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## The myriad structures of liquid water: introduction to the essential Materials Science



### Abstract

The significance of water to life, including humans and human society and human technologies including energy, surpasses by orders of magnitude that of any other single material that MST members will ever work with. Yet, by and large, water has been left to chemists to study, and neglected by materials researchers. This paper focuses on the materials scientists' contribution to defining the structure, and the structure-property relations of water and ultradilute aquasols including all natural waters.

The "black holes" in the materials science as we have learned and taught it, include: truncation of the number of easily accessed intensive variables in our thermodynamics textbooks from P, T E and H, to only P and T. Hence the gross neglect of the remarkable influence of radiation (acoustic and EM) on matter, especially at those special and rare frequencies which cause resonance in the system at various levels.

We present a summary of the 2008 version of the leading physicists' and chemists' views of the structure of water. We then summarize our own recent materials science perspective on the structure of water and present the substantive body of experimental evidence largely, but not only, from our laboratory, of some truly extraordinary changes caused by these new vectors on the structure of water, including some radically new phenomena such as the burning of water and imprinting of water by highly specific frequencies, and the creation of the myriad new (albeit poorly defined) and possibly metastable structures of water.

### Introduction

#### a) The Materials Science Approach to the Structure of Water

It should be unnecessary to introduce water to any scientist, but perhaps it is not amiss for those of us in ceramics, metallurgy and polymer science. None of us considers water

as part of our territory! Yet water in its liquid and solid states are the 1st and 2nd most abundant mineral phases on our earth. While the structure of solid water—ice, has been well studied for decades by materials scientists-physicists, and even glassy water, a rare laboratory creation, has received a great deal of attention from them, liquid water has, almost unbelievably, been neglected. Of course, part of that is due to the enormous difficulty of dealing with the structure of aperiodic matter. One might have expected that materials scientists could devote extraordinary energy to overcome these challenges if one considered the significance of dealing with the single phase which outranks all other materials by orders of magnitude in its importance to human life. One part of the explanation for this omission is that "water" as a material was considered to be part of the "territory" of chemists, not of materials scientists. This paper, therefore, is a beginning to rectify that situation. Liquid water is the world's most important (ceramic) material by several orders of magnitude and only condensed matter, or materials, scientists can do justice to the study of this phase.

The fine detailed studies by chemists have indeed contributed to the detailed understanding of the composition and chemical reactions of, and in, water. And masterful analyses have been made of the "structure of water" and that is the source of today's problem. Michael Faraday, Joseph Priestley and Antoine Lavoisier in various iterations around 1831 gave us the H<sub>2</sub>O composition correctly. The problem started with the fact that water was a very rare composition of matter that could be easily produced and easily put to use in all three states solid, liquid and gaseous. It was but a small slip thence, to begin to equate water with H<sub>2</sub>O. The structure of water equated then to the "Structure of H<sub>2</sub>O". H<sub>2</sub>O as a molecule is present only in the gas. But H<sub>2</sub>O is also used to describe liquid water, which is a condensed phase and its structure can only be described in the appropriate metrics and language for condensed phases, very different from those for molecules.

There is no better illustration of the saying "a little learning is a dangerous thing!". 'Everyone' since the 19th century knew that water was "just water", hence, "everyone" believes that since water is JUST H<sub>2</sub>O; i.e. always - just the same H<sub>2</sub>O- hence the term "structured water" is obviously absurd. It is after all JUST H<sub>2</sub>O. The confusion caused, worldwide, and society wide, for well over a century equated the fact of the composition

being always the same—JUST H<sub>2</sub>O, with the structure being always the same, and this has had profoundly negative consequences in Science and Medicine as we will show. The confusion starts, but does not end, with the term “structure”. What does this mean to the non-specialist? It can apply of course to the molecular level—the shape and linkages and interactive distances among atoms, often analyzed in a vapor. But we, here, are focusing now on condensed matter: liquid or solid, focusing largely on the liquid phase. To a materials scientist, the structure of a condensed phase—the periodic condensed phase, is the knowledge of the position of each atom in the 3D crystal. This can be known with great precision—such as 0.001Å—in most crystalline phases today. It can be determined by X-rays, neutron and electron diffraction, and confirmed by direct imaging by HRTEM, seeing literally atom by atom. However, when we enter the world of ‘aperiodic’ matter; i.e. liquids and glasses (frozen liquids), such precision vanishes. But the meaning of the term “structure” to a materials scientist remains the same—the 3D positions of each particular atom or molecule, and secondarily the bonds between atoms or molecules holding them together, and recognizing the unavoidable Brownian motion effects on any structure in a liquid.

For determining the structure of liquids one has to resort, largely to spectroscopy of various kinds which tell one, statistically, of the bond lengths and distances of nearest neighbors, next nearest neighbors and further neighbors., etc. Moreover, the bonds between atoms which are associated inside a molecule, and those holding molecules together can be very, very different. The bonds are nearly equal in completely ionic (like NaCl) or metallic (Fe) liquids to those in the same solids. Hence, bonding in a liquid can make a profound difference to structure. Those materials with equal bonds are called isodesmic, and unequal bonds, anisodesmic. And degree of anisodesmicity makes this profound difference. Liquid structures of NaCl and Fe for, example near the melting point look similar to the crystal with bigger amplitude in the simple harmonic motion of the ions or atoms. Anisodesmicity however can cause profound differences within two crystalline phases with exactly the same structure. We illustrate this with an easily and most clearly understood example, because it is confirmed by personal experience, repeated over and over by everyone. It has been very effective in changing—wherever known—the widely held belief that water must be the same, “just

water,” if it is really pure compositionally. The element carbon is well known worldwide in two forms—‘graphite’, the softest (experienced whenever we write with a pencil) and diamond, the hardest material known. These are both composed 100% of carbon; just carbon, “JUST C”. Obviously, this useful illustration proves to everyone that just having the same composition is no indication whatsoever of a unique set of properties for any condensed matter material. Thus, “just water,” is just inadequate!

The diamond-graphite example has two other important implications. Firstly, if not composition, to what must we ascribe what is evidently a massive difference in properties? The obvious answer is what we accept as the “1st law of Materials Science”. Properties reflect, and are determined by, structure. Hence, we know that it is structure that is paramount in determining the properties we encounter. The third useful illustration in this diamond-graphite example is the importance of bonding in determining and reflecting properties. In both graphite and diamond we have very strong covalent bonds between two carbon atoms. In graphite, they are sp<sup>2</sup> bonds lying in the plane of a sheet, in diamond, they are sp<sup>3</sup> covalent bonds forming tetrahedra in a continuous 3D network. The extreme softness of graphite arises from the anisodesmicity—unequalness of bonds—involved in the structure. While the bonds in the plane of the graphite sheets are indeed even stronger than in diamonds, the interatomic distances (inversely related to hardness) are 1.54 Å in diamond and only 1.43 Å in graphite within the sheet, but 3.35 Å between the sheets. The bonds between the sheets—van der Waals bonds—are extremely weak (bond length of 3.35 Å). The thoroughly studied carbon example provides the blueprint to argue the case that in all condensed phases, it is the weakest bonds which provide the most interesting properties. Hence, in all anisodesmic phases like water, it will be the weakest bonds that must be studied in detail. Being more difficult, this also makes them less studied.

**b) The “black hole” in ceramic sciences. The near total neglect of liquid water:**

Obviously, water is a ceramic. It is by orders of magnitude the most abundant component on the earth. It is at least also the most important phase on the planet, and uniquely significant scientifically as the sine qua non for life. Yet it escapes the attention of all younger scientists. This neglect has led to

the misleading use of the term "structure of water" by those trained in chemistry and the consequent "disaster" in major sections of science, especially those connected to living systems, especially modern medicine. The chemists' use of the term "structure of water" referred exclusively to the structure of the molecules in the liquid water. None of it dealt with the "structure of water" as material scientists use that term: the arrangement of the atoms in 3D space. Yet the elegant computer drawn images of molecules have confused an entire generation of scientists from theoretical physicists

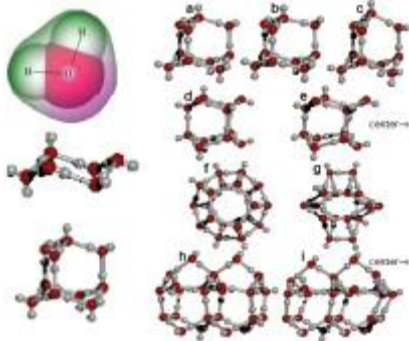


Figure 1: The enormous variety of structures of the molecules in which almost certainly the chemical entity  $H_2O$  can exist. The well known  $H_2O$  monomer with its precisely defined tetrahedral angle is shown on the top left and below it a series of dimers, trimers, tetramers, etc.(1)

to biologists and most consequentially, medical researchers far removed from these precise distinctions, into substituting in their minds, these beautiful images for the real structure of liquid water. Prof. Martin Chaplin is without doubt, the world authority on the molecular structures of water and Figure 1 shows an array of monomers,—the classic rabbit-eared  $H_2O$ —and several calculated structures of oligomers of  $H_2O$  (taken from his work).<sup>1</sup>

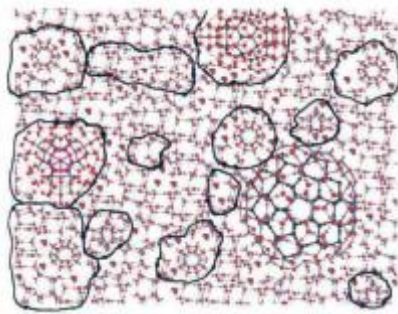


Figure 2: Cartoon of schematic presentation

of the kind of spacefilling mixture of molecular units which must exist in some proportion of smaller 2-4 molecule clusters (Fig.1) and other larger molecules up to the calculated 280 molecule units, to emphasize the key element of nano-heterogeneity of structure within water.

In 2005, the senior author and his colleagues presented the first thorough analysis of the "crystal" structure description of water to which the reader is referred to for details.<sup>2</sup> Of course, limited by the fact that it is a liquid and relatively fluid, it is meaningless at this stage to attempt anything other than the concept of the structure of water as a nanoheterogeneous assemblage—determined by statistical mechanics (at equilibrium) of a mixture of oligomers. No one has any data on which combinations are present at any particular combination of all the relevant intensive variables:  $P$ ,  $T$ ,  $E$ ,  $H$ ; nor on the concentration of each, and certainly not on their distribution in space, or their stability or metastability. Our cartoon makes one much more general and significant point. In all such covalent liquids, as we have hinted above, the structures are strongly anisodesmic. The covalent bonds of O-H inside the oligomers are much, much stronger than the van der Waals bonds (black-black) holding different oligomers together as shown in Figure 2. Unfortunately, the figure cannot easily present the scaled spatial relations among the actual molecules, nor the probable clusters which are present; because no such data exist. The forces between the clusters outlined in black must be very much weaker than the intracuster forces, although the bond terminations are not drawn thus.

**c) Some neglected branches of Science: The "black holes" in thermodynamics taught in Materials Science and physics**

Although thermodynamics is routinely taught in chemistry and physics, it is a core of the learning which is specific to Materials Science—and which is increasingly diminished in favor of the fashion of the decade: superconductors, ceramic engines, room pressure diamonds and "nano-X". Examine if one will, the textbooks from which one learned thermodynamics. One of us (RR) taught graduate students about the Phase Rule (the most relevant part of thermodynamics for Materials Scientists) from the book by Ricci.<sup>3</sup> This and all other such books treated the stability of any phase judged by the free energy function;  $G$ , as dependent on two (and only two) intensive

variables, pressure (P) and temperature (T). Of course, they are by far the most common, important and invaluable. One of us (RR) also spent 30 years of his career determining some of the most significant phase diagrams in ceramic science such as  $\text{Al}_2\text{O}_3$ - $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ - $\text{SiO}_2$ - $\text{H}_2\text{O}$  and  $\text{BaO}$ - $\text{TiO}_2$ . And the only variables other than the chemical composition (an extensive variable) were always pressure and temperature, P, T.

But surely it was simply a truncation of thermodynamics to state only that:

$$G = H - TS \text{ and } \frac{\partial G}{\partial T} = -S \quad \frac{\partial G}{\partial P} = -V$$

and we rarely even went on to the second derivatives, specific heat  $C_p$ , compressibility and thermal expansion.

$$\frac{\partial^2 G}{\partial T^2} = -\frac{C_p}{T} \quad \frac{\partial^2 G}{\partial P^2} = -\kappa \quad \frac{\partial^2 G}{\partial P \partial T} = -\beta \alpha$$

And when discussing phase transitions we used Ehrenfest's simple criteria<sup>4</sup> for a beginning. A first order transition is accompanied by a step function in the 1<sup>st</sup> derivative function of G; i.e. in volume or entropy. In a second order transition there are only changes of slope in those parameters and a step function in the second derivative of G. And so on. But now consider: are not electric fields (E) and magnetic fields (H), also intensive variables? Surely they are: and they can change properties. Hence, according to the first law of Materials Science they must change structure also. Materials scientists, if not most chemists and physicists, deal with ferro-magnetic and ferro-electric materials. At least in these cases, E & H play a profound role in major changes in properties. And further they interact directly with the other intensive variables. Temperatures change the magnetic (or electrical) properties drastically. It is clear that materials scientists have allowed a major error, a truncation of its most fundamental science to go unnoticed. At least four intensive variables are closely involved in changing the properties and structure of all matter in our everyday materials research. Of course, it is true that the changes are de minimis in the vast majority of ceramic and metals studied. But not in all. And that brings us back to water. We start with two examples of startling changes in solids and in water caused by E and H.

Crystalline, high temperature solid materials are dramatically affected by E & H fields:

During the period 1984-2007 our laboratory

at Penn State has published over 200 papers and a dozen patents on the incredible structural changes which occur in any phase that contains unpaired electron spins. The effects include changes in reaction kinetics of  $10^2$ - $10^3$ ; changing crystalline- "glassy" matter in the solid state, unpredicted microstructure, all these effects are achieved at specific frequencies and typically in polarized fields<sup>4</sup>.

Dissociation of Liquid water into H & O: Yes "water burns!"

This serendipitously discovered observation by John Kanzius, achieved by a polarized RF beam at  $\sim 13.56$  MHz makes the importance of E & H fields effects on water immediately undeniable. But it goes much further. Since this requires the almost unimaginable: That a 5.2 eV O-H bond can be ruptured by a  $\sim 10^{-6}$  eV photon requires a new approach to physics which we attributed to the specific condition of resonance of the bonds involved at the frequencies which are effective. This also suggests that much early literature on the effects of weak E and H fields on water structure and properties cannot be discounted.

This conventional wisdom accepted by ceramic scientists worldwide through the 1950's that, "We cannot have different structures of the same pure liquid" was challenged first by Roy et al. in 1969, with relevance to the structure of liquids in general. They showed conclusively in their experimentally determined P-T phase diagrams that very common liquids can have stable P-T regions for different, liquid structures of fixed composition (specifically even monatomic, covalently bonded systems such as S, Se, Te, and even a partially metallic Bi).<sup>5</sup> Most of these have highly anisodesmic bonds (like water) best known in the chains of sulfur atoms. By a coincidence a month after the first presentation in April 2004, of the structure of water paper by Roy et al.<sup>6</sup>, a paper by Kawamoto et al.<sup>7</sup> appeared in which they presented an exact analogue to the P-T diagrams of S, Te, Bi diagrams, the P-T phase diagram for water showing at least one high pressure stable liquid region [Figure 3]. Thus, this experimental thermodynamic evidence confirms the plausibility argument adduced by us of the existence of at least some different stable structures in liquid water.

Further comments on metastable (in addition to stable) phases:

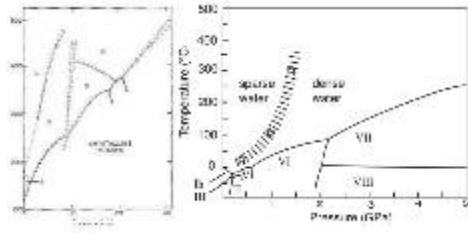


Figure 3(a): The Pressure-Temperature phase diagrams of liquid sulphur (6) [left]. (b) On the right is the Pressure- temperature phase diagram of water (a) showing the phase transition between low-pressure "sparse water", and high-pressure water "dense water" in the liquid stable water region, exactly analogous to the experimental data on several liquid structures such as in liquid sulfur (8).

We must also record the fact that in all strongly bonded phases the probability of metastable phases is high. In solid  $\text{SiO}_2$  the closest analogue (structurally) to water,<sup>8</sup> we have nearly an infinite number of tridymites, and cristobalites<sup>9</sup> and a literally infinite number of structure of glasses of  $\text{SiO}_2$  composition.<sup>2,10</sup> In the case of carbon, when we include the anisodesmicity, we already know of the infinite variations of glassy carbons and recently of carbon nanotubes—all of exactly the same composition—C. Hence in water the number of structural possibilities are obviously similar.

The entire matter of the existence of myriad - structures of water is essentially settled. The question that remains is, which can they be retained metastably and for how long and under what conditions of P, T, E & H. In materials science we retain such metastable phases by rapid "quenching" of the variable. In liquids the problem is that they most will usually freeze to crystalline matter. Albeit water, of course, has long been known to form glass just like its ceramic twin  $\text{SiO}_2$  . But how faithfully its structure will be retained is unknown. One set of metastable states of water have received an inordinate amount of attention in the chemical literature. These are the low temperature ( $<0^\circ\text{C}$ ) glasses and inference from them can be drawn from them for liquid water. Angell<sup>11</sup> has provided a very thorough recent review of the subject. Can magnetic fields or electric field-quenching have similar effects? These are all huge areas for study on ordinary liquid water.

Current State of thermodynamic knowledge on the structure of water

The phase behavior of solid water, ice is now

widely accepted and well understood. The work of Tammann and Bridgman<sup>12</sup> and many others indicate that solid ice under different conditions of temperature and pressure forms different structures, and their work was intensively followed by Whalley and colleagues.<sup>13</sup> The present state of the solid water phase diagram is now well understood. Although various attempts have been made by scientists to explain the multiple anomalous properties of liquid water until the 1950s when physicochemical studies of water and its interactions with solutes gathered momentum and several molecular models were proposed. This gained scientific respectability in the 1960's when Frank<sup>14</sup> proposed the existence of long-lived structures in liquid water and aqueous solutions having (ion-solvent interactions) with the formation of "flickering clusters" wherein the formation of one hydrogen bond is a co-operative phenomenon making and breaking many other hydrogen bonds .

Many others have contributed to the concept of various molecular - size "structures" present in varying concentrations in various waters under different P-T conditions<sup>15-18</sup>. The uniqueness of water is that it exhibits many such discontinuous changes in at least 65 properties as identified by Chaplin<sup>1</sup> and Stanley<sup>18</sup> in its density, material, physical and thermodynamic properties, many of them in the 0-100°C liquid stable region on which we focus here. Among their "65 property anomalies", the most interesting ones are those that occur in the most significant thermodynamic functions, i.e. the first and second derivatives of the Gibbs function. These are illustrated in Fig. 4. Compressibility: In typical liquids, compressibility decreases as we lower the temperature, while in water the average isothermal compressibility is twice as large compared to a typical liquid and undergoes the most unusual non-monotonic change. The second significant function is the specific heat which is similar and twice as large as a normal liquid. The discrepancy gets larger as the temperature is lowered and changes sign at 35°C. The third 2<sup>nd</sup> order thermodynamic function is the coefficient of thermal expansion: Figure 4 shows the data on these specific thermodynamic functions of (a) specific heat  $C_p$ , (b) isobaric cubic expansion and (c) isothermal compressibility of liquid water as a function of temperature T taken from the review by Kumar, Franzese and Stanley.<sup>18</sup> The behavior of a normal liquid is shown as the dashed curve. It is only possible to explain the change in thermal expansion from a low positive to a high

negative as the evidence for a substantial structural transition.

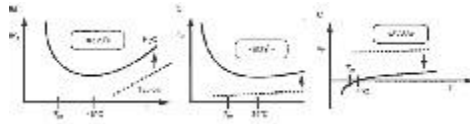


Figure 4: Schematic dependence on temperature of (a) isothermal compressibility  $K_T$ , (b) the constant-pressure specific heat,  $C_p$ , and (c) the coefficient of thermal expansion  $\alpha_p$ . The behavior of typical liquid is indicated by dashed line, which, very roughly, is an extrapolation of the high-temperature behavior of liquid water. The anomalies displayed by liquid water are apparent about the melting point  $T_m$ , but are more striking below it.

Structure of water: Learning from water's nearest cousin,  $SiO_2$

Materials Scientists have written tens of thousands of papers on  $SiO_2$ . Its many crystalline structures, perhaps 6 major, stable and hundreds of metastable ones are not relevant here. But  $SiO_2$  -glass research is certainly the most relevant to water research. This enormous body of work is rarely mentioned in the chemical literature. We only select a few relevant learnings from the silicate-glass structure research: In 1960, Roy<sup>19</sup> first proposed the thermodynamic consideration which favored the tendency to phase separate in all systems with non-ideal Raoult's law, liquidus line. This fundamental concept was used to interpret and predict what compositions were likely to form the very valuable glass ceramics. Extremely small regions of nanoheterogeneity formed in the liquid made possible minute crystal formation without the usual nucleation and growth of crystals. This nano-heterogeneity of many glasses made

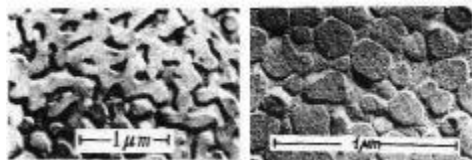


Figure 6: TEM images of binary, ternary and some quenched glasses clearly show actual phase separation, in sharp contrast to Zachariasen's random network theory. Structural (-compositional) fluctuations exist in most glasses and many liquids (22).

from anisodesmic liquids challenged the ruling paradigm of the Zachariasen glass

model<sup>20</sup>. In 1971, Roy<sup>21</sup> first proposed that this nano-heterogeneous model dominated the structure of many useful glasses and also other important covalently bonded liquids including, specifically water.

In 1986, when Porai-Koshits and Mazurin<sup>22</sup> demonstrated by their TEM data that the nano-heterogeneity model was not challengeable. With direct TEM images, they showed that many glasses consist of 2 or 4 separated phases. The concept of nano-heterogeneity was clearly established and has never been challenged; it has been ignored! At any given time liquid water exists as a statistical - mechanical thermodynamic equilibrium of multiple oligomeric units arranged in space. Bockris and Reddy<sup>23</sup> also provide cartoons as in Roy's 1971 paper requiring different size nano-units of structure.

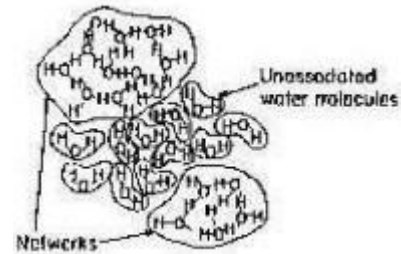
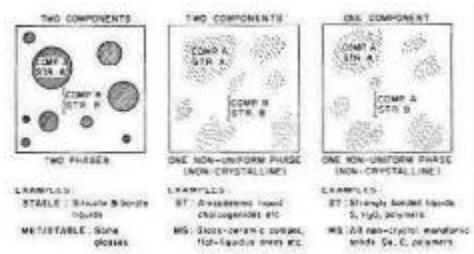


Figure 7: The cartoon version of the more generalized structure of glass clearly indicating its heterogeneous (with respect to structure or structure and/or composition) (21). Note that water is mentioned in the third column. A similar representation of the water structure by Bockris and Reddy (23) is shown above.

Chaplin's website shows numerous, splendid water clusters<sup>1</sup>, but no 3D picture of the structures of the assembled liquid. Roy et al.<sup>2</sup> have proposed the only such crude generic nano-heterogeneous cartoon model for liquid water which at a given time exists as Chaplin's  $(H_2O)_x$  trimers, oligomers and polymers where  $x$  varies from 2 - 250.

**Experimental data on the Structure of water and aquasols:**

A sol or colloid is a two phase system consisting of finely divided solid matter (< 100-1000 nm) permanently dispersed in a liquid. The finely divided phase in a stable colloid consists of (either positively or negatively) charged particles which prevent them from clustering together and / or precipitating out. Einstein, in his 1905 paper on Brownian motion, a typically colloidal phenomenon, and one of his three earthshaking papers of that year commented on the fact that 'colloids' are 'atoms' structurally different from the parent liquid. The colloidal state provides an excellent bridge to demonstrate the "structuring effect" in water- the liquid phase. What is the nature and the influence of the charged solid-phase on the structure of the surrounding liquid phase, layer by layer, and the role of the structured cluster on it first, second and subsequent nearest neighbors? We have looked into the detailed analysis of silver aquasols in an attempt to answer some of these questions.

The colloidal state also provides an excellent bridge to demonstrate the biological effects on ultradiluted water samples. Metallic silver has been known for millennia and used for its exceptional antibacterial properties. Silver aquasols at 1-10 atom ppm concentrations are powerful broad spectrum antibiotic. The synergistic and additive affects of colloidal silver with various well established antibiotics has been well documented<sup>24</sup> For the study, we obtained our samples from several different companies that produce colloidal metal particles suspended in minuscule quantities (~ few ppm) in water.

We have analyzed the samples prepared by various technologies of 10 ppm, 30 ppm, 200 ppm and 400 ppm of such silver aquasols. Further we have investigated particle size, morphology and the nature of the colloidal particles in waters. We have for the first time analyzed in detail the solid and the liquid phases using standard materials science analysis tools. The solid phase is analyzed using DTA, TGA, XRD, SEM and TEM, while the liquid phase was analyzed using FT IR, UV and Raman spectroscopy. We observe that there are atleast three different phases in the system: Ag-O: Ag, Ag<sub>2</sub>O and Ag<sub>4</sub>O<sub>4</sub> which are stable in air. In an aqueous environment between 0 and 100°C, there is evidence that various combinations of metal oxides, and possibly 'oxy-hydroxides' exist.<sup>24</sup>

Figure 8(a), shows the UV- VIS absorption spectra of a series of silver aquasols varying in Ag concentration, ranging from 10- 200

ppm. The UV absorption spectra was carried out in a double beam monochromatic UV-VIS spectrophotometer using silica glass cuvettes. While Ag Plasmon radiation in the UV absorption spectra occurs in the 400-420 nm regime, our analysis indicate major structural absorption effects due to the changes in the structure of water. Notable changes are also seen in the Raman spectra as

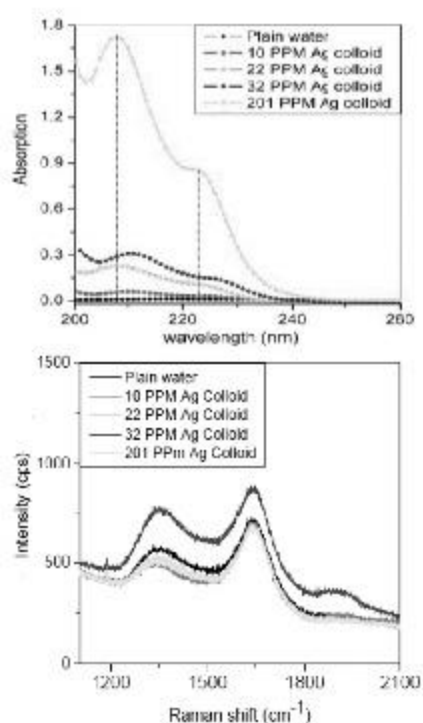


Figure 8: UV spectra of colloidal silver samples with varying silver concentration. Note their implication on the structure of water at lower wavelengths (200-240 nm). (b) Raman spectra of silver aquasols.

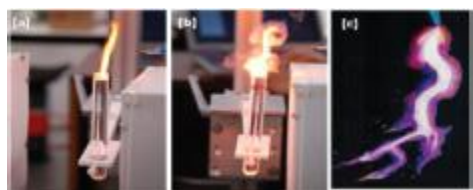
indicated in 8(b). The presence of charged nanoparticles in water alters the bulk structure of water, by the influence of charge (positive or negative) on the first nearest neighbors to the charges species, which in turn affect the second nearest neighbor and so on.

### Effect of radiation on the structure of water:

A considerable body of work now demonstrates the effects of magnetic fields on aqueous solutions.<sup>25</sup> The influence of modest d.c. magnetic fields on the nucleation and growth of CaCO<sub>3</sub> (phases, sizes, morphology) in dilute aqueous solutions have been thoroughly studied and demonstrated by Duncan<sup>26</sup>, Higashitani et

al,<sup>27</sup> and Pach et al<sup>28</sup>. The former demonstrates a strong memory effect in the constituent solutions exposed to the H-field. Tiller et al<sup>2</sup>. have shown the remarkable effect of a static magnetic field on the pH of water in a conditioned space.<sup>2</sup>

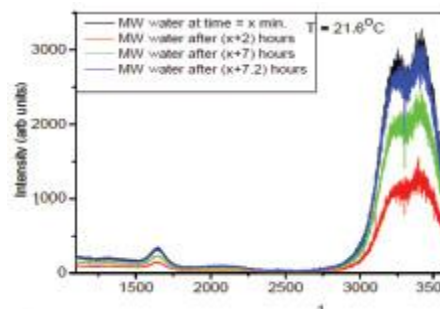
We do not treat here, in any detail the rich patent literature on the use of RF and RF plasma transformation of water into new structures: only because the compositions of the phases are not carefully specified<sup>29</sup> The most dramatic effects of EM radiation came in a serendipitous discovery of Mr. J. Kanzius when he devised a circularly polarized radio frequency generator that was accidentally found to be able to 'burn' salt water. Our initial studies using his device indicate that very low energy radio-frequency photons (~ millionth of an eV) are capable of and do break the O-H bond of water. A typical experiment involved the irradiation of NaCl solution in pyrex/quartz/Teflon test-tubes by the polarized RF fields. On ignition the water combusts with an obvious flame as shown in Fig. 9. Various compositions and dilutions of NaCl ranging from 0.03 to 30 percent NaCl in water were investigated resulting in combustion of the gases, O, O<sub>2</sub> and H<sub>2</sub> liberated by the decomposition of the O-H bonds in H<sub>2</sub>O.<sup>30</sup>



**Figure 9: Mixtures of various concentrations of NaCl and water combusting (when ignited) in the presence of a 13.56 MHz RF radiation (a) 0.3% NaCl (b) 30% NaCl (c) droplet of natural sea water self-combusting in the RF fields.**

An extremely stimulating result that sprang up from one of our experiments showed that spontaneous dissociation of water in the RF field leading to self-ignition as a drop of natural sea water, as it falls freely from tip of a micropipette. Fig. 9c shows the spectacular image captured during the self-ignition of a drop of water in presence of the circularly polarized RF field. Structural analysis using Raman spectroscopy indicate that there is a definitive change in the structure of the pure NaCl- water solution after RF irradiation. Furthermore, it is important to note that the Raman spectral analysis of the saline solutions before and after the combustion confirms that there are substantial structural changes. These are not

discussed further in this context, but show that such changes in the structure of the liquid phase are caused by radiation effects. The parallel influence of polarized 2.45 GHz microwave fields on water using Sedlmayr's process<sup>31</sup> shows dramatic effects. The Raman spectra shown in Fig. 10 shows the changes in the intensity of the main OH stretch band of H<sub>2</sub>O by an order of magnitude. It is interesting to note that such effects are metastable and relax over time, ~ 7 hours in this particular example shown.



**Fig 10: Raman spectra of microwave water measured at 21.6°C as a function of time. Note the time of relaxation for the structured water is ~ 7.2 hours.**

Although 2.45GHz and 13.56 MHz are typical frequencies in the microwave and radio frequency regions, it is interesting to note that unlike conventional fields, the radiation used in all these experiments is 'vectored'.

### Conclusion

Drawing especially on the long and extensive work of Chaplin on the various molecular structures or clusters, and on the large amount of physical data on collected and collated by Stanley, to establish the large number of transitions in liquid water in the stable range, and largely on our own data on the spectroscopic data providing evidence for – structural changes produced by EM fields we believe that the following conclusions can be safely drawn:

1. Liquid water exists in dozens of different structures.
2. At one atmosphere pressure, the well known, stable, anomalous changes in properties provide the fingerprints of transitions between these thermodynamically stable phases. The P-T dependencies of such anomalies can provide useful thermodynamic parameters on such phase changes between specific structures.
3. In addition to our work, there is

overwhelming empirical evidence especially in the patent literature that appropriate electrical and magnetic fields can cause structural changes in water, as they have been conclusively shown to do in high temperature solid matter.

4. Hence we believe that the materials science community has a great opportunity both to expand the science of the understanding and display of the structures of water, and to create and stabilize metastable structures of water which could no doubt open up major opportunities in the materials industries and in the world of human healing.

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the form of the object you are concentrating vanishes and only its meaning remains in the mind. This is Samyama. "When one has succeeded in making this Samyama," says Patanjali, "all powers of the mind come under your control." This exercise should be done in stages, he adds. The process of concentration, retention and absorption, according to Patanjali, results in the "glorification of the body." In other words, the body becomes indestructible. Nothing can destroy it until the Yogi wishes.

### **Controlling the Mind**

Mind control ensures free flow of "the light of knowledge," says the ancient Indian sage Patanjali (circa B.C. 200). When you concentrate on one particular object (Dharana), and keep it for some time (Dhyana), you are fully absorbed (Samadhi). In this state of mind,