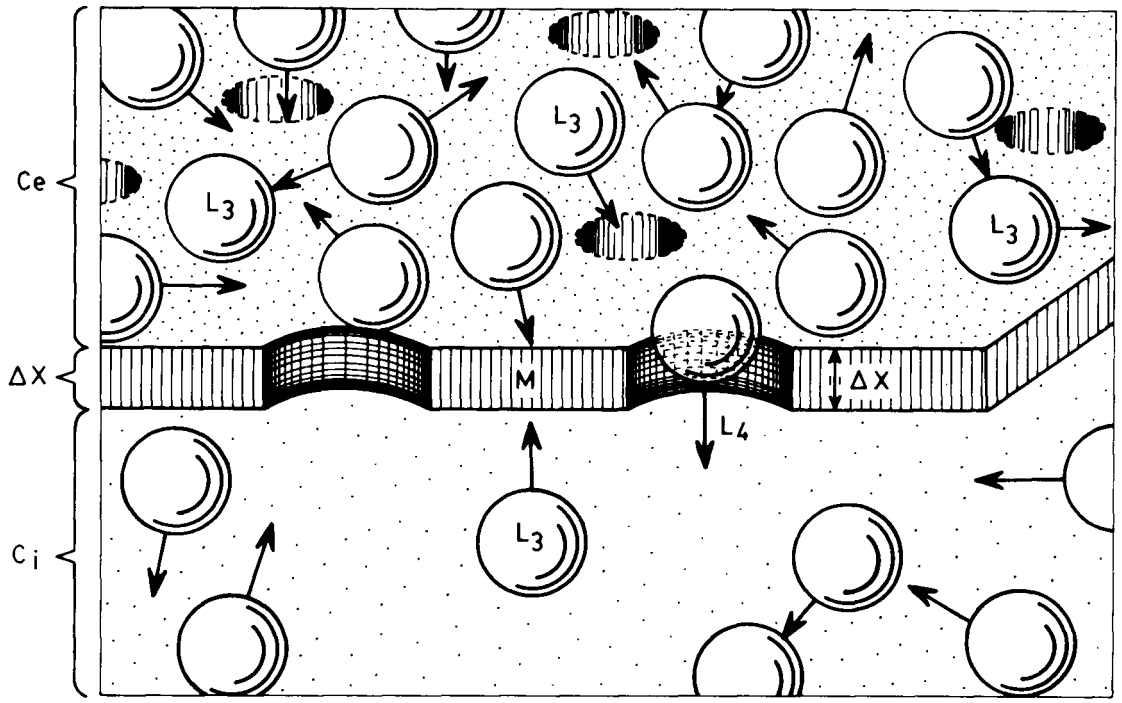

Fig. 2: Diagram of the four-dimensional diffusion process at the porous membrane (M), which separate two compartments, whose particle concentration is (C_e) for the external medium and (C_i) for the internal medium. The membrane thickness is represented by Δx, in accordance to Fick's equation. Each spherical particle is three-dimensional (L_3) at rest; but due to the brownian motion a fourth dimension (L_4) should be added, which is indicated by the corresponding vector.

The *quantum similarity* is equivalent to our original *transport similarity*. It also has a four-dimensional space as deduced from Fick's law of diffusion at the cellular level (Günther & Morgado, 1984). During the diffusion process (Fig. 2) only particles at rest are three-dimensional (L_3); but, due to the random thermal motion of atoms or molecules (brownian motion) each of these particles has an associated vector (L_4), whose minimal length is equivalent to the membranes thickness (ΔX, in Fick's equation). In consequence, the fourth dimension of space of the *transport similarity* is represented by the scalar value of this vector.

Since *transport and quantum similarities* are characterized by the same second postulate, whose dimensional formula is $|L^2 T^{-1}|$, the general equation for these similarities is the following

$$\chi = \lambda^{4\alpha + \beta + 2\gamma} \qquad (16)$$

which is equivalent to

$$\chi = \omega^{\alpha + 1/4\beta + 1/2\gamma} \qquad (17)$$

when expressed as a function of the body weight ratio (ω).

Comparison between theoretical predictions and experimental results

Any theory should be submitted to a comparison with the experimental findings. In the present case this falsification procedure (Popper, 1980) must also be applied, provided that the different biological functions are previously defined in accordance with the MLT-system, i.e., a velocity $|v| = |LT^{-1}|$, a volume flow $|\dot{Q}| = |L^3 T^{-1}|$, and energy or work as $|E| = |ML^2 T^{-2}|$. The exponents (α, β, γ) correspond to the numerical values of the mass (M), length (L) and time (T) ratios (μ, λ, τ). Since each of the three similarities (gravitational, electrodynamic, quantum) has different numerical coeffi-

cients (a, b, c), it is possible to write the following general equation of biological similarities:

$$\chi = \omega^{a\alpha + b\beta + c\gamma} \qquad (18)$$

The theoretical predictions (Table I) of the "reduced exponent" of the weight ratio (ω), which are significantly different in the triad of biological similarities, can be compared with Huxley's (1932) allometric exponent (b), in accordance with his power formula

$$Y = aW^b \qquad (19)$$

where

Y = any biological function which can be expressed in accordance with the MLT-system;
a = empirical parameter;
W = body weight (g); and
b = allometric exponent, which can be compared with the theoretical reduced exponent in accordance with Eq. 18.

A correlation coefficient r of 0.9937 was found when the theoretically calculated reduced exponents (Eq. 18) were compared with the experimental findings (N = 96), tabulated by Günther (1975a, b), and which were expressed in accordance to Huxley's allometric equation (Eq. 19). Moreover, in the most extensive compilation of allometric equations of interspecific size relations done by Peters (1983), where in particular the ecological implications of body size were thoroughly discussed, the author submitted the theoretical predictions from the original theories of biological similarity (Günther, 1975b) to a new statistical analysis, and he obtained for 88 allometric equations a value of $r^2 = 0.98$, which implies that the regression accounts for 98% of the variation.

A satisfactory correspondence between the theoretical predictions and the experimental findings was also obtained by Günther & Morgado (1984) for the *transport similarity*.

TABLE I

Dimensional analysis of 20 physical entities of biological interest and the calculated reduced exponent (b) according to equations 13, 15 and 17. The figures in parenthesis correspond to the exponent (β) in a four-dimensional space ($V \alpha L^4$), in accordance with Eqs. 15 & 17

Item	Physical quantity	Dimensions			Calculated reduced exponents (b)		
		M	L	T	Gravitational	Electrodynamic	Quantum
		α	β	γ	Eq. 13	Eq. 15	Eq. 17
1	Mass	1	0	0	1.00	1.00	1.00
2	Length	0	1	0	0.33	0.25	0.25
3	Time (period)	0	0	1	0.17	0.25	0.50
4	Area	0	2 (3)	0	0.67	0.75	0.75
5	Volume	0	3 (4)	0	1.00	1.00	1.00
6	Density	1	−3 (−4)	0	0.00	0.00	0.00
7	Volume-flow	0	3 (4)	−1	0.83	0.75	0.50
8	Velocity	0	1	−1	0.17	0.00	−0.25
9	Acceleration	0	1	−2	0.00	−0.25	−0.75
10	Force	1	1	−2	1.00	0.75	0.25
11	Pressure; stress	1	−1 (−2)	−2	0.33	0.00	−0.50
12	Peripheral resistance	1	−4 (−6)	−1	−0.50	−0.75	−1.00
13	Energy; work	1	2	−2	1.33	1.00	0.50
14	Power	1	2	−3	1.17	0.75	0.00
15	Action	1	2	−1	1.50	1.25	1.00
16	Momentum	1	1	−1	1.17	1.00	0.75
17	Surface tension	1	0	−2	0.67	0.50	0.00
18	Viscosity (dynamic)	1	−1 (−2)	−1	0.50	0.25	0.00
19	Viscosity (kinematic)	0	2	−1	0.50	0.25	0.00
20	Heat quantity	1	2	−2	1.33	1.00	0.50

CONCLUDING REMARKS

If all masses (m) pertaining to both the macroscopic and microscopic world are represented on a logarithmic scale (Fig. 3), whose range includes both the farthest galaxies and the electrons, one finds that living organisms (McMahon & Bonner, 1983) are located almost in the middle, the extreme values being 10^{-13} g for mycoplasmas and 10^{8} g for blue whales. It is for this very reason that the physical laws, and the corresponding universal constants, should also be valid for this biological universe, whose range is enormous (10^{21}).

In the present study we have attempted to establish a triad of biological similarity criteria based on three universal constant, namely

1. the *acceleration of gravity* (LT^{-2}), which is produced by the mutual attraction of two masses (earth and organism) and directed along the line joining their centers of mass. It is worth mentioning that the acceleration of gravity (g) is one of the factors which determines the *potential energy* of a system, since $E = m \cdot g \cdot H$, were *m* is the mass, and *H* the height above the reference level, and where energy (E) represents the capability of doing work.

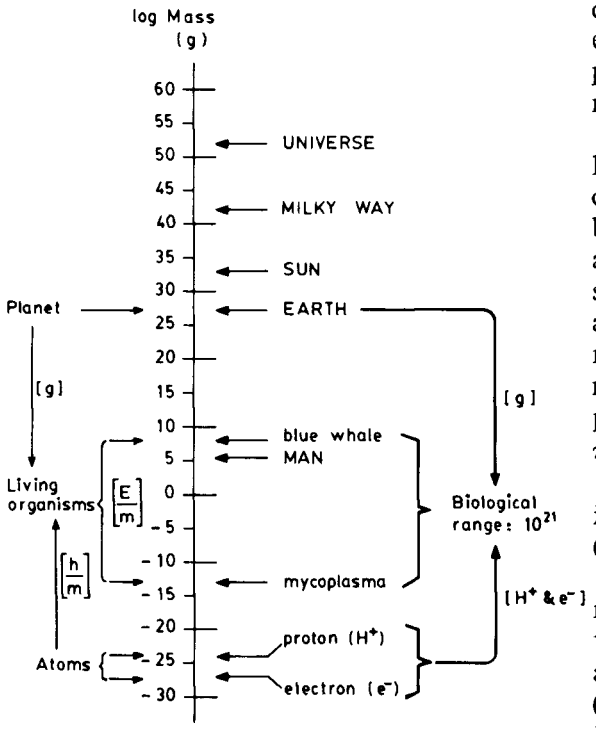

Fig. 3: Logarithmic scale of the mass range (g) in the physical world, from the mass of the electron to the mass of the whole universe. The biological world is located almost in the middle. The gravitational influence (g) and the physico-chemical activity of protons (H^+) and electrons (e^-) in living beings are symbolized by means of arrows. The symbolism on the right side (g, H^+, e^-) indicate qualitative relationships, whereas those on the left, correspond to the quantitative (mass-specific) aspects which relate living organisms to their external or internal milieu.

2. The velocity (LT^{-1}) of light (c), one of the universal constants of nature, of basic importance in Einstein's theory of relativity, is a reference value to which any other velocity (v) should be related (Von Baeyer, 1985). Furthermore, the velocity of light (c) is the factor which unites mass (m) with the atomic energy ($E = mc^2$). On the other hand, in the *kinetic energy* ($E = 1/2\ mv^2$) the velocity (v) also appears squared. Moreover, the speed of light (c) is dimensionally correlated with all electrodynamic phenomena (Hund, 1961) through electric permitivity (ϵ_0) and magnetic permeability (μ_0) in vacuum, as has been mentioned previously.

It is interesting to note, that the equivalence of the length and time ratios ($\tau = \lambda$) of the electrodynamic similarity can also be obtained (Heusner, 1983, 1984) by assuming the constancy of the mass-specific heat capacity ($M^{\circ}L^2T^{-2}\theta^{-1}$), or of a constant mass-specific enthalpy (constant relationship between energy content and mass), since energy or work ($E = ML^2T^{-2}$) per unit mass (M) yields $\lambda^2\tau^{-2} = 1.0$, or $\tau = \lambda$.

3. The quantum similarity deals with the invariance of the *mass-specific quantum* (h/m), which has the dimensional formula L^2T^{-1}, and which can be applied to the masses (m) of both electrons (e) and protons (p). Electrons (e^-) and protons (H^+) are involved in the energetics of foodstuffs (sugars, fatty acids, and aminoacids). As it is well known, most metabolic processes are oriented to the production of ATP, a usable form of energy, which is utilized for various kinds of physiological work (muscle contraction, nerve conduction, glandular secretion, or renal excretion). These chemical processes are governed by quantum mechanics, and for this reason the variables involved (h, m) should be taken

into account when establishing similarity criteria in living beings.

It is worth mentioning that the former theory of biological similarity (Lambert & Teissier, 1927; Günther, 1975a, b), where the time ratio (τ) is equivalent to the length ratio (λ), could be deduced from the constancy of the velocity of light (c). On the other hand, the "transport" similarity, based on Fick's law on diffusion (Günther & Morgado, 1984), can be obtained from the mass-specific quantum ratios (h/m), which are constant for both the electron (7.28 erg sec/g), and proton (0.00396 erg sec/g).

Incidentally, the (h/m) ratio is also an expression of Heisenberg's uncertainty principle, which excludes the definiteness of momentum (mv) and position (x), especially of particles of small mass (electron and protons), since

$$\Delta x \cdot \Delta v \gtrsim \frac{h}{m} \qquad (20)$$

where Δx is the uncertainty of position, and Δv the indefinitness of velocity. The principle of uncertainty is pertinent to the present analysis, since living matter depends on particles of subatomic dimensions, which must interact according to the laws of quantum mechanics.

In conclusion, a triad of biological similarity principles was deduced from three universal constants pertaining to gravitational fields, to the theory of electrodynamics, and to quantum mechanics. Each similarity is based on two postulates: the first is common to all three, i.e., the constancy of *body density*, while the second is different in each instance.

The spacetime relationship in each case were as follows: in the *gravitational* similarity $\tau = \lambda^{1/2}$, in the *electrodynamic* $\tau = \lambda$, and in the *quantum similarity* $\tau = \lambda^2$. These three different types of biological clocks, defined by their length-time relationships, have been recently discussed (Günther & Morgado, 1985).

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REFERENCES

CHANCE, B. (1977). Electron transfer: pathways, mechanisms, and controls. *Ann. Rev. Biochem. 46:* 967-980.

ECONOMOS, A.C. (1982). On the origin of biological similarity. *J. Theor. Biol. 94:* 25-60.

ELSASSER, W.H. (1966). *Atom and Organism. New Approach to Theoretical Biology.* Princeton, Princeton University Press.

FLOREY, E. (1966). *An Introduction to General and Comparative Animal Physiology.* Philadelphia, Saunders, p. 49.

FREEDMAN, D.A.; VAN NIEUWENHUIZEN, P. (1985). The hidden dimensions of space-time. *Scient. Amer. 252:* (3), 74-81.

GUNTHER, B. (1975a). On theories of biological similarity. *Fortschr. exper. theor. Biophys. 19:* 1-111.

GUNTHER, B. (1975b). Dimensional analysis and theory of biological similarity. *Physiol. Rev. 55:* 659-699.

GUNTHER, B. (1983). Invarianza de la forma cilíndrica en biología y anisotropía del espacio. *Arch. Biol. Med. Exp. 16:* R118. (Abstract).

GUNTHER, B.; GUERRA, E. (1955). Biological similarities. *Acta Physiol. Latinoamer. 5:* 169-186.

GUNTHER, B.; MORGADO, E. (1982). Theory of biological similarity revisited. *J. theor. Biol. 96:* 543-559.

GUNTHER, B.; MORGADO, E. (1984). Transport similarity: dimensional analysis of diffusion at cellular level. *J. theor. Biol. 108:* 437-449.

GUNTHER, B.; MORGADO, E. (1985). Intrinsic times in biology. *Acta Physiol. pharmacol. latinoamer. 35:* 349-360.

HEUSNER, A.A. (1983). Body size, energy metabolism, and the lungs. *J. Appl. Physiol. 54:* 867-873.

HEUSNER, A.A. (1984). Biological similitude: statistical and functional relationships in comparative physiology. *Am. J. Physiol. 246:* R839-R845.

HIMMS-HAGEN, J. (1976). Cellular thermogenesis. *Ann. Rev. Physiol. 38:* 315-351.

HINKLE, P.C., McCARTY, R.E. (1978). How cells make ATP. *Scient. Amer. 238:* 104-123.

HUND, F. (1961). *Theorie des Aufbaues der Materie.* Stuttgart, Teubner (pp. 4-6).

HUXLEY, J.S. (1932). *Problems of Relative Growth.* London, Methuen.

LAIDLER, K.J. (1978). *Physical Chemistry with Biological Applications.* Menlo Park, Benjamin.

LAMBERT & TEISSIER, G. (1927). Théorie de la similitude biologique. *Ann. physiol. Physiochim. biol. 3:* 212-246.

McMAHON, T.A.; BONNER, J.T. (1983). *On Size and Life.* New York, Scientific American Library.

MITCHELL, P. (1977). Vectorial chemiosmotic processes. *Ann. Rev. Biochem. 46:* 996-1005.

MOORE, W.J. (1962). *Physical Chemistry.* Englewood Cliffs, Prentice.

MOROWITZ, H.J. (1968). *Energy Flow in Biology.* New York, Academic Press (p. 47).

NADEL, E.R. (1985). Physiological adaptations to aerobic training. *Am. Scient. 73:* 334-343.

PETERS, R.H. (1983). *The Ecological Implications of Body Size.* Cambridge, Cambridge University Press.

POPPER, K.R. (1980). *The Logic of Scientific Discovery.* London, Hutchinson.

VON BAEYER, H.C. (1985). Bartlett's familiar equation. *The Sciences,* March/April, (pp. 2-3).

WEAST, R.C., edit. (1983). *Handbook of Chemistry and Physics* (64 Ed.). Boca Raton, Fla., CRC Press.