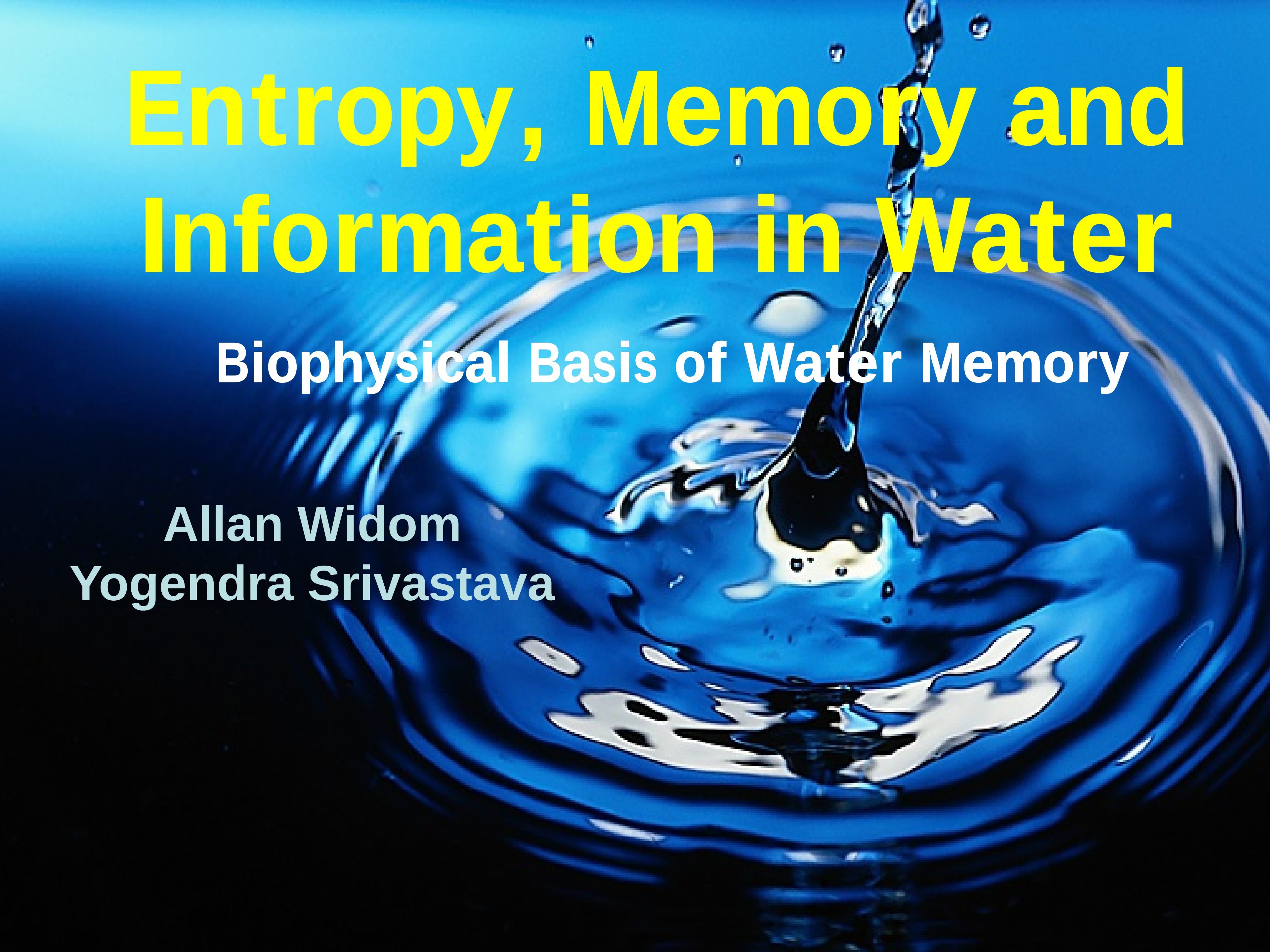
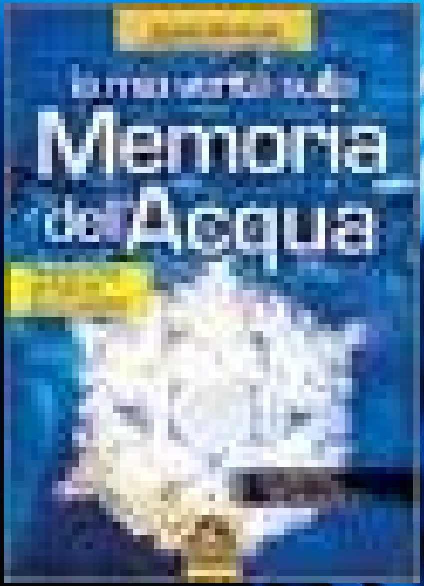


Entropy, Memory and Information in Water

Biophysical Basis of Water Memory

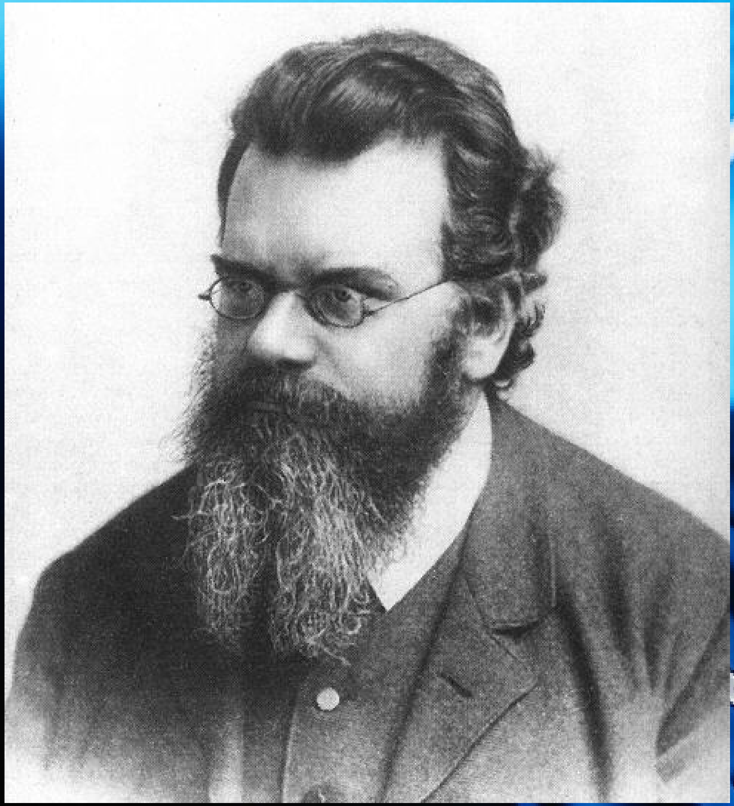
Allan Widom
Yogendra Srivastava

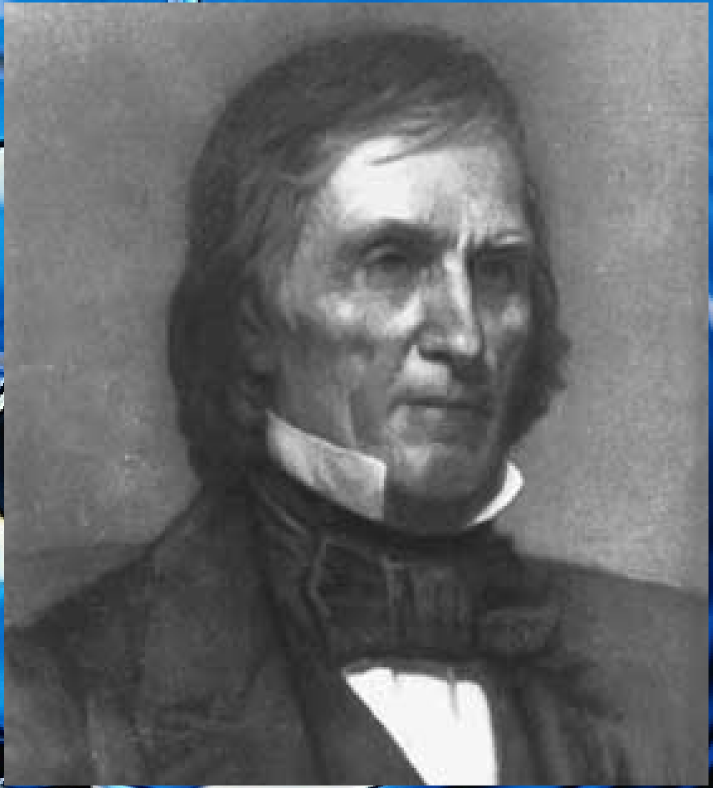

la mia verità sulla
Memoria
dell'Acqua

J Benveniste had observed that highly dilute (and even in the absence of physical molecules) biological agents still triggered relevant biological systems. Some of these experiments were reproduced in three other laboratories Nature 333, 816 (1988). Further work, Medical Hypotheses 54, 33 (2000), showed that molecular activity in more than 50 biochemical systems and even in bacteria could be induced by electromagnetic signals transferred through water solutes. The sources of the electromagnetic signals were recordings of specific biological activities.

These results suggest that electromagnetic transmission of biochemical information can be stored in the electric dipole moments of water in close analogy to the manner in which magnetic moments store information on a computer disk. The electromagnetic signals would enable in vivo transmissions of the specific molecular information between two functional biological molecules. The physical nature of such biological information storage and retrieval in ordered quantum electromagnetic domains of water will be explored.

$S = k_B \ln \Omega$





$k_B = 1.3806503 \times 10^{-16}$ erg/K

- **Memory and Information**
- **Information and Entropy**
- **Thermodynamics of Water**
- **Memory and Entropy in the Genome**
- **Polarization Elements and Water Domains**
- **Diamagnetism in Water**
- **Ionic Domains and Computer Switches**
- **Conclusions**

Memory and Information Theory

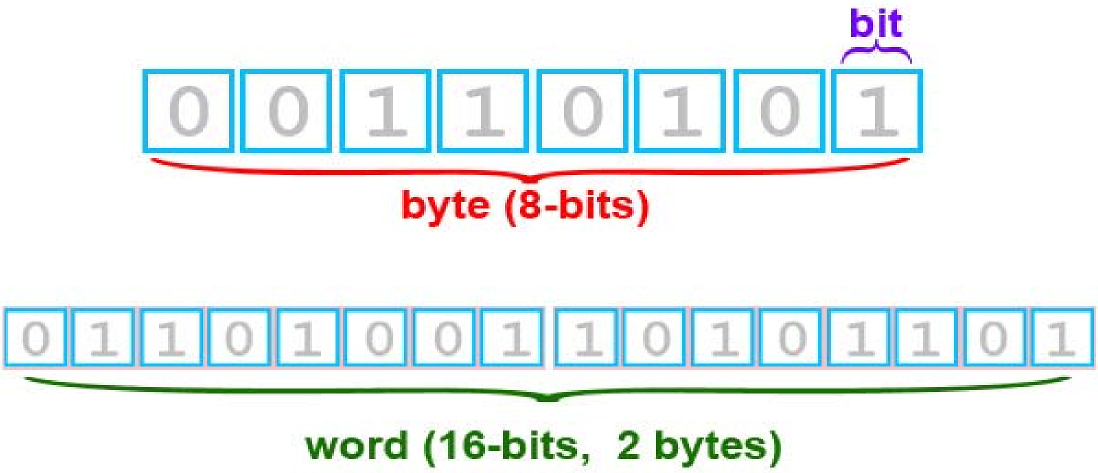
Information Theory I

$$N = \lg \Omega \qquad \Rightarrow \qquad \Omega = 2^N$$

$$S = k_B \ln \Omega \qquad \Rightarrow \qquad S = (k_B \ln 2) N$$

$$N = 8I \qquad \Rightarrow \qquad S = (k_B 8 \ln 2) I$$

$$\frac{I}{\text{byte}} = \left(\frac{1}{8 \ln 2} \right) \frac{S}{k_B}$$



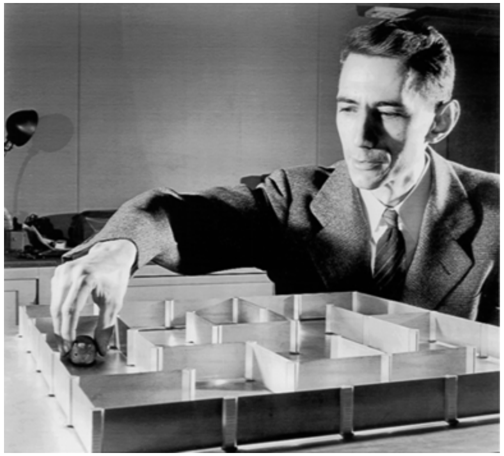
Information Theory II

Statistical Information

$$N^* = -\sum_{i=1}^{\Omega} p_i \lg p_i \equiv \lg \Omega^* \le \lg \Omega = N$$

$$N^* = N \ \text{ if and only if } \ p_i = \frac{1}{\Omega}$$

$$\text{As } N^* \to \infty \text{ the Shannon theorem holds true.}$$

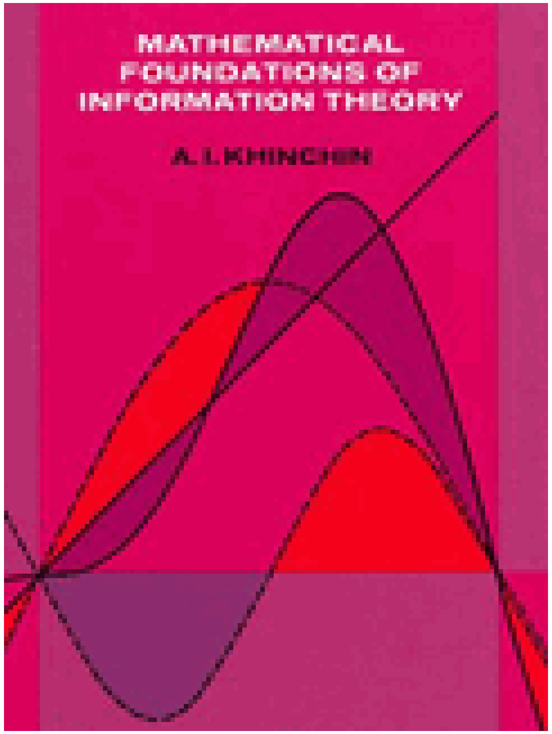


Shannon's Theorem:

If a program is stored on an N bit device and if the a priori probability of the i^{th} state in the device is p_i with information bits $N^* >> 1$, then the program can be "compressed" to fit onto an N^* bit device with ever smaller coding error.

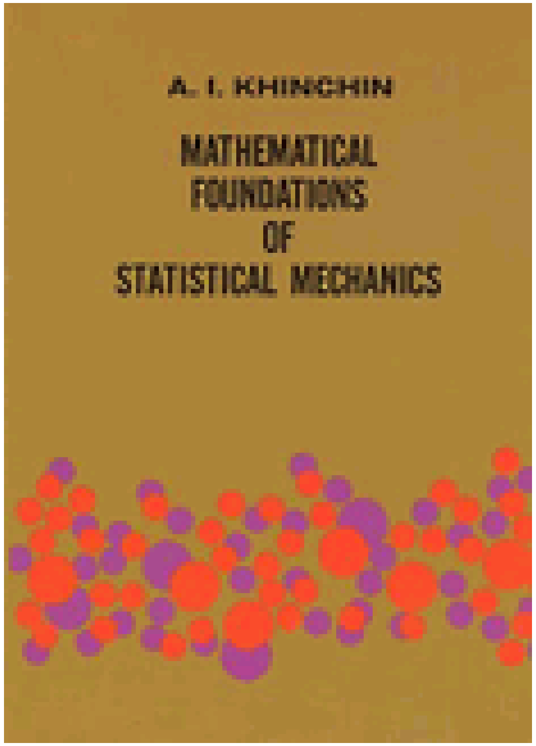
Information Theory III

$$I = \left(\frac{1}{8 \ln 2} \right) \frac{S}{k_B} \approx (0.18033688011112 \text{ byte}) \times \left(\frac{S}{k_B} \right)$$



MATHEMATICAL FOUNDATIONS OF INFORMATION THEORY

A. I. KHINCHIN

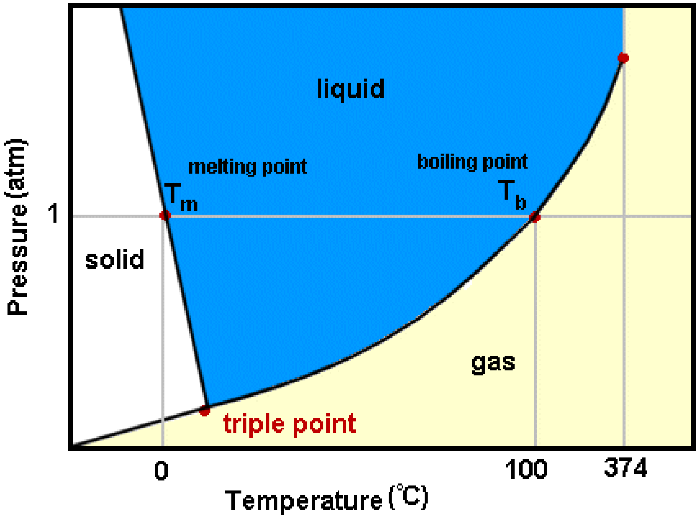


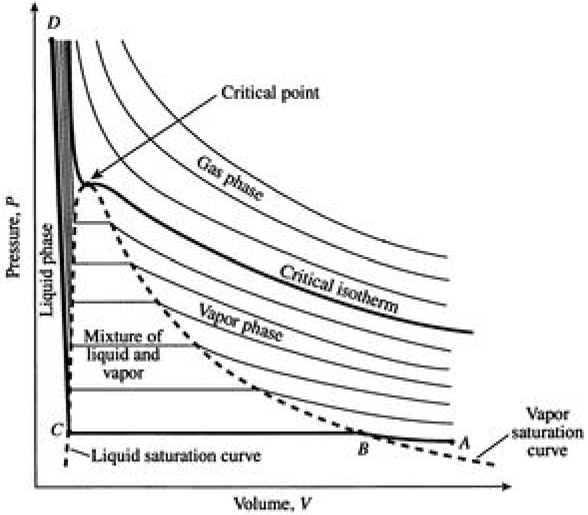
A. I. KHINCHIN

MATHEMATICAL FOUNDATIONS OF STATISTICAL MECHANICS

Memory in Pure Water and Thermodynamics

Water Thermodynamics I





$$\frac{dP}{dT} = \frac{\Delta s}{\Delta v}$$

$$\Delta s = s_{gas} - s_{liquid}$$

$$\Delta v = v_{gas} - v_{liquid}$$

heat of vaporization q

$$q = T\Delta s$$

$$\frac{dP}{dT} = \frac{q}{T\Delta v}$$

Water Thermodynamics II

Along the liquid-vapor coexistence curve the heat ***q*** of vaporization obeys

$$q = T\Delta s = \Delta \mathrm{v}\left(T\,\frac{dP}{dT}\right)$$

Water Thermodynamics III

The information lost ΔI when a molecule evaporates from the liquid into the vapor is as follows:

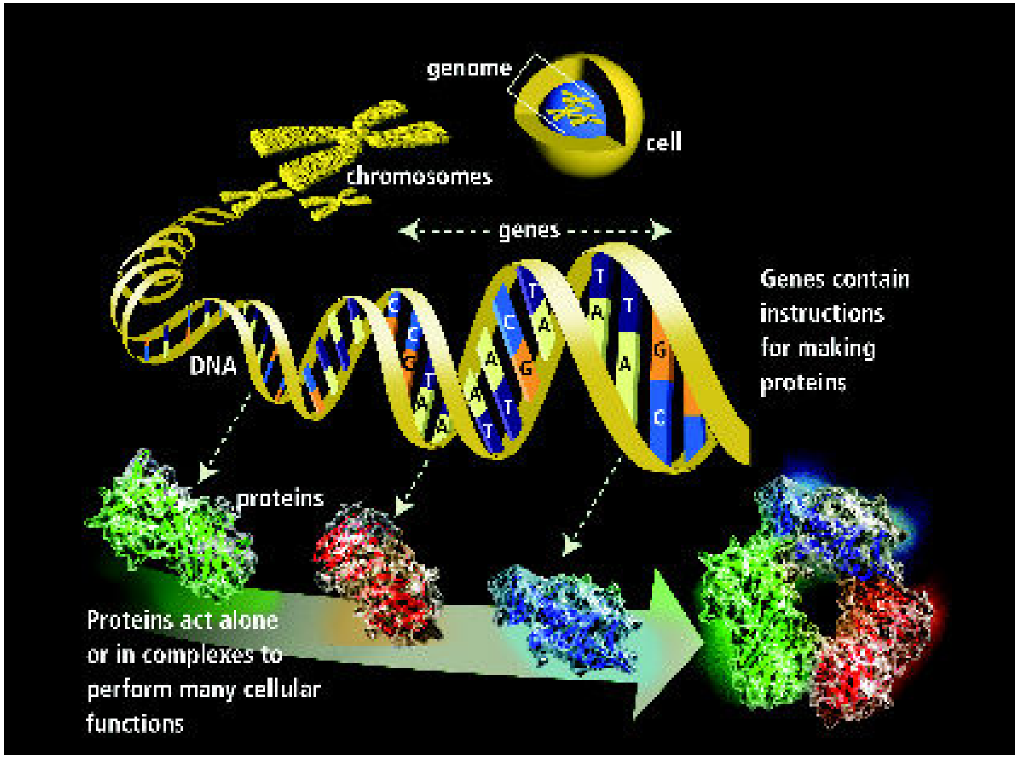
$$\Delta I = \frac{1}{8\ln 2}\left(\frac{\Delta s}{k_B}\right) = \frac{1}{8\ln 2}\left(\frac{q}{k_B T}\right)$$

$$\Delta I \approx 2.938 \ \frac{\text{byte}}{\text{molecule}} \approx 23.50 \ \frac{\text{bit}}{\text{molecule}}$$

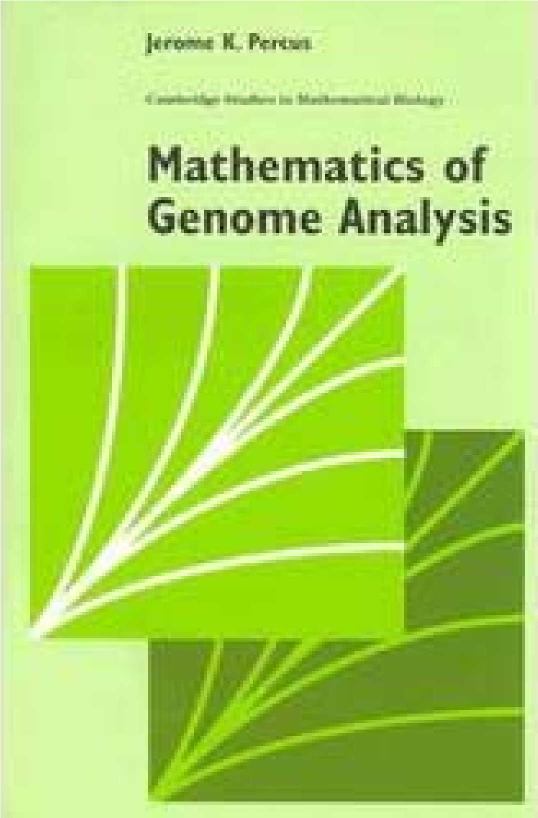
The anomalously high heat of water vaporization implies an ordered state of water with a high information capacity per atom of ~ one byte.

Memory in the Genome

Memory in DNA I



Memory in DNA II



Jerome K. Percus

Cambridge Studies in Mathematical Biology

Mathematics of Genome Analysis

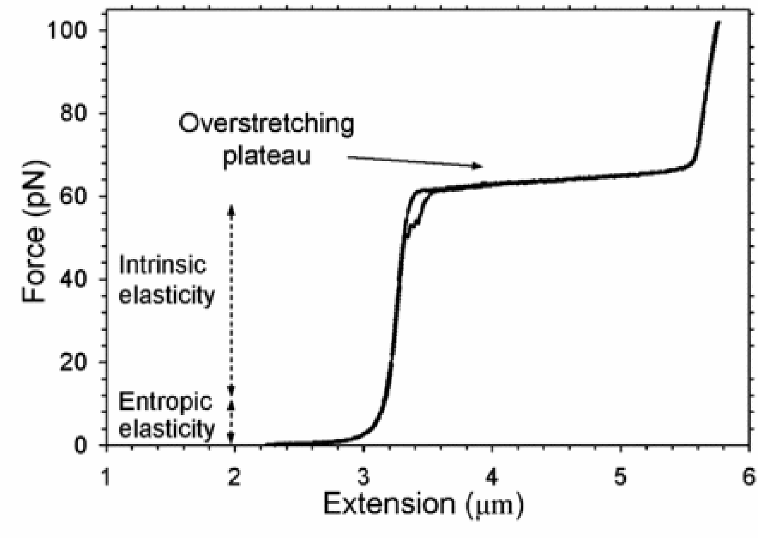
The human DNA polymer molecule is thought to contain an approximately 3 gigabyte program. It is stored on an approximately 100 gigabyte memory capacity polymer chain. The “unused” portion of the chain has been called “junk” DNA since its purpose is unknown.

Memory in DNA III

The thermodynamic properties of a DNA polymer chain of length *l* per molecule under tension force τ may be described theoretically and experimentally (with optical tweezers) as follows:

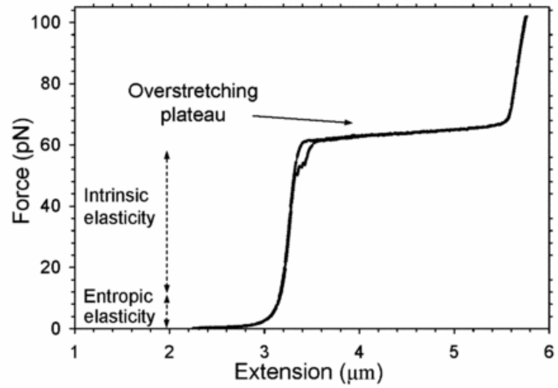
$$df = -s\,dT + \tau\,dl$$

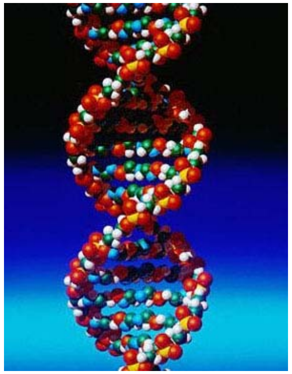
$$-\left(\frac{\partial s}{\partial l}\right)_T = \left(\frac{\partial \tau}{\partial T}\right)_l$$

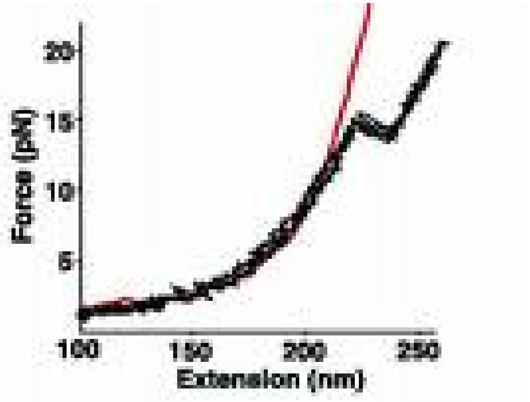


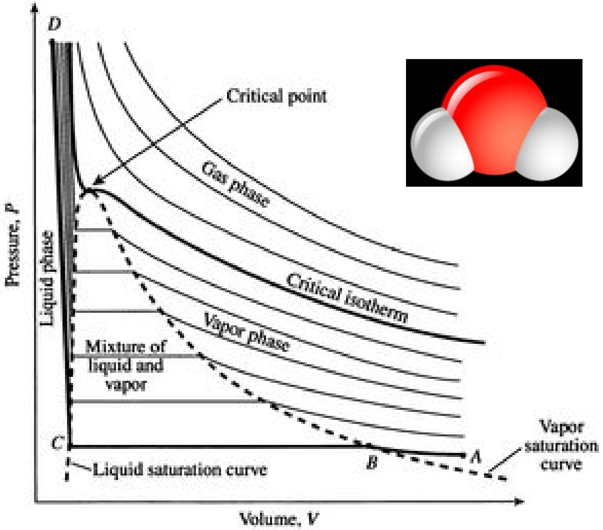
The thermodynamic analysis of the information capacity of the chain leads to ~ 30 kilobyte per meter in agreement with information analysis of the genome project if the "junk" is included as information.

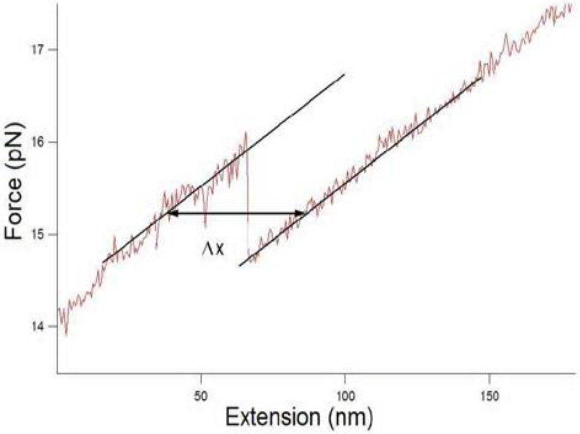
Phase Transitions









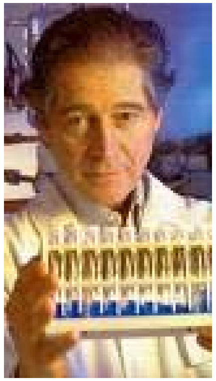


Hysteretic RNA Transition

Memory in DNA IV

C.M. Ajo-Franklin, D.A. Drubin, J.A. Eskin, E.P.S. Gee, D. Landgraf, I. Phillips and P.A. Silver, *Genes & Dev*. **21**, 2271 (2007)

A loop function (subroutine) was inserted into a DNA genetic program within a yeast cell. The modification of the DNA program was induced by exposure to galactose. After many cell divisions, the loop function (subroutine) remained intact *without galactose nor without any other sort of molecular trigger*.



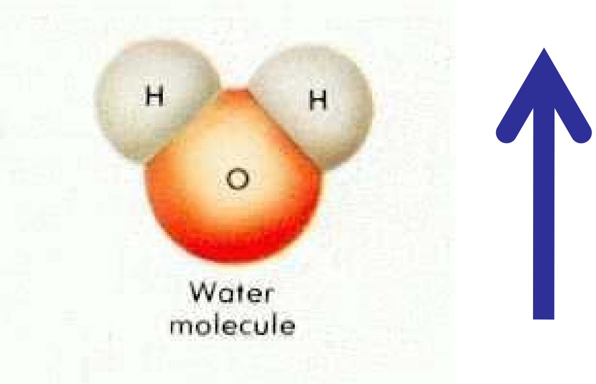
Memory in Water

Highly dilute (and even in the absence of physical molecules) biological agents still trigger relevant biological systems.

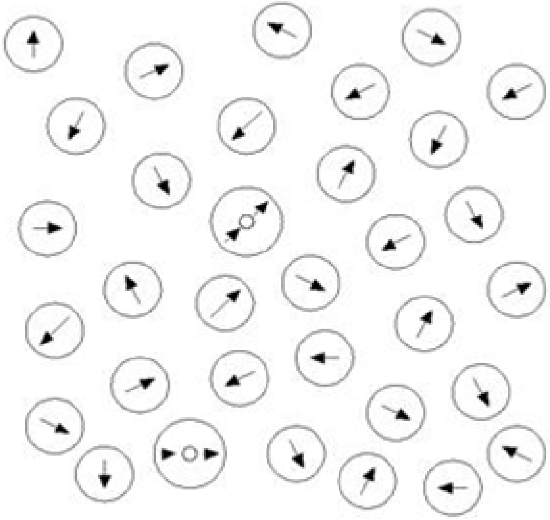
Ordered Domains in Water

Low Entropy Ordered Domains in Water I

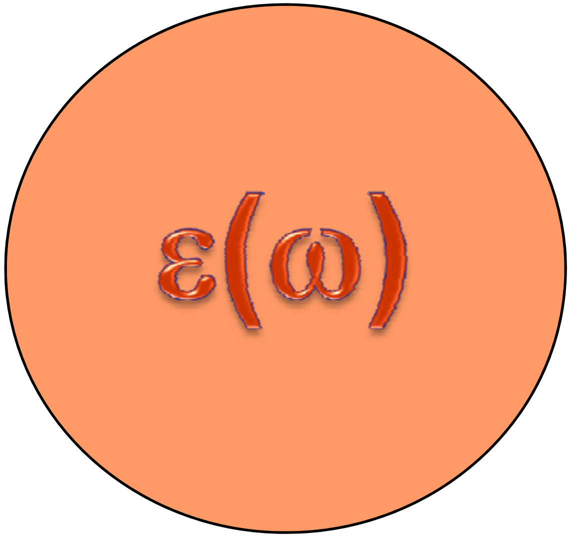
Water has coherent polarized domains of radius $R \sim 10^{-5}$ cm. Some domains contain ionic impurity. The memory of water and its information content is controlled by the polarized domain positions and by the diamagnetic magnetic field configurations.



Dipole Moment d



Low Entropy Ordered Domains in Water II



Shown is a spherical sample of *N* water molecules in a sphere of radius *R* subject to an electric field at frequency *ω*. The polarizability per molecule of the spherical domain is denoted by *α*(*ω*).

In the static limit one finds the following:

$$\text{v} = \frac{N}{(4\pi R^3/3)}$$

$$\frac{4\pi\alpha(\omega)}{3\text{v}} = \frac{\varepsilon(\omega)-1}{\varepsilon(\omega)+2}$$

Lorentz-Lorenz

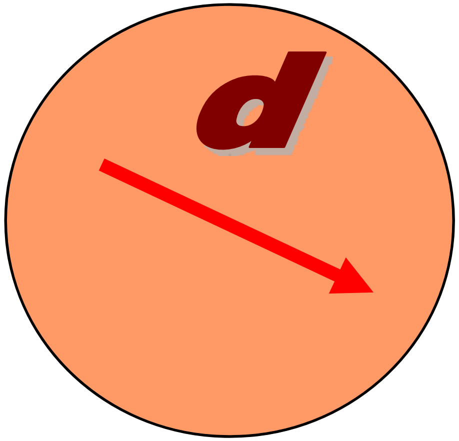
$$\text{As } \omega \to 0$$

$$\varepsilon = \frac{1+(8\pi\alpha/3\text{v})}{1-(4\pi\alpha/3\text{v})}$$

$$\text{Stable for } \left(\frac{4\pi\alpha}{3\text{v}}\right) < 1$$

$$\text{Net dipole moment for } \left(\frac{4\pi\alpha}{3\text{v}}\right) > 1$$

Low Entropy Ordered Domains in Water III

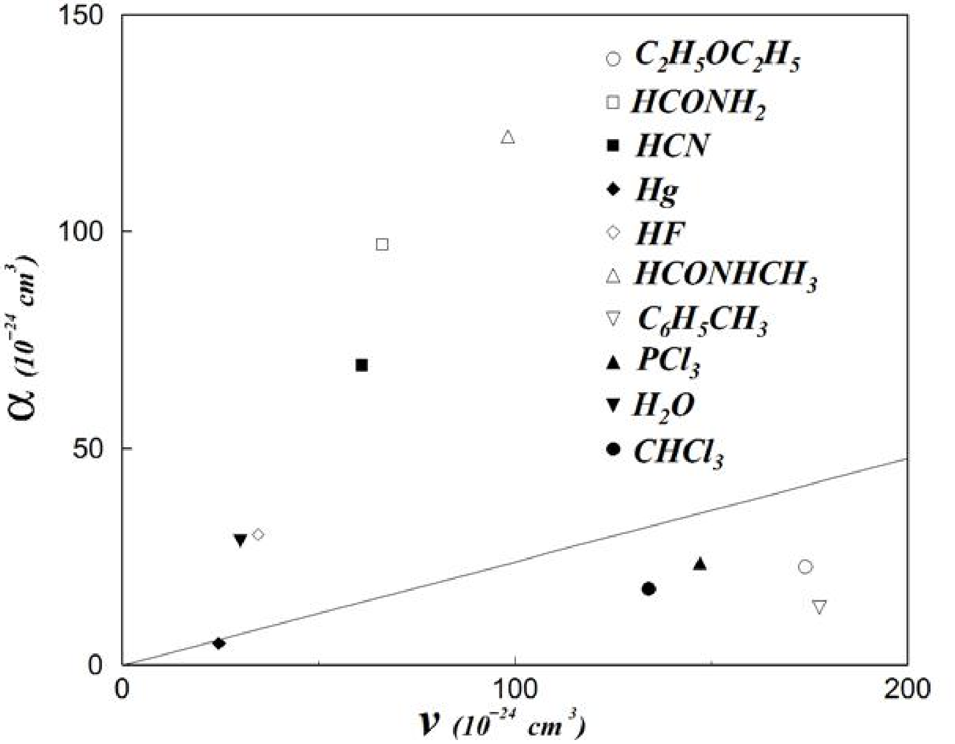


An ordered domain with dipole moment

$$\mathbf{d} = \left(\frac{4\pi R^2}{3}\right)\mathbf{P} \qquad \Leftarrow \qquad \alpha > \frac{3\mathrm{v}}{4\pi}$$

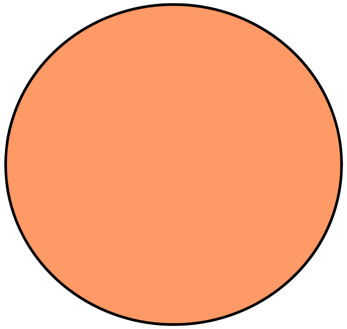
Liquids with ordered polarized domains lie above the line while unordered liquids lie below the line. The line is determined by

$\alpha = 3v/4\pi$



Low Entropy Ordered Domains in Water IV

Two Energy Level Model and Collective Oscillations in the Domain



A single molecule will exhibit an oscillation frequency as a pole in $\alpha(\omega)$, i.e. at $\omega = \omega_0$.

A collective oscillation with N dipole moments will yield a lower frequency as a pole in $\varepsilon(\omega)$, i.e. at $\omega = \Omega_0$.

$$\hbar\omega_0 = \Delta E \quad \text{linewidth} \quad \gamma$$

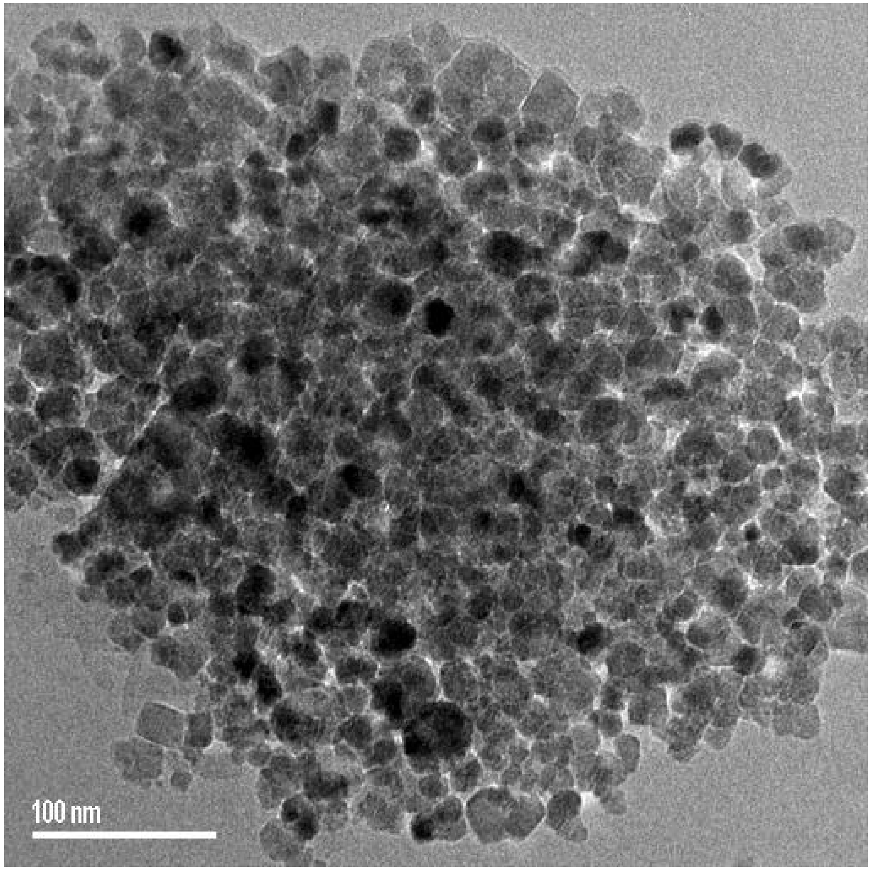
$$\alpha(\omega) = \frac{\omega_0{}^2 \alpha}{\omega_0{}^2 - \omega^2 - i\omega\gamma/2}$$

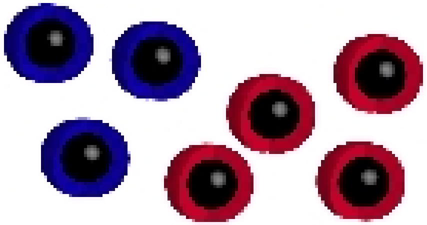
$$\varepsilon(\omega) = \frac{1 + (8\pi\alpha(\omega)/3\mathrm{v})}{1 - (4\pi\alpha(\omega)/3\mathrm{v})}$$

$$\Omega_0 = \omega_0 \sqrt{1 - \left(\frac{4\pi\alpha}{3\mathrm{v}}\right)}$$

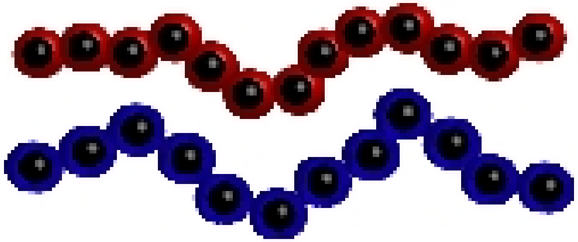
Low Entropy Ordered Domains in Water V

Ferroelectric ordering in water domains may be expected to produce electric ordered clusters within water in the same manner in which Ferromagnetic domains produce ordered clusters in ferrofluids.

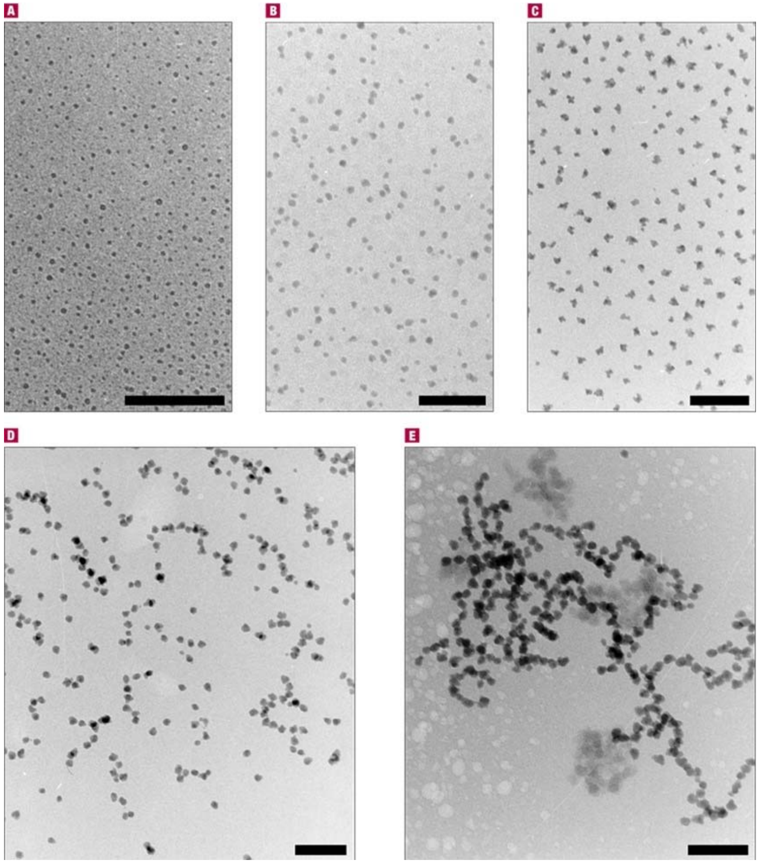




under the application of a small static field



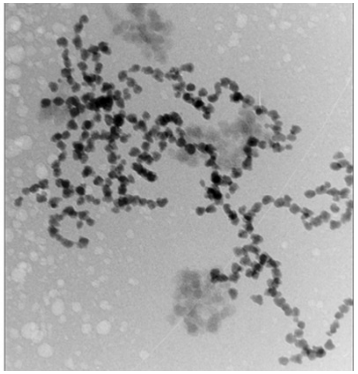
Low Entropy Ordered Domains in Water VI



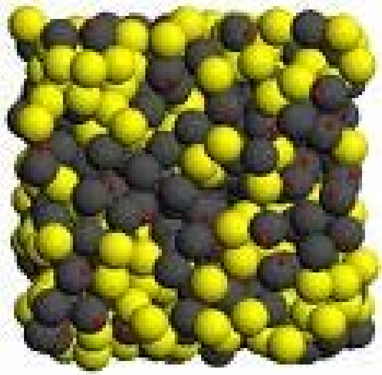
In ferrofluids with artificially made magnetic moment domains, as the concentration of such domains increases, the magnetic moments form networks of chains.

Water contains electric dipole domains which arise out a polar liquid electrodynamics phase transition. From the mathematical similarity between magnetic and electrical dipole field interactions, one would expect similar "trees" to form in pure water.

Low Entropy Ordered Domains in Water VII



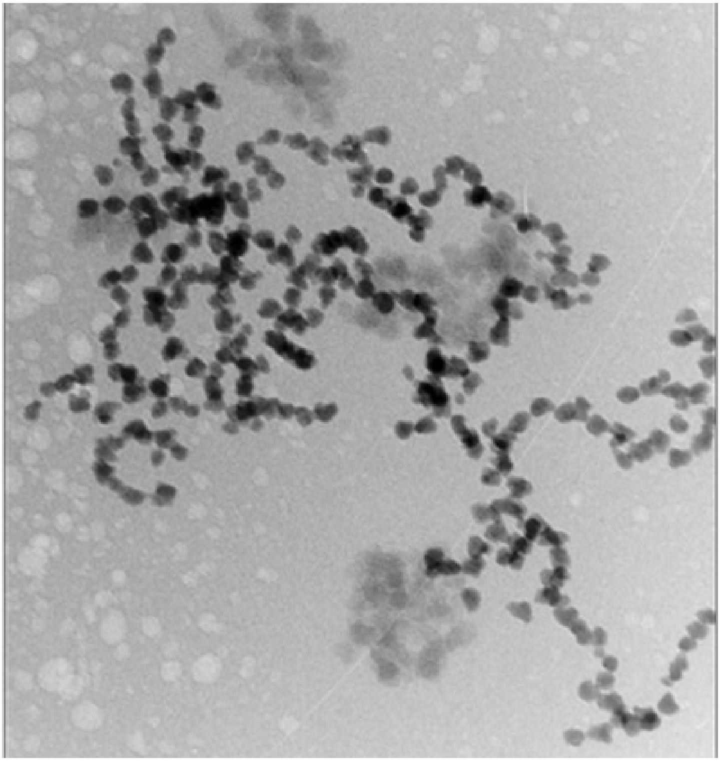
Water coherent domains repel alcohol.



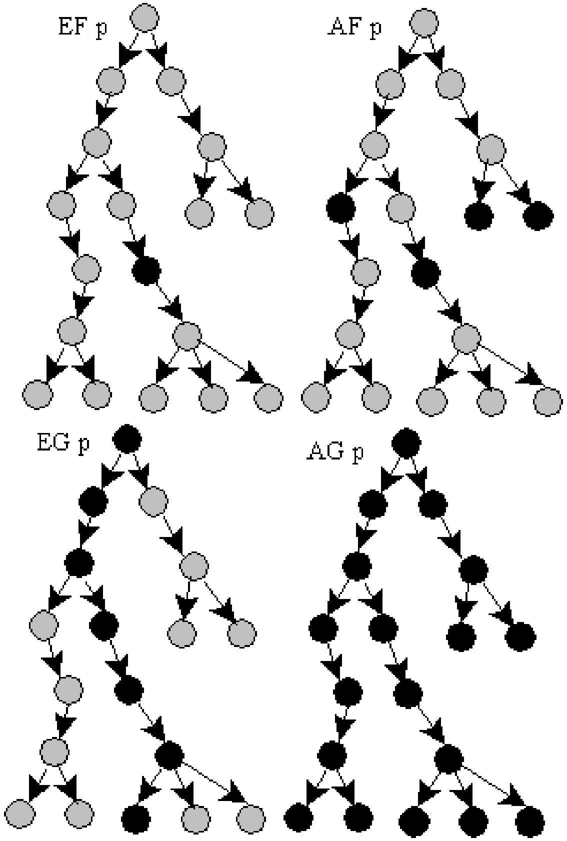
Water alcohol mixtures studied by neutron scattering.

Alcohol and water do not (really) mix! Illustration of the micro-segregation that takes place in alcohol-water solutions, The hydroxyl group on the alcohol molecule prefers to bond to water molecules than to other alcohol molecules, giving rise to clusters of methyl groups in contact, surrounded by sheets and globules of hydrogen-bonded water molecules.

Low Entropy Ordered Domains in Water VIII

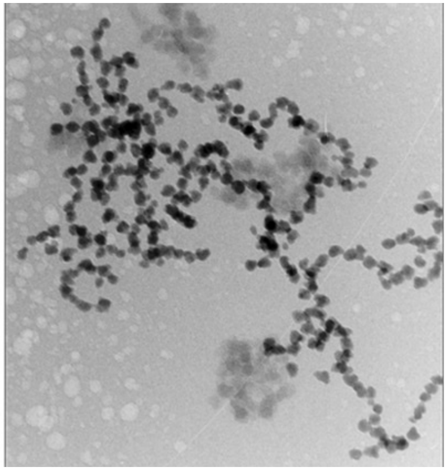


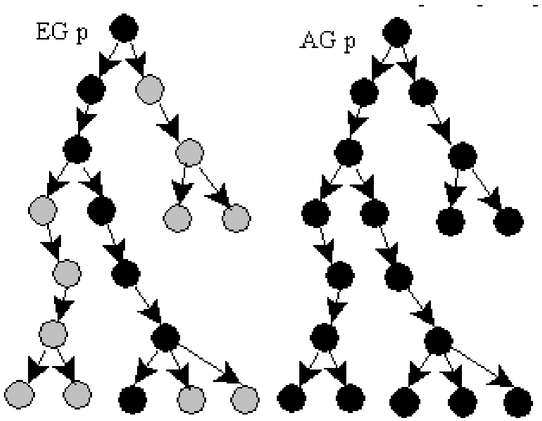
Computer Programs in the Form of decision "Trees"



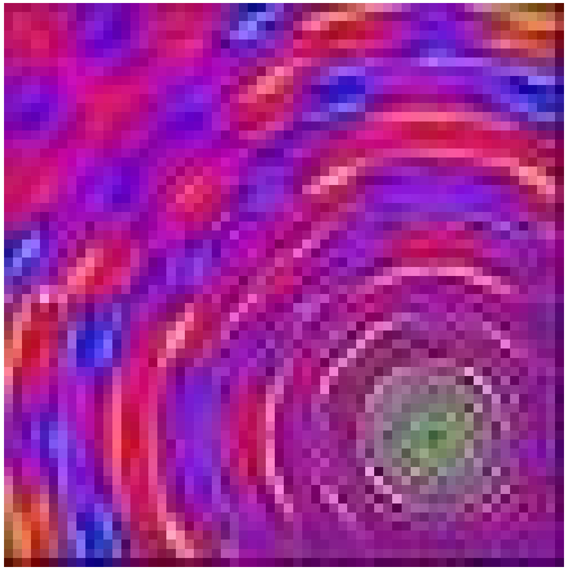
Water domains differ in size and ionic content and have a high information tree content partly responsible for the high heat of vaporization.

Low Entropy Ordered Domains in Water IX





A wireless connection to ordered dipole domains (and thereby programs) may be made via electromagnetic waves which shift the tree configurations.



Diamagnetic Water

Diamagnetism in Water I

A small high temperature superconductor floats over a rare earth ferromagnetic slab.

Water and Superconductors both expel magnetic field lines.

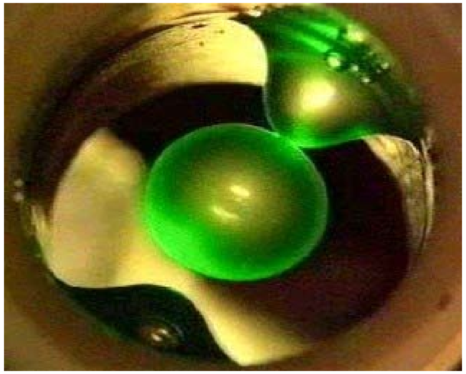
A small live frog floats over the coil endpoint fringing magnetic fields of a 16 Tesla Bitter magnet.

Diamagnetism in Water II

$$K = \frac{1}{2m}\sum_{j=1}^{Z} p_j^{\,2} \qquad \mathbf{A}(\mathbf{r}) = \frac{1}{2}\mathbf{B}\times\mathbf{r}$$

$$H_{electronic} = \frac{1}{2m}\sum_{j=1}^{Z}\left(\mathbf{p}_j - \frac{e}{c}\mathbf{A}(\mathbf{r}_j)\right)^2 + U$$

$$H_{electronic} = K + U - \left(\frac{e}{2mc}\right)\mathbf{L}\cdot\mathbf{B} + \left(\frac{e^2}{8mc^2}\right)\sum_{j=1}^{Z}|\,\mathbf{B}\times\mathbf{r}_j\,|^2$$



For a spherical water domain with Z electrons in a magnetic field with rotational symmetry about the magnetic field axis, one finds the diamagnetic energy

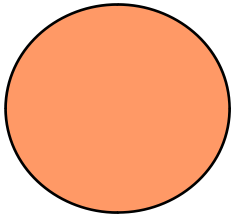
A water droplet gets pressed into a torus by magnetic field focused through the center.

$$W(\mathbf{B}) = \frac{Ze^2}{8mc^2}B^2\left\langle|\,\mathbf{r}_\perp\,|^2\right\rangle$$

$$\mathbf{m} = -\frac{\partial W}{\partial \mathbf{B}} = -\beta\mathbf{B}$$

$$\beta = \frac{Ze^2}{4mc^2}\left\langle|\,\mathbf{r}_\perp\,|^2\right\rangle$$

Diamagnetism in Water III



Single water domain magnetic polarizability β

almost perfect diamagnetism in a single domain

$$\frac{\beta}{V}=\frac{Z}{6V}\left(\frac{e^2}{mc^2}\right)\overline{r^2}$$

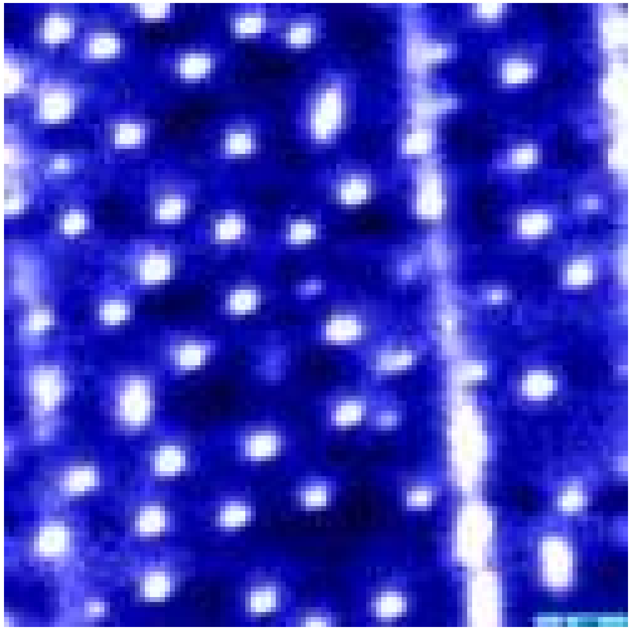
$$\frac{\beta}{V}=\frac{Z}{8\pi}\left(\frac{r_e}{R^3}\right)\overline{r^2}$$

$$\frac{\beta}{V}\sim Z\left(\frac{r_e}{8\pi R}\right)\sim 10^{-9}Z\sim 1$$

Water surface gets depressed by a normal magnetic field .

Diamagnetism in Water IV

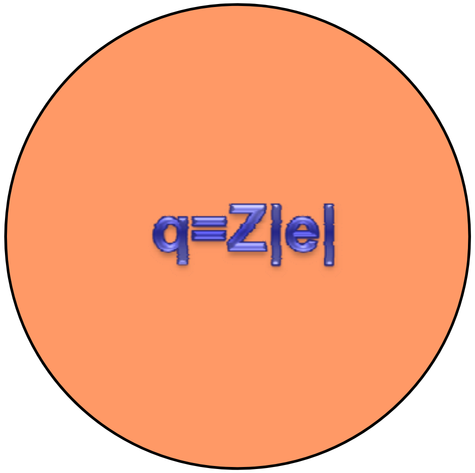
The magnetic field is well expelled from the coherent polarized water domains, yet water is only weakly diamagnetic. The magnetic fields must thereby enter the water in filamentary magnetic flux tubes in the normal regions of water. This is closely analogous to how magnetic fields penetrate a type II superconductor as vortex lines in the normal regions. Such flux tubes in water should be visible in nuclear magnetic resonant imaging.



Experimental picture of Abrikosov magnetic flux tubes piercing through a type two superconducting surface.

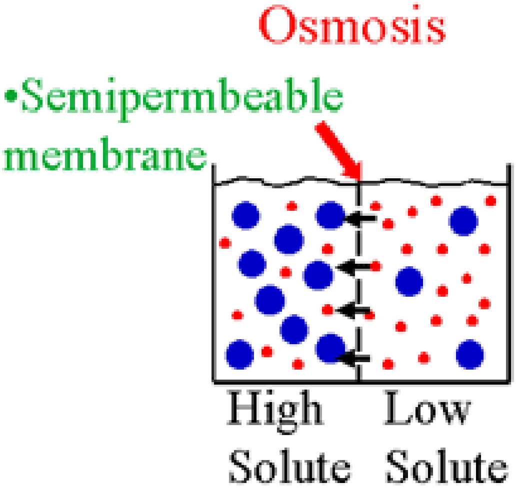
Ions in Water Coherent Domains

Ions in Water Coherent Domains I

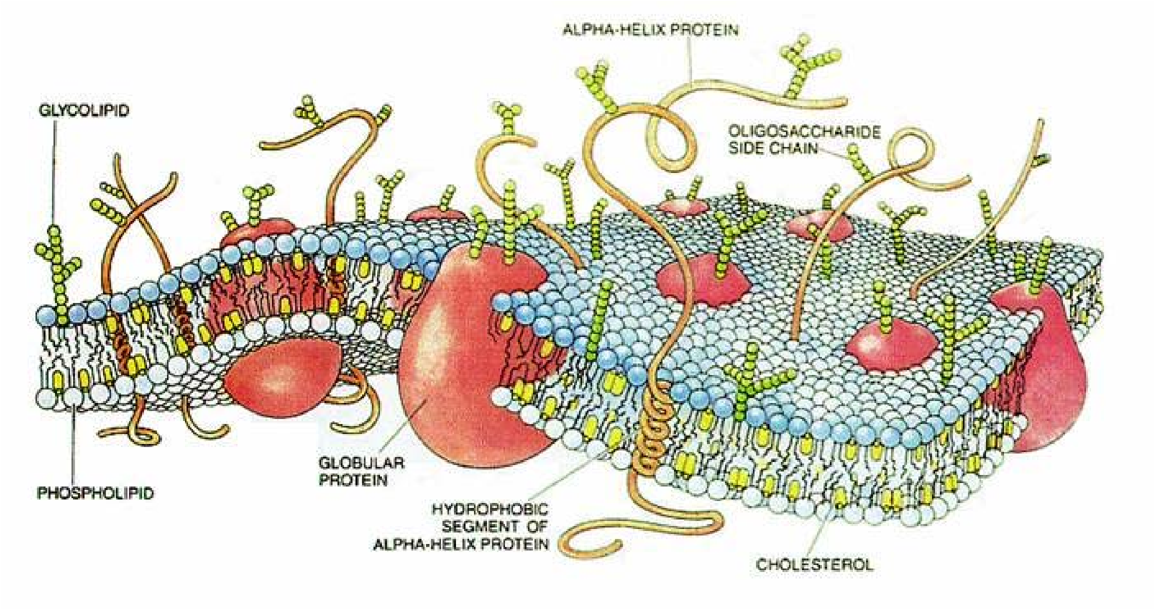


The radius *R* of a coherent water domain depends on the charge *q* and the chemical nature of the contained ion.

An atomic size ion ($r \sim 10^{-8}$ cm) will pass through almost any hole in a membrane. But if the ion has to drag a coherent water domain (say about $R \sim 10^{-5}$ cm), then the full balloon might not make it through the membrane channel.

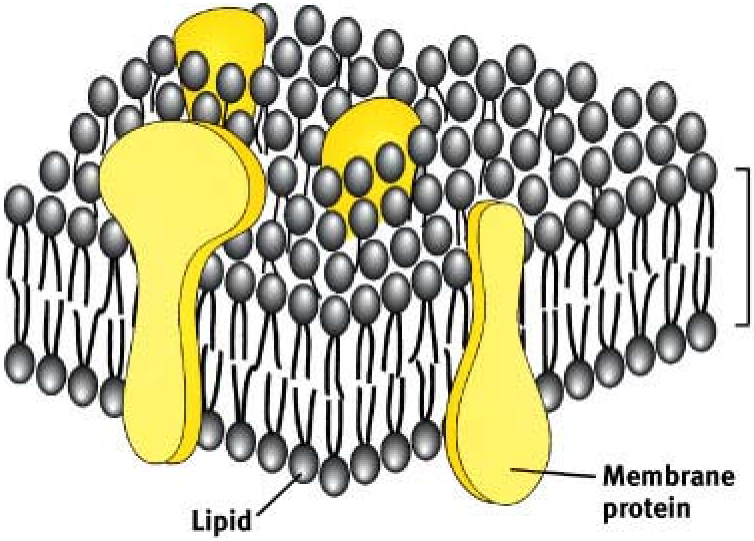


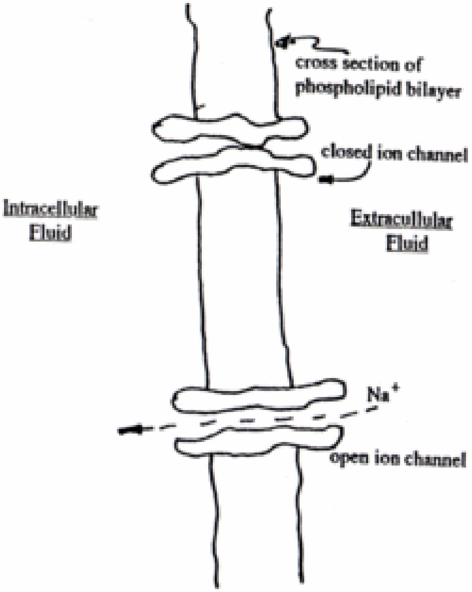
Ions in Water Coherent Domains II

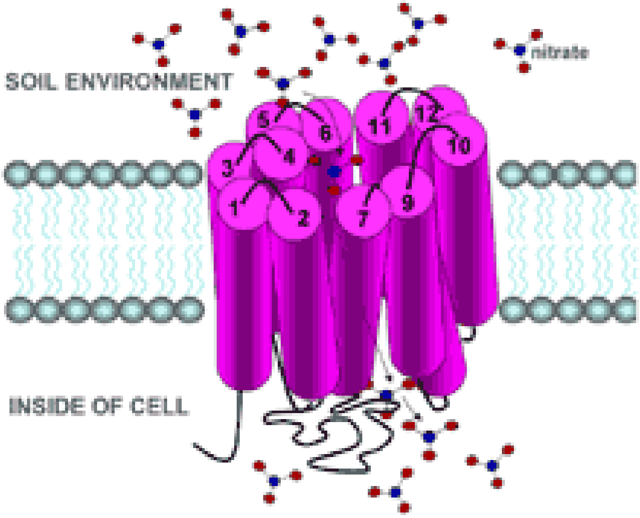


The charged q=Ze ion may or (may not) make it through a channel in a biological cell wall depending on whether or not the radius *R* of the coherent domain is too sizable.

Ions in Water Coherent Domains III



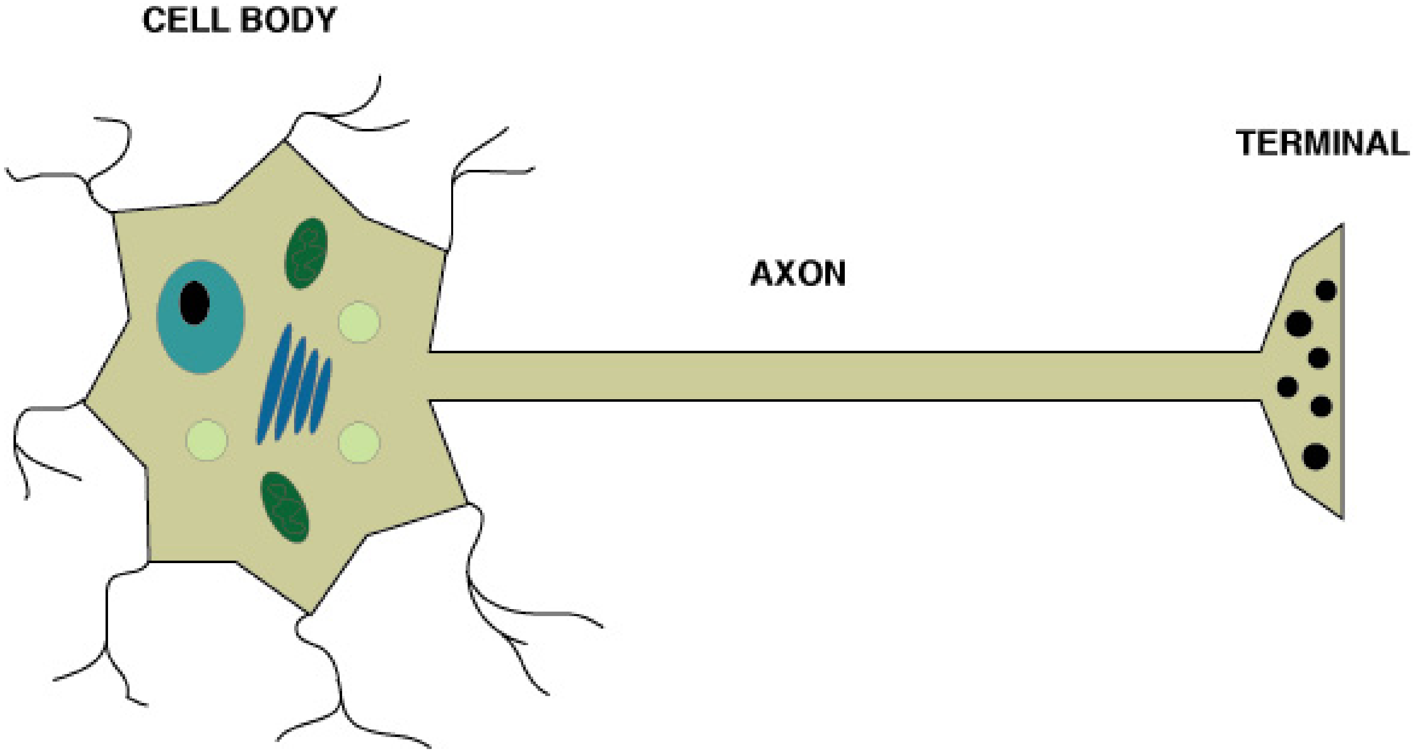




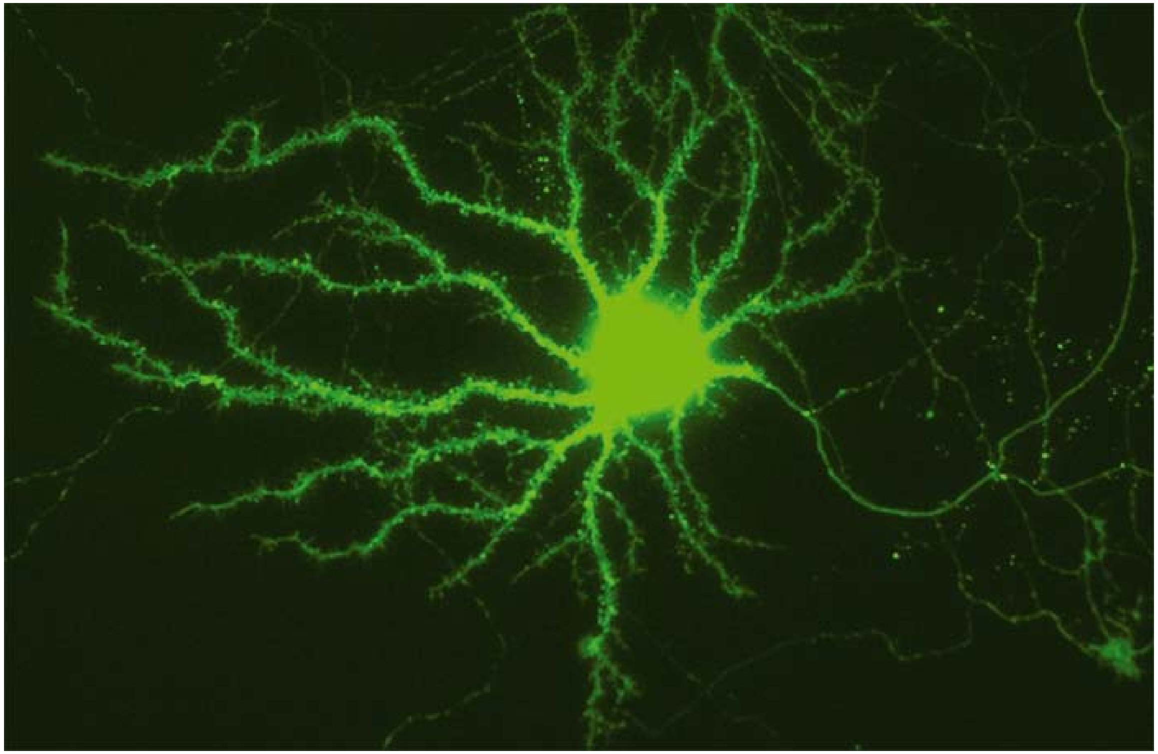
Ionic Pathways into and out of Biological Cells

Ions in Water Coherent Domains IV

The memory in the human brain is largely born of nerve cell codes from environmental experience and not so much from intrinsic genome codes. But nerve cells work by receiving ions into the body of the cell, sending a pulse down the axon and expelling ions out of the terminal. The process starts all over again for the next nerve cell.

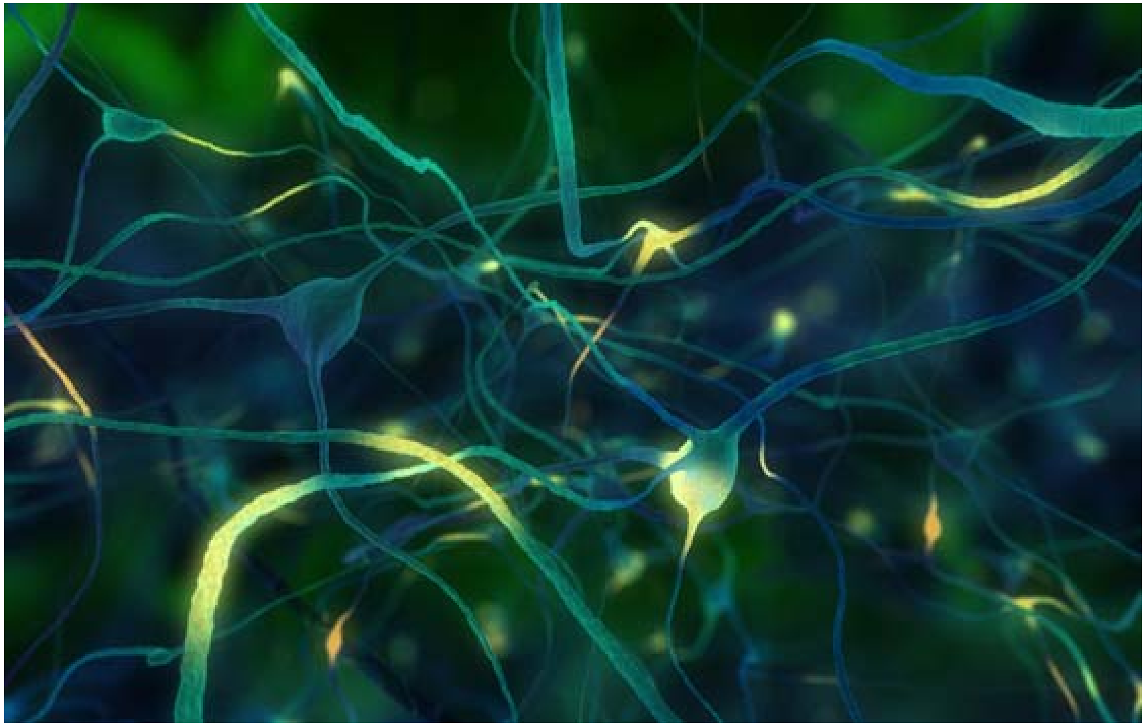


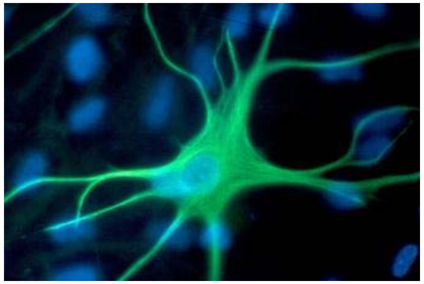
Ions in Water Coherent Domains V



Ion Channels into a Nerve Cell Body

Ions in Water Coherent Domains VI



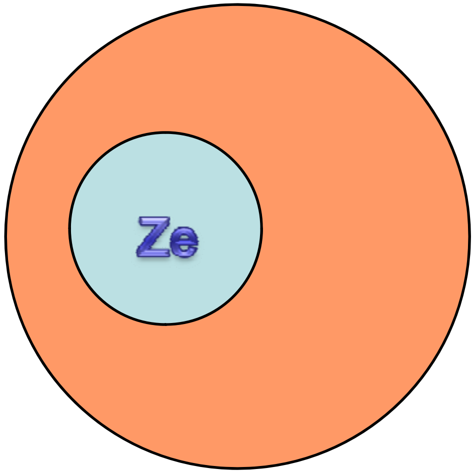


Node

Network

Nerve Cell Network with Switching Nodes Depending on Ion Transport

Ions in Water Coherent Domains VII



Dynamics of a Single Ion Transport Within a Coherent Water Domain

$$\mathbf{A}(\mathbf{r}) = \frac{1}{2}\mathbf{B}\times\mathbf{r}$$

$$H_{ion} = \frac{1}{2M}\left(\mathbf{p} - \frac{Ze}{c}\mathbf{A}(\mathbf{r})\right)^2 + U - Ze\mathbf{E}\cdot\mathbf{r}$$

Because of the mass of the ion is large on the electron mass scale, one may neglect the ionic diamagnetism.

$$\mathbf{L} = \mathbf{r}\times\mathbf{p}$$

$$H_{ion} \approx \frac{p^2}{2M} + U - \left(\frac{Ze}{2Mc}\right)\mathbf{L}\cdot\mathbf{B} - Ze\mathbf{E}\cdot\mathbf{r}$$

Ions in Water Coherent Domains VIII

The ionic magnetic **m** and electric **d** dipole moments may be written, respectively, as follows:

$$\mathbf{m} = -\frac{\partial H_{ion}}{\partial \mathbf{B}} = \gamma\,\mathbf{L} = \left(\frac{Ze}{2Mc}\right)\mathbf{L}$$

$$\mathbf{d} = -\frac{\partial H_{ion}}{\partial \mathbf{E}} = Ze\,\mathbf{r}$$

The rate of change of angular momentum is thereby the torque.

$$\frac{d\mathbf{L}}{dt} = \frac{i}{\hbar}[H_{ion}, \mathbf{L}] = \mathbf{m}\times\mathbf{B} + \mathbf{d}\times\mathbf{E}$$

Summing over all of the ionic water domains yields the ionic driven magnetic resonance equation.

$$\frac{\partial \mathbf{M}}{\partial t} + \gamma(\mathbf{B}\times\mathbf{M}) = \gamma(\mathbf{P}\times\mathbf{E})$$

Ions in Water Coherent Domains IX

Ionic driven magnetic resonance equation will have a relation time τ which is not so short as to spoil the Larmor frequency ω_L.

$$\frac{\partial \mathbf{M}}{\partial t} + (\mathbf{M} \times \boldsymbol{\omega}_L) + \frac{\mathbf{M}}{\tau} = \gamma(\mathbf{P} \times \mathbf{E})$$

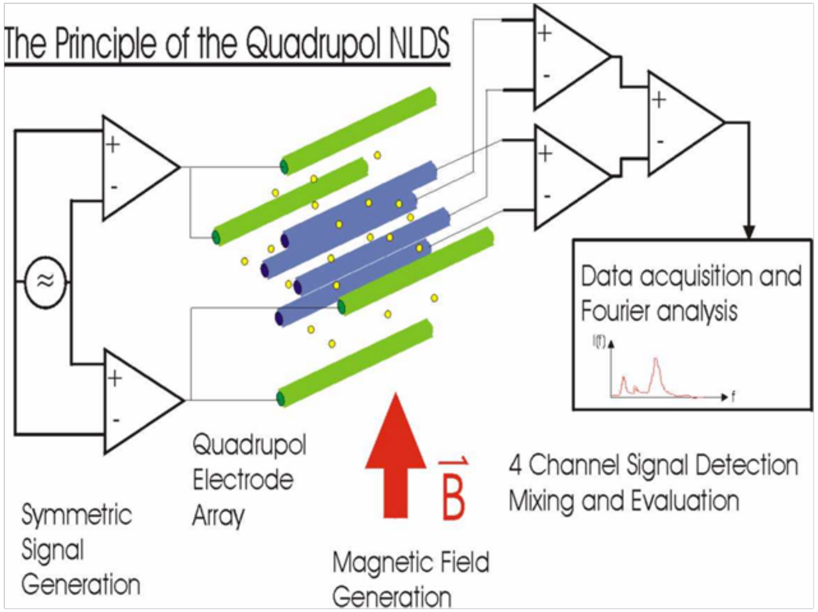
$$\boldsymbol{\omega}_L = -\gamma \mathbf{B} = -\frac{Ze\mathbf{B}}{2Mc}$$

The Larmor frequency can make its appearance as a resonant peak for magnetic fields of the form

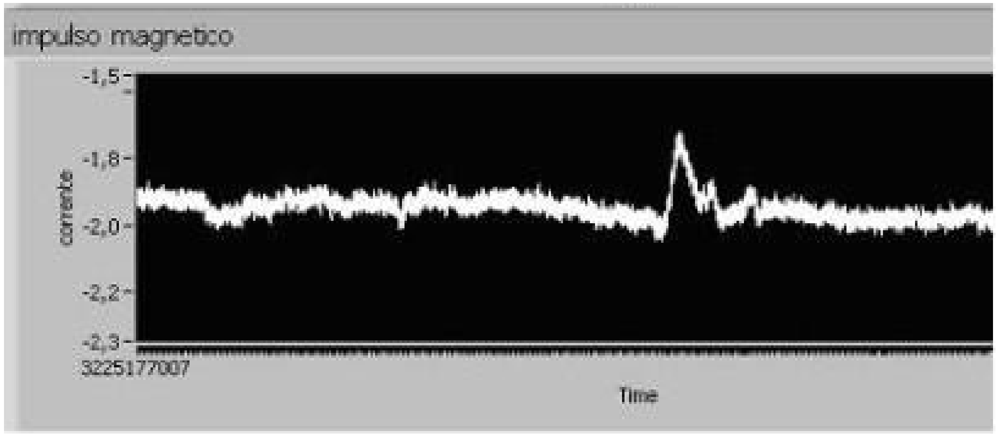
$$\mathbf{B}(t) = \mathbf{B}\left(1 + a\cos(\omega t)\right)$$

$$a << 1$$

Ions in Water Coherent Domains X



The conductance as a function of magnetic field modulation frequency gives rise to the magnetic Zhadin resonance peak at the Larmor frequency.



Conclusions

- **The ordering of water via coherent domains yields sufficient structure for memory capacity.**
- **Statistical thermodynamics and thereby information theory supports this view.**
- **The information coding estimates of the genome project are in full agreement with the thermodynamic view**
- **Ionic motions are effected by ordered water domains and can serve as electronic switches in nerve cell networks. These form the basis of conscious human memory.**
- **Electrical polarization networks and the resulting filament magnetic flux tubes in pure water should be measureable employing magnetic resonance imaging.**