

Hierarchic Theory of Complex Systems

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Materials, presented in this original article are based on following publications:

[1]. A. Kaivarainen. Book: Hierarchic Concept of Matter and Field. Water, biosystems and elementary particles. New York, NY, 1995 and 2nd edition of this book.

(see URL: <http://kftt.karelia.ru/~alexk>).

[2]. A. Kaivarainen. New Hierarchic Theory of Matter General for Liquids and Solids:

dynamics, thermodynamics and mesoscopic structure of water and ice

(see URL: <http://kftt.karelia.ru/~alexk>).

[3]. A. Kaivarainen. Hierarchic Concept of Condensed Matter and its Interaction with Light: New Theories of Light Refraction, Brillouin Scattering and Mössbauer effect

(see URL: <http://kftt.karelia.ru/~alexk>).

[4]. A. Kaivarainen. Hierarchic Concept of Condensed Matter : Interrelation between mesoscopic and macroscopic properties (see URL: <http://kftt.karelia.ru/~alexk>).

Computerized verification of described here new theories are presented, using special computer program, based on Hierarchic Concept of Condensed Matter (copyright, 1997, A. Kaivarainen).

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Summary to Part I of book:
Hierarchic Theory of Matter and Field
(by: A. Kaivarainen)

A basically new hierarchic quantitative theory, general for solids and liquids, has been developed.

It is assumed, that anharmonic oscillations of particles in any condensed matter lead to emergence of three-dimensional (3D) superposition of standing de Broglie waves of molecules, electromagnetic and acoustic waves. Consequently, any condensed matter could be considered as a gas of 3D standing waves of corresponding nature. Our approach unifies and develops strongly the Einstein's and Debye's models.

Collective excitations, like 3D standing de Broglie waves of molecules, representing at certain conditions the molecular Bose condensate, were analyzed, as a background of hierarchic model of condensed matter.

The most probable de Broglie wave (wave B) length is determined by the ratio of Plank constant to the most probable impulse of molecules, or by ratio of its most probable phase velocity to frequency. The waves B are related to molecular translations (tr) and librations (lb).

As the quantum dynamics of condensed matter does not follow in general case the classical Maxwell-Boltzmann distribution, the real most probable de Broglie wave length can exceed the classical thermal de Broglie wave length and the distance between centers of molecules many times.

This makes possible the atomic and molecular Bose condensation in solids and liquids at temperatures, below boiling point. It is one of the most important results of new theory, which we have confirmed by computer simulations on examples of water and ice.

Four strongly interrelated new types of quasiparticles (collective excitations) were introduced in our hierarchic model:

1. *Effectons (tr and lb)*, existing in "acoustic" (a) and "optic" (b) states represent the coherent clusters in general case;
2. *Convertons*, corresponding to interconversions between *tr* and *lb* types of the effectons (flickering clusters);
3. *Transitons* are the intermediate [$a \rightleftharpoons b$] transition states of the *tr* and *lb* effectons;
4. *Deformons* are the 3D superposition of IR electromagnetic or acoustic waves, activated by *transitons* and *convertons*.

Primary effectons (tr and lb) are formed by 3D superposition of the **most probable standing de Broglie waves** of the oscillating ions, atoms or molecules. The volume of effectons (tr and lb) may contain from less than one, to tens and even thousands of molecules. The first condition means validity of **classical** approximation in description of the subsystems of the effectons. The second one points to **quantum properties of coherent clusters due to molecular Bose condensation**.

The liquids are semiclassical systems because their primary (tr) effectons contain less than one molecule and primary (lb) effectons - more than one molecule. *The solids are quantum systems totally because both kind of their primary effectons (tr and lb) are molecular Bose condensates.*
These consequences of our theory are confirmed by computer calculations.

The 1st order [*gas* → *liquid*] transition is accompanied by strong decreasing of rotational (librational) degrees of freedom due to emergence of primary (lb) effectons and [*liquid* → *solid*] transition - by decreasing of translational degrees of freedom due to Bose-condensation of primary

(tr) effectons.

In the general case the effecton can be approximated by parallelepiped with edges corresponding to de Broglie waves length in three selected directions (1, 2, 3), related to the symmetry of the molecular dynamics. In the case of isotropic molecular motion the effectons' shape may be approximated by cube.

The edge-length of primary effectons (tr and lb) can be considered as the "parameter of order".

The in-phase oscillations of molecules in the effectons correspond to the effecton's (a) - *acoustic* state and the counterphase oscillations correspond to their (b) - *optic* state. States (a) and (b) of the effectons differ in potential energy only, however, their kinetic energies, impulses and spatial dimensions - are the same. The *b*-state of the effectons has a common feature with **Frölich's polar mode**.

The ($a \rightarrow b$) or ($b \rightarrow a$) transition states of the primary effectons (tr and lb), defined as primary transitons, are accompanied by a change in molecule polarizability and dipole moment without density fluctuations. At this case they lead to absorption or radiation of IR photons, respectively.

Superposition (interception) of three internal standing IR photons of different directions (1,2,3) - forms primary electromagnetic deformons (tr and lb).

On the other hand, the [$lb \rightleftharpoons tr$] *convertons* and *secondary transitons* are accompanied by the density fluctuations, leading to *absorption or radiation of phonons*.

Superposition resulting from interception of standing phonons in three directions (1,2,3), forms **secondary acoustic deformons (tr and lb)**.

Correlated collective excitations of primary and secondary effectons and deformons (tr and lb), localized in the volume of primary *tr* and *lb* *electromagnetic* deformons, lead to origination of **macroeffectons, macrotransitons** and **macrodeformons** (tr and lb respectively).

Correlated simultaneous excitations of tr and lb macroeffectons in the volume of superimposed *tr* and *lb* *electromagnetic* deformons lead to origination of **supereffectons**.

In turn, the coherent excitation of *both: tr and lb macrodeformons and macroconvertons* in the same volume means creation of **superdeformons**. Superdeformons are the biggest (cavitational) fluctuations, leading to microbubbles in liquids and to local defects in solids.

Total number of quasiparticles of condensed matter equal to $4! = 24$, reflects all of possible combinations of the four basic ones [1-4], introduced above. This set of collective excitations in the form of "gas" of 3D standing waves of three types: de Broglie, acoustic and electromagnetic - is shown to be able to explain virtually all the properties of all condensed matter.

The important positive feature of our hierarchic model of matter is that it does not need the semi-empiric intermolecular potentials for calculations, which are unavoidable in existing theories of many body systems. The potential energy of intermolecular interaction is involved indirectly in dimensions and stability of quasiparticles, introduced in our model.

The main formulae of theory are the same for liquids and solids and include following experimental parameters, which take into account their different properties:

[1]- **Positions of (tr) and (lb) bands in oscillatory spectra;**

[2]- **Sound velocity;**

[3]- **Density;**

[4]- **Refraction index (extrapolated to the infinitive wave length of photon).**

The knowledge of these four basic parameters at the same temperature and pressure makes

it possible using our computer program, to evaluate more than 150 important characteristics of any condensed matter. Among them are such as: total internal energy, kinetic and potential energies, heat-capacity and thermal conductivity, surface tension, vapor pressure, viscosity, coefficient of self-diffusion, osmotic pressure, solvent activity, etc. Most of calculated parameters are hidden, i.e. inaccessible to direct experimental measurement.

The new interpretation and evaluation of Brillouin light scattering and Mössbauer effect parameters may also be done on the basis of hierarchic theory. Mesoscopic scenarios of turbulence, superconductivity and superfluidity are elaborated.

Some original aspects of water in organization and large-scale dynamics of biosystems - such as proteins, DNA, microtubules, membranes and regulative role of water in cytoplasm, cancer development, quantum neurodynamics, etc. have been analyzed in the framework of Hierarchic theory.

Computerized verification of our Hierarchic concept of matter on examples of water and ice is performed, using special computer program: Comprehensive Analyzer of Matter Properties (CAMP, copyright, 1997, Kaivarainen). The new opto-acoustical device (CAMP), based on this program, with possibilities much wider, than that of IR, Raman and Brillouin spectrometers, has been proposed (see URL: <http://www.karelia.ru/~alexk>).

This is the first theory able to predict all known experimental temperature anomalies for water and ice. The conformity between theory and experiment is very good even without any adjustable parameters.

The hierarchic concept creates a bridge between micro- and macro- phenomena, dynamics and thermodynamics, liquids and solids in terms of quantum physics.

Domain granular structure is pertinent to solid bodies, liquid crystals, and polymers of artificial and biological origin. In liquids, as is seen from the X-ray data, the local order is also kept like in solid bodies. Just like in the case of solids, local order in liquids can be caused by the most probable - primary effectons (see Introduction to [1] and [2]), but smaller in size.

In water, the relatively stable clusters of molecules are revealed by the quasielastic neutron scattering method. The diameter of these clusters are (20-30) Å and the lifetime is of the order of 10^{-10} s (Gordeyev and Khaidarov, 1983). These parameters are close to those we have calculated for librational water effectons (Fig. 7a of [1] or Fig4a of [2]).

A coherent-inelastic neutron scattering, performed on liquid D_2O at room temperature revealed collective high-frequency sound mode. Observed collective excitation has a solid-like character with dimension around 20 Å, resembling water clusters with saturated hydrogen bonds. The observed sound velocity in these clusters is about 3300 m/s, i.e. close to velocity of sound in ice and much bigger than that in liquid water: 1500 m/s (Teixeira et al., 1985). Such data confirm the existence of primary librational effectons as molecular Bose condensate, leading from our hierarchic theory.

Among the earlier theoretical models of water the model of "flickering clusters" proposed by Frank and Wen (1957) is closer to our model than others. The "flickering" of a cluster consisting of water molecules is expressed by the fact that it dissociates and associates with a short period ($10^{-10} - 10^{-11}$) s. Near the non-polar molecules this period grows up (Frank and Wen, 1957, Frank and Evans, 1945) and "icebergs" appear. The formation of hydrogen bonds in water is treated as a cooperative process. Our [lb/tr] convertions, i.e. interconversions between primary lb and tr effectons, reflect the properties of flickering clusters better than other quasiparticles of hierarchic model.

Proceeding from the flickering cluster model, Nemethy and Scheraga (1962), using the methods of statistical thermodynamics, calculated a number of parameters for water (free energy, internal energy, entropy) and their temperature dependences, which agree with the experimental data in the limits of 3%. However, calculations of heat capacity were less successful. The quantity of water molecules decreases from 91 at $0^{\circ}C$ to 25 at $70^{\circ}C$ (Nemethy and Scheraga, 1962). It is in rather good agreement with our results (Fig. 7a of [1] or Fig.4a of [2]) on the change of the number of water molecules in a primary librational effecton with temperature.

The stability of primary effectons (clusters, domains), forming the condensed media, is determined by the coherence of heat motions, the equality of the most probable 3D standing waves B of atoms (molecules), increasing distant Van der Waals interaction in the volume of the effectons.

It could be possible that molecules, atoms, or ions of *different molecular masses* belong to the same effectons. The equality of wave B lengths for such different particles, forming the effectons:

$$\lambda_1 = \frac{h}{m_1 v_1} = \lambda_2 = \frac{h}{m_2 v_2} = \dots = \lambda_i = \frac{h}{m_i v_i} \quad 1$$

means that differences in masses are compensated by differences in the group velocities of these particles so that their most probable impulses are equal:

$$P_i = m_1 v_1 = m_2 v_2 = \dots = m_i v_i \quad 2$$

The domains or the crystallites in solid bodies, which could be considered as a primary effectons, can contain a big number of elementary cells. Transitions between the different types of elementary cells (second order phase transitions) means cooperative redistribution in the positions and dynamics of atoms, leading to origination of new primary effectons. In accordance with our model, the second order phase transitions are related sometimes also with emergency of conditions for primary effectons polymerization or distant association in coherent superclusters, and concomitant shifting of their ($a \leftrightarrow b$) equilibrium to the left.

The mesoscopic theory could be used to describe a wide range of physico-chemical and

biological phenomena.

1. Protein domain mesoscopic organization

If the geometry of cavities of protein surface are complementary to the geometry of water librational effectons, then the latter are stabilized. In the opposite case, the water effectons in cavities are either not realized, or unstable. In that case, the probability of the water cluster dissociation in the cavity, related to $[lb \rightarrow tr]$ conversion, increases. The evolution of biological macromolecules could have gone in such a way that they "learned" to use the cooperative properties of water clusters and their dissociation for regulation of their large-scale dynamics and signal transmission. Calculated frequency of $[lb/tr]$ convertions $(10^6 - 10^7) c^{-1}$ coincide with frequency of protein cavities large-scale pulsations, accompanied by domains relative fluctuations.

All sufficiently large globular proteins consist of domains whose dimensions under normal conditions vary in the narrow limits: $(10-20)\text{\AA}$ (Käiväräinen, 1985). This value is close to dimensions of librational water effecton (Fig. 7a of [1] or Fig. 4a of [2]) that confirms the important role of water in evolution of biopolymers. We may predict that the lower is the physiological temperature of given organism the larger are the interdomain cavities and domains of its proteins. It is known that the water in pours or cavities with diameter less than 50\AA freeze out at very low temperatures (about $-60^{\circ}C$) and its viscosity is high (Martini et al., 1983). For the other hand, our calculations shows (Fig.17b of [1]), that freezing in normal conditions should be accompanied by increasing the linear size of primary librational effectons just till 50\AA .

As far the condition for librational effectons growth in narrow pours is absent, the formation of sufficiently big primary translational effectons is also violated. As a result of that, condition (6.6 of [1]) for [liquid \rightarrow solid] phase transition occurs in such cavities at much lower temperature than in bulk water.

If the sound velocity in proteins and the positions of maxima in their oscillatory spectra, which characterize the librations of atoms *are known*, then the most probable wave B length of aminoacids groups and atoms, forming the domains $(\lambda_1, \lambda_2, \lambda_3)$ can be estimated. If the volume of an effecton is approximated by a sphere:

$$V_{ef} = \frac{9(\lambda_1\lambda_2\lambda_3)}{4\pi} = \frac{4}{3}\pi r^3, \quad 3$$

then its radius:

$$r = \left[\frac{27(\lambda_1\lambda_2\lambda_3)}{16\pi^2} \right]^{1/3} = 0.555\lambda_{res}, \quad 4$$

where: $\lambda_{res} = (\lambda_1\lambda_2\lambda_3)^{1/3}$, and the diameter: $d = 2r = 1.11\lambda_{res}$.

The collective properties of protein's primary effectons presented by α -structures, β -sheets and whole domains can determine the cooperative properties of biopolymers.

Heat oscillations of atoms and atom groups, forming the protein effectons must be coherent, like in any other condensed matter.

Such ideas agree with the Fröhlich hypothesis about the possibility of Bose-condensation in biological systems (Fröhlich, 1975).

The notion of "knots" in proteins was introduced by R.Lumry and B. Gregory (1986). The knots are regions, containing very slow $H \leftrightarrow D$ exchangeable protons in composition of compact cooperative structures.

The dimensions of knots are less than dimensions of domains.

It looks that knots could represent a translational effectons, as far their $(a \leftrightarrow b)_{tr}$ transitions, in contrast to $(a \leftrightarrow b)_{lb}$ ones of librational effectons do not accompanied by reorganization of hydrogen bonds. Consequently, the possibility for $H \leftrightarrow D$ exchange in knots is more limited.

The molecular dynamic computer simulations of proteins reveal, indeed, a highly correlated collective motion of groups of atoms, inhomogeneously distributed in proteins structure

(Swaminathan et al., 1982).

It looks that the traditional theory of protein tertiary native structure self-organization from primary one (Cantor and Shimmel, 1980) is not totally successful as far it does not take into account quantum process, related to formation the protein effectons as 3D standing waves B of protein atoms.

The change of interdomain interactions, the stabilization of its small-scale dynamics of proteins by ligands leading to the increase of λ_{res} (see eq.4) as a measure of cooperativeness, can provide the long- distance signal transmission in macromolecules and allosteric effects in oligomeric proteins. The $[lb/tr]$ convertions, i.e. dissociation of librational water effectons in the protein cavities is the key phenomenon in the above mentioned processes.

The described events interrelate the small-scale dynamics of atoms and the large-scale dynamics of domains and subunits to the dynamics of water clusters in protein interdomain cavities, dependent in turn on the properties of bulk water (Käiväräinen, 1985,1989b, Käiväräinen et al., 1993).

Our mesoscopic mechanism of signal transmission in proteins is alternative to *Davidov's soliton* mechanism. The latter is good only for highly ordered systems with small dissipation..

2. Quantum background of lipid domain organization in biomembranes

The importance of lipid domains in membranes for their functioning is known, but the physical background for domains origination remains unclear.

Our mesoscopic theory was used for computer simulations of lipid domain dimensions in model membranes. The known data on the position of IR bands, corresponding to asymmetric $[N - (CH_3)_3]$ stretching in holine for *trans* ($920cm^{-1}$) and *gauche* (900 and $860cm^{-1}$) conformations where taken for calculations. The knowledge of sound velocity and its changes as a result of phase transitions: $(1.97 \cdot 10^5 cm/s)^{38^\circ} \rightarrow (1.82 \cdot 10^5 cm/s)^{42^\circ}$ is also necessary for calculations of the domain dimensions, using eq.(2.59 of [1]). The results of calculations are presented on Fig.1. In our approach the lipid domains in biomembranes and their artificial models are considered as quasiparticles-primary librational -*effectons*, formed by 3D superposition of the most probable de Broglie waves ($\lambda = h/p$)_{1,2,3}, determined by coherent thermal oscillations of lipid molecules. The lesser the value of the most probable impulse ($p = mv$)_{1,2,3} of lipid, the bigger is corresponding $\lambda_{1,2,3}$ and the effecton volume (eq.3).

According to our calculations, a rise in temperature from 0 to 70^0 leads to a decrease in the most probable λ from 88 to 25 Å. In the phase transition region ($38 - 42^0$) λ decreases from 46 to 37 Å (Fig.1). The former process corresponds to change of the lipid domains volume from $(50$ to $2) \cdot 10^4 \text{Å}^3$ and the latter one from $(7.5$ to $5) \cdot 10^4 \text{Å}^3$, respectively (Fig. 2). The values of these changes coincide with available experimental data. Like the calculations we made earlier for ice and water, these results provide further support of our theoretical approach.

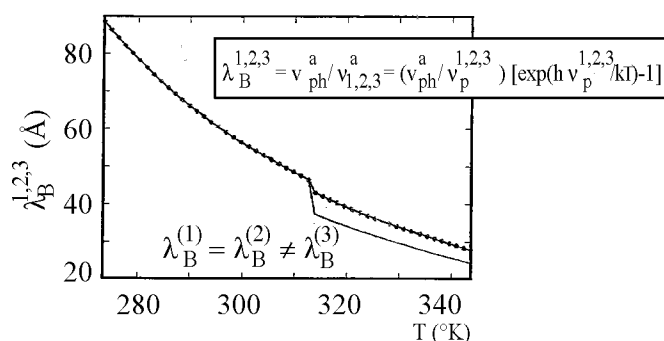


Fig. 1. Temperature dependencies of the most probable de Broglie wave length of lipids ($\lambda_1, \lambda_2, \lambda_3$), related to their *stretching*. The values of $\lambda_1, \lambda_2, \lambda_3$ determine the spatial

dimensions of lipid domains. Domains are considered as quasiparticles (primary effectons), formed by 3D superposition of the most probable de Broglie waves of lipids.

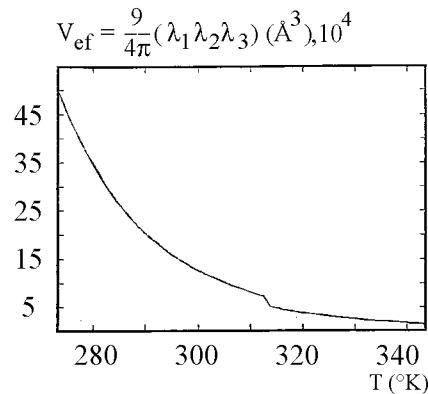


Fig. 2. Temperature dependence of the volume of lipid domains: $V = \frac{9}{4\pi} \lambda_1 \lambda_2 \lambda_3$. The volume is determined by 3D superposition of the most probable de Broglie waves of lipid molecules or their fragments. Phase transition occurs in the region of 312K (39^o) and accompanies by *trance* - *gauche* change of lipid conformation.

As discussed in Chapter 17 of [1] and my paper: **Hierarchic Model of Consciousness in URL: [http://kftt.karelia.ru/~alexk/papers] the mesoscopic organization of biomembranes, related to their dynamics and that of microtubules system - may play an important role in elementary act of consciousness.**

3. Mesoscopic approach to theory of solutions

The action of the dissolved molecules can lead to the shift of ($a \leftrightarrow b$) equilibrium to the right or to the left for effectons (tr and lb) of solvent. In the former case the lifetime of unstable state for primary effectons increases, and in the latter case the stabilization of molecular associates (clusters) takes place.

The same is true for convertions equilibrium: [$lb \leftrightarrow tr$], reflecting [association \leftrightarrow dissociation] of water clusters (primary librational effectons).

The effects of stabilization of clusters can be reinforced at such concentration of dissolved molecules, when the mean distances between them (r) coincide with one of the primary effectons ribs ($\lambda_1, \lambda_2, \lambda_3$) or their integer number:

$$r = \frac{11.8}{(C_M)^{1/3}} (\text{\AA}) \quad 5$$

where C_M is the molar concentration.

So the concentration dependence of the stabilizing action brought by the dissolved substance upon the solvent can be non-monotonic and periodic. Such data have been published indeed (Tereshkevitch et al., 1974).

If the wave B length of the dissolved molecule or atoms exceeds the dimensions of primary effectons, then it must increase the degree of liquid association. In the opposite case the ordering of liquid structure decreases. To prove the aforementioned, it should be noted that the *structure-forming* ions, with a positive hydration (Li^+, Na^+, F^-), as a rule, have a lesser mass and lesser impulse (i.e. a larger value of $\lambda_B = h/mv_{gr}$) than those with a negative hydration (Rb^+, Cs^+, Br^-, I^-) with the same charges.

In accordance with such ideas, nonpolar atoms, minimally distorting the properties of a pure

liquid, e.g. He, Ne, Ar, have a maximal structuring action, stabilizing *a*-states of primary librational effectons.

Our Hierarchic model may be useful for elaboration a general theory of solutions.

In host-guest systems a following situations are possible:

1) guest molecules stabilize (a)-states of host effectons (tr and lb) and increases their dimensions. The ($a \leftrightarrow b$) equilibrium of the effectons and [$lb \leftrightarrow tr$] equilibrium of convertions becomes shifted leftward decreasing potential energy of a system, corresponding to its stabilization effect;

2) guest molecules destabilize (a)-states of host effectons. The ($a \leftrightarrow b$) and [$lb \leftrightarrow tr$] equilibriums of the primary effectons and convertions correspondingly are shifted rightward, inducing general destabilization effect of the system;

3) guest and host molecules form separate individual effectons (mesophase) without separation in two macrophases;

With the increasing concentration of guest in solution of two molecular liquids (for example, water - ethanol) the roles of guest and host may change.

It was shown that conductivity of aqueous solutions of NaCl, containing ions: Na^+ , Cl^- , H_3O^+ and OH^- show to vary in a different linear fashion over two ranges of temperature: $273 \leq T \leq 323K$ and $323 \leq T \leq 360K$. The change in slope of the plot shows transition in the character of water-ions interaction near 323 K (Roberts et al.1994). In the same work was revealed, that the above aqueous systems exhibited some "memory" of the temperature effects after changing the temperature from low to high and then from high to low values. Such memory could mean a slow relaxation process, accompanied by redistribution between populations of different excitations and their equilibrium constants, i.e. the new type of self-organization in solution.

In accordance with our theory, all reorganizations of liquid's properties must be accompanied by correlated changes in the following parameters of solutions:

- 1) sound velocity;**
- 2) positions of translational and librational bands in oscillatory spectra;**
- 3) density;**
- 4) refraction index;**
- 5) share and bulk viscosities;**
- 6) coefficient of self-diffusion**
- 7) light scattering;**
- 8) heat capacity and thermal conductivity;**
- 9) vapor pressure and surface tension.**

There are also a lot of other parameters and properties that should change in solutions as a result of solute-solvent interaction. It could be revealed by computer simulations, using software, elaborated.

The first four of the above listed parameters are present in the main formulas of Hierarchic theory and must be determined under similar conditions (temperature, pressure, etc.).

There are some experimental data which are in general agreement with the consequences of our theory, pointing to interrelation between the above listed parameters. The changes of sound velocity in different water - ethanol mixtures as well as that of light and neutron scattering were studied in detail by D'Arrigo and Paparelli (1988a, 1988b, 1989), Benassi et al. (1988), D'Arrigo and Teixeira (1990).

Correlations between density, viscosity, the refractive index, and the dielectric constant of mixed molecular liquids at different temperatures were investigated by D'Aprano's group in Rome (D'Aprano et al., 1989, 1990a, 1990b).

The interaction of a solute (guest) molecule with *librational* solvent effectons can be subdivided into *two cases*: when the rotational correlation time of a guest molecule (τ_M^{rot}) is *less* (a) and *more* (b) than the rotational correlation time of *librational effectons* (τ_{ef}^{lb}):

$$a) \quad \tau_M^{\text{rot}} < \tau_{ef}^{\text{lb}} \quad 6$$

and

$$b) \quad \tau_M^{\text{rot}} > \tau_{ef}^{\text{lb}} \quad 7$$

In accordance with the Stokes-Einstein formula the corresponding rotational correlation times:

$$\tau_M^{\text{rot}} = \frac{V_M}{k} \frac{\eta}{T} \quad \text{and} \quad \tau_{ef}^{\text{lb}} = \frac{V_{ef}^{\text{lb}}}{k} \cdot \frac{\eta}{T} \quad 8$$

where: η and T are the share viscosity and absolute temperature of the solvent;

τ_M^{rot} and τ_{ef}^{lb} are dependent on the effective volumes of a guest molecule (V_M) and the volume of primary librational effecton:

$$V_{ef}^{\text{lb}} = n_M^{\text{lb}}(V_0/N_0) = \frac{9}{4}\pi(\lambda_1\lambda_2\lambda_3) \quad 9$$

$\lambda_{1,2,3}$ are most probable wave B length in 3 selected directions; n_M^{lb} - number of molecules in a librational primary effecton, depending on temperature: in water it decreases from 280 till to 3 in the temperature interval 0 – 100⁰C (Fig. 7a of [1] or Fig. 4a of [2]).

When the condition (6) is realized, small and neutral guest molecules affect presumably only the translational effectons.

In the second case (7) guest macromolecules can change the properties of both types of effectons: translational and librational and shift the equilibrium [$lb \leftrightarrow tr$] of convertions to the left, stimulating the cluster-formation.

In accordance with our model, **hydrophilic interaction** is related to the shift of the ($a \leftrightarrow b$) equilibrium of *translational* effectons to the *left*. As far the potential energy of the (a) state (V_a) is less than that in the (b) state (V_b), it means that such solvent-solute (host- guest) interaction will decrease the potential and free energy of the solution. Hydrophilic interaction does not need the realization of condition (7).

Hydrophobic interaction is related to the shift of the ($a \leftrightarrow b$)_{lb} equilibrium of *librational effectons* to the *right*. Such a shift results in the increased potential energy of the system. The dimensions of coherent water clusters representing librational effectons under condition (7) may even increase. However, the decrease in of entropy (ΔS) in this case is more than that in enthalpy (ΔH) and, consequently, free energy will increase: $\Delta G = \Delta H - T\Delta S > 0$. This is a source of hydrophobic interaction, leading to aggregation of hydrophobic particles.

Clusterphilic interaction was introduced by the author in 1980 already (Käiväräinen, 1980, 1985) to describe the cooperative water cluster interaction with nonpolar protein cavities. This idea has got support in the framework of our hierarchic concept. **Clusterphilic interaction is related to the leftward shift of ($a \leftrightarrow b$)_{lb} equilibrium of primary librational effectons under condition (7), similar shift of the equilibrium of [$lb \leftrightarrow tr$] of convertions and increasing of lb effectons dimensions due to water immobilization (eqs.. 1 and 9)**

The latter effect is a result of decreasing of the rotational correlation time of librational effectons and decreasing of the most probable impulses of water molecules (2), related to librations under the effect of guest particles. **Clusterphilic interactions can be subdivided into:**

1. Intramolecular -when water cluster is placed in the "open" states of big interdomain or intersubunit cavities and

2. Intermolecular clusterphilic interaction. *Intermolecular clusterphilic interactions* can be induced by very different sufficiently big macromolecules.

Clusterphilic interactions can play an important role in the self-organization of biosystems, especially multiglobular allosteric enzymes, microtubules and the actin filaments. **Cooperative**

properties of the cytoplasm, formation of thixotropic structures, signal transmission in biopolymers, membranes and distant interactions between different macromolecules can be mediated by both types of clusterphilic interactions.

From (4.4 of [1, 2]) the contributions of primary translational and librational effectons to total internal energy are:

$$U_{ef}^{tr,lb} = \frac{V_0}{Z} [n_{ef}(P_{ef}^a E_{ef}^a + P_{ef}^b E_{ef}^b)]_{tr,lb} \quad 10$$

The contributions of this type of effectons to total kinetic energy (see 4.33) are:

$$T_{ef}^{tr,lb} = \frac{V_0}{Z} \left[n_{ef} \frac{\sum_1^3 (E^a)_{1,2,3}^2}{2m(V_{ph}^a)^2} (P_{ef}^a + P_{ef}^b) \right]_{tr,lb} \quad 10a$$

Subtracting (10a) from (10), we get the potential energy of primary effectons:

$$V_{ef} = V_{tr} + V_{lb} = (U_{ef} - T_{ef})_{tr} + (U_{ef} - T_{ef})_{lb} \quad 11$$

Clusterphilic interaction and possible self-organization is promoted mainly by *decreasing* of V_{lb} in the presence of macromolecules.

Hydrophilic interaction, in accordance with our model, is a result of V_{tr} . decreasing.

On the other hand, *hydrophobic interaction* is a consequence of V_{lb} and V_{tr} increasing in the presence of guest molecules.

Clusterphilic interaction has been revealed, for example, in dependencies of freezing temperature (T_f) for buffer solutions of polyethyleneglycol (PEG) on its molecular mass and concentration (Käiväräinen, 1985). The anomalous increasing of T_f in the presence of PEG with molecular mass more than 2000 D and at concentration less than 30mg/ml, pointing to increasing water activity, were registered by the cryoscopy method. It may be explained as a result of clusterphilic interaction increasing, when the fraction of ice-like water structures with saturated hydrogen bonds, presented by primary librational effectons, increases. Big macromolecules and small ions should have the opposite: positive and negative effects on the stability and volume of primary librational effectons.

Macromolecules or polymers with molecular mass less than 2000 do not satisfy the condition (7) and can not stimulate the growth of librational effectons. On the other hand, a considerable increase in the concentrations of even big polymers, when the average distance between them (eq.5) comes to be less than the dimensions of a librational water effecton, perturbs clusterphilic interactions and decreases freezing temperature, reducing water activity (Käiväräinen, 1985, Fig.82).

In general case each guest macromolecule has two opposite effects on clusterphilic interactions. The equilibrium between these tendencies depends on the temperature, viscosity, concentration of a guest macromolecule, its dynamics and water activity.

When solute particles are sufficiently small they can associate due to distant Van der Waals interaction, forming coherent primary effectons, when [solute-solvent] interaction is more preferable than [solvent-solvent] and the conditions (1 and 2) are fulfilled.

Important confirmation of this consequence of mesoscopic theory of complex systems is the observation of compact clusters of ions even in dilute salt solutions. For example, the extended x-ray absorption fine structure data showed that the average distance between Zn^{2+} and Br^- is 2.37 Å in 0.089M $ZnBr_2$ aqueous solutions and 2.30 Å in 0.05 M solutions (Lagarde et al., 1980).

These values are very close to the inter ionic distance observed in the crystalline state (2.40Å).

The same conclusions was reached for $NiBr_2$ ethyl acetate solutions (Sadoc et al., 1981) and aqueous $CuBr_2$ solutions (Fontaine et al., 1978). The average distance between ions for the case of monotonic spatial distribution (see eq.5) are much bigger than in ionic clusters under experimental conditions.

Our theory of solutions consider formation of crystallites (inorganic ionic clusters), as a solute coherent primary effectons self-organization. It is more favorable process, than

separate ion-water interactions.

For quantitative application of hierarchic theory to the description of the processes in different solutions, using our special software, it is necessary to have four experimental parameters, obtained under the same conditions (temperature and pressure):

- density,
- sound velocity,
- positions of translational and librational bands in oscillatory spectra,
- refraction index.

The Combined analyzer of matter properties (CAMP), proposed by us (see URL: <http://kftt.karelia.ru/~alexk>), could be the main tool for such a measurements and study of complicated properties of solutions and colloid systems.

The multi-fractional nature and properties of interfacial water, leading from hierarchic theory

We can present here a classification and description of four interfacial water fraction properties, based on our hierarchic model:

1. The first fraction - primary hydration shell with maximum energy of interaction with surface. The structure and dynamics of this 1st fraction can differ strongly from those of bulk water. Its thickness: (3-10 Å) corresponds to 1-3 solvent molecule;

2. The second fraction - vicinal water (VW) is formed by elongated primary lb effectons with saturated hydrogen bonds. It is a result of lb effecton adsorption on the primary hydration shell from the bulk volume. The thickness of this fraction of interfacial water: (30-75 Å) corresponds to 10-25 molecules and is dependent on temperature, dimensions of colloid particles and their surface mobility. VW can exist in rigid pores of corresponding dimensions;

3. The third fraction of interfacial water - the surface-stimulated Bose-condensate (SSBC), represented by 3D network of primary lb effectons has a thickness of (50-300 Å). It is a next hierarchical level of interfacial water self-organization on the surface of second fraction (VW). The time of gradual formation of this 3D net of linked to each other coherent clusters (strings of polyeffectons), is much longer than that of VW and it is more sensitive to temperature and other perturbations. The second and third fractions of interfacial water can play an important role in biological cells activity;

4. The biggest and most fragile forth fraction of interfacial water is a result of slow orchestration of bulk primary effectons in the volume of primary (electromagnetic) lb deformons. The primary deformons appears as a result of three standing IR photons (lb) interception. Corresponding IR photons are superradiated by the enlarged lb effectons of vicinal water. The linear dimension of primary IR deformons is about half of librational IR photons, i.e. 5 microns ($5 \cdot 10^4$ Å). This "superradiation orchestrated water (SOW)" fraction easily can be destroyed not only by temperature increasing, ultrasound and Brownian movement, but even by mechanical shaking. The time of spontaneous reassembly of this fraction after destruction has an order of hours and is dependent strongly on temperature, viscosity and dimensions of colloid particles. The processes of self-organization of third (SSBC) and forth (SOW) fractions can be interrelated by feedback interaction.

Consequences and predictions of new model of interfacial solvent structure

In accordance to generally accepted and experimentally proved models of hydration of macromolecules and colloid particles, we assume that the first 2-3 layers of strongly bound water molecules, serves like intermediate shell, neutralizing or "buffering" the specific chemical properties of surface (charged, polar, nonpolar, etc.). Such strongly bound water can remain partially untouched even after strong dehydration of samples in vacuum.

This first fraction of interfacial water serves like a matrix for second fraction - vicinal water shell formation. The term '**paradoxal effect**', introduced by Drost-Hansen (1985) means that the properties of vicinal water are independent on specific chemical structure of the surface from quartz plates, mineral grains and membranes to large macromolecules (Clegg and Drost-Hansen, 1991). This can be a result of "buffering" effect of primary hydration shell.

Vicinal water (VW) is defined as a water the structure of which is modified in the volume of pores, by proximity to curved and plate interfaces and interaction with strongly 'bound' water.

For discussion of Vicinal water (VW) properties we proceed from the statement that if the rotational correlation time of hydrated macromolecule is less than that of primary librational effecton of bulk water, corresponding to condition (1.3 and 1.4), these effectons should have a tendency to "condensate" on their hydration shell. It is a condition of their "surviving" and life-time increasing, because the resulting impulse of the primary effectons is close to zero, in accordance to our model.

The decreasing of most probable lb thermal impulses of water molecules, especially in direction, normal to the surface of macromolecule or colloid particle, should lead to increasing of corresponding edges of the 1st "ground" layer of primary lb effectons as compared to the bulk ones:

$$[\lambda = h/mv_{gr}]_{lb}^{vic} > [\lambda = h/mv_{gr}]_{lb}^{bulk} \quad 20b$$

This turns the cube-like shape of effectons of the bulk water to shape of elongated parallelepiped..

Consequently, the volume of these waves B three-dimensional (3D) superposition, representing *the vicinal lb* and *tr primary* effectons - is bigger than that of bulk liquid effectons. As far the stability and life-time of these enlarged primary lb effectons are increased, it means the increasing of their concentration as well.

As far we assume in our multifractional model, that **VW** is a result of "condensation" of primary librational effectons on primary hydration shell and their elongation in direction, normal to surface, we can make some predictions, related to properties of this 2nd interfacial water fraction:

1. The thickness of VW can be about 30-75 Å, depending on properties of surface (geometry, polarity), temperature, pressure and presence the perturbing solvent structure agents;
2. This water should differ by number of physical parameters from bulk water. It can be characterized by:
 - a) lower density;
 - b) bigger heat capacity;
 - c) bigger sound velocity
 - d) bigger viscosity;
 - e) smaller dielectric relaxation frequency, etc.).

These differences should be enhanced in a course of third fraction of interfacial water formation: surface-stimulated Bose-condensate (SSBC) as far the concentration of primary librational effectons in this fraction is bigger than that in bulk water. The time, necessary for SSBC three-dimensional structure self-organization can have an order of minutes or hours, depending on temperature, geometry of surface and average distance between interacting surfaces.

From Fig.4b we can see that the linear dimension of primary librational effecton of bulk water

at 25°C is about $[\lambda]_{lb}^{bu} \sim 15 \text{ \AA}$. The lower mobility of water molecules of vicinal water is confirmed directly by almost 10-times difference of dielectric relaxation frequency ($2 \cdot 10^9 \text{ Hz}$) as respect to bulk one ($19 \cdot 10^9 \text{ Hz}$) (see Clegg and Drost-Hansen, 1991). The consequence of less mobility and most probable impulse (momentum) of water molecules should be the increasing of most probable wave B length and dimensions of primary effectons. **The enhancement of lb primary effecton edge should be more pronounced in the direction, normal to the interface surface. In turn, such elongation of coherent cluster can be resulted in increasing the intensity of librational IR photons superradiation.**

The increasing of temperature should lead to decreasing the vicinal librational effectons dimensions.

The dimensions of primary translational effectons of water is much less than of librational ones (see Fig. 4a). The contribution of translational effectons in vicinal effects is correspondingly much smaller than of librational.

Our model predicts that not only dimensions but as well concentrations of primary librational effectons should increase near rigid surfaces. The *system of vicinal 3D polyclusters* can emerge.

In accordance to our model the Drost-Hansen thermal anomalies of vicinal water behavior near 15°, 30°, 45° and 60° has the same explanation as presented in comments to Fig. 4a for bulk water. Because the dimensions, stability and concentration of vicinal librational effectons are bigger than that of bulk effectons the temperature of anomalies for these two water fraction can differ also.

As far the positions of disjoining pressure sharp maxima of water between quartz plates did not shift markedly when their separation change from 100 Å to 500 Å it points that the main contribution in temperature anomalies is related to bulk librational effectons. The same is true for viscosity measurements of water between plates with separation: 300-900 Å.

The possible explanation of Drost-Hansen temperature values stability is that the vicinal water layer (50-70Å) has the bigger dimensions of primary librational effectons edge, than that of bulk water, presumably only in the direction, normal to the surface of the interface. Such first layer of surface - stimulated Bose-condensation induces the formation of string-like librational polyeffectons, composed from elongated in the same direction bulk primary effectons and stabilized by Josephson's junctions and distant Van-der-Waals interactions. These strings can be cross-linked by short "chains" of primary lb effectons, making such 3D polyeffecton net more stable as respect to Brownian motion. We can term this fraction of interfacial water as "Surface-stimulated Bose-condensate (SSBC)". As far in such mesophase the linear dimensions of two of three edges of primary lb effectons, approximated by parallelepiped, remains the same as in the bulk water, it explains the relative stability of thermal anomalies at temperature scale. It means the similar conditions of maximum stability for primary lb effectons (see eq.20c), in composition of SSBC and calculated for bulk water.

For the other hand, the elongated structure of primary lb effectons, composing SSBC, should increase all the effects, related to intensive and coherent superradiation of lb IR photons in directions of the longest edge of the effectons (see Introduction). **This largest and most subtle fraction of interfacial water also has more orchestrated cooperative properties than the unperturbed by superradiation bulk water due to stronger distant Van-der-Waals interaction between primary lb effectons. Such a "superradiation-orchestrated water (SOW)" is even less ordered and stable than the second fraction of interfacial water: surface-stimulated Bose-condensate (SSBC).**

Its 3D structure of SSBC and SOW could be easily destroyed by mechanical perturbation or heating. The relaxation time of "regeneration" or self-organization of these water fractions can take an hours and depends on temperature and mobility of the surface.

The sharp conditions of maximum stability of librational primary effectons at certain temperatures - the integer number of molecules in the edge of lb effecton:

$$\kappa = 6, 5, 4, 3, 2 \quad (\text{see comments to Fig.4a}) \quad 20c$$

are responsible for deviations of temperature dependencies for many parameters of water from monotonic ones.

Vicinal water (VW) and surface-stimulated Bose-condensation of water near biological membranes and filaments (microtubules, actin polymers) can play an important regulation role in cells and their compartments dynamics and function. Its highly cooperative properties and thermal sensitivity near Drost-Hansen temperatures can be used effectively in complicated processes, related to cells proliferation, differentiation and migration. Changing of water activity: its increasing as a result of VW and SSBC deassembly and decreasing in a course of it 3D structure self-organization, can affect strongly the dynamic equilibrium [association \rightleftharpoons dissociation] of oligomeric proteins, their allosteric properties and osmotic processes in cells.

COMPARISON OF EXPERIMENTAL DATA WITH THEORETICAL PREDICTIONS

It will be shown below that our hierarchic model of interfacial water explains the comprehensive and convincing experimental data, available on subject.

The following experimental results, illustrating the difference between the second (VW) and third (SSBC) fractions of interfacial and bulk water will be discussed:

- 1. The lower density of vicinal water near plates and in pores ($\sim 0.970 \text{ g/cm}^3$) as compared to bulk one ($\sim 1.000 \text{ g/cm}^3$) (Etzler and Fagundus, 1983; Low, 1979; Clegg 1985);**
- 2. Different selectivity of vicinal water in pores to structure-breaking and structure-making inorganic ions;**
- 3. Volume contraction on sedimentation of particles dispersed in water (Braun et al. 1987);**
- 4. Higher heat capacity of vicinal water as compared to bulk water (Etzler 1988);**
- 5. Higher ultrasound velocity in the interfacial water;**
- 6. Higher ultrasound absorption in the interfacial water;**
- 7. Higher viscosity of interfacial water (Peshel and Adlfinger 1971) and its dependence on shearing rate;**
- 8. Sharp decreasing of the effective radius of dilute solution of polystyrene spheres, in a course of temperature increasing.**

In accordance to our model, the water molecules in composition of primary librational effectons (see Fig. 4a) are four-coordinated like in ideal ice structure with lowest density. In contrast to that, the water in the volumes of translational effectons, [lb/tr] convertions and *lb* and *tr* macroeffectons and supereffectons has the nonsaturated hydrogen bonds and a higher density. The compressibility of primary [lb] effectons should be lower and sound velocity - higher than that of bulk water. It is confirmed by results of Teixeira et. al. (1985), obtained by coherent- inelastic- neutron scattering. They point on existence in heavy water at 25 °C the solid-like collective excitations with bigger sound velocity than in bulk water. These experimental data can be considered as a direct confirmation of our primary librational effectons existence..

As far the fraction of water involved in primary librational effectons in vicinal water is much higher than in the bulk one, this explains the result [1] at the list above. The biggest decreasing of density occur in pores, containing enlarged primary librational effectons, due to stronger water molecules immobilization.

Different selectivity of vicinal water in pores of silica gel (result [2]) to structure-breaking and structure-making inorganic ions (Wiggins 1971, 1973), leading to higher concentration of the former (like K^+) as respect to latter (like Na^+) ones in pores was revealed. It is in total accordance with our model as far for penetration into the pore the ion have at first to break the ordered structure of enlarged librational effectons in the volume of pore. Such kind of Na/K selectivity can be of great importance in the passive transport of ions throw the pores of biological membranes.

Result [3] of volume contraction of suspension of 5- μm silica particles in a course of their sedimentation - is a consequence of mechanical perturbation of cooperative and unstable 3D fraction: surface - stimulated Bose condensation (SSBC), its partial 'melting' and increasing of water fraction with nonsaturated hydrogen bonds and higher density.

The available experimental data of the vicinal water thickness evaluate it as about 50-70 Å (Drost-Hansen, 1985). In totally or partly closed volumes like in silica pores the vicinal effect must be bigger than near the plain surface. This explains the maximum heat capacity of water at 25⁰ (result [4]) in silica pores with radii near 70 Å (Etzler and White, 1988).

As far the cooperative properties of 2nd and 3d fractions of interfacial water, corresponding to vicinal water and surface - stimulated Bose condensation are higher than that of bulk water, it explains the bigger heat capacity of both of these fractions.

The higher sound velocity in the VW and SSBC fractions as compared to bulk water (result [5]) is a consequence of higher concentration of primary librational effectons with low compressibility due to saturated H-bonds.

Higher absorption of ultrasound by interfacial water (result [6]) can be a consequence of dissipation processes, accompanied the destruction of water fraction, corresponding to SSBC by ultrasound.

The higher viscosity of vicinal water (result [7]) is a result of higher activation energy of librational macrodeformons excitation (ϵ_D^M)_{lb} in a more stable system of vicinal polyclustrons (see our mesoscopic theory of viscosity).

Sharp decreasing of the effective dimensions of dilute solution of polystyrene (PS) spheres (0.1%), in a course of temperature increasing (result [8]) - is a consequence of cooperative destruction (melting) of 3d fraction of interfacial water (SSBC).

The corresponding transition occur at 30-34 °C, as registered by Photon correlation spectroscopy and is accompanied by the effective Stocks radius of PS spheres decreasing onto 300 Å.

The "regeneration time" of this process is about 20 hours. It may include both: time of SAPS self-organization and self-organization of the less stable forth interfacial fraction: "Water, orchestrated in the volume of IR primary deformons".

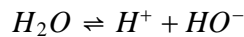
The frequent non-reproducibility of results, related to properties of interfacial water, including Drost-Hansen temperature anomalies, can be resulted from different methods of samples preparation and experimental conditions.

For example, if samples where boiling or strongly heating just before the experiment, the 3d

and 4th fractions of interfacial water can not be observable. The same negative result is anticipated if the colloid system in the process of measurement is under stirring or intensive ultrasound radiation influence.

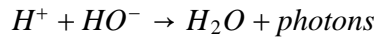
Nonobserved yet predictions, related with third (SSBC) and forth (water, orchestrated by IR standing photons) fractions of new interfacial model

1. Gradual increasing of pH of distilled water in a course of these fractions formation near nonpolar surface - due to enhancement of probability of superdeformons excitation. Corresponding increasing of concentration of cavitation fluctuations are accompanied by dissociation of water molecules:



and the protons concentration elevation;

2. Increasing the UV and visible photons spontaneous emission near nonpolar surface as a result of increasing of the frequency of water molecules recombination:



These experiments should be performed in dark box, using sensitive photon counter or photo-film.

The both predicted effects should be enhanced in system, containing parallel nonpolar multi-layers, with distance (l) between them, corresponding to conditions of librational IR photons standing waves formation: $l = 5, 10, 15, 20$ microns.

3. More fast and ordered spatial self-organization of macromolecules, like described in the next section is anticipated also in the volume of forth fraction of interfacial water.

The dynamics of such process can be registered by optical confocal or tunneling microscope.

4. Our model predicts also that the external weak coherent electromagnetic field, generated by IR laser, like the internal one, also can stimulate a process of self-organization in colloid systems.

4. Distant solvent-mediated interaction between macromolecules

The most of macromolecules like proteins can exist in dynamic equilibrium between two conformers (A and B) with different hydration (n_{H_2O}) and flexibility:



Usually correlation time of more hydrated B- conformer (τ_B) and its **effective** volume are less than that of A-conformer (τ_A) :

$$\tau_{A,B} = \frac{V_{A,B}}{k}(\eta/T)$$

$$\tau_A > \tau_B \quad \text{and} \quad V_A > V_B$$

This means that flexibility, determined by large-scale dynamics of B-conformer is more than that of A-conformer.

For such case a changing of the bulk water activity (a_{H_2O}) in solution by addition of another type of macromolecules or by inorganic ions induce the change of the equilibrium constant:

$K_{A \rightleftharpoons B} = (K_{B \rightleftharpoons A})^{-1}$ and the dynamic behavior of macromolecules (Käiväräinen, 1985, 1986) :

$$\Delta \ln K_{B \rightleftharpoons A} = n_{H_2O} \cdot \Delta \ln a_{H_2O} \quad 12$$

In mixed systems: [PEG + spin-labeled antibody] the dependence of **large-scale (LS)** dynamics of antibody on the molecular mass of polyethyleneglycol (PEG) is similar to dependence of water activity and freezing temperature (T_f) of PEG solution, discussed above (Käiväräinen, 1985, Fig. 82).

The presence of PEG with mass and concentration increasing (a_{H_2O}) and (T_f) stimulate the LS-dynamics of proteins decreasing their effective volume V and correlation time τ_M in accordance to eq.(12).

If $\Delta T_f = T_f^0 - T_f$ is the difference between the freezing point of a solute (T_f^0) and solution (T_f), then the relation between **water activity in solution** and ΔT_f is given by the known relation:

$$\ln a_{H_2O} = - \left[\frac{\Delta H/R}{T_f^0} \right]^2 \cdot \Delta T_f \quad 13$$

where ΔH is the enthalpy of solute (water) melting; R is the gas constant.

In our experiments with polymer solutions 0.1 M phosphate buffer ($pH 7.3 + 0.3M NaCl$) was used as a solvent (Käiväräinen, 1985, Fig. 82).

One can see from (13) that the negative values of ΔT_f in the presence of certain polymers means increasing water activity in three component [water - ions - polymer] system ($\Delta \ln a_{H_2O} > 0$). In turn, it follows from (12) that the $[A \rightleftharpoons B]$ equilibrium of guest proteins in the same system will shift to the right. Consequently, the flexibility of the proteins will increase. Correlation between T_f , water activity (a_{H_2O}) and immunoglobulin flexibility (τ_M), corresponding to (11 - 13) was confirmed (Käiväräinen, 1985, Table 13).

It was shown in our experiments that protein-protein distant interaction depends on their large-scale (LS) dynamics and conformational changes induced by ligand binding or temperature (Käiväräinen, 1985). Such distant solvent-mediated effects may be explained using our idea of inter- and intramolecular clusterphilic interactions, discussed above.

We use the assumption that between inter- and intra-clusterphilic interaction the positive correlation exist. It means that increase of dimensions and *stabilization of the librational bulk (inter) water effectons induce an increase of the water clusters dimensions in protein cavities* and shift $A \rightleftharpoons B$ equilibrium of the cavities to the right, i.e. to the more flexible conformer. This leads to decreasing of resulting correlation time and effective volume of protein.

Our interpretation is confirmed by fact that a decline in temperature, increasing the dimensions of the bulk librational effectons has the stimulating influence on the flexibility of protein like the presence of guest macromolecules. *Decreasing of the temperature shifts the equilibrium between hydrophobic and clusterphilic interaction to the latter one.*

At low concentration of macromolecules (C_M), when the average distance (r) between them (eq.5) is much more than dimensions of primary librational water effecton ($r \gg \lambda_{lb}$), the intermolecular clusterphilic interaction does not work effectively. In this case the large-scale $[A \rightleftharpoons B]$ pulsations of proteins, accompanied by **acoustic impulses in solvent** can enhance the *activity of water*.

This dynamic effect of proteins on solvent can be responsible for the distant solvent- mediated interaction between macromolecules at low concentration (Käiväräinen, 1985, 1987).

Acoustic impulses in protein solutions are result of the jump-way $B \rightarrow A$ transition of interdomain or intersubunit cavities with characteristic time about 10^{-10} sec. This rapid transition follows the cavitation fluctuation of a water cluster formed by 30 - 50 water molecules. The fluctuation is a result of conversion of (lb) primary effecton to (tr) one: [lb/tr] convertion excitation.

The hydrodynamic Bjorkness interaction between different type and identical proteins can be induced by acoustic wave packets in solvent, stimulated by large-scale pulsations of proteins (Käiväräinen et al., 1988). This new approach was used for estimation of frequency of LS-pulsations of interacting proteins like (immunoglobulins) as $(10^4 - 10^5)s^{-1}$.

In very concentrated solutions of macromolecules, when the distance between macromolecules

starts to be less than linear dimension of primary librational effecton of water:

$r \leq \lambda_{lb}$, the trivial aggregation process begins to dominate. It is related to the decrease of water activity in solutions.

Let us analyze in more detail the new effect - increasing water activity (a_{H_2O}) under the effect of macromolecules in a three component [water - salt - macromolecules] system. The Gibbs-Duhem law for this case can be presented as (Käiväräinen, 1988):

$$X_{H_2O} \Delta \ln a_{H_2O} + X_M \frac{\Delta \bar{\mu}_M}{RT} + X_i \Delta \ln a_i = 0 \quad 14$$

where X_{H_2O} , X_M , X_i are the molar fractions of water, macromolecules and ions in the system;

$$a_j = y_j X_j = \exp\left(-\frac{\mu_0 - \mu_j}{RT}\right) = \exp\left(-\frac{\Delta \mu_j}{RT}\right) \quad 15$$

is the activity of each component related to its molar fraction (X_j) and coefficients of activity (y_j);

$$\Delta \mu_M \simeq (G_B - G_A) \Delta f_B \quad 16$$

- the change of the mean chemical potential ($\bar{\mu}_M$) of a macromolecule (protein) pulsing between A and B conformers with corresponding partial free energies \bar{G}_A and \bar{G}_B , when the change of B-fraction is Δf_B and

$$\mu_M \simeq f_B G_B + f_A G_A \quad 17$$

$$\Delta \ln a_i = (\Delta a_i / a_i) \simeq -\Delta \kappa_i \quad 18$$

where

$$\kappa_i = 1 - y_i \quad 19$$

is the fraction of thermodynamically excluded ions (for example, due to ionic pair formation).

One can see from (15) that when $a_{H_2O} < 1$, it means that

$$\mu_{H_2O}^0 > \mu_{H_2O}^S = H_{H_2O}^S - TS_{H_2O}^S \quad 20$$

It follows from (20) that the decrease of water entropy (\bar{S}) in solution related to hydrophobic and clusterphilic interactions may lead to increased $\mu_{H_2O}^S$ and water activity.

It is easy to see from (14) that the elevation of concentration and X_M of macromolecules in a system at constant temperature and $\Delta \bar{\mu}_M$ may induce a rise in water activity (a_{H_2O}) only if the activity of ions ($a_i = y_i X_i$) is decreased. The latter could happen due to increasing of fraction of thermodynamically excluded ions (κ) (eqs. 18 and 19).

There are *two processes* which may lead to increasing the probability of ionic pair formation and fraction κ elevation.

The *first* one is the forcing out of the ions from the ice-like structure of enlarged librational effectons, stimulated by the presence of macromolecules. This exclusion volume phenomenon increases the effective concentration of inorganic ions and their association probability.

The *second* one dominates at the low concentration of $[A \leftrightarrow B]$ pulsing macromolecules, when thixotropic structure fail to form ($r = 11.8/C_M^{1/3} \gg \lambda_{lb}$). Acoustic impulses in solvent generated by pulsing proteins stimulate the fluctuation of ion concentration (Käiväräinen, 1988) increasing the probability of ionic pairs formation.

5. Spatial self-organization in the water-macromolecular systems

The new type of self-organization in aqueous solutions of biopolymers was revealed in Italy (Giordano et al., 1981). The results obtained from viscosity, acoustic and light-scattering measurements showed the existence of long-range structures that exhibit a *thixotropic behavior*. This was shown for solutions of lysozyme, bovine serum albumin (BSA), hemoglobin and DNA. Ordered structure builds up gradually in the course of time to become fully developed after more than 10-15 hours.

When a sample is mechanically shaken this type of self-organization is destroyed. The

”preferred distance” between macromolecules in such an ordered system is about $L \approx 50 \text{ \AA}$ as revealed by small angle neutron scattering (Giordano et al., 1991). **It is important that this distance can be much less than the average statistical distance between proteins at low molar concentrations (C_M) (see eq.5).**

This fact points to attraction force between macromolecules. In accordance with our mesoscopic model, this attraction is a result of external intermolecular clusterphilic interaction. It has been shown experimentally that hypersonic velocity in the ordered thixotropic structures of 10% lysozyme solutions is about 2500 m/s , i.e. 60% higher than that in pure water (1500 m/s) (Aliotta et. al., 1990) Quasielastic and elastic neutron scattering in 10% lysozyme aqueous system at 20° shows that the dynamic properties of the ”bound” water in a thixotropic system are similar to the properties of pure water at $3 - 4^\circ \text{C}$, i.e. 16°C below actual temperature (Giordano et al., 1991). Experimental evidence for heat capacity increasing in lysozyme solutions during 10-15 hours of self-organization was obtained by adiabatic microcalorimetry (Bertolini et al., 1992). The character of this process is practically independent on pH and disappears only at the very low concentration of protein ($< 0.2\%$), when the average distance between macromolecules becomes too big. Increasing the temperature above 40° also inhibits thixotropic-type of self-organization in water-macromolecular systems.

In the series of experiments with artificial polymers - polyethyleneglycols (PEG) with decreasing molecular mass it was shown that self-organization (SO) in 0.1 M phosphate buffer ($\text{pH} 7.3$, 25°) exists in the presence of PEG with a weight of 20.000, 10.000 and 8.000 daltons, but disappears at a molecular mass of 2.000 and lower (Salvetti et al., 1992).

These data are in good agreement with the influence of PEG on the freezing temperature and intramolecular interaction described above.

Independently of Italian group, similar ordering process were observed in Japan (Ise and Okubo, 1980) for aqueous solutions of macroions.

The process of ”compactization” or ”clusterization” of solute (guest) molecules in one volumes of solution or colloid system, should lead to emergency of voids in another ones. Such a phenomena were revealed by means of confocal laser scanning microscope, ultramicroscope and video image analyzer (Ito et al., 1994; Yoshida et al., 1991; Ise et al., 1990).

Inhomogeneity of guest particles distribution were revealed in different ionic systems, containing ionic polymers or macroions, like sodium polyacrylate, the colloid particles, like polystyrene latex ($N300$, $1.3 \mu\text{C}/\text{cm}^2$) and Langmuir-Blodgett films. The time evolution of the numbers of different clusters from such particles were followed during few hours.

The colloid crystal growth at 25°C in H_2O and $(\text{H}_2\text{O} - \text{D}_2\text{O})$ systems can be divided on four stages (Yoshida et al., 1991).

In the first stage the particles were diffusing freely.

In the second stage the local concentration of the particles took place.

In the third stage clusters from 3-10 particles were formed.

In the last fourth stage the smaller clusters turns to the bigger ones and macroscopically well ordered structures were formed. Simultaneously the huge voids as large as $50 - 150 \mu\text{m}$ were observed.

Such an ordering can be immediately destroyed by mechanical shaking or by adding of inorganic salts (NaCl), even in such relatively small concentrations as $10^{-4} \text{ mol}/\text{dm}^3$.

Authors conclude that the repulsion as only one assumption is not enough for explanation of the phenomena observed. The model, considering a *short-range repulsive* interaction and *long-range attraction* between particles should be used. They try to explain attraction between similar charged macroions by presence of small inorganic counterions. Authors believe that short range repulsion can be overwhelms by attraction. But such a simple model does not explain ”clusterization” of electrically neutral guest macromolecules and acceleration of this process due to decreasing the concentration of inorganic salts in presence of ionic sorbents.

Despite a large amount of different experimental data and great importance, the mechanism of

spontaneous type of self-organization in colloid systems remains unknown. It is evident, however, that it can not be attributed to trivial aggregation.

Our explanation of distant attraction between macromolecules, by means of clusterphilic interaction and polymerization of clustrons in the volume of primary electromagnetic deformons (see below) is more adequate for description of self-organization phenomena in aqueous colloid systems, than counterion hypothesis.

Just clusterphilic interactions determines the attraction between large guest molecules or colloid particles on mesoscopic scale. They are responsible for the lot of vicinal water effects described below.

Our computer calculations of water properties based on the mesoscopic theory show that the volume of primary librational effecton of water at 25⁰ includes about 100 water molecules (Fig. 7a of [1] or Fig. 4a of [2]).

In accordance with condition (7) for clusterphilic interactions, the macromolecules with volume

$$V_M > 100 \cdot (V_0/N_0)$$

can decrease the librational mobility of H_2O molecules, their impulses and, consequently, (eqs. 1 and 9) increase the dimensions of the librational effectons of water. Obviously, there must exist a direct correlation between the effective Stokes radius of a macromolecule (i.e. its molecular mass) and the process of self-organization.

The mass of a lysozyme (Lys) is about 13.000 D, and available experimental data (Giordano et al., 1991) show that the mobility of water in a hydration shell in composition of thixotropic system at 25⁰ is about 3 times less than that of pure water. This mobility is directly related to the most probable group velocity and impulse of H_2O (mv_{gr}). It means a three-fold increase in the dimensions of librational effectons in the presence of lysozyme (see eq. 1).

$$[\lambda_{H_2O} \approx 15 \text{ \AA}] \rightarrow [L_{(H_2O)} \approx 45 \text{ \AA}] \quad 20a$$

This value is quite close to the experimental *preferred distance* (50 Å) between proteins after self-organization (SO). Because the shape of the effectons can be approximated by parallelepiped or cube, we suggest that each of its 6 sides can be bordered and stabilized by at least one macromolecule (Table). We termed *corresponding type of quasiparticles "clustrons"*. Enlarged librational effectons serve as a "glue", promoting interaction between surrounding macromolecules or colloid particles. Probability of librational effectons dissociation to translational ones, i.e. $[lb/tr]$ convertions excitation,- is decreased in composition of clustrons.

Cooperative water clusters in the volume of clustrons are very sensitive to perturbation by temperature or by ion-dipole interactions. When the colloid particles have their own charged groups on the surface, very small addition of inorganic salts can influence on clustrons formation.

Our model can answer the following questions:

1. **Why polymers with a molecular mass less than 2000 D do not stimulate self-organization ?**
2. **Why is self-organization inhibited at sufficiently high temperature (> 40⁰) ?**
3. **What causes the repulsive hydration force?**

The answer to the **first question** is clear from condition (7) and eqs.(8). Small polymers can not stimulate the growth of librational effectons and clustrons formation due to their own high mobility.

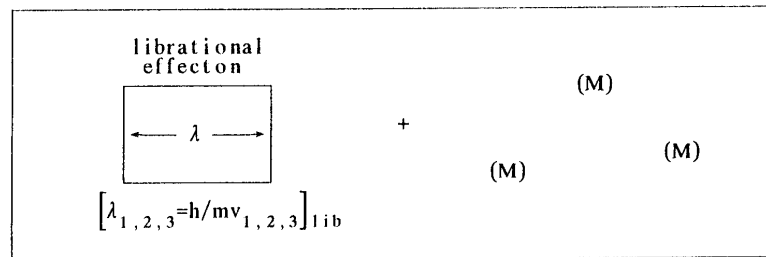
The response to the **second question** is that a decrease in the dimensions of librational effectons with temperature (Fig. 7 of [1]) leads to deterioration of their cooperative properties and stability. The probability of clustrons formation drops and thixotropic structures can not develop.

The **repulsion**, like attraction between colloid particles can be explained by clusterphilic interaction.. The increasing of external pressure should shift the $(a \leftrightarrow b)_{lb}$ equilibrium of librational

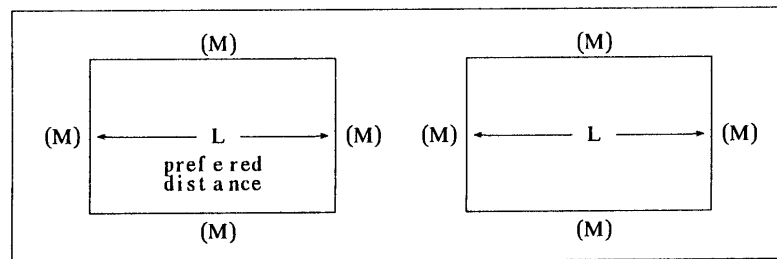
water effectons to the left, like temperature decreasing. This means the enhancement of librational water effecton (and clustron) stability and dimensions. For this reason a *repulsive or disjoining hydration force* arises in different colloid systems. The swelling of clays against imposed pressure also is a consequence of clusterphilic interactions enhancement, i.e. enlargement of water librational effectons due to H_2O immobilization.

In accordance with our model, effectons and their derivatives, *clustrons*, are responsible for self-organization in colloid systems on a *mesoscopic* level (Stage II in Table).

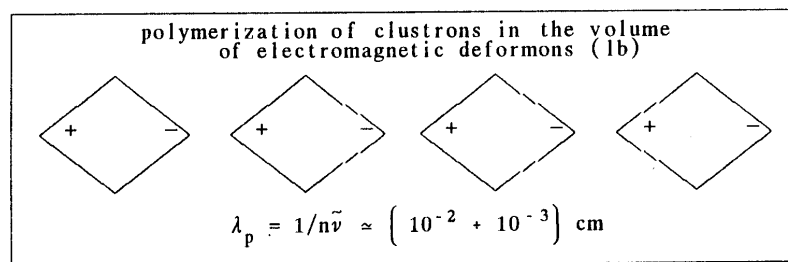
The *macroscopic* level of self-organization (polyclustrons), responsible for the increase of viscosity and long-distance interaction between clustrons originates due to interaction between the electric and magnetic dipoles of clustrons (Stage III, Table). Because the thermal movement of the H_2O molecules, composing clustrons is coherent, the *dipole moment of clustron* is proportional to the number of H_2O in its volume.



I. Unperturbed librational water effectons and macromolecules just after mixing



II. Mesoscopic level of selforganization (fast process) [librational effectons → clustrons].



III. Macroscopic level of selforganization (slow process) [clustrons → polyclustrons].

Table. Schematic representation of three stages (*I* → *II* → *III*) of gradual spatial self-organization in aqueous solutions of macromolecules (*M*).

Formation of polyclustrons (Stage III, Table) as the space-time correlated large group of clustrons can be stimulated in the volume of primary electromagnetic deformons (tr and lib), having almost macroscopic dimensions.

Clustrons (stage II) are complexes of enlarged primary librational effectons, bordered by each of 6 side with macromolecules. The increase of librational effecton dimensions ($\lambda \rightarrow L$) is related to decreased water molecule mobility due to external clusterphilic interaction.

Polyclustrons (stage III) are space and time correlated systems of a large group of clustrons in the volume of electromagnetic deformons. Their linear dimensions

(0.01 – 0.001 cm) correspond to translational and librational wave numbers:

$$\tilde{\nu}_{tr} \simeq 60 \text{ cm}^{-1} \quad \text{and} \quad \tilde{\nu}_{lb} \simeq 700 \text{ cm}^{-1}$$

We suppose that for optimal process of self-organization, the molar concentration of macromolecules (C_M) must satisfy the condition:

$$10L > [r = 11.8 \cdot C_M^{-1/3}] \geq L,$$

where: $L \cong q\lambda_{lb} = h/m(v_{lb}/q)$ is the dimension of a clustron ($\lambda_{lb}^{1,2,3} = h/mv_{lb}^{1,2,3}$ is the dimension of primary librational effecton in pure water; r - statistically most probable distance between macromolecules (eq.5); q is the *lib* effecton magnification number, reflecting the effect of water molecules immobilization (decreasing of their group velocity) in presence of macromolecules or colloid particles.

Under condition $r \gg 10L$, formation of *clustrons* can be accompanied by big voids in colloid system. At the opposite limit condition $r < L$, the trivial aggregation will dominate, accompanied by "melting" of vicinal librational effectons.

The librational IR photon wave length, calculated from the oscillatory spectra of water, is about (eq. 1.37):

$$\lambda_p = (n \cdot \tilde{\nu})^{-1} \approx (1.33 \cdot 700)^{-1} \approx 0.001 \text{ cm}$$

where $\tilde{\nu} \simeq 700 \text{ cm}^{-1}$ is the wave number of librational band in the oscillatory spectra of water; $n = 1.33$ is the water refraction index.

The 3D superposition (interception) of such three photons forms primary electromagnetic deformons, stimulating development of polyclustron system.

Our model predicts that the external electromagnetic field, like internal one, also can stimulate a process of self-organization in colloid systems. On the other hand, the agents perturbing the structure of librational effectons (temperature, ions, organic solvents) should have the opposite effect. The slowest stage of self-organization, polyclustrons and polyclustron net formation (thixotropic-like structure), is also sensitive to mechanical shaking. Due to the collective effect the energy of interaction between clustrons in polyclustrons is higher than kT at sufficiently low temperatures.

The model presented explains the increasing of viscosity, heat capacity and sound velocity in an aqueous system by enhancing the cooperative units with ice-like water structure - clustrons and polyclustrons (Table) due to self-organization in water-macromolecular systems.

The density of ice-like structures in clustrons and polyclustrons is lower than in usual bulk liquid water.

Consequently, one can predict that the free volume of water will increase as the result of self-organization in aqueous systems of macromolecules.

Such a type of effect was revealed in our microcalorimetry study of large-scale and small-scale protein dynamics contributions in the resulting heat capacity of solvent (Käiväräinen et al., 1993). The additional free volume (v_f) in [0.2 – 0.3%] (w/v) concentration of different proteins is quite close to the volume occupied by macromolecules in the solution itself. The v_f is dependent on the active site state (ligand-dependent) and large-scale dynamics of proteins. The more intensive the large-scale pulsations of proteins and their flexibility and the less its effective volume, the smaller the additional free volume solvent. This correlation could be resulted from acoustic impulses generated by pulsing protein. This additional acoustic noise can stimulate dissociation (melting) of water clusters - librational effectons with saturated hydrogen bonds in a system (Käiväräinen et al., 1993). In terms of mesoscopic model it means increasing the probability of [lb/tr] convertions excitation.

The vicinal water in combination with osmotic processes could be responsible for coordinated intra-cell spatial and dynamic reorganizations.

7. Osmosis and solvent activity. Traditional and mesoscopic approach

It was shown by Van't Hoff in 1887 that osmotic pressure (Π) in the dilute concentration of solute (c) follows a simple expression:

$$\Pi = RTc \quad 24$$

This formula can be obtained from an *equilibrium condition* between a solvent and an ideal solution after saturation of diffusion process of the solvent through a semipermeable membrane:

$$\mu_1^0(P) = \mu_1(P + \Pi, X_1)$$

where μ_1^0 and μ_1 are the chemical potentials of a pure solvent and a solvent in solution; P - external pressure; Π - osmotic pressure; X_1 is the solvent fraction in solution.

At equilibrium $d\mu_1^0 = d\mu_1 = 0$ and

$$d\mu_1 = \left[\frac{\partial \mu_1}{\partial P_1} \right]_{X_1} dP_1 + \left[\frac{\partial \mu_1}{\partial X_1} \right]_{P_1} dX_1 = 0 \quad 24a$$

Because

$$\mu_1 = \left(\frac{\partial G}{\partial n_1} \right)_{P,T} = \mu_1^0 + RT \ln X_1 \quad 25$$

then

$$\left(\frac{\partial \mu_1}{\partial P_1} \right)_{X_1} = \left(\frac{\partial^2 G}{\partial P \partial n_1} \right)_{P,T,X} = \left(\frac{\partial V}{\partial n_1} \right) = \bar{V}_1 \quad 26$$

where \bar{V}_1 is the partial molar volume of the solvent. For dilute solution: $\bar{V}_1 \approx V_1^0$ (molar volume of pure solvent).

From (25) we have:

$$\frac{\partial \mu_1}{\partial X_1} = RT \left(\frac{\partial \ln X_1}{\partial X_1} \right)_{P,T} \quad 27$$

Putting (26) and (27) into (24a) we obtain:

$$dP_1 = -\frac{RT}{V_1^0 X_1} dX_1$$

Integration:

$$\int_P^{P+\Pi} dP_1 = -\frac{RT}{V_1^0} \int_1^{X_1} d \ln X_1 \quad 28$$

gives:

$$\Pi = -\frac{RT}{V_1^0} \ln X_1 = -\frac{RT}{V_1^0} \ln(1 - X_2) \quad 29$$

and for the dilute solution ($X_2 \ll 1$) we finally obtain Van't Hoff equation:

$$\Pi = \frac{RT}{V_1^0} X_2 \cong RT \frac{n_2/n_1}{V_1^0} = RTc \quad 30$$

where

$$X_2 = n_2/(n_1 + n_2) \cong n_2/n_1 \quad 31$$

and

$$\frac{n_2/n_1}{V_1^0} = c \quad 32$$

Considering a real solution, we only substitute solvent fraction X_1 in (29) by solvent activity: $X_1 \rightarrow a_1$. Then taking into account (25), we can express osmotic pressure as follows:

$$\Pi = -\frac{RT}{\bar{V}_1} \ln a_1 = \frac{\Delta \mu_1}{\bar{V}_1} \quad 33$$

where: $\Delta\mu_1 = \mu_1^0 - \mu_1$ is the difference between the chemical potentials of a pure solvent and the one perturbed by solute at the starting moment of osmotic process, i.e. the driving force of osmose; $\bar{V}_1 \cong V_1$ is the molar volume of solvent at dilute solutions.

Although the osmotic effects are widespread in Nature and are very important, especially in biology, the physical mechanism of osmose remains unclear (Watterson, 1992).

The explanation following from Van't Hoff equation (30) and pointing that osmotic pressure is equal to that induced by solute molecules, if they are considered as an ideal gas in the same volume at a given temperature is not satisfactory.

The osmose phenomenon can be explained quantitatively on the basis of our mesoscopic theory and state equation (11.7). To this end, we have to introduce the rules of conservation of the main internal parameters of solvent in the presence of guest (solute) molecules or particles:

$$\left. \begin{array}{l} 1. \text{ Internal pressure of solvent: } P_{\text{in}} = \text{const} \\ 2. \text{ The total energy of solvent: } U_{\text{tot}} = \text{const} \end{array} \right\} \quad 34$$

This conservation rules can be considered as the consequence of Le Chatelier principle.

Using (11.6), we have for the pure solvent and the solvent perturbed by a solute the following two equations, respectively:

$$P_{\text{in}} = \frac{U_{\text{tot}}}{V_{\text{fr}}^0} \left(1 + \frac{V}{T_k} \right) - P_{\text{ext}} \quad 35$$

$$P_{\text{in}}^1 = \frac{U_{\text{tot}}^1}{V_{\text{fr}}^1} \left(1 + \frac{V_1}{T_k^1} \right) - P_{\text{ext}}^1, \quad 36$$

where:

$$V_{\text{fr}}^0 = \frac{V_0}{n^2} \quad \text{and} \quad V_{\text{fr}}^1 = \frac{V_0}{n_1^2} \quad 37$$

are the free volumes of pure solvent and solvent in presence of solute (guest) molecules as a ratio of molar volume of solvent to correspondent value of refraction index.

The equilibrium conditions *after osmotic process saturation*, leading from our conservation rules (34) are

$$P_{\text{in}} = P_{\text{in}} \quad \text{when} \quad P_{\text{ext}} = P_{\text{ext}} + \Pi \quad 38$$

$$U_{\text{tot}} = V + T_k = V_1 + T_k^1 = U_{\text{tot}}^1 \quad 39$$

From (39) we have:

$$\text{Dif} = T_k - T_k^1 = V_1 - V \quad 40$$

The index (1) denote perturbed solvent parameters.

Comparing (35) and (36) and taking into account (37 - 39), we obtain a new formula for osmotic pressure:

$$\Pi = \frac{n^2}{V_0} U_{\text{tot}} \left[\frac{n_1^2 T_k - n^2 T_k^1}{T_k T_k^1} \right] \quad 41$$

where: n , V_0 , U_{tot} and T_k are the refraction index, molar volume, total energy and total kinetic energy of a pure solvent, respectively; T_k^* and n_1 are the total kinetic energy and refraction index of the solvent in the presence of guest (solute) molecules, that can be calculated from the mesoscopic theory (eq.4.33).

For the case of dilute solutions, when $T_k T_k^1 \cong T_k^2$ and $n \cong n_1$, the eq.(41) can be simplified:

$$\Pi = \frac{n^2}{V_0} \left(\frac{U_{\text{tot}}}{T_k} \right)^2 (T_k - T_k^1) \quad 42$$

or using (40):

$$\Pi = \frac{n^2}{V_0} \left(\frac{U_{\text{tot}}}{T_k} \right)^2 (V_1 - V) \quad 43$$

The ratio:

$$S = T_k/U_{\text{tot}} \quad 44$$

is generally known as a structural factor (see eq. 2.46):

We can see from (42) and (43) that osmotic pressure is proportional to the difference between total kinetic energy of a free solvent (T_k) and that of the solvent perturbed by guest molecules:

$$\Delta T_k = T_k - T_k^1$$

or related difference between the total potential energy of perturbed and pure solvent:

$$\Delta V = V_1 - V \quad \text{where: } \Delta T_k = \Delta V \equiv \text{Dif} \quad (\text{see Fig. 3}).$$

As far $\Delta T_k > 0$ and $\Delta V > 0$, it means that:

$$T_k > T_k^1$$

or

$$V_1 > V$$

45

Theoretical temperature dependence of the difference

$$\text{Dif} = \Delta T_k = \Delta V$$

calculated from (42) or (43) at constant osmotic pressure: $\Pi \equiv Pos = 8 \text{ atm}$, pertinent to blood is presented on Fig. 3.

The next Fig. 4 illustrate theoretical temperature dependence of osmotic pressure (43) in blood at the constant value of **Dif** = $6.7 \cdot 10^{-3} (J/M)$, corresponding on Fig. 3 to physiological temperature (37^0).

The ratios of this **Dif** value to total potential (V) and total kinetic energy (T_k) of pure water at 37^0 (see Fig. 5b) are equal to:

$$(\text{Dif}/V) \simeq \frac{6.7 \cdot 10^{-3}}{1.3 \cdot 10^4} \simeq 5 \cdot 10^{-7} \quad \text{and}$$

$$(\text{Dif}/T_k) \simeq \frac{6.7 \cdot 10^{-3}}{3.5 \cdot 10^2} \simeq 2 \cdot 10^{-5}$$

i.e. the relative changes of the solvent potential and kinetic energies are very small.

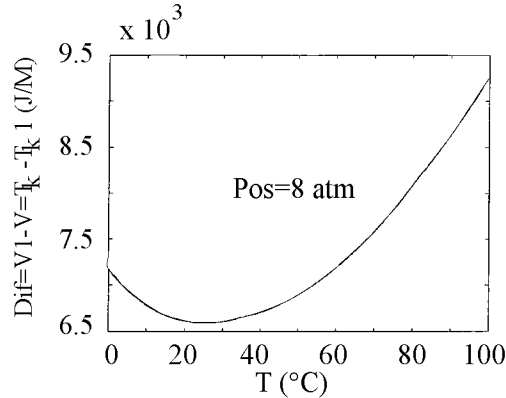


Fig. 3. Theoretical temperature dependence of the difference: **Dif** = $V_1 - V = T_k - T_k^1$ at constant osmotic pressure: $\Pi \equiv Pos = 8 \text{ atm}$, characteristic for blood. The computer calculations were performed using eqs. (42) or (43).

For each type of *concentrated macromolecular solutions the optimum amount of water is needed to minimize the potential energy of the system* determined mainly by clusterphilic interactions. The conservation rules (34) and self-organization in solutions of macromolecules (clustron formation) may be responsible for the *driving force of osmose* in the different compartments of biological cells.

Comparing (43) and (33) and assuming equality of the molar volumes $V_0 = \bar{V}_1$, we find a relation between the difference in potential energies and chemical potentials ($\Delta\mu$) of unperturbed solvent and that perturbed by the solute:

$$\Delta\mu = \mu_1^0 - \mu_1 = n^2 \left(\frac{U_{\text{tot}}}{T_k} \right)^2 (V_1 - V) \quad 46$$

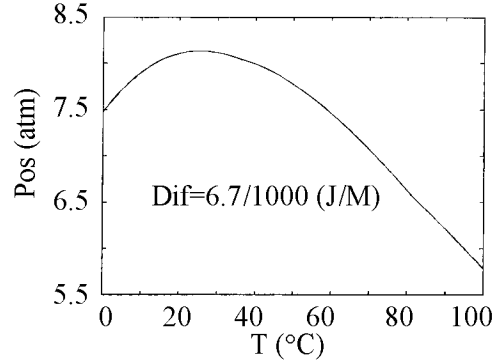


Fig. 4. Theoretical temperature dependence of osmotic pressure (eq. 43) in blood at constant value of difference: $\text{Dif} = \Delta T = \Delta V = 6.7 \cdot 10^{-3} \text{ J/M}$. This value in accordance with Fig.3 corresponds to physiological temperature (37^0).

The results obtained above mean that solvent activity (a_1) and a lot of other thermodynamic parameters for solutions can be calculated on the basis of our hierarchic concept:

$$a_1 = \exp\left(-\frac{\Delta\mu}{RT}\right) = \exp\left[-\left(\frac{n}{S}\right)^2 \frac{V_1 - V}{RT}\right] \quad 47$$

where: $S = T_k/U_{\text{tot}}$ is a structural factor for the solvent.

The molar coefficient of activity is:

$$y_i = a_i/c_i, \quad 48$$

where

$$c_i = n_i/V \quad 49$$

is the molar quantity of i-component (n_i) in of solution (V - solution volume in liters).

The molar activity of the solvent in solution is related to its vapor pressure (P_i) as:

$$a_i = P_i/P_i^0 \quad 50$$

where: P_i^0 is the vapor pressure of the pure solvent. Theoretical temperature dependence of water activity (a_1) in blood at constant difference: $\text{Dif} = \Delta T = \Delta V = 6.7 \cdot 10^{-3} \text{ J/M}$ is presented on Fig. 5.

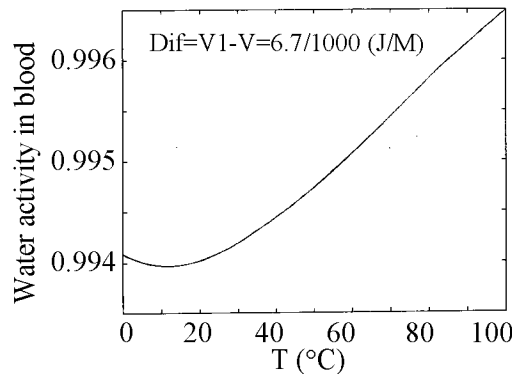


Fig. 5. Theoretical temperature dependence of water activity (a_1) (eq.47) in blood at constant difference: $Dif = \Delta T = \Delta V = 6.7 \cdot 10^{-3} J/M$.

Another *colligative parameter* such as low temperature shift of freezing temperature of the solvent (ΔT_f) in the presence of guest molecules also can be calculated from (47) and (13):

$$\Delta T_f = -\frac{R(T_f^0)^2}{\Delta H} \ln a_1 \frac{(T_f^0)^2}{\Delta H \cdot T} \left(\frac{n}{S} \right)^2 (V_1 - V) \quad 51$$

where: T_f^0 is the freezing temperature of the pure solvent; T is the temperature corresponding to the conditions of calculations of $V_1(T)$ and $V(T)$ from (eqs. 4.33 and 4.36 of [1,2]).

The partial molar enthalpy (\bar{H}_1) of solvent in solution are related to solvent activity like:

$$\bar{H}_1 = \bar{H}_1^0 - RT^2 \frac{\partial \ln a_1}{\partial T} = \bar{H}_1^0 + \bar{L}_1 \quad 52$$

where \bar{H}_1^0 is the partial enthalpy of the solvent at infinitive dilution;

$$\bar{L}_1 = -RT^2 \frac{\partial \ln a_1}{\partial T} = T^2 \frac{\partial}{\partial T} \left[\left(\frac{n}{S} \right)^2 \frac{V_1 - V}{T} \right] \quad 53$$

is the relative partial **molar enthalpy of solvent** in a given solution.

From (52) we obtain partial molar heat capacity as:

$$C_p^1 = \frac{\partial}{\partial T} (H_1) = C_p^0 - R \left(T^2 \frac{\partial^2 \ln a_1}{\partial T^2} + 2T \frac{\partial \ln a_1}{\partial T} \right) \quad 54$$

An analogous equation exists for the *solute* of this solution as well as for partial *molar volume* and other important parameters of the solvent, *including solvent activity* (Godnev et al., 1982).

It is obvious, the application of Hierarchic theory to solvent activity determination might be of great practical importance for different processes in chemical and colloid technology.

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